Sedimentological Study of Exposed Successions of the Sargelu Formation, Middle Jurassic, Northeastern, Iraq

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Abstract
The Middle Jurassic Sargelu Formation spreads out widely in North-Eastern Iraq, particularly within the High Folds Unstable Shelf Zone. The Sargelu Formation was studied in two exposed sections, Hanjira and Gorin, in the Northeastern part of Iraq. The Lower contact of the formation with the Sehkaniyan Formation and the Upper contact with the Naokelekan Formation in the two sections appears conformable. The thickness of the Formation in the Hanjira section is 40 m. and in the Gorin section is 70 m. The sampling was done by taking samples from two sections and thin sections were made for all samples and were studied under a polarizing microscope. Three main microfacies donated as M, W, P, and eight submicrofacies were diagnosed which reflects the deposition of the formation within the FZ-1 zone known as the Deep Sea Basin and the FZ-2 known as the Deep Shelf.

Keywords: Sedimentology; Middle Jurassic; Sargelu; Northeastern Iraq

1. Introduction
During the Late Triassic, throughout the Middle East area, the facies which are deposited during it, differed from those deposited during the Middle Jurassic (Sharief, 1982). The reason for these difference is due to the subordination of this region during the Late Triassic to tectonic movements that led to a major marine recession. This receding led to the emergence of two ridges, the first represented by the Rutba uplift centered in the stable shelf area, and the second elevation is the Al-Khalisiah that extends in the form of a Hail arc composed of clastic sediments in the southwestern parts of the stable shelf area and the lands of Saudi Arabia and Jordan (Buday, 1980). The Hail Arc extended from the Northern part of the foothill zone to the South-western parts of the Mesopotamian zone. The Iraq and its neighboring countries were subjected during the Middle Jurassic to continuous tectonic movements that greatly affected it (Jassim and Buday, 2006b). These movements led to transgression and regression, which resulted in the emergence of several isolated deep and shallow basins (Moshrif, 1987). Two basins with a toxic environment were formed, namely the Mesopotamian Basin and the basin formed in northeastern Iraq, where carbonate and clastic facies were deposited in its shallow parts, while limestone facies of the Sargelu Formation were deposited in its deep parts (Bhasin, 1982), in addition to the formation of a shallow carbonate basin in the stable shelf area (Rutba subzone) (Fig.1). This was accompanied by the formation of elevated areas and carbonate barriers extending parallel to the inactive northern edge of the Arabian plate (Rabu et al., 1990).
The Middle Jurassic sedimentary succession of the Sargelu Formation spread out widely in northeastern Iraq, particularly within the high-folds of the Unstable Shelf Zone. Most of the Jurassic period sediments, including the Sargelu Formation, are located within the greatest sedimentary sequence of the Arab Plate (Arabian Plate, Late Toarcian- Early Tithonian Megasequence-AP7) (Sharland et al., 2001), and it covers most of Iraq except for the (Rutba-Jezira zone) and part of Mosul High. The greatest sedimentary sequence of the Arabian Plate (AP7) is divided into two minor sedimentary sequences: the first (Late Jurassic) sequence, which includes the Najma, Cotnia, Saggar, Naokelekan, and Barsarin formations, while the second (Late Toarcian-Callovian) sequence includes the Sargelu and Mhewer Formations (Jassim and Buday, 2006b).

Wetzel (1948) in Bellen et al. (1959) was the first to choose the type section of the Sargelu Formation near the village of Sargelu, located in the northeastern part of the Sordash anticline, and stated that the formation consisted of black limestone, which is thinly bedded, dolomite limestone, and black-foliated shale, as well as the presence of bands of black flint that appear in the upper parts of the formation. He also recognized many fossils, including:


Ditmar et al. (1971) in Buday (1980) showed that the thickness of the exposed Sargelu Formation in the high folded zone, imbricate and Northern thrust zone ranged between (20-250) meters. They noticed that the thickness of the formation in the sub-surface sections of the mesopotamian and foothill zone ranged between (250-500) meters.

Buday (1980) pointed out that the sequences of the Sargelu and Mhewer formations are considered from the basin sediments resulting from the marine progress that occurred during the middle Jurassic, where he identified the environment of the deposition of the Sargelu Formation in its type section in the open marine environment extending to the shallow marine environment. He also indicated that the
Sargelu Formation was deposited in a toxic marine environment, in addition to that some of its beds show good aeration conditions.

On the other hand, Ahmed (1997) stated, during his subsurface study of the Jurassic period successions in North-western Iraq that the sedimentary environment of the Sargelu Formation is a marine environment (a deep- pelagic slope), and that the sedimentary basin of the formation is part of the regional concavity of the Neo- Tethys.

The conditions of the sedimentary environment of the Sargelu Formation are generally considered to be reducing marine environment, inferred through the bio-geochemical study of the Sargelu Formation in selected sections in northern Iraq (Al-Ahmed, 2006). Al-Ahmed (2001) and Jafar, (2010) indicate through their study of the sources of hydrocarbons and oils in the Mushrif formation reservoir for selected fields in southeastern and northern Iraq, that the Sargelu formation with high organic content and thermal maturity qualifies them to be source and oil-generating rocks for the upper Jurassic and lower Cretaceous formations in Iraq and that the conditions of the depositional environment of the formation are deep marine. The aim of the study is to identify the sedimentary environment of the formation in the two study sections

2. Geological Setting

The Jurassic successions are exposed in many parts of north and northeastern Iraq, and they usually appear in the core of the folds located within the high folded zone and the imbricate zone, as well as the thrust zone (Buday, 1980).

The Sargelu Formation was studied in two exposed sections located in the Northern part of Iraq within the of Erbil and Sulaymani, 2 km North-West of Rania town in the village of Hangira, which is located on the south-western flank of the Shaweri anticline, at the intersection point (44° 51’ 25” E) and (36° 17’ 7” N). While the second section is located in the Gorin area in the northeastern part of Iraq, within the Erbil, Soran, in the Gorin village, 75.5 km northeast of the Erbil governorate center, and about 10 km northeast of Soran town at the intersection of the point (36°38’17.6”N) and (44°38’23.1”E) (Fig. 2).

Fig. 2. A map showing the locations of the studied sections (from database ARC GIS)
Several geological formations are revealed in the two study areas that limit the Sargelu Formation from the bottom and from the top. The formation in the two sections bounded from the bottom by Sehkaniyan Formation, which consists of dolomitic rocks of high hardness and a dark gray color, and sometimes appears brown because of its exposure to weathering processes. While the formation is bounded from the top and in the two sections also by the Naokelekan formation, which consists of light gray, thin to medium limestone beds as well as thin limestone beds intertwined with the thin-beds black shale.

3. Materials and Methods

The research methods in this study included two stages: a field study and a laboratory study. The field study included several field trips to the study sections in the areas of Hangira and Gorin. During these trips, the best exposed paths were chosen, in terms of the clarity of the formation successions and the exposure of its lower and upper contact. The formation rocks were collect according to the rocky changes and many observations were recorded about the rock beds such as thickness, color and the relationship of the layers with each other, describing the nature of the stratification, veins and mineral nodes, especially the flint in them. As well as describing all the effects of life activities and manifestations of mineralization and bituminous materials. As well as taking many photographs in the field. The sampling was done by taking 33 samples of the Hanjira section and 31 samples of the Gorin section.

As for the laboratory study, it was represented in preparing the samples for the study by making the thin sections of the 63 samples in the geological workshop of the Department of Geology, University of Mosul. The thin sections were dyed with Alizarin Red-S, in order to distinguish dolomite from Calcite which is colored red according to the method of Friedman (1959). Then, all these slides were subjected to a precise petrographic examination using a polarizing microscope to determine the quality of the rock components, the nature of their textures, and the effects of diagenesis processes on them. As well as determining the micro facies and comparing them with the standard microfacies of Flügel (2010) in order to determine the facies and then elicit the ancient depositional environment of the formation.

4. Results

4.1. Lithostratigraphy

The Sargelu formation was studied in two exposed sections, Hanjira and Gorin, as shown below:

4.1.1. Description of the Sargelu formation in Hanjira section

The thickness of the Sargelu Formation in the Hangira section is 40m (Fig. 3). The lower boundary of the formation conformable with the Sehkaniyan Formation located below it (last appearance of a hard dolomite bed) (Fig. 4a). It is followed by a succession of 16m. thick, consisting of successive hard dolomitic limestone beds, sugary, dark gray and the thickness of the beds ranges between 10-35 cm. As well as the prevalence of fractures, joints and calcite veins and interspersed with beds of shale rich in organic matter with a thickness of (10-25 cm.). It is topped by another succession with a thickness of 11 m. consisting of limestone beds ranging in thickness between 5-40 cm. containing ammonite fossils (Fig. 4b), interbedded with thin beds of flint (1-5 cm. thick)(Fig. 4c), successively with shale beds (5 cm) brown in color, hard, containing cracks and fractures. Followed by a succession of 13m thick, composed of limestone beds, light brown in color of medium hardness, overlapping with beds of high-Fissility shale, and interspersed with several thin beds of flint (3-5cm. thick). The Sargelu Formation closed with an conformable surface with the Naokelekan Formation, which characterized by hard Limestone rocks (Fig. 4d).
Fig. 3. Columnar section of the Sargelu Formation in Hanjira section

Fig. 4. Field photographs showing: a) The lower boundary between Sehkaniyan and Sargelu formations; b - ammonite fossils; c - thin beds of flint (1-5cm.); d) The upper boundary between Sargelu and Naokelekan formations.
4.1.2. Description of the Sargelu formation in Gorin section

The thickness of the Sargelu Formation at the Gorin section is 70 m (Fig. 5). Its lower contact appears conformable with the hard dolomite bed located below it (Fig. 6a). The Sargelu Formation begins with a succession of 15 m. thick consisting of gray, sugar-dolomitic limestone beds containing calcite nodules, cracks and bitumen. It is topped by a succession of 35 m. thick of limestone beds of thin to medium thickness (5-25cm.), pale gray, with beds of hard, brown organic argillaceous limestone (5-10cm.), interbedded with thin flint beds, followed by hard limestone beds (20m. thick) well-bedded, interbedded with argillaceous limestone (5-10cm.) containing joints and fractures. This succession ends sharply with thick beds of light brown limestone belonging to the Naokelekan Formation (Fig. 6b).

![Fig.5. Columnar section of the Sargelu Formation in Gorin section](image-url)
4.2. Microfacies Analysis

The Sargelu Formations is composed of three main microfacies donated as *Lime mudstone, Lime wackestone* and *Lime packstone*, and eight sub microfacies according to Dunham (1962), which reflects the paleoecology and bathymetry of the formation.

4.2.1. *Lime mudstone* microfacies (M)

This microfacies is represented by limestone beds with a very low grains content that does not exceed 10% of the grains components embedded in the micrite matrix. The specific granular content of this microfacies are skeletal grains and debris of the shells of pelagic mollusk fossils, ammonites, radiolaria and planktonic foraminifera. This microfacies were divided into two submicrofacies, depending on their skeletal grain content, as follows:

- **Radiolarian lime mudstone submicrofacies (M1)**

  The grains of this submicrofacies consist of the spherical shells of the radiolaria fossils (Coccodisca), which do not exceed 6% of the components of the microfacies as a whole, accompanied by some fossils of Ostracods and pelagic Mollusk, which are buried in the micritic matrix, (Fig. 7a). This microfacies affected by dolomitization, cementation and dissolution processes, as well as the compaction. The characteristics of this microfacies are identical to the standard microfacies of Flügel (2010) represented by the standard microfacies (SMF-3) deposited within the facies zone (FZ-1), as known as the deep Sea Basin.

- **Bioclastic lime mudstone submicrofacies (M2)**

  This microfacies is formed from the debris of pelagic shells as foraminifera and radiolaria, which does not exceed the total percentage of these grains (5%) of the components of the microfacies as a whole (Fig. 7b). Also, its affected by diagenesis processes such as compaction, cementation and dolomitization. This microfacies occur within the lower part of the formation in Hangira section and the middle part of the formation in the Gorin section. This microfacies are identical to the standard microfacies of Flügel (2010), which were found to be similar to the standard microfacies (SMF-2) deposited within the facies zone (FZ-1), known as the Deep Sea Basin.
4.2.2. Lime wackestone microfacies (W)

This microfacies is composed of grains ranging between 10%-50% of the components of the microfacies as a whole, embedded in a micrite matrix. Pelagic oysters, ammonites, radiolaria and planktonic foraminifera shells and debris are present. This microfacies affected by dissolution, physical and chemical compaction, as well as dolomitization, which led to the obliteration of the skeletal grains features. This microfacies were divided into three submicrofacies, depending upon their skeletal grain content, as follows:

- **Radiolarian lime wackestone submicrofacies (W1)**

  The tests of the spherical radiolaria fossils (Coccodisca) are the predominant skeletal grains within this microfacies, with a percentage that may reach 15% of the skeletal components, which were accompanied by a few planktonic foraminifera at a percentage 1% and small ammonite tests at a percentage 2%, pelagic mollusk and ostracoda with a percentage of 5% in addition to the debris of the shells of these fossils, they are buried in the micritic matrix and sometimes mixed with bituminous materials, (Fig. 7c). The most important diagenesis processes identified within this microfacies are cementation, compression, silification and neomorphism.

  This microfacies are identical to the standard microfacies of Flügel (2010), which were found to be identical to the standard microfacies (SMF-3) deposited within the facies zone (FZ-1), known as the deep marine basin zone.

- **Bioclastic filaments lime wackestone submicrofacies (W2)**

  The filament shells and its debris, which are thin, longitudinal and wavy shells that represent the larval stage of the pelagic marine mollusks, are the dominant grains of this fauna, as they account for about 45% of the components, associated with the debris and shells of bositra, radiolaria, ammonite and planktonic foraminifera in the micrite groundmass (Fig. 7d). The most important diagenesis processes diagnosed in this microfacies are cementation, dissolution and compression, as well as the dolomitization. This microfacies are identical to the standard microfacies of Flügel (2010), which were found to be identical to the standard microfacies (SMF-2) deposited within the facies zone (FZ-1), known as the deep sea basin zone.

- **Bioclastic lime wackestone submicrofacies (W3)**

  This microfacies consists of pelagic oyster shells bioclasts and a few ostracoda, radiolaria and ammonites tests. The proportion of these grains may reach 40% of the rock components, buried in a light micritic matrix (Fig. 7e). This microfacies are affected by compaction, cementation, and dolomitization processes. This microfacies is appeared within the upper and middle part of the Hanjira and Gorin sections. These microfacies are identical to the standard microfacies of Flügel (2010), which were found to be identical to the standard microfacies (SMF-10) deposited within the facies zone (FZ-2), known as the deep shelf zone.

4.2.3. Lime packstone microfacies (P)

This microfacies is composed of shells test and debris of the pelagic oysters, ammonites, radiolaria and planktonic foraminifera, which is embedded in the micritic matrix and its percentage is limited between 50% to 85% of the total components of the facies. This microfacies were divided into three submicrofacies, depending on their skeletal grain content, as follows:
• **Bositra lime packstone submicrofacies (P1)**

The shells of the bivalve bositra oysters are the predominant skeletal granules within this microfacies, as their percentage may reach 45% of the total skeletal components, which are accompanied by bioclasts (10%-15%), small ammonites, planktonic foraminifera and ostracoda not exceeding 2% buried within the matrix, (Fig. 7f). cementation, dissolution, and compression, in addition to the dolomitization process are present. This microfacies is identical to the standard microfacies of Flügel (2010), which turned out to be similar to the standard microfacies (SMF-8) deposited within the fractal zone (FZ-2). , known as the deep shelfzone.

• **Ostracoda lime packstone submicrofacies (P2)**

This microfacies is characterized by the prevalence of small-sized Ostracoda bivalve shells (0.25 < 2 mm) with a percentage that may reach 40% of the total skeletal grains of the microfacies, accompanied by the filament bioclasts, mollusks pelagic bositra at a rate of up to 5% and ammonite shells embedded in the micrite and often contain bitumen (Fig. 7g). Compaction, cementation and neomorphism are presence. This microfacies is identical to the standard microfacies of (Flügel, 2010), which turned out to be similar to the (SMF-8) deposited within the facies zone (FZ-2) . , known as the deep shelfzone.

• **Filaments lime packstone submicrofacies (P3)**

This microfacies is characterized by the prevalence of wavy filaments shells bands of pelagic marine mollusks known as filaments, which are believed to represent the larval period of the Bosittra fossils, as they represent 30%-45% of the total components of the rock associated with the bioclasts of these shells, at a rate of 20% of the total grains components, as well as the debris of ammonite and ostracoda shells, with a percentage of not more than 2% buried in a brown micrite, sometimes containing bitumen (Fig. 7h). The diagenesis processes affecting on this microfacies are the compaction, that led to the rearrangement of the filament shells in a bands. The cementation and calcite veins are documented. This microfacies is identical to the standard microfacies of Flügel, (2010), which turned out to be similar to the (SMF-3) deposited within the facies zone (FZ-1), known as the deep shelfzone.

5. Discussion

The sedimentary environment is defined as part of the earth’s surface in which sediments accumulate, which are characterized by certain physical, chemical and life conditions. Any difference between these conditions leads to the production of different types of sediments, and therefore different types of microfacies. In other words, each sedimentary environment has its own specific facies and its own sedimentary and biological characteristics that distinguish it from the rest of the other environments (Boggs, 2006; Scholle et al, 1983). In the current study, the Sargelu Formation was relied upon in deducing the sedimentary environment on the lithology, sedimentary structure, biological data and evidence extracted from the precise microfacies analysis of the formation sequences, as follows: The results of the microfacies analysis in the current study showed that the sedimentation environment of the Sargelu Formation is the basinal environment, and this is consistent with many previous studies (Wetzel, 1948 in Bellen et. al., 1959; Buday, 1980; Al-Fariji, 2008; Al-Ta’i, 2013; Abdula et.al., 2015; Al-Assi, 2016). The microfacies analysis also showed match with the standard microfacies (SMF 2, SMF 3, SMF 8, SMF 10) proposed by Flügel (2010), which indicates that the microfacies was deposited within the FZ-1 zone known as the Deep Sea Basin and the FZ-2) known as the Deep Shelf. Which seems to match the model proposed by Koutsoukos (1985) (Fig. 8).
Fig. 7. a) Radiolarian lime mudstone submicrofacies; b) Bioclastic lime mudstone submicrofacies; c) Radiolarian lime wackestone submicrofacies; d) Bioclastic filaments lime wackestone submicrofacies; e) Bioclastic lime wackestone submicrofacies; f) Bositra lime packstone submicrofacies; g) Ostracoda lime packstone submicrofacies; h) Filaments lime packstone submicrofacies.

Fig. 8. The proposed environmental zones of Koutsoukos, (1985) and their standard equivalents (F-z) of the Sargelu Formation.
As the FZ-1 corresponds to the bathyal zone and the microfacies are M1, M2, W1, W2, P3 the deposits of this environment consist of micrite, silicates deposits, planktonic foraminiferalshells and, filaments shells. The results of the petrographic study indicate that the microfacies of the Sargelu Formation are characterized by a high content of micrite and, fossils that reflect the sedimentation in the bathyal environment. The prevalence of fine sediments indicates their deposition in a deep and, calm marine environment. This is supported by the abundance of planktonic foraminifera, low abundance of the benthic foraminifera, and the abundance of radiolaria, organic materials and bituminous materials, reflect the conditions of a calm, deep and reducing sedimentary environment (Flügel, 2010) (Malak, 2015) (Malak et al., 2021).

As the (FZ-2) corresponds to the outer shelf zone and the microfacies are Bioclastic lime wackestone submicrofacies (W3), Bositra lime packstone submicrofacies (P1), and Ostracoda lime packstone submicrofacies (P2), this environment is characterized by the water of normal salinity and temperatures ranging between 10-30 degrees celsius (Flügel, 2010). It is generally located below the level of the base of the waves, in which fine particles are often deposited, where the rate of sedimentation is low, so its sediments are laminated and mention to deep sea environments.

The presence of bioclasts and, the lack of radiolaria and planktonic foraminifera within the microfacies confirms the shallowing of the sedimentary environment. These microfacies deposits in the environment of the outer shelf connected to the open sea (Fig. 9).

![Sedimentary model of the Sargelu Formation.](image)

Fig. 9. Sedimentary model of the Sargelu Formation.

6. Conclusions

The main conclusions from this study are:

- The thickness of the Sargelu Formation (40m. thick) in the Hangira section and 70 m. thick in Goren section. It consists of limestone, dolomitic limestone and argillaceous limestone, rich in organic matter, and thin bundles of black to brown flint.
- The upper and lower contact surfaces in both sections with the formation of Sehkaniyan and Naokelekan respectively are conformable.
- The formation consist of the shells of bivalve mollusks (Bositra Sp., Posidonia Sp. and Filaments), as well as fossils of Radiolaria, Ammonites, Planktonic Foraminifera, Ostracoda and some bioclasts.
• Three main microfacies were identified, represented by mudstone, wackestone, and packstone microfacies, and eight submicrofacies.

• The microfacies of the Sargelu Formation reflected its deposition in two environments, its lower parts were deposited in the environment of the Bathyal (lower, middle, and upper), While its upper parts were deposited in the outer shelf, in a marine environment that reflects a relative shallowness.

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References


