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Depositional Environment of the Ibrahim Formation and Determining the Oligocene-Early Miocene Boundary in Eastern Iraq

Ameer Abdulrahman^{1,*} and Salih M. Awadh¹

¹ Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

* Correspondence: ameerwaissey@yahoo.com

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Abstract

The aim of this study is to investigate the sedimentation environments and diagenetic processes of the Ibrahim Formation (Oligocene-early Miocene) in Zurbatiya, eastern Iraq. The Ibrahim Formation is comprised mostly of clayey micrite and skeletal grains composed of planktonic foraminifera, calcispheres, radiolaria, and benthic foraminifera. Glauconite and pyrite were documented in some restricted zones of this formation; they reflect quiet and reducing conditions. Radiolaria were identified in Late-Oligocene which was not known previously at this age regionally in carbonate formations of the Arabian Plate (AP). Mudstone, wackestone, and planktonic foraminiferal wackepackstone are the main microfacies that are affected by dissolution, cementation (granular), and replacement covering the age of the latest Eocene-Oligocene to the early-middle Miocene. Microfacies analysis indicates a basinal environment with a hemipelagic character of the deep shelf, toe-of-slope, and lower slope. Oligocene-Miocene outcrops have not been known previously in eastern Iraq although they have 160 m thick was first recorded in this study, whereas it was estimated as 56 m in the type section (well-1). Hence, the studied section is therefore suggested to be considered as a type section of the Ibrahim Formation. The Oligo-Miocene boundary is marked by restricted shallow-marine facies at the middle part of the formation indicating a short-term sea-level regression.

Keywords: Ibrahim Formation; Oligocene; Miocene; Basinal environment; Microfacies

1. Introduction

The Oligocene sequence in Iraq is consisted of nine formations (Shura, Sheikh Alas, Palani, Bajawan, Baba, Tarjil, Anah, Azkand, and Ibrahim formations) called the Kirkuk Group. The Oligocene succession was divided into the Early Oligocene age (Shura, Sheikh Alas, and Palani formations), the middle Oligocene (Bajawan, Baba, and Tarjil formations), and the late Oligocene which includes Anah, Azkand, and Ibrahim formations (Al-Hashimi and Amer, 1986). The Oligocene succession is a complex reef system (back-reef, reef, and fore-reef) that had been developed in three cycles during the early, middle, and late Oligocene (Al-Kubaysi et al., 2014). The Oligocene basin has NW-SE trend in which the Ibrahim Formation is an important stratigraphic unit as it has oil productivity in northern oil fields in Iraq. It consists of globigerina marly limestone with granules of pyrite, occasional glauconite and planktonic micro Foraminifera (Jassim and Goff, 2006). The Oligocene is documented in the west and south of Mosul by Sissakian and Al-Jibouri (2012), and in western Iraq was studied Awadh and

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Hussien, 2015). Moreover, there are limited exposures in the north of Iraq. The Late Oligocene-Early Miocene boundary is marked by a major erosional unconformity (Al-Kubaysi et al., 2014; Sissakian et al., 2016). The study area is located in the eastern part of Iraq, within the Wasit governorate (Fig.1), and is determined by the coordinates shown in Table 1. This study documented the Ibrahim Formation in eastern parts of Iraq and its relics along the thrust faults within the Himreen structure. It is characterized by several distinct lithologic subunits forming about 160 m thick (Fig.2). The main target of this study is to conclude the sedimentary environment and determine the Oligocene - Early Miocene boundary.

Fig. 1. The 3D Aerial image shown the sampling sites on section IB of the Ibrahim Formation

Table 1. The coordinates of the study area

Easting	Northing
46° 8' 45"	33° 16' 55"
46° 11' 00"	33° 15' 00"
46° 8' 45"	33° 15' 00"
46° 11' 00"	33° 16' 55"

Fig. 2. Geological map of the study area shows the sampling sites on the IB section studied

2. Material and Methods

A total of 31 samples were collected from composite sections in the study area which represents the ideal strata of the center Kirkuk-Dezful basin (Fig. 3). Thin sections were made and stained with Alizarin red using Dickson's method (1965) for the criterion petrographic analyses to identify the mineralogy, textural (Calvet & Tucker, 1988). The microfacies were analyzed based on Dunham (1962), Wilson (1975) and Flügel (2010).

3. Geological Setting

The Kirkuk Group belongs to the Latest Eocene-Recent tectonostratigraphic megasequence (AP11) (Sharland et al., 2004). During this epoch, the opening of the Neotethys and the development of the Paratethys, the collision of the AP with Eurasia plate with the north and east edges of the AP, and the development of the Zagros mountains had happened. The Megasequence located in the Foothill Zone in southeastern Iraq separated into two basins, Dezful-Kirkuk in the southeast and Mosul in Northwest.

The Oligocene sediments are absent from most parts of the (AP) but are well-preserved in the north-eastern part and Iran. The Megasequence (AP11) as mentioned in Jassim and Goff (2006) is divided into the latest Eocene-Oligocene, early-middle Miocene, and the late Miocene-Recent. The Oligocene-Early Miocene Savian tectonic movement which influenced the Zagros suture was outstanding by the lifting of the Balambo-Tanjero Trough. It is possible, however, that some more internal parts of this zone which are now overthrust, might have been invaded by a shallow sea during the Early Miocene. The Ibrahim formation is a transition for two sub-cycles, the Latest Eocene-Oligocene, and early middle Miocene composing mainly of alternative marl and marly limestone underlying the marker bed (Basal anhydrite) (Jassim and Goff, 2006; Aqrabi et al., 2010). It is comprised of 56 m of globigerina marly limestone with patches of pyrite and gluconite, and fauna of planktonic foraminifera precipitated in a basinal environment during the late Oligocene (Jassim & Goff, 2006).

Era	Age	Fn.	S. NO.	Thickness (m)	Lithology	Description
Cenozoic/ Tertiary	Early Miocene	Himreen?			V V V V V V V V V V V V V V V V V V V V	Basal anhydrite: whitish grey in color, tough, thick bed, sharp contact.
			IB31	160		
			IB30			
			IB29			Marl: greenish grey in color, medium tough, thick bed, sharp contact.
			IB28			
			IB27			
	Late Oligocene	Ibrahim	IB26	140		Alternation of Marl and Marly limestone: green to dark grey in color, friable, medium bed.
			IB25			
			IB24			
			IB23			
			IB22			
			IB21			
			IB20			
			IB19	120		
			IB18			Shally limestone: dark grey in color, friable, thinly bedded, sharp contact.
			IB17			
			IB16			
			IB15			
			IB14			
			IB13	80		Marly limestone: Olive in color, medium tough, thick bed, sharp contact,
			IB12			
			IB11			Marly limestone: grey in color, tough, thick bed, sharp contact.
			IB10			
			IB9	40		Sandy limestone: brownish grey in color, tough, sharp contact.
			IB8			
			IB7			
			IB6			Interbedded Marl and Marly limestone: pale gray in color, tough, thick bed.
			IB5			
			IB4			
			IB3			Marl: Olive in color, medium tough, massive, slope forming.
			IB2			
			IB1			

Fig. 3. Stratigraphic column and field description of the ideal strata of the Ibrahim Formation at center of Kirkuk – Dezful basin

4. Results

The Ibrahim Formation consists of several distinct lithologic subunits forming about 160m thick (Fig. 3). It is exposed as traces along thrust faults within a part of the Hamrin structure in the study area (Fig.2). The basinal anhydrite rests directly and conformably on the Ibrahim formation (Aqrabi et al., 2010). However, the upper contact is conformably composed of basal anhydrite, while the lower contact is obscured.

The bottom layer (20m thick) of the Ibrahim Formation is characterized by an olive color and consisted of thick beds to massive, medium to tough with a conchoidal fracture, follows this layer a thick bed of marly limestone (17 m thick), this layer is followed by a layer of sandy limestone (3 m thick) brown to gray color, and tough, follows this layer a layer composed of marly limestone, olive to gray color, medium to thickly bedded, (15 m thick) it represents the top of the lower part. The middle part (55m thick) appears as isolated hills in the study area, friable materials composed of thick beds of shaly limestone. At the base of the upper part (20m thick) an alternation of marl with marly limestone of green to dark gray color. The top layer of the formation (30m thick) is dominant by marl, greenish gray color, and friable massive bed (Fig. 3). Three microfacies types are recognized in the Ibrahim Formation within the study area using classification stated by Embry & Klovan (1971) that was modified from Dunham, (1962), Wilson, (1975) and Flügel, (2010). All these standard facies is illustrated in Fig. 4. Various features and textures were identified based on Scholle & Ulmer-Scholle (2003) and Flügel (2010). The important note is that the original textures was well preserved.

Fig. 4. Standard microfacies after Wilson (1975) and Flügel (2010)

4.1. Skeletal Grains

The skeletal grains are either fragments or complete shells and the remnants or excrement of organisms. Their size varied from 0.05 mm to several centimeters. The skeletal grains are consisted of calcite, high and low Mg - calcite, aragonite, and may be silica (Flügel, 2010). The identified skeletal grains in the Ibrahim Formation are mainly composed of planktonic foraminifera, calcispheres, radiolaria, and to a lesser extent benthic foraminifer and bioclasts.

4.1.1. Planktonic foraminifera

The fauna is identified with varied Planktonic forams such as *Globorotalia kugleri* sp., which is dominant in the formation. Krasheninnikov (1973) had considered this species as adopted as the index fossils to the lower boundary of Neogene, while Kennett & Srinivasan (1983) stated that this species indicates a tropic climate of the early Miocene. Globigerinoides are extensively used to determine and to find out the paleoceanography and paleoclimate. Spezzaferri et al. (2018) mention that their availability

during the Neogene has been used for biochronology as the first appearance was at the Oligocene-Miocene (Plate 1A and B and Plate 2C, D and E). *Globigerina binaiensis* sp, the genus is an important as it intergraded in the late Oligocene and early Miocene (Wade et al., 2018). The Miocene-Oligocene boundary was identified by samples IB25 to IB27 located at the upper part of the middle of the Ibrahim Formation (Plate 2C and D).

4.1.2. *Calcspheres*

Calcspheres are usually denoted as hollow, spherical calcareous microfossils of various origins (Berkyová and Munnecke, 2010). Calcspheres of various origin linked to a nutrient-rich, well-sheltered (Berkyová and Munnecke, 2010). Munnecke et al (2008) and Servais et al (2009) had described calcspheres as probably planktonic organisms of unknown origin. However, calcspheres are mostly associated with an open shelf to ocean pelagic deposits (Scholle and Ulmer-Scholle, 2003). In the present study, calcspheres are abundant and exist in most of the formation. The calcspheres have different sizes and regularly thick of wall consisting of fine granular (micritic) calcite, and sometimes sparite (Plate 1C and D).

4.1.3 *Radiolaria*

Neogene radiolaria fauna has been used to reconstructed environmental changes such as paleotemperature, sea level, and marine productivity, which are the primary controlling factors of evolution (Kamikuri et al., 2009). In the present study, radiolarian assemblage as interval occurrence, which is the first appearance in base, two intervals at the top of the middle part of the succession. (Plate 1, D and Plate 2, A and D).

4.1.4 *Benthonic foraminifera*

Benthic species have been used in paleoceanographic reconstructions (Gooday and Alve, 2001). Benthic foraminifera were identified as a small in size. *Textularia* sp is the dominant species assemblage, whereas the rear assemblage is *Rotalia* sp. Benthic species are successfully used for the analysis of bathymetry of sediments. Abundant pelagic foraminifera represents a more pelagic, deep offshore environment (Mateu-Vicens et al., 2008). The benthonic foraminifera species occur in the mudstone facies suggesting quiet and restricted shallow marine environments (Plate 1E, F and Plate 2B).

4.2. Non-skeletal Grains

Chert, glauconite, and pyrite are the main non-skeletal grains.

4.3. Microfacies Type

The microfacies of carbonates of different ages can be classified into main types reflecting the sedimentary and environmental conditions in a specific sedimentary environment with associated sedimentological datum (Flügel, 2010). Three microfacies types are recognized in the Ibrahim Formation, as following:

4.3.1 *Mudstone microfacies*

These microfacies are varicolored (pale grey and brownish-grey), tough, consist of few skeletal grains less than 10%, benthic, calcspheres, and planktonic forams. It is divided into the following submicrofacies: Planktonic foraminiferal lime mudstone, laminated mudstone, and bioclastic mudstone. All these are slightly affected by the diagenetic processes. The mud matrix consists of micritic calcite.

Benthic lime mudstone microfacies are equivalent to the (SMF-3) Standard Microfacies (Wilsons, 1975), which belongs to (FZ-3) suggesting a deep-sea, low energy environment while bioclastic calcareous mudstone reflects restricted shallow-marine and low-energy (SMF-3).

4.3.1.1. Benthic foraminiferal lime mudstone

The microfacies in the middle parts consists of less than 10% skeletal grains. The groundmass is essentially micritic calcite admixed with siliciclastic clay, which is slightly affected by diagenetic processes like cementation, and dissolution. Benthic foraminifera is recognized as the main skeletal grains such as *Textularia* sp as shell fragments, submerged in muddy ground. The benthic foraminiferal lime mudstone microfacies are equivalent to the (SMF-1) Standard Microfacies (Wilsons, 1975). It represents deposition at (FZ1) that is a deep-sea and basinal setting. Samples (IB15- IB16) and (IB21-IB23), (Plate 1, E), (Fig. 5).

4.3.1.2 Bioclastic mudstone

This microfacies is found in the middle and upper parts with a color of dark grey to grey. The groundmass is consisted of very fine to fine crystalline calcite and matrix composition (more than 90%), with benthic foraminiferal species such as *Textularia* sp, *Rotalia* sp. These facies have less effect by diagenetic processes. This microfacies indicate changes from open-marine to shallower marine environment with low-energy. It is equivalent to the SMF-3 Standard Microfacies of Wilsons (1975). (Plate 2B). Samples (IB15-IB17) and (IB29-IB31), (Fig. 5).

4.3.2. Wackestone microfacies

This microfacies is common facies has skeletal component up to 15%, planktonic, Radiolaria, calcispheres forms and small benthic foraminifera. The groundmass is micrite mixed with siliciclastic and several non-carbonate such as, pyrite, and glauconite. Wackestone is widely distributed in the Ibrahim Formation showing basinal and lower slope environments. Wackestone microfacies include each of the following submicrofacies.

4.3.2.1. Planktonic wackestone

This facies is a common, characterized by predominant grains about (10% - 45%), from rocks component total, with abundant planktonic foraminifera, calcispheres, and very rare benthic foraminifera. The groundmass content of the admixed of siliciclastic and calcite micrite, it brown to grey. This facies was affected by diagenetic processes such as dissolution and equivalent to the (SMF-1) Standard Microfacies (Wilsons, 1975) which belongs to Facies Zones (FZ-1) indicating a deep-sea, Sample (IB24- IB28) in Plate 1, C, and D, (Fig. 5).

4.3.2.2. Radiolaria wackestone

This facies consists of granules about (12% - 43%), from components total of the rock, and the percentage of radiolaria and planktonic foraminifera (including calcispheres with little bioclast and small foraminifera (*Rotalia* and *Textularia*)). The groundmass is micrite admixed with siliciclastic with light to dark brown. This facies is equivalent to Wilson's (1975) Standard Microfacies (SMF-1) which belongs to Facies Zones (FZ-1) described deep sea. Sample (IB11 - IB14) (Plate 2A, C and D), (Fig. 5).

4.3.3. Planktonic foraminiferal wackepackstone

These microfacies is mainly contained radiolaria, planktonic foraminifera, and benthic foraminifera at the base of the formation. It is highly fossiliferous. The skeletal grains are composed of

approximately 50%, converted to 70% packstone. Most of the components are Planktonic foraminifera and Radiolaria, with little benthic forams of *Textularia* sp and *Rotalia* sp and shell fragments. The groundmass is micrite of calcite admixed with siliciclastic. Planktonic foraminiferal wackepackstone facies are equivalent to the SMF-2 Standard Microfacies of Wilsons (1975) indicates a deposition a deep shelf (FZ 2) (Sample IB1 to IB10) (Plate 1A, and B) and (Plate 2E, and F), (Fig. 5).

Table 2. Description of the main facies and depositional environment (DE) of the Ibrahim Formation

Main facies	Characteristics	DE	S. No
Bioclastic mudstone	Benthic foraminiferal species	Restricted shallow-marine	IB29-IB31
Planktonic wackestone	Radiolaria and planktonic foraminifera	Slope, deep shelf, and basinal setting	IB24-IB28
Benthic foraminiferal lime mudstone	planktonic foraminifera	deep sea and basinal setting	IB21-IB23
Bioclastic mudstone	Benthic foraminiferal species	Restricted shallow-marine	IB17-IB20
Benthic foraminiferal lime mudstone	Trace-fossil and shell fragments	Restricted shallow-marine	IB15-IB16
Radiolaria wackestone	Radiolaria, planktonic foraminifera, and benthic foraminifera	Slope, deep shelf, and basinal setting	IB11-IB14
Planktonic foraminiferal wackepackstone	Radiolaria and planktonic forms and benthic foraminifera	Slope, deep shelf, and basinal setting	IB1-IB10

1: Bioclastic mudstone 2: Benthic foraminiferal lime mudstone

3: Planktonic wackestone 4: Radiolaria wackestone 5: Planktonic foraminiferal wackestone

Fig. 5. Microfacies interpretation of the stratigraphic column of the Ibrahim Formation

Plate 1. A and B: Planktonic foraminifera (p), *Globorotalia kugler SP* in wackepackstone facies, S.No. IB9 and IB10 respectively; C and D: Calcispheres (Cs) and radiolarian (R), wackstone facies, S.No. IB24 and IB28; E and F: Benthonic Foraminifera, *Textularia sp* (T) in mudstone and wackepackstone, S. No. IB15 and IB1 respectively. All samples were examined under polarized light with a lens 10X.

4.4. Diagenesis

Dissolution and cementation are the main diagenetic events that influenced the sediments of the Ibrahim Formation. Replacement is less affected sediments. The majority of these processes are early diagenetic and reflected shallow-marine burial environments. Dissolution is generally characterized by fabric selective dissolution represented by molding of skeletal grains (Plate 3A). Cementation occurs as a result of the precipitation of minerals inside the primary or secondary pores and requires that the pore fluids be saturated with these minerals (Flügel, 2004). This process is common in carbonate rocks, it may take place soon after depositional at any late time. The samples have been cemented by calcite as drusy cement, this type is common in the studied carbonates and represented by subhedral to euhedral crystals, ranges in size from 10 to 60 μm , filling molds (Plate 3B and C). Replacement is an allochemical constructive diagenesis involves calcification of aragonite (Plate 3B and C) and/or partially replaced by other minerals like phosphate pyrite and glauconite (Plate 3D, E and F) respectively, it can be seen in most of the samples.

Plate 2. A: Radiolaria (R), in wackestone facies, S.No IB11; B: Benthonic Foraminifera *Rotalia* sp (Ra), in mudstone facies, S.No IB30; C and D: Planktonic foraminifera (P), *Globigerina binaiensis*, wackestone facies, S.No. IB 25 and IB 27 respectively; E) Planktonic foraminifera (P), *Globigerinoides* with olive glauconite Wackepackstone facies, IB2; F: Glauconite (G) green color and observed Radiolaria (R), Wackepackstone facies, S.No. IB 9. All samples were examined under polarized light with a lens 10X.

5. Discussion

In the easternmost part of Iraq, the Oligocene–Miocene age are not previously known to crop out in the area, whereas in nearby areas only Middle-Late Miocene represent by the Fatha, Anjana, and Mukdadiya formations are exposed. The previous authors have not mentioned the Oligocene rocks in the studied. However, recently, the area was studied by Geosurve Iraq to draw a detailed geological map (1:25 000) in 2013 – 2016. The Latest Oligo–Miocene age in northern Iraq has been observed unconformity (Al-Kubaysi et al., 2014;). The succession comprises about 160 m of marly limestones and marl, with faunal assemblages and diversified Planktonic forams with the interval of radiolaria and rare benthic forams. The age of the formation is of critical importance for the evaluation of the Kirkuk-Dezeful basin. The main biogenic components of the Ibrahim Formation are planktonic foraminifera, radiolaria, calcispheres, and benthic foraminifera. Krashennnikov (1978) considered *Globorotalia kugleri* sp., which is found throughout the formation, as the index fossils to lower boundary of Neogene. (Kennett and Srinivasan, 1983) state that this species appears only in the tropics of the early Miocene. *Globigerina binaiensis* sp., This genus is important because they are intergraded in the late Oligocene. It's absent in the upper part of the succession. The presence of *Globorotalia kugleri* sp. in most of the samples and the absence of *Globigerina binaiensis* indicates transitional between two cycles of Megasequence AP11, latest Eocene-Oligocene, and Early-Middle Miocene. Calcispheres can usually define as hollow calcareous spherical shapes microfossils of different origins, (Berkyová &

Munnecke, 2010). In the present study, calcispheres are plenty with other planktonic and appear in most of the formation. These calcispheres have varied sizes and moderately thick walls composed. Calcispheres are associated mainly with an open shelf to ocean pelagic deposits; (Scholle & Ulmer-Scholle, 2003). According to Apel *et al.* (2002).

Plate 3. A. Dissolution processes, fabric selective represented by molding of skeletal grains, IB25 and IB24; B and C: Cementation of granular calcite and replacement forming calcification, IB 5 and IB4; D: skeletal grain replacement partially by phosphate (Ph); E: A chamber of fossils filled with pyrite (pyr); F: skeletal grain replacement partially by glauconite (G). All samples were examined under polarized light with a lens 10X.

Global calcisphere bio event associated with OAE (Ocean Anoxic Event). Because there are common appearances in all samples, suggesting reduction conditions during the depositional time. Radiolaria have been employed with great success in studies of climate change, in biostratigraphic dating of both Cenozoic deep-sea sediments and more ancient sedimentary rocks, often in metamorphosed tectonic terranes, and in studies of evolutionary processes, Radiolaria preservation linked to productivity triggered by climatic cooling during the early Oligocene, (Zachos *et al.*, 1999, and Apel *et al.*, 2002). In this study, the radiolaria faunal change was documented as well as intervals of their appearance about the outstanding climate cooling. Modernistic radiolarians are considerable in deep-sea deposits, especially in Pacific equatorial regions. The accumulation of radiolarian mud in the high latitude regions indicates deposition at great depths (Flügel, 2010). As a result of the difference in temperature between the polar regions and the tropics, an intra-oceanic current is produced that significantly supplies nutrients (Kennett, 1977). Radiolaria and spread are in parallel with nutrients

supplies (Apel *et al.*, 2002). Radiolaria is affected by nutrients and the amount of sediments, so its abundance increases with depth in any sedimentary basin (Empson, 1984). In the current study, Radiolaria clusters refer to the change in sea level in response to the that tectonics or perhaps cooling seawater and the upwelling controls the sedimentary basin. This is evident by the radiolaria clusters at the bottom of the formation (samples IB1- IB 14) and at the middle part of the formation (samples IB21-IB28). The radiolaria are well preserved, because they were slightly affected by the dissolution processes rather than another interval. This indicate a deep environment with acidic pH. Calcification of radiolaria is also noticed, it starts during the early diagenetic stage and it continues through the first stages of the burial. The calcification of radiolaria is a common process in limestones and the radiolarian crusts are replaced by calcite (Daoud et al., 2010). Microfacies are indicative of the deep marine environment. Planktonic wackestone and mud-wackestone is the most abundant microfacies type in the formation, within an interval of radiolarian wackestone, which is distributed through the different level in the studied succession, reflecting highest deepening in a quiet depositional environment. The bioclastic calcareous mudstone facies indicate a shift to more restricted conditions with normal marine of low-energy. According to the microfacies analyses and petrography, the I brahim Formation was deposited in a deep-sea outer shelf.

Conclusions

Based on the radiolaria and the mine microfacies, it is evident that the sedimentary basin of the Ibrahim Formation was affected by tectonics, which affected the sedimentation environment in the transition from the deep environment (the lower part of the formation and upper of the middle part) to the continental shelf environment twice. The fossil data (*Globigerina binaiensis* sp.) indicate that the Miocene-Oligocene boundary is in the upper of the middle part marked by samples IB25. The distribution of calcispheres indicates a deep hypoxic reductive environment.

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