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ORIGINAL ARTICLE

SEQUENCE STRATIGRAPHY AND PALEOENVIRONMENT OF AALIJI FORMATION IN BAI HASSAN OIL FIELD IN KIRKUK PROVINCE, NORTHERN IRAQ

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ABSTRACT

The Aaliji Formation in wells (BH.52, BH.90, BH.138, and BH.188) in Bai Hassan Oil Field in Low Folded Zone northern Iraq has been studied to recognize the palaeoenvironment and sequence stratigraphic development. The formation is bounded unconformably with the underlain Shiranish Formation and the overlain Jaddala Formation. The microfacies analysis and the nature of accumulation of both planktonic and benthonic foraminifera indicate the two microfacies associations; where the first one represents deep shelf environment, which is responsible for the deposition of the Planktonic Foraminiferal Lime Wackestone Microfacies and Planktonic Foraminiferal Lime Packstone Microfacies, while the second association represents the deep-sea environment that is responsible for deposition of Lime Mudstone Microfacies. The sequence boundaries were marked on SB1 surface on the bottom and the top of the succession while SB2 surface is placed at the top of the sequence (1) as shallowing-upward beneath deepening upward units. Sequence (1) placed on SB1 surface that separates the Cretaceous from the Palaeogene successions where it formed outer shelf to upper-middle bathyal, and comprised the Planktonic Foraminiferal Lime Wackestone Microfacies as a Transgression System Tract TST deepening-upward ended with Maximum Flooding Surface MFS represented by Mudstone microfacies in BH.188 Well. It is followed by the Planktonic Foraminiferal Lime Packstone Microfacies that represent the Highstand System Tract HST as a shallowing-upward ended by SB2. Sequence (2) begins with a new Transgression System Tract TST that formed the outer shelf and bounded with Maximum Flooding Surface MFS. The Highstand System Tract HST that shallowing-upward which ended by SB1 between the Aaliji and Jaddala Formations.

Keywords: Aaliji Formation, Bai Hassan, Iraq, Sequence Stratigraphy, Palaeoenvironment.

INTRODUCTION

The Aaliji Formation was first described by Bellen (1950) in northwest Syria beside a supplementary section (Well Kirkuk.109) in Iraq as marl and marly limestone with light to dark grey color, the lower contact represents a regional unconformity surface with Shiranish Formation. Al- Omari, (1970) determined the age of the formation as Early-Late Paleocene while Al-Kassab *et al*., (1986) showed that the formation belongs to the Middle Paleocene-Early Eocene. The depositional environment was determined based on the ostracods accumulation as deep marine within the bathyal zone (Aziz, 1997) during the Middle-Late Paleocene (Al-Juboury, 2011). Also, the upper contact is an unconformity surface with Jaddala Formation due to the changing of lithology and fossils in addition to the occurrence of glauconite and pyrite with an extensive increase in the gamma-ray log at the top of the formation (Al-Jwaini, 2016). Al-Hyaly and Al-Badrani, (2019) determined the age of the formation as Middle Paleocene Early Eocene depending on calcareous nannofossils.

The present research aims to determine the palaeoenvironment and sequence development of Aaliji Formation in accordance with the microfacies associations and the nature of planktonic and benthonic foraminifers occurrence.

MATERIALS AND METHODS

Four wells were selected within Bai Hassan Oil Field about 30 Km northwest of Kirkuk City which is considered as a subsurface anticline extended to northwest-southeast with the same direction of Zagros Mountain extension between (397000 - 407000) eastern and (3945000 - 3951000) northern in accordance with UTM coordinates in Hemrin-Makhul Subzone within the Foothill Zone (Jassim and Goff, 2006). The field is bounded by Kirkuk Oil Field in the east and northeast while is bounded by the Khabaz structure in the southeast (Map 1).

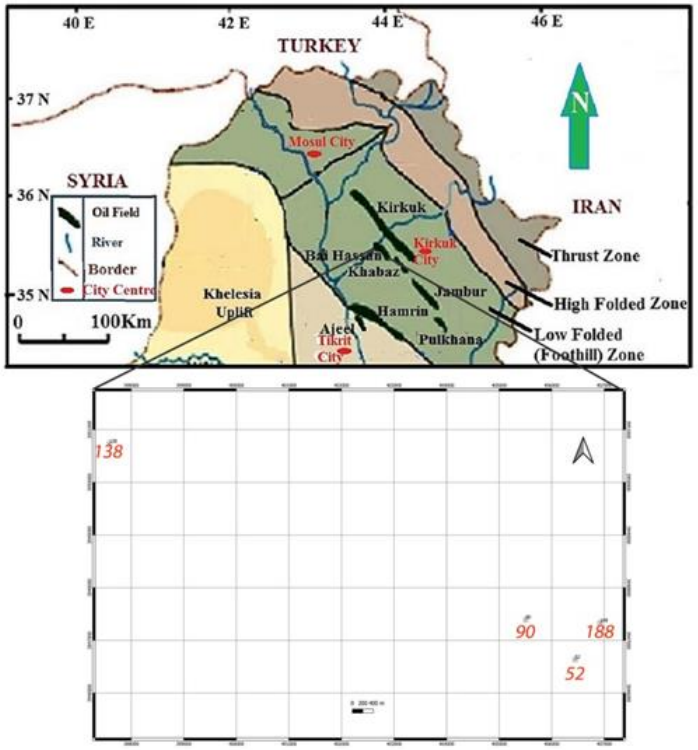
Forty cutting samples and one hundred thin sections from four wells (BH.52, BH.90, BH.138, and BH.188) in Bai Hassan Oil Field were chosen for this study. Twenty-five thin sections were made in the Applied Geology Department, College of Sciences, Tikrit University, while seventy-five thin sections were lent from the Geology Department in North Oil Company (NOC). A detailed petrographic examination was made on these thin sections using a polarized microscope in addition to well logs analysis to determine microfacies associations, diagenesis process, palaeoenvironment, and sequence development of the Aaliji Formation.

Petrography

The petrographic description showed that the Aaliji Formation is comprised of many skeletal grains and non-skeletal grains besides the matrix.

Skeletal grains are mainly represented by well preserved, small-sized, thin-walled, and light-colored planktonic foraminifera like: *Morozovella*, *Acarinina*, *Subbotina*, *Globorotalia*, and *Iogarina*. Sometimes benthonic foraminifera such as *Anomalinoides*,

Lenticulina, *Cibicidoides*, *Rosalia*, and *Textularia* are found with large size, thick walls, and compacted chambers relative to the planktonic foraminifera (Pl. 1A). In addition, rare well-preserved ostracoda and different bioclasts are existed (Pl. 1B). Non-skeletal grains are not recognized within Aaliji Formation.



Map (1): Location map and tectonic setting of study area (Al-Juboury, 2011).

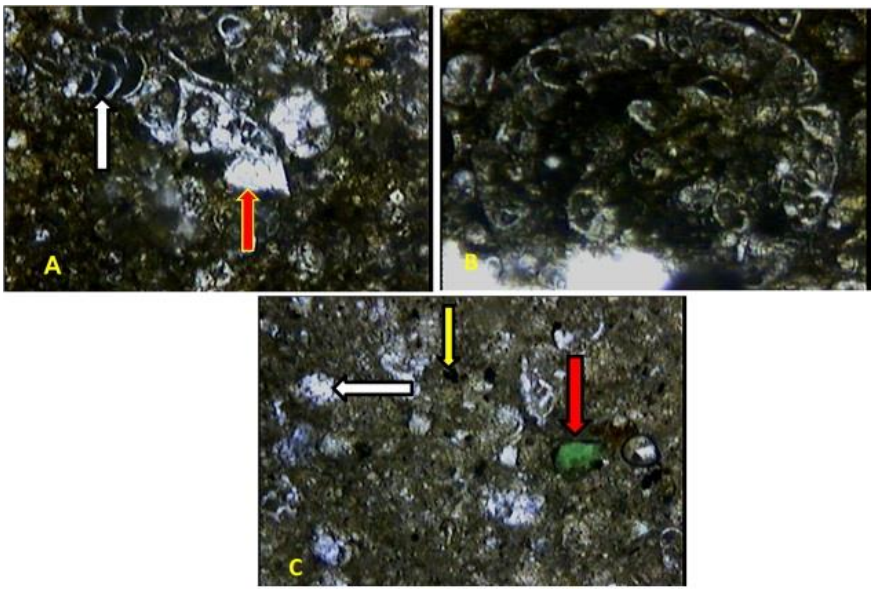


Plate (1): (A) Planktonic foraminifera *Morozovella* (red arrow) and biserial fossil with pyritization (white arrow), BH.138, Depth (1624 m), 20x, (B) Ostracods with micritic matrix, BH.52, Depth (1172-1173 m), 20x. (C) Authigenic minerals glauconite (red arrow) and pyrite (yellow arrow) with intraparticle porosity (white arrow), BH.52, Depth (1154-1155m), 20x.

Some pyrite was recognized filling pores and shells in all studied wells (Pl.1C), whereas some glauconite was recognized concentrated on the upper limit of the formation associated with pyrite with increasing gamma-ray log in wells BH.52, BH.138, and BH.188, which may indicate an unconformity surface (Pl. 1, Diag. 1). The matrix is represented only by fine-grained carbonate (micrite) with dark brown color which indicates low energy depositional environment. Finally, the Aaliji Formation carbonates are consisting of mud-supported textures like lime mudstones and wackestones.

RESULTS AND DISCUSSION

Microfacies associations

The Aaliji Formation carbonates were classified using Dunham (1962) classification. Two microfacies association were distinguished in the studied succession each representing a distinct depositional environment; they include deep sea and deep shelf environments as shown below:

Deep shelf environment

This environment is represented by two microfacies; planktonic foraminiferal lime wackestone microfacies, and planktonic foraminiferal lime packstone microfacies. The planktonic lime wackestone microfacies has widespread distribution within the Aaliji Formation where it is recognized in the lower and upper parts of the formation (Diag.1) and it formed about (10-40%) of skeletal grains which composed mainly of planktonic

foraminifera such as *Subbotina, Morozovella,* and *Acarinina*, in addition to rare benthonic foraminifera and bioclasts. The skeletal grains are distributed within a dark brown micrite matrix (Pl.3A). This microfacies is affected by many types of diagenesis process like compaction (mechanical and chemical), cementation like blocky cement, and pyritization filling the shells of foraminifera (Pls. 2 A, B). The percent of planktonic foraminifera to the total assemblages foraminifera (planktonic and benthonic) has been calculated to be about 70-80%, which mean that this facies was deposited in the outer shelf- upper bathyal environment with depth between (150-300 m) (Gibson, 1989; Haq and Boersma, 1998). The planktonic lime packstone microfacies has restricted distribution and is found only within the lower part of the formation above the Planktonic Foraminiferal Lime Wackestone Microfacies (Diag. 1); and it essentially comprised from planktonic foraminifera with spherical chambers, such as the genus Subbotina and Acarinina in addition to rare shells of benthonic foraminifera and bioclasts. This microfacies contains glauconite mineral that distributed within the micrite matrix. In addition, microspar and pyrite appear filling the shells of planktonic foraminifera (Pl.2D). The percentage of planktonic foraminifera/total assemblage of planktonic and benthonic foraminifera in this microfacies reaches 90%, which indicates deposition within the middle-upper bathyal with depth about (200-800 m) (Gibson, 1989; Alegret and Thomas, 2001).

Deep-sea environment

This association is characterized by the lime mudstone microfacies which occurs in the middle parts of the formation (Diag.1) and it essentially consists of dark brown micrite with a low percentage of skeletal grains (less than 10%) that mainly composed of planktonic foraminifera in addition to some benthonic foraminifera and bioclasts. Dolomitization with subhedral and euhedral rhombs is the most affected diagenetic features on this microfacies (Pls.2C, 3F). The planktonic/total foraminifera accumulation percent is about (60-75%) which indicates that the microfacies was deposited within the outer shelf environment with a depth ranging between (100-200 m) (Gibson, 1989).

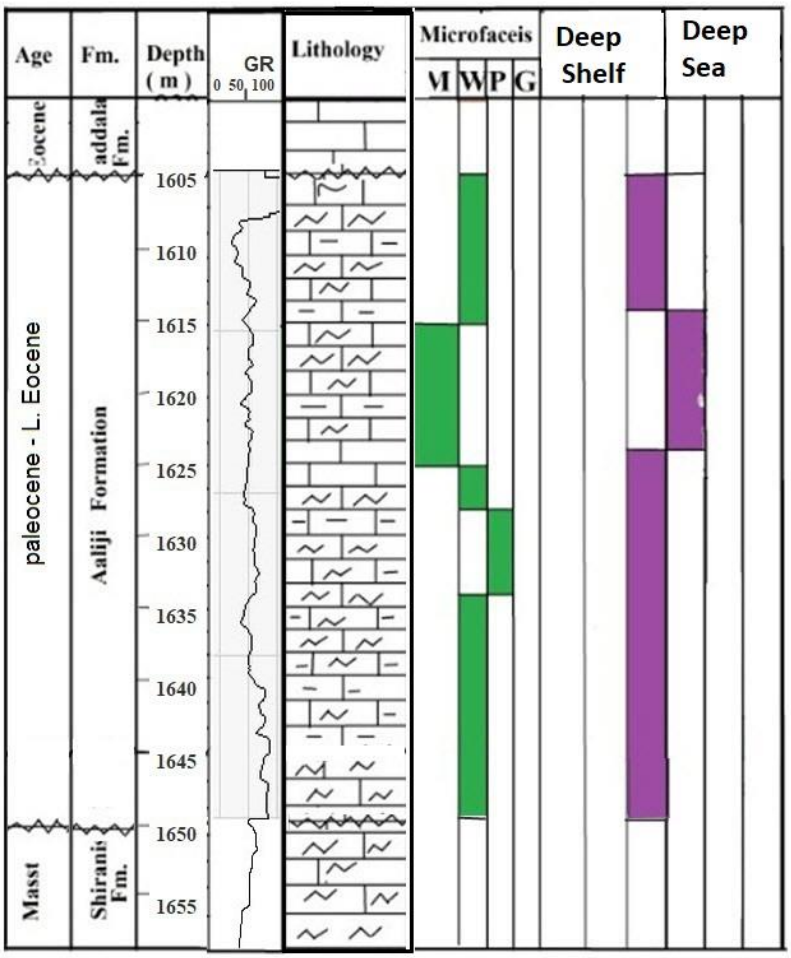


Diagram (1): Microfacies and depositional environment of Aliji Formation in BH.52 Well.

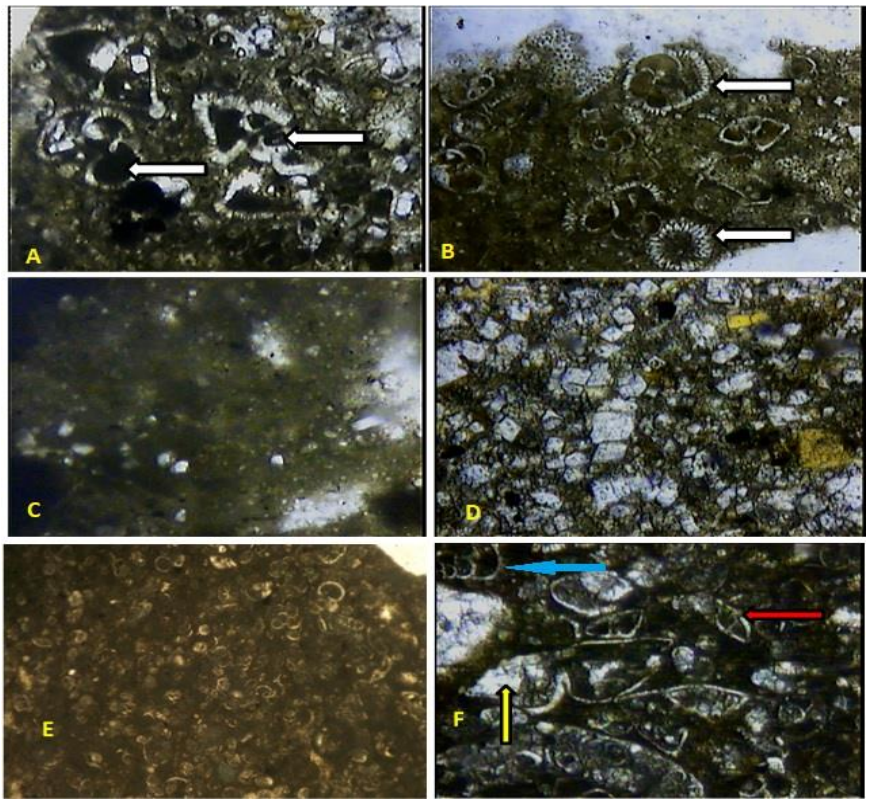


Plate (2): (A) Planktonic foraminiferal lime wackestone microfacies with micritic matrix and planktonic genus *Morozovella* with molded pyrite, BH.90, Depth (1250-1252m), 20x.; (B) Planktonic foraminiferal lime wackesone microfacies with micritic mass ground and *Rotalia*, BH.188, 20x.; (C) Lime mudstone microfacies, BH.52, Depth (1164 m), 20x.; (D) Planktonic foraminiferal lime packstone microfacies with extensive dolomitization BH.52, Depth (1175- 1176m), 20x.; (E) Planktonic foraminiferal lime packstone microfacies with planktonic foraminifera and micritic matrix, BH.188, Depth (1310m), 20x.; (F) Planktonic foraminiferal lime packstone microfacies with *Morozovella* affected by micritization (red arrow) and cementation (yellow arrow) and biserial (blue arrow), BH.52, Depth (1172-1173m), 40x.

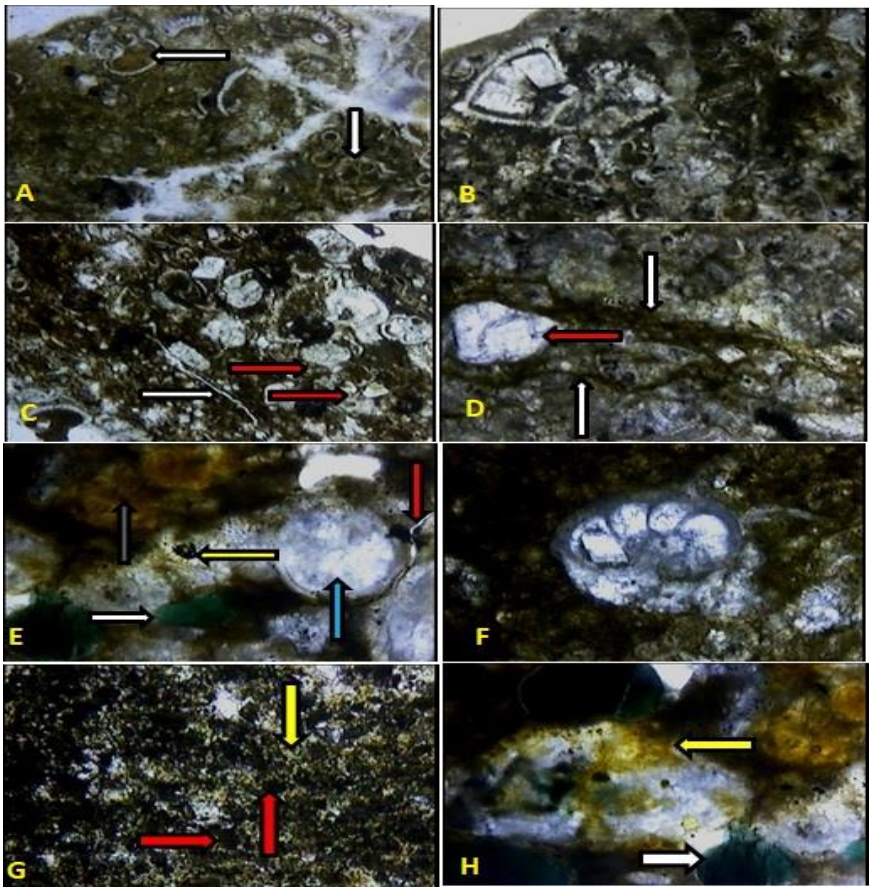


Plate (3): (A) Micritization in Planktonic foraminiferal lime wackestone microfacies (white arrows), BH.52, Depth (1157-1158m), 20x;(B-) Blocky cement in Planktonic foraminiferal lime wackestone microfacies, BH.90, Depth (1248-1249m),20x; (C) Fractures generation (white arrow) and fossils deformation (red arrows) due to mechanical compaction in Planktonic foraminiferal lime packstone microfacies, BH.52, Depth (1172-1173m), 20x; (D) Hummocky stylolite due to chemical compaction (red arrows) and cementation by blocky cement in Planktonic foraminiferal lime wackestone microfacies, BH.52, Depth (1180m), 20x; (E) Deformed planktonic foraminifera with diagenetic features include fracturing due to mechanical compaction (red arrow), cementation (blue arrow), silicification (grey arrow), and precipitation of authigenic minerals of pyrite (yellow arrows) and glauconite (white arrow) in Planktonic foraminiferal lime wackestone microfacies, BH.138, Depth (1604 m), 40x; (F) Benthic foraminifera with a euhedral crystal of dolomite in Planktonic foraminiferal lime wackestone microfacies, BH.138, Depth (1604 m), 40x; (G) Silicification (yellow arrow) and pyritization (red arrow), BH.52,Depth (1153-1154 m), 20x.; (H) Silicification (yellow arrow) and glauconite (white arrow), BH.138, Depth (1604m), 40x.

Palaeoenvironment

In the current study, two palaeoenvironments of the Aaliji Formation were concluded depending on classification of environments by Koutsokos and Hart (1990) (Diag.1). As it is known that various species of foraminifera coexist within deep or shallow environments where the planktonic foraminifera are abundant in deep water environments in contrast to benthonic foraminifera which become abundant in shallow environments (Keller *et al*., 2007) and the increasing in the ratio of planktonic / benthonic foraminifera can give an indicator to the open sea environment (Murray, 1978). furthermore, benthonic foraminifera can be use as indicator to the depth of environment because of their sensitivity to the environments changing (Sari *et al*., 2008).

Aaliji Formation consists of three microfacies: wackestone bearing planktonic foraminifer's microfacies (the dominant microfacies in the formation), mudstone microfacies and packstone microfacies where the third one has limited occurrence in the formation. These microfacies have been associated with different species and genus of foraminifera such as *Morozovella*, *Acarinina*, *Subbotina*, *Iogarina*, *Oragonesis*, *Globorotalia*, Nodosarids and Bolivinids. It is seen that the percent ratio of planktonic / total of foraminifera reaches to (70-85%) which means that the deposition was taken place in upper bathyal in deep-sea environments with depth ranging between (200 – 500 m) (Gibson, 1989 and Haq and Boersma, 1998). In addition, many genera of benthonic foraminifera have been distinguished in the Aaliji Formation like *Anomalinoides*, *Lenticulina*, *Bathysiphon*, *Cibicidoides*, *Gyroidinoides*, *Nuttallides*, and *Marrsonella*; which refer to deposition in outer shelf within deep shelf environments. Koutsoukos (1985) showed that the foraminifera of genuses *Anomalinoides* and *Lenticulina* are coexist in outer shelf – upper bathyal environments.

The climate conditions during the period of Aaliji deposition can be concluded from the high prevalent coexisting of planktonic foraminifera percent ratio especially of both genera *Morozovella* and *Acarinina* which indicated tropic and semi tropic conditions (Haq and Boersma, 1998) where the percent ratio increased in the low latitude and decreased in high latitudes (Arenillas and Molina, 1996). Therefore, it can be concluded that the prevalent climatic conditions during deposition of Aaliji Formation were tropic to semi-tropic in deep shelf environment and deep-sea environment (Diag. 2).

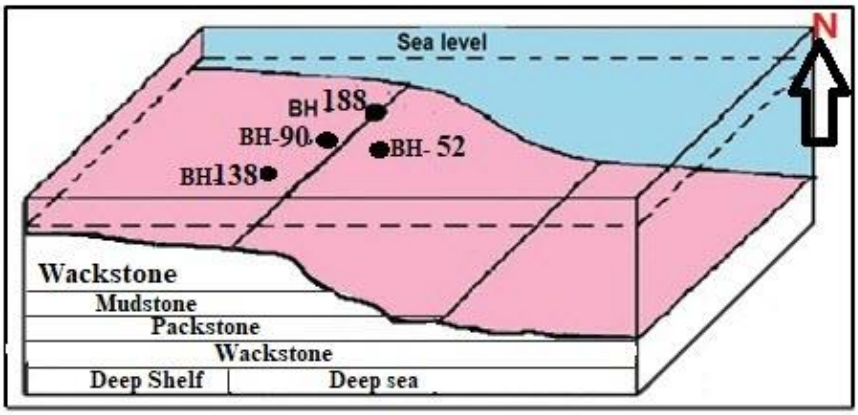


Diagram (2): A depositional model of the Aaliji Formation in the studied area.

Sequence Development

The main geological processes that control the formation of sediments are the change in sea level, the tectonic factor, accommodation, and the preparation of sediments (Brown and Fisher, 1977; Emery and Myers, 1996). The Aaliji Formation belongs to AP10 and it consists of two 3rd order sequences bounded by two SB1 surfaces in Bai Hassan oilfield, where the lower boundary that separates between the Cretaceous and the Palaeogene sequences is considered as a regional unconformity surface. As well as, the existence of the Palaeogene planktonic foraminifera instead of the absence of the keeled Cretaceous planktonic foraminifera, and the occurrence of the glauconite and pyrite authegenic minerals associated with extensive increasing with gamma ray log. The first sequence starts with a Transgressive System Tract (TST) after a regional regression located as SB1 surface on the top of the lower succession (Late Cretaceous Shiranish Formation). This system tract is thickest in well BH.188 towards the east of the study area, and it is represented by deep shelf association of planktonic foraminiferal lime wackestone microfacies that followed by deep-sea association of lime mudstone microfacies, which represent the maximum flooding surface (MFS). A short Highstand System Tract (HST) followed this (MFS) as shallowing upward of deep shelf association with planktonic foraminiferal lime packstone microfacies. This sequence is bounded by (SB2) surface. The second sequence begins with a new transgressive system tract (TST) of deep-sea association of lime mudstone microfacies, which ended with Maximum Flooding Surface (MFS) followed by a Highstand System Tract (HST) of deep shelf association with planktonic foraminiferal wackestone microfacies that ended with (SB1) surface which separate the Paleocene Aaliji Formation from the Eocene Jaddala Formation **(**Diag. 3).

Correlation sequences during the Palaeogene

The sequence (AP10) took a period of time (29 Ma) extending between ages (63-34 Ma), where the lower boundary of this sequence was fixed at age (63 Ma) at the surface of the unconformity between the late Cretaceous and early Palaeogene sequences, which

occurred at the end of the collision that led to the rise of ophiolites along the northeastern edge of the Arabian plate at the end of the Cretaceous (Sharland *et al*., 2001).

The upper boundary, it was set at age (34 Ma), which represents the beginning of the opening of the Red Sea between the Arabian and African plates (Beydoun, 1991; Goff *et al*., 1995). Also Sharland *et al.* (2001) recorded two maximum flooding surfaces during the succession (AP10), the first surface (MFS Pg10) at age (58 Ma) and the second (MFS Pg20) at age (49 Ma).

Al-Jubouri (2011) study of the formation in Khabbaz field, recorded the loss of biozones of Early Paleocene represented by (P0, Pα, P1, P2), and that the *Morozovella angulata* zone represents the beginning of the marine transgressive it deposited Aliji Formation in that region and in which the Maximum Flooding Surface at Paleocene period, which is comparable to (MFS Pg10) in Saudi Arabia and northern Iraq. Despite the relative discrepancy with the age of the Maximum Flooding surface in northern Iraq, the Arabian plate suffered from a wide marine transgressive during the Paleocene (Sharland *et al*., 2001).

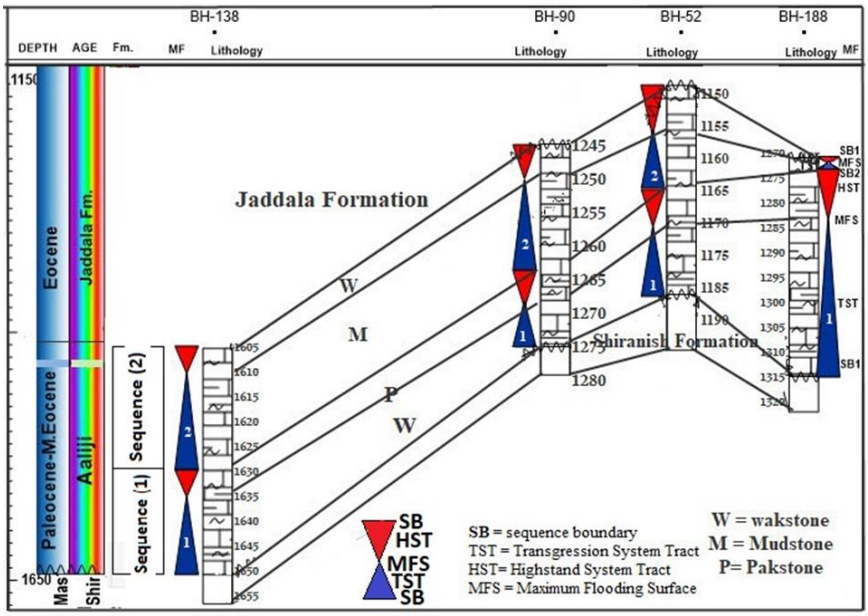


Diagram (3): Sequence stratigraphic correlation of Aaliji Formation in the studied area.

CONCLUSIONS

The dominant microfacies are planktonic wackestone microfacies, lime mudstone microfacies with less abundant of planktonic packstone microfacies. Both lower contact with Shiranish Formation and upper contact with Jaddala Formation are unconformity surfaces due to faunal changing and concentration of pyrite and glauconite. The

palaeoenvironments of formation have been deduced on basis of petrographic study and microfacies analysis with coexisting of planktonic and benthonic foraminifera as outer shelf-upper bathyal environments. Determine sequence (1) started SB1 surface that separates the Cretaceous from the Palaeogene successions the sequence begins with a Transgression System Tract TST deepening-upward ended with Maximum Flooding Surface MFS and the Highstand System Tract HST as a shallowing-upward ended by SB2 and Sequence (2) begins with a new Transgression System Tract TST and bounded with Maximum Flooding Surface MFS. The Highstand System Tract HST of this sequence that shallowing-upward which ended by SB1 that separate between the Aaliji Formation and the Jaddala Formation.

Despite the relative discrepancy with the age of the Maximum Flooding surface in northern Iraq, the recent study considers the Arabian plate suffered from a wide marine transgressive during the Paleocene.

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CONFLICT OF INTEREST STATMENT

The authors have no conflicts of interest to declare.

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الطباقية التتابعية والبيئة القديمة لتكوين عليجي في حقل باي حسن النفطي في محافظة كركوك، شمالي العراق

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الخلاصة

تم دراسة تكوين عليجي في ابار BH.52، BH.90، BH.138 و BH.188، ضمن حقل باي حسن النفطي ضمن نطاق الطيات الواطى شمالي العراق لتحديد البيئة الترسيبية و طباقية التتابع. يتحدد التكوين بسطحين غير متوافقين مع تكوين شيرانش في الأسفل وتكوين جدالة في الأعلى.

بينت طبيعة التحليل السحني وتجمعات الحشود الحياتية لكل من الفورامنيفيرا الطافية القاعية وقد حددت حدود التتابع السفلى والعليا بسطحي تتابع غير توافقي من النوع الأول(SB1) ؛ بينما حدد التتابع الثاني من الاسفل بحد من النوع الثاني (SB2)، حيث تموضع التتابع الأول على سطح عدم التوافق من النوع الأول (SB1) الذي يفصل تتابعات الكريتاسي الاعلى عن تتابعات الباليوجين والذي تكون في بيئة الرصيف الخارجي الى الباثيال المتوسط- العلوي وهو يتألف من سحنة الحجر الجيري الواكي الحامل للفورامنيفيرا الطافية الدقيقة ممثلا مسار النظام التقدمي TSTو ينتهي التعمق نحو الأعلى بسطح الفيضان الأقصى MFS متمثلا بسحنة الحجر الطيني الدقيقة في البئر BH.188 التي تبعتها سحنة الحجر الجيري المرصوص الحاملة للفورامنيفيرا الطافية الدقيقة ممثلة مسار النظام التراجعي HST دالة على التضحل نحو الأعلى والذي ينتهي بسطح تتابعي من النوع الثاني (SB2).

اما التتابع الثاني فإنه بدأ بمسار نظام تقدمي جديد TST متمثلا بسحنة الحجر الجيري الطيني الدقيقة المتكونة ضمن بيئة الرصيف الخارجي والتي حددت من الأعلى بسطح الفيضان الأقصى MFS حيث كان اكبر سمك له في البئر BH.138 بينما تمثل مسار النظام التراجعيHST بتضحل نحو الأعلى دلت عليه سحنة الحجر الجيري الواكي الحاملة للفورامنيفيرا الطافية والذي انتهى بسطح تتابع من النوع الأول SB1 الذي يفصل بين تكوين عليجي وتكوين جدالة.