*Iraqi Bulletin of Geology and Mining* *Vol.15, No.1, 2019* *p 31 – 42*

# MICROFACIES AND DEPOSITIONAL ENVIRONMENT OF CHIA GARA FORMATION (UPPER JURASSIC – LOWER CRETACEOUS) IN KURDISTAN REGION, NORTHERN IRAQ

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Received: 23/ 07/ 2018, Accepted: 06/ 12/ 2018
Key words: Chia Gara; Microfacies; Depositional environment; Kurdistan Region; Northern Iraq

## ABSTRACT

The depositional environment of Chia Gara Formation (Upper Jurassic – Lower Cretaceous) in Northern Iraq is studied. The formation is exposed in the High Folded Zone, and Imbricated Zone of Iraq. The selected sections for this study are Banik (outcrop), Barsarin, (outcrop) and well Aj-12; located in the High Folded, Imbricated, and Foothill Zones respectively. The Chia Gara Formation is lithologically composed of black shale, thinly bedded brown argillaceous limestone, thin to medium limestone, and marly limestone in uppermost part. Skeletal grains consist of macro and micro pelagic fauna. Pelagic fossils include Ammonites, radiolarian (Spumellarian Group), ostracods, planktonic forams (Globigerina), pelecypods, and others. Non-skeletal grains are not observed in the current study. The groundmass of the Chia Gara Formation is dominated by micrite which is often replaced by coarser microspar. Limestones of Chia Gara Formation are divided into three principal microfacies: Mudstone, Wackestone, and Packstone. Each of these is further subdivided into submicrofacies. Using lithology, paleontology, and microfacies criteria, the most likely depositional environment of the Chia Gara Formation is concluded as toe of slope to deep open marine environment.

## السحنات المجهرية والبيئة الترسيبية لتكوين جيا كارا (الجوراسي الاعلى – الطباشيري الاسفل) في اقليم كوردستان- شمال العراق

**كوفند حسين شيرواني و أياد نوري فقي ادلبي**

**المستخلص**

تمت دراسة السحنات المجهرية والبيئة الترسيبية لتكوين جياكارا (الجوراسي الأعلى – الطباشيري الأسفل) في عدة مقاطع في شمال العراق. ينكشف هذا التكوين في نطاق الطيات العالية ونطاق التداخل في شمال العراق. المقاطع المدروسة شملت: مقطع بانك، مقطع بارسرين، وبئر عجيل-12، الواقعة في نطاق الطيات العالية، نطاق التداخل، ونطاق اقدام الجبال على التوالي. تتكون صخارية تكوين جياكارا من سجيل أسود رقيق التطبق مع حجر جيري طيني، حجر جيري رقيق الى متوسط التطبق، اضافة الى حجر جيري مارلي في الأجزاء العليا. شملت الحبيبات الهيكلية أنواعا بحرية مجهرية وكبيرة منها الأمونايت، الراديولاريا (مجموعة السبوميلاريا)، الأوستراكودا، الفورامنفرا الطافية (كلوبجرينا)، فأسية القدم وغيرها. وقد لوحظ غياب الحبيبات غير الهيكلية في التكوين. أرضية التكوين يسودها المكرايت المتحول غالبا الى ميكروسبار. قسمت السحنات الدقيقة في التكوين الى ثلاث مجاميع رئيسية (الحجر الطيني والحجر الواكي والحجر المرزوم) مع تقسيمات ثانوية لكل منها. وبينت الدلائل من دراسة البتروغرافية والمتحجرات والسحنات الدقيقة أن تكوين جياكارا ترسب في بيئة بحرية تتدرج من بيئة أطراف الأنحدار الى بيئة بحرية عميقة ومفتوحة.

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**INTRODUCTION**

The Chia Gara Formation (Upper Jurassic – Lower Cretaceous) was first defined by Wetzel (1950 in Bellen *et al*., 1959) at the Chia Gara anticline, located to the south of Amadia town in the High Folded Zone. The thickness of the formation at its type locality is 232 m, comprised of a succession of thin bedded limestone and shales, containing rich ammonite faunas, and grading upwards to yellowish marly limestone and shale with a zone of bullion beds (Ball and Pillow structure), 21 m thick at base (Bellen *et al.,* 1959). During the Late Mesozoic and Early Cenozoic, sedimentation in the area of the present Mesopotamian Basin and Zagros Fold Belt was controlled by local tectonics, eustatic sea-level changes, and climate variations. From Jurassic through Late Cretaceous, sea-level fluctuations, in conjunction with slow subsidence, led to the formation of large, but shallow intrashelf basins on the passive margins of the Neo-Tethys Ocean and the Arabian Plate (Murris, 1980; Alsharhan and Nairn, 1997). The Chia Gara Formation was deposited in Late Jurassic – Early Cretaceous (Fig.1) as global separation and expansion time within the deep outer shelf of the Arabian Plate Margins (Numan, 1997). In the Kurdistan territory, the Tithonian – Berriasian Chia Gara Formation appears to be continuous in some sections, and arbitrarily limited at the Valanginian – Berriasian stage limit, as determined from fauna (Bellen *et al*., 1959).

Many criteria can be used to interpret depositional environment of the sedimentary rocks. The constituents commonly described in carbonate and clastic sediments, such skeletal and non-skeletal grains, are some common criteria in this respect. Likewise, microfacies study has a key role in the assessment of depositional environment. In sedimentology, facies are determined based on depositional rock properties such as texture, constituent composition and sedimentary structures (Ahr, 2008). The classification of Dunham (1962) is an easy and widely applied classification for microfacies. In the present study, this classification is employed to establish the depositional environment of Chia Gara sediments.

Specific studies on the petrography and depositional environment of Chia Gara Formation are scarce. Al-Qayim and Saadallah (1992) studied the stratigraphic sequence of Chia Gara Formation in Bekhme Gorge and Rowanduz area. They concluded that the formation reflects deep marine characters. Naqishbandi (1999) studied the palynofacies of the Upper Jurassic units and believed that Chia Gara Formation, in well Beiji (Bj-1), is of deep marine environment but not as deep as other sections of the Chia Gara. Sharland *et al.* (2001), in a modern investigation dealing with sequence stratigraphy, considered the Chia Gara Formation as a part of the tectonostratigraphic megasequence AP8 (149 – 49 Ma), which was deposited during both TST and HST parts of a sequence. Mohyaldin (2008) believed that the deep outer shelf to carbonate slope environments is possibly the depositional model of the Chia Gara Formation.

The main aim of the current research is to study the Chia Gara Formation in selected surface and subsurface sections through petrographic observation leading to the identification and classification of microfacies and highlight the depositional environmental. Three sections are selected for the present study of Chia Gara Formation, located in various tectonic zones of Iraq. According to the tectonic subdivisions of Numan (2000) and Jassim and Buday (2006) (Fig.2), they have the following locations:

- Section at Barsarin village (Duhok Governorate) is located within the Imbricated Zone of the Foreland Basin (Longitude 44° 39' 14'' E, Latitude 36° 37' 46'' N).
- Section at Banik village (Erbil Governorate) is situated within the High Folded Zone of the Foreland Basin (Longitude 42° 58' 2.6'' E, Latitude 37° 13' 33.4'' N).

- Section of well Ajil-12 (Salahaddin Governorate) is located within the Foothill Zone (Longitude 43° 48' 20.04" E, Latitude 34° 51' 34.31" N).

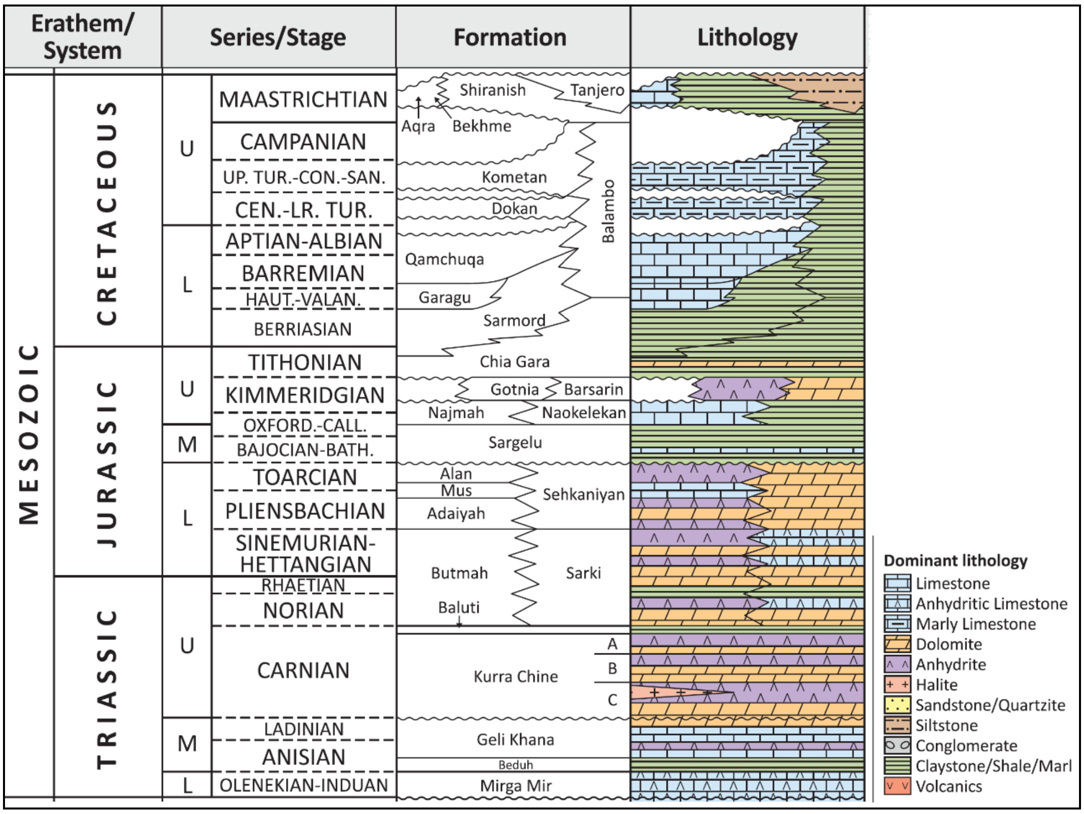


Fig.1: Mesozoic lithostratigraphic column of Kurdistan Region
( Modified from English *et al.*, 2015)

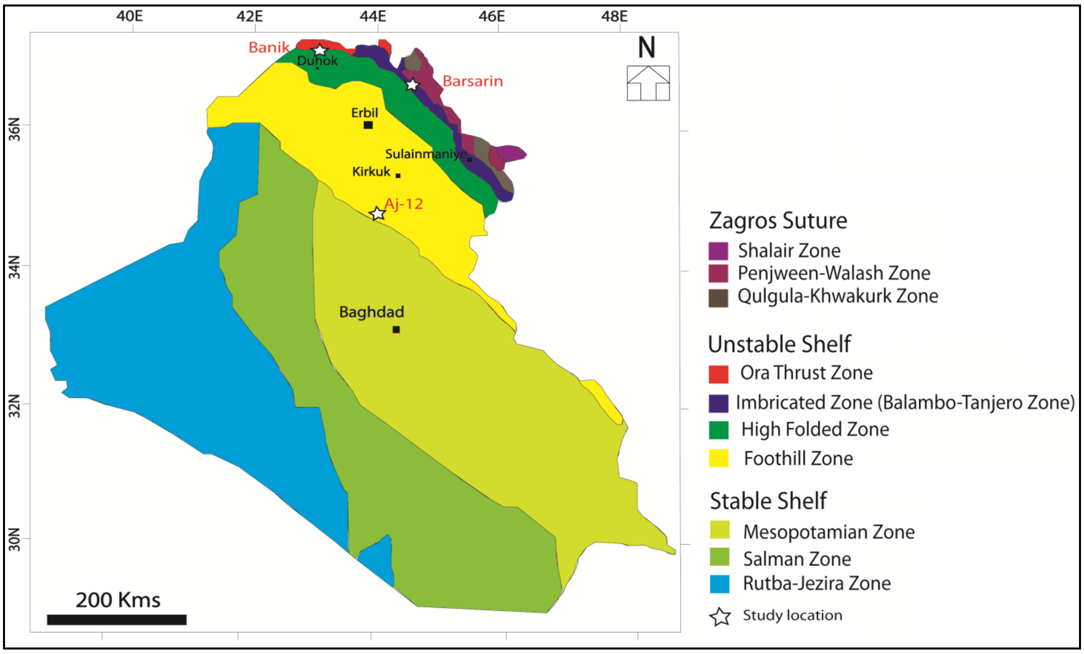


Fig.2: Approximate location and tectonic map of the study areas
(The map is modified from Numan, 2000 and Jassim and Buday, 2006)

## MATERIALS AND METHODS

- **Field Work**

An intensive work has been carried out in collecting rock samples from the outcrops followed by description and drawing columnar sections. Sampling in Barsarin section was systematic (3 meters spacing); however, in Banik section, random sampling (at every change in lithology) was preferred. The boundaries between formations were marked for each outcrop. The lower contact of Chia Gara with Barsarin Formation (Kimmerdgian) and upper contact with the Sarmord Formation (Valanginian – Aptain) are conformable. All samples were taken along a line perpendicular to the bedding plane.

- **Laboratory Work**

Sixty-nine (69) thin sections were prepared in the Department of Geology, College of Science, Salahaddin University. Additionally, 28 cuttings samples were borrowed from Northern Oil Company (NOC). Thin sections of limestone samples were examined, using polarizing microscope, to demonstrate the petrographic constituents, texture and microfacies. All thin sections were oriented and stained with Alizarin Red Solution (ARS) following Dickson's (1966) technique for detecting calcite and dolomite.

## RESULTS AND DISCUSSION

- **Lithostratigraphic Description**

– **Barsarin section:** The thickness of Chia Gara Formation in Barsarin section is around 198 meters. The lower part mainly comprises (5 – 45) cm thick shale with argillaceous limestone and black limestone. The ''Ball and Pillow'' structure (Phacoid bed of Bellen *et al*., 1959) are common in the lower part and considered an index feature of the Chia Gara Formation. In middle part, argillaceous limestones increases while shale decreases. The upper part of the formation commonly consists of limestone interbedded with thin beds of argillaceous limestone and laminated shale. The uppermost part of this section is characterized by alternating limestone, marly limestone with marl (Fig.3). Ammonite fossils are well observed in this section.

– **Banik Section:** The thickness of the formation in this section is around 60 meters and the lithology is more homogenous with repeated alternation between shale and thin bedded argillaceous limestones. The ''Ball and Pillow'' structures are common in the lower part. The middle part is mainly composed of thin beds of shale and argillaceous limestone. From the lower to the upper parts, shale decreases and argillaceous limestone and limestone increase. The uppermost part is marl and marly limestone (Fig.4). The ammonite fossils in carbonate concretions and limestone are clearly observed in the Banik area.

– **Well Aj-12 section** (depth interval 3222 – 3444 m)**:** The thickness of the formation is reported as 222 meters and the lithological description is based on the final report of North Oil Company (NOC, 1985). The formation, in general, is composed of dark grey limestone, fine crystalline, medium hard, pyritic and shaly limestone. The shale in the lower part is mainly fissile. Moreover, bituminous limestone, black micritic soft to medium hard, and slightly fissile, shaly carbonaceous limestone are reported (Fig.5).

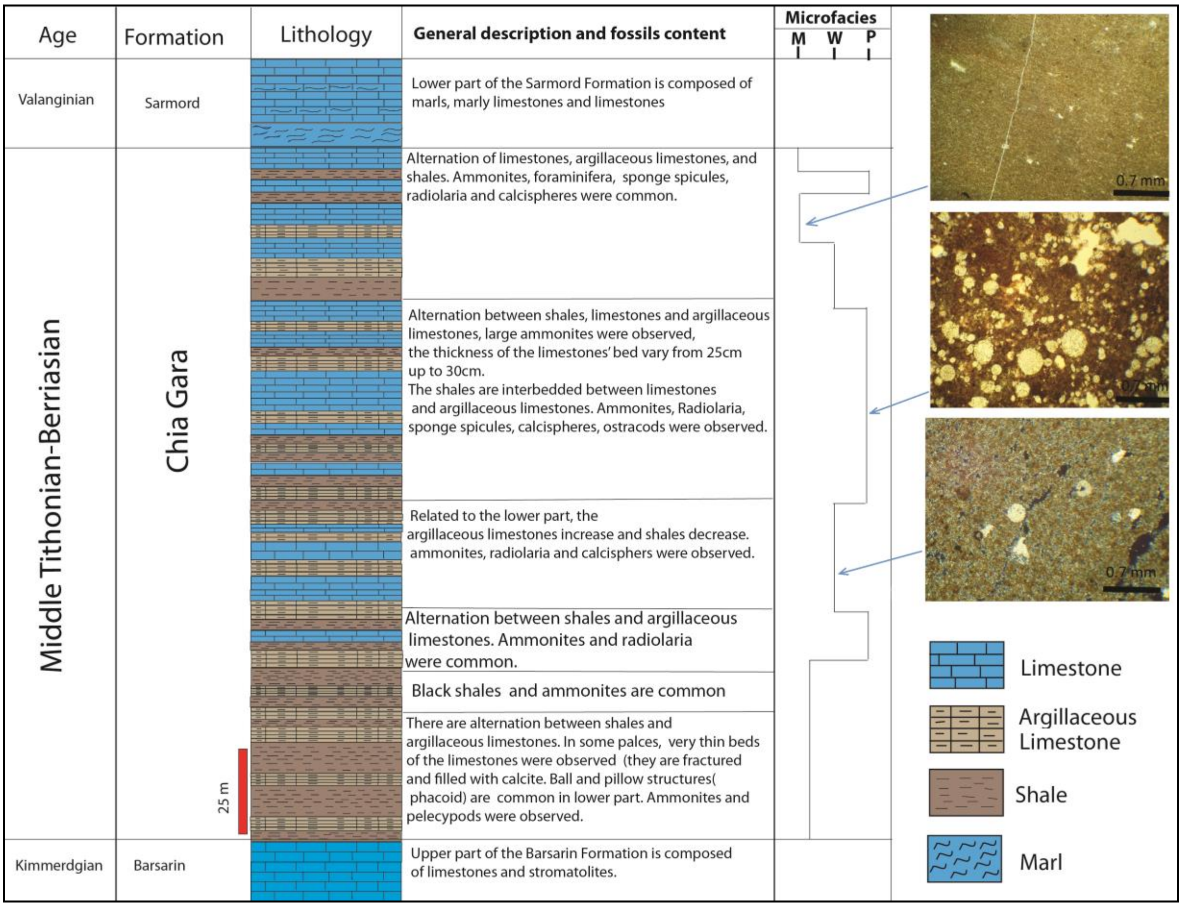


Fig.3: Stratigraphic Column of the Chia Gara Formation in Barsarin section

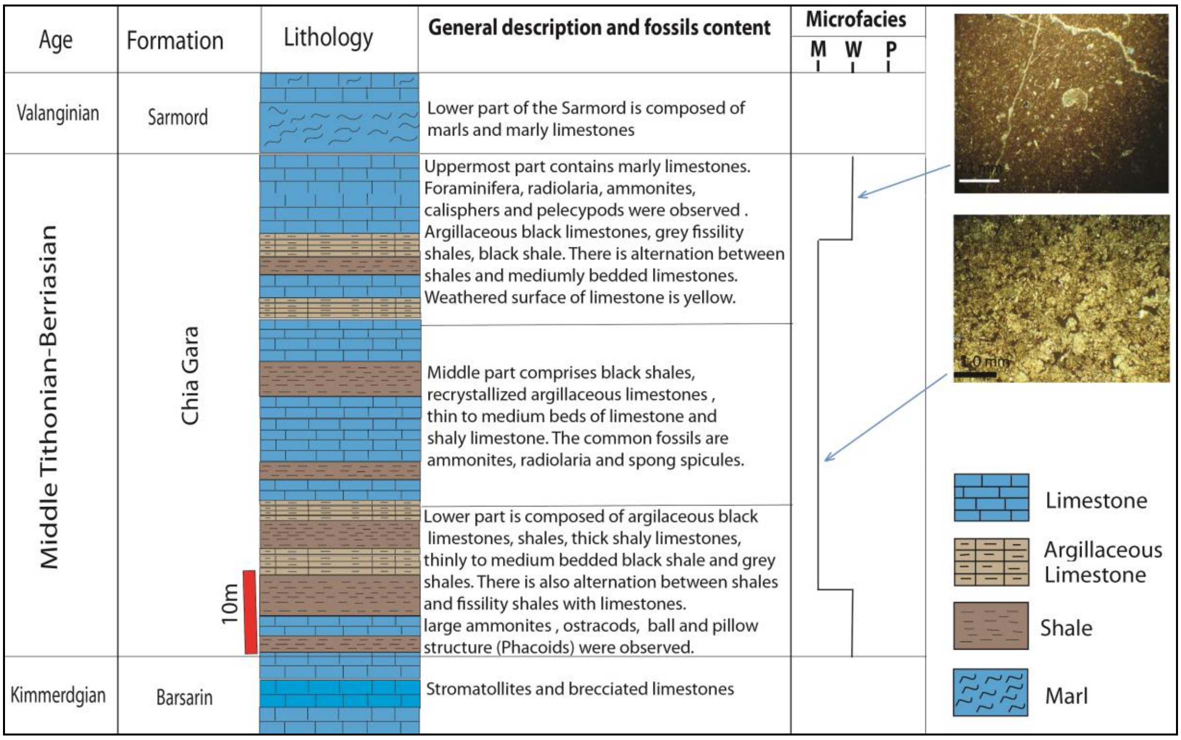


Fig.4: Stratigraphic Column of the Chia Gara Formation in Banik section

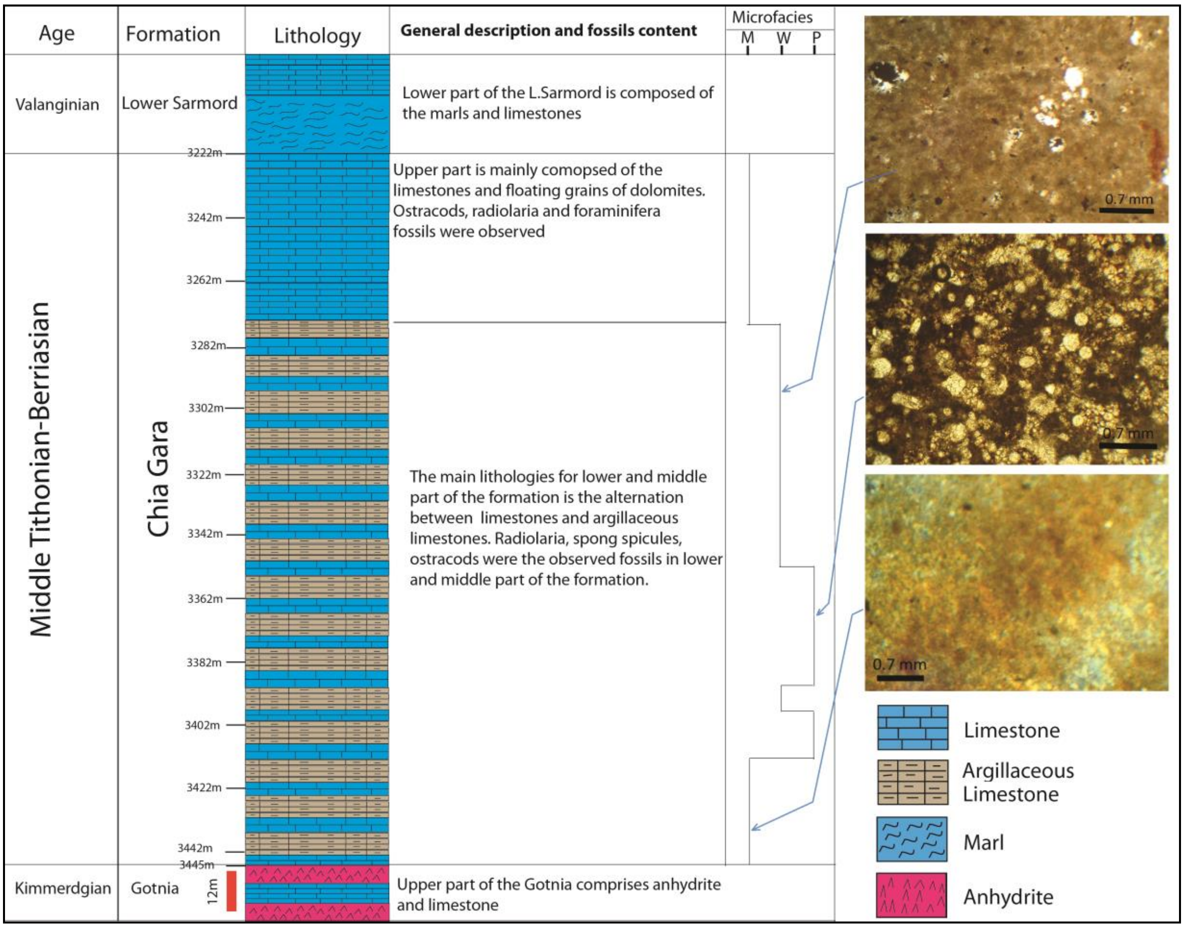


Fig.5: Stratigraphic Column of the Chia Gara Formation in Well Aj-12, (based on description from NOC Report, 1985)

- **Petrography**

The limestones are, in general, widely vary in composition. Their constituents can be divided into: skeletal grains that include fossils and their clasts, non-skeletal grains, matrix (micrite) and cement (Tucker, 2001). Due to intensive diagenetic processes that affected the rocks of Chia Gara Formation, the skeletal grains became very poor, sometimes absent and difficult to identify. The effect of diagenesis varies among the studied sections, being rather intensive in outcrop sections of Barsarin and Banik (Figs.6.8, 6.5 and 6.3). This may be due to the proximity to tectonically active areas, as well as due to exposure at ground surface, or they might have been buried deeper than those in well Aj-12 section.

– **Skeletal grains:** Fossils are the main skeletal grains in Chia Gara Formation, but since they belong to deep marine environment and anoxic/ euxinic conditions, these grains became subjected to intensive diagenesis. However, the main recognized fossils (foraminifera, sponge spicules, ostracods, ammonites, radiolaria, calcispheres, pelecypods, echinoid spines) are similar in all the studied sections.

- **Foraminifera:** They are small, predominantly marine heterotrophic protists that construct chambered shells (tests). Most planktonic foraminifers live in the upper 300 m of the water column, although after death, their tests fall to deeper seafloor (Scholle and Ulmer-Scholle, 2003). Petrography displayed that planktonic foraminifera in the rocks of the Chia Gara Formation (Fig.6.1) are present in small quantities, possibly due to removal by intensive diagenesis. Most foraminifera are found in the upper part of the formation.

- **Sponge spicules:** The fossil record of many sponge groups, particularly those of siliceous sponges, consists mainly of spicules which are studied in standard micropaleontological samples, and sometimes recognized in thin sections of limestones (Flugel, 2010). Like other skeletal grains, sponge spicules are common in the Chia Gara rocks except in Banik section where sponge spicules are found in only one thin section. This may be attributed to diagenesis or fragile nature of the spicules themselves and the small size of the samples (Fig.6.2).

- **Ostracods:** They are inhabitants of several environments; marine, transitional, and fresh water at various depths (Scholle and Ulmer-Scholle, 2003). In all three sections of the current study, Ostracods are observed with their articulated valves filled with spary calcite (Fig.6.3). In the Banik section, articulated ostracods are commonly filled with drusy cement, while in the other sections, they have granular cements.

- **Ammonites:** They are usually wholly marine (open marine) animals with a dominantly nektonic or nekto-planktonic mode of life (Tucker, 2001). They are common in pelagic, often relatively deep water deposits (Wilson, 1975 and Tucker, 2001). Ammonites are observed in all the studied sections; in Barsarin and Banik sections, large ammonite are clear and well preserved (Fig.6.4). In well Aj-12 and Banik section, some juvenile, clearly calcitized ammonites were observed.

- **Radiolaria:** Radiolarians predominantly occur in micritic carbonates and in marls. They are found in lime mudstones, wackestones, and packstones (Flugel, 2010). The distribution of radiolarians ranges from the photic zone down to the abyssal plains (Flugel, 2010). The Chia Gara rocks procure high fraction of radiolaria, particularly in the middle-upper parts where limestone dominates. The majority of the radiolarians are spherical (globular) in shape and belong to spumellarian group (Fig.6.5a). The observed skeletons of the radiolaria are mostly replaced by calcite, thus hardly distinguished from calcispheres. Due to the dissolution, radiolarian would have empty molds, later filled with spary calcite and partially pyrite. Radiolaria is observed in all selected sections, but they are little in Banik section compared to other sections.

- **Calcispheres:** The are spherical objects, up to 0.5 mm in diameter, composed of calcite (usually sparite), often with a micritic wall (Tucker, 2001). Paleozoic calcispheres occur in shallow marine platform and ramp carbonates, while those of Jurassic and Cretaceous are predominantly found in pelagic limestones (Flugel, 2010). Scholle (1978) stated that sometimes, unwalled calcispheres might be formed by alteration of radiolarians, and this is probably the case in Chia Gara Formation in which calcitized radiolaria, might be the source of dominant calcispheres (Fig.6.5b). In two sections (Barsarin and Aj-12), calcispheres were common, while in Banik only few ones were noticed, possibly due to intensive diagenesis. All the observed calcispheres were filled by postdating spary calcite.

- **Pelecypods:** These bivalve skeletons vary in composition, most of them are purely aragonite; some have interlayered calcite and aragonite (Scholle and Ulmer-Scholle, 2003). They are rare in the samples of the present study, possibly due to the dominance of deep marine conditions in the Chia Gara environment. The existing pelecypods of Chia Gara Formation (Fig.6.6) are mostly of allochthonous nature.

- **Echinoids:** They are common in both warm and cold water settings, although they are rarely major rock-forming organisms. Marine echinoderms are characterized by numerous individual calcite elements. Echinoderm spines exhibit open meshwork structure in the center and denser towards the margins (Flugel, 2010). In the current study, echinoderm spines are recognized in the Chia Gara Formation and seem to be affected by weak to intensive diagenetic processes (Fig.6.7).

– **Non-skeletal grains:** In the current study, non-skeletal grains (peloids, ooids, oncoids, intraclasts and extraclasts) are not observed in the limestones of Chia Gara Formation. This may indicate that this formation was deposited in deep marine setting (Tucker, 2001).

– **Matrix:** The groundmass of the Chia Gara Formation is dominated by micrite (Figs.6 and 7). Micrite is produced within the basin of deposition and shows little or no evidence of significant transport (Folk, 1962). The presence of micrite in ancient limestones commonly indicates deposition in quiet-water condition where little winnowing of fine mud took place (Boggs, 2006).

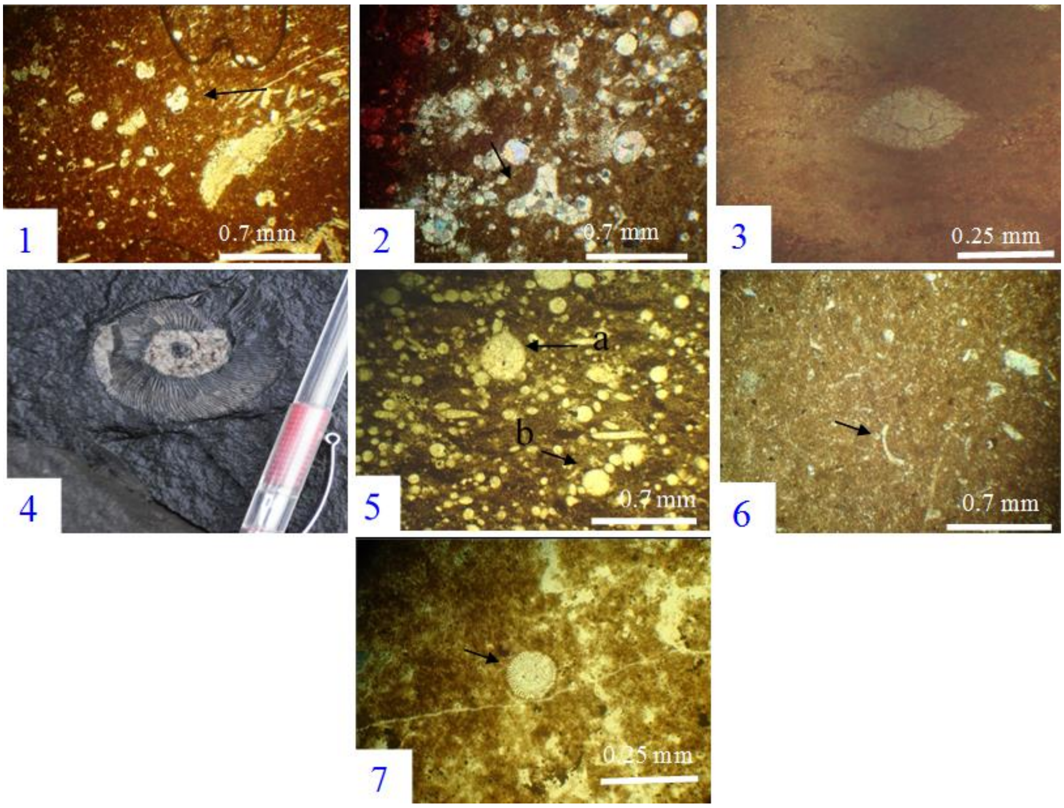


Fig.6: **1)** Foraminiferal Lime Wackestone Sub-microfacies. Planktonic Forams (Globigerina) in micrite matrix, chamber partially bearing pyrite (arrow), Bk-38, P.P.; **2)** Sponge Spicules, Br-43, X.N.; **3)** Articulated ostracods, Bk-1, P.P.; **4)** Large ammonite in Banik section; **5)** Radiolaria-Calcisphere Lime Packstone Submicrofacies **(a)** Radiolaria **(b)** Calcisphere), Br-65, PP.; **6)** Articulated pelecypod (arrow) in micritic matrix. Some unknown skeletal grains observed in groundmass, Bk-40, P.P.; and **7)** Echinoid spine (arrow) associated with radiolaria, the chambers are clear, Br-42, P.P.;

(**Note**\ Bk: Banik, Br: Barsarin, Aj-12: Well Ajil-12, P.P.: Plane Polarized, X.N.: Crossed Nicols)

- **Microfacies Analysis**

Currently, the term microfacies is defined as the total of all sedimentological and paleontological data which can be described and classified from thin sections, peels, polished slabs, or rock samples (Flugel, 2010). The determination of environmental condition and depositional history of a basin is dependent upon the microfacies analysis and explaining variation in stratigraphic units. Due to its easy and practical nature, nomenclature of facies is based on the classification of Dunham (1962) for carbonate rocks which is favored in the current study. The facies are also defined following the concept of Standard Facies Zones (FZ) of the Wilson Model (modified by Schlager, 2002) that describes rimmed carbonate platform (Flugel, 2010). Based on the relationship between fossil content and groundmass type, each of the main microfacies is subdivided into several submicrofacies. The main microfacies identified in the current study are:

***A- Lime Mudstone (Micrite) Microfacies*****:** This microfacies is present in the three sections; it is common in the limestones of the lower and middle parts in the outcrop sections at Barsarin and Banik. While in well Aj-12 section, it is commonly found in the upper part. Severe neomorphism of micrite to microspar and pseudospar is well recognized in this microfacies. Skeletal grains are rare and/ or absent, except for few calcispheres, ostracods, and radiolarians. Organic matter is common in the groundmass. Depending on composition, this microfacies is further specified:

***A-1- Radiolarian Lime Mudstone Submicrofacies*** (Fig.7.1)**:** This submicrofacies is common in the upper part of Chia Gara Formation in well Aj-12, where it is associated with small floating crystals of dolomite at the interval (3232 – 3247) m. The radiolaria are small in size, compared to those found in the other microfacies, and their molds are sometimes filled with calcite. Organic matter and particles of pyrites are common in this submicrofacies.

***B- Lime Wackestone Microfacies*****:** In this microfacies type, the percent of grains ranges between (10 – 50) % in the micrite matrix (Dunham, 1962). This represents the most common microfacies in Barsarin and well Aj-12 sections, but rare in Banik section. The wackestone of Chia Gara has undergone variable diagenetic processes. The skeletal grains noticed are thin-shelled pelagic pelecypod (broken valves), ammonites, pelagic microorganisms (radiolarians "Spumellaria" and calcispheres), planktonic forams and pelagic ostracods. Depending on the ratio of dominant grains and diagenetic processes, the wackestones are further divided into three submicrofacies listed below:

***B-1- Radiolaria-Calcisphere Lime Wackestone Submicrofacies*** (Fig.7.2)**:** This submicrofacies is observed within the limestone and argillaceous limestone-shale lithofacies of middle and upper parts of Barsarin and middle part well Aj-12 sections, while in Banik section, it is only found in the uppermost part of the formation. Some radiolarian’s molds are partially filled with pyrite. Calcispheres, Echinoid spines and planktonic forams are also present in this submicrofacies, which has an organic-rich matrix. The observed calcispheres may be of radiolarian origin (Scholle, 1978), as deduced from abundant calcareous molds of radiolaria accompanying these constituents.

***B-2- Ostracods Lime Wackestone Submicrofacies*** (Fig.7.3)**:** This submicrofacies is well recognized in all the studied sections particularly in the lower part of the Chia Gara Formation in Banik section. In Barsarin and well Aj-12 sections, this submicrofacies consists of radiolaria and calcispheres and found in the middle and upper parts. Diagenetic process, such as neomorphism, is noticed and the existing ostracods often underwent solution, followed by calcification.

***B-3- Foraminifera Lime Wackestone Submicrofacies*** (Fig.6.1)**:** This submicrofacies is observed in the uppermost part (in marly limestone) of Banik section and is dominated by planktonic forams (Globigerina) with other skeletal grains, such as radiolaria, pelecypod (bivalve), ammonite and calcispheres. Organic matter, as in the other microfacies, is common in the micritic matrix.

***C- Lime Packstone Microfacies*****:** This microfacies is characterized by predominant fossils and skeletal components that dominate the framework of the rock reaching up to (60) %, leaving minor micrite in between grain-supported limestones (Dunham, 1962). The dominance of grains over micrite refers to high agitation level. This microfacies has only one submicrofacies which is:

***C-1- Radiolaria-Calcisphere Lime Packstone Submicrofacies*** (Fig.7.4)**:** This submicrofacies is found in most parts of the Chia Gara Formation. It is found within the limestone and argillaceous limestone-shale lithofacies of Barsarin and Aj-12 and found absent in Banik section. This submicrofacies commonly consists of radiolaria, of which few are preserved while the majority seems to be replaced by calcite. This submicrofacies is associated with calcispheres, sponge spicules and little ostracods particularly in Barsarin and well Aj-12 sections. Organic matter is still a common constituent and found in high amounts. Some diagenetic processes have affected this submicrofacies such as solution and calcification of radiolaria. The effect of compaction is evident in the deformed skeletal grains.

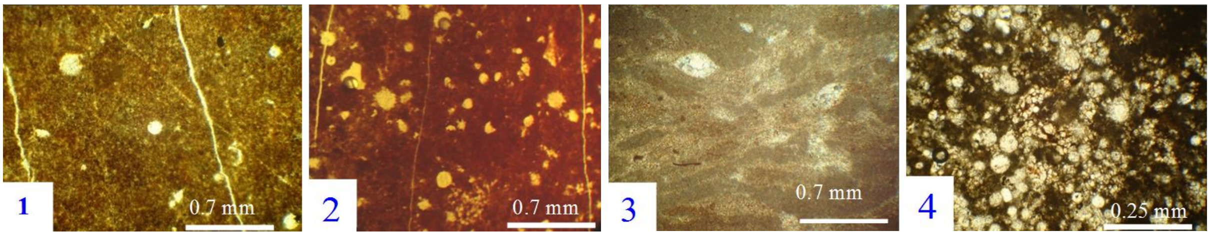


Fig.7: **1)** Radiolaria Lime Mudstone Sub microfacies, highly fractured limestone with micritic matrix. Br-59, P.P.; **2)** Radiolaria-Calcisphere Lime Wackestone Submicrofacies. Br-40, X.N.; **3)** Ostracod Lime Wackestone Submicrofacies. Articulated ostracods filled with granular cement, in micritic matrix, Bk-1, P.P.; and **4)** Radiolaria and Calcisphere Lime Packstone Submicrofacies. Calcitized radiolaria (Spumellaria), the tests are replaced by spary calcite cement, well Aj-12 (3402 m), P.P.

- **Depositional environment**

The microfacies analysis is used in the current study to identify the depositional environment of Chia Gara Formation in the localities covered by sampling. This is achieved following the concepts of Standard Facies Zones (FZ) of the Wilson Model (modified by Schlager, 2002), indicating a Rimmed Carbonate Platform (in Flugel, 2010), that displays dominant Standard Microfacies (SMF 1) which belongs to Facies Belt (Zone) (1B, 2 and 3). These standard microfacies imply beginning of Toe of Slope to Cratonic Deep-Water Basin as the most possible environments for the Chia Gara Formation.

## CONCLUSIONS

- The Chia Gara Formation show homogenous petrographic constituents in all studied sections, represented by the following; **1)** Matrix mainly composed of micrite. **2)** Non-skeletal grains which are rare or absent, and **3)** Skeletal grains which are very common and include a variety of pelagic (open sea) fauna which are, in order of dominance: Ammonites, radiolaria (Spumellarian Group), calcispheres, ostracods, planktonic forams (Globigerina), pelecypod, sponge spicules and echinoid spines. Various diagenetic processes have influenced the limestones of the Chia Gara Formation, which are, in ascending order of significance: neomorphism, dissolution, calcification, cementation, compaction and fracturing.

- Three principal microfacies are identified:

**A-** Lime Mudstone Microfacies,

**A-1**- Radiolarian Lime Mudstone Submicrofacies.

**B-** Lime Wackestone Microfacies. This microfacies can be subdivided into three submicrofacies:

**B-1-** Radiolaria-Calcisphere Lime Wackestone Submicrofacies

**B-2-** Ostracod Lime Wackestone Microfacies Submicrofacies

**B-3-** Foraminifera Lime Wackestone Submicrofacies

**C-** Lime Packstone Microfacies,

**C-1**- Radiolaria and Calcispheres Lime Packestone Submicrofacies

- The depositional environment of the Chia Gara Formation in the studied localities is concluded as quiet pelagic and reducing basin, belonging to the so-called Toe of Slope to Cratonic Deep-Water Basin of Wilson`s Model. The textural and paleontological characteristics of the Chia Gara Formation suggest that the formation maintained deposition in a quiet deep basin throughout its depositional history.

## ACKNOWLEDGMENTS

The authors wish to thank the geologist staff of NOC in Kirkuk for lending cuttings of rock samples and for their kind cooperation. Appreciation is extended to Mr. Ababakir and Mr. Yahya at The Directorate of Groundwater-Duhok for their help during field work.

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