Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org

Biostratigraphy of the Mauddud Formation from selected Boreholes, central Iraq

Luay S. Shakir [1], Anwar K. Mousa [1,*]

[1] Department of Geology, College of Science, University of Baghdad. Baghdad, Iraq
* Correspondence: anwar.mousa@sc.uobaghdad.edu.iq

Received: 25 March 2023

Accepted: 9 May 2023

Published: 30 September 2023

Abstract

The Mauddud Formation was one of the important and widespread Lower Cretaceous period formations in Iraq. It has been studied in three wells (EB. 55, EB. 58, and EB. 59) within the East Baghdad Oil Field, Baghdad, central Iraq. 280 thin sections were studied by microscope to determine fauna, the formation composed of limestone and dolomitized limestone in some parts which tends to be marl in some parts, forty species and genus of benthic foraminifera have been identified beside algae and other fossils, three biozones have been identified in the range which is: *Orbitolina qatarica* range zone (Late Albian), *Orbitolina sefini* range zone (Late Albian – Early Cenomanian) and *Orbitolina concava* range zone (Early Cenomanian), The age of the Mauddud Formation was determined using these three biozones, and it was then suggested that the formation was Late Albian–Early Cenomanian based on careful comparison and correlation with foraminifera species found locally and globally.

Keywords: Mauddud; Formation; Biostratigraphy; Biozone; Foraminifera; Orbitolina,; Albian; Cenomanian.

1. Introduction

Important hydrocarbon reservoirs are found in the Cretaceous carbonate succession in many areas of the Arabian Plate, including Central and Southern Iraq. Some of these reservoirs are found in the Mauddud Formation, which is dispersed throughout many oil fields (Sadooni and Al Sharhan, 2003). Owen and Nasr (1958) characterized the Mauddud Formation from Zubair well No. 3 in Southern Iraq, where it is composed of pseudo-oolitic creamy layers of shale ranging in color from green to blue, they identified the following fossils. *Boggia* sp., *Trocholina* sp., *Praealveolina* sp., *Iraqia simplex* sp., and *Archaeolithothamnium* sp. The Mauddud reservoir, part of the Khabaz oil field, is regarded as one of the principal carbonate reservoirs in northern Iraq (Ahmed and Hamd-Allah, 2021). Bellen *et al*. (1959) characterized this formation in Central Iraq from the Falluja-1, Awasil-5, Makhul-1, and Makhul-2 wells. More recently, Mauddud described it from the Ahdab, and East Baghdad fields in these regions. Formation is made up of organic detrital limestone with a marly matrix and recognized the following foraminifera *Trocholina altispira*,*Trocholina arbica*, *Trocholina lenticularis*, *Orbitolina cf.concava*, *Rabanitina basranesis*. The Mauddud Formation is made up of orbitolina-bearing

DOI: 10.46717/igj.56.2C.19ms-2023-9-25

limestone and dolomites that were formed in the Albian-Early Cenomanian sequence age. According to Sadooni and Al sharhan (2003), the facies in the formation vary in thickness due to eroisional truncation. The depositional environment, according to Cross et al., (2010) was a shallow marine ramp setting with low to high energy.And according to Faisal and Mahdi, (2020) the facies model of Mauddud Formation shows the dominance of open marine facies in the upper and middle parts of the formation, whereas mid-ramp facies occupies the lower part. The shoal facies represents approximately continuous units in their wells which are studied in Badra oil field. The lower contact of the Mauddud Formation is conformable and gradational with the Nahr Umar Formation, whereas the upper contact of the formation is unconformable with the Ahmadi Formation. It is composed of neomorphosed and dolomitized limestone (Shubber,1986) While in northern Iraq, the Qamchuga Formation, an equivalent of the Mauddud Formation, has been given a distinct stratigraphic description (ponikarov et al.,1967) (Fig.1). Mauddud Formation produces oil from limestone units; it represents the main reservoir in the Badra oil field (Faisal and Mahdi, 2020). Hameed and Faisal, (2023) studied Petrophysical Properties of Mauddud Formation in Selected Wells in Al- Ahdab Oil Field , Middle Iraq and founded that the formation was divided into five units, two of them were considered good reservoirs having good petrophysical properties (high porosity, Low water saturation, and low shale volume) and the other three are not reservoirs because of poor petrophysical properties. Ahmed and Hamd-Allah (2021) researched the geological model for Mauddud Reservoir in Kirkuk, northern Iraq's Khabaz Oil Field. The reservoir in their study is oil-bearing with the original gas cap, and they are concerned with its geological modeling. By defining the facies, evaluating the petrophysical characteristics of this complicated reservoir, and estimating the amount of hydrocarbon. Depending on the variations in petrophysical properties (porosity and permeability), the reservoirs were divided into four zones. By analyzing the formation's biostratigraphy in the Badra oil field in Eastern Iraq by Al-Yassery (2015) and Norri et al., (2016) and in the Ratawi oil field in Southern Iraq by Ezzulddin and Ibrahim (2022), they identified three biozones of benthonic foraminifera, and the age of the formation is determined according to these biozones to be Late Albian–Early Cenomanian. This study focuses on the biostratigraphy of the Mauddud Formation in the East Baghdad oil field. It identifies the foraminifers' zonation and determines the formation's age in the examined section using assemblages of microfossils (foraminifera and algae).

2. Stratigraphy and Tectonic setting

The study area is located in the Mesopotamian zone, the eastern most unit of the stable shelf; it was likely uplifted during the Hercynian deformation but began to subside from the late Permian period onward. The zone contains buried faulted structures beneath the Quaternary cover that are separated by broad synclines. The Mesopotamian zone is divided into three subzones: the Zubair, Tigris, and Euphrates subzones, which are then acknowledged in the northern Gulf of Iraq and Kuwait, the Eastern Arabian Peninsula of Saudi Arabia and Bahrain, as well as the Southern Gulf of the United Arab Emirates and Oman (Fig. 1), (Jassim and Goff, 2006). The Mauddud Formation was first described by Henson in 1947 from the subsurface section of Dukhan well No. 1 in Qatar, where it gets its name from the town of Ain Mauddud, which is close to Dukhan, Qatar, the definition was revised and amended by (Sugden ,1958; Buday. 1980). The Nahr Umr, Jawan, Rim Siltstone, Qamchuqa, and Balambo Formations, as well as the Mauddud Formation carbonate succession, were all assigned to the Albian-Early Turonian sequence (Wasia Group) (Wasia Group) during the Cretaceous period (Jassim and Goff, 2006). Southeast Iraq's Mauddud Formation was the subject of an investigation by Al Siddiki in 1978, which concentrated on the most important microfossils, lithology, and depositional environment. He assigned the age of formation as Cenomanian and used an isopach map to describe the distribution and direction of the increase in thickness and the depositional basin. Although the upper contact of the studied Formation is marked by a break and is either nonsequential or unconformable, it is an unconformity in the north-central, north, and northeast parts of Iraq, while the formation may be lost locally in northwest Iraq as a result of Cretaceous erosion. The lower contact this formation is conformable and gradational with Nahr Umr, Lower Balambo, or Lower Sarmord Formation (Jassim and Goff, 2006). The formation was originally believed to extend into the Cenomanian because of the frequent occurrence of some species of *Orbitolina concava* group (Bellen *et al*., 1959). During his research of Cretaceous rocks in numerous wells in South Iraq, (Brun, 1970) listed various microfossil species in the Mauddud Formation, but the fauna of theformation in West Iraq is only of Albian age (Catroky and Karim, 1981in Jassim and Goff,2006; Jassim *et al*., 1984). Mohammed (2012) discovered and described a new species of Orbitolinid foraminifera in the Mauddud Formation related to the Late Albian period. This formation is Albian in age, according to Ibrahim, (1981). The Mauddud Formation's age was revised and amended by (Sayyab and Mohammed, 1984; 1985) to Albian-Early Cenomanian due to the existence of a group of fossils with a narrow stratigraphic range. (Mohammed, 1996) established the biostratigraphy of the Orbitolinids in the Mauddud Formation and dated the formation by studying Orbitolinids (foraminifera) from the Lower Cretaceous (Barremian-Turonian) of Iraq, and gave the age of the formation Early Albian- Early change, and it is composed of limestone, dolostone, and dolomitic limestone with unique marl interaction (Al-Qayim *et al*., 2010). Al-Khersan, (1973) studied the fossils present in this formation and discussed the biostratigraphy and paleoecology of the formation. This formation was deposited over the Nahr Umr Formation during transgressive cycles, and the final part of regressive cycles, which are separated by transitional cycles (Al-Khayat and Razoian, 1978). A ramp bordered by shoals and rudist biostromes depicts the depositional setting of the Mauddud Formation in the Arabian plate (Cross *et al*., 2010). Albian carbonates in northern Iraq have a thickness of 400 meters, and the formation is 50 to 250 meters deep below the surface (Jassim and Goff, 2006). In their study of the depositional environment of the Mauddud formation done by Al-Dabbas et al. (2012), they note that the sedimentary microfacies of the formation include dolostone lithofacies and green shale lithofacies in addition to lime mudstone, wackestone, and packstone. In their study of the microfacies interpretation and deposition environment for the Mauddud Formation in the Rataw oil field, Hameed and Saleh, (2021, 2022) concluded that the formation was deposited in five different types of environments: outer ramp, mid ramp, inner ramp, restricted, and shoal. In his investigation of the microfacies of the Mauddud Formation from the subsurfaces of southern and southeastern Iraq, (Mohammed, 1981) divided the formation into six units based on the fossils that made up the

formation. At the Badra oil field in Central Iraq, Fasial and Mahdi (2020) examine the diagenetic processes over the print and pore types of the Mauddud Formation. The Albian portion of the Sarvak Formation is equivalent to the Mauddud Formation in southwest Iran, The neritic dolomitic limestone of the upper portion of the Aasafir Formation in central Syria and the Palmyrides is equivalent to the Mauddud Formation (Jassim and Goff, 2006). The Mauddud Formation declines in Southeast across the Anah Qalat Dizeh fault as the formation changes into the basinal limestones of the Balambo Formation,the Mauddud Formation outcrops in western Iraq on the southeast side of the Hauran Anticlinorium (Bellen et al., 1959).

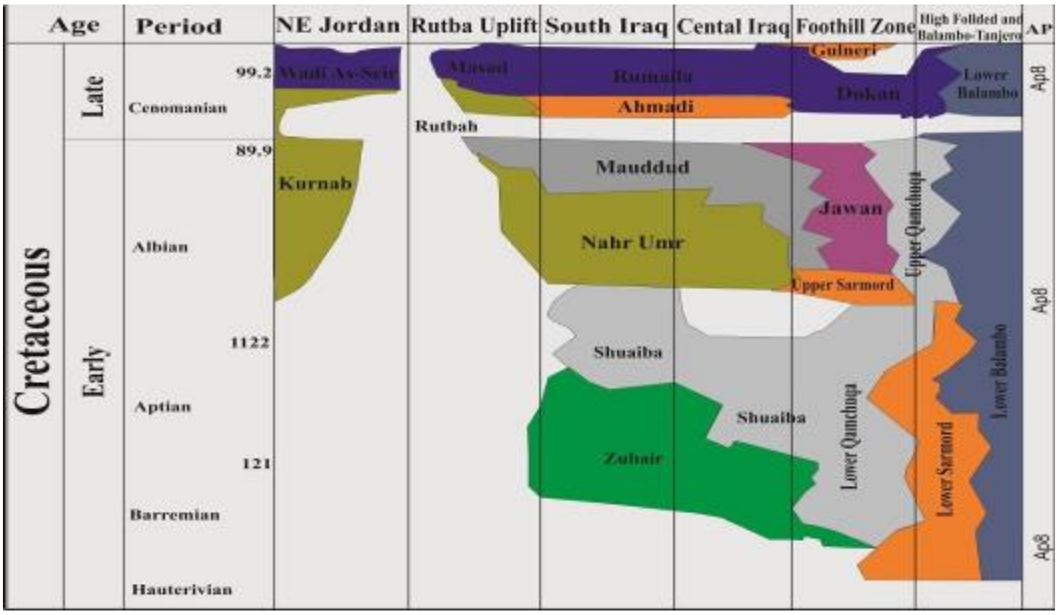

Fig.1. Lithostratigraphy correlation of the Early Cretaceous succession in Iraq, after Jassim and Goff, 2006with some modifications

3. Material and Methods

The study area is located in the East Baghdad oil field, which is about 20 kilometers from Baghdad's city center and is over 120 kilometers long and between 20 and 30 kilometers wide. Table.1 Fig.2; Oapec, 1987). Three wells have been chosen for the study that are distributed along the anticline structure and oriented NE-SE of the East Baghdad oil field. In this study, a subsurface section of the Mauddud Formation was selected for investigation. 290 samples of core and cutting were collected from the studied area, with typical sampling intervals of 2 to 5 meters. Thin sections were prepared from each sample for fossils identification. Benthic foraminifera are often well preserved and abundant and it is used to classify the studied interval into three biozones based on Brun (1970); Al-Khersan, (1973); Al-Siddiki, (1978); Mohammed (1981,1992, 1996, 2017); Sampo, (1969); Sugden and Standring, 1975; Peybernes,1976; Sayyab and Mohammed, 1984; Bozargani,1964; Leoblich and Tappan, (1988); Satorio and Venturina,(1988); Boudagher, (2008); Al-Yassery, (2015); Khazaal and Shaki, (2022); Ezzulddin and Ibrahim, (2022); Al-Mamory and Al-Dulaimi, (2020).

Table 1. Coordinates of three selected sections of the research region and thickness with the top and bottom of the formation

Well no.	Longitude	Latitude	Thickness of Fm.	Top of Fm.	Bottom of Fm.
EB55	43°'10.500" E	37° 15'600"N	205.5 m.	2661.5m	2866m
EB58	43°66'08" E	37° 05'883"N	215 m.	2634m	2849m
EB59	43°07'56" E	37° 07'587"N	184.5 m.	2710m	2894.5m

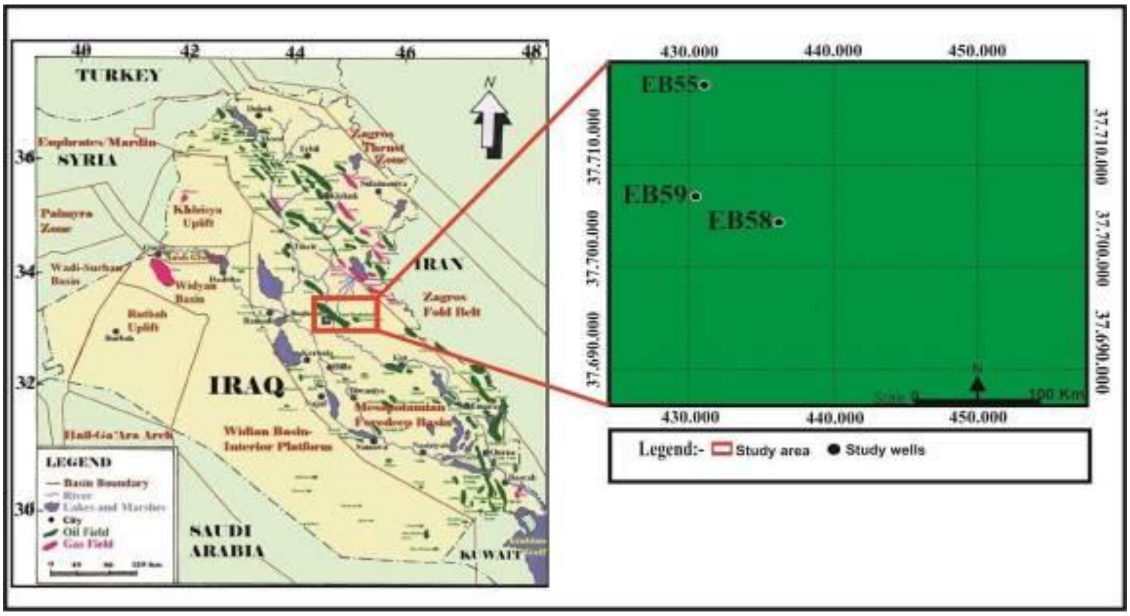

Fig.2. Location map of studied area (After Al-Khafaji, 2014)

4. Biostratigraphy and Biozone

Biostratigraphy is the study of the relative ordering of strata based on their fossil content. Descriptive biostratigraphy is used in determination zones for regional or local stratigraphic correlation (Keller, 2004). The Mauddud Formation, which consists of limestone and dolomitic limestone, has a trend to be marly in some areas. The Mauddud biostratigraphy Based on the distribution of benthic foraminifera and associated fossils, the formation of three subsurface wells, whose thickness varied from (184.4 to 215) meters, has been investigated. These wells yielded a foraminiferal and algae fauna that included 20 species that belonged to 15 taxa. Common foraminifera of the Mauddud Formation in studied sections are consisted of: Mesorbitolina oculate Douglass (Plate.1, Fig. A), Orbitolina qatarica Henson (Pl. 1, Figs. B, C, and D), Iraqi simplex Henson (Pl. 1, Figs. E, K, and L), Orbitolina sefini Henson (Pl. 1, Figs. F, G), Orbitolina concava Lamarck (Pl. 1, Figs. H, I, and M), Iraqi sp. (Pl. 1, Fig. J), Orbitolina sp. (Pl. 1, Fig. N), Praealveolina cretacea Darchiac (Pl. 1, Fig. O), Praealveolina simplex Reichel (Pl. 1, Fig. P), Praealveolina sp. (Pl. 1, Fig. Q), Cisalveilina fraasi Gumbel (Pl. 1, Fig. R), Pseudotextulariella sp. (Pl. 2, Fig. A and Pl. 3, Fig. C), Spiroplectammina sp. (Pl. 2, Fig. B), Pseudolitunella sayyabi Mohammed (Pl. 2, Fig. C and Pl. 3, Fig. A), Nezzazata simplex Omar (Pl. 2, Figs. D, G, I and J), Nezzazata picardi Henson (Pl. 2, Fig. E), Nezzazata conica Smout (Pl. 2, Figs. F, and H), Valvulammina picardi Henson (Pl. 2, Figs. K, L, and M), Trocholina alpina Arid (Pl. 2, Figs. N, and O), Trocholina arbica Henson (Pl. 2, Figs. P, and Q), Pseudolitunella sp.(Pl. 2, Fig. R), Spirolectammina sp. (Pl. 3, Figs. B and I), Valvulina sp.(Pl. 3, Figs. D and J), Textularia sp. (Pl. 3, Fig. E), Cuneolina pavonia Dorbigny(Pl. 3, Fig. F), Spiroloculina sp. (Pl. 3, Fig. G), Quinquiloculina sp. (Pl. 3, Fig. G), Miliolds sp.(Pl. 3, Fig. H), Chrysaldina gradata Dorbigny (Pl. 3, Fig. K), Nautiloculina oolithica Mohler (Pl. 3, Fig. L),Conicorbitolina conica DArchia,Nezzazata sp., Hedbergella sp., Globigerinelloides sp., Pseudochrysaldina conica Henson, Trocholina sp., Neoiraqi convex Henson, and common algae in Mauddud Formation : Cylindroporella sugden Elliot (Pl. 3, Fig. M), Acicularia sp., Acicularia antiqua Pia (Pl. 3, Fig. N), Permocalculus irenae Elliot, Permocalculus inopinatus Elliot (Pl. 3, Fig. O), Permocalculus sp. Other fossils discovered during the detailed biostratigraphy analysis of the formation in wells (EB.55; EB.58; and EB.59) these fossils include gastropods shells (Pl. 3, Fig. P), echinoid debris(Pl. 3, Fig. Q), rudist fragments(Pl. 3, Fig. R), Ostracoda, bivalve, and coral fragments (Figs. 3, 4, and 5). There are three distinct biozones represented: Orbitolina qatarica (Late Albian), Orbitolina sefini (Late Albian_Early Cenomanion), and Orbitolina concava (Early Cenomanian). The following discussion and description of the biozones are given:

4.1. *Orbitolina Qatarica* Range Zone

Definition: From *Orbitolina qatarica*'s first appearance to *Orbitolina sefini*'s first appearance, this zone is designated.

Age: Late Albian.

Occurrence: This zone is located in the Mauddud Formation's bottom portion and measures

approximately 60 meters in thickness in EB.55, 71 meters in thickness in EB.58, and 64 meters in thickness in EB.59 (Figs. 3, 4, and 5).

Remarks and correlation: Index fossils identify this zone as *Orbitolina qatarica*. The taxonomic genus related to this taxon includes: Mesorbitolina aculata, Trocholina alpina, Nezzazata conica, and Nezzazata simplex, Textularia sp., Valvulina sp., Quinquiloculina sp., Other specimens include Pseudochrysalidina conica, Praealveolina sp., Trocholina arabica, Chrysaldina qradata, Cuneolina pavonia, Acicularia sp., Acicularia antiqua, Permocalculus sp., Permocalculus irenae. etc.. According to several researchers, some of these occurrences have been reported (Table 2): (Sampo, 1969) found that this biozone refers to the Albian age in Iran. (Loutfi and Jaber, 1970) mentioned *Orbitolina qatarica* designated Albian age from Saudi Arabia and Kuwait in the off-shore region, and (Sugden and Standring, 1975) described the zone as the origin of Qatar's Albian rocks. The index species *Orbitolina qatarica* designated Late Albian age in many parts of the world: Lawa and Gharib (2014) characterize this biozone as belonging to the Late Albian period and are found in the upper Qamchuqa Formation of North Iraq's Zagros fold-thrust belt. This biozone is Late Albian, according to Schröder (1975) and Mohammed (1996), Al-Yassery (2015), Norri et al., (2016) in eastern Iraq, and Ezzulddin and Ibrahim (2022) in south Iraq. Berthou, 1984 dated the *Orbitolina qatarica* from Portugal as Late Albian-Early Cenomanian. Henson (1947) first discovered *Orbitolina qatarica* in the Early Cenomanian of Qatar, which was identified in German as Early Cenomanian by Schröder (1962). According to Scott (2010), this zone was discovered in the Early Cenomanian of China. Simmons and Williams (1992) describe the biozone of the Middle Cenomanian Zone in the Middle East. This research uses the *Orbitlina qatarica* biozone, which dates from the Late Albian.

4.2. *Orbitolina Sefini* Range Zone

Definition: This zone is described as beginning with *Orbitolina sefini* and ending with the first appearance of *Orbitolina concava*.

Age: Late Albian_Early Cenomanian.

Occurrence: This zone is situated in the middle part of the Mauddud Formation and has a thickness of about 58 meters (EB. 55), 47 meters (EB. 58), and 50 meters (EB. 59). (Fig. 3, 4, and 5).

Remark and correlation: The faunal characterized this zone, *Nezzazate simplex*, *Nezzazata conica*, *Trocholina arbica*, *Globigerinelloides* sp.,*Chrysalidina qradata*, *Nautiloculina oolithica*, *Quniqueloculina* sp., *Spiroloculina* sp., *Pseudochrysaldina conica*, *Cuneolina pavonia*, *Praealveolina* sp., *Textularia* sp., *Valvulina* sp., *Spiroplectammina* sp., *Mesorbitolina oculate*, *Hedbergella* sp., *Orbitolina* sp., *Iraqi simplex*, *Neoiraqi convex*, *Pseudolitunella sayyabi*, *Permocalculus* sp., *Chrysaldina gradate*, Miliolds sp. In addition to algae represented by: *Cylindroporella sugden*, *Permocalculus irenae*, *Acicularia* sp. and other fossils such as: gastropoda shell, coral fragments. Many scientists from various nations have characterized this biozone (Chatton and Hart, 1960) and dated the *Orbitolina sefini* from southern Iraq as Albian age within the Mauddud Formation. This biozone was discovered and classified as Late Albian in Spian (Peybernes, 1976), but its age is classified as Late Albian- Early Cenomanian by many researchers: (Mohammed, 1981 from the Mauddud Formation in southern Iraq (Table 2); Schröder (1975); Sayyab and Mohammed, (1984); Ezzulddine and Ibrahim, (2022) found in the Mauddud Formation, south Iraq; Mohammed (1996), and Al-Yassery (2015), Norri et al. (2016) in eastern Iraq; Al-Mamory and Al-Dulaimi, (2020), in northern Iraq; the Sarvak Formation at the Zagros Mountains in Iran by Safari et al., (2009); and in the Middle East by Simmons and Williams, (1992). Whereas the Early Cenomanian is specified in Portugal (Berthou and Schröder, 1978) and in Turkey Manara section at the Levant Margin by Homberg and Bachmann, (2010). The Cenomanian in Sefin Dogh comes from the so-called upper Qamchuqa Formation in Northern Iraq (Hensone 1947). In this study, the *Orbitolina sefini* biozone is referred to as being Late Albian-Early Cenomanian in age.

4.3. *Orbitolina Concava* Range zone. Definition: This zone was established with the first appearance of the species as the lower limit and its disappearance as the higher limit.

Age: Early Cenomanian

Occurrence: This zone is situated on the upper portion of the Mauddud Formation and ranges in thickness from 83 meters (EB.55), 90 meters (EB.58), and 68 meters (EB.59) (Figs. 3, 4, and 5)

Remark and correlation: This zone is marked by index fossils *Orbitolina concava* associated with other taxa like: Cuneolina paronia, Pseudolitunella sp. , Cisalveolina sp. , Miliolids sp.,Textulari sp.,Spirolectammina sp., Mesorbitolina sp., Hedbergella sp., Iraqi sp. , Spiroliculina sp. , Praealvelina sp., Chrysalidina gradata, Neoiraqi convex, Trocholina arbica, Trocholina alpine, Nezzazata simplex, Pseudolitunella sayyabi, Cisalveilina fraasi, Nezzazata picardi, Quinquiloculina sp., Valvulina sp., Mesorbitolina oculate, Globigerinelloides sp., Valvulammina picardi, Orbitolina sp., Nautiloculina oolithica, Praealveolina simplex, Trocholina sp., Praealveolina cretacea, Pseudotextulariella sp. Pseudochrysalidina conica, Conicorbitolina conica, Chrysaldina gradate, Miliolds sp. etc .. And alage: Acicularia sp., Acicularia antiqua, Permocalculus sp., Permocalculus inopinatus, Cylindroporellasugden and other fossils gastropoda shell, rudist fragments and coral fragments. According to several researchers, some of these occurrences have been documented: (Bozargani, 1964) describes Orbitolina cf. concava from the Albian-Early Cenomanian, and limits it to the Late Albian-Early Cenomanian age in the south of Iraq (Al-Siddiki, 1978; Ezzulddin and Ibrahim, 2022; (Table 2) and the same age given to this zone in Iran at the Sarvak Formation (Haftlang et al., 2020).

Leoblich and Tappan (1988) stated that Orbitolina concava was found in the Albian-Cenomanian rocks of France, Spain, and Qatar. While (Schröder, 1975) and (Mohammed, 1996) determined this zone is of Early Cenomanian age. The species Orbitolina concava was discovered in strata dating to the Cenomanian age in all of the following nations: Iran (Sampo, 1969), Iraq and Qatar (Henson, 1947), Southern France (Dufaure, 1959), Germany (Schröder, 1962), Italy, Switzerland, and Spain (Ellis and Messina, 1966), Zagros (Satorio and Venturina, 1988), Chia (Zhang, 2000), Qamchuqu Formation in the north of Iraq (Lawa and Gharib, 2014), Eastern Iraq (Al-Yassery, 2015) In this study this Orbitolina concava biozone refers to the Early Cenomanian age. The presence of an abundance of fauna, particularly benthic foraminifera and algae, suggested a shallow marine environment, represented by a shoal environment, which indicated the ideal environment for Orbitolina. It also suggested that the decreasing distribution of orbitolina was a result of rising salinity (Lozo, 1944; Cobban, 1957 in Douglass, 1960). Orbitolina's environment can be characterized as clear, warm, shallow water with normal salinity that thrives in a shoal environment. The depositional environment of the Mauddud formation in the examined wells occurred in a shallow marine environment represented by a shoal environment, which designated the optimum condition for Orbitolina, and the reasons for the poor distribution of Orbitolina as a result of increasing ocean acidification. Comminuted rudist clasts, echinoderm grains, benthic foraminifera (such as Orbitolina sp., Textularia sp., Nezzazata sp., and miliolids), and other findings point to re-sedimentation that was likely caused by turbidity currents on the slope. Foraminifera and mixed algae both support this. The fact that they were moved from a shallow-water environment to the outer shelf in front of shoals is further supported by the abundance of conical Orbitolina (Esfandyari et al., 2023). Large rudist grains that exhibit well-preserved interior structure and are occasionally bored, along with tiny rudist grains. Rudists (average 15%) occasionally coexist with small bioclastic grains in a mud-supported matrix and are encircled by a lime-mud matrix. More frequently found are large benthic foraminifers (such as Orbitolina), oysters, and fauna from lagoons such as miliolids, Textularia, and Nezzazata (Esfandyari et al., 2023). The rudist fragments are poorly sorted and comminuted with evidence of burial compaction. Large rudist grains imply a high energy level above the Fair Weather Wave Base (FWWB) in an open marine setting (Wilson, 1975). Morphological variation of Orbitolina is an indicator of environmental condition, particularly, the water depth (Simmons et al., 2000). Elongate and smooth shells indicate a middle shelf setting (Reiss and Hottinger, 1984; Grafe, 2005).

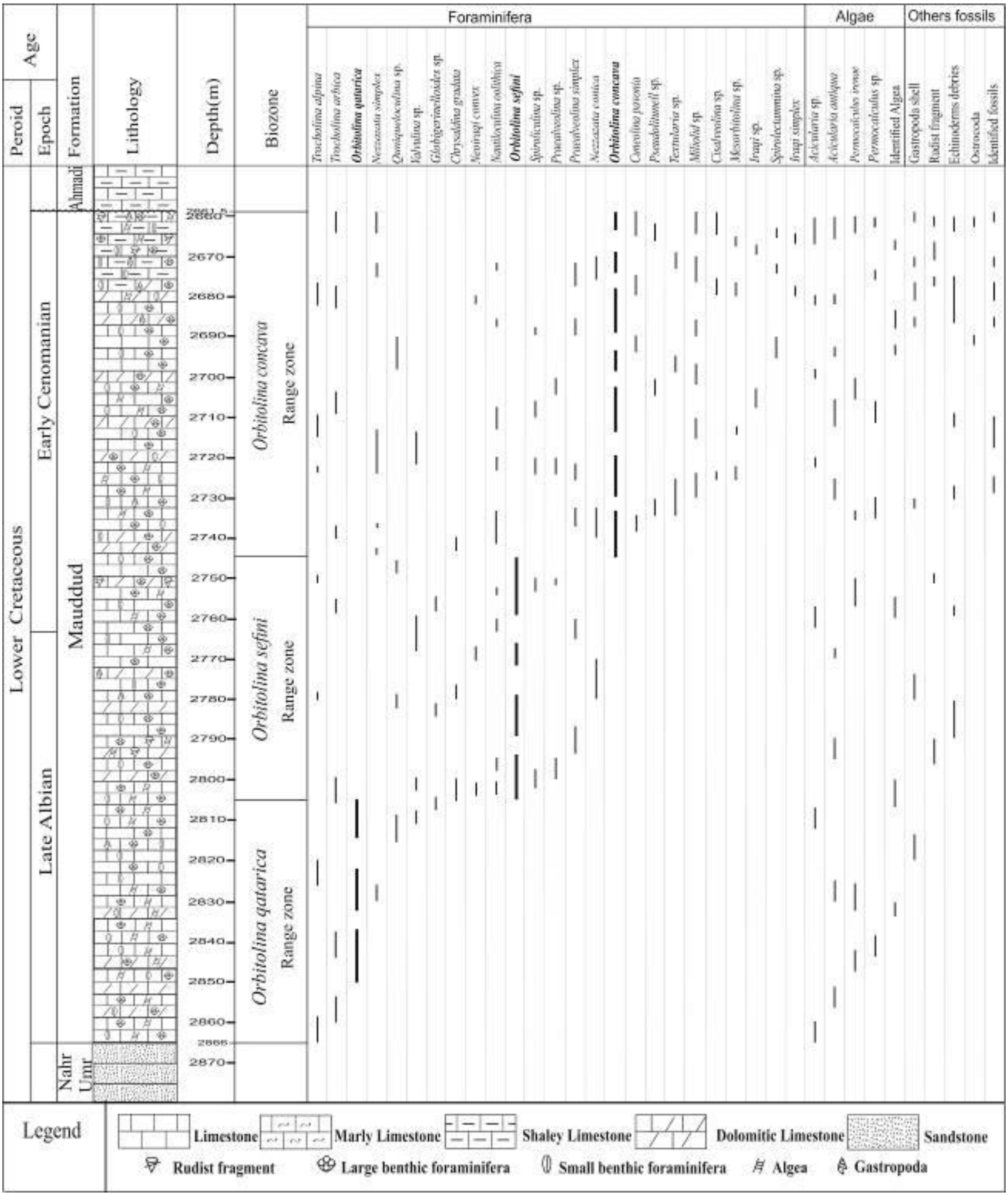

Fig.3. Biozone and Biostratigraphic distribution of Foraminifers and Skeletal grain of Mauddud Formation in well EB-55.

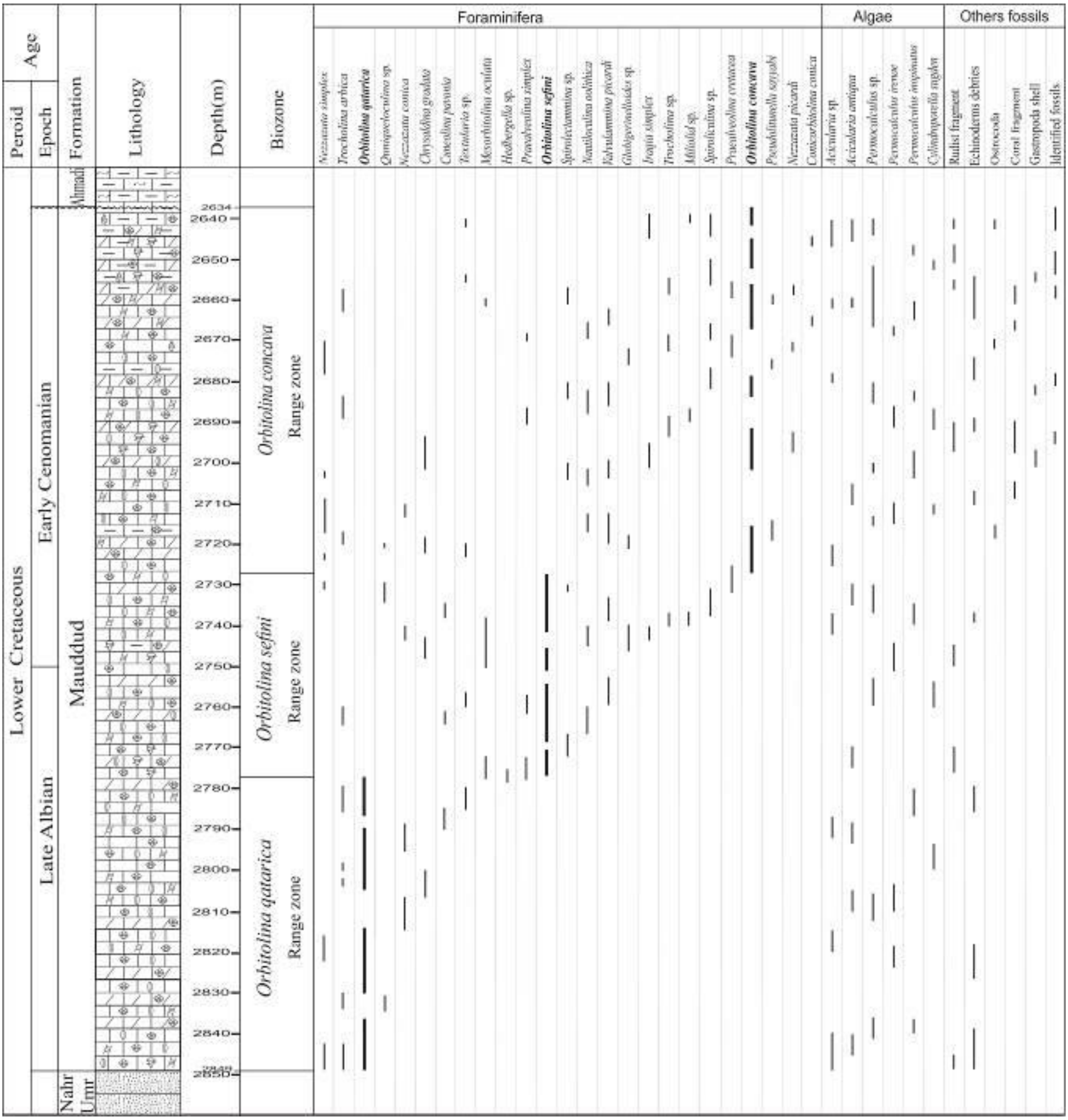

Fig.4. Biozone and Biostratigraphic distribution of Foraminifers and Skeletal grain of Mauddud Formation in well EB-58

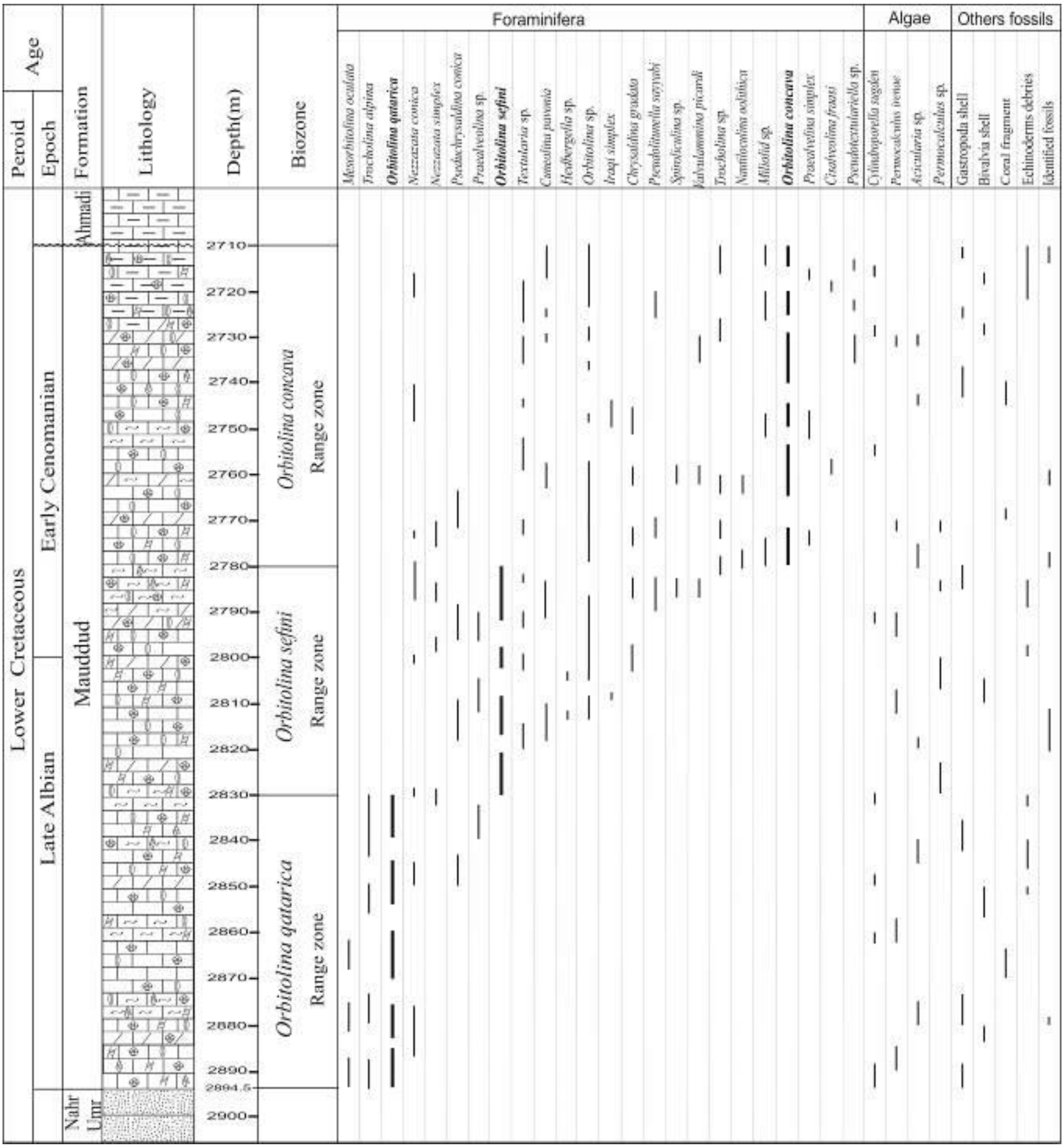

Fig.5. Biozone and Biostratigraphic distribution of Foraminifers and Skeletal grain of Mauddud Formation in well EB-59.

Table 2. Correlation chart showing the Foraminiferal biostratigraphic zones of Lower Cretaceous in the studied section with the foraminiferal zonation commonly used in Iraq and different country.

Peroid	Epoch	Sampo, 1969	Schröder, 1975	Mohammed, 1996	Pegah, 2010	Ghanem, 2012	Lawa & Gharib, 2014	Al-Yassery, 2015	Al-mamory and Al-Dulaimi, 2020.	Ezzulddin & Ibrahim, 2022	Present study
Lower Cretaceous	Early Cenomanian	*Orbitolina concava*	*Orbitolina concava*	*Orbitolina concava*	*Conicorbitoina concava*	*Pseudedomia drorimensis & Rotalipora cushmani*	*Orbitolina concava*	*Orbitolina concava*	*Orbitolina sefini*	*Orbitolina concava*	*Orbitolina concava*
	L. Albian-E. Cenomanian		*Orbitolina sefini*	*Orbitolina sefini*	*Mesorbitolina texana*	*Praelveolina iberica & Rotalipora globotruncanoides*	*Orbitolina sefini*	*Orbitolina sefini*	*Orbitolina sefini*	*Orbitolina sefini*	*Orbitolina sefini*
	Late Albian	*Orbitolina qatarica*	*Orbitolina qatarica*	*Orbitolina qatarica*	*Mesorbitolina subconcava & Hemicyclammina sigali*	*Neoiraqia convexa & Rotalipora subticinensis*	*Orbitolina qatarica*	*Orbitolina qatarica*	*Mesorbitolina subconcava & Orbitolina concava*	*Orbitolina qatarica*	*Orbitolina qatarica*

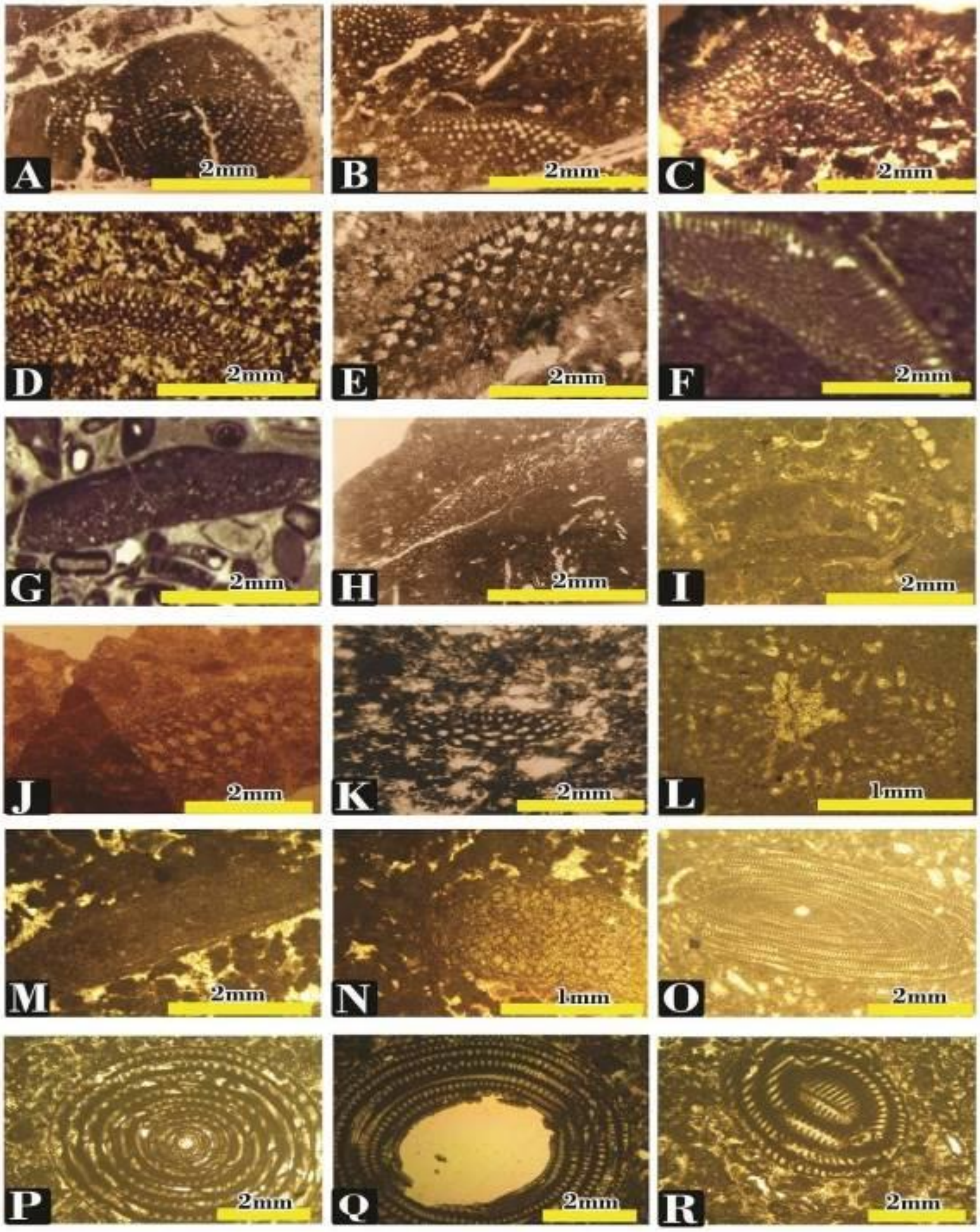

Plate 1. A- *Mesorbitolina oculate* (EB.58, 2740m); B- *Orbitolina qatarica* (EB.55, 2820m); C- *Orbitolina qatarica* (EB.58, 2840m); D- *Orbitolina qatarica* (EB.59, 2880m); E- *Iraqi simplex* (EB.59, 2745m); F- *Orbitolina sefini* (EB.55, 2785m); G- *Orbitolina sefini* (EB.58, 2740m); H- *Orbitolina concava* (EB.59, 2760m); I- *Orbitolina concava* (EB.55, 2720m); J- *Iraqi* sp. (EB.55, 2670m); K- *Iraqi simplex* (EB.55, 2680m); L- *Iraqi simplex* (EB.58, 2700m); M- *Orbitolina concava* (EB.58, 2650m); N- *Orbitolina* sp. (EB.59, 2790m); O- *Praealveolina cretacea* (EB.58, 2670m); P- *Praealveolina simplex*(EB.59, 2750m); Q- *Praealveolina* sp. (EB.55, 2720m); R- *Cisalveilina fraasi* (EB.59, 2758m).

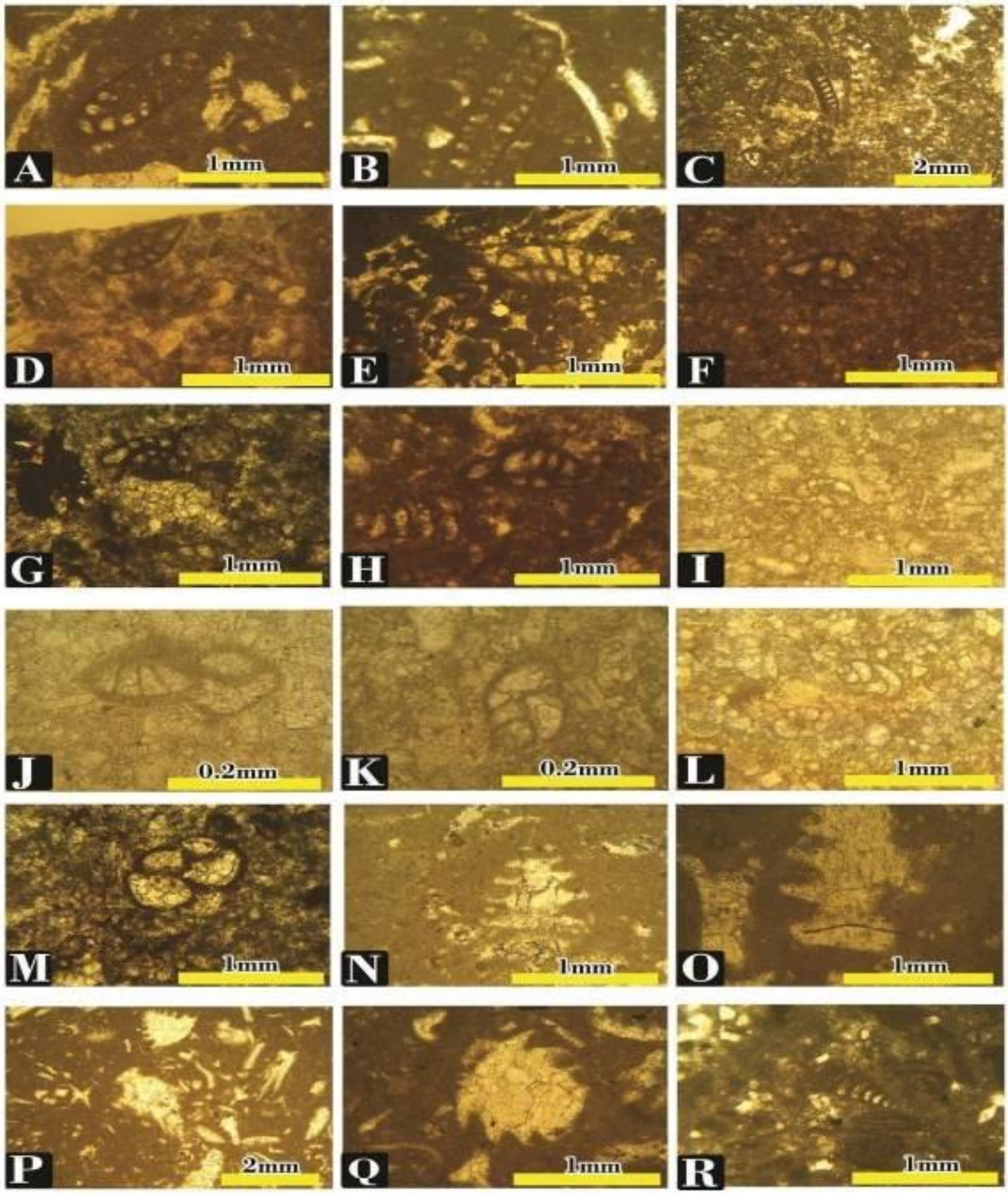

Plate 2. A- *Pseudotextulariella* sp. (EB.59, 2715m); B- *Spiroplectammina* sp. (EB.55, 2665m); C- *Pseudolitunella sayyabi*(EB.59, 2770m); D- *Nezzazata simplex* (EB.55, 2720m); E- *Nezzazata picardi* (EB.58, 2670m); F- *Nezzazata conica* (EB.58, 2790m); G- *Nezzazata simplex* (EB.55, 2828m); H- *Nezzazata conica* (EB.55, 2740m); I- *Nezzazata simplex* (EB.58, 2710m); J- *Nezzazata simplex* (EB.59, 2830m); K- *Valvulammina picardi* (EB.59, 2760m); L- *Valvulammina picardi* (EB.59, 2735m); M- *Valvulammina picardi* (EB.58, 2700m); N- *Trocholina alpine* (EB.55, 2735m); O- *Trocholina alpine* (EB.59, 2840m); P- *Trocholina arbica* (EB.55, 2840m); Q- *Trocholina arbica* (EB.58, 2660m); R- *Pseudolitunella* sp.(EB.55, 2700m).

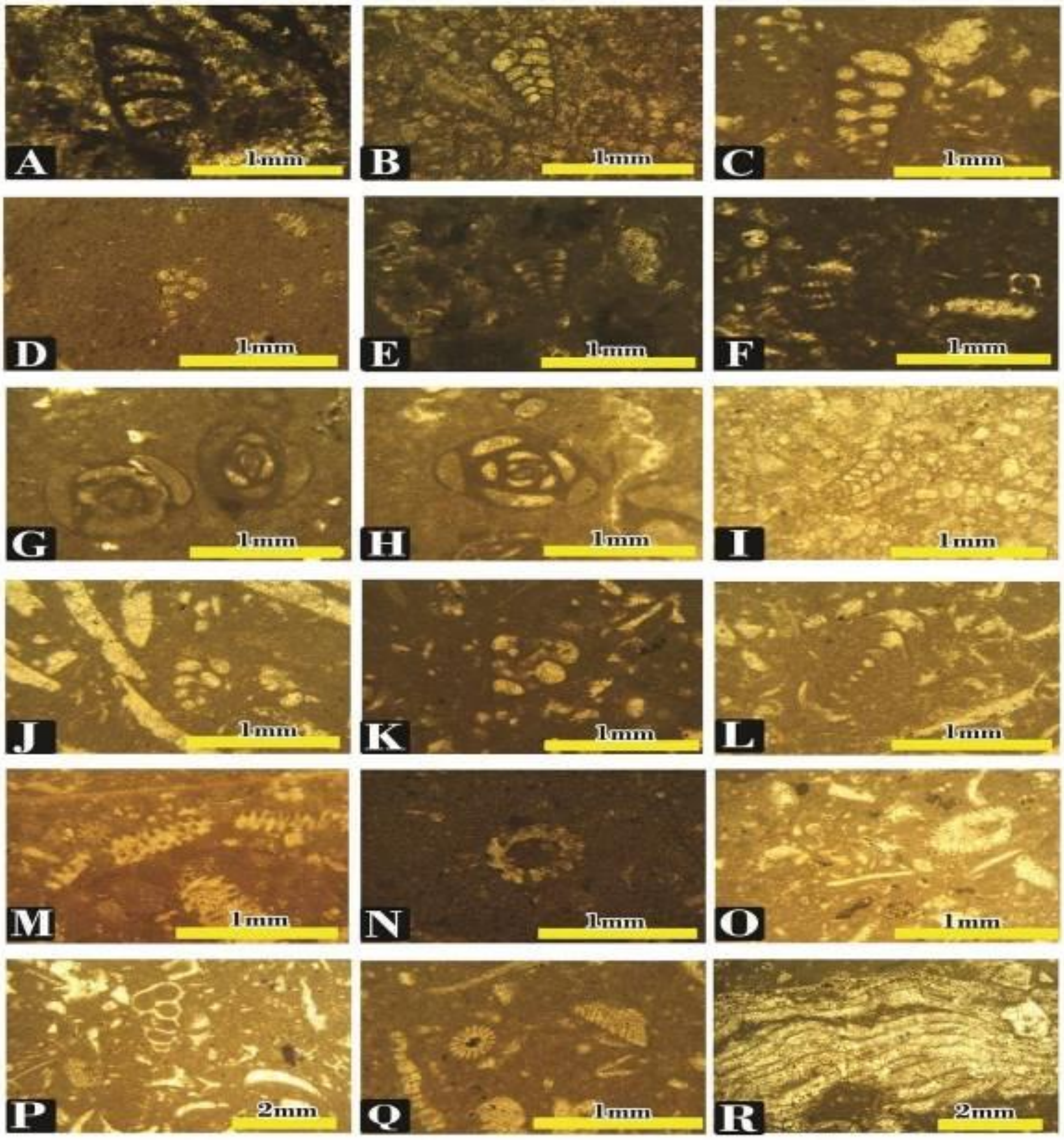

Plate 3. A- *Pseudolitunella sayyabi* (EB.58, 2710m); B- *Spirolectammina* sp. (EB.58, 2700m); C- *Pesdotextulariella* sp. (EB.59, 2730m); D- *Valvulina* sp. (EB.55, 2760m); E- *Textularia* sp. (EB.55, 2730m); F- *Cuneolina pavonia* (EB.59, 2785m); G- *Spiroloculina* sp. and *Quinquiloculina* sp. (EB.55, 2690m); H- Miliolds sp. (EB.59, 2750m); I- *Spirolectammina* sp. (EB.58, 2680m); J- *Valvulina* sp. (EB.55, 2800m); K- *Chrysaldina gradata* (EB.58, 2700m); L- *Nautiloculina oolithica* (EB.58, 2740m); M- *Cylindroporella sugden* (EB.58, 2690m); N- *Acicularia antiqua* (EB.58, 2790m); O- *Permocalculus*i *inopinatus* (EB.58, 2700m); P- Gastropods shells (EB.59, 2780m); Q-Echinoid debris(EB.55, 2730m); R-Rudist fragments (EB.55, 2790m).

5. Conclusions

The Mauddud Formation carbonate succession is a significant formation made up of limestone, limestone that has undergone dolomitization, and marly limestone in some areas. The formation's lower contact is conformable with the Nahr Umr Formation, while its upper contact is unconformable with Ahmadi Formation. Investigations have been made into the creation of three subsurface wells, whose thickness ranged from 184.4 to 215 meters. The foraminiferal and algae fauna from these wells contained 20 species that belonged to 15 groups. Based on benthic foraminifera, the Mauddud Formation was divided into three biozones: the *Orbitolina concava* range zone, the *Orbitolina sefini* range zone, and the *Orbitolina qatarica* range zone. These foraminiferal biozones provide information on the formation's age (Late Albian-Early Cenomanian). The depositional environment of the Mauddud formation in the examined wells occurred in a shallow marine environment represented by a shoal and lagoonal environment.

References

Ahmed, R. A. and Hamd-Allah, S. M.,2021. Geological Model for Mauddud Reservoir in Khabaz Oil Field, Kirkuk, northern Iraq, Iraqi Geological Journal, 54 (1D), 29-42.

Al-Dabbas, M., Jassim, A. and Qaradaghi, I., 2012. Sedimentological and depositional environment studies of the Mauddud Formation, central and southern Iraq, Arabian Journal of Geosciences, 5(2), 297-312.

Al-Khayat, A., and Razoian, A.W., 1978, the geology of Mauddud Formation in Ratawi Field. Unpublished INOC, No. 15.

AL-Khafaji, A., J. , 2014. The Mishrif, Yamama, and Nahr Umr reservoir characterization and quality analysis of Carbonate rock types,case study, Southern Iraq, Journal Petroleum Exploration, (10), 2137-3177.

Al-Mamory, W. and Al-Dulaimi, S., 2020. Biostratigraphy of Qamchuqa Formation in Jambur Oil Field in Kirkuk Area, Journal of University of Babylon for Pure and Applied Sciences, 28, 216-242.

Al-Qayim, B., Qadir, F. M. and Albeyati, F., 2010. Dolomitization and porosity evaluation of the Cretaceous Upper Qamchuqa (Mauddud) Formation, Khabbaz oil field, Kirkuk area, northern Iraq, GeoArabia, 15(4),49-76.

Al-Siddiki, A. A., 1978. Subsurface geology of southreastern Iraq, 10 th Arbian Petroleum Cong., Tripoli, Paper, 141, Sec. B3,47.

Al-Yassery, N., 2015. Biostratigraphy and Microfacies Analysis of Mauddud Formation in Badra Oil Field, Eastern Iraq, unpublished MSc. thesis, University of Baghdad, 58.

Bellen, R. C. Van., Dunnington, H. V., Wetzel, R., and Morton, D .M., 1959. Lexique Stratigraphique International, Asia, Iraq. Int. Geol.Congr. Comm. Stratig. V.3, 10a,1-333.

Berthou, P., 1984. Repartition stratigraphique actualisee des principaux foraminiferas benthiques du Cretace moyen et superior du basin occidental In Oertli, H. J. (ed); Benthos 83 (2nd International Symposium On Benthonic Foraminifera, Portugais', Elf Aquitaine, Pau (France, 1983),45–54.

Berthou, P. Y. and Schröder, R., 1978. Les Orbitolinidae et Alveolinidae de 1 Albien superieur Cenomanien inferieur et le problem de la limite Albien/Cenomanien dans le sud - oust de la region de lisbonne (Portugal), Cahiers Micropaleont., Paris, 51-104.

Boudagher, M. K., 2008. Evolution and Geological Significance of Larger Benthic Foraminifera., Elsevier, Amsterdam, 540.

Bozargani, F., 1964. Microfacies and micro-organism of Paleozoic through Tertiary sediments of some parts of Iran, Nati. Iran oil comp.,6-22,75P.

Brun, L., 1970. Cretaceous microfossils and microfacies form Iraq, ELFR.E. International report. Iraq.

Buday, T. ,1980. The Regional Geology of Iraq, Part I, Stratigraphy and Paleogeography. Kassab, I.I. and Jassim, S.Z. Eds., Baghdad, 445.

Chatton, M. and Hart, E., 1960. Revision of the Tithonian to Albian stratigraphy of Iraq. INOC inter.rept. No. 3111/141, 62(2374), Baghdad.

Cross, N., Goodall,I., Hollis,C., Burchette, T., Al-Ajmi,H.Z., Johnson,I.G., Mukherjee, R., Simmons, M., and Davies, R.,2010. Reservoir description of a mid-Cretaceous siliciclastic-carbonate ramp reservoir: Mauddud Formation in the Raudhatain and Sabiriyah fields, North Kuwait. GeoArabia, 15(2), 2010, 17-50.

Dufaure, P., 1959. Proplémas stratigraphiques Dans Le Crétace Supérieur Des Pays De Bigare Et De Comminges. 316Rev. Micropal., 2(2), 99–112.

Ellis, B. F. and Messina, A. R., 1966. Catalogue of Index Foraminifera. New York, Amer. Mus. Nat. Hist., Spec. Publi., 2.

Esfandyari, M., Mohseni, H. and Heidari, M., 2023. Facies analysis , depositional sequences and platform evolution of the Sarvak Formation (late Albian-Turonian) in the Zagros Basin , West of Iran, Journal of African Earth Sciences, 198.

Ezzulddin, L, N, and Ibrahim,Y, K., 2022. Biostratigraphy of the Early Cretaceous Mauddud Formation in Ratawi Oilfield Basrah Governorate, Southern Iraq, Iraqi Journal of Science, 63(6), 2598-2607.

Faisal, M. and Mahdi, T., 2020. Diagenetic Processes Overprint and Pore Types of Mauddud Formation, Badra Oil Field, Central Iraq, Iraqi Journal of Science, 61(6), 1353-1361.

Faisal, M. and Mahdi, T., 2020. Geological Model Of Mauddud Formation In Badra Oilfield, Iraqi Geological Journal, 53(1C), 58-67.

Grafe, K.U., 2005. Late cretaceous benthic foraminifera from the Basque-Cantabrian basin, northern Spain. Iberian Geology 31, 277–298.

Haftlang, R. Afghah, M., Aghanabati, A., & Parvaneh Nejad Shirazi, M., 2020. Biostratigraphy correlation of Cretaceous successions in Kuh-e-Rahmat and Kuh-e-Sabz sections, NE Shiraz, Zagros (SW Iran), 12(4), 327, 250-265.

Hameed, H.,and Saleh, A. H., 2021.Petrophysical evaluation of Mauddud Formation in selected wells from Ratawi Oil field, Southern Iraq. Iraqi journal of science, 62(9) , 2956-2969.

Hameed, H.,and Saleh, A. H., 2022.3D Petrophysical modeling of Mauddud Formation at Ratawi Oil Field , Southern Iraq, IOP Conference Series: Earth and Environmental Science . IOP Publishing, 1-11.

Hameed, A. S., and Faisal, R. F., 2021. Petrophysical properties of Mauddud Formation in selected wells in Al-Ahdab Oil Field , Middle Iraq. Iraqi journal of science, 64 (2) , 718-728.

Henson, F. R. S.,1947. Foraminifera of genus Trochlina in the Middle East, Ann. Mag. Nat. Hist., Ser. 11, V. 14, 332. 115, 445-459, Pl. 11-13.

Homberg,.and Bachmann ,M., 2010. Evolution of the Levant margin and western Arabia platform since the Mesozoic: Introduction, Geological Society Special Publication, 341.

Ibrahim, M.W., 1981. Lithostratigraphy and subsurface geology of the Albian rocks of south Iraq, Journal of Petroleum Geology, 4(2), 147-162.

Jassim S. Z., and Goff J. C., 2006. Geology of Iraq .Dolin, Prague and Moravian Museum, Brno. 341.

Jassim, S. Z., Karim, S. A., Basi, M., Al-Mubarak, M. A. and Munir, J., 1984. Final report on the regional geological survey of Iraq, Vol.3, Stratigraphy. Manuscript report, Geological Survey of Iraq.

Keller,. A.E., 2004. Introduction to environmental geology, springer, 508.

Khazaal, F. A., Shakir, L. S, 2022, Biostratigraphy of Yamama Formation at Luhais and Rifaee oilfield, South Iraq, Iraqi Journal of Science, 63(6), 2619-2629.

Lawa, F. A. and Gharib, H., 2014.Biostratigraphy of the Tethyan cretaceous successions from northwestern Zagros fold- thrust belt, Kurdistan region, NE Iraq, Arabian Journal of Geosciences, 7(7), 2689-2710.

Leoblich, A. R. and Tappan, H., 1988. Foraminiferal genera and their classification. Van Nostrand Reinhold Comp., New York, 2, 970.

Loutfi, G. and Jaber, A. 1970.Geology of Upper Albian - Campanian succession in the Kuwait - Saudia Arabia Neutral zone, offshore area', 7 th Arab Petrol. Congr,. 1-14.

Mohammed, M. U., 1981. The microfacies of Mauddud Formation. Unpubl.M.Sc. Thesis, University of Baghdad, 34861.

Mohammed, M. U., 1996. Orbitolinids (Foraminifera) of the Lower Cretaceous (Barremian - Turonian) of Iraq, Unpubl.Ph.D Thesis, University of Baghdad, 144.

Mohammed, M. U., 2012. Orbitolina arcuala sp. nov. a new Orbotolinid foraminifera from the Cretaceous (Albian) of Iraq. Iraqi Bulletin of Geology and Mining, 8(2), 31 – 43.

Mohammed, M. U., 2017. Pressure Solution Styles In The Mauddud Formation Of Abu Ghirab Oilfield,Southeast Iraq, (January 1992).

Norri, N. A, Al-Sheikly, S. S., Al-Dulaimi, S. I., 2016.Biostratigraghy of Mauddud Formation in Badra well-1; Eastern Iraq. Journal of University of Babylon, 24(3), 740-754.

Oapec, 1987. Appraisal and development of East Baghdad field(an experiment to understand a complex field). In addenendum of papers and case studied presented at seminar on peteoleum reservoirs, Kuwait 11- 14, A36-A47.

Owen, R. M,. and Nasr, S., 1958. 'No Title', In Habitat of Oil-A Symposium, Spec. Publ. AAPG, 1252 – 1278.

Peybernes, B., 1976. Le Jurassique et le Cretace inferieur des Pyrenees franco - espagnoies entre la GaronneMditerranee. These Doct. Toulouse, 459.

Ponikarov, V. P., Kazmm, V. G., Mikhailov, I. A., Razvaliayev, A. V., Krasheninnikov, V. A., Kozlov, V. V., Soulid-Kondratiyev, E. D., Mikhailov, K. Ya., Kulakov, V. V., FaradzHev, V. A. and Mirzayev, K. M., 1967. The geology of Syria pan I. Stratigraphy, igneous rocks and tectonics. Dept. Geology and Min. Research, Ministry of Industry, Syria, 230.

Reiss, Z., Hottinger, L., 1984. The Gulf of Aqaba: Ecological Micropaleontology: Ecological Studies, vol. 50. Springer-Verlag, Berlin, 1–354.

Sadooni, F. N. and Alsharhan, A. S., 2003. Stratigraphy, microfacies, and petroleum potential of the Mauddud Formation (Albian-Cenomanian) in the Arabian Gulf basin, American Association of Petroleum Geologists 37, Bulletin, 87(10), 1653- 1680.

Safari, H., Pirasteh, S. and Pradhan, B., 2009. Upliftment estimation of the Zagros Transverse Fault in Iran using geoinformatics technology., Remote Sensing 1, 1240e1256.

Sampo, M., 1969.Microfacies and microfossils of the Zagros area, southwest Iran (from pre- Permian to Miocene), Inter. sed. petrograph. Ser.(E.J.B(Leiden),12–102.

Satorio, D. and Venturini, S., 1988. Southern Tethys biofacies. Agip S.p.A., S. Donato Milanese, Italy, 236.

Sayyab, A.S., and Mohammed, M.U., 1984. The age of the Mauddud Formation in Southern Iraq. Iraqi Journal of Science. , 37925(12), 47-55.

Sayyab, A.S., and Mohammed, M.U., 1985. Biostratigraphic study of some subsurface sections of Mauddud Formation (south of Iraq). Iraqi Journal of Science. 26, 45 -67.

Schröder, R., 1962. Orbitolines des Cenomans sudwesteuropas. Pal. Zeitscher. Stuttgart, 383 Germany,36(3)-4,171-202.

Schröder, R., 1975. General evolutionary trends in Orbitolinas. Riv. Esp. Micropal., Madrid, num. spec., 117–128.

Scott, R. W., Wan, X., Sha, J., Wen, Sh., 2010. Rudists of Tibet and the Tarim Basin, China: Significance to Requieniidae phylogeny', Journal of Paleontology, 84(3), 444-465.

Simmons, M.D. and Williams,C.L, 1992.Cretaceous Orbitolinidae (Foraminifera) from Onshore South- West England, Journal of Micropaleontology, 11(1), 21-30.

Simmons, M., Whittaker, J., Jones, R., 2000. Orbitolinids from cretaceous sediments of the Middle East: a revision of the FRS Henson and Associates Collection. In: Proceedings of the 5th International Workshop on Agglutinated Foraminifera. Special Publication, Grzybowski Foundation, 411–437.

Shubber, B.A., 1986. Sedimentology of Muddud Formation in middle and southern Iraq, Unpublished M.Sc. Thesis, University c Baghdad, 104 .

Sugden, W. and Standring, A., 1975. Lexique Stratigraphiqu International, Asie, Qatar Peninsula. Inter. Geol. Congr. Comm Stratig., V.3, Fasc. 10b3, 120.

Zhang, K. J., 2000. Cretaceous palaeogeography of Tibet and adjacent areas (China): Tectonic implications', Cretaceous Research, 21(1), 23-33.

Wilson, J.L., 1975. Carbonate Facies in Geologic History. Springer Verlag, New York, 471.