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Microfacies and Diagenetic Processes of the Late Jurassic Naokelekan Formation in selected wells at Balad, Ajil and Baiji Oilfields, Central Iraq

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ABSTRACT

This work depends on detailed petrographic and diagenetic processes studies of collected cutting rock samples, from the Late Jurassic Naokelekan Formation from Ajil-8, Balad-1 and Baiji-1 wells. Based on the thin sections study, the formation contains various petrographic components represented by pelecypods, calcispheres, planktonic and benthonic foraminifera, in addition to the groundmass of micrite and microspars. Many diagenetic processes affected the rock successions such as, compaction, micritization, authigenic minerals (pyrite), cementation, neomorphism, dissolution, porosity, replacement and dolomitization. The detailed microfacies analysis reveals that the rock successions consist mainly of three microfacies including; lime mudstone, which is divided into non-fossiliferous lime mudstone, bioclastic lime mudstone and planktonic foraminiferal lime mudstone, lime wackestone which also divided into calcispheres lime wackestone, benthonic lime wackestone, and pelcypodal lime wackestone, and lime packstone include, bioclastic lime packstone, peloidal lime packstone, and calcispheres lime packestone. The overall characters of these microfacies indicate the formation was deposited in two different environments: (1) shallow marine subtidal environment at the lower and upper parts (2) outer shelf in an euxinic environment at its middle part.

Introduction

The Jurassic Period is considered as one of the important geological ages in Iraq due to the importance of its stratigraphic units with a wide geographical spread in the western, northern and northeastern parts of Iraq represented by the organic matter producing environments [1]. During that period, Iraq was distinguished by the form of sedimentary basins in which the source rocks of hydrocarbons were deposited. It is also included the beginning of the formation of the New-Tethys Sea in the east and north parts of the Arabian Plate. This study focuses on the central Iraq (Fig.1) includes three wells (Aj-8, Bj-1, and Ba-1) (Table.1). The main objective is to determine depositional environment based on the diagenetic processes and microfacies analysis. The study also tries to define the lower and upper boundaries of the Naokelekan Formation and determine the thickness of formation for each location and tries to reconstruct the paleogeography of the area according to fauna indicators. 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. The Ajil Oilfield 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 Tikrit City. As for the Balad-1 Well, it is located within the Balad Oilfield, 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 Area in the Tigris Subzone. Naokelekan Formation is underlaid by the Sargelu Formation in all wells and is overlaid by the Najmah Formation in Bj-1 and Ba-1, but in Aj-8 overlaid by the Gotnia Formation, the lower contact is unconformable with the Sargelu Formation, but the upper contact is gradational and conformable. The thickness of the Naokelekan Formation in Ajil-8 is 11m. The formation sequences are restricted to the studied well between the depths 3232.5-3243.0 m and consist mainly of a succession grey to black shaly limestone and laminated dark shale. In the well Bj-1 it has a thickness of 13 m. The formation sequences are existed between the depths of 2399.5-2412.5m. It consists of successions of balck laminated bituminous shale interbeded with thin layers of limestone. The thickness of the formation in the well Ba-1 is 11m, the formation sequences found between the depths 4160-4149 m. They consist of layers of muddy limestone, shale and shaly limestone. The Naokelekan Formation was first described in outcrop section from the Imbricated Zone (Balambo – Tanjero Subzone) near the Rowanduz Town in the NE of Iraq by Wetzel and Morton [3]. The type locality of the Naokelekan Formation is located near the Naokelekan Village, about 25 Km southeast of Soran Town, Erbil Governorate, NE Iraq. A supplementary type section was established in the Gara Mountain of the High Folded Zone [3]. The formation was reported in Jassim and Buday [4] as one of the units that was assigned to Megasequence Arabian Plate 7 (AP7) [5]. The age of the Naokelekan Formation was reported as Upper Oxfordian – Lower Kimmeridgian (Upper Jurassic) [3], Callovian – Lower Kimmedgian (Middle – Upper Jurassic) [5]. According to Abdula [6], it can be placed between Callovian and Upper Oxfordian (Middle – Upper Jurassic), based on the occurrence of *Cyclagelosphaera deflandrei* sp. and *lotharingius* sp. Abdula [7] studied the source rock assessment of Naokelekan Formation in Iraqi Kurdistan. Hussein and Abdula [8] 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. Abdula *et al.* [9] studied the petrographical features of organic matter from upper Jurassic Naokelekan Formation, Kurdistan-Iraq. Abdula *et al.* [10] through the Rock-Eval analysis and organic petrographical characterization of the upper Jurassic Naokelekan formation, northern Mesopotamian basin, Kurdistan region-Iraq, evaluated the formation and concluded that the Naokelekan Formation contains types II and III kerogen. Abdula *et al.* [11] studied the hydrocarbon potentiality and depositional environment of Naokelekan Formation in Binari Serwan-1 Well, NE-Iraq using infrared factors and palynological analysis evidence. Sharezwri *et al* [12] concluded through his study on the Naokelekan Formation that this formation was mainly deposited within a ramp setting in two sub-environments: lagoon and shallow marine. Albeyati *et al.* [13] studied the organic geochemistry of the Middle to Upper Jurassic source rocks in Balad-1 Well, Balad Oilfield, Central Iraq and stated that the formation can be considered as a good source rock.

Table1: Well coordinates, thickness of the Naokelekan Formation, and number of slides.

Sections	Well coordinates	Thickness of Naokelekan Fn. (m)	No. of thin sections
Aj-8	34° 52′ 35″ N 43° 47′ 10″ E	11	15
Bj-1	34° 78′ 74″ N 43° 49′ 53″ E	13	25
Ba-1	37° 55′ 165.5″ N 41° 34′ 9.5″ E	11	17

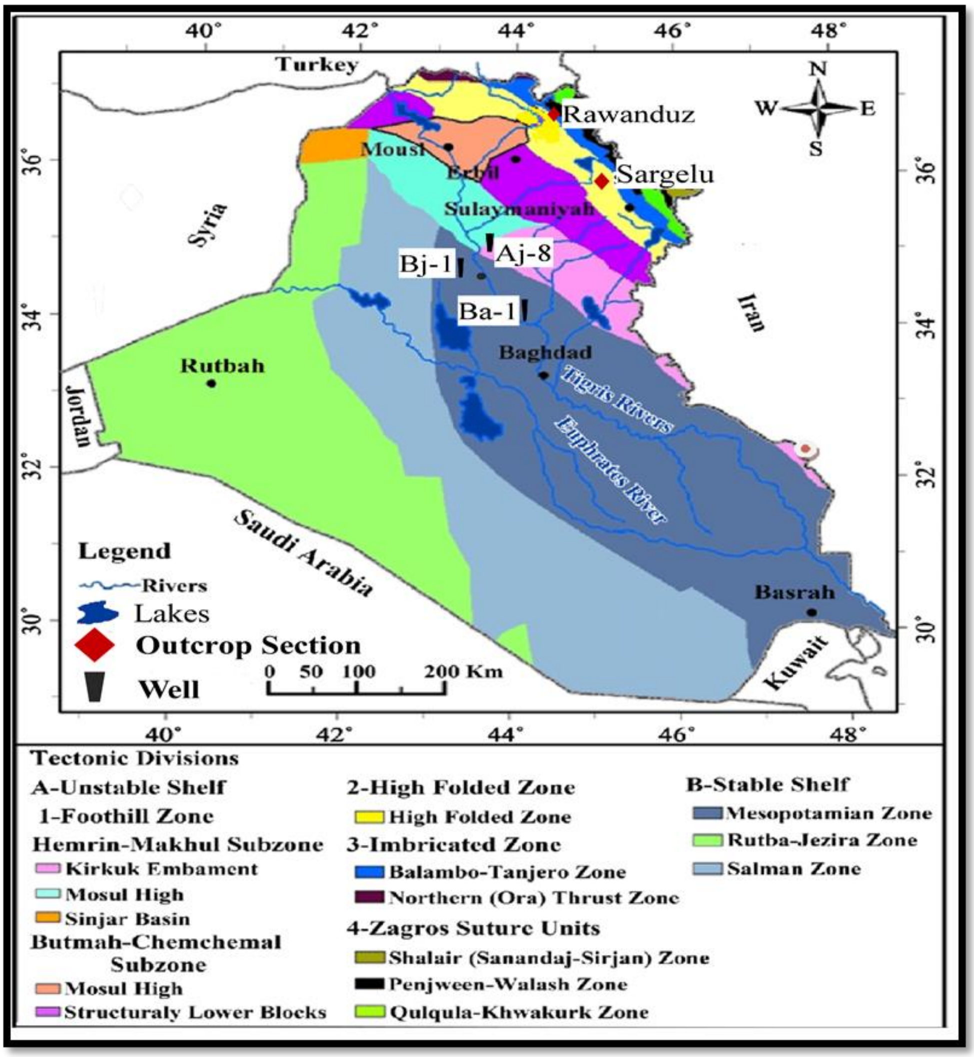

Fig.1: Tectonic zones of Iraq showing the study area (modified from Al-Zubaydi et al.[14]).

Materials and Methods

The data base for this study consists of cuttings from three selected wells (Ajil-8, Baiji-1, and Balad-1) in the North Oil Company. Fifty seven thin sections were carefully studied using a polarizing microscope for the purpose of studying petrography and recognizing the diagenetic processes. The gamma ray log obtained from the North Oil Company through which the lithology was identified. The gamma ray log is useful in diagnosing the shale layers,and distinguishing its presence from other lithologies and accordingly defining the boundaries of the layers.

Results and Discussion

Diagenetic Processes

Diagenetic processes were defined as all the changes that happened to the deposits by biological, chemical, and physical parameters and before reaching the metamorphism stage [15]. The diagenetic processes considered as important processes because of their effect on the essential textures of the carbonate rocks [16]. The main diagenetic processes that affected the Naokelekan Formation in the study area include:

Cementation

Cementation is the diagenetic process by which voids and porosities are filled by calcite cement. It occurs during the deposition by filling the interparticle pores or after deposition, fractures and joints as a consequence of compaction. Different types of cement that can be recognized e.g. Druzy mozaic cement is represented by anhedral and subhedral crystals filling vugs and channels porosity in different sizes and represented by crystals showing an increase in sizes towards the center of these pores (Plate 1A) . Druzy cement is also reflecting an early meteoric cementation process. It was recognized within the Naokelekan succession dominating the middle and the lower parts of the Naokelekan Formation (Plate 1A). Syntaxial rim cement was recognized within the upper part of the Naokelekan succession (Plate 1B). Blocky cement consists relatively of large anhedral to subhedral calcite crystals (Plate 1C) usually formed after lithification and compaction of sediment and sometimes used as synonymous of granular cement [17; 18]. This type of cement was observed in the upper and lower parts of the Naokelekan Formation (Plate 1C).

Neomorphism

This process dominating the Naokelekan succession especially in the middle part (Plate 1D), which was represented by partially recrystallization of micrite [14]. It is related to meteoric condition [19] and it usually increases in humid conditions [17].

Dolomitization

This process affected most of the studied carbonate rocks in the studied wells. The petrographic study of the carbonate rocks indicates that the nearshore and shallow-marine sediments are relatively more affected by dolomitization. The recognized dolomite texture was diagnosed based on classification of Randazzo and Zachos [20]. Spotted mosaic fabric, (Plate 1E), aphanotopic texture, (Plate 1F), contact rhomb fabric, (Plate 2A), and floating rhombs fabric (Plate 2B), are also exist within the Naokelekan Formation.

Compaction

Compaction refers to any process that decreases the bulk volume of single grains or that causes closer packing of grains and pressure solution [21]. The degree of compaction is strongly influenced by the cause of early cementation which may inhibit or diminish compaction [18]. In the present study two types of compactions are recognized: 1) mechanical or physical compaction that is one of the isochemical processes that lead to cracking, distortion and compaction of grains as a result of the sedimentary cover's weight [22] indicated that this process increases in deep marine environment (Plate 2C); and 2) Chemical compaction is one of the late diagentic processes, which is irregular surfaces resulting from differential vertical movements under the influence of pressure solutions [23;24]. Among the most important phenomena of chemical compaction, which was identified in the current study is stylolites (Plate 2D).

Dissolution

Dissolution is the most important diagenetic process affecting the Naokelekan Formation. It produced many types of porosity: vuggy and interparticles (Plate 2E,F). The effect of dissolution decreases with increasing depth and disappears in some horizons.

Microfacies Analysis

The classification of Dunham [25] modified by Embry and Klovan [26] was used to describe the texture of carbonate rocks. Three main microfacies types can be recognized in the Naokelekan Formation, they are: Lime Mudstone, Wackestone, and Packstone. These microfacies are divided into submicrofacies and compared with standard microfacies and facies zones that were developed by Wilson [27] and Flügel [18].

1- Lime Mudstone Microfacies

Based on Dunham [25], this facies consists of micrite with rare fossil content, generally less than 10%. This microfacies was observed in different parts of the Naokelekan Formation in the sections studied. This facies appears clearly to be affected by diagenetic processes (dissolution, cementation, and neomorphism). Depending on the skeletal grains, the facies was divided into two submicrofacies:

A- Non-Fossiliferous Lime Mudstone Submicrofacies

The effect of diagenetic processes is clearly visible in this facies represented by several types of dolomite texture such as the suture mosaic, aphanotopic and floating rhombs texture. This facies also contains pyrite. The appearance of this facies is dominated in the lower parts of the Naokelekan Formation in two wells (Aj-8 and Ba-1) (Plate 3A). This facies is equivalent to the standard facies SMF-23 and deposited in FZ-8 of the restricted environment [21].

B- Bioclastic Lime Mudstone Submicrofacies

This microfacies consists of micrite matrix with a percentage exceeding 90% of dark brown color mixed bituminous and organic materials and shale fragments containing bioclasts (Plate 3B). The effect of diagenetic processes is evident in this microfacies through the aphanotopic texture and chemical compaction. This microfacies is equivalent to the standard microfacies SMF-10 and deposited in FZ-7 open marine platform [21].

2- Lime Wackestone Microfacies

Based on Dunham [25], grains of wackestone range between 10- 40% in micritic matrix. This microfacies is widely spreads in all wells within different depths, as it is characterized by common skeletal grains represented by pelecypoda, foraminifera and calcispheres. It was divided into three submicrofacies:

A- Benthonic Foraminiferal Lime Wackestone Submicrofacies

Foraminiferal shells constitute a percentage ranging between 20-40% of the components of this fauna in addition to containing bioclasts and some calcispheres in addition to authigenic mineral pyrite and embedded in a dark micritic matrix due to presence of high percentage of shale and other organic materials (Plate 3C).It is equivalent to the standard microfacies SMF-18 deposited in the FZ-7 open marine platform.

B- Calcispheres Wackestone Submicrofacies

It appears in the middle parts of the Naokelekan Formation in the Bj-1 Well. The calcispheres appear in micritic matrix and affected by diagenetic processes, including chemical compaction (stylolites) (Plate 3D). It is equivalent to the standard microfacies SMF-3 that was deposited in FZ-3 of toe of slope.

C- Pelycipodal Wackestone Submicrofacies

It appears in the middle parts of the Naokelekan Formation in the Aj-8 Well. The pelycypods exist in a dark micritic matrix (Plate 3E), and was affected by diagenetic processes, including chemical compaction (stylolites). It is equivalent to the standard microfacies SMF-10 and was deposited in FZ-7 open marine platform..

3- Lime Packstone Microfacies

Based on Dunham [25], skeletal grains in this facies are 40-60%. This microfacies can be founded at all studied wells. Three types of submicrofacies could be distinguished, depending on the presence of skeletal grains:

A- Bioclastic Lime Packstone Submicrofacies

A very high amount of thin shells of pelagic pelecypod exist in this microfacies (Plate 3F,G), This microfacies can be found at the lower part of the wells 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 microfacies SMF-10 that was deposited in the FZ-7 open marine platform.

B- Peloidal Lime Packstone Submicrofacies

Dark colored spherical peloids constitute 40-60% of the components of this submicrofacies with good to medium sorting (Plate 3H). It embedded in a dark micrite groundmass due to high percentage of organic materials. This submicrofacies exist in the lower part of the Naokelekan Formation. It is equivalent to the standard microfacies SMF-16 and deposited in FZ-8 restricted zone.

C- Calcispheres Lime Packestone Submicrofacies

It appears in the middle part of the Naokelekan Formation in the Ba-1 Well. The calcispheres embedded in dark micrite matrix (Plate 3I) with some bituminous materials and pyrite. It is equivalent to the standard microfacies SMF-16 deposited in FZ-8 that represents deposition in restricted settings.

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:2,3,4) then the depositional model was drawn (Fig.5).

Conclusion

The Naokelekan Formation shows petrographic constituents represented by skeletal grains which are very common include, pelecypod, planktonic forams, benthonic forams, and calcispheres and non-skeletal grains represented by peloids. The Naokelekan Formation was affected by many diagenetic processes include: cementation, neomorphism, dolomitization, compaction and dissolution. Microfacies analysis during this study has led to the recognition of three microfacies, they are:

1- Lime Mudstone Microfacies

A- Non-Fossiliferous Lime Mudstone Submicrofacies.

B- Bioclastic Lime Mudstone Submicrofacies

2- Lime Wackestone Microfacies.

A- Benthonic Foraminiferal Lime Wackestone Submicrofacies

B- Calcispheres Wackestone Submicrofacies

C- Pelycipodal Wackestone Submicrofacies

3- Lime Packstone Microfacies

A- Bioclastic Lime Packstone Submicrofacies

B- Peloidal Lime Packstone Submicrofacies

C- Calcispheres Lime Packestone Submicrofacies

These microfacies suggest that the Naokelekan Formation is a shallow marine subtidal environment at the lower and upper parts and outer shelf in an euxinic environment at its middle part.

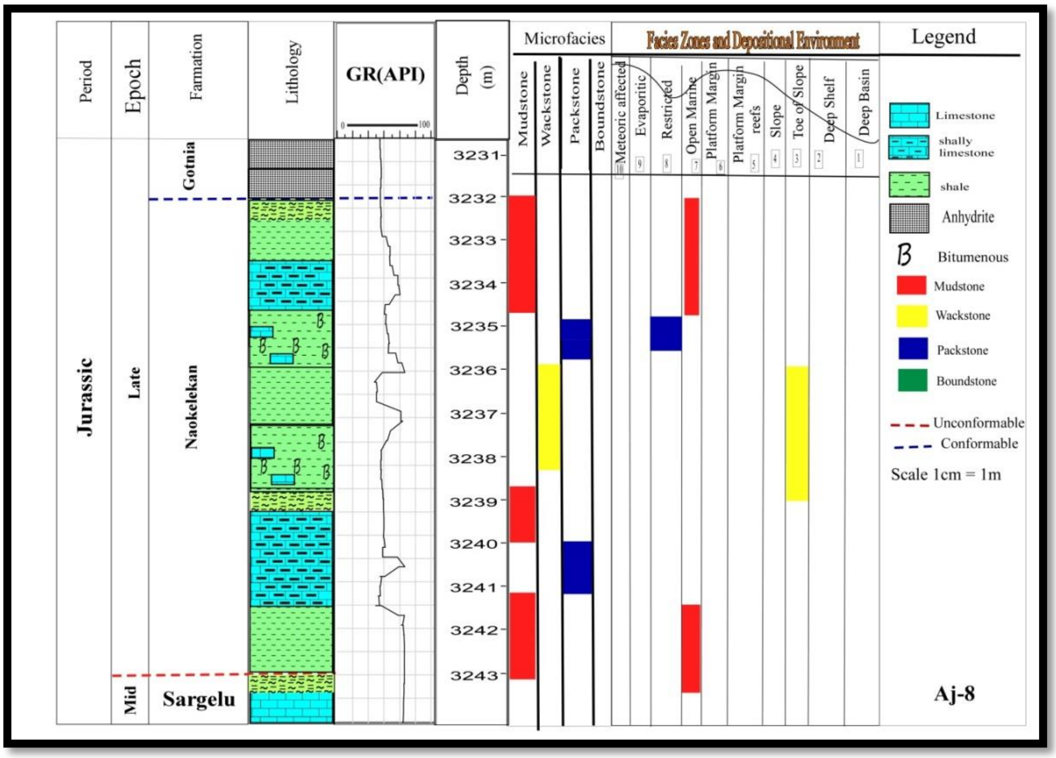

Fig. 2: Microfacies & environment zones distribution, Aj-8 Well.

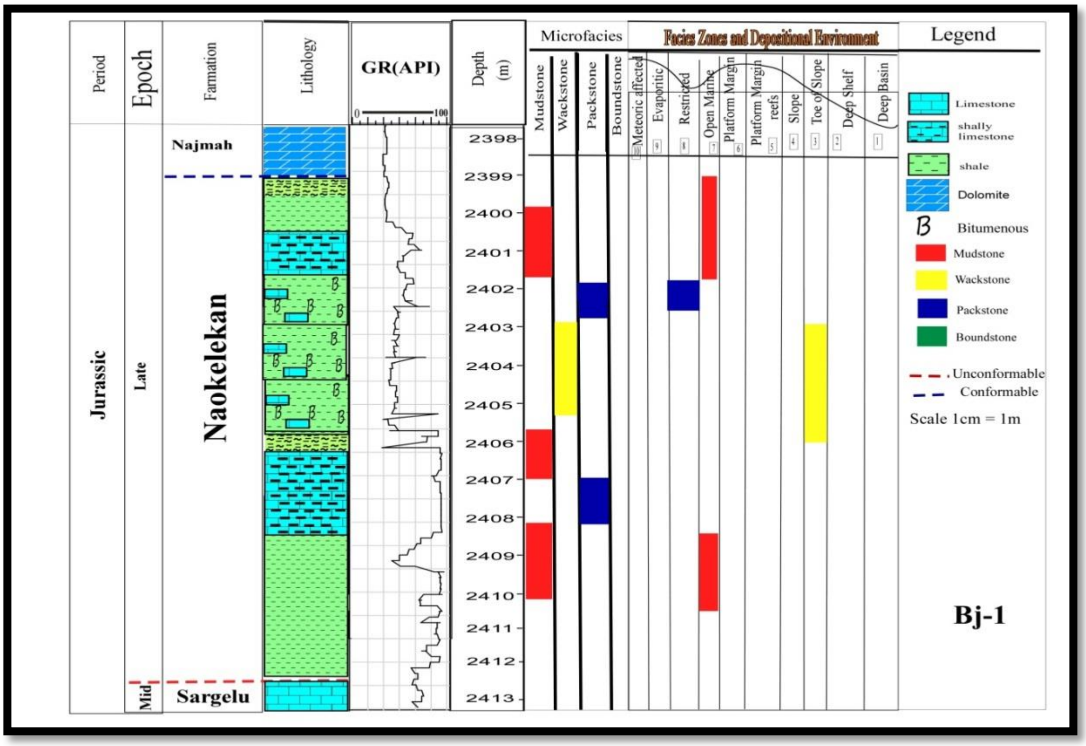

Fig. 3: Microfacies & environment zones distribution, Bj-1 Well.

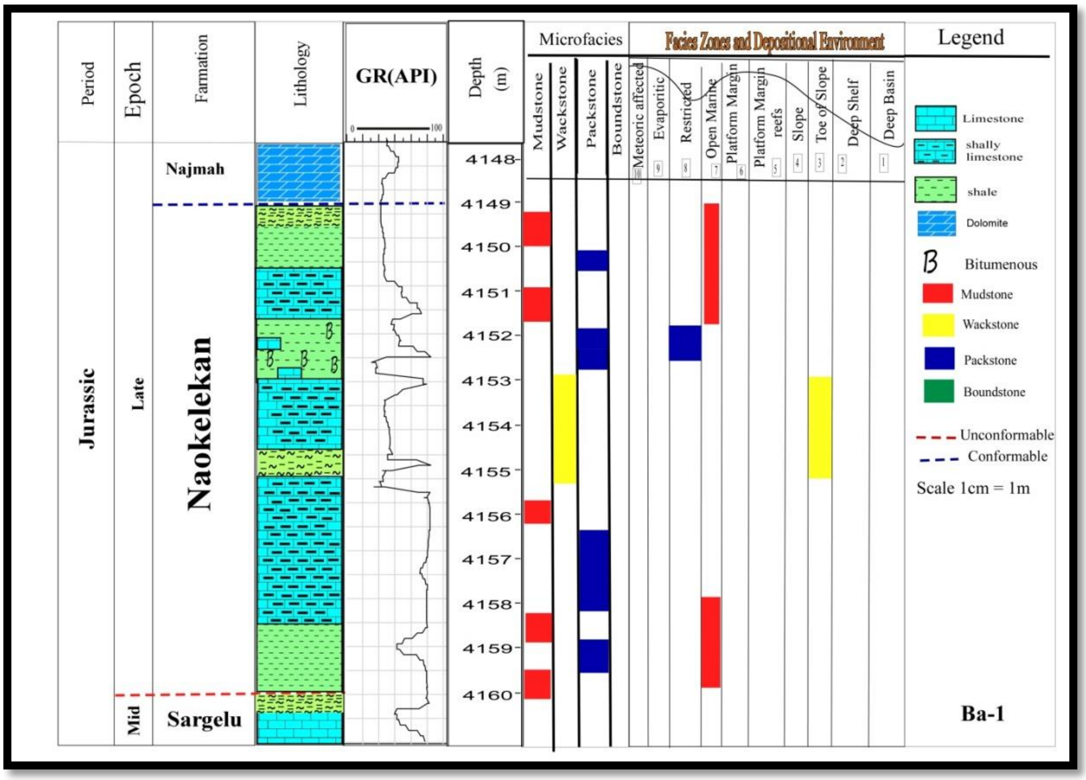

Fig. 4: Microfacies & environment zones distribution, Ba-1 Well.

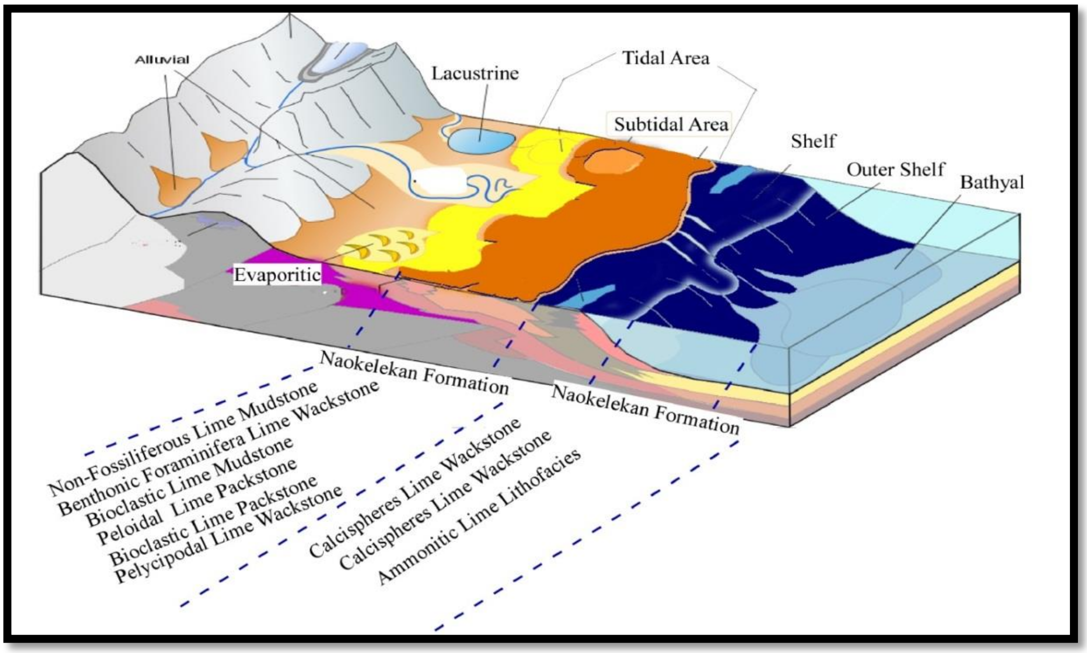

Fig. 5: Depositional model of Naokelekan Formation.

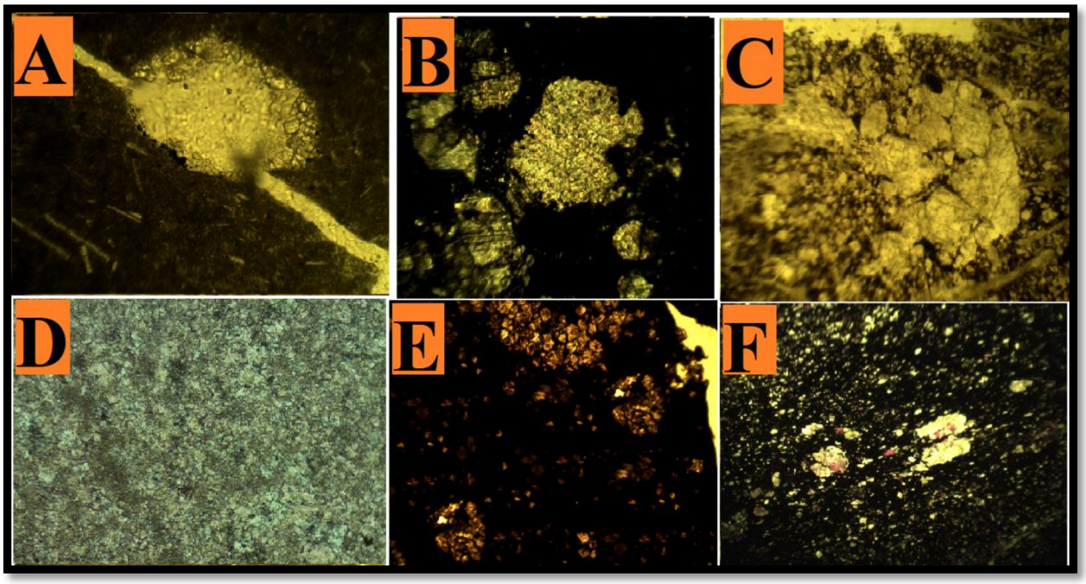

Plate.1: A, Druzy mosaic cement, in micritic matrix, in lower part of well Bj-1, P.L. (X10). B, Syntaxial rim cement in upper part of well Aj-8, P.L. (X10). C, Blocky Cement, consists relatively of large anhedral to subhedral calcite crystals, P.L. (X40). D, Neomorphism, partially recrystallization of micrit, P.L. (X10). E, Spotted mosaic fabric in lower part of well Ba-1, P.L. (X10). F, Aphanitic texture in the Lime-Packestone Microfacies.

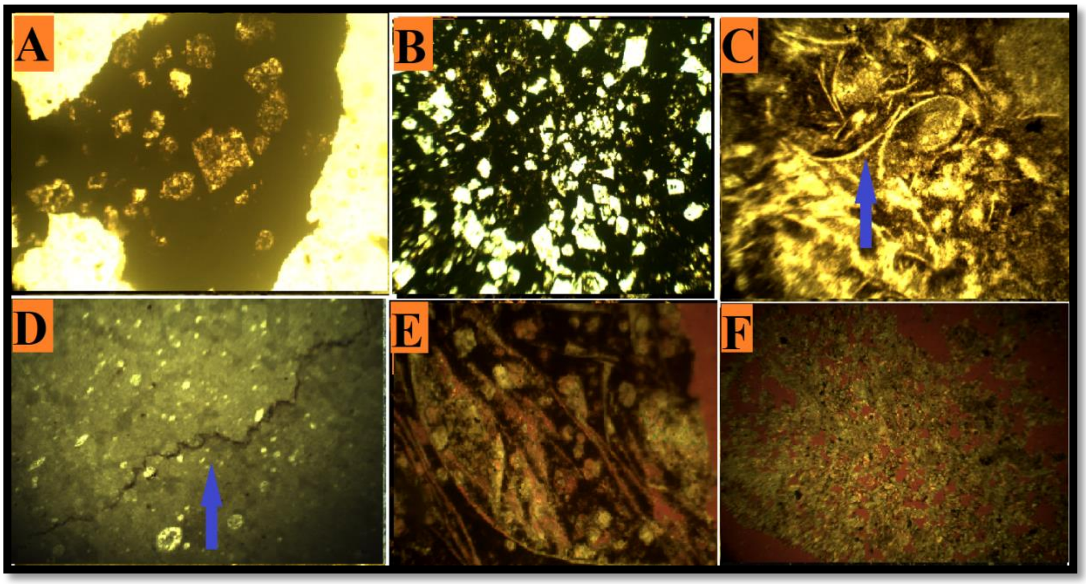

Plate.2: A, Contact rhomb fabric, in micritic matrix, in lower part of well Ba-1, P.L. (X10). B, Floating rhombs fabric in middle part of well Bj-1, P.L. (X10). C, Physical compaction, tangential contact between particles, P.L. (X10). D, Irregular stylolites in lower part of well Aj-8, P.L. (X10). E, Interparticles porosity in the Lime-Packstone Microfacies. F, Vuggy porosity in lower part of well Bj-1, P.L. (X10).

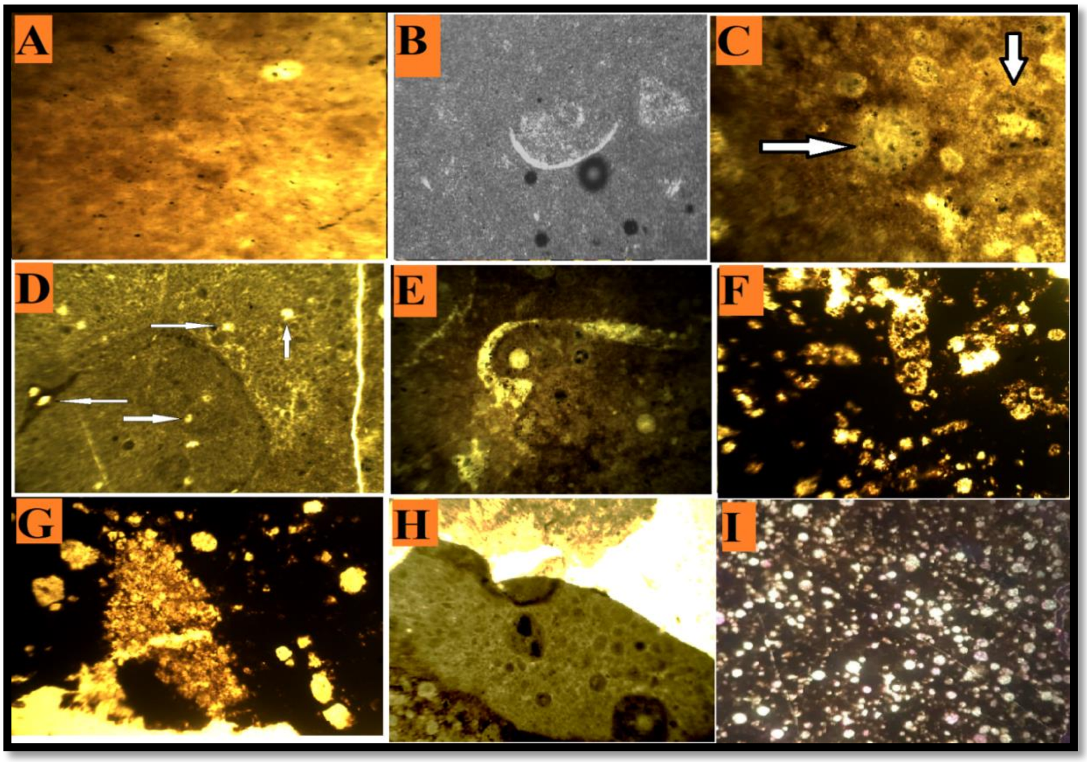

Plate 3: A, Non-fossiliferous lime mudstone submicrofacies in well Ba-1, P.L. (X10). B, Bioclastic lime mudstone submicrofacies in well Ba-1, P.L. (X10). C, Benthonic foraminifera in the lime-wackestone microfacies in well Aj-8, P.L. (X40). D, Calcisphere filled with calcite, in the lime-wackestone microfacies in middle part of well Ba-1, P.L. (X10). E, Pelecypod in micrite matrix affected by dissolution and made up of secondary porosity filled with sparry calcite (granular cement), in the lime-wackestone microfacies in upper part of well Aj-8, P.L. (X40). F,G, Bioclasts in the lime-packestone microfacies in upper and lower parts of well Ba-1 P.L. (X10)., H, Peloids in the lime-packestone microfacies, in lower part of well Bj-1, P.L. (X10). I, Calcisphere in the lime-packestone microfacies.

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السحنات الدقيقة والعمليات التحويرية لتكوين ناوكليكان في آبارمختارة من حقل عجيل وبيجي وبلد النفطي, وسط العراق

علي حكيم دوهان ، لفته سلمان كاظم ، فارس نجرس حسن

قسم علوم الارض التطبيقية ، كلية العلوم ، جامعة تكريت ، تكريت ، العراق

الملخص

تمت دراسة تكوين ناوكليكان في ثلاثة حقول (عجيل وبيجي وبلد) وسط العراق دراسة بتروغرافية لتشخيص السحنات الدقيقة وبالتالي تحديد البيئة القديمة التي ترسب فيها التكوين. وتم أختيار ثلاثة آبار (Aj-8, Bj-1, Ba-1)، يتألف التكوين من الحجرالسجيلي المتورق الغني بالشواهد النفطية والجيري السجيلي والحجر الجيري الطيني يحده من الاسفل تكوين ساركلو وبشكل غير متوافق أما حده الاعلى فيكون متوافق مع تكوين نجمة في بئري Ba-1 و Bj-1 ومع تكوين قطنية في بئر Aj-8. من خلال التحليل السحني والبتروغرافي تم تقسيم سحنات التكوين إلى ثلاث سحنات رئيسية وهي:سحنة الحجرالجيري الطيني الرئيسية وسحنة الحجرالجيري الواكي الرئيسية وسحنة الحجرالجيري المرصوص الرئيسية. وقسمت السحنات الرئيسية إلى ثمانية سحنات ثانوية . وبالاعتماد على الدراسة البتروغرافية وتوزيع السحنات تم الاستنتاج بأن البيئة التي ترسب فيها التكوين هي بيئة تحت المدية وبيئة الرصيف الخارجي.