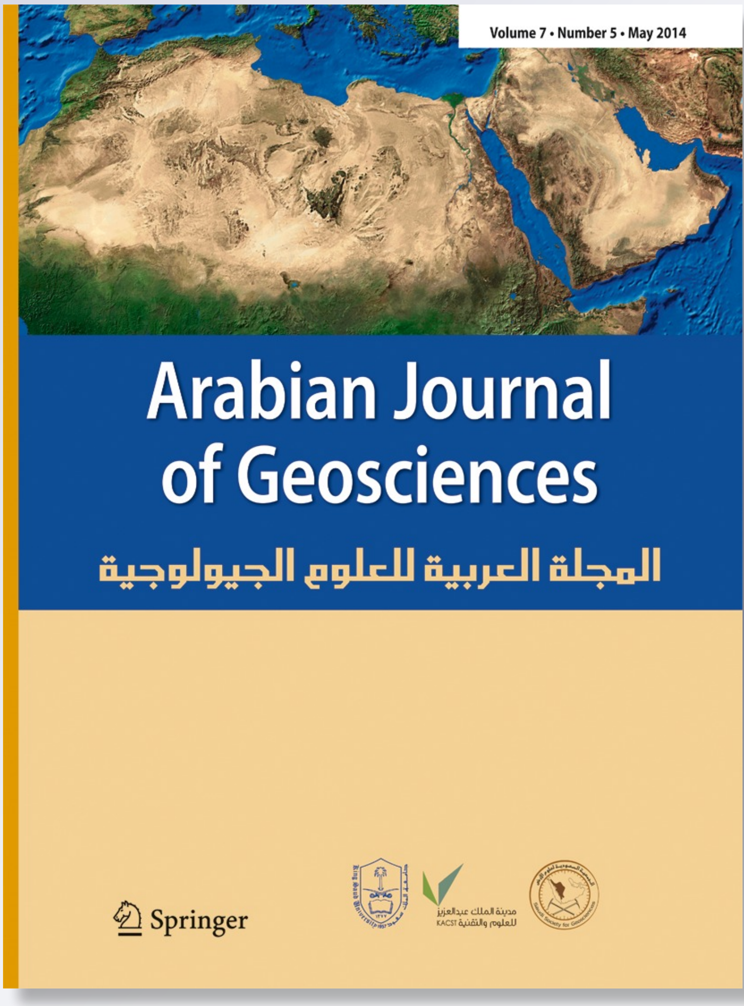
Facies analysis and geochemistry of the Euphrates Formation in Central Iraq

Moutaz A. Al-Dabbas, Salih Muhammad Awadh & Ayad Abed Zaid

Arabian Journal of Geosciences

ISSN 1866-7511
Volume 7
Number 5

Arab J Geosci (2014) 7:1799-1810
DOI 10.1007/s12517-013-0932-3



Arab J Geosci (2014) 7:1799–1810
DOI 10.1007/s12517-013-0932-3

ORIGINAL PAPER

Facies analysis and geochemistry of the Euphrates Formation in Central Iraq

Moutaz A. Al-Dabbas · Salih Muhammad Awadh · Ayad Abed Zaid

Received: 26 December 2012 / Accepted: 15 March 2013 / Published online: 28 March 2013

Abstract The Euphrates Formation (Lower Miocene) in the Central Iraq consists mainly of shallow marine carbonates. Two hundred ten samples were collected from 21 wells (1E to 21ED) at Bahar Najaf area, and 18 samples were collected at Wadi Asadi in Baghdadi area, from Euphrates Formation. Four microfacies are identified, namely mudstone, wackestone, packstone, and rare grainstone with ten submicrofacies. The allochems in the Euphrates Formation are dominated by bioclasts. Peloids, ooids, and intraclasts are less abundant. The common fossils in the Euphrates Formation are miliolids, algae, ostracods, *Miogypsina*, and abundant shells of pelecypods and gastropods. Calcite and dolomite are the predominant mineral components of the Euphrates Formation. The carbonates of the Euphrates Formation have been affected by a variety of diagenetic processes such as micritization, dissolution, neomorphism, cementation, stylolitization, dolomitization, dedolomitization, and silicification. The Euphrates Formation was deposited in open to restricted platforms which indicated lagoonal environment with warm and restricted open circulation. In fact, prevalence and abundance of micrite provide an evidence of a shallow marine of low-energy environment and, in some places, may be approaching to be stagnant environment. The average of CaO in Najaf area (51.5 %) is slightly lower than that in Baghdadi area (53.3 %), which was reflected in calcite content found being 91 % in Najaf and 94 % in Baghdadi. Dolomite and gypsum appeared as minor minerals beside calcite, so low concentration of MgO (0.83 % in Najaf; 0.63 in Baghdadi) and SO_3 (0.55 % in Najaf; 0.53 % in Baghdadi) was reflected information of small amounts of dolomite (2 % in Najaf; 1.6 % in Baghdadi) and gypsum (0.7 % in Najaf and 0.6 in Baghdadi) in the Euphrates Formation. The insoluble residue in Najaf area (4.37 %) is relatively higher than that in Baghdadi area (1.9 %), indicating that the Euphrates Formation in Najaf Area has deposited in an environment closer to the shoreline. Concentrations of the trace elements Sr, Mn, and Fe which support the conclusion that reminds the Euphrates Formation had been deposited in a shallow marine environment of quiet energy, with the likelihood that the shoreline was the nearest to Najaf rather than to Baghdadi.

Keywords Euphrates Formation · Bahr Najaf · Petrography · Carbonate facies · Geochemistry · Depositional environment

M. A. Al-Dabbas · S. M. Awadh (✉) · A. A. Zaid
Department of Geology, College of Science, University of Baghdad, P. O. Box 47182, Aljaderia, Baghdad, Iraq
e-mail: salihauad2000@yahoo.com

M. A. Al-Dabbas
e-mail: profaldabbas@yahoo.com

Introduction

The Euphrates Formation (Lower Miocene) was first described by (Bellen RC et al. 1959) where the type section was near Wadi Fuhaimi near Anah. The formation is composed of dolomitic, fossiliferous, and oolitic limestone with green marls at the top (Cytroky and Karim 1971). Buday (1980) divides this formation into three units from bottom to top: unit A, cavernous and conglomeratic limestone; unit B, shelly limestone; and unit C, marly and chalky limestone. Many scientists studied this formation in different locations from the stratigraphy, sedimentology, and the environment of deposition, point of view (Al-Ghreri 1985; Gayara and Taha 1989, 1995; Ali 2011; Al-Dabbas et al. 2013). Some researchers recommended or used the geochemical studies in solving geological problems, especially those relating to the environments of deposition (Banat and Al-Dyni 1981; Kettaneh and Sadik 1989). Therefore, it is believed that the use of chemical elements analysis is useful to interpret the depositional environment of sedimentary rocks and their origin, in the light of few researches, which had been done on the geochemistry of this formation, (Al-Kufaishi and Al-Aasm 1978).

This research included petrographical, mineralogical, and geochemical studies for Euphrates Formation (Lower Miocene) in two areas, the first at the area within the Najaf Governorate and the second at the Baghdadi area within Anbar Governorate. The first study area is located near Bahar Najaf area with the longitudes (44 00′ 00″ to 44° 30′ 00″) and latitudes (31° 30′ 00″ to 32° 00′ 00″), southwest of Bahr Najaf area to the west of Najaf city with distance of about 35 km (Fig. 1). The lower contact of the Formation at Bahar Najaf area is unconformable with the underlying Dammam Formation (Middle Eocene), while the quaternary deposits rising up over this formation (Fig. 2) (Jassim and Goff 2006). The second study area is located in Wadi Asadi at Baghdadi area with the longitudes (42° 32′ 20″ to 42° 30′ 20″) and latitudes (33° 52′ 30″ to 33° 50′ 30″) (Fig. 1). The lower contact of the formation at the Wadi Asadi at Baghdadi area is unconformable with the underlying Anah Formation (Upper Oligocene), while the Fatha Formation (Middle Miocene) conformably overlies the Euphrates Formation (Fig. 3).

This study aims to analyze the sedimentary facies and geochemistry to establish the deposition environment of the Euphrates Formation at the studied areas

Methods of study

Sample collection

At Bahar Najaf area, 210 samples were collected from 21 wells (1E to 21ED) (ten core samples are collected from each well) of the Euphrates Formation from Bahar Najaf area (Fig. 4) according to variations in color, hardness, degree of crystallization, and texture (Figs. 2 and 4). These wells were drilled by the Iraqi Geological Survey. The wells were drilled as a square net square (500×500 m), while the total area is 4 km^2 (Fig. 4). The description of lithology is shown in Fig. 2. At Wadi Asadi, Baghdadi area, 18 samples were collected from Euphrates Formation (Lower Miocene) along cliff of 18 m in Wadi Asadi, Baghdadi area (Fig. 1). The description of lithology is shown in Fig. 3.

Laboratory works

Laboratory works comprised petrographical, mineralogical, and geochemical studies. Thin sections were studied by using polarized microscope (at the Department of Earth Sciences, College of Science, University of Baghdad). X-ray diffraction technique was also used beside polarized microscope for confirming the identity of minerals at the Iraqi Geological Survey (Geosurv). Clay minerals were separated from non-clay minerals in order to recognize the type of clay minerals. Laboratory works can be described as 100 thin sections were made from the boreholes and outcrops (four to five for each well) for Bahr Najaf area and 18 thin sections for Wadi Asadi at Baghdadi area, to study the petrography according to the classification of Dunham (1962) and Folk (1962). Thin sections were stained with Red Alzarine stain to facilitate discrimination of calcite–dolomite. Each microfacies was compared by Flugel (1982, 2004) and Wilson (1975). The diagenetic processes, such as micritization, neomorphism, dissolution, stylolitization, dolomitization, dedolomitization, cementation, and silicification, were also studied. Stratigraphic sequences at Najaf and Baghdadi areas are illustrated in Figs. 2 and 3.

Twenty samples were prepared for mineralogical study using X-ray diffraction technique (XRD-7000, type Maxima, 2008) at the Geosurv Laboratories. The mineralogical composition (in percent) of calcite, dolomite, and gypsum is calculated based on molecular weight of oxides (Table 1). One hundred rock samples collected from 21 wells at Bahr Najaf area, in addition to 18 rock samples from Wadi Asadi in Baghdadi area, were analyzed for CaO, MgO, SiO_2, Al_2O_3, Na_2O, K_2O, SO_3, Cl^-, loss on ignition (LOI), Sr, Fe, and Mn. The percentages of calcite, dolomite, and gypsum were calculated based on CaO, MgO, and SO_3 as well as the excess of CaO, respectively (Table 1).

Results and discussion

Petrography

The petrographic results revealed that the carbonate rocks of the Euphrates Formation in the study areas (Baghdadi and Najaf) consist mainly of micrite and various skeletal grains, as well as nonskeletal grain components as follows:

1. Grains and micrite

   The grains are divided into skeletal grains, which include fossils and its fragments and nonskeletal grains which include pellets, intraclast, and oolites (Tucker 1982). The common fossils in the Euphrates Formation are miliolids, alga, ostracods, *Miogypsina*, and abundant shells of pelecypods and gastropods, in addition to mollusks (Gayara and Taha 1989), as well as different sizes of shells of coquina and foraminifera. It was noticed that the voids of some fossils are filled with micrite which is found in small spots. It was also noticed that sparry calcite cement filled the other gaps of fossils due to recrystallization. Micrite is represented by microcrystalline and neomorphised to microspar.

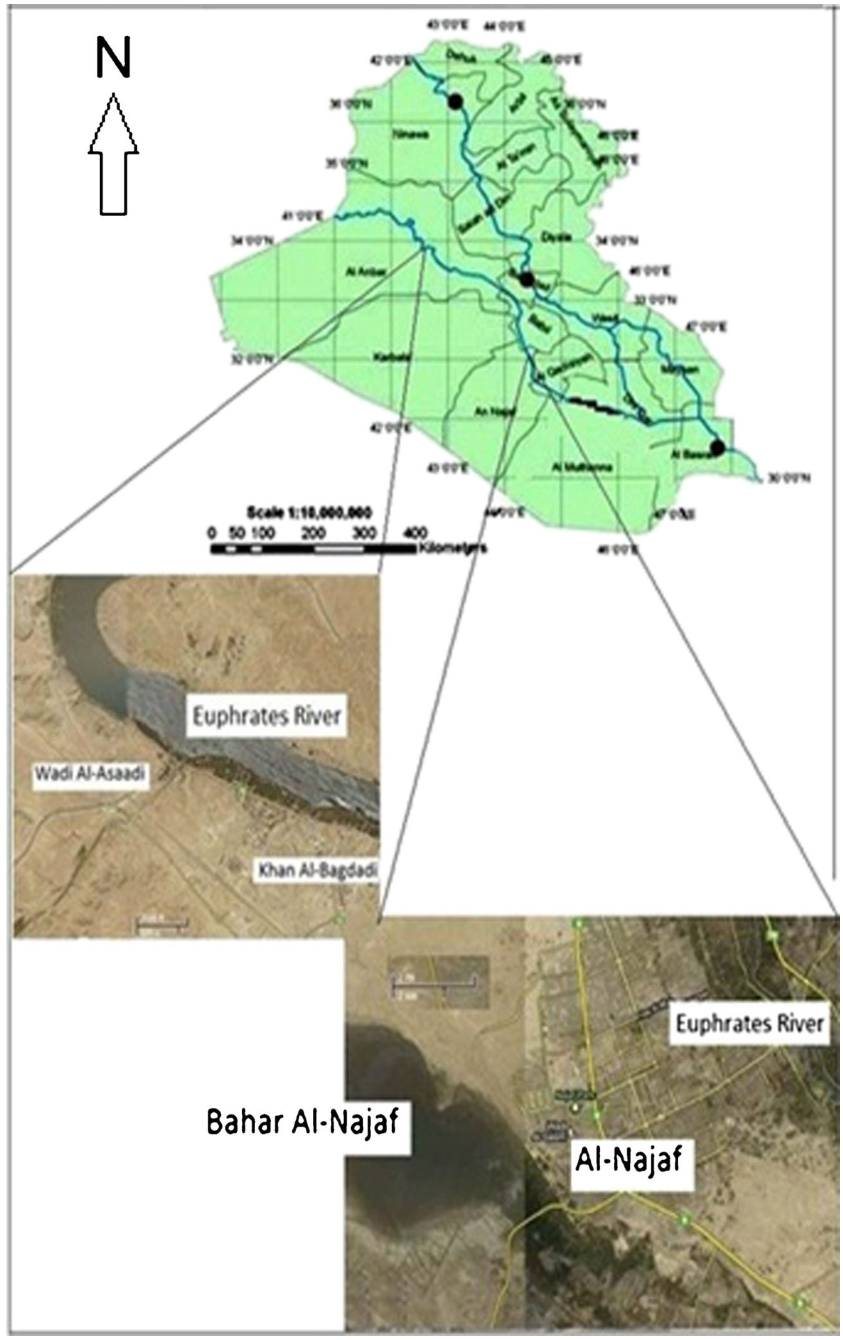


Fig. 1 Location map of the studied areas at Bahar Najaf and Wadi Asadi in Baghdadi area

In the Euphrates Formation, pellets are the main nonskeletal grains, especially in packstone microfacies. Some pellets are probably micritized doolites. Pellets occur in packstones and wackestones, and they have characteristics of shoal and subtidal environments, respectively (Tucker 1982, 1985). In addition, Intraclast are interpreted to be reworked grains within the sub- and intertidal environments arising from current agitation (Wilson 1975).

The micrite results to transformation of lime mud which has composed of calcite and or aragonite minerals (Tucker and Wright 1990). Diagenetic processes were effected with some parts of the matrix. The micrite percentage in this formation of rocks is more than (90 %). Its color is brown, and its appearance is red brown rich of iron oxides. The micrite fills the voids in most of the fossils.

2. Diagenetic processes

The diagenetic processes are all the processes which happened on the sediments after deposition, such as dissolution, cementation, and lithification (Flugel 1982; Selley 2000, 2007). These processes give sedimentary rocks many characteristics observed in outcrops, hand specimen, and in

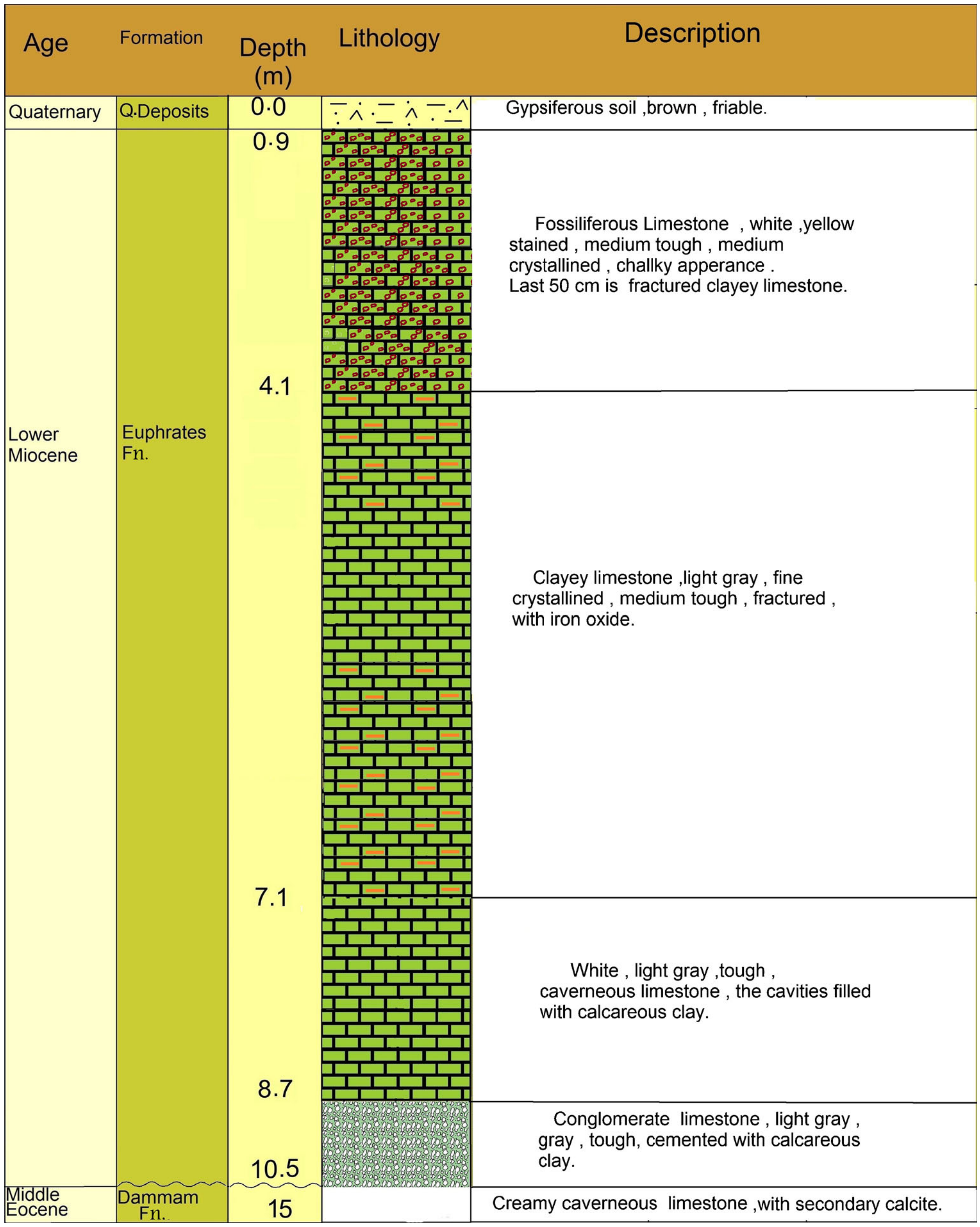


Fig. 2 Stratigraphic sequence of Euphrates Formation in the Bahar Najaf area (well no. 5ED, depth 15 m.); (after Al-Shammari 2010)

thin section. The Euphrates Formation underwent several diagenetic processes as follows:

a. Micritization

The micritization is the most common process affecting the skeletal fragments in the packstone and wackestone microfacies in the shallow environment of the Euphrates Formation. It is an early diagenetic process where skeletal grains were micritized shortly after deposition due to fungi action and construction of micritic envelopes (Tucker and Wright 1990).

b. Dissolution

Dissolution is considered as one of the most important diagenetic processes in the Euphrates Formation. It is a more effective diagenetic process than cementation in most of the studied facies. The effect conditions on the dissolution are temperature, partial pressure for dioxide carbon and pH with increase of the hydrostatic pressure, and the rock fractures (Flugel 1982). Dissolution in this environment improved the carbonates porosity. This process acts to destroy the internal structures of the skeletal grains leaving the micritic envelope to form moldic porosity or vuggy porosity or to enlarge the presenting vugs to form cavern porosity or channel porosity. In some times, there are open space structures due to the effect of the selective dissolution. The porosity was studied in the Euphrates Formation according to Choquette and Pray (1970). The results indicated the following:

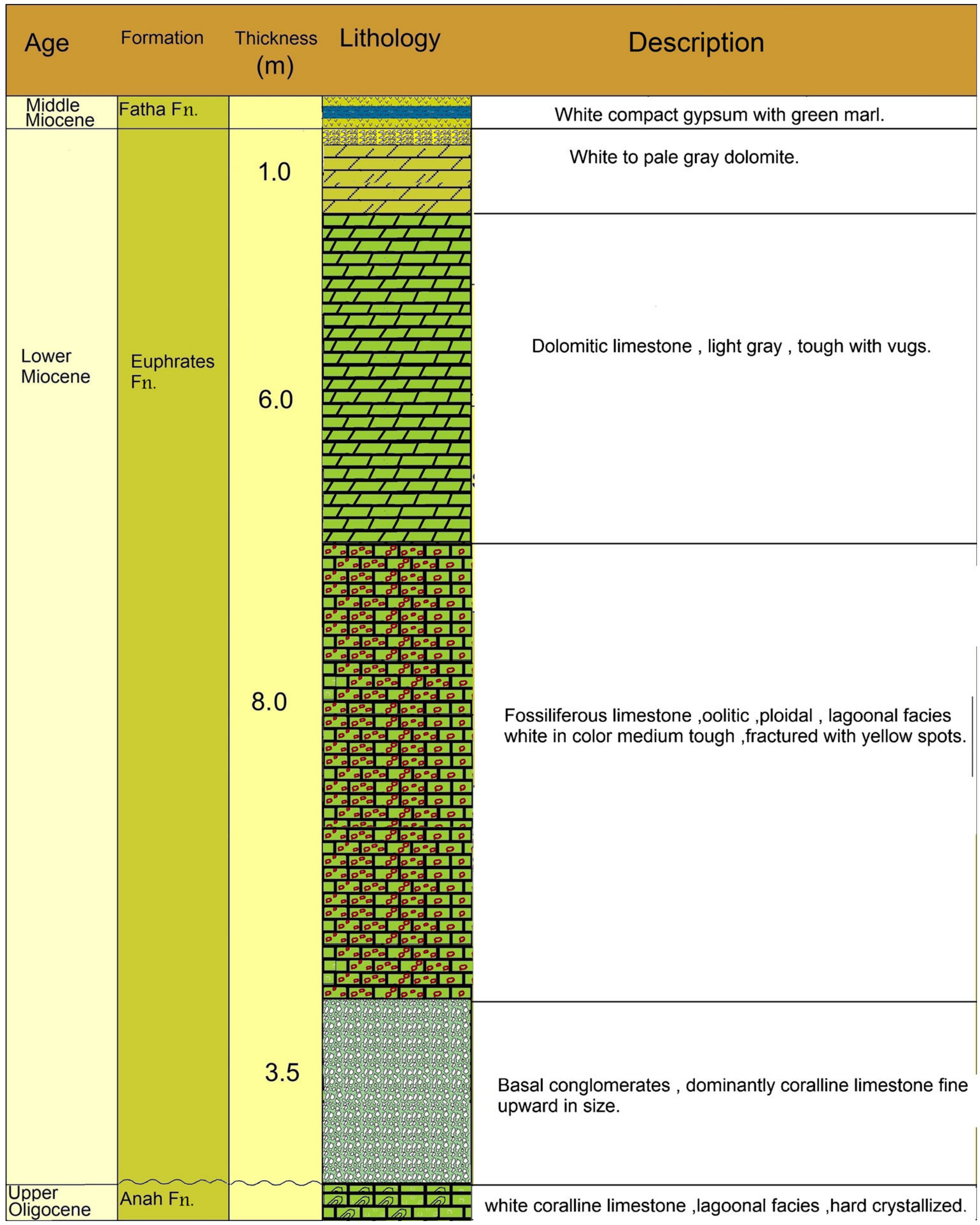


Fig. 3 Stratigraphic sequence of Euphrates Formation in the Wadi Asadi in Baghdadi area; (after Al-Ghreri 1985, 2007)

1. Interparticle porosity is distinguished in packstone and grainstone microfacies (Fig. 5a).
2. Vugs porosity is present in mudstone and wackestone microfacies (Fig. 5b).
3. Moldic porosity was indicated in the grain- and mud-supported microfacies, where the algae disappears in the first microfacies and left their moldic shapes in the packstone rich of algae (Fig. 5c).
4. The high porosity was indicated in the high-energy microfacies as intraparticles and that porosity may reach more than 5 to 30 % (Fig. 5d).

c. Neomorphism

Recrystallization is one of the earliest processes affecting the formation and is restricted to the upper part of the sequence (Gayara and Taha 1995). All stages of recrystallization were recognized from recrystallization of the matrix only or from recrystallization of both matrix and grains. Sometimes, it was so intense that it masked the original depositional texture of the rock. This process reflects the effect of freshwater phreatic environment. It is of two types in this formation: either as inversion that the aragonite changes to calcite or changing the calcite to another calcite that is called recrystallization. Both types are completed during dissolution and redeposition processes (Longman 1980). The neomorphism may change the micrite partially or totally to sparite (4–10 μm) or pseudosparite (10–

Fig. 4 Locations of the study areas, photo of Baghdadi section and simplified geological map (Bahr Najaf) with *top view* showing the distribution of boreholes drilled at Najaf area

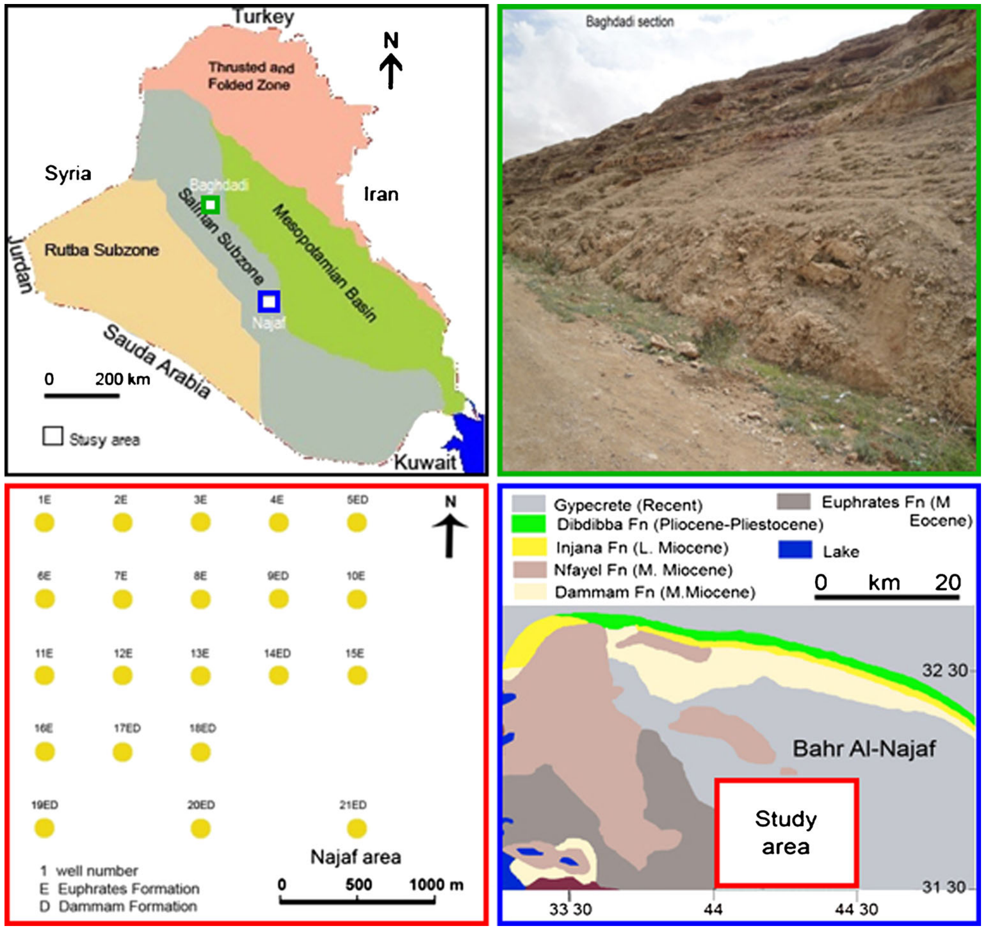


Table 1 Results of chemical analyses and mineralogical composition (in percent) of the Euphrates Formation

Elements and minerals		Najaf			Baghdadi		
		Min	Average n=100	Max	Min	Average n=18	Max
CaO	%	46.4	51.5	54.6	51.6	53.3	54.1
MgO		0.37	0.83	2.2	0.47	0.63	0.8
SiO_2		0.71	4.3	10.4	1.0	1.31	1.8
Al_2O_3		0.14	0.92	3.4	0.2	0.52	0.94
K_2O		0.02	0.14	0.035	0.02	0.04	0.08
Na_2O		0.03	0.08	0.2	0.03	0.08	0.2
LOI		35.6	40	43.4	37	41	42
SO_3		0.07	0.55	2.5	0.07	0.53	2.25
Cl		0.09	0.1	0.18	0.09	0.11	0.18
IR		1.1	4.37	10.7	1.55	1.9	2.1
Calcite		83	91	97	92	94	96
Dolomite		0.35	2.0	5.4	1.2	1.6	2
Gypsum		0.13	0.7	2.7	0.11	0.66	2.8
Sr	ppm	147	233	492	742	760	794
Mn		38	89	136	86	162	115
Fe		350	1925	7700	595	1855	7875

n number of samples

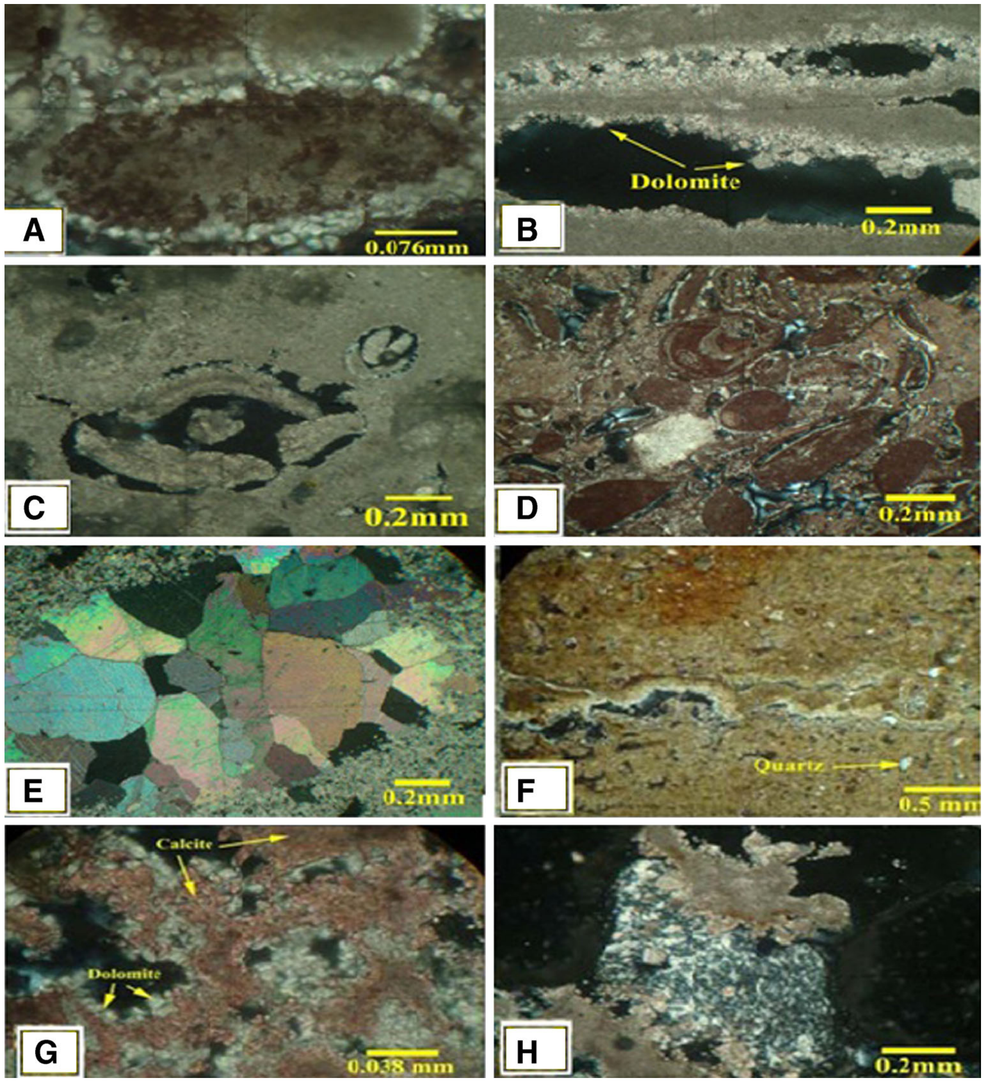


Fig. 5 Representative types of diagenetic processes in the Euphrates Formation (after Al-Shammari 2010). **a** Interparticle porosity was distinguished in packstone microfacies, with drusy cemented and dog teeth cement (well no. 1E, 1 m) XPL. **b** Dedolomitization process, scattered, fine-grained rhombs of the dolomite crystals, with partially cemented and moldic porosity, stained by alizarin red solution (well no. 6E, 2 m) XPL. **c** Moldic porosity was existed in mudstone and wackestone microfacies, with fossils (miliolids) (well no. 20ED, 2 m) XPL. **d** Intraparticles porosity was distinguished in packstone, with cementation (well no. 18ED, 8 m) XPL. **e** Neomorphism process (recrystallization) in the Euphrates Formation (well no. 8E, 8 m) XPL. Cementation process in the Euphrates Formation (well no. 6E, 2 m) XPL. **f** Stylolitization process in the Euphrates Formation, with the quartz crystals as chert nodules (well no. 15E, 10 m) XPL. **g** Dolomitization process, scattered, fine-grained rhombs of the dolomite crystals, stained by alizarin red solution (well no. 4E, 7 m) XPL. **h** Silicification process in the Euphrates Formation (well no. 4E, 8 m) XPL

50 μm). It could be a useful process that preserve the original shape of the fossil shells through changing the aragonite of their original shells into calcite during this process that is called calcitization (Tucker 1998) (Fig. 5e).

d. Cementation

Cementation is defined as a diagenetic process of cavity filling or open space filling through chemical precipitation of material from a solution on a free surface (Flugel 1982). In this process, the effect conditions on the cement sediment depend on the rocks mineralogy and the chemical composition of waters (Bathurst 1975). Calcite cement is a common diagenetic feature filling both inter- and intraparticle pores. Syntaxial rim cement in the form of optical continuous growth of calcite crystals on echinoderm fragments may indicate a relatively early fresh water phreatic cementation (Tucker 1998) (Fig. 5f). The main types of cement which are found in the Euphrates rocks are drusy mosaic, micritic envelope, and sparry calcite cement. Drusy mosaic cement is observed as fine crystal perpendicular with grain walls (Banat and Al-Dyni 1981), and it is also common and represented by crystal showing an increase size towards the centers of pores (Fig. 5a, b). This type of cement may also represent an early meteoric process (Gayara and Taha 1995). Micritic envelope cement is found as cryptocrystalline cement coating the grains, especially fossils (Banat and Al-Dyni 1981). The presence of drusy mosaic and micritic envelope cements of early diagenetic origin may suggest shallow marine environment of deposition (Bathurst 1975).

e. Stylolitization

Pressure solution has resulted in the formation of dissolution surfaces, clay seams, and stylolites. Organic material and other relatively insoluble particles (dolomite rhombs, early calcite-cemented grains, and clay particles) commonly occur on the stylolite surfaces, indicating a late diagenetic origin. These stylolites in these formation rocks appear in some of study wells parallel to sets of bedding surfaces (Fig. 5f).

f. Dolomitization

Scattered rhombs of fine-grained dolomite occur within the mud-supported microfacies (Fig. 5g), where are often concentrated along stylolite surfaces. Dolomitization is an effective diagenetic process affecting some parts of the Euphrates Formation rocks (Gayara and Taha 1995). The dolomite texture is recognized in the study area including the microsucrosic, which is composed of 10 to 50 μm size euhedral rhombs. Finely, crystalline dolomite may represent an early dolomitization of the intertidal and shallow restricted subtidal facies under the effect of freshwater–seawater.

The dolomite mineral was distinguished by using Alizarin red stain, which sections are colorizing calcite and low-magnesium calcite in red color, while the dolomite mineral is not affected. Rare dolomite crystals appear in the form of rhombohedral which refers to partial dolomitization in the Euphrates Formation rocks.

g. Dedolomitization

Dedolomitization in the Euphrates sequence is restricted to a narrow zone associated with the upper unconformable boundary of the formation and the exposure surface at the top of the first shallowing upwards cycle (Gayara and Taha 1989, 1995). It is represented by euhedral to subhedral dolomite rhomb whose centers are completely replaced by a fine crystalline calcite. This may reflect the effect of near-surface processes (Evamy 1967). This process is rare in the study area.

h. Silicification

Selective replacement of fossils by silica was identified. The appropriate chemical conditions to dissolve calcite and precipitation of silica are supersaturated pores solutions by silica and decrease of pH and temperature. The silicification can take place during early or late diagenetic processes (Tucker 1982). The silica appears in the carbonate rocks for Euphrates Formation as chert nodules (Fig. 5f). They show the replacement of silica instead of calcite into fossils, especially basal conglomerate (unconformity) between Al-Dammam and Euphrates Formations in the Najaf study area (Fig. 5h).

3. Depositional microfacies

The Euphrates Formation carbonates were classified according to Folk (1962) and Dunham (1962), modified by Embry and Klovan (1972) and revised by Wright (1991). This microfacies is compared with standard microfacies (SMF) and also with the facies zones (FZ) as suggested by Wilson (1975) and Flugel (1982). Each type of it consists of principal microfacies, as shown in description of Figs. 2 and 3.

1. Lime mudstone microfacies

This microfacies is common within the Euphrates Formation. This microfacies consists of mainly micrite with its content less than 10 % skeletal grains, as well as the presence of some quartz crystals. This microfacies is divided into two submicrofacies as follows:

a. Ioclastic foraminiferal lime mudstone submicrofacies: This submicrofacies consists mainly of micrite with its content on small amounts of Ostracoda and little percentage of foraminifera such as miliolids. This facies is similar to the SMF-9. It is present within the FZ-7 (Wilson 1975; Flugel 1982), which represents sedimentation of shallow water with open circulation.

b. Unfossiliferous lime mudstone: This facies consists mainly of micrite, or it may contain a very little rate of Ostracoda, Pelecypoda, and algae. This facies is similar to the SMF-23, and it is present within the FZ-8 and FZ-9 (Wilson 1975; Flugel 1982), which represents sedimentation of hypersaline tidal ponds.

2. Lime wackestone microfacies

It represents one of the most common microfacies in the Euphrates Formation and may locally be dominated by a specific type of bioclast at various levels within the succession. The grains such as fossils, pellets or oolites, and algae comprised more than 10 % of the lithology.

The characteristics of this microfacies are shallow and open marine environments (Flugel 2004). This microfacies is divided into three submicrofacies as follows:

a. Foraminiferal lime wackestone submicrofacies: It consists of different types of Foraminifera, which represents about 50 % of the rock. This facies also contains a little of Ostracoda, Pelecypoda, and algae. The fossils are important in this facies. They include Miogypsinidae and Lepidocyclinidae that represent the fore-reef environment below the wave effective zone at depth of 35–40 m. Also, *Miogypsina globulina*, *Quinqueloculina* sp., *Triloculina* sp., and miliolids are present too. The characteristic of this facies is similar to SMF-8. It is present within the FZ-7 (Wilson 1975; Flugel 1982), which represents the shelf lagoon with open circulation.

b. Bioclastic lime wackestone submicrofacies: It mainly consists of fossils, such as (Ostracoda, Pelecypoda, and algae) and also biosiliceous. It occasionally contains a little of large peloids. This facies is similar to SMF-9. It is present within the FZ-7 (Wilson 1975; Flugel 1982), which is deposited in the shelf lagoon with open circulation in the shallow water.

c. Oolitic lime wackestone submicrofacies: It consists of oolites with percentage about 90 % and its distribution on micrite ground, and it may be transformed to microspare. This facies is similar to SMF-15. It is deposited within the FZ-6 (Wilson 1975; Flugel 1982). This submicrofacies is found in some of study wells. Flugel (1982) suggests that these oolites exist in the tropical and semitropical regions and in shallow water environments.

3. Lime packstone microfacies

It represents the third common microfacies in the formation. This microfacies is principally composed of pellets of various sizes. Foraminifera, *Miogypsina*, miliolids, and Ostracods also occur. The matrix of this microfacies consists of microspare with little micrite.

This microfacies is divided into three submicrofacies as follows:

a. Bioclastic foraminiferal lime packstone submicrofacies: It is composed of different types of foraminifera, such as *Ammonia beccarii* with *Elphidium* sp. that represent the warm shallow marine environment with relatively high salinity, open to the sea (Al-Hashimi and Amer 1985), in addition to Ostracoda, Pelecypoda, and algae, as well as a little ratio of small pellets. This facies is similar to SMF-18, which represents the open platform, (Wilson 1975; Flugel 1982).

b. Oolitic lime packstone submicrofacies: This facies mainly consists of oolites ina matrix of sparite. It may occasionally contains a little of peloids and pellets. It is similar to SMF-15. It is deposited within the FZ-6 (Wilson 1975; Flugel 1982), which represents the winnowed platform edge sands.

c. Peloidal lime packstone submicrofacies: This facies is mainly composed of peloids, with large size of pellets. It has many forms including globular, ovoid, and irregularity because of micritization processes (Bathurst 1975). This peloids and pellets are indications of quiet environment with warm waters that connected to the open sea by channels (Flugel 1982). This facies is affected by dissolution and dolomitization processes. The characteristic of this facies is similar to SMF-17. It is deposited within the FZ-8 (Wilson 1975; Flugel 1982), which represents restricted platform.

4. Lime grainstone microfacies

The percentage of skeletal grains in this microfacies is more than 90 % (Dunham 1962), while the matrix consists of sparry calcite and may contain a very small amount of micrite. It is present in some of the studied wells. This microfacies is divided into two submicrofacies as follows:

a. Oolitic lime grainstone submicrofacies: This facies contains plenty of oolites grains, as well as a very small amount of peloids. It is similar to SMF-15. It is deposited within the FZ-6 (Wilson 1975; Flugel 1982), which represents the winnowed platform edge sands. This study facies is described by Ibrahim (1997) in Efak-1 and Abu-Jir-1 wells within the Euphrates Formation, but it is rare in the study area.

b. Peloidal lime grainstone submicrofacies: It mainly consists of peloids with sparry calcite matrix without the other fossils. This facies is affected by dolomitization process. The characteristics of this facies are similar to SMF-17. It is deposited within the FZ-8 (Wilson 1975; Flugel 1982), which represents restricted platform.

Mineralogy

The carbonate samples are examined by X-ray diffraction method (XRD). Samples are prepared as bulk sample in order to study non-clay minerals. The results indicate that the recognized non-clay minerals are represented by calcite, dolomite, quartz, feldspar, and gypsum, where calcite appears to be the predominant and participated more than 90 % of the total constituents (Fig. 6). Quartz has heterogeneous distribution wherever silicification has happened but, in general, existed in small quantities. Gypsum has scarce and heterogeneous distribution (Fig. 6). The results show clay minerals as well as quartz for the different samples that had been treated with 10 % HCl acid to remove the carbonates existed. Small quantities of kaolinite, montmorillonite, illite, and palygorskite were detected by XRD (Fig. 7). Kaolinite primarily formed due to weathering of feldspars under acidic conditions. Palygorskite appear to be formed directly in shallow marine of alkali pH. This mineral requires alkaline conditions and high silicon and magnesium activities for stability (Kadhim 2009). Montmorillonite is very rare. The origin of illite is preferred to be potash feldspar. Illite is recognized by the weathering of silicates (primarily feldspar) through the alteration of other clay minerals (Al-Dabbas et al. 2013).

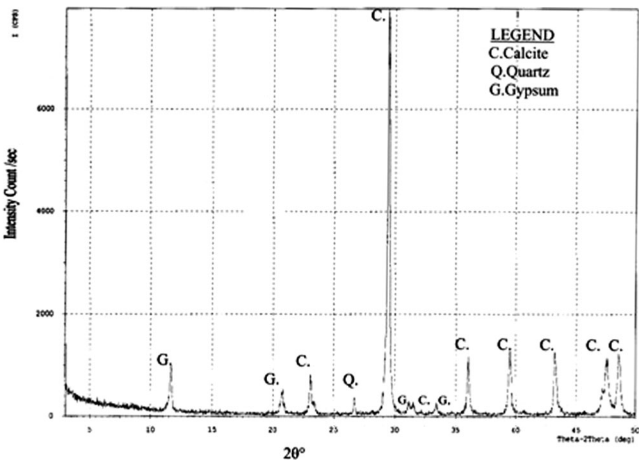


Fig. 6 Difractograph of XRD scan of sample no. 21ED

Geochemistry

The results of chemical analyses are listed in Table 1. A high content of CaO characterizes the Euphrates Formation. In the Najaf area, the range (46.4–54.6 %) and average (51.5 %) of CaO are slightly to be lower than those in Baghdadi area which are characterized by 51.6–54.1 % range and 53.3 % average of CaO. LOI in Najaf is ranging from 35.6 to 43.4 % with an average of 40 %, and in Baghdadi, 37–42 % with an average of 41 %. SO_3 ranged in Najaf area from 0.07 to 2.5 % with an average of 0.55 %, whereas in Baghdadi, it varies between 0.07 and 0.25 % with an average of 0.53. It yielded from gypsum lenses that are presence within the Euphrates Formation. The domination of calcite with lack of dolomite is reflected in the content of the MgO which ranged from 0.37 to 2.2 % with an average of 0.83 % in Najaf and varies between 0.47 and 0.8 % with an average of 0.63 %. The average composition (in percent) of calcite, dolomite, and gypsum in the Euphrates rocks in Najaf and Baghdadi are 91, 2, and 0.7 %, and 94, 1.6, and 0.66 %, respectively. Silica (SiO_2) and alumina (Al_2O_3) are originated from clay mineral suites and quartz. At Najaf area, the average silica is 4.3 %, while in Baghdadi, 1.31 %. Alkalis appear to have low content; the average of K_2O and Na_2O in Najaf are 0.14 and 0.08 %, and in Baghdadi, 0.04 and 0.08, respectively. Chloride (Cl^-) may be originated from the groundwater or from halite during evaporation of seawater (Al-Dabbas et al. 2013); its average in Najaf and Baghdadi is the same (0.1 and 0.11 %, respectively).

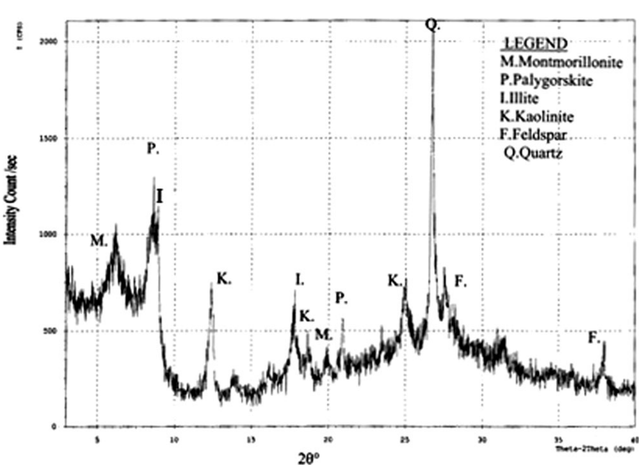


Fig. 7 Difractograph of XRD scan of sample no. 14ED

Strontium

Strontium content in Najaf varies between 147 and 492 ppm, with an average of 233 ppm, while in Baghdadi, it varies between 742 and 794 ppm with an average of 760 ppm (Table 1). Aragonite permits the incorporation of considerable amount of Sr in the crystal lattice. The average global carbonate ranges between 425 and 765 ppm (Bausch 1968). Strontium content in Najaf area appears to be lower than the global carbonate, whereas in Baghdadi area, this looks similar of global carbonate. This attributed in general to the diagenetic processes which transformed aragonite into calcite. Accordingly, it is clear that Sr has been early admitted in aragonite; later, Sr has expelled from lattice of calcite. Strontium content decreased toward dolomitized facies. It is known that Sr exists with high concentration in the deep environment (Flugel 1982). Low Sr content has been pointed a shallow carbonate rocks (Bausch 1968). On this basis, the Sr content is good evidence for shallow depositional environment. Consequently, the depositional environment of the Euphrates Formation in the Najaf area was relatively shallower than that in Baghdadi.

Manganese

Manganese in the Euphrates Formation at Najaf area varies between 38 and 136 ppm with an average of 89 ppm, while in Baghdadi, it varies between 86 and 115 ppm with an average of 162 ppm (Table 1). In the global carbonate, Mn is 385 ppm. In the shallow water, carbonate is mainly aragonite where Mn cannot replace Ca with appreciated amount, and it was found as 20 ppm in pure marine aragonite. Manganese in the Euphrates Formation was incorporated with insoluble residue rather than with carbonate. Basically, Mn is present in a high concentration in the deep marine (Wangersky and Joensn in Friedman 1969). The low content of Mn in the Euphrates Formation confirms that the shallow water was the depositional environment with taking into consideration that the environment in Baghdadi was relatively deeper.

Iron

The Euphrates Formation is characterized by high variation of iron content which varies between 350 and 7,700 ppm with an average of 1,925 ppm in Najaf area, whereas in Baghdadi area, it varies between 595 and 7,875 ppm with an average of 1,855 ppm (Table 1). Iron similar to Mn is mainly incorporated with insoluble residue due to the similarity of ionic potential for both. The high content of iron enhances the shallow water environment which was the depositional environment because Fe in deep water tends to form siderite and pyrite, but Fe may be originated from calcite, dolomite, and clay minerals.

Depositional environment

Most of the previous studies show that the sedimentation of Euphrates Formation is deposited in shallow marine and lagoonal environment (Bellen RC et al. 1959; Al-Ghreri 1985, 2007; Ali 2011). Early diagenetic dolomite which characterizes the upper parts of Euphrates rocks suggests that the deposition is a relatively high evaporative environment (Banat and Al-Dyni 1981), and an increase of evaporation in the Euphrates basin may have led to the formation of evaporites instead of carbonates. The first sedimentation in Lower Miocene is connected with transgression, making what is known as the Euphrates (Buday 1980). The main facieses represent the Euphrates Formation as follows: lime mudstone, lime wackestone, and lime packstone, while lime grainstone is rare. These facieses are characterized by the abundance and diversity of fossils consisting mainly of algae, miliolids, gastropods, pelecypods, and *Quinqueloculina*. It represents a low-energy environment. The micrite is the main in the matrix, and it is an indication of a deposition in a shallow marine with low energy. Presence of micrite also supports this opinion because the lime mud or micrite was afforded to/from deposition and stagnation (Wilson 1975; Dunham 1962).

The high differentiation and large number of Miliolidae is a guide of the back-reef environment and a warm shallow marine environment of deposition, where the benthonic Foraminifera, especially miliolids, and Peneroplis constitute the main percentages of fossils, calcareous algae, Pelecypoda, and Gastropoda (Banat and Al-Dyni 1981; Ibrahim 1997).

The Euphrates Formation in the study areas is believed to be deposited in open shallow marine environment that may be of different distances from the shore line (i.e., Baghdadi and Bahr Najaf sections). It may be deduced from the presence of certain groups of fossils (benthonic forams and algae), early digenetic cement, and pellets.

Conclusions

The Euphrates Formation (Lower Miocene) consists mainly of shallow marine carbonate environment. Many microfacieses have been identified as follows: lime mudstone, lime wackestone, and lime packstone, while lime grainstone is rare. These facieses are characterized by the abundance and diversity of fossils consisting mainly of algae, miliolids, gastropods, pelecypods, and *Quinqueloculina*. It represents a low-energy environment. The micrite is the main in the matrix, and it is an indication of a low-energy shallow marine environment. These carbonates have been affected by a variety of diagenetic processes. The principal depositional environments, in which the Euphrates Formation laid down was restricted and open platforms, were dominated by shallow water inner-shelf environments. The main responsible factor in microfacies developments and their distribution are the relative sea level fluctuations. Geochemical differences can be noticed between Euphrates Formation at the two studied sections Najaf and Baghdadi. Relatively, the carbonate facies at Najaf area are richer in silica, alumina, and Fe, while the carbonate facies at Baghdadi area is richer in CaO, Sr, and Mn. Consequently, it is believed that the Najaf section rocks have been deposited in relatively shallower deposition environment and closer to the shoreline. The relative variation in the depositional environment of the Euphrates Formation may be also attributed to simultaneous movement of blocks along the Abu-Jir fault Zone with the deposition processes (Awadh et al. 2013). It is believed that the insoluble residues as well as clasts were brought to the depositional basin of Euphrates Formation from the nearby continent as a terrestrial derivation.

References

Al-Dabbas M, Awadh SM, Zaid AA (2013) Mineralogy, geochemistry, and reserve estimation of the Euphrates limestone for Portland cement industry at Al-Najaf area, South Iraq. Arab J Geosci 6(2):491–503. doi:10.1007/s12517-011-0370-z

Al-Hashimi HAJ, Amer RM (1985) Tertiary microfacies of Iraq. Directorate General for Geological Survey and Mineral Investigation, Baghdad, p 56

Ali RA (2011) Petrographical and mineralogical study of Anah Formation and Euphrates Formation in Khan Al-Baghdadi area/Iraq. Journal of Babylon University/Pure and Applied Sciences 19(3):1240–1254

Al-Ghreri MF (1985) Biostratigraphy of the Euphrates Limestone Formation in the upper Euphrates valley. M. Sc. Thesis, Coll. Sci., Baghdad Univ., Iraq

Al-Ghreri MF (2007) Biostratigraphic succession of the formation of Euphrates valley between Hit and Al-Qaim in Iraq. Unpublished Ph. D. College of Science, University of Baghdad, p 121

Al-Kufaishi F, Al-Aasm I (1978) A contribution to the geochemistry of carbonates the s-I limestone: lower fares formation. Iraqi J Sci 19(1):101–108

Al-Shammari AA (2010) Petrographic study of Euphrates Formation in Al-Najaf area and reserve characterization for cement industry, unpublished. M.Sc., Thesis, Baghdad University. Iraq

Awadh SM, Ali KK, Alazzawi AT (2013) Geochemical exploration using surveys of spring water, hydrocarbon and gas seepage, and geobotany for determining the surface extension of Abu-Jir Fault Zone in Iraq: A new way for determining geometrical shapes of computational simulation models. J Geochem Explor 124, 218–229

Banat KM, Al-Dyni NK (1981) Petrology and mineralogy of selected sections from the Euphrates and Jeribe formations (Miocene) Iraq. J Geo Soc of Iraq 14(1):1–14

Bathurst RGC (1975) Carbonate sediments and their diagenesis, 2nd edn. Development in Sedimentology-12. Elsevier Publ. Co., Amsterdam, p 658

Bausch WM (1968) Outline of distribution of Strontium in marine limestone. In: Muller G, Friedman GH (eds) Recent developments in carbonate sedimentology in Central Europe. Springer, Berlin, pp 106–115

Bellen RC Van, Dunnington HV, Wetzel R, Morton D (1959) Lexiquestratigraphique internal Asie, Iraq Intern Geol Conger Comm Stratigr, 3, Fasc. 10a, p 333

Buday T (1980) The Regional Geology of Iraq. Stratigraphy and Paleogeography. Publ. of GEOSURV, Baghdad, 1:445

Choquette PW, Pray LC (1970) Geologic nomenclature and classification of porosity in sedimentary carbonates: AAPG. Bull 54:207–250

Cytroky P, Karim SA (1971) Stratigraphy and paleontology of the Oligocene and Miocene strata near Anah, Euphrates valley. NIMCO report no. CZ 140, SOM Library, Baghdad

Dunham RJ (1962) Classification of carbonate rocks according to depositional texture. In: Ham, W. E., (eds.), Classification of carbonate rocks. Amer. Assoc. Petrol. Geol. Mem 1:108–121

Embry AF, Klovan JE (1972) A late Devonian reef on North Easter Banks Island, north west territories. Bult Can Petrol Gect 19:730–781

Evamy BD (1967) Dedolomitization and development of rhombohedral pores in limestone. Jour Sed Petrology 37:1204–1215

Flugel E (1982) Microfacies analysis of limestones. Springer, Berlin, p 633

Flugel E (2004) Microfacies of carbonate rocks. Springer, Berlin, p 976

Folk RL (1962) Spectral subdivision of limestone types. In: Ham WE (ed) Classification of carbonate rocks—a symposium. Amer. Assoc. Petrol. Geol., Mem. 1:62–84

Friedman GM (1969) Trace element, a possible environmental indicators in carbonate sediments. In: Friedman, G. M, (ed), Depositional environments, in carbonate rocks. S. E. P. M. Spec, Publ., 14:193–200

Gayara AD, Taha LS (1989) Microfacies analysis of the Euphrates Limestone Formation. Northern Iraq Jour Geol Soc Iraq 22(1):123–129

Gayara AD, Taha LS (1995) Eustatic control on carbonate diagenetic development of the Euphrates Limestone Formation. Northern Iraq Jour Geol Soc Iraq 28(2):137–144

Ibrahim YK (1997) Biostratigraphy of the Euphrates and Jeribe Limestone Formations in Middle-South of Iraq. Msc. Thesis, Baghdad University, Iraq, unpublished, p 56

Jassim SZ, Goff JC (eds) (2006) Geology of Iraq. Published by Dolin, Prague and Moravian Museum, Brno, p 341

Kadhim MA (2009) Geochemistry and mineralogy of palygorskite-rich clays in Gercus Formation in Dohuk governorate, north of Iraq. M. Sc. Thesis, University of Baghdad, p 115

Kettaneh YA, Sadik AJ (1989) Mineralogy and geochemistry of Shiranish formation, North Iraq. Jour Geol Soc Iraq 22(1):98–111

Longman MW (1980) Carbonate diagenetic textures from near surface diagenetic environments. AAPG Bull 64(4):461–486

Selley RC (2000) Applied sedimentology. Academic Press, San Diego, p 521

Selley RC (2007) Applied sedimentology, 2nd edn. Academic Press, San Diego, p 543

Tucker ME (1982) Sedimentary petrology: an introduction. Wiley, New York, p 252

Tucker ME (1985) Sedimentary petrology, an introduction. Blackwell Scientific Publ, Oxford, p 252

Tucker ME, Wright VP (1990) Carbonate sedimentology. Blackwell, Oxford, p 182

Tucker ME (1998) Sedimentary rocks in the field, 2nd edn. Wiley, New York, p 155

Wilson JL (1975) Carbonate facies in geological history. Springer, Heidelberg, p 475

Wright VP (1991) A revised classification of limestones. Sed Geol 76:177–185