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Biostratigraphy and Paleoenvironment of Garagu Formation in Kirkuk well-116, North Iraq

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ABSTRACT
The Garagu Formation Tongue has been investigated from biostratigraphic view in one subsurface section in Kirkuk field, well No-116, North Iraq. Many genera and species of benthic foraminifera and calcareous algae have been identified. One assemblage zone has been determined, *Pseudocyclamminia lituus- Choffatella decipiens* assemblage zone (Valanginian - Barremian age). Suggest that age of Garagu Formation (Valanginian-Barremian). Furthermore, the primary and secondary microfacies of the Garagu Formation have been identified that represented by: *Pseudocyclammina lituus* bearing wackestone submicrofacies, Peloidal lime packstone submicrofacies, oolitic grainstone microfacies, *Choffatella decipiens* bearing wackestone submicrofacies, oolitic and peloidal packestone submicrofacies, Algal bearing wackestone submicrofacies, and Lime mudstone microfacies. It was established that the formation's paleoenvironment was an open platform (shelf lagoon with restricted platform and platform margin).

Keywords: Garagu Formation, *Pseudocyclomminia lituus*, *Choffatella decipiens*, Valanginian, Hauterivian, Barremian.

1. Introduction
Garagu Formation is one of the vital formations deposited during Lower Cretaceous period with the main regressive depositional subcycle (Berriasian-Aptian). This subcycle is represented from shore to deep basin by the Garagu, Yamama, lower Qamchuqu, lower Sarmod, Ratawi, Zubair, and lower Balambo formations (Buday, 1980). Wetzel 1950, in Bellen *et al*. (1959) is credited as being the first to define the type site of the Garagu Formation from the Chia Cara anticline in the high folded zone of Gali Garagu Amadia region in northern Iraq with a total thickness of (92) m. In the type locality, the Garagu Formation is made up of a series of limestone beds that include oolitic limestone, siltstone, and sandy limestone. Some of the beds are rich in iron oxides, while others are similar to those of other nearby formations. Bivalves and other fossils are also common in some horizons (Mirza *et al*., 2016).
Garagu Formation was studied in different wells North of Iraq such as Kirkuk -109 and Awasel -5, Milh Therthar -1, Makhol -1, Najmah -29, in Kurdistan's exposed regions the Formation is known in Amadia, Bani, Chia Gara, and Ru Kuchuk (Bellen *et al*.,1959). The aim of the study is to identify the biostratigraphic and biozone based on foraminifera, algae, and other associated fossils to determined formation's age and microfacies analysis and defining the paleoenvironment in well Kirkuk 116.

2. Geological setting
The Garagu Formation is extensively dispersed in Iraq and is a diverse sequence of sediments with shallow-water origins in its type site. The coarse ferruginous clastics, ferruginous oolites, and coral banks that are typical of the formation indicate the deposits of the concluding period of extensive retreat. The Sarmord Structure contains the Garagu formation, which appears like a tongue (Bellen *et al*.,1959).

3. previous studies
The Garagu Formation, which is located in well Kirkuk 109, North Iraq, was examined by Bellen *et al*. in 1959. They discovered that the formation is made up of clastic rocks, coral-algal banks, and has a tongue within the Sarmord Formation and includes the following fossils in the type area: *Pseudocyclammina lituus* (Yokoyama),*Terebratula cf waldensis* (de Lorial), *Calamophyllia* sp. *Stylina subtubulata* Gregory, *Cuneolina* sp. *Cyclamminids* sp, *Trichites aff suprajurensis* (Krumbeck), *Neocomites* sp., Hexacorella sp., *Ayosomilia neocomiensis* (Gregor), *Lochamosmilia* sp., *Stylina* sp., *Thracia neocomiensis* (Orbigny) , *T. russellensis* (de Loroil) , *Nautiliculina oolithica* (Mohler) Gastropoda, *Lamellibranch* sp. etc. In the well Awasel-5 in the Lower part of Garagu Formation, Hart (1960) detected the following fossils: *pseudocyclammina* sp., *Nautiloculina oolithica*, *Trocholina* sp., In the well Samara-1, the same

fossils were also identified in addition to *Choffatella decipiens*, *Cuneolina* sp., *Orbitolina* sp., *Hensonella cylindrica*. *Terbratula waldensis*, *Pseudocyclammina lituus*, *Trocholina cf elongate*, *Groebericeras* sp., *Primitire cuneolina*, and *Subthurmannia occitanica* are among the fossils that Hart (1962) identified in Garagu Formation in northern Iraq. Elliott (1963) determined the *Coptocampylodon lineolatus* fossil found in borehole Falluja-1. These algal species are mentioned by Elliott (1968) in Kirkuk -116: *Acroporella assurbanipali Clypnia parvula*, *Acicularia Antigua*, *Salpingoporella dinarica*, and in Makhol -1. *Triploporella* sp. and in Makhol -2. *Cylindropolla barnesi* In well Khabaz-1, AL-Abawi (1984) displayed the following fossils from the upper part of the Garagu Formation: *Cuneolina aff. pavonia* Orbigny, *Nautiloculina oolithica* Mohler, *Hensonella cylindrica* Ellsott. In subsurface sections from various oil fields in northern Iraq, Amin (1989) separated the biostratigraphy of the Garagu Formation into four zones (*pseudocyclammina lituus*, *Orbitolina lenticularis*, *Choffatella decipiens*, and *Hensonella cylindrical* zones) and proposed that the formation is Valanginian-Aptian in age. Chafor and Mohidldeen (2016) investigated the variety and paleoenvironmental conditions of the Garagu Formation's (Early Cretaceous) fossil distribution and facies analyses. Foraminifera, ostracodes, algae, and other fossils from the Kurdistan Region in northern Iraq are studied, as well as *Globigerinalioides* sp., *Palorbitalina lenticulari* (Blumenbach), *Hedberegela* sp., *Rotalipora* sp., and *Hedbergella washitensis*, etc. and suggested that age of the formation is early Hautervian- Barremian. Al Khashab *et al.* (2011) found that the Garagu Formation was formed in a shallow marine sublittoral environment with normal salinity and warm water by analyzing the Ostracoda assemblages from the Garagu and Ratwi formations (Lower Cretaceous) from wells in East Baghdad well -1 and Makhul -2. The formation can be divided into three lithologic units from the base to the top: the lower oolitic, middle organic, detrital limestone, and upper oolitic. Balaky et al. (2016) studied facies analysis and depositional environment of Garagu Formation in Gara Mountain, Gali Garagu, Sarsang District, Iraqi Kurdistan Region and suggest the facies association represent shelf margin (Shoal) and shelf lagoon association. Buday, 1980 refused the name of Zangura Formation and used Garagu for the age (Late Bereassian-Hauteravian) that composed of oolitic and pseudo-oolitic and organic detrital limestone with pellitic. Chatton and Hart ,1960 merge Garagu Formation with the Yamama Formation in one unit.

The age and stratigraphic position of this formation determined as Hauterivian- Barremian (Buday, 1980; Aljumaily and Abdulla, 2003; Mohidldeen, 2016). Balaky et al., (2016) suggest the age of formation is Valanginisan - Hauterivian. The gradational contact determined in upper contact with the Sarmord Formation (Valanginian- Aptian) and the lower contact is with the Chia Gara Formation (Tithonian-Berriasian) is also gradational and conformable (Bellen *et al*,. 1959; Mirza *et al*,. 2016).

4. Methodology

One stratigraphic rock succession, in Kirkuk well-116has been chosen for analysis. The studied area is a part of High folded Zone of Iraq (Jassim and Goff, 2006). For this study, core and cutting samples were taken at spacing ranging from1-2 meters intervals along a ~154meter thickness; 135 thin sections prepared by North oil Company laboratories. The thin-section analysis is utilized for foraminiferal identifications; this section is characterized by containing rich and diverse benthonic foraminifera assemblages and algae, the studied of skeletal, non-skeletal grain and texture between components are studied to estimate microfacies and deposition environment. Benthic foraminiferal identifications enable the determination the age of formation that able to create biostratigraphy range chart of Garagu Formation Fig (2).

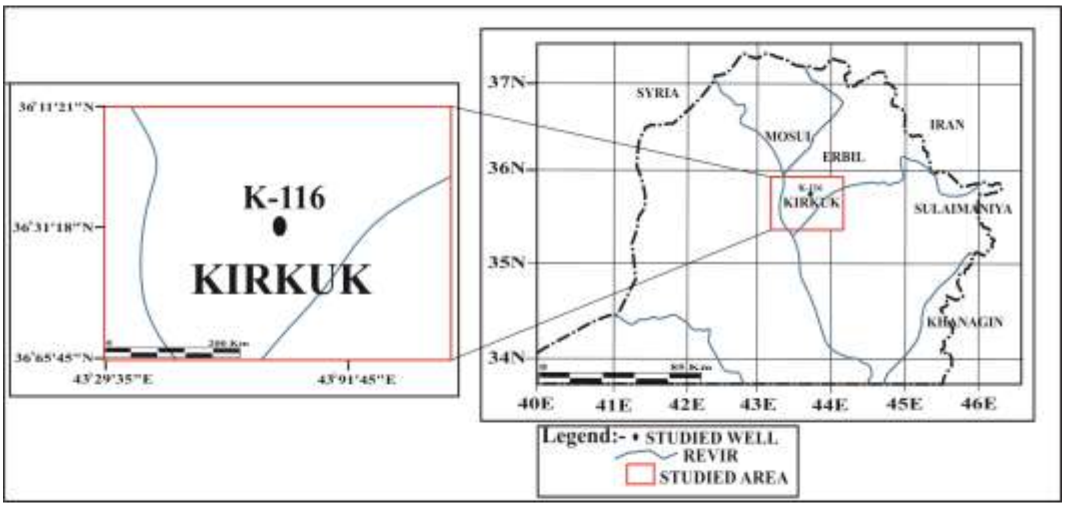

Fig. 1:- Location map of studied well

5. Biostratigraphy and Biozone of Garagu Formation in Kirkuk well-116

Biostratigraphy utilizes fossils to focus on correlating and assigning relative ages of rock strata by using the fossil assemblages contained within them. Descriptive biostratigraphy is used in the determination the zones for regional or local stratigraphy correlation (Megowran, 2005). The importance of foraminifera especially those from Cretaceous, as index fossils for biostratigraphy zonation and regional correlation in Middle East is well Known.

Garagu Formation is located between the depth (2481 - 2635) m, the thickness of formation has reached (154) m, and lithology consist of sandy pellitic limestone, pellitic limestone, oolitic limestone, sandy oolitic and limestone. (Fig 2)

Thin sections were examined in order to view the fossils that were found in the deposit. The degree of fossil preservation was good; however some of them had distortions from digenetic processes. These digenetic processes include pyritization (Pl.2. Fig 3, 4), neomoephism (Pl.2. Fig 3, 5), dissolution (Pl.2. Fig 5), cementation (Pl.2. Fig 8, 9), pressure solution and stylolite (Pl.2. Fig 4)

Foraminifera:

Pseudocyclammina lituus Yokoyama (Pl.1. Fig7), *Pseudocyclammina* sp., *Trcholina elongata* Leupold, *Trocholina* sp., *Textularia* sp. (Pl.1. Fig 8), *Miliolids* sp. (Pl.1. Fig 9), *Nautiloculina oolithica* Mohler, *Choffatella decipiens* Schlumberger (Pl.1.Fig. 3B,5,6), *Choffatella* sp., *Montsciella arbicus* Henson(Pl.1.Fig.3A), *Cuneolina cff pavonia* Orbigny, *Gyrodinoides* sp., *Cyclummina* sp., *Palorbitolina lenticlaris* Blumenbach (Pl.1.Fig1.2.4A), *Orbitolina* sp. (Pl.1.Fig4B), *Glomospir* sp., *Campanellula capuensis* Decastro (Pl.1.Fig.8A).

Algae:

Salpingoporella dinarica RODOCIC (PlpL.1.Fig.10), *Salpingoporella* sp., *Permocalculus* sp., *Permocalculus ampullaceous* ELLOTT (Pl.2.Fig.1), *Acicularia* sp., *Acicularia comanchense* JOHNSON (Pl.2.Fig.2), *Cylindroporella* sp., *Cylindroporella sugdeni* Ellott, *Hensonella cylindrica* Ellott, *Hensonella* sp.

Other fossils:

Gastropoda shell (Pl.2.Fig.9), Ostracoda, Echinod spine, Pelecypoda shell, sponge spicules, Coral patchs, Brachiopoda shell, calcispheres, fossils lndet.

Through the biostratingraphic study of Garagu Formation depending on the presence of benthic foraminifera and algae one biozone is distinguished as shown below (Fig.2)

1-*Pseudocyclammina lituus - Choffatella decipiens* assemblage zone

Definition: defined this zone is the biostratigraphic interval from the first appearance of *Pseudocyclammina lituus* and in the upper limit of this interval it begins to appearance of *Choffatella decipiens*

Age:the age of this assemblage zone is Valinginian-Beriamian

Thickness: of the zone is (154) m

Remarks and correlation: The *Pseudocyclammina lituus* biozone was described by several authors, including Hart (1962) (Late Berriasian-Valinginian), Gollesstaneh (1965) (Berriasian- Hautervian), Sampo (1969) (Valinginian- Hautervian), Jaffrezo (1973) (Valinginian), Cherchi (1979) (Barremian-Early Aptian), Velic (1988) (Late Berriasian -Valanginian), Al- Shahwan (1993) (Berriasian-Hautervian), Shakib (1994) (Hautervian), Pirbalouti and Abyat (2019) (Valanginian-Hautervian), Al- Hassani and Al-Dulaimi (2021) (Valanginian), Khazzal and Shakir (2022) (Valanginian). The age of the zone in this investigation is (Valanginian-Early Hautervian).(Fig.3)

Remarks and correlation: *Choffatella decipiens* biozone described by several authors have characterized this biozone, including Brun (1970) who describes the Early Aptian- Barremian, Sartorio And Venturini (1988) who describes the Barremian, Salman And Abdl- Karim (1992) who describes the Barremian-Aptian, Gordon Gorden (1997) who describes the Hautervian-Aptian, Saleh (2007) who describes the Early Aptian, and Al-Dujili (2014) who describes the Hautervian (Hautervian-Barremian).According to this study, the age of this zone is (Late Hautervian- Barremian) (Fig.3). Based on the age of the biozones and the notable fossils, the Garagu Formation in the Kirkuk well-116 is believed to be Valanginian- Barremian.

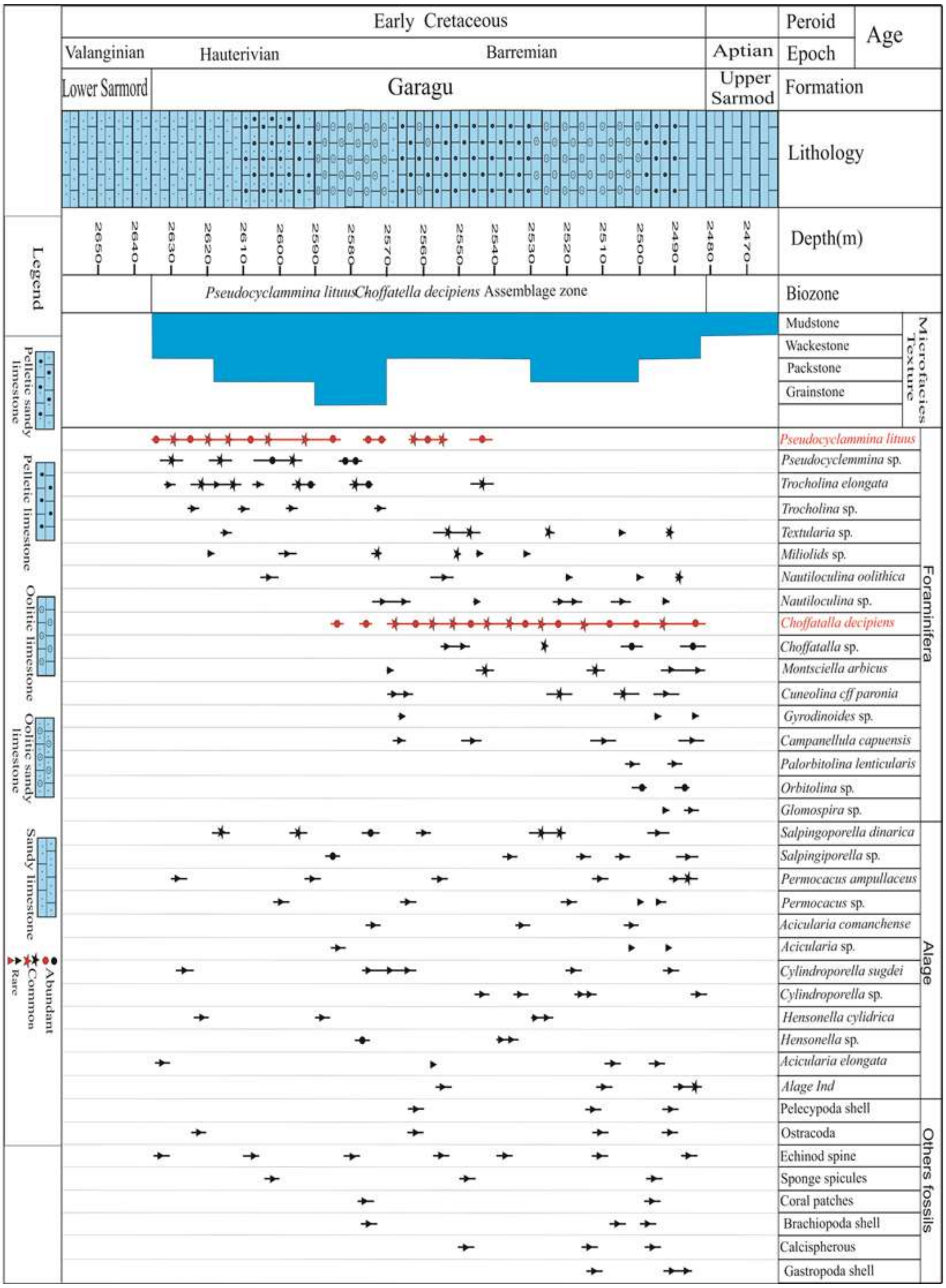

Fig. 2: Biostratigraphic range and microfacies unit chart of Garagu Formation in Kirkuk well-116.

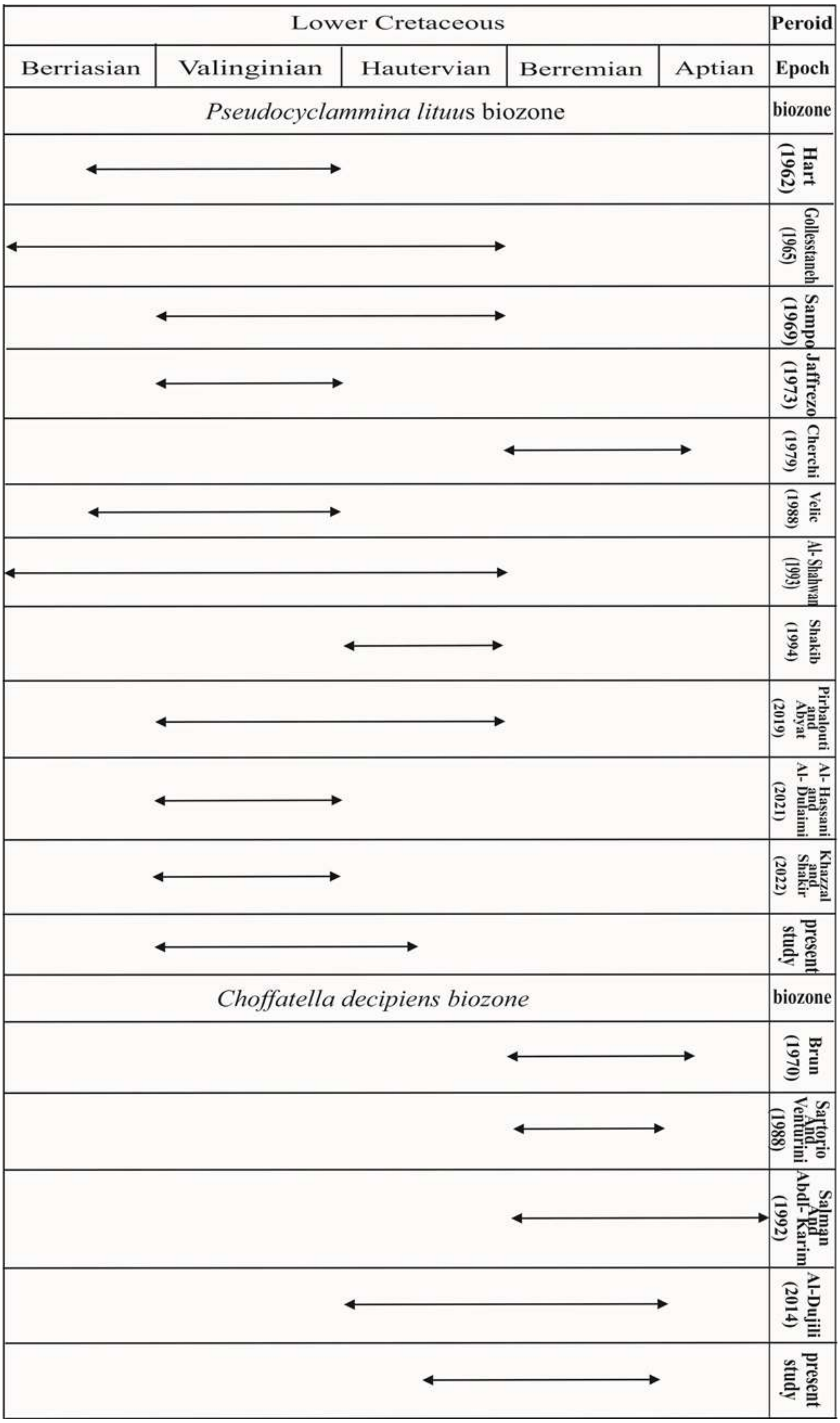

Fig. 3:- Correlation chart showing the biostratigraphic zones of Lower Cretaceous in the studied section with the zonation commonly used in Iraq and different country.

6. Microfacies and paleoenvironment in Garagu Formation

Both descriptive (texture, grain type, and grain size) and interpretive (depositional environment, diagenetic processes) aspects are explored in the study of microfacies, and both elements can be researched through the petrographic inspection of thin sections (Flugel, 2010). The facies association were compared with the models of standard microfacies and depositional environments belt of carbonate presented by Flugel (2004), and the microfacies classification in this work was based on Dunham's classification (1962). Garagu Formation is located between the depth (2481 - 2635) m, the thickness of formation has reached (154) m, and lithology consist of sandy pellitic limestone, pellitic limestone, oolitic limestone, sandy oolitic and limestone. (Fig 2)

The degree of fossil preservation was good; however some of them had distortions from digenetic processes. These digenetic processes include pyritization (Pl.2. Fig 3, 4), neomoephism (Pl.2. Fig 3, 5), dissolution (Pl.2. Fig 5), cementation (Pl.2. Fig 8, 9), pressure solution and stylolite (Pl.2. Fig 4)

In order to identify and categorize microfacies, it is crucial to consider the petrographic components of the Garagu Formation. Skeletal grain, non-skeletal grain, and matrix are the most significant of these components.

1- Matrix: groundmass is an interstitial substance made up of small grains that is found between bigger grains or adjacent intergranular holes (Flugel 2010). Micrite and microspar make up the matrix of the Garagu Formation (Pl.2. Fig. 3). (Pl.2. Fig.5).

2- Skeletal Grains: The skeletal grains are the fragmented or whole skeletons of organisms, and they range in size from 0.05 millimeters to several centimeters (Flugal, 2004). Foraminifera, calcareous algae, and other bioclasts comprise the skeletal grains that make up the majority of the Garagu Foraminifera, calcareous algae, and other bioclasts are among the skeletal grains that make up the majority of the Garagu Formation.

3- Non-skeletal grains: Ooids, peloids, and intraclasts are the formation's non-skeletal grains.

Ooids: (Oolith) are spherical to ellipsoidal grains with nuclei that are coated with one or more precipitated concentric coatings and range in diameter from 0.25 to 200 mm (Scholle and Ulmer Scholle, 2003).

peloids: are micrite-based ovoid, spherical, or rod-shaped objects that lack interior structure (Boggs, 2009).

Intraclasts are carbonate sediment that has been eroded and redeposited, however they are more frequently created in environments with sporadic high energy conditions (Scholle and Ulmer scholle, 2003).

In this section it was possible to distinguish four main facies which are (mudstone, wackestone, packestone, grainstone) and it was possible to divide them into submicrofacies:

1-Lime mudstone microfacies: Abundant *Palorbitolina lenticalaris*, *Orbitolina* sp., calcispheres, *Hensonella* sp. The microfacies were affected by several diagenetic processes including pyritization, stylolitization, and recrystallization. This microfacies are similar to the standard microfacies SMF23 within the FZ.8 (Pl.2 Fig. 3, 4, 5).

2-Wackestone microfacies: This microfacies consist of three submicrofacies represented by *Pseudocyclammina lituus* wackestone submicrofacies, *Choffatella decipiens* wackestone submicrofacies, and algal wackestone submicrofacies

A-*Pseudocyclammina lituus* wackestone submicrofacies:- Abundant *pseudocyclammina lituus*, *pseudocyclammina* sp., *Trocholina elongate*, less common *Textularia* sp., rare occurrence of Miliolids sp., Gastropoda shell, Pelecypoda shell… etc. This submicrofacies is similar to the standard microfacies SMF 18 within FZ 7 (Wilson, 1975; Flugal, 2004) (Pl.1, Fig 7).

B-*Choffatella decipiens* wackestone submicrofacies:- Aboundant *Choffatella decipiens*, *Choffatella* sp., *Montsciella arbicus*, *Cyclammina* sp., *Salpingoporella dinarica*, *Acicularia comanchense*, calcispheres, Gastropoda shell…. etc. This submicrofacies are similar the standard microfacies SMF18 within the FZ.7 (Wilson, 1975; Flugal, 2004) Pl.1 Fig. 5, 6).

C-Algal wackestone submicrofacies:- Abundant algae, *Salpingoporella dinarica*,*Permucalculus ampullaceus*, *Acicularia* sp., *Acicularia comanchense*, *Cylindroporella* sp., *Palorbitolina lenticularis*, *Orbitolina* sp., *Glomospira* sp. This submicrofacies are similar to the standard microfacies SMF18 within the FZ.7 (Wilson, 1975; Flugal, 2004) (Pl.1 Fig 10.Pl.2 Fig.1, 2).

3-Packstone microfacies:- This microfacies consist of two submicrofacies represented by peloidal lime packstone submicrofacies and Oolitic and peloidal packestone submicrofacies

A-Peloidal lime packstone submicrofacies:- Abundant peloids and *pseudocyclammina lituus*, *Textularia* sp., rare of Miliolids sp., Gastropoda shells, Ehinoderm spine, calcisphere… etc. The submicrofacies is similar to the standard microfacies SMF 21 within FZ 9,8 (Wilson, 1975; Flugal, 2004) (Pl.2, Fig 6.7 Pl.1, Fig9).

B-Oolitic peloidal packestone submicrofacies:- Abundant intraclasts, oolits and peloids, *Choffatella* sp., *Cneolina cff pavonia*, *Orbitolina* sp., rare of *Nautilolocuina* sp., *Permocalculus* sp., sponge spicules…. etc. This submicrofacies are similar to the standard microfacies SMF 15within the FZ.6 (Wilson, 1975; Flugal, 2004) (Pl2.Fig. 8, 9).

4-Grainstone microfacies:- This microfacies consist of one submicrofacies represented by Oolilic grainstone submicrofacies

A-Oolilic grainstone submicrofacies:- Abundant ooids, *Pseudocyclammina* sp., common of *Textularia* sp., *Salpingoporella dinarica*, rare of *Nautiloculina* sp., *Nautiloculina oolithica*, Miliolids sp., *Permocalculus* sp., Gastrapoda shell, Pelecypoda shell… etc. This microfacies are similar to the standard microfacies SMF 15 within the FZ 6 (Wilson, 1975; Flugal, 2004) (Pl. 2, Fig 10).

7. Paleoenvironment of Garagu Formation:

By reviewing the microfacies in the Garagu Formation in Kirkuk well-116 and comparing them with the standard microfacies of carbonate rocks depositional environment and their location within the facies proposed by (Wilson, 1975; Flugal, 2004) , It was found that the rocks of the Garagu Formation were deposited in the facies FZ 8, 7, and 6 which include standard microfacies SMF 23, 21, 18, and 15. Zones sedimentation occurred in the strip located between open marine (shelf lagoon) and restricted platform and platform margin (sand shoals). Orbitolina inhabit shallow coastal waters in tropical to subtropical climates, when the temperature would have been between 15 and 25 C. (Douglass, 1960). *Salpingoporella dinarica*. described from restricted environment of ramp system (Flugel, 2004). The formation was deposited in shallow tropical to semi tropical water of normal to high salinity.

plate 1

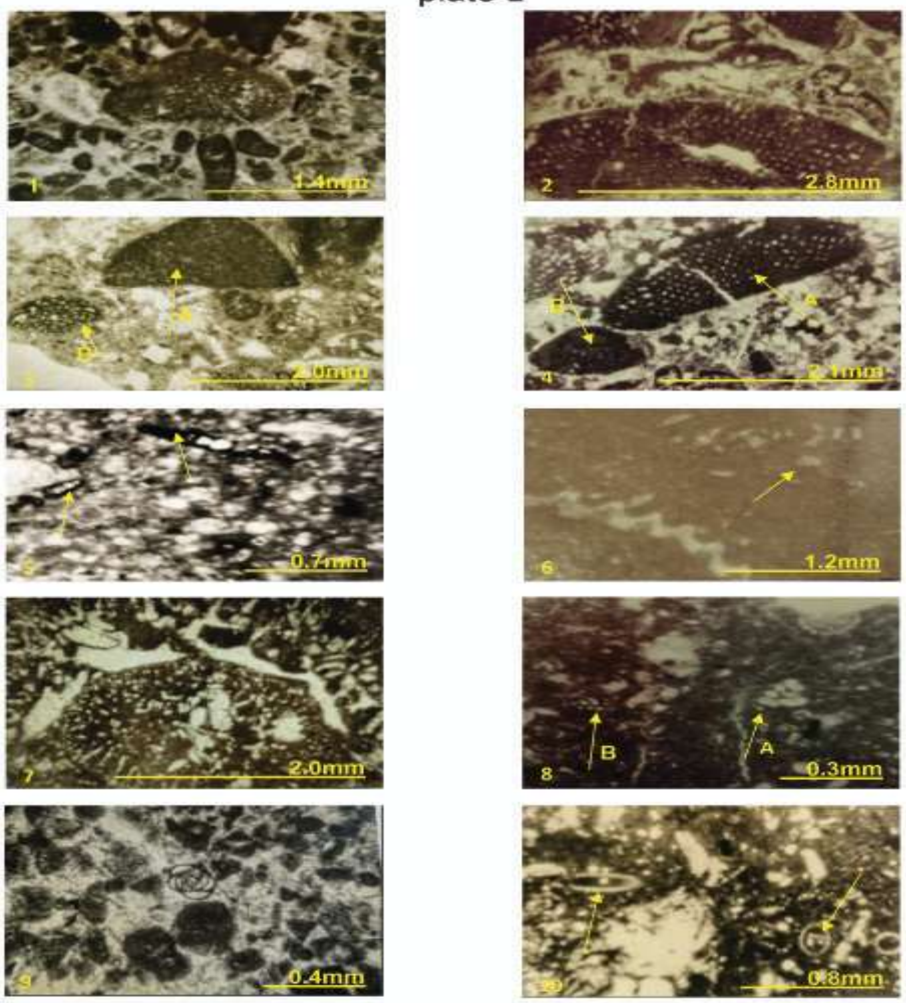

Plate 1:- All figure from Garagu Formation (Valanginian- Barremian) in Kirkuk well-116:

Fig .(1): *Palorbitalina lenticulari* Blumenbach, depth (2490) m; Fig .(2): *Palorbitalina lenticulari* Blumenbach, depth (2492) m; Fig .(3):(A) *Montsciella arbicus* Henson , (B) *Choffatella decipiens* Schlumberger ;depth (2510) m; Fig .(4): *Palorbitalina lenticulari* Blumenbach, depth (2502) m; Fig .(5): *Choffatella decipiens* Schlumberger wackestone submicrofacies, depth (2495) m; Fig .(6): *Choffatella decipiens* Schlumberger wackestone submicrofacies, depth (2550) m; Fig .(7): *Pseudocyclammin lituus* Yokoyama wackestone submicrofacies, depth (2625) m; Fig .(8): (A) *Campanellula capuensis* Decastro; (B) *Textularia* sp., depth (2510); Fig .(9): Miliolids and peloidal lim-packestone submicrofacies, depth (2600) m Fig .(10): *Salpingoporella dinarica* Rodocic, depth (2560).

plate 2

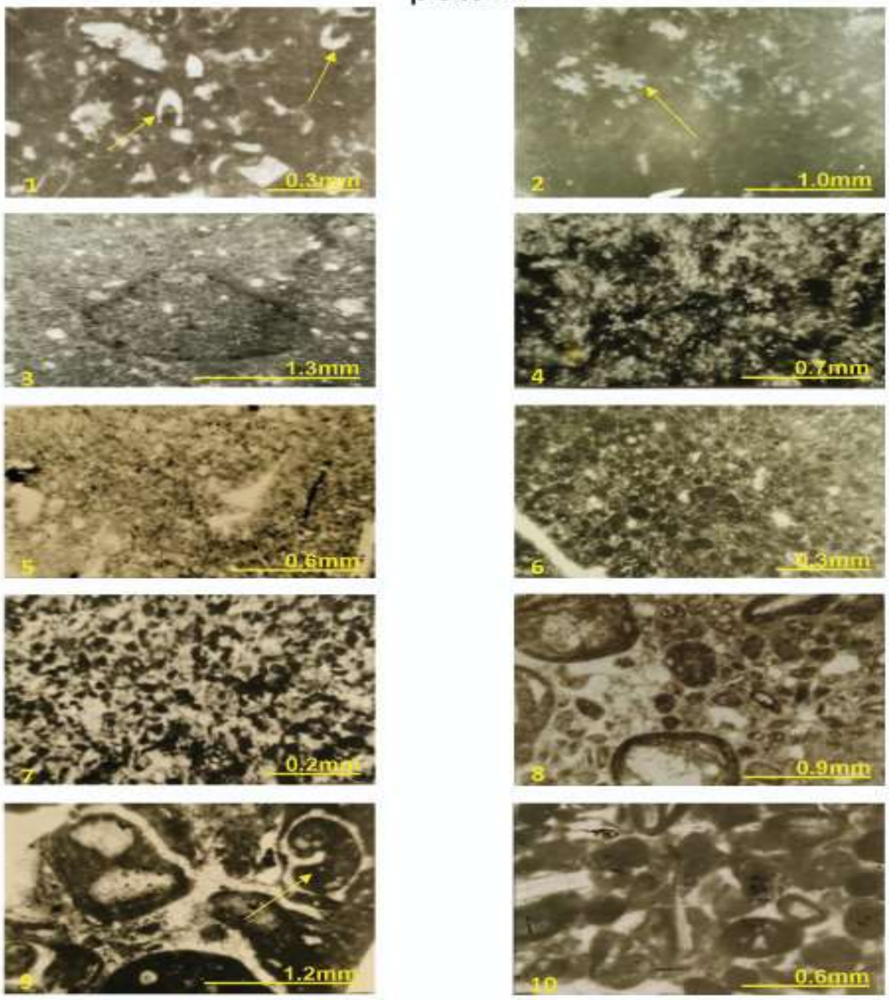

Plate 2:- ll figures from Garagu Formation (Valanginian- Barremian) in Kirkuk well-116
Fig .(1): *Permocalculus ampullaceous* Ellott wackestone submicrofacies, depth (2490) m; Fig .(2): *Acicularia comanchense* Johnson wackestone submicrofacies, depth (2532) m; Fig .(3): Lime mudstone microfacies, depth (2481) m; Fig .(4): Lime mudstone microfacies (Pyritic and Stylolitic), depth (2482) m; Fig .(5): Lime mudstone microfacies (Microspar), depth (2481) m; Fig .(6): Peloidal lime packstone submicrofacies, depth (2495) m; Fig .(7): Peloidal packstone submicrofacies, depth (2592) m; Fig .(8): Oolitic and peloidal packstone submicrofacies, depth (2500) m; Fig .(9): Gastropoda shell: Oolitic and peloidal packstone submicrofacies, depth (2590) m; Fig .(10): Oolitic grainstone microfacies, depth (2575) m.

8. Conclusion

Garagu Formation occurs as a toungu within the lower and upper Sarmod Formation. pelletic limestone, Oolitic limestone, sandy limestone, marly limestone, and sandy pelletic limestone constitute the Garagu Formation. The formation's thickness reached a maximum of (154m). Numerous genera and species of calcareous algae and benthic foraminifera are included in the biostratigraphy study of the Garagu Formation. One assemblage biozone is distinguished in the formation based on benthic foraminifera, and they are as follows:

Pseudocyclammina lituus - Choffatella decipiens assemblage zone

The Lower Certaceous (Valanginian- Barremian) age of the formation was determined, and the primary and secondary microfacies in the Garagu Formation were distinguished, the main microfacies represented by (mudstone, wackestone, packestone, grainstone) that divided into submirofacie exemplified by *Pseudocyclammina lituus* wackestone submicrofacies, *Choffatella decipiens* wackestone submicrofacies, Algal wackestone submicrofacies, Peloidal lime packstone submicrofacies, Oolitic peloidal packestone submicrofacies, and Oolilic grainstone submicrofacies. The paleoenvironment of this formation was determined to be an open platform (shelf lagoon and restricted platform and platform margin).

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الطباقية الحياتية والبيئة الترسيبية لتكوين كَركَو في بئر كركوك -116شمال العراق

الملخص

تمت دراسة لسان تكوين الكركو من الناحية الطباقية الحياتية في مقطع حقل كركوك في بئر 116 شمال العراق و قد امكن تمييز العديد من الاجناس و الانواع من الفورامنيفرا القاعية و الطحالب الكلسية فضلا عن تحديد نطاق تجمعي حياتي واحد هو:

Pseudocyclamminia lituus –*Choffatella decipiens* assemblage zone

وتم اقتراح عمر التكوين (الفلانجين– بارميين) كما تم تحديد السحنات الدقيقة الرئيسية و الثانوية في تكوين الكركووالتي تتمثل ب:– سحنه حجر الجير الواكي الثانوية الحامله لمتحجرات *Pseudocyclamminia lituus* وسحنه الحجر الجيري المرصوص الثانويه الحامله لحبيبات الدمالق و سحنه الحجر الجيري الحبيبي الرئيسية الحامله للسرئيات و سحنه الحجر الجيري الواكي الثانويه الحامله لمتحجرات*Choffatella decipiens* و سحنه الحجر الجيري المرصوص الثانويه الحمله لحبيبات الدمالق و السرئيات وسحنه الحجر الجيري الواكي الثانويه الحاملة للطحالب وسحنه الحجر الجيري الطيني الرئيسية و البيئة الترسيبية القديمة له و التي تمثلت بالمنصة المفتوحة و المنصة المنعزلة و حاجز الرصيف.