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Depositional Setting of the Euphrates Formation (Early Miocene) in Selected Wells, Hamrin Oil Field, Northern Iraq

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ABSTRACT

The Euphrates Formation (Early Miocene) is studied in three selected subsurface sections in the Hamrin oil field in northern Iraq. The formation consists of limestone, dolomitic limestone, and dolomite. The petrographic study shows the dominance of the skeletal grains represented by the benthic foraminifera (Milliolid, Nummulites, Peneroplis, Dendritina, Miogypsina, Textularia, and Ammonia) forming the most important genera available within the formation in addition to red algae, echinoderms, molluscs, and bioclast, While the non-skeletal components constitute a smaller percentage compared to the skeletal grains, and they are represented by the peloids and intraclast. The matrix is composed mainly of micrite which is sometimes affected by the recrystallization process and transformed into microspar. According to the variety of petrographic constituents, five main microfacies are distinguished; lime mudstone (Fm), wackestone (Fw), packestone (Fp), grainestone (Fg), and boundstone (Fb) which are subdivided into fifteen submicrofacies. The sedimentary model represents deposition within a shallow marine environment extending from the lagoon to forereef slope environments according to the facies analysis and their environmental implications and paleogeography of the Early Miocene. The rimmed platform model is the most acceptable model for the Euphrates Formation in the study area.

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الموضع الترسيبي لتكوين فرات (المايوسين المبكر) في آبار مختارة من حقل حمرين النفطي، شمالي العراق

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الملخص

دُرست تتابعات تكوين فرات (المايوسين المبكر) في ثلاث مقاطع تحت سطحية ضمن حقل حمرين النفطي في شمالي العراق، وتتكون تتابعات التكوين من الحجر الجيري والحجر الجيري الدولوميتي و حجر الدولوميت. اظهرت الدراسة البتروغرافية ان الفورامنيفرا القاعية تمثل أهم المكونات الهيكلية ضمن تتابعات التكوين حيث تمثلت بالمجاميع التالية (Milliolid, Nummulites, Peneroplis, Dendritina, Miogypsina, Textularia and Ammonia) فضلا عن وجود الطحالب الحمراء وشوكيات الجلد والرخويات والفتات العضوي، بينما تشكل المكونات غير الهيكلية نسبة أقل بالمقارنة بالهيكلية والتي تمثلت اساسا من الدمالق والفتات الداخلي، اما الارضية، فانها تتكون بشكل اساسي من المكرايت المتاثرة في بعض المناطق بعملية اعادة التبلور والمتحولة الى الاسبار الدقيق. اعتمادا على التباين في المكونات البتروغرافية الاساسية، تم تقسيم تتابعات التكوين الى خمسة سحنات رئيسة وهي سحنة الحجر الجيري الطيني الدقيقة وسحنة الحجر الجيري الواكي الرئيسة وسحنة الحجر الجيري المرصوص الرئيسة وسحنة الحجر الجيري الحبيبي الرئيسة وسحنة الحجر الجيري المترابط الرئيسة، قسمت هذه السحنات بدورها الى خمسة عشر سحنة ثانوية. اعتمادا على التحليل السحني ووضعية الجغرافية القديمة لمنطقة الدراسة خلال فترة (المايوسين المبكر)، تم استنتاج الموديل الرسوبي للتكوين والذي يظهر ترسب تتابعات التكوين ضمن بيئة بحرية ضحلة امتدت من بيئة اللاكون الى بيئة امام الحيد، وبذلك تبين ان موديل المنصة الحافية هي من اكثر الموديلات قبولا لتتابعات تكوين لفرات ضمن منطقة الدراسة.

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Introduction

The Euphrates Formation (Early Miocene) is one of the important limestone formations that was deposited within the Burdigalian age. This importance is evident from two aspects; the first is its wide distribution in the northern, central, and western parts of Iraq, either in outcrops or in oil wells; the second is its reservoir importance within the Neogene age petroleum system in most of the fields located in northern Iraq. The formation was described for the first time by Boekh (1929; in Bellen et al., 1959) at the type locality near Wadi Al-Fahimi in the Anah Region, which is reported to be composed of well-bedded and recrystallized shaley limestone. The age of the formation is proven to be Early-Late Miocene (Burdigalian) by the emergence of Miogypsina globulina and Miogypsina intermedia (Ctyorky and Karim, 1971). Several studies were conducted on the Euphrates Formation including (Al-Eisa, 1992; Abbasi, 1994;

Agwan and Abbasi, 1996; Al-Jubouri, 2003; Al-Ghurairy et al., 2010; Yilmaz, 2017; Al-Mashaikhi, 2018; Al-khaykanee and Al-Dulaimi, 2019) and confirmed that the formation was deposited within a shallow marine and lagoon environments.

The present study aims to describe the petrographic components and microfacies to distinguish the sedimentary environments and draw a sedimentary model for the formation in the Hamrin oil field, noting that this study is the pioneering study on the formation in the Hamrin oil field.

Geological setting

The study area is located in the Hamrin oil field in northern Iraq near the Hamrin fold. The oil field is a convex asymmetric fold. It consists of a series of three domes extending from northwest to southeast (Abed Fadil Dome, Nekeel Dome, and Sheikh Alas Dome). It is worth noting that the Euphrates Formation extends within these three domes in the oil field with varying thicknesses. Three wells are selected within the field and distributed over the three domes, with a well in each dome (Fig.1). Tectonically, the study area is located in northern Iraq within the Hemrin-Makhul subzone, which represents a part of the Unstable Shelf according to the divisions of Jassim and Buday (2006).

The Euphrates Formation is a part of the main sequence (Megasequence AP11) (Sharland et al., 2004), which is divided into three sequences (Late Eocene-Oligocene, Early-Middle Miocene, and Late Miocene-Recent). The Early-Middle Miocene cycle is further divided into two secondary cycles, where the Euphrates Formation was deposited within the Early Miocene period with several equivalent formations (Jassim and Buday, 2006). This period is characterized by tectonic activity, which led to the formation of shallow and wide basins. The sediments deposited in these basins include marine deposits (Serikagni, Dhiban and Euphrates) and clastic river sediments (Ghar Formation; Fig. 2). The lower and upper contacts of the formation within the study area are conformable with the Dhiban and Serikagni formations respectively, where gradual change from the shallow facies of the Euphrates Formation to the deep basin facies of the Serikagni Formation is commonly observed by common planktonic foraminifera in the latter formation, as well as by the change in the gamma-ray probe record between the two formations. These conformable contacts with the underlying and overlying formations are recognized in other areas of Iraq (El-Eisa, 1992; Lawa et al., 2020; Ameen, 2022; Farouk et al., 2023).

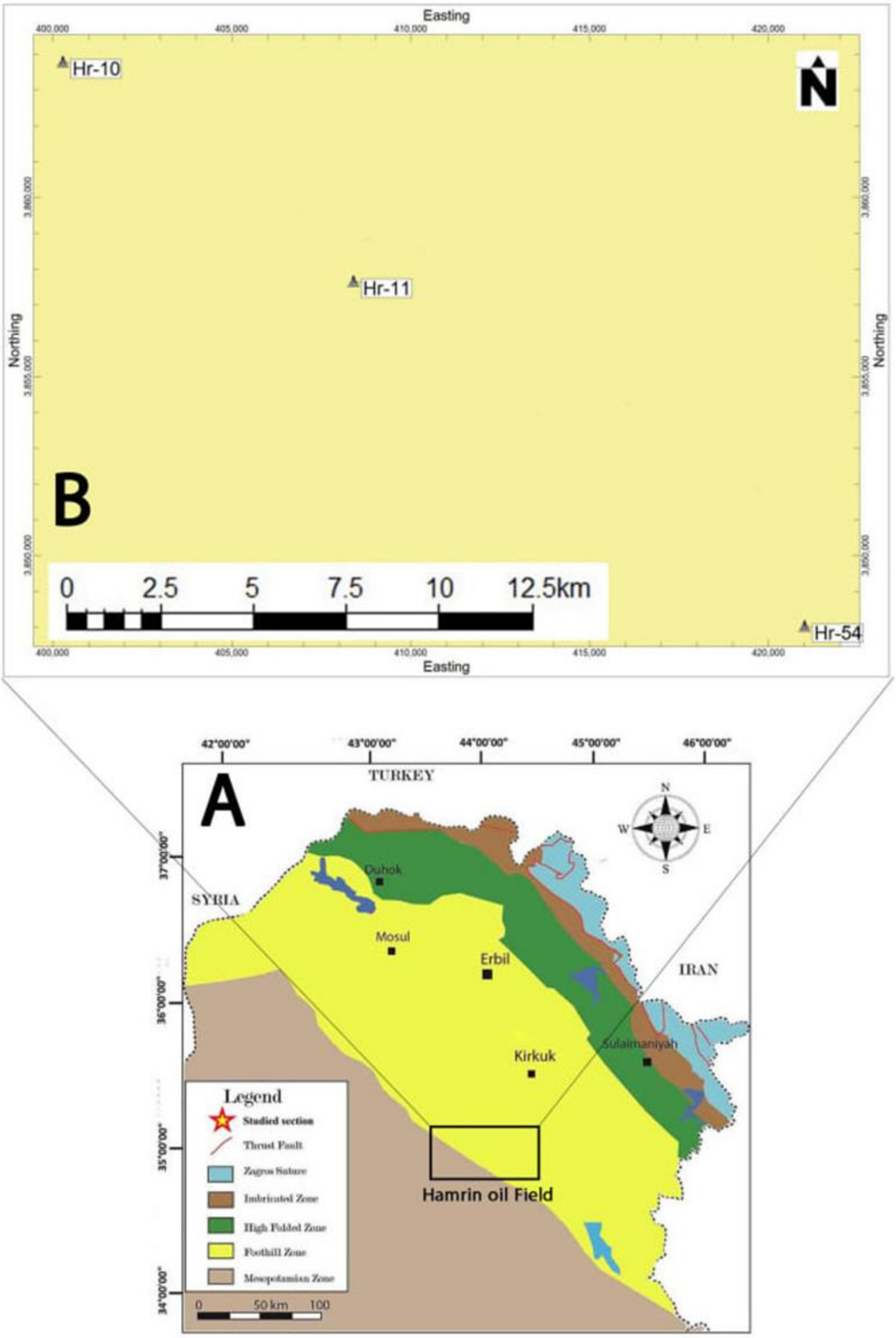

Fig. 1. Tectonic map of Iraq showing the location of the studied area (Jassim and Goff, 2006) (A); and location of the studied wells in the Hamrin oil field (B).

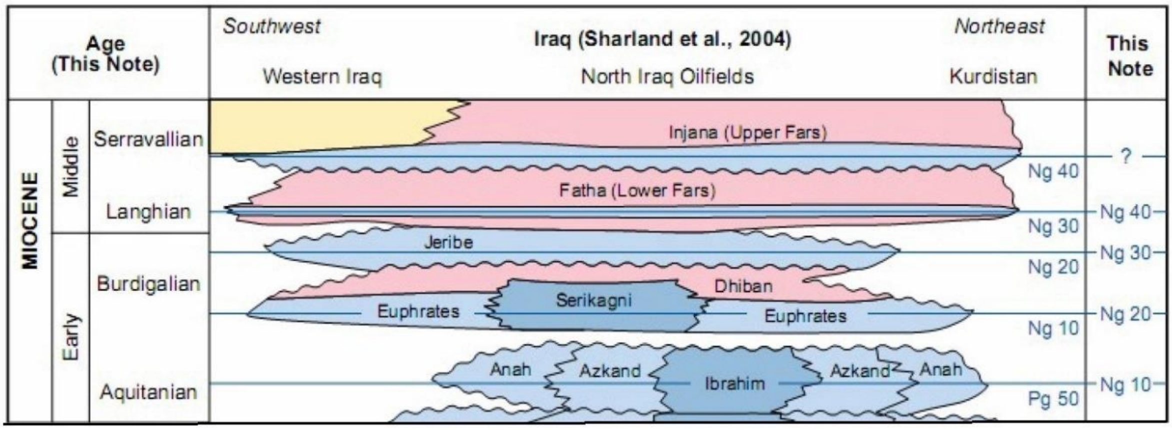

Fig.2. stratigraphic correlation of Miocene Formations in Iraq (Sharland et al., 2004)

Materials and Methods

The research methods include the selection of three wells within the Hamrin oil field (Table 1). The differentiation of the rock succession and the contacts of the formation were established by review of the final well reports. A total of 112 rock slides are examined by polarizing microscope to distinguish the petrographic components and diagenetic processes as well as the classification of the facies according to Dunham (1962) modified by Embry and Klovan (1971).

A few representative samples are also analyzed by X-ray diffraction (XRD) in the laboratories of Premier Corex in Houston, Texas, USA using the (Bruker D8) device Advance XRD, the minerals are determined using the TOPAS software package.

Table 1: Tops and thicknesses of the Euphrates Formation in the studied wells

Well no	Hr-10		Hr-11		Hr-54	
Formation	Top (m)	Thick (m)	Top (m)	Thick (m)	Top (m)	Thick (m)
Euphrates	625	62	578	50	561	29
Serikagni	687	25	628	25	590	17
Coordinates U.T.M	E:400 274.737 N:3863 798.756		E:1 403 402.495 N:1 428 116.348		E: 421 007.6 N:3848 039.4	

Results

Mineralogy, Petrography and Microfacies

The Euphrates Formation consists mainly of carbonate minerals, among which calcite and dolomite are the most important minerals, in addition to a small percentage of quartz (Fig. 3).

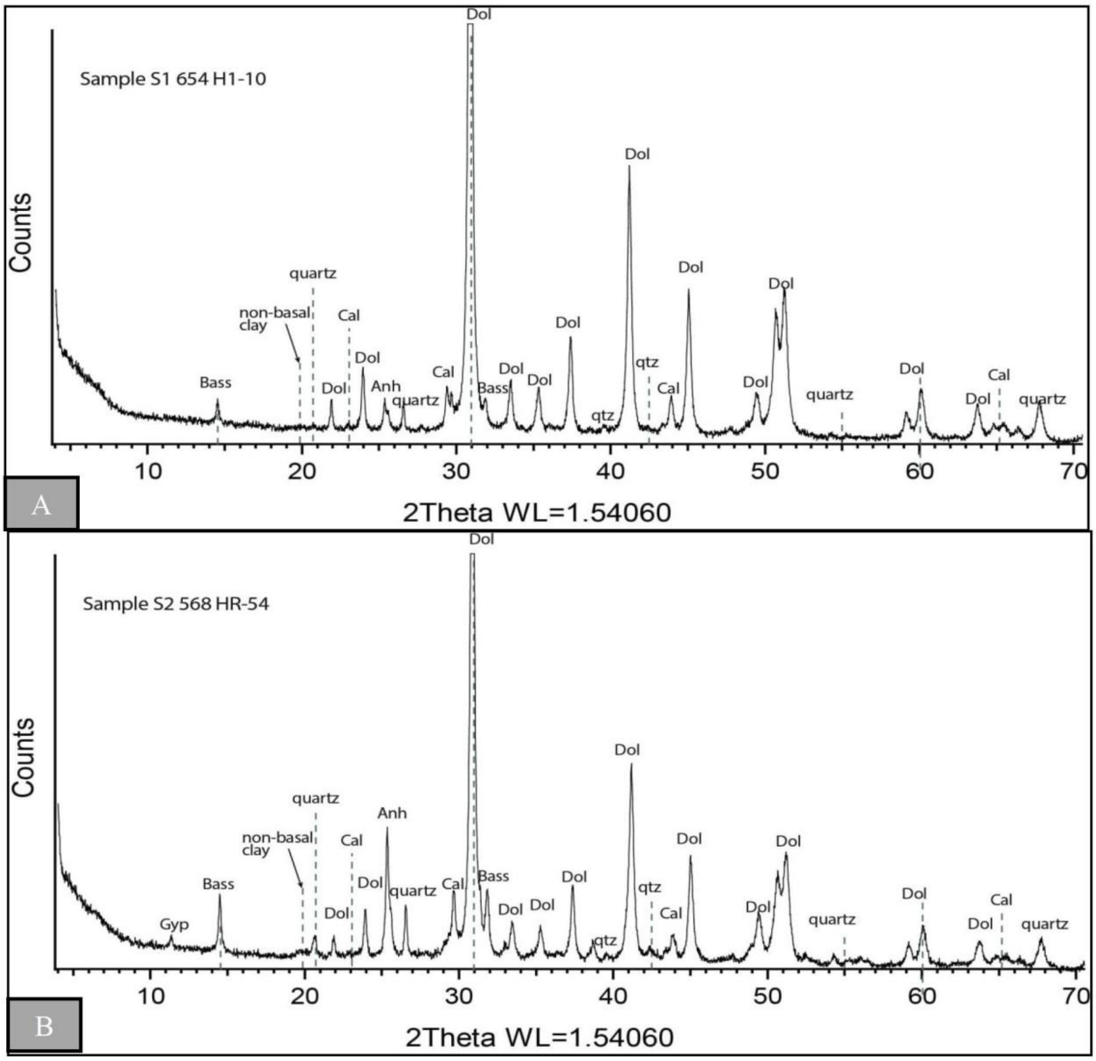

Fig.3. (A) X-ray diffraction diagrams (bulk samples) from the well (Hr-10), Depth (654m), and (B) well (Hr-54), Depth (568 m).

Petrographically, the benthic foraminifera constitute the largest proportion of skeletal components within the formation; the most important types of benthic foraminifera according to their abundance are (Milliolid, Nummulite, Peneroplis, Dentrina, Rotalina, Miogypsina, and Textularia).

As for the planktonic foraminifera, the percentage of its presence is very low compared to the benthic foraminifera and they are mostly recognized near the lower contact of the formation with the Serikagni Formation. Other types of fossils have also been identified within these sediments, such as red algae, echinoderms, molluscs, and bioclasts. The peloids are the most important non-skeletal grains within the formation, which are either fecal pellets or peloids from the micritization process on the skeletal grains, in addition to a few intraclast fragments. Micrite represents the most important component of the matrix, sometimes affected by the recrystallization process and transformed into microspar.

Microfacies of the Euphrates Formation

The classification of Dunham (1962) developed by Embry and Klovan (1971) is used to describe the textures of carbonate rocks the studied facies are divided into five main microfacies which in turn were subdivided into (15) secondary microfacies (Figs. 4,5,6) depending on the most important petrographic components. These are:

Lime Mudstone Microfacies (Fm)

Micrite, which does not exceed (10%) of the total percentage of the facies components, is the main constituent of these facies containing a small percentage of skeletal and non-skeletal grains. These microfacies are divided into two sub-microfacies:

- **Lime mudstone sub-microfacies (Fm1)**

  These microfacies are identified in the upper and middle parts of the formation, which consists of micritic groundmass and is characterized by the absence of allochems. It is affected by several diagenetic processes such as recrystallization, stylolite formation, and fenestral porosity, as well as dolomitization as represented by the fine-grained dolomite fabric, in addition to the presence of anhydrite nodules with scattered silt grains within the micritic matrix (Fig.7-A). These microfacies correspond to the standard microfacies (SMF-23) within the facies range (FZ-8) according to (Wilson, 1975; Flügel, 1982; 2004). It represents the restricted lagoon environment.

- **Bioclastic lime mudstone sub-microfacies (Fm2)**

  These microfacies consist mostly of micrite with about 90% of the total facies' components. It also contains a small percentage of benthic foraminifera, mostly affected by dolomitization (Fig. 7-B) with distinguished floating rhomb dolomite within the micrite matrix and developed at some depths into contact rhomb dolomite fabric (Randazzo and Zachos, 1984). These microfacies can be compared with the standard microfacies (SMF-19) deposited within the facies range (FZ-8) according to (Wilson, 1975; Flügel, 1982; 2004). It represents the restricted environment.

Wackestone microfacies (Fw)

This microfacies is widely distributed in the studied formation. The skeletal and non-skeletal do not exceed 50% of the total components. This main microfacies is divided into four sub-microfacies according to the main petrographic compound as follows:

- **Milliolid wackestone sub-microfacies (Fw1)**

  The grains of this microfacies consist mainly of millioids of different types (pyrgo, Quinquiloculina, Spiroluculina, Triloulilioculina, Austrotillina) (Fig. 7-C), in addition to containing bioclasts and few echinoderms. The matrix of these microfacies is composed mainly of micrite which in some parts is affected by anhydritization. These microfacies are recorded in different locations within the studied formation. It is equivalent to the standard microfacies (SMF-18) deposited within the facies zone (FZ-8) according to the models of (Wilson, 1975; Flügel, 1982, 2004) which represent the lagoonal environments.

- **Bioclastic wackestone sub-microfacies (Fw2)**

  This facies is identified in the upper and lower parts of the formation. The bioclast are the main constituents, which form about 30-35% of the total skeletal grains. It includes fragments of echinoderms, benthic foraminifera, and rare planktonic foraminifera. The matrix is micrite that was affected in some parts by dolomitization in different textures within the microfacies, such as the floating, contact, and mosaic textures. This microfacies is affected by recrystallization, and dissolution in the form of moldic and vuggy porosity, in addition to blocky cement (Fig. 7-D). This microfacies is equivalent to the standard facies (SMF-9) deposited within the facies zone (FZ-7) according to (Wilson, 1975; Flügel, 1982; 2004) models, which represent the (open circulation) lagoonal environment.

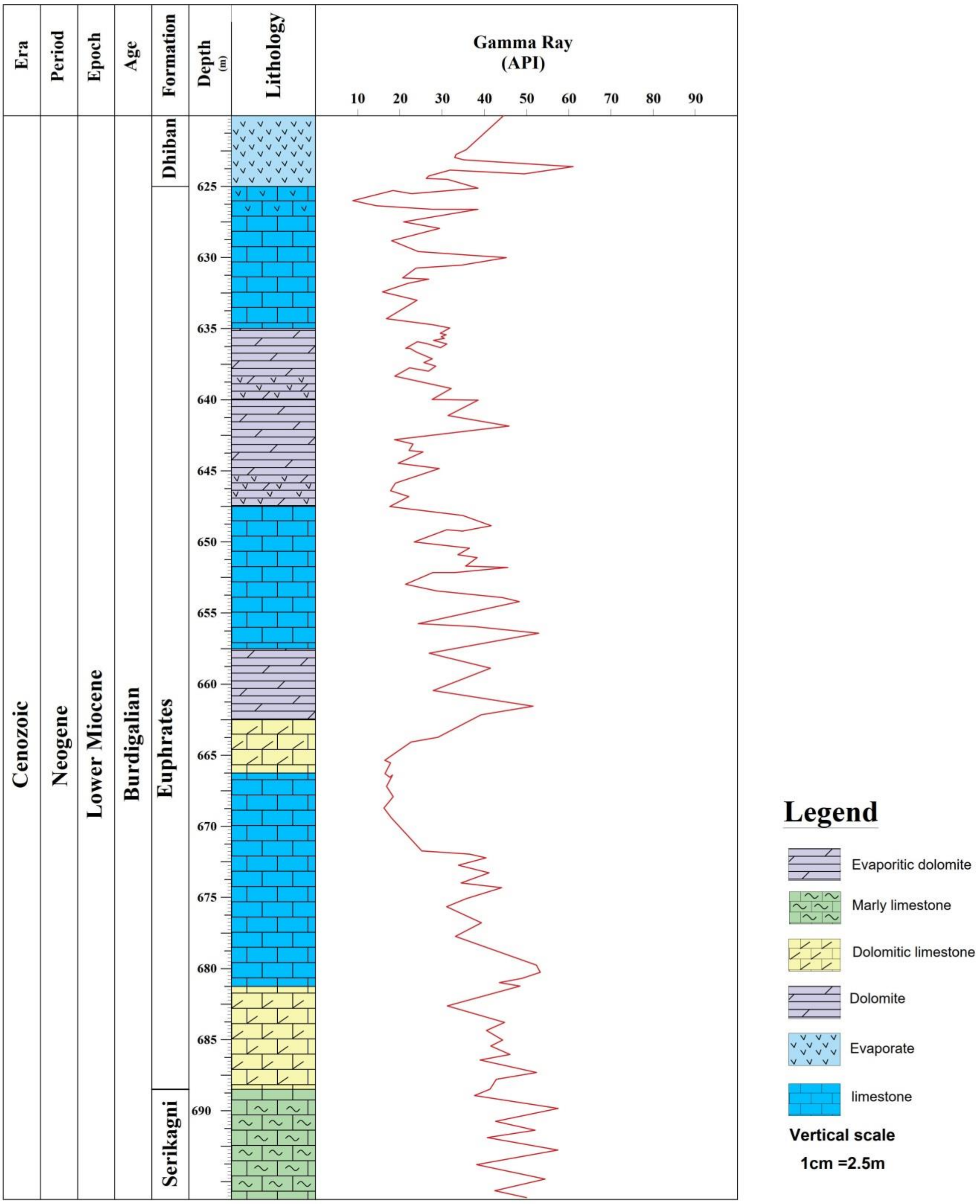

Fig.4. Distribution of main petrographic components and microfacies of the Euphrates Formation in (Hr-10) well.

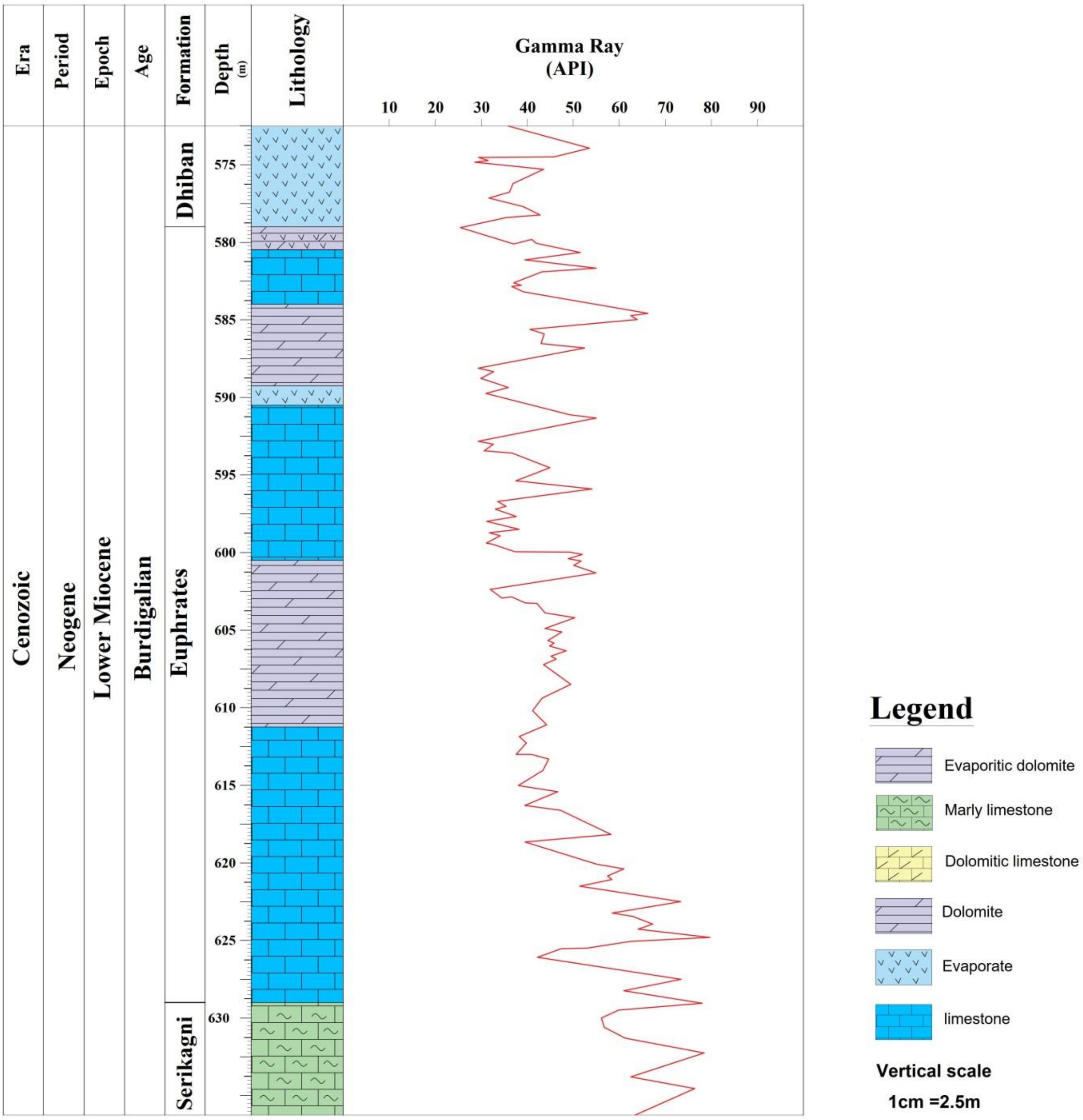

Fig. 5. Distribution of main petrographic components and microfacies of the Euphrates Formation in (Hr-11) well

• Intraclastic wackestone sub-microfacies (Fw3)

These microfacies consist mainly of intraclast, which are identified in the central parts of the formation. Dolomatization is the main diagenetic process in the form of sieve mosaic fabric in some parts of the microfacies (Fig. 7-E). These microfacies are equivalent to the standard microfacies (SMF-24) which are deposited within the facies zone (FZ-8) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent the semi-restricted environment.

• Benthonic foraminiferal wackestone sub-microfacies (Fw4)

These microfacies are identified in different parts of the formation. The benthic foraminifera (Milliolid, Peneroplis, Dentrina, Rotalina, and Textularia) form the largest percentage of the components in addition to echinoderms in a micritic matrix (Fig. 7-F).

The main diagenetic processes that affected the microfacies were dolomitization and dissolution, which formed moldic, channels and vuggy porosity. These microfacies are equivalent to the standard microfacies (SMF-8) which are deposited within the facies zone (FZ-7) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent an open marine environment.

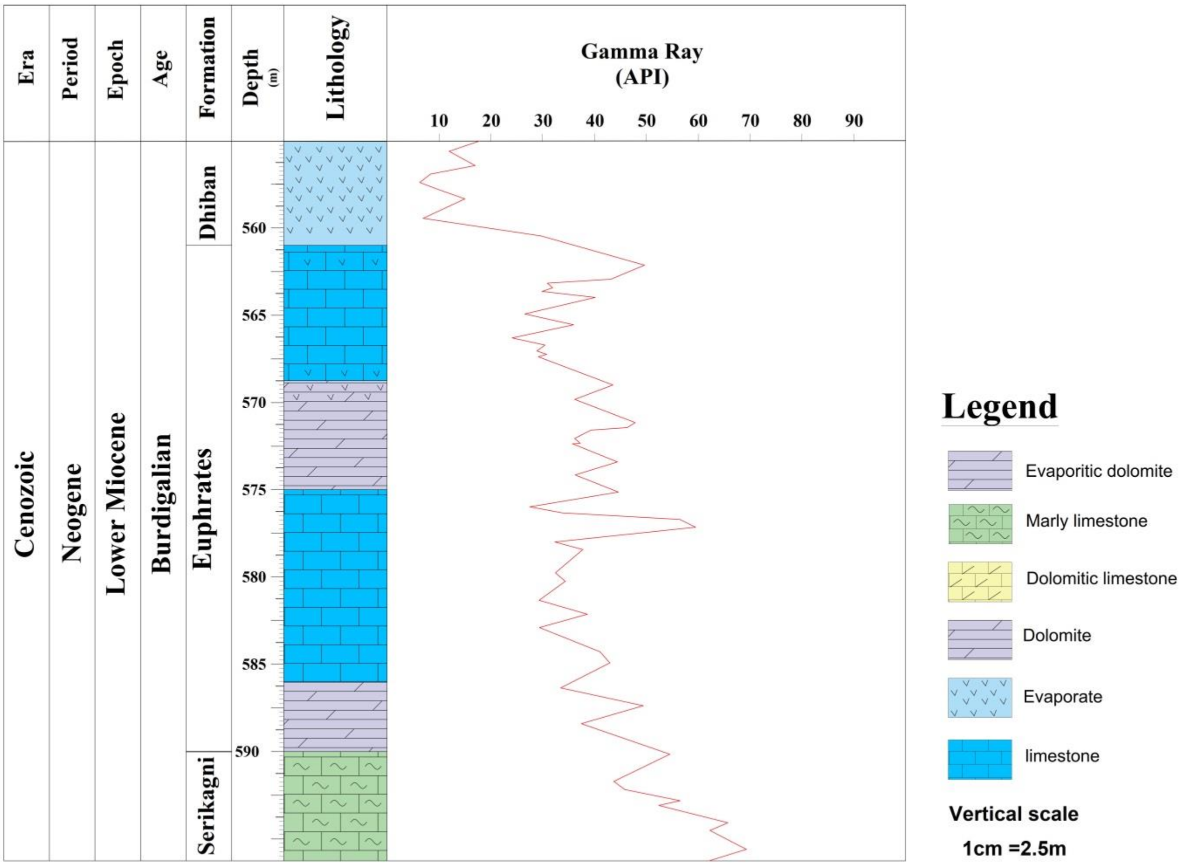

Fig.6. Distribution of main petrographic components and microfacies of the Euphrates Formation in (Hr-54) well.

Packestone microfacies (Fp)

This microfacies is considered as one of the most important microfacies in the formation. It is characterized by grain-supported facies, where the percentage of the grain ranges between 50-90% of the total components, while the matrix is composed of micrite. This microfacies is divided into five sub-microfacies as follows:

• Milliolid packstone sub-microfacies (Fp1)

These facies are identified in the upper and middle parts of the formation. These facies consist mainly of millioids of different types such as (*pyrgo*, *spiroloculina*, *Austrotillina*), which constitute about (50%) of the total components. Other types of benthic foraminifera such as (peneroplis sp) are also diagnosed, in addition to the presence of molluscas such as gastropods, pelecypods, red algae, and red algae (Fig. 7-G). Dolomitization, micritiztion, anhydritization, and dissolution in the form of moldic porosity are the main diagenetic process that affects these microfacies. According to (Wilson, 1975 and Flügel, 1982, 2004), these microfacies are equivalent to the standard microfacies (SMF-18) deposited within the facies zone (FZ-8), which represents a restricted lagoon environment.

• Peloidal packstone sub-microfacies (Fp2)

These microfacies are identified in separate parts of the formation. It consists mainly of non-skeletal grain represented by peloids with a range between 70-75% of the total facies' components in addition to few amounts of intraclast. Skeletal particles are represented by different types of benthic foraminifera, echinoderms, algae, and bioclasts. Many diagenetic processes affected these microfacies including dolomatization as represented by sieve mosaic dolomite texture, micritization, anhydritization, and dissolution that led to the form moldic porosity (Fig. 7-H). These facies are equivalent to the standard microfacies (SMF-16) deposited within the facies zone (FZ-8) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent the restricted platform.

• Milliolid-bioclastic packstone sub-microfacies (Fp3)

These microfacies mainly consist of skeletal grains represented by millioids and bioclast. The process of dissolution affected this microfacies forming the moldic porosity, it also was affected by anhydritization (Fig. 7-I). These microfacies are equivalent to the standard microfacies (SMF-10) deposited within the facies zone (FZ-7) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent the open platform environment (open marine).

• Gastropoda packstone sub-microfacies (Fp4)

This microfacies mainly consists of gastropod shells (Fig. 8-A), as well as bioclast, peloids, and skeletal grains represented by miliolid. The matrix is made of micrite. Micritization and anhydritization are the main diagenetic processes affecting these microfacies. These microfacies are equivalent to the standard microfacies (SMF-10) deposited within the facies zone (FZ-7) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent the open marine platform environment.

• Nummulitic packstone sub-microfacies (Fp5)

This microfacies is identified at the bottom of the well (Hr-54). It consists mainly of nummulite, with a percentage ranging between (70-75%) of the total skeletal grain content (Fig. 8-B), in addition to the presence of a small percentage of benthic foraminifera such as (Miogypsina, Ammonia), corals, algae, echinoderms, gastropods, bioclast, and intraclast.

Micritization and dolomitization (in the form of contact rhomb fabric) are the main diagenetic processes that affected these microfacies, in addition to mechanical compaction which led to imbrication in nummulite. These facies are equivalent to the standard microfacies (SMF-4) deposited within the facies zone (FZ-4) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent fore reef environment.

Grainstone microfacies (Fg1)

This microfacies is considered one of the main microfacies that are sparsely distributed within the sections. This microfacies is characterized by a very high ratio of skeletal and non-skeletal components exceeding (90%) of the total components embedded in aspartic groundmass. This microfacies is considered one of the most affected microfacies by diagenetic processes, such as micritization, dissolution, dolomitization, and anhydratization. Two sub-microfacies have been distinguished: Pelloidal grainstone sub-microfacies (Fg1)

It is recorded in the upper part of the well (Hr- 10, Hr-11). This microfacies consists mainly of peloid, which constitutes about (80%) of the total components in the microfacies; it mostly resulted from the micritization of skeletal grains, in addition to the small percentage of benthonic foraminifera (Fig. 8-C). The main diagenetic processes are micritization, anhydritization, and dissolution. These micrfacies are equivalent to the standard microfacies (SMF-16) deposited within the facies zone (FZ-8) according to the (Wilson, 1975; Flügel, 1982, 2004), which represents a shallow environment (shoal) within the open-circulating lagoons.

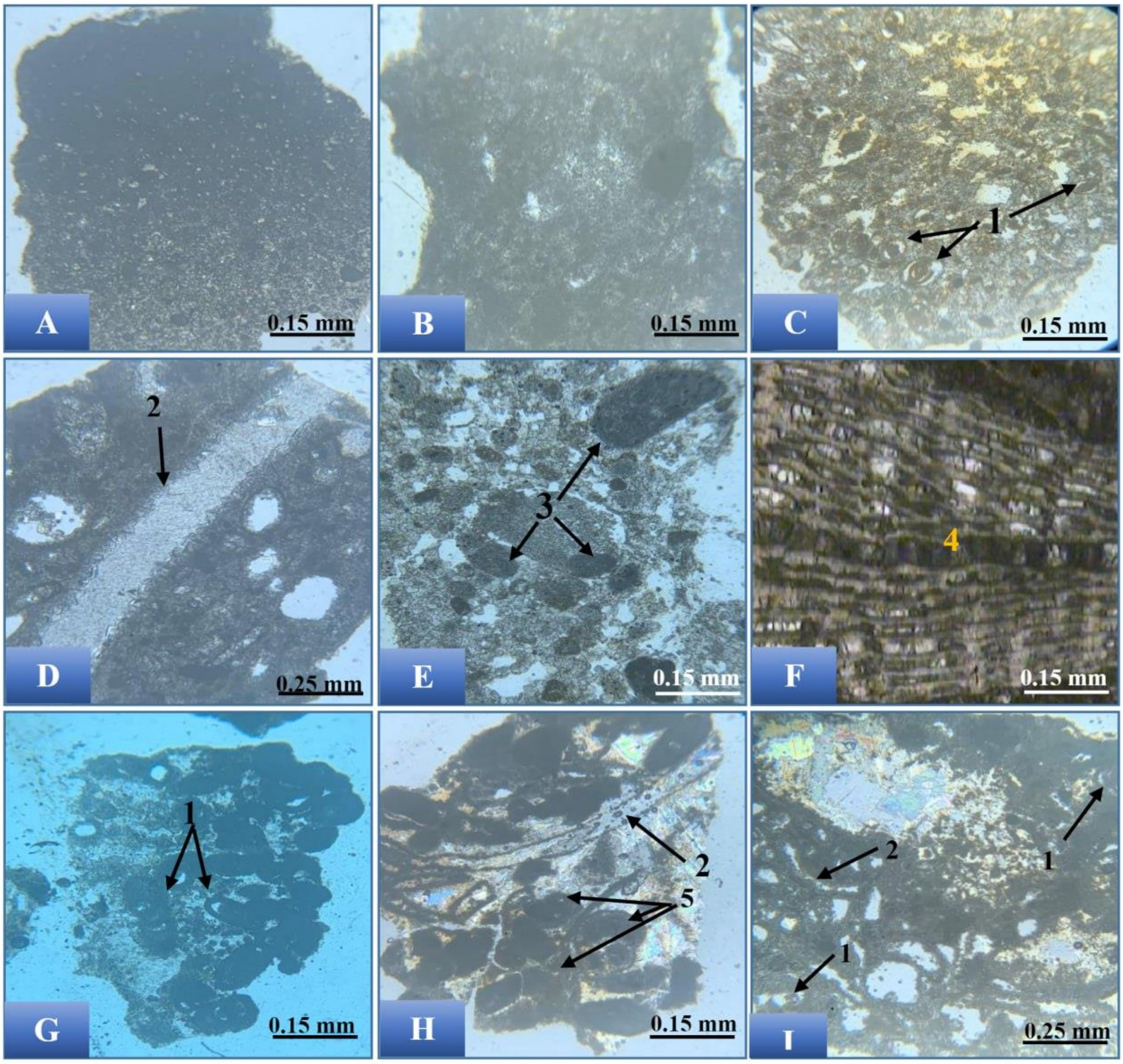

Fig. 7. Photomicrographs of some selected microfacies types of the Euphrates Formation: (A) Lime Mudstone Submicrofacies (Fm1), Hr-11, (578 m). (B) Bioclastic Lime Mudstone Submicrofacies (Fm2), Hr-10, (654 m). (C) Milliolid wackestone Submicrofacies (Fw1) (1- Milliolid), Hr-10, (648m). (D) Bioclast wackestone Submicrofacies (Fw2), Hr-10, (682 m). (E) Intraclast wackestone Submicrofacies (Fw3), Hr-10, (642 m). (F) Benthonic wackestone Submicrofacies (Fw4), Hr-10, (627m). (G) Milliolid packestone Submicrofacies (Fp1), Hr-11, (582 m). (H) Peloidal packestone Submicrofacies (Fp2), Hr-10, (632 m). (I) Milliolid-Bioclast packestone Submicrofacies (Fp3), Hr-11, (622 m). (1- Milliolid 2- bioclast 3- intraclast 4- Miogypsina 5- Peloid).

Benthonic foraminiferal grainstone submicrofacies (Fg2)

This microfacies is diagnosed in the middle part of the well (Hr-10). It consists mainly of different types of benthic foraminifera such as (*Peneroplis* sp, *Spiroloculina* sp, *Dentrina* sp) in addition to the presence of gastropods (Fig. 8-D). Dissolution is the main diagenetic process in the form of moldic porosity. It is equivalent to the standard microfacies (SMF-

18) deposited within the facies zone (FZ-8) according to (Wilson, 1975; Flügel, 1982, 2004), which represents the restricted platform.

Boundstone microfacies (Fb)

These microfacies have been identified in the lower parts of the formation. It represents calcareous deposits bounded together during sedimentation, such as ridges and domes (reef and bioherms) (Dunham, 1962). The skeletal components form about (90-95%). It is composed of in situ organisms such as red algae, coralline algae, and bryozoan; it includes also pores and voids that exist within the reef frame. These facies are divided according to Embry and Klovan (1971) into two microfacies:

• Framestone sub-microfacies (Fb1)

These microfacies consist of red algae or (coralline algae). It is diagnosed in the lower part of the well (Hr-11), and its main microfacies that make up the structure of the reef, represent the skeletal organisms (James, 1979) (Fig. 8-E). It is noted that they exist in a form similar to beehives, and they are little affected by the diagenetic processes. These microfacies are equivalent to the standard microfacies (SMF-7) deposited within the facies zone (FZ-5) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent the reef buildings.

• Rudstone sub-microfacies (Fb2)

These microfacies are identified in the lower parts of the well (Hr-54). It consists mainly of pieces of algae, echinoderms, and benthic foraminifera, in addition to the presence of a few planktonic foraminifera (Fig. 8-F). Flügel (2004) mentioned that these microfacies are caused by the precipitation of large bioclast from the reef core into slop areas. These microfacies are equivalent to the standard microfacies (SMF-6) deposited within the facies zone (FZ-4) according to (Wilson, 1975; Flügel, 1982, 2004) models, which represent of the slope environment.

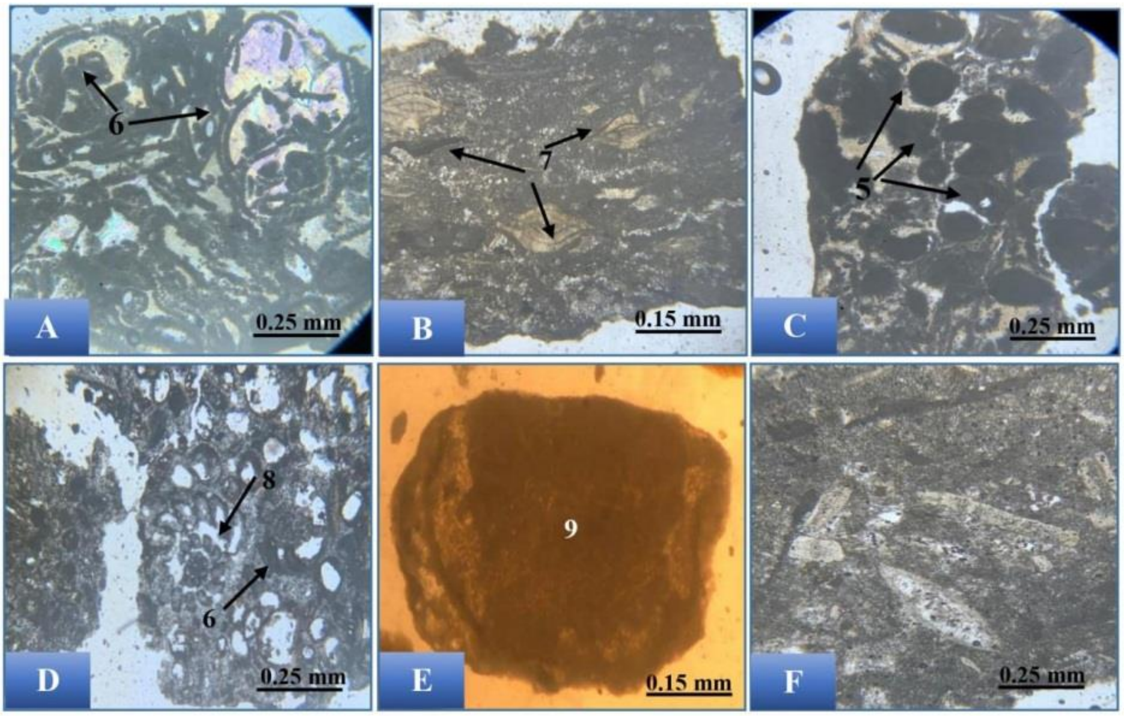

Fig.8. Photomicrographs of Euphrates Formation: (A) Gastropoda packestone Submicrofacies (Fp4), Hr-10, (621 m). (B) Nummulitic packestone Submicrofacies (Fp5), Hr-54, (588 m). (C) Peloidal rainstone Submicrofacies (Fg1), Hr-10, (632 m). (D) Benthonic Foraminifera grainstone Submicrofacies (Fg2), Hr-10, (648 m). (E) Framestone Submicrofacies (Fb1), Hr-11, (622 m). (F) Rudstone Submicrofacies, Hr-(54), (594 m). (5- Peloid 6-Gastropoda 7- Nummulite 8- Peneroplis 9- Alge).

Discussion

Depositional Environment

Based on the petrographic and microfacies studies of the Euphrates Formation, it is found that the formation was deposited within a shallow marine environment that extends from the restricted lagoon to the slope area, represented by the rimmed platform. It has been divided into several secondary environments and compared with the standard microfacies (Flügel, 2010), which include (lagoon, back reef (shallow), and reef core, for reef environments) as shown in Table (2).

Lagoon Environment

This environment is confined between the land and any marine barrier, where it is considered as a restricted environment, but most often it is connected to the open sea through tidal channels that extend within the body of the reef or marine barrier. It is equivalent to the facies zone (FZ-8) of Wilson (1975). The succession of this secondary environment is among the most common succession in the Euphrates Formation.

Table 2: Microfacies and environment zones within the Euphrates Formation

Environment zones	SMF of Flugel (1982) and FZ of Wilson (1975)			Microfacies of Euphrates Formation
	Location of SMF	FZ	SMF	
Lagoon Environment	Restricted	8	23	Lime mudstone sub-microfacies (Fm1)
			19	Bioclastic lime mudstone Sub-microfacies (Fm2)
			18	Miliolid wackestone Sub-microfacies (Fw1)
			24	Intraclast wackestone Sub-microfacies (Fw3)
			8	Benthonic foraminifera wackestone sub-microfacies (Fw4)
			18	Miliolid packstone sub-microfacies (Fp1)
			16	Peloidal packstone Sub-microfacies (Fp2)
			18	Milliolid- bioclastic packstone sub-microfacies (Fp3)
Back reef	Open marine	7	9	Bioclast wackestone Sub-microfacies (Fw2)
			10	Gastropoda packstone sub-microfacies (Fp4)
			16	Peloidal grainstone sub-microfacies (Fg1)
			18	Benthonic foraminifera grainstone sub-microfacies (Fg2)
Reef Environment	Margin reef	5	7	Framestone sub-microfacies (Fb1)
Fore reef Environment	Slope	4	4	Nummulitic packstone Sub-microfacies (Fp5)
			6	Rudstone sub-microfacies (Fb2)

The most important microfacies characterized this environment are; lime mudstone sub-microfacies (Fm1), Bioclastic lime mudstone sub-microfacies (Fm2), miliolid wackestone sub-microfacies (Fw1), intraclast wackestone sub-microfacies (Fw3), benthonic foraminiferal wackestone sub-microfacies (Fw4), miliolid packstone sub-microfacies (Fp1), peloidal packstone sub-microfacies (Fp2), milliolid- bioclastic packstone sub-microfacies (Fp3)).

The presence of anhydrite nodules in abundance within microfacies (Fm1) indicates sedimentation during hot, dry climatic and in a restricted and evaporitic environment (Pratt and James, 1986). In addition, association of aphanotopic dolomite texture with anhydrite nodules indicates its deposition within the restricted lagoon (Shinn et al., 1965).

The presence of miliolids indicates that the sedimentation has occurred in a shallow and confined marine environment. The diversity and abundance of milliolid numbers indicate a lagoon environment, with common species of milliolid such as (*pyrgo, Quinquelaculina, Triloculina*) are usually found in back reef lagoon environment (Jordan, 1973). Pomar et al. (1996) characterized this environment by benthic foraminifera lime packstone and grainstone containing, fragments of molluscs, echinoderms, and red algae. The presence of a few anhydrite nodes indicates that the environment of this lagoon is semi-restricted with common evaporation.

Longman (1981) mentioned that the type of sediment in this environment varies depending on the nature of the lagoon. The deposits of the restricted lagoon are characterized by a muddy nature with different salinity levels, while the open circulation lagoon is characterized by normal salinity and diversity in biota and sediment types, and is connected with the open sea through tidal channels (tidal inlet).

Back Reef (Shoal) Environment

Is a shallow marine environment that extends from the coast to the body of the reef and is represented by the facies zone (FZ-7) of Wilson (1975). The main microfacies represented in this facies zone are (bioclastic wackestone sub-microfacies (Fw2), Gastropoda packstone sub-microfacies (Fp4), peloidal grainstone sub-microfacies (Fg1), benthonic foraminifera grainstone sub-microfacies (Fg2). The presence of Miogypsina indicates a shallow marine environment behind the reef (Renama and Troelstra, 2001). The association of miliolides and large rotalides with algae fragments within the lime packstone microfacies indicates a shallow high energy-back reef (shoal) environment (Moussavian and Vecsei, 1995; Ehrenberg et al., 1998; Asaad et al., 2022; Farouk et al., 2022). Ghose (1977) mentioned that the presence of rotalides with milliolid indicates the environment of the back reef lagoons, while Milliman (1974) indicated that the presence of echinoderms indicates an open, shallow marine environment with medium salinity.

Reef Environment

The sediments of the reef environment are formed from the gathering of reef-building organisms in addition to the debris of these organisms in the shallow marine areas between the back reef lagoon and the fore-reef slope. The rate of reef growth is highest near the sea level and decreases with increasing depth (Sarg, 1988; Pomar, 1991). Red algae are the main reef-building organism in the Euphrates Formation. The most important microfacies of this environment are (Framestone Submicrofacies, Fb1), which are represented by the facies zone (FZ-5), where these microfacies consist of red algae as the main organisms that build reef structures, in addition to some organisms and their debris confined between their voids (Longman, 1981).

Fore-reef Environment

It represents the marine environment that extends towards the sea from the front end of the reef body, i.e., from the bottom of the growth site of the reef-building organisms (Longman, 1981). This environment is represented by the facies zone (FZ-4) of Wilson (1975). The most important facies that characterized this environment are (Nummulitic packstone sub-microfacies (Fp5) and rudstone sub-microfacies (Fb2)), where these microfacies are located in the shallow part of the environment in front of the ridge. This environment is characterized by a wide distribution of red algae debris, and benthonic foraminifera (Nummulite) which is considered one of the most common benthic foraminifera in the areas in front of the reef (Al-Haq et al., 1988; Haq and Boersma, 1998). They exist in a shallow rise (shoal) (Al-Haj, 2001) or it is merged with the debris of the reef resulting from the breaking of marine waves, as in facies of the Euphrates Formation, where large pieces of red algae with Nummulite are observed. On the other hand, the presence of pieces of algae and corals indicates high-energy environments that led to their breakage and sedimentation in the sloped parts in front of the reef. Additionally, the presence of a few planktonic foraminifera within the microfacies of this environment indicates that it is near the open sea. Henson (1950) mentioned that the formation of such a shallow environment in the region of the reef slope resulted from the accumulation of large benthic foraminifera, especially the nummulite. The large-size nummulite accumulated in the shallow parts of the fore reef (Chose, 1977).

Sedimentary model of the Euphrates Formation

According to facies analysis data and their environmental implications for the current study, a sedimentary model is derived for the formation, which should explain the process that led to the deposition of the facies of the formation taking into regard the tectonic processes that affected the topography of the sedimentary basin.

The most acceptable model for formation succession is the rimmed platform model (Read, 1985). This type of platform model is usually formed when there is a diversity of fauna, which is usually accompanied by transgression of the sea. This is manifested by the presence of great diversity in the fauna and calcareous nannofossils associated with the marine transgression during the Burdigalian period in other regions (Shama et al., 2023; Fig. 9). Depending on the facies analysis with the facies distribution, the paleogeography of the study area during the early and middle Miocene period for the Euphrates Formation, it was found that the formation was deposited in a relatively wide and shallow sedimentary basin, where during the Oligocene - early Miocene, the movement of (Savian) on the Zagros line, the basin was shallow due to rise of the Tanjero-Balambo basin, and then developed into a shelf environment during the early and middle Miocene, where a relatively wide basin appeared (Jassim and Buday, 2006). This led to shallow facies deposition of several formations such as the Euphrates, Jeribi, and Dhiban, where sedimentation processes continued in the deep parts of the basin in northern Iraq represented by the sequences of the Serikagni Formation, the evaporite facies that spread in the coastal continental parts of the study area, which corresponded with the sequences of the formation of the Euphrates and Jeribe with coastal and shallow marine facies, which interbedded with the deep marine facies for the Serikagni Formation (Farouk et al., 2023).

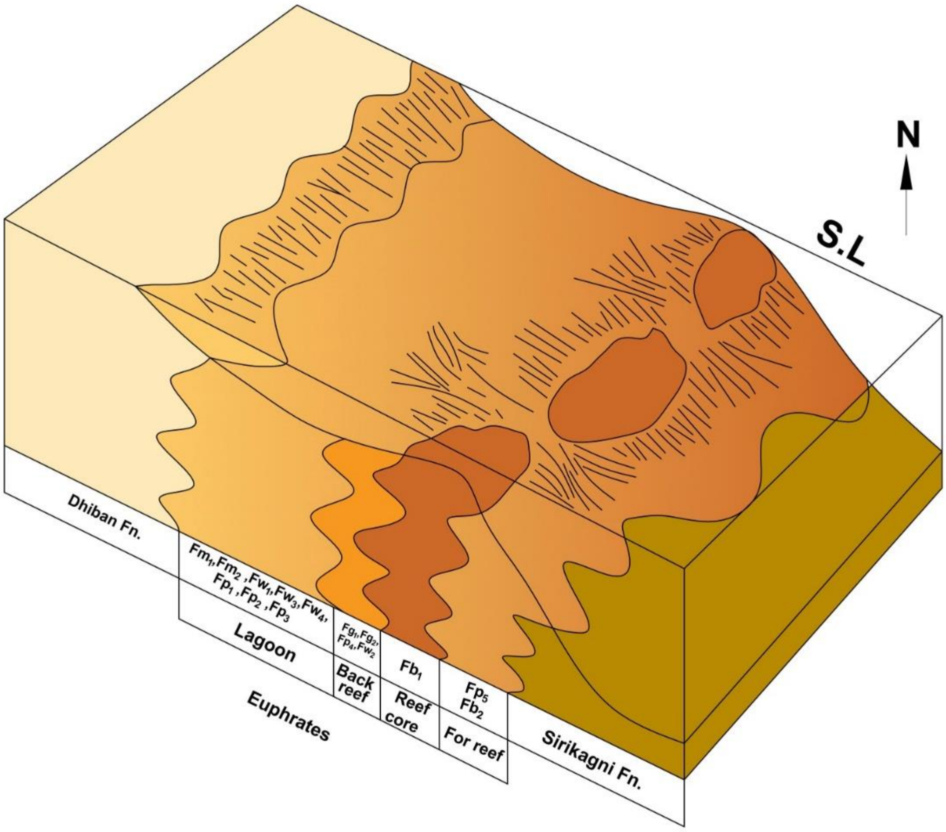

Fig. 8. Depositional model of the Euphrates Formation in the study area

Conclusion

The Euphrates Formation appears in all sections of the wells under study with varying thicknesses and consists of limestone, dolomitic limestone, and dolomite. The lower and upper contacts of the formation within the study area are conformable with the Dhiban and Serikagni formations respectively. The gradual change from the shallow facies of the Euphrates Formation to the deep basin facies of the Serikagni Formation is indicated by the abundance of planktonic foraminifera, and the change in the gamma-ray between the two formations in addition to the dominance of anhydrite in the Dhiban Formation.

The mineralogical study shows that the formation consists mainly of calcite, and dolomite and a very small percentage of quartz. The petrographic study shows the dominance of the skeletal grains represented by the benthic foraminifera (Milliolid, Nummulites, Peneroplis, Dendritina, Miogypsina, Textularia, and Ammonia) of the most important genera available within the formation sequences, as well as the presence of a good percentage of red algae, echinoderms, algae, bioclast, molluscs, and bryozoan. While the non-skeletal components constitute a smaller percentage represented by the peloids and intraclast. The matrix is composed mainly of micrite, which is affected by diagenetic processes (dolomitization and anhydritization) with a small presence of sparite, which is in the form of cement filling voids or formed by recrystallization. The formation also was affected by several diagenetic processes (recrystallization, compaction, micritization, and dissolution). Five main microfacies, which can be divided into (15) microfacies, are distinguished.

The diversity of the microfacies reflects the sedimentation within a range of shallow marine environments, four facies zone (FZ) (8, 7, 5, 4) were deposited within four environments (the lagoon, back reef (shoal), reef core, and fore reef environment). According to the facies analysis and their environmental implications, the sedimentary model is derived for the formation sequences within the Hamrin field, and the rimmed platform model proposed by (Read, 1985) is the most acceptable model for Euphrates succession. Depending on the paleogeography of the Burdigalian period within the study area and the equivalent formations of the Euphrates formation, it is found that the formation was deposited in a relatively wide and shallow basin, where during the (Oligocene - Early Miocene) it was affected by the (Savian) movement on the Zagros line, which became shallow through the rise of the Tanjero-Balambo basin, then developed into a shelf environment during the early and middle Miocene, where a relatively wide basin appeared (Jassim and Goff, 2006). This in turn led to the sedimentation of several shallow formations represented by the formation of the Euphrates and Jeribe deposits in a shallow marine environment within coastal areas and restricted lagoons, while sedimentation processes were continued in the deep parts of the basin, which are represented by the Serikagni Formation.

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