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Microfacies of Shiranish Formation (Late Cretaceous) in Tikrit Oilfield, Central Iraq

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ABSTRACT

The late Campanian-Maastrichtian cycle in TK.1 and TK.2 wells within Tikrit Oilfield in central Iraq is represented by basinal facies of the Shiranish Formation. The lithology consists of marly limestone in the lower part referred as unit (A) followed by unit (B) in the middle part, which is composed of shaly limestone with bands of shale and marl with detrital particles and dolomite rock fragments. The upper part unit (C) comprises marly limestone with less shale and carbonate rock fragments. Two biostratigraphic zones are distinguished; *Globotrun-canita calcarata* Total Range Zone referred to Middle-Late Campanian, and *Globotruncana aegyptiaca* Interval Zone referred to Early Maastrichtian. The Bioclasts Foraminiferal Wackestone Microfacies (Sh1), Foraminiferal Wackestone Microfacies (Sh2), Foraminiferal Wackestone-Packstone Microfacies (Sh3) and Mudstone Microfacies (Sh4) characterize the dominant microfacies. Those were affected by different diagenesis processes. In accordance to microfacies analysis and the biological components, the succession was deposited in basinal to toe of slope environments. The deeper part is located in the well TK.1 at the eastern side of Tikrit Oilfield, where it was responsible for depositional microfacies association of (Sh1) and (Sh4). The repetition of (Sh1, Sh2, Sh3 and Sh4) microfacies associations toward the west of the field within TK.2 well indicates that the shallowest part of depositional basin is located at the western side of the field due to the occurrence of quartz particles, rock fragments and benthonic foraminifera within unit (B) in this well. Those may be provided from the higher parts of the Rutba-Khleisia basin, which is not covered by the sea or partially covered.

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السحنات الدقيقة لتكوين شيرانش (الطباشيري المتأخر) في حقل تكريت النفطي، وسط العراق

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الملخص

تتمثل دورة الكامباني المتأخر-الماسترختي في بئري TK.1 وTK.2 ضمن حقل تكريت النفطي وسط العراق بتكوين شيرانش، وتتكون من حجر جيري مارلي في الجزء الأسفل تمثل الوحدة (A)، تليها في الجزء الأوسط صخور الوحدة (B) المكونة من الحجر الجيري السجيلي مع احزمة من السجيل والمارل وحبيبات من الكوارتز مع قطع من صخور الدولومايت، بينما تتكون الوحدة العليا (C) من حجر جيري مارلي مع قليل من السجيل وزيادة القطع الصخرية الكربوناتية. تم تشخيص نطاقين حياتيين هما نطاق المدى الكلي *Globotruncanita calcarata* Total Range Zone الدال على عمر الكامباني الأوسط – الأعلى ونطاق فاصل *Globotruncana aegyptiaca* Interval Zone الدال على عمر الماسترختي المبكر. تتمثل السحنات الدقيقة السائدة بسحنة الحجر الجيري الواكي الدقيقة الحاملة لفتات الفورامنيفيرا (Sh1) وسحنة الحجر الجيري الواكي الفورامنيفيرية الدقيقة (Sh2) وسحنة الحجر الجيري الواكي-المرصوص الفورامنيفيرية الدقيقة (Sh3) وسحنة الحجر الجيري الطيني الدقيقة (Sh4)، وقد تأثرت بعمليات تحويرية عديدة. اعتمادا على التحليل السحني والمكونات الحياتية، تبين ان التتابع قد ترسب في بيئات الحوض العميق وامتد الى نهاية المنحدر، حيث تمثل الجزء العميق من الحوض الرسوبي في البئر TK.1 ضمن الجزء الشرقي من حقل تكريت والذي كان مسؤولا عن ترسيب التجمعات السحنية (Sh1 و Sh4) ، بينما ترسبت بشكل متكرر التجمعات السحنية الدقيقة (Sh1 وSh2 وSh3 وSh4) في الجهة الغربية من الحقل ضمن البئر TK.2 مشيرة الى الجزء الاضحل من الحوض بسبب وجود حبيبات الكوارتز والقطع الصخرية والفورامنيفيرا القاعية ضمن الوحدة (B) في هذه البئر والتي يحتمل انها جهزت الى الحوض الترسيبي من الأجزاء العليا من حوض الرطبة-الخليصية الذي لم تغمره مياه البحر او غمرته جزئيا.

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Introduction

This research deals with subsurface study of the Shiranish Formation in wells TK.1 and TK.2. Henson (1940 in Bellen *et al*., 1959) first described Shiranish Formation near Shiranish Islam village in northern Iraq. It was subdivided into three lithological units; the lower unit that consists of blue marl and marly limestone, the middle unit that is composed of massive marly limestone with layers of marl, and the upper unit that is represented by marly limestone with marl and limestone (Al-Rawi, 1973). Two main biostratigraphic zones; *Globotruncana fornicate - stuartiformis - elevate - rosetta - ventricosa* Zone and *Globotruncana contuse-esnehensis - duwi* Zone represent the main biozones in this formation (Kassab, 1973). The formation was deposited within an open sea environment during the late Campanian – Maastirichtian age (Al-Qayim, 1992; Abdula *et al*., 2018). The study of sequence stratigraphy by Al-Banna *et al*. (2010) showed that the succession consists of two third order cycles, these cycles were bounded by two surface boundaries (SB) in the lower part of each cycle and two maximum flooding surfaces (MFS) in the upper parts which is represented by *Globotruncana ventricosa* Zone and *Gansserina gansseri* Zone (Al-Juboury, 2011).

The formation has been suffered from many diagenesis processes according to its probable timing like bioturbation, compaction, cementation, dissolution, micritization, recrystallization, authigenic minerals, fractures and formation of veins within stagnate burial, marine phreatic, and fresh groundwater phreatic diagenetic environments (Alatroshe *et al*., 2023).

Tikrit Oilfield has 70 km length and about 1 km width as a subsurface structure site in Salah Al-din Governorate, about 10 km west of Tikrit City in the Mesopotamia area within the Unstable Shelf on the northeastern Arabian Plate (Fouad, 2010) (Fig.1). Relative to the depositional basin, the field is located on the marginal Stable Shelf that is indicated by the stratigraphic column revealed with shallow basin facies of continental shelf (Jassim and Buday, 2006). The study area has been affected by the subsidence during the Cretaceous Period, which caused many structural features that led to the deposition of various facies with different lithologies and fauna.

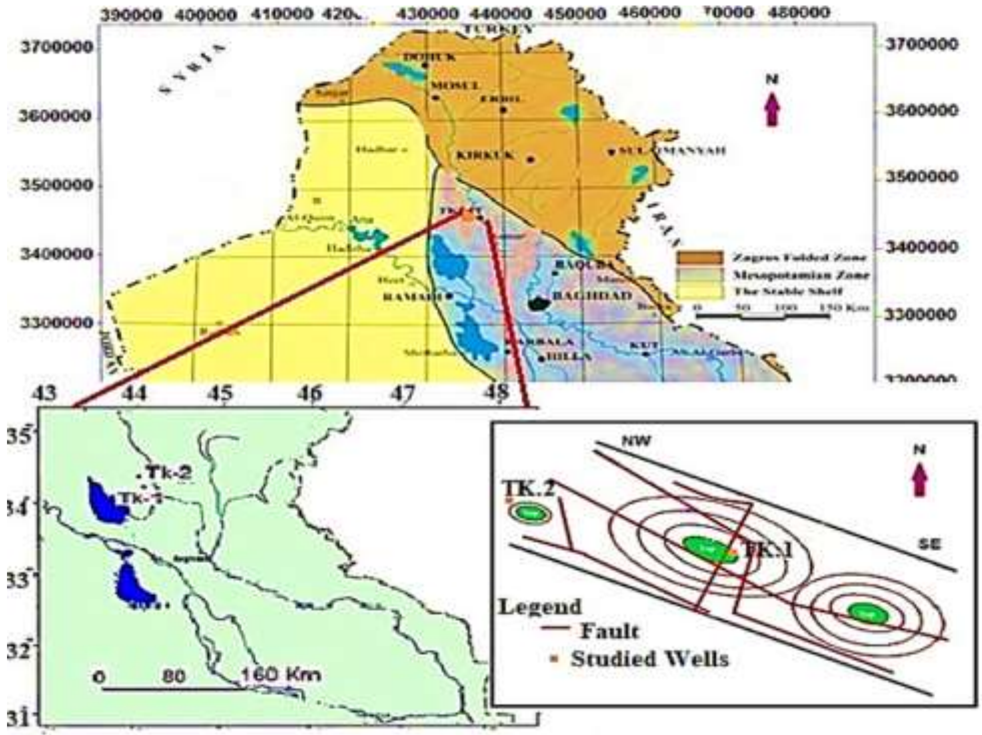

Fig. 1. Location map of the study area (modified from Fouad, 2010)

Aim of Study

This paper focuses on the following: 1. Evaluation of the Shiranih Formation and identifying the apparent lithological variation using samples and thin sections of Shiranish Formation. 2. Determining the nature of the lower and the upper boundaries of the Shiranish Formation with the Hartha and the Jaddala formations, respectively. 3. Facies analysis and Palaeoenvironmental interpretation.

Materials and Methods

1. Collecting the available data about Tikrit Oilfield. This includes the final wells reports. In addition, gathering information from previous studies.

2. Choosing 300 cuttings samples from the Late Cretaceous succession approximately every two meters depth in each studied well. Sample descriptions include rock type and vertical succession of lithologies

3. Petrographic study and description have been made on 268 thin sections (most of them are lent from Geology Department in the North Oil Company) using the polarized microscope and the Alizarine Red Solution, which is used in staining the carbonate minerals for numerous thin sections to distinguish between the calcite and dolomite. An extended Dunham classification (Dunham 1962; Embry and Klovan, 1971) is used for classifying the carbonate rocks.

4. Study of the vertical variations and lateral distribution of the facies and diagenetic modifications to evaluate the formation and concluding the depositional environment.

Results

Lithological Description

Shiranish Formation is considered one of the most formations of Campanian-Maastrichtian cycle that has widespread distribution in Iraq and partial occurrence in the neighboring countries (Buday, 1980).

The Shiranish Formation represents a basinal facies, which exist in the whole wells of Tikrit Oilfield, where in the study area, the highest thickness reaches 268 m in well TK.2, while it is about 230 m in well TK.1. The lower boundary is conformable with Hartha Formation, while the upper boundary is unconformable with Jaddala Formation due to missing part of Late Maastrichtian-Early Eocene, which is determined by the change in lithology and fauna.

Shiranish Formation is subdivided into three units depending on the lithological and biological contents as follows (Figs 2 and 3):

1. ***Unit (A)***

This unit represents the lower part of the formation and its thickness ranges between 37 m in well TK.1 and 70 m in well TK.2. It is composed of grey marly limestone with low hardness and pronounceable increased ratio of planktonic foraminifera especially Calcisphere and *Archaeoglobigerina cretacea* (d'Orbigny, 1840), *Globotruncana plummerata*, *Globotruncana ventricosa*, *Globotruncana fornicata*, *Globotruncanita calcrata*, *Globotruncana aegyptiaca*, *Globotruncana stuartiforms*, *Globotruncana roseta*, *Globogernoides* sp., *Globotruncana bulloides*, *Lagena* sp. and *Heterohelix* sp. with abundant of rchinoids and bryozoa with rare carbonate rock fragments and dolomite rhombs.

The diagenetic features associated with this unit are silicification, cementation, recrystallization and pyritization as authigenic mineral.

2. ***Unit (B)***

This unit is situated between the unit (A) and unit (C) with thickness ranging between 105 m in TK.1 well and 155 m in well TK.2. The lower part of this unit is represented by dark grey to brown color of shaly limestone, while the upper part of about 35 m thick is characterized by grey color. The unit contains high amount of shale bands with marl in addition to quartz particles, carbonate rock fragments, chert and dolomite rhombs but less than the upper unit (C).

The planktonic foraminifera and their debris form most skeletal grains in addition to Calcispheres. Also, Heterohelix sp., Globotruncana fornicata, Archaeoglobigerina cretacea, Globotruncana plummerata, Globotruncana aegyptiaca, Globotruncanita calcarata, Globotruncana elevate, Globotruncana bulloides and Globogerinelloides sp. with rare benthonic foraminifera are distinguished. Lithoclasts and anhydrite nodules are recognized at depths 1064 m and 1167 m in well TK.2 and at depth 1135 m in well TK.1 as authigenic mineral in addition to pyrite mineral. This unit is clearly affected by silicification, cementation and neomorphism diagenesis.

3. Unit (C)

This unit is located on the upper part of the formation with a thickness reaches 88 m in well TK.1 and 43 m in well TK.2. It mainly consists of brittle light grey marly limestone with less shale and carbonate rock fragments instead that of unit (B) with micritic matrix. Also, it is characterized by existing of glauconite as authigenic mineral in the upper part, in addition to scattering dolomite rhombs and botryoidally pyrite within mass ground or filling the fossils chambers. Most skeletal grains are formed from planktonic foraminifera including:

Globotruncana fornicate, Globotruncana aegyptiaca, Globotruncana elevata, Globotruncana ventricosa, Globotruncana mariei, Globotruncana roseta, Globotruncana stuartiformis, Globotruncana plummerata, Oligostigina, Heterohelix sp., and *Globogerinelloides sp.*

Rare benthonic foraminifera like; *Loftusia*, *Bulivina*, *Bulimina*, *Rotalia* sp. and *Uvigerina* are distinguished too in the upper part of this unit at depth 1031 m besides bioclasts and lithoclasts such as quartz particles and carbonate rock fragments.

Biostratigraphy

Two biostratigraphic zones are distinguished within Shiranish Formation in the studied wells, they are:

1. *Globotruncanita calcarata Total Range* Zone

Definition: This biozone was originally established by Caron (1985). The lower boundary is represented by the first appearance of *Globotruncanita calcarata* while the upper boundary is represented by the last appearance of the same index species (Figs. 2 and 3). The age of this biozone is Middle - Late Campanian as it is determined by Van Hart (1976); Robaszynski *et al*. (1984); Caron (1985); Sliter (1989); Sliter and Leckie (1993); Li *et al.* (1999); and Al-Juboury (2011).

2. *Globotruncana aegyptiaca* Interval Zone

Definition: This biozone also was originally established by Caron (1985). The lower boundary is represented by last appearance of *Globotruncanita calcarata* and the upper boundary is represented by last appearance of *Globotruncana aegyptiaca* (Figs. 2 and 3). The age of this biozone refers to the Early Maastrichtian as it determined by Caron (1985); Sliter and Leckie (1993); Robaszynski and Caron (1995); Premoli Sliva *et al.*, (1998), Robaszynski *et al*, (1998); and Al-Juboury (2011).

Microfacies Analysis

Microfacies represent the completely sedimentological and biological features that are denoted by studying thin sections under the microscope (Flugel, 1982) and comprise various sedimentological textures, which reflect the depositional energy and environment. The microfacies are recognized depending on the classification of Dunham (1962) developed by Embry and Klovan (1971) and improved by Flugel (2004). Four microfacies are identified:

1. Bioclasts Foraminiferal Wackestone Microfacies (Sh1)

This microfacies is identified in well TK.1 followed by and alternated with the Foraminiferal Wackestone bearing Calcisphers Microfacies Sh2, while it coexists within both units (A and C) in well TK.2. It is comprised of micritic matrix with organic and clay materials associated with planktonic foraminifera such as Calcisphere, *Globotruncanita calcarata, Globotruncana* sp. and *Heterohelix* sp. besides bioclasts and lithoclasts like quartz particles, chert, carbonate rock fragments and rhombs of dolomite. In some parts, it is affected by recrystallization and silicification diagenesis.

This microfacies is compatible with SMF 4 that deposited in FZ1 as toe of deep-sea environment (Figs. 2, 3, and 4; Pates 1A, 2A and B).

2. Foraminiferal Wackestone Bearing Calcisphers Microfacies (Sh2)

This microfacies is identified only within unit (B) in well TK.2, where it is characterized by micritic matrix with rare organic materials whereas the skeletal grains with more than 10% represented by planktonic foraminifera *Globlgerinelloides* sp., *Hedbergella* sp., *Heterohelix* sp. and *Globotruncana* sp. and Calcisphere with infrequent bioclasts. Other grains like quartz, chert, carbonate rock fragments and spread of dolomite rhombs exist too.

The main diagenesis processes affected on this microfacies are silicification, which is only confined with calcispheres, recrystallization, compaction and cementation with sparry calcite cement in fossils chambers in addition to pyrite minerals, which spread out randomly through the matrix as cubic rhombs and/or filling molds of shells.

This microfacies is similar to SMF9 that deposited in FZ2 as deep shelf environment (Figs. 2 and 4; Plate 1B, C, D and E, 2C and D).

3. Foraminiferal Wackestone-Packstone enriched with Calcispheres Microfacies (Sh3)

It is just marked out within unit (B) in well TK.2, where it composed of skeletal grains of more than 60% exemplified by abundant planktonic foraminifera such as *Globogerinelloides* sp., *Heterohelix* sp. and *Globotruncana* sp. as well as Calcispheres. Rare benthonic foraminifera like *Bolivina* sp., *Textularia* sp. and *Loftusia* in addition to bioclasts of planktonic and benthonic foraminifera with lithoclasts of quartz particles, chert fragments and carbonate rock fragments are identified too. The most diagenetic features affected on this microfacies are represented by recrystallization, silicification and compaction.

This microfacies is compared with the SMF1 that deposited in FZ3 within the toe of slope (Figs. 2 and 4; Plates 1F and 2F and G).

4. Mudstone Microfacies (Sh4)

This microfacies has widespread distribution within Shiranish Formation especially in the upper part in both studied wells, and it consists of light to dark brown micrite as microcrystalline carbonate mud less than (4 micron) with mechanical or biological origin (Folk, 1974) and it indicates to deposition in low energy environment (Friedman, 1964 and1985). Rare skeletal grains less than 10% like Calcisphere, Ostracoda, *Globotruncanita calcarata*, *Globotruncana aegyptiaca*, *Globlgerinelloides* sp. and *Globotruncana* sp. with bioclasts in addition to quartz particles, fragments of carbonate rocks and rhombs of dolomite are existed too.

Major diagenetic features recognized within this microfacies include recrystallization, dissolution and silicification. Pyrite mineral, which is distributed within the matrix and/or filling the fossil's chambers, beside to glauconite and anhydrite nodules are identified within this microfacies in the upper part of the formation. These authigenic minerals require reductional conditions, anaerobic bacterial activity and organic matter (Siesser and Rogers, 1977). The occurrence of glauconite and pyrite together in addition to the last appearing of *Glubotruncanita calcarata* and *Globotruncana aegyptiaca* with fauna changing to *Globigerina* of the Eocene Epoch indicating to hiatus.

This microfacies is compatible with SMF3 within FZ3 as toe of slope environment (Figs. 2, 3 and 4; Plates 1G, H and I 2G and H).

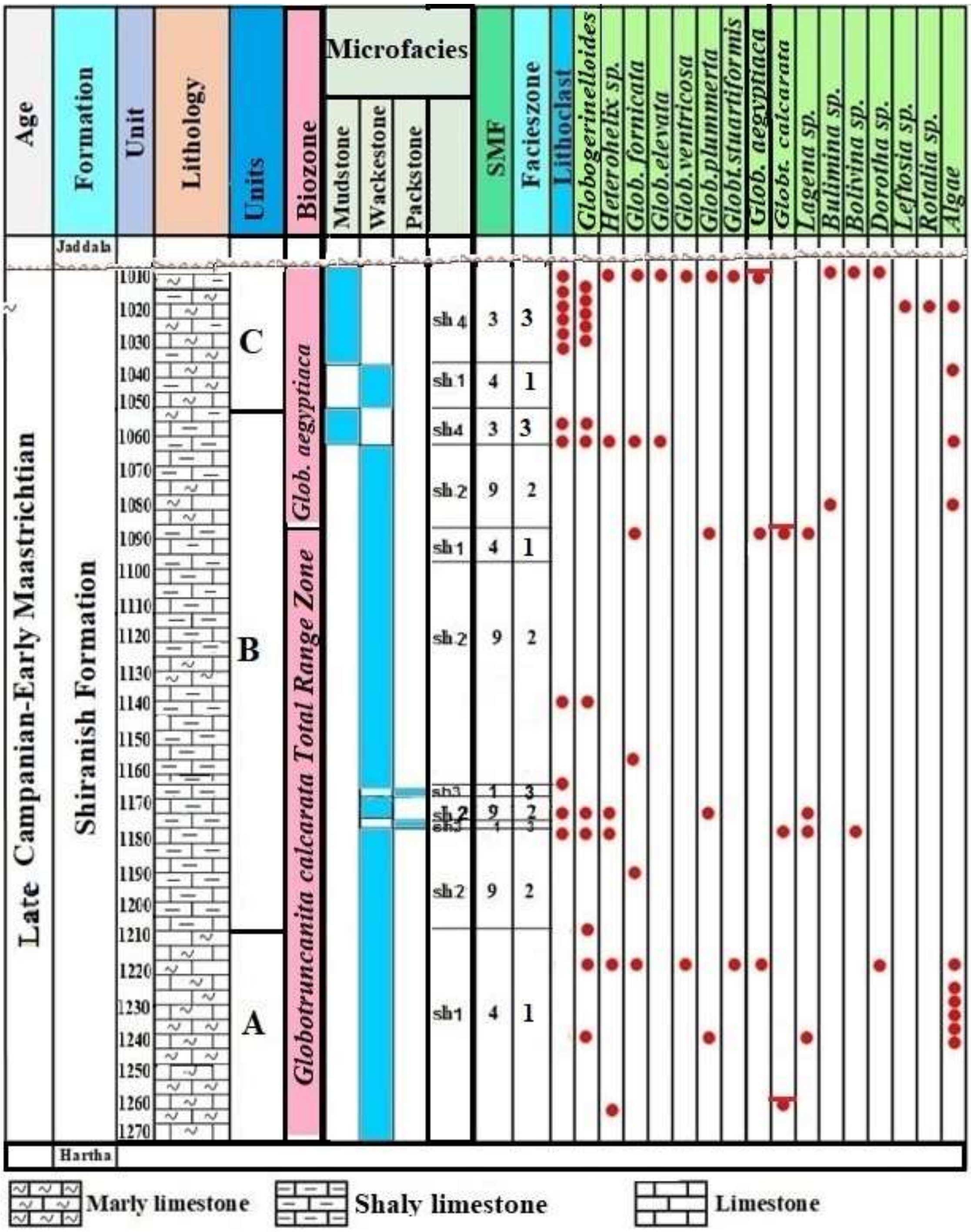

Fig. 2. Lithological, biostratigraphic and fauna distribution in the stratigraphic column in well TK.2

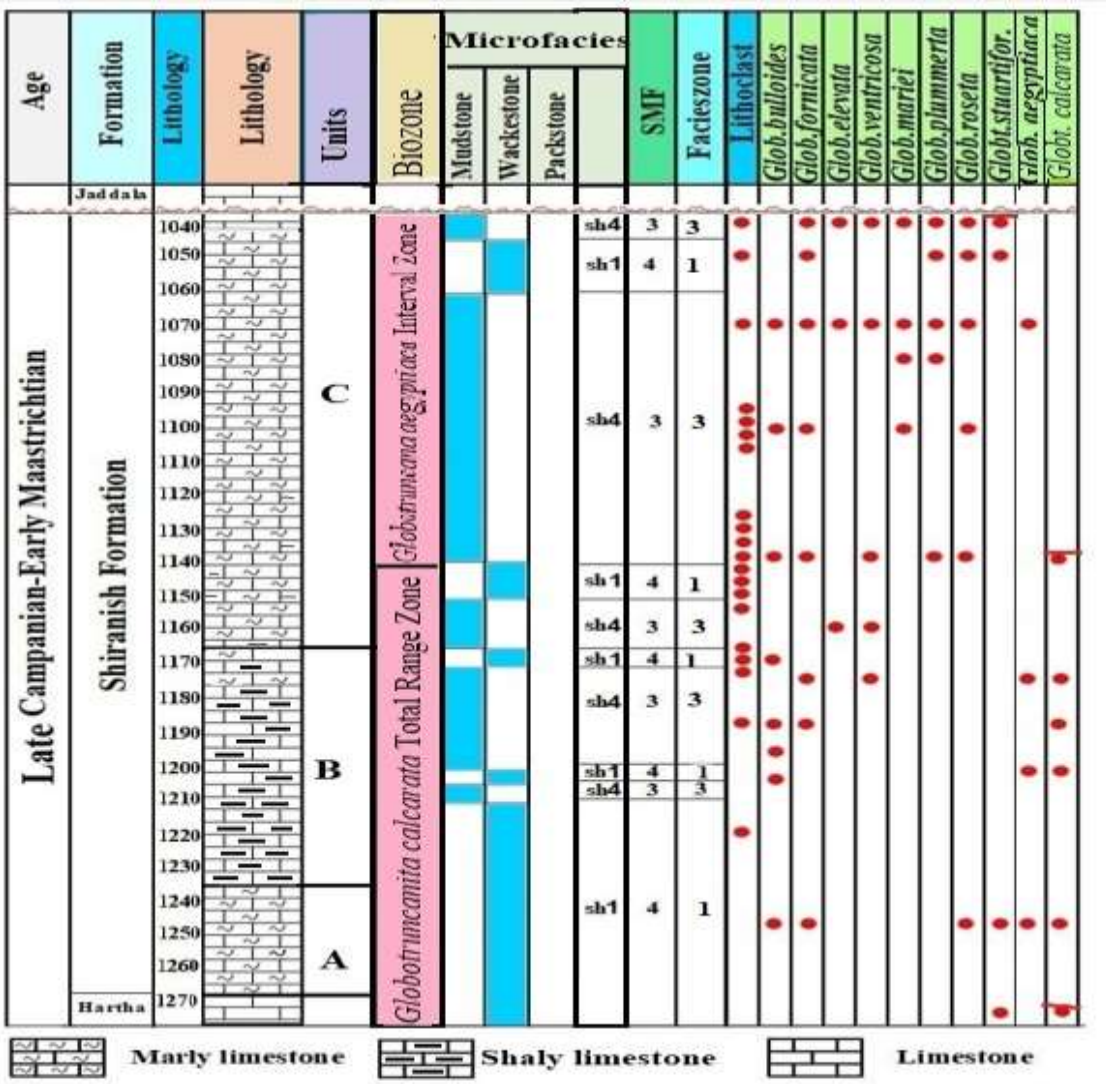

Fig. 3. Lithological, biostratigraphic and fauna distribution in thestratigraphic column in well TK.1

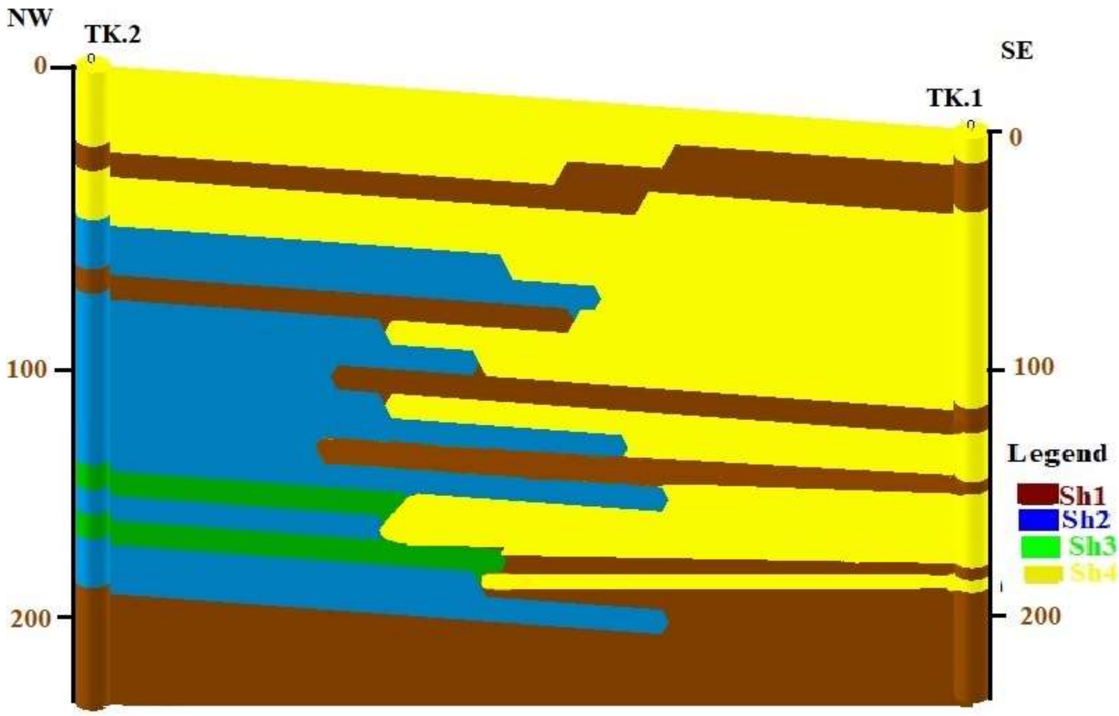

Fig. 4. Correlation of the Shiranish microfacies in Tikrit Oilfield.

Discussion

In order to determine the depositional environment and locating the site of deposition of the studied rocks, many factors must be taken in our consideration. These include the petrographic study and microfacies analysis, which differ as a result of variation of depositional system that are controlled by fluctuation of sea level, depth of water, salinity, temperature and the nature of water currents (Mall, 1984).

The petrographic components and microfacies association of the Shiranish Formation in this study indicate that the mudstone microfacies is the most abundant in the studied formation followed by wackestone-packstone microfacies with micrite matrix. Although various microfacies are identified, there are no large environmental variations have been reflected where they refer to the skeletal grains/matrix ratio that caused due to the difference velocity of particles accumulation to micrite accumulation (Dunham, 1962). The mudstone microfacies indicate relatively quiet depositional conditions due to the abundance of micrite, which referred to low water energy that means they are deposited in the basinal environment as pelagic facies. The mud-supported wackestone microfacies indicate to quiet depositional environment below the wave base as existing abundant planktonic foraminifera and calcispheres referred to relatively deep marine environment. On the other hand, the packstone microfacies with grain supported and rare micrite indicate a higher depositional energy of this facies than the previous facies with wave movements.

Most of the skeletal grains are composed of planktonic foraminifera, which could be used as an indicator to conclude the depositional environment, where they either indicate to the outer shelf environment when they represent less than 50% of skeletal grains or may refer to the upper continental slope when they exceed 50% of whole skeletal grains (Bandy, 1967). The genus *Globlgerinelloides* is related to the mudstone microfacies, which deposited in relatively a deep marine environment away from wave currents activity (Reekman and Friedman, 1982). The *Heterohelix* sp. and *Hedbergella* sp. are implying to deep water environment (continental slope), the genus *Globotruncana* sp. verify the deposition in deep marine environment in quiet conditions away from wave currents. Calcispheres may indicate to an open marine environment (Banner, 1972 in Master and Scott, 1978), or perhaps refer to an intermediate marine environment (Rupp, 1968 in Master and Scott, 1978), and they could exist in both shallow and deep environments (Master and Scott, 1978).

Finally, the comparing of the studied sedimentary microfacies with the standard limestone microfacies (SMF) described by Flugel (2004) and corresponding with the facies belt zones (FZ) assumed by Wilson (1975) show that the mudstone microfacies (Sh1) is conform to the SMF4 within FZ1, which represents basinal environment. The bioclasts foraminiferal wackestone microfacies (Sh2) is similar to standard microfacies SMF9 within the facies belt zone FZ2 as deep shelf environment. The foraminiferal wackestone bearing silicified calcisphers microfacies (Sh3) is similar to SMF1 within FZ3 that deposited at the bottom of slope, which represent the toe of slope environment. While the foraminiferal wackestone-packstone enriched with calcisphers microfacies (Sh4) are correspondent with SMF3 within FZ3 deposited in the toe of slope environment. So, the lithological and biological information besides the microfacies analysis emphasize that the deposition of Shiranish Formation in Tikrit Oilfield on the west of depositional basin has been took place in deep marine environment, and it was sited within the facies belt zones FZ1 and FZ2, which represent the deep sea and deep shelf. The area of depositional environment of well TK.1 located in the east of well TK.2 is deeper than the area of well TK.2 during the time of Shiranish Formation deposited in Tikrit Oilfield. The distribution of deep marine facies in well TK.1 instead of the existing quartz particles and carbonate rock fragments besides to benthonic foraminifera in unit (B) within well TK.2 could give an indicator about the provenance of the detrital materials. Perhaps provided by the higher parts of Rutba-Khleisia basin, which has been not covered by the sea or discontinuously covered, and its sediments were characterized by thin sandy phosphate deposits which are mostly removed during the Maastrichtian age (Buday, 1980). The shelf in which Shiranish Formation has been deposited was open shelf graded from shallow to deep marine.

Conclusions

1- Depending on the lithological variation of Shiranish Formation, the succession is divided into three lithological units. The lower unit (A) is composed of grey marly limestone with low hardness and pronounceable increased ratio of planktonic foraminifera. Unit (B) that is situated between unit (A) and unit (C) is represented by dark grey to brown color shaly limestone with high amount of shale bands and marl in addition to quartz particles, carbonate rock fragments, chert and dolomite rhombs. The upper unit (C) mainly consists of brittle light grey marly limestone and less shale and carbonate rock fragments, with existing glauconite as authigenic mineral.

2- Based on the biostratigraphic distribution, two biostratigraphic zones are distinguished; *Globotruncanita calcarata Total Range* Zone that indicates to the age of Middle - Late Campanian, and the *Globotruncana aegyptiaca* Interval Zone that refers to the age of Early Maastrichtian; therefore, the age of the Shiranish Formation is concluded as Middle - Late Campanian - Early Maastrichtian.

3- The lower contact of Shiranish Formation is conformable with Hartha Formation, while the upper contact is unconformable with Jaddala Formation due to missing of part of Late Maastrichtian-Early Eocene, which is determined by the change in lithology and fauna.

4- According to the microfacies analysis, three facies' associations are responsible for deposition of the microfacies of Shiranish Formation. Deep sea facies association is responsible for deposition of bioclasts foraminiferal wackestone microfacies (Sh1), deep shelf facies association is responsible for deposition of foraminiferal wackestone bearing calcisphers microfacies (Sh2) and toe of slope facies association responsible for deposition of foraminiferal wackestone-packstone enriched with calcispheres microfacies (Sh3) and mudstone microfacies (Sh4).

5- Based on the microfacies analysis and facies associations, the deeper part of the depositional basin in the study area is located in the well TK.1 in the eastern side of Tikrit Oilfield, where (Sh1) and (Sh4) microfacies deposited. Whereas the shallowest part of depositional basin is located in the west side of the field due to the repetition of (Sh1, Sh2, Sh3 and Sh4) microfacies and the occurrence of quartz particles, rock fragments and benthonic foraminifera within unit (B) in TK.2 well.

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Conflict of Interest

The authors declare that they have no conflict of interest

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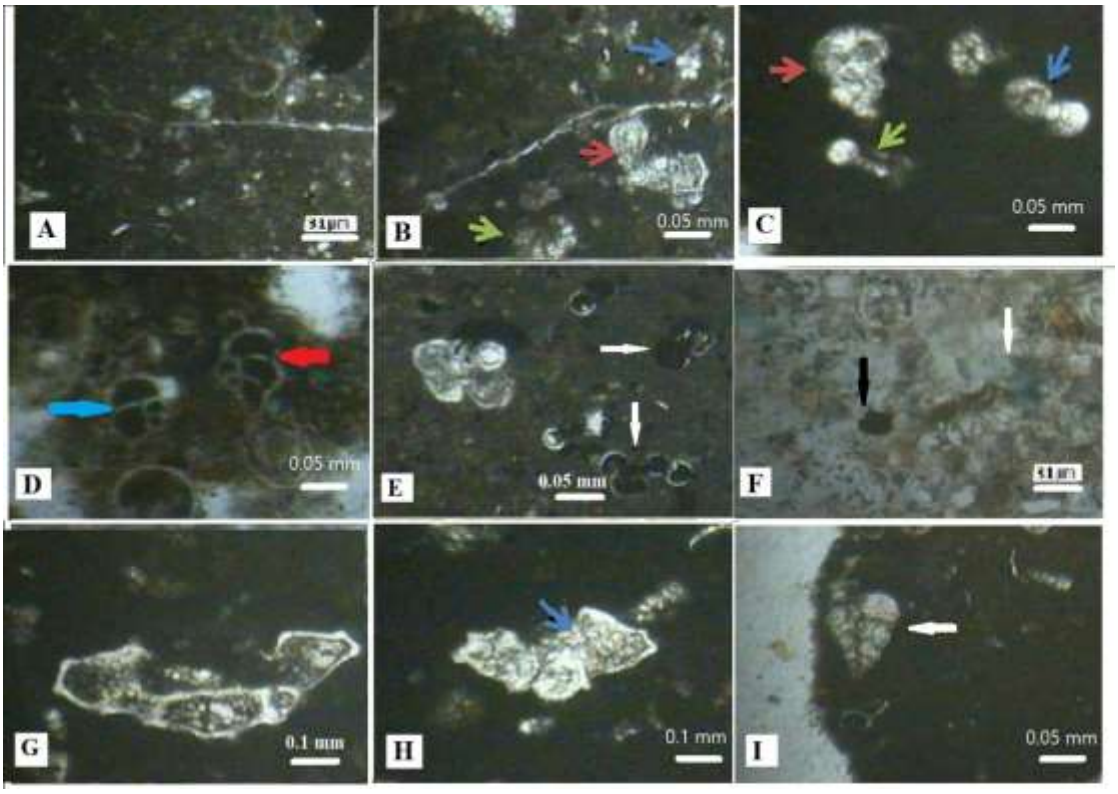
Pate (1)



Explanation of Plate (1)

(A) Bioclasts Foraminiferal Wackestone Microfacies (Sh1), Shiranish Formation, Wells Tk.1 and TK.2, Depths 1056 m and 1040 m respectively.

(B) Foraminiferal Wackestone bearing Calcisphers Microfacies (Sh2) with *Contusatruncana contusa* (red arrow), *Heterohelix* (blue arrow), *Cibicidoides* (green arrow), Shiranish Formation, Well Tk.2, Depth 1070 m.

(C and D) Foraminiferal Wackestone bearing Calcisphers Microfacies (Sh2) with *Heterohelix* (red arrow), *Hedbrgella* (blue arrow), green color *Globigerinelloides* (green arrow), Shiranish Formation, Well Tk.2, Depths 1140 m and 1182m respectively.

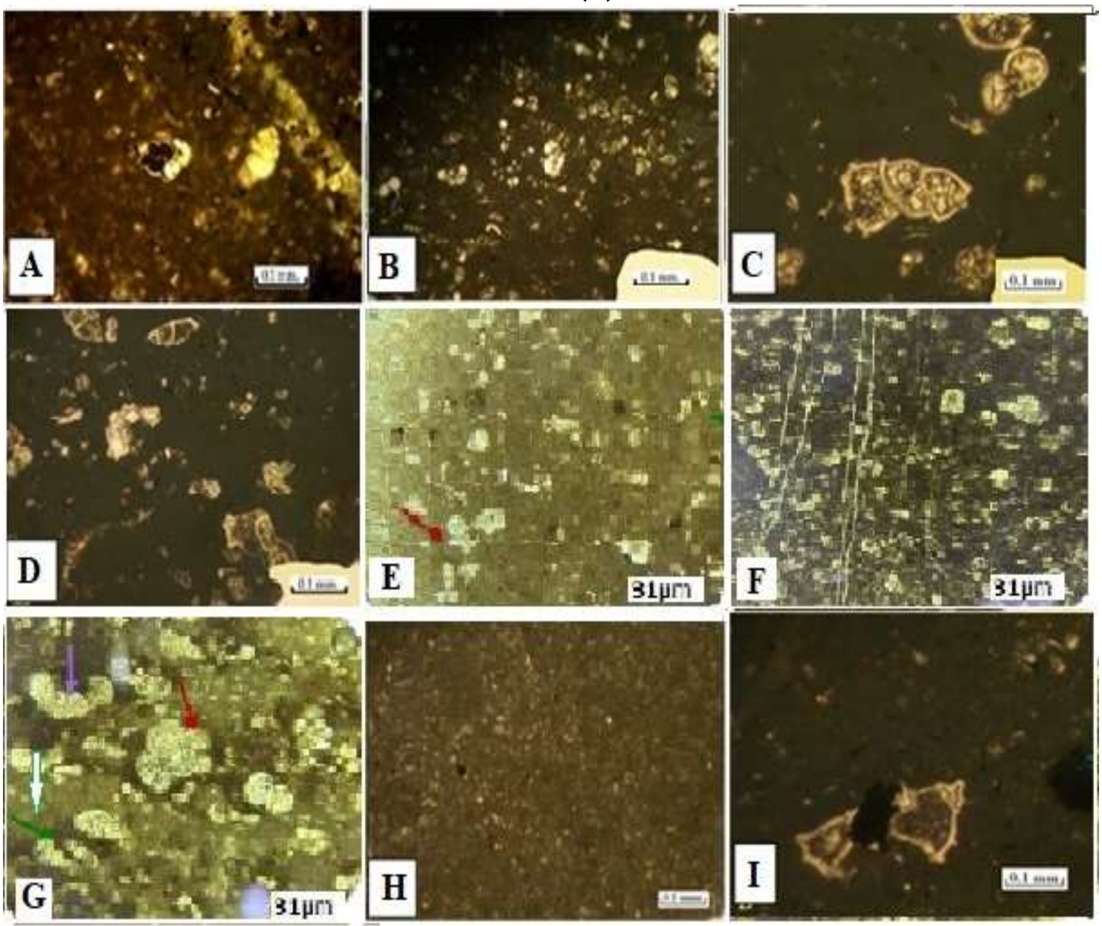
(E) Foraminiferal Wackestone bearing Calcisphers Microfacies (Sh2) with moldic pyrite (white arrow), Shiranish Formation, Well Tk.2, Depth1080 m.

(F) Foraminiferal Wackestone-Packstone enriched with Calcispheres Microfacies (Sh3) with pyrite (black arrow) and chert (white arrow), Shiranish Formation, Well Tk.2, Depth 1166 m.

(G) Mudstone Microfacies (Sh4) with *Globotrucana arca*, Shiranish Formation, Well Tk.1, Depth 1200 m.

(H and I) Mudstone Microfacies (Sh4) with *Contusatruncana roseta* (in H) and *Heterohelix* (in I), Shiranish Formation, Well Tk.1, Depth 1022 m and Well Tk.2, Depth 1012 m.

Plate (2)



Explanation of Plate (2)

(A and B) Bioclasts Foraminiferal Wackestone Microfacies (Sh1), Shiranish Formation, Wells Tk.1 and TK.2, Depths 1250 m and 1260 respectively.

(C, D and E) Foraminiferal Wackestone bearing Calcisphers Microfacies (Sh2) with *Hedbrgella* (red arrow in E) and cementation diagenesis, Shiranish Formation, Well Tk.2, Depths 1080, 1130 and 1190 m respectively.

(F and G) Foraminiferal Wackestone-Packstone enriched with Calcispheres Microfacies (Sh3) with *Hedbrgella* (red arrow), *Heterohelix* (green arrow), *Globotrucana* (violet arrow) and glauconite (white arrow) in G, Shiranish Formation, Well Tk.2, Depths 1174 m.

(H and I) Mudstone Microfacies (Sh4) with *Globotruncana* and moldic pyritization (in I), Shiranish Formation, Well Tk.1, Depth 1100 m and Well Tk.2, Depth 1022 m.