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Depositional Environment of Middle Jurassic Sargelu Formation Based on Petrographical Study in selected wells at Balad, Ajil, and Baiji Oilfields, Central Iraq

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ABSTRACT

This work were carried out on 193 thin sections from Middle Jurassic Sargelu Formation. These samples are from three wells (Ajil-8, Balad-1 and Baiji-1). Petrographically, the Sargelu Formation composed of skeletal component (radiolaria, pelecypods, calcispheres, planktonic, benthonic foraminifera and ostracods), in addition non-skeletal such as pellets, groundmass of micrite and recrystallized microspars. Many diagenetic processes affected this formation the main which have been recognized are: compaction, micritization, cementation, neomorphism, dissolution, fractures and veins, silicifaction and dedolomitization in addition authigenic minerals (pyrite). Depending on the petrographic studies the following microfacies have been recognized: **Lime Mudstone Microfacies** which was divided into three submicrofacies (Pelecypodal Lime Mudstone, Radiolarian Lime Mudstone and Planktonic Foraminiferal Lime Mudstone), **Wackestone Microfacies** which was divided into four submicrofacies (Radiolarian Lime Wackestone, Halobia Wackestone, Calcispheres Wackestone and Planktonic Foraminiferal Wackestone) and **Packstone Microfacies** (Halobia Lime Packstone and Peloidal Lime Packstone). The overall characters of these microfacies indicate that the formation was deposited in two different environments: (1) upper Bathyal environment at the lower part (2) Outer shelf environment at the upper part.

Introduction

Jurassic marine carbonates are the major sources of hydrocarbons produced in the Zagros basin and fold belt [1]. During the middle Jurassic most of the sedimentary basins were rich in organic and hydrocarbon deposits. At that time a tectonic activities affected on the development of New-Tethys Sea in east and north parts of the Arabian Plate [2]. The present study constructed on three wells (Aj-8 , Bj-1 and Ba-1) (Fig. 1 and Table.1). The main objective is petrographical study and interpretation of microfacies, in addition to define the lower and upper boundaries of Sargelu formation and inferring the paleogeography during deposition of the formation according to the fauna contents. The Ajil-8 Well is located within the Ajil Oilfield, about 30 km northeast of Tikrit City, within the Low Folded Zone in Hamrin — Makhul Subzone (Fig. 1). The Ajil Field is distinguished by its location within an area characterized by narrow longitudinal structures, in the direction of its axes, in a northwest-southeast direction. The structures are affected by deep faults that penetrate its northern and southern limbs [2] . Baiji-1 is located in Salah al-Din Governorate, about 30 km northwest of the city of Tikrit. As for the Balad-1 Well, it is located within the Balad Oil field, which is located 15 km from the southwestern part of Balad City and 55 km southeast of Samarra City. The field is 25 km long and 12.5 km wide. As for tectonics, the Balad-1 and Baiji-1 wells are located within the Stable Shelf Zone in the Tigris Subzone. Sargelu Formation is underlaid by Alan Formation and is overlaid by Naokelakan Formation in all wells. The lower contact is gradational and conformable, but the upper contact is unconformable. The thickness of Sargelu Formation in Ajil-8 is 84.5m. The formation sequences are confined within the studied wells between the depths 3327.5-3243.0 m consists mainly of a succession of limestone, shaly limestone, marly limestone and shale. In the well Bj-1 with a thickness of 141.5 m, the formation sequences are confined between the depths of 2412.5-2554.0 m. It consists of successions of limestone, marly limestone and shaly limestone. The thickness of the formation in the well Ba-1 is 73.0 m, the formation sequences are confined between the depths 4160.0-4233.0 m, consists of succession layers of limestone, shale and shaly limestone. Sargelu Formation at Surdash anticline, Sulaimani Governorate of the High Folded Zone in Iraqi Kurdistan, was first recognized and described by Wetzel [3]. Buday [4] Point out this formation was deposited in an euxinic marine environment. Also Salae [5] studied aspect of the Upper Jurassic succession in Iraqi Kurdistan, described the upper contact of the Sargelu Formation with the Naokelekan Formation. Alsharhan [6] studied sedimentary basins and petroleum geology of the Middle East, and included Sargelu Formation within the Middle Jurassic units .Balaky [7] studied the stratigraphy and sedimentology of Sargelu Formation in three localities in Iraqi Kurdistan; he divided Sargelu Formation into four main lithofacies and investigated a variety of diagenetic processes. Al-Badry [8] studied two Jurassic sections within Duhok Governorate in Iraqi Kurdistan in terms of lithostratigraphy, microfacies, diagenesis, mineralogy, trace elements, stable isotopes, and petroleum potential. Abdula [9] evaluated organic matter in Sargelu Formation from eight localities in Iraqi Kurdistan and stated that land-derived organic matter contribution increases toward the northeast of Iraqi Kurdistan. Abdula *et al*. [10] studied the microfacies analysis and depositional environment of the Sargelu Formation (Middle Jurassic) from Kurdistan region, Northern Iraq, he proved the occurrence and distribution of microfacies indicate that the position overall is marine basin. Hakimi *et al*. [11] studied the generation and expulsion history of oil-source rock (Middle Jurassic Sargelu Formation) in the Kurdistan of north Iraq and considered it to be oil-source rock, containing kerogen Type II-S. Hussein and Abdula [12] studied the multiple linear regression approach for the vitrinite reflectance estimation from well logs: A case study in Sargelu and Naokelekan formations - Shaikhan-2 Well, Shaikhan Oilfield Iraq, concluded that the Sargelu and Naokelekan formations are representing good source rocks according to their TOC wt% contents and hydrogen indices. Also Abdula *et al.* [13] studied the volumetric calculation of hydrocarbon generated from the Sargelu Formation in the Kurdistan Region, Iraq. Bayet-Goll *et al.* [14] suggested that changes in tectonic regime from an extensional deformation (Early Jurassic) to cooling subsidence (Middle Jurassic), accompanied by a long-term transgressive sea-level trend during the Middle Jurassic, were important factors in the development of anoxic trough environments with the deposition of organic-rich intervals.

Table.1 Well coordinates, thickness of formation, and number of slides.

Sections	Wells coordinates	Thickness of Sargelu Fn (m)	No. of Slides
Aj-8	34° 52′ 35.0″ N 43° 47′ 10.0″ E	84.5	33
Bj-1	34° 78′ 74.0″ N 43° 49′ 53.0″ E	141.5	108
Ba-1	37° 55′ 165.5″ N 41° 34′ 9.5″ E	73.0	52

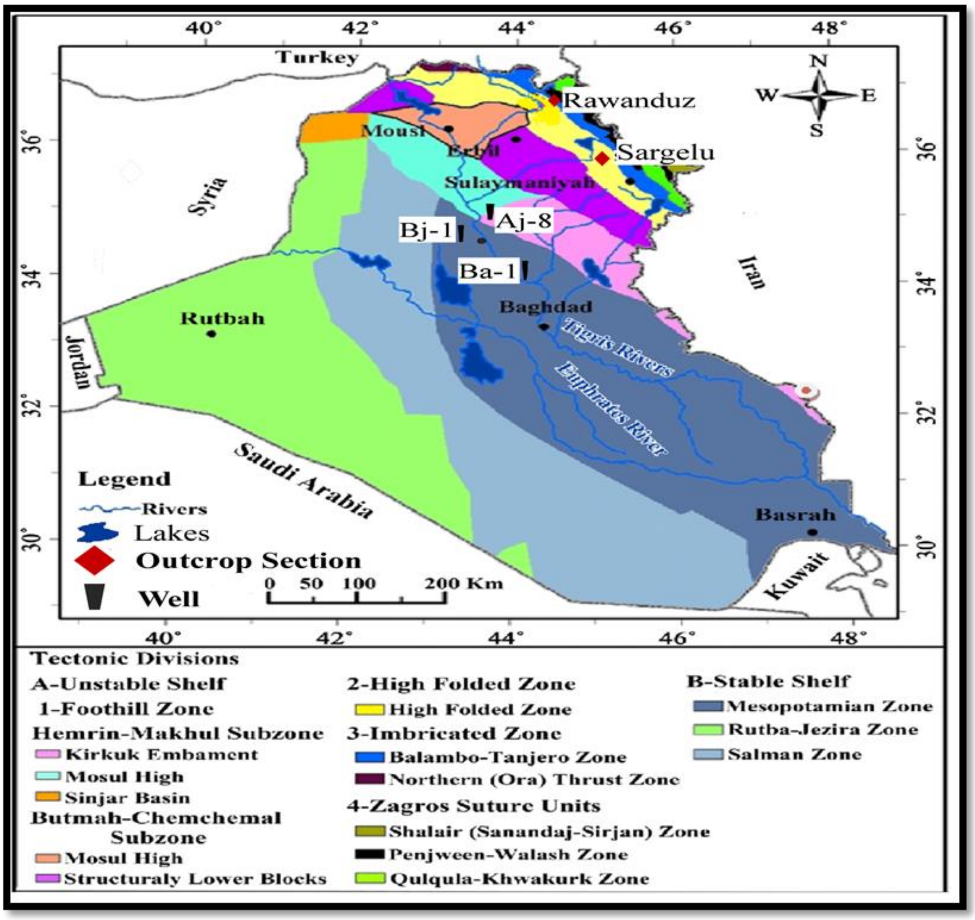

Fig.1: Map of Iraq indicates the tectonic zones (modified from Al-Zubaydi *et al*' [15]).

Methods and Materials

Three selected wells (Ajil-8, Baiji-1, and Balad-1) in central Iraq have been studied through 193 thin sections by using a polarizing microscope. This selection was collected from the North Oil Company. The petrographic study carried out on these thin sections to determine detailed petrographical components and type of diagenetic processes in Department of Applied Geology, Tikrit University. In addition to the petrographic study, the Gamma-ray log has been used to indicate the change in the composition and lithology of the carbonate rocks and the source of the shale layers.

Petrography

The components of the Sagelu Formation were described and diagnosed according to Flügel [16] and Flügel [17] in the subsurface sections represented by the three wells (Aj-8, Bj-1, and Ba-1) through the petrographic study. The components of skeletal grains were identified which include: radiolaria and calcispheres where its appearance associated together in the lower and middle successions of the formation, and most of them are located within a micrite affected by the dissolution process and filled with sparry cement forming moldic porosity (Fig.2,A,B,C). As diagnosed planktonic and benthonic foraminifera (Fig2.D,E,F) and ostracods (Fig.3.A), generally present in a small proportion and affected by diagenetic processes such as compaction which leads to elongation and distortion and filling the chambers with authogenic minerals (pyrite) , sparry calcite and micrite particles. The most important genesis identified was *Globigerina*، *Hedbergella* (Fig2.D,E). The spread of bioclast (Fig.3.B) is concentrated in different proportions throughout the formation succession, especially in the middle and upper parts, and the varying rates of the presence of bioclasts may be due to the fluctuation of the current energy caused by the changing in sea level [17, 18]. The origin of the diagnosed bioclast goes back to pelcypoda, radiolaria and foraminifera. The pelagic pelecypods and ammonite were diagnosed in all the studied wells, where they are characterized by their prevalence in large proportions in the lower and middle parts of the formation sequences, and less in the upper part of it. Two types of pelecypoda have been diagnosed: single valve (*Halobia sp.*) (Fig.3.C) and double valve (*Bositra sp.*) (Fig.3.D). As for non-skeletal grains include peloids only (Fig.3. E). All components diagnosed are located in a micrite and microsparite.

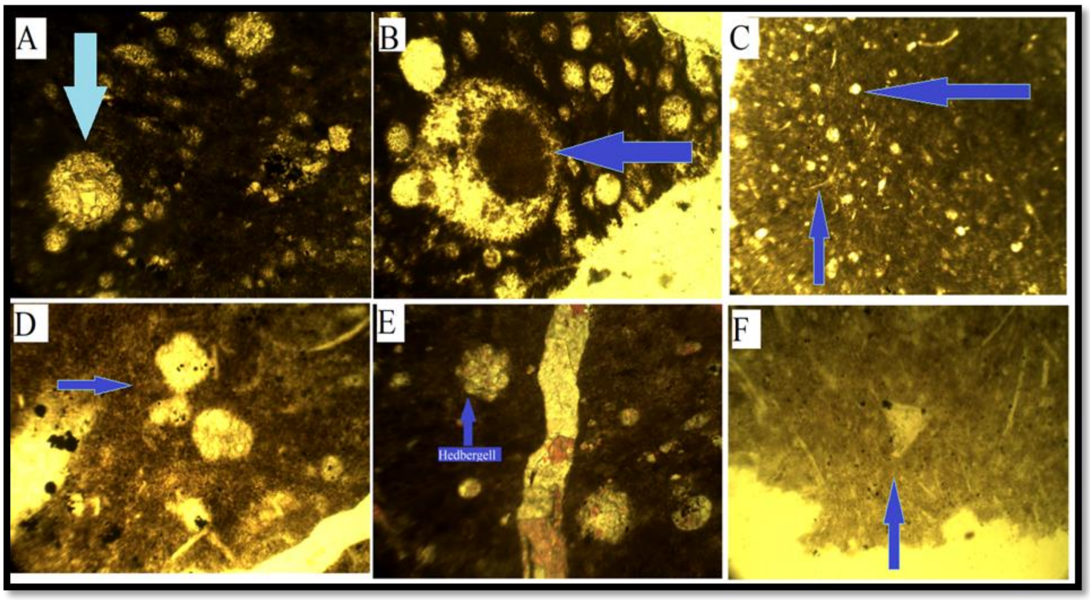

Fig. 2: A,B Radiolaria in micrite matrix affected by dissolution and made up of secondary porosity filled with sparry calcite (granular cement), in upper part of Bj-1, P.L. (X10). C Calcisphere filled with calcite, at depth 2431m in Bj-1, P.L. (X10). D Planktonic forams (*Globigerina* and *Hedbergella*) in micrite matrix, chamber partially bearing pyrite, at depth 2431m in Ba-1, P.L (X40). F Benthonic foraminifera in Bj-1, P.L. (X10).

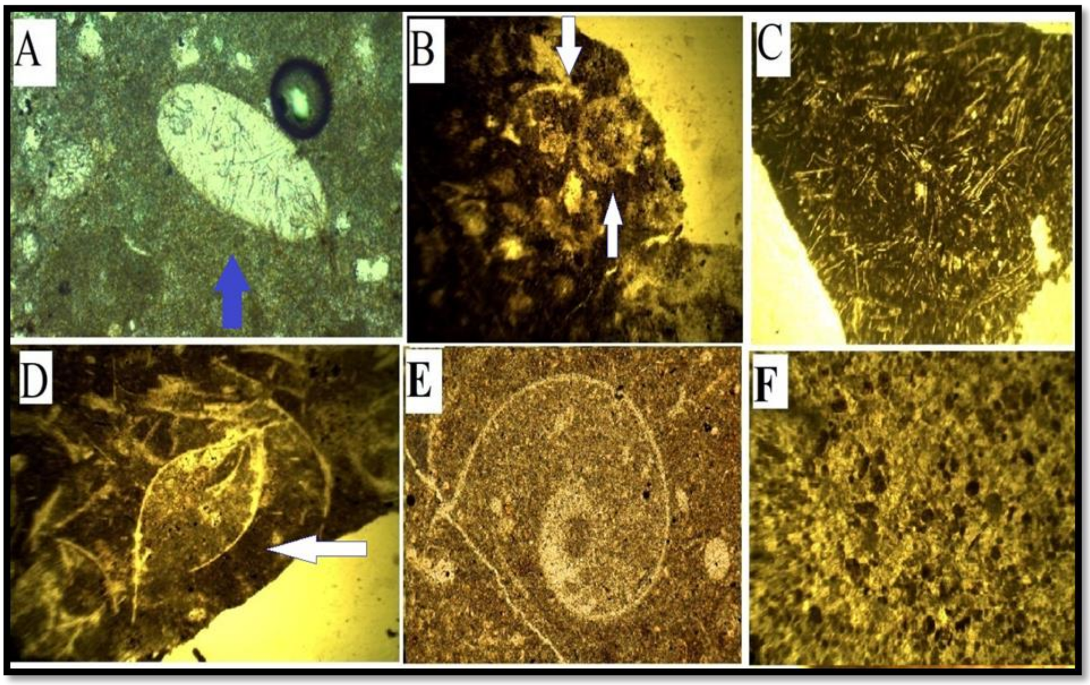

Fig. 3: A Ostracods filled with granular cement, in micritic matrix, in middle part of Aj-8, P.L. (X10). B Bioclasts at depth 2435m in Bj-1, P.L. (X10). C Thin shelled pelagic pelecypod (*Halobia*), at depth 2483m in Bj-1, P.L. (X10). D Pelagic pelecypod (*Bositra*), in micrite matrix, chamber partially bearing pyrite, at depth 4166 m of Ba-1, P.L (X40). E Ammonite in microsparite matrix, in middle part of Aj-8, P.L. (X10). F, Peloids in the Lime-Packestone Microfacies (X10).

Microfacies Analysis

The classification of Dunham [19] modified by Embry and Klovan [20] was used to describe the texture of limestone rocks due to its ease and comprehensiveness of this classification. Three main microfacies types can be recognized in Sargelu Formation, they are Lime Mudstone, Wackestone, and Packstone which, in turn, is divided into submicrofacies and then these microfacies are compared with Standard Microfacies and Facies Zones that were developed by Wilson [21] and Flügel [22].

1- Lime- Mudstone Microfacies

Based on Dunham [19], this facies consists of micrite with rare fossil content, generally less than 10%. This microfacies can be seen in different parts of Sargelu Formation in the sections studied. This facies appear clearly to be affected by diagenetic processes (dissolution, cementation, and neomorphism). Depending on the skeletal grains, the facies were divided into three secondary facies:

A- Pelecypodal Lime Mudstone Submicrofacies

This facies appears in the middle and lower sequences of the Sargelu Formation, where -**p**elecypoda appear within the micrite matrix at a rate of 3-6%, above and below Radiolarian Lime Mudstone Submicrofacies. The facies appears in a light to dark brown color due to occurrence of shales and organic materials within the facies. It is similar to the standard facies (SMF-3) and deposited in (FZ-2) deep shelf [21;22].

B- Radiolarian Lime Mudstone Submicrofacies

This facies consists of micrite matrix with a percentage exceeding 90% of dark brown color mixed with bituminous and organic materials and shale containing radiolarian, in addition to a smaller percentage of calcispheres. The effect of diagenetic processes is evident in this facies through the processes of dissolution and cementation. This facies is identical to the standard facies (SMF-3) and deposited in (FZ-1) of the deep sea basin [17].

C- Planktonic Foraminiferal Lime Mudstone Submicrofacies

This facies appears at a well Bj-1, in a medium proportion, as it appears within the lower sequences of the Sargelu Formation, bearing the planktonic foraminifera (*Globigerin* Sp.). Fossils appear at a rate of up to 8%, where the facies appear in a dark brown color, and this is due to the presence of clay and organic materials. This facies is similar to the standard facies (SMF-3) and deposited in the (FZ1) deep sea and deep shelf.

2- Lime Wackestone Microfacies

Based on Dunham [19], grains of wackestone range between 10- 50% in micritic matrix. This facies is widely spread in all wells within different depths, as it is characterized by containing skeletal grains represented by radiolarian, pelecypoda, foraminifera, and calcispheres. It was divided into four submicrofacies:

A-Radiolarian Lime Wackestone Submicrofacies

Radiolarian shells constitute a percentage ranging between 20-40% of the components of this fauna in addition to containing pelecypoda shells and some calcispheres in addition to the mineral pyrite, with good to medium sorting, buried in a dark micrite matrix because it contains a high percentage of shale and other organic materials. One of the most prominent diagenetic processes affecting this facies is cementation, compaction and neomorphism. This facies is one of the most common facies in the Sargelu Formation sequences. Its identical to the standard facies (SMF-3) deposited in the (FZ1) deep sea.

B- Halobia Wackestone Submicrofacies

This facies is common in middle and lower sequences of the Sargelu Formation in wells selected in the form of curved threads belonging to the *Halobia* sp. In addition to the pelecypods and other gastropods, it appears in a micrite matrix affected by diagenetic processes, including chemical compaction, staylolites, and dolomitization. This facies is identical to the standard facies (SMF-3) and deposited in (FZ-2) deep shelf [21,22].

C- Calcispheres Wackestone Submicrofacies

It appears in the middle sequences of the Sargelu Formation in the Bj-1 Well. The calcispheres appear precipitated in a spherical micrite matrix affected by diagenetic processes, including chemical compaction, and staylolites. It is similar to the Standard Facies (SMF-3) deposited in (FZ-1) of the deep sea basin [21,22].

D- Foraminiferal Wackestone Submicrofacies

This facies is made of foraminiferal (*Globigerina* Sp.), and found in Ba-1 and Bj-1 wells, in the micrite matrix, and were affected by diagenetic processes. It is also noted the presence of pyrite-filled some of shells, which appear completely and sometimes broken, as the effect of physical compaction that appears clear. This facies is similar to the Standard Facies (SMF-3) and deposited in the (FZ-1) deep sea zone [21,22].

3- Lime Packstone Microfacies

Based on Dunham [19] , skeletal grains in this facies are more than 50%. This microfacies can be found at all wells. Two types of submicrofacies were distinguished, depending on the presence of skeletal grains:

A- Halobia Lime Packstone Submicrofacies

This facies contains very high amount of thin shells of *Halobia* (pelagic pelecypod), and can be found at the middle part of Ba-1 and Bj-1. It is distinguished by a dark color, which is due to the presence of clay and organic matter. This facies is equivalent to Standard Facies (SMF-1) deposited in the (FZ-1) deep sea zone [21, 22].

B- Peloidal Lime Packstone Submicrofacies

Dark colored spherical peloids constitute 40-60% of the components of this facies, with good to medium sorting, buried in a dark micrite groundmass because they contain a high percentage of shale and other organic materials. This facies is very few in the lower sequences of the Sargelu Formation. This facies is equivalent to the Standard Facies (SMF-2) deposited in the (FZ-3) toe of slope.

Results and Discussion

Depositional Environment

The process of determination the sedimentary environment represents one of the most important objectives of this research. Through petrographic studies and fauna evidence, the distribution of environmental zones was determined (Figs:4,5,6) then the depositional model was drawn (Fig.7).

Bathyal

The results of the facies analysis indicated that the sediments of the Sargelu Formation are rich in micrites matrix, and radiolaria, calcicphere and foraminifera. The abundance of planktonic fossil shells is also evidence of the deep environment, as it includes *Globigerina* Sp. According to Flügel [17] and Oxford et al. [23], this genus is commonly found in the bathyal environment within the deep marine environment. The formation deposited in an environment with low current energy which is suitable for the deposition of lime mud particles [17;24]. Also, the abundance of organic materials within the formation facies reflects the calm marine environment with low energy under reduction conditions that work to preserve planktonic shells [25]. Also the abundance of planktonic foraminifera shells in the facies of this range compared to other calcareous skeletal components is indicative of the deep marine environment [23]. According to Adams et al. [26], the abundance of calcicphere in the facies refers to the deep marine environment, specifically the Bathal Zone and Outer Shelf. Although Bein, and Reiss [27] refer to the presence of calcicphere in the shallow and deep marine environments like, but, what indicates that the environment is deep marine is the association of the presence of calcicphere with radiolaria and planktonic foraminifera. According to Al- Guburi and Sagular [28], the abundance of radiolaria in the partial range sequence at the bottom of succession and its increase with depth is considered evidence of the deep marine environment. The authogenic mineral (pyrite) in the calcareous shale deposits rich in organic matter indicates that the deposition occurred in a deep marine environment with low sedimentation rates [29]. Tucker [30] mentioned that the presence of pyrite mineral simultaneously with the radiolaria and foraminifera within the source rocks is common in most of the fields of the Middle East. According to Flügel [17], stylolite is often found within sediments confined within depths 200-2000m, which cover most parts of the deep pavement environment.

Outer shelf

This environment represents the deep part of shelf confined between the depths 100-200m, and characterized by normal salinity and temperatures between 10-30 C^{o} [31;21;17]. This environment is located under the level of base effected waves, which often precipitate fine grains. It is characterized by a slow rate of sedimentation in it [32;33] . According to Goss [34] and Siter [35], the occurrence of benthic foraminifera, ostracoda, bioclastic,and peloids in the facies of the Sargelu Formation, and the rare of radiolarin and calcispher indicates the deposition of this facies in Outer Shelf connected to the open sea environment.

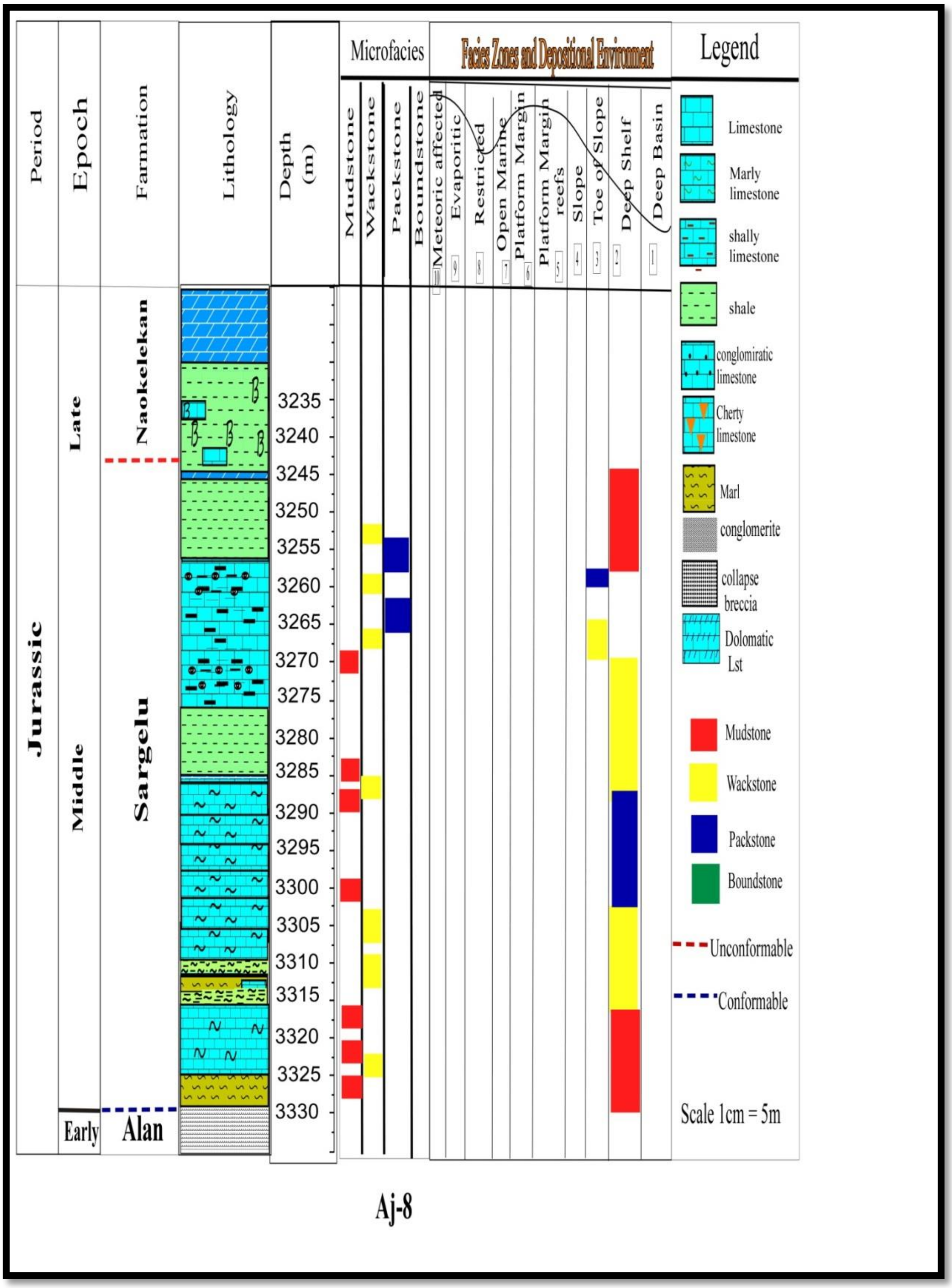

Fig. 4: Microfacies & environment zones distribution, Aj-8 Well.

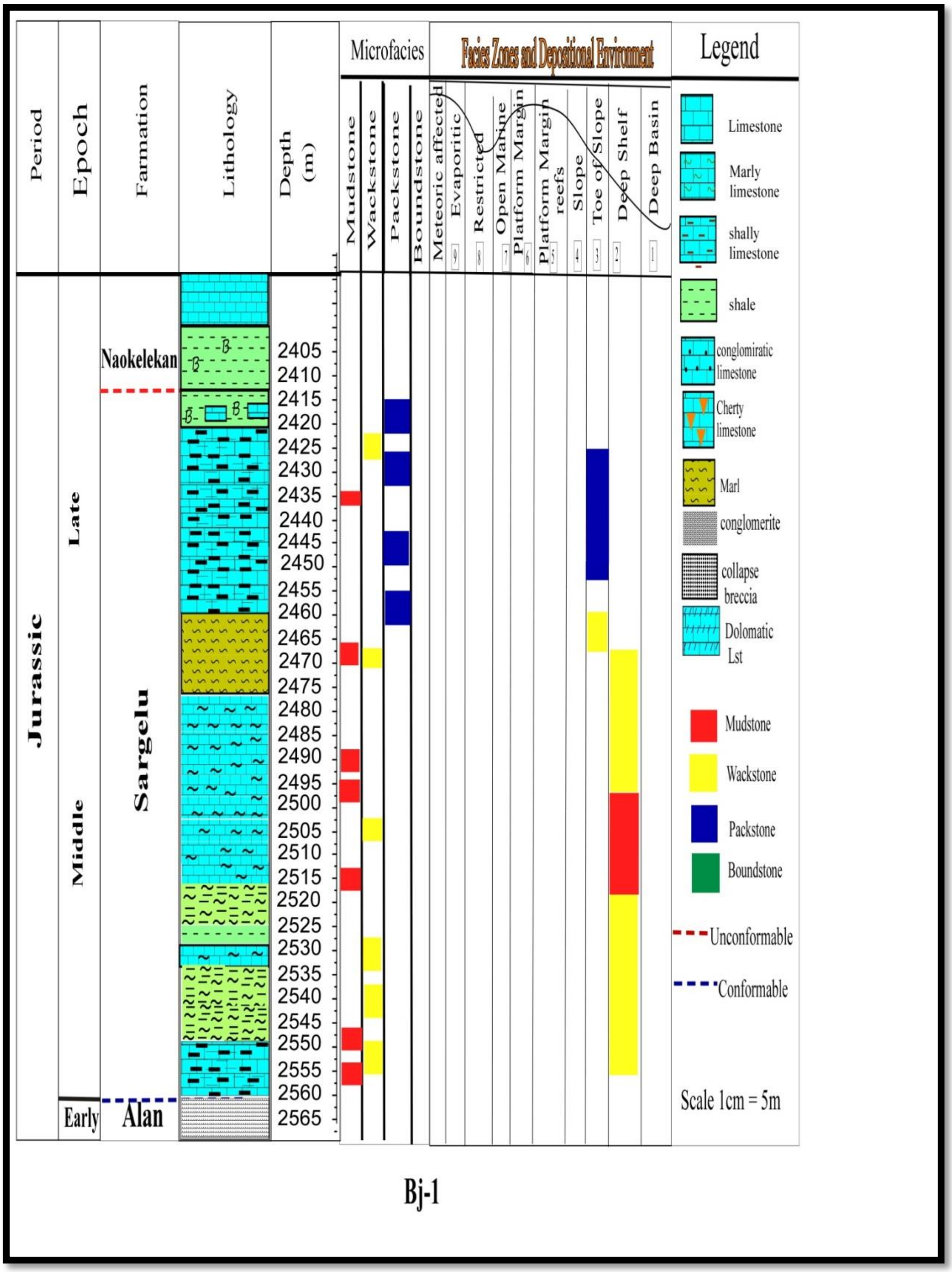

Fig. 5: Microfacies & environment zones distribution, Bj-1 Well.

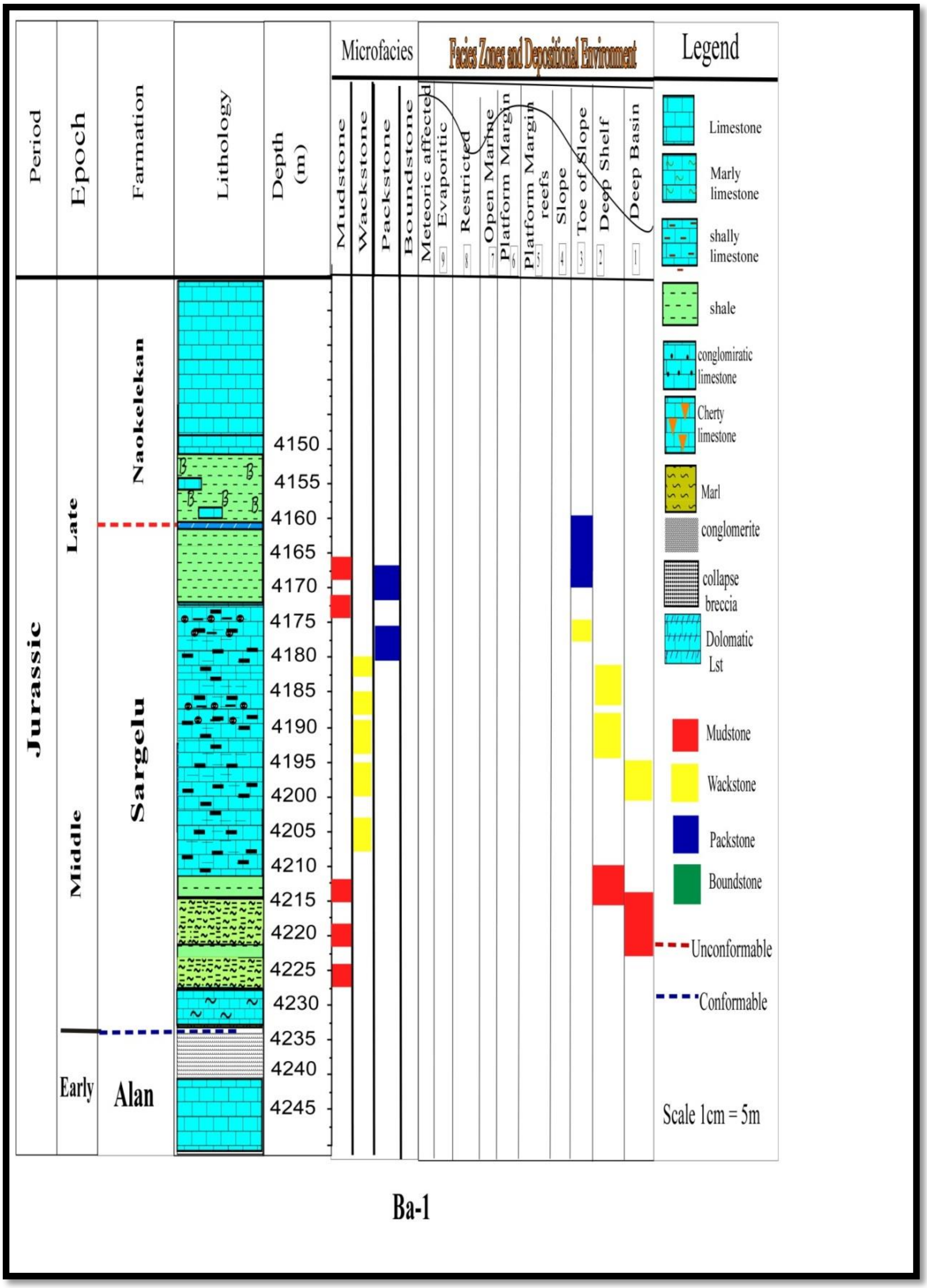

Fig. 6: Microfacies & environment zones distribution, Ba-1 Well.

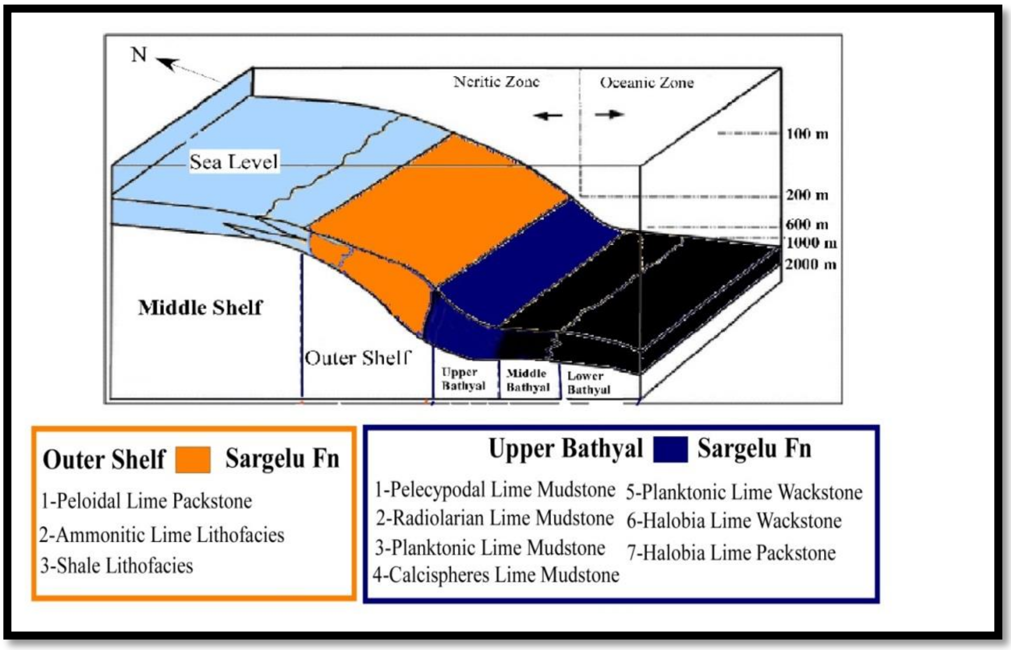

Fig. 7: Depositional model of the Sargelu Formation.

Conclusions

Depending on the petrographic studies the following microfacies have been recognized: Lime mudstone microfacies, Wackestone microfacies and Packstone microfacies. The overall characters of these microfacies indicate that the formation was deposited in two different environments: (1) upper bathyal environment at the lower part, and (2) outer shelf environment at the upper part.

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البتروغرافية والبيئة الترسيبية لتكوين ساركلو في آبارمختارة من حقل عجيل وبيجي وبلد النفطي في وسط العراق

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الملخص

تمت دراسة تكوين ساركلو في ثلاث آبار من حقول (عجيل وبيجي وبلد) النفطية، وسط العراق متمثلة بالابار Aj-8 و Bj-1 و Ba-1 .تم فحص 193 شريحة صخرية ودرست هذه الشرائح بدقة باستخدام المجهر المستقطب لغرض دراسة المكونات البتروغرافية والعمليات التحويرية المؤثرة فيها بتروغرافياً وتحليلها سحنيا لاحقآ. يتألف التكوين من الحجرالجيري والحجرالجيري السجيلي الحاوي على الشواهد النفطية .يحده من الاسفل تكوين علان بصورة متوافقة أما حده العلوي فيكون غير متوافق مع تكوين ناوكليكان. يتألف تكوين ساركلو بتروغرافيا من المكونات الهيكلية وغيرالهيكلية. أهم المكونات الهيكلية هي الراديولاريا والكرات الكلسية والمحاريات و الفورامنيفرا الطافية والقاعية، أما المكونات غير الهيكلية فتم تشخيص الدمالق. تتعرض صخور التكوين وبدرجات متفاوتة إلى تأثير العمليات التحويرية وأهمها عملية الدلمتة و الإذابة والسمنتة والتشكل الجديد ومن خلال التحليل السحني فأن التكوين متكون من ثلاثة سحنات دقيقة رئيسية وهي: سحنة الحجرالجيري الطيني الدقيقة الرئيسية والتي تم تقسيمها إلى ثلاث سحنات ثانوية وسحنة الحجرالجيري الواكي الدقيقة الرئيسية والتي تم تقسيمها إلى أربع سحنات ثانوية وسحنة الحجرالجيري المرصوص الدقيقة الرئيسية والتي تم تقسيمها إلى سحنتين ثانويتين ، تتوزع هذه السحنات على بيئات الرف الخارجي وبيئة الباثيال العميقة.