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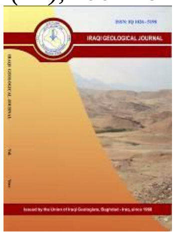

Microfacies Analysis of Bajawan and Baba Formations in Selected wells of Bai Hassan Oil Field, North Iraq

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Abstract

The current study aims to analyze the microfacies, diagenetic processes, and depositional environments of the Baba and Bajawan formations in three wells of the Bai Hassan oil field, located in the northwest of Kirkuk Governorate in northern Iraq, namely BH-80, BH-193, and BH-194. The study involved the analysis of 60 rock thin sections from well BH-80, 23 thin sections from well BH-193, and 22 thin sections from well BH-194, which led to determining the microfacies and the associated depositional environments. The results showed that the rocks of both formations contain many benthic foraminifera shells, such as *Nummulites*, *Lepidocyclina*, and Miliolid, in addition to a low percentage of echinoderms, algae, corals, and rock fragments, all embedded in a matrix composed of micrite and microspar. Five main types of microfacies were identified: homogeneous non-fossiliferous lime mudstone, wackestone, packstone, grainstone, and coralline boundstone, in addition to secondary facies types. The depositional environments were also determined, with the Bajawan Formation being deposited in shallow marine waters within a lagoonal environment of normal salinity, characterized by moderate energy and semi-restricted conditions near a tidal flat, within a lagoon-back reef environment. In contrast, the Baba Formation was deposited in calm, low-energy, deep waters with normal salinity, within environments such as back-reef (shallow lagoon), reef, and fore-reef. The observed diagenetic processes include cementation, dissolution, compaction, dolomitization, and micritization.

Keywords: Microfacies; Diagenesis; Paleoenvironment; Baba Formation; Northern Iraq

1. Introduction

The Bai Hassan oil field is considered one of the important oil fields in Iraq. It was discovered in the 1930s and is a major part of the renowned Kirkuk oil field complex. The Bai Hassan field consists of geological formations rich in hydrocarbons, with the Baba and Bajawan formations being key components of the Kirkuk Group (Oligocene) (Ghafor and Rajabi, 2024), which contains significant hydrocarbon reserves in Iraq. According to Fouad's (2015) classification, the Bai Hassan oil field is located within the Low Folded Zone in northeastern Iraq. This zone is part of the Unstable Arabian Shelf and is situated near the Zagros Fold Belt, which extends along Iraq's eastern border. The stratigraphic framework of the carbonates of the Kirkuk oil field was first established by (Henson, 1950), and subsequent studies on the stratigraphy and geology of the "Main Limestone" were conducted by the researchers (Al-Naqib, 1955 and 1960; Bellen, 1956; Dunnington, 1958; Al-Qayim et al., 2016; Muhammad, 1983; Majid and Feizer, 1986). The Oligocene stratigraphic sequence in Iraq, which includes the Kirkuk Group, comprises nine formations representing three distinct carbonate depositional

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cycles characterized by back-reef facies, reef facies, and fore-reef to basin facies (Bellen et al., 1959; El-Eissa, 1992). Since the lithology of the underlying and overlying formations affected the contact surfaces, the stratigraphic record of the Baba and Bajawan formations was ascertained by examining the contact surfaces and lithological characteristics. According to a study by Jassim and Goff (2006), which cited Buday (1980), the upper contact surface between the Baba Formation and the Bajwan Formation above it is conformable in the type section. The Bajawan and Jeribe formations' contact surface is unconformable, indicating a period of erosion or depositional hiatus prior to the Jeribe Formation's deposition on top of the Bajawan Formation. According to Al-Naqib (1960), the Bajawan Formation and the Baba Formation's upper contact surface are conformable in the southern part of the Kirkuk field. Kharajiani (2008) explained that the Tarjil Formation, which lies beneath the Baba Formation, is likely to have a conformable contact surface between them. The representative section of the Bajawan Formation in well BH-194 consists of creamy-white limestone, medium-hard to hard, crystalline, dense, containing pyrite, marl, and light brown porous crystalline layers. The lower part of the Bajawan Formation, which overlaps with the Baba Formation, consists of light gray creamy limestone, medium-hard, fine-crystalline, marly, and light brown dolomitic porous layers with vugs (Final Well Report). On the other hand, the Baba Formation consists of light brown dolomitic limestone, medium-hard, fine-crystalline, with vuggy pores. The Baba Formation is underlain by the Tarjil Formation, which is 12 m thick and consists of medium-hard, brown, crystalline, porous, and marly limestone (Final Well Report). This study focuses on analyzing the microfacies and diagenetic processes that influenced Bajawan and Baba formations in the Bai Hassan oil field, Kirkuk Governorate, northern Iraq (Fig. 1).

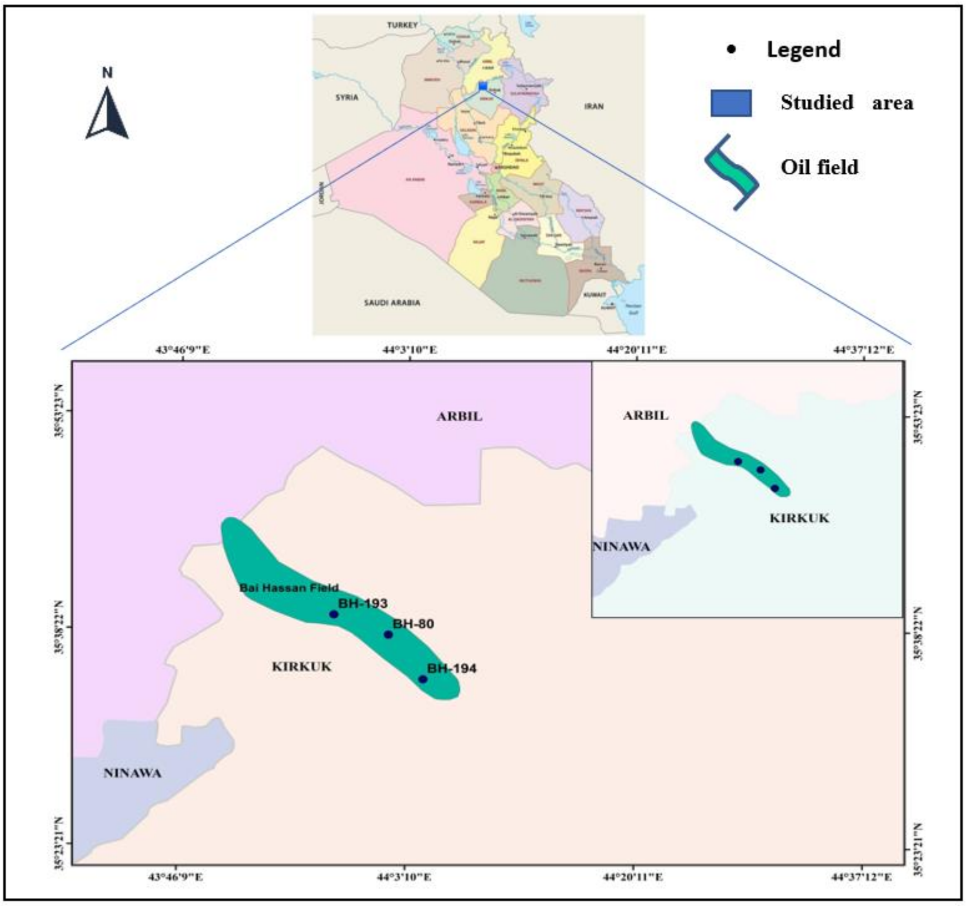

Fig.1. Location map of the studied oil wells

2. Materials and Methods

The data were collected and obtained from three wells provided by the North Oil Company, in addition to the final reports for the selected wells studied for the Baba and Bajawan formations. The number of thin sections studied was 60 from well BH-80, 23 from well BH-193, and 22 from well BH-194. These thin sections were examined using a polarized microscope to obtain high-quality images, and they were accurately described to determine their detailed components. This step is essential for identifying their specific facies and comparing them with the standard microfacies (SMF) and facies zones (FZ) according to Wilson (1975). Subsequently, the depositional environment of the formation was inferred, along with a precise evaluation of the diagenetic processes affecting the rocks.

3. Results and Discussion

3.1. Microfacies Analysis

The facies analysis study of the Baba and Bajawan formations within the studied wells of the Bai Hassan Oil Field revealed the presence of several main facies, some of which were subdivided into secondary facies. This classification was based on a detailed microscopic description of the rock thin sections and using the classification methods of (Dunham ,1962 and Wilson, 1975). These facies were then correlated with the standard microfacies of (Wilson, 1975).

3.1.1. Homogeneous non-fossiliferous lime mudstone

Muddy carbonate rocks containing less than 10% grains and characterized by a micrite matrix devoid of fossils (Flugel, 2010). This microfacies has been described in the Baba and Bajawan formations at the lower parts of well BH-80 at depths of 1378 m and 1974 m (Plate1.a). This microfacies corresponds to the standard microfacies SMF-23 (Wilson, 1975), which was deposited in facies zones FZ8, indicating a restricted platform interior in tidal flat environment (Flugel, 2010).

3.1.2. Wackestone microfacies:

3.1.2.1. Bioclastic wackestone submicrofacies

This facies is mainly composed of bioclastic fragments, including foraminiferal shells represented by the genus *Nummulite*, as well as echinoderm fragments (less than 15%) and rock fragments. This facies is found in well BH-193 at depths of 890 and 892 m (Plate 1.b). The presence of a micritic matrix combined with an abundance of typical open marine fauna, particularly benthic foraminifera, is characteristic of the back reef environment, which is sheltered from oceanic wave energy. Based on these faunal components, it is inferred that was deposited in a lagoonal-back reef setting (Sadeghi et al., 2010). This microfacies is equivalent to Wilson’s (1975) SMF8, corresponding to facies zone FZ7.

3.1.2.2. Peneroplis, miliolid wackestone submicrofacies

This microfacies was identified in the lower part of the Bajawan Formation within well BH-193 at a depth of 892 m (Plate 1.c and d). The primary skeletal components of this microfacies include *Peneroplis* and miliolids. The formation is characterized by a micritic matrix combined with an abundance of typical open-marine skeletal fauna, such as miliolids and *Peneroplis,* which thrived in deeper, low-energy marine and lagoonal environments with high salinity (Nebelsick et al., 2005). Based on these faunal elements, the microfacies was deposited in a low-energy lagoon-back reef setting. This microfacies is similar to the standard microfacies SMF8 of Wilson (1975), deposited in restricted platform interior environment (FZ7).

3.1.3. Packstone microfacies

3.1.3.1. Bioclastic packstone submicrofacies

This microfacies is mainly composed of bioclasts, ranging between 50% to 70%, consisting mostly of foraminifera shells. Rock fragments were also found in very small amounts, approximately 1% to 5%. It occurs in the Baba and Bajawan formations in well BH-80 at depths 1342 m and 1332 m as well as in well BH-193 at a depth of 878 m (Plate 1.e). The microfacies reflects a back reef to reef environment, and it is equivalent to SMF10 of Wilson (1975) deposited in open marine environment (FZ7).

3.1.3.2. Peloidal packstone submicrofacies

This microfacies is abundantly found in the Baba Formation, where it is dominated by peloids. It appears in well BH-80 at a depth of 1368 m (Plate 1.f). It is conformable with SMF16 of Wilson (1975), indicating a restricted platform interior (FZ7).

3.1.3.3. Miliolid packstone submicrofacies

This microfacies was described in the Bajawan Formation, where it appeared in well BH-194 at various depths of 1284 m and 1388 m and in BH-193 at depth 880 m (Plate 2.a). The microfacies, is mostly composed of benthic foraminifera, miliolid, *Austrotrillina*. The presence of numerous imperforate foraminifera in packstone indicates restricted shallow sub-tidal environments characterized by relatively low current energy. The prevailing texture of the packstone implies deposition in a low-energy setting, interpreted as a protected embayment within a lagoon-back reef (Buxton and Pedley, 1989). Larger benthic foraminifera, particularly from the Miliolid and Rotaliid groups, inhabit shallow marine environments and are typically found in carbonate platforms and lagoon-back reef areas (Brandano et al., 2008). Miliolids are commonly present in back-reef-lagoon environments and the sheltered areas on the reef banks (Ghosh, 2002). The porcelaneous foraminifera such as miliolids (*Austrotrillina sp.*) preferentially live in low turbulence water, where abundant fine sediments accumulate in restricted lagoonal and/or relatively nutrient-rich back reef environments. This microfacies is comparable to Wilson’s (1975) SMF18, which is related to the restricted platform lagoon (FZ8).

3.1.3.4. Lepidocyclina packstone submicrofacies

This microfacies is described in Baba Formation, where it occurs in well BH-80 at a depth of 1425 m (Plate 2.b and c). The main components of this microfacies are the small, oval-shaped tests of large benthic foraminifera, namely *Lepidocyclina*, miliolids, and *Nummulites*, in a micrite matrix. The dominance of micrite indicates a low-energy environment. The abundance of large *Lepidocyclina* suggests low-energy depositional conditions (Beavington-Penney*and Racey*., 2004). *Lepidocyclina* thrived in warm, light-filled back-reef environments as nests for diatoms, while Nummulites can inhabit various environments and form banks on swells; however, small and medium-sized Nummulites lived in back-reef environments (Jorry et al., 2006). This microfacies is equivalent to Wilson’s (1975) SMF10, which indicate an open marine environment (FZ7).

3.1.4. Grainstone microfacies

3.1.4.1. Bioclastic grainstone submicrofacies

This facies type has been identified in the studied formations in well BH-193 at a depth of 884 m, and in well BH-194 at depth 1386 m (Plate 2.e). It is primarily characterized by grain-supported

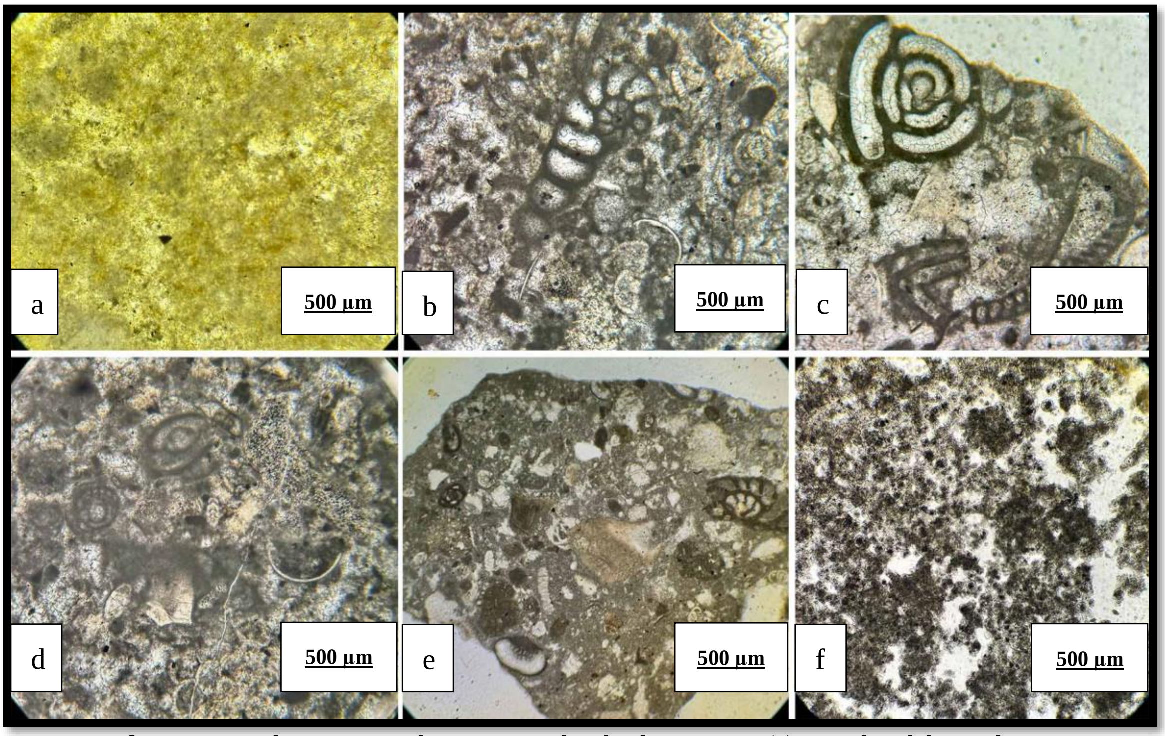

Plate 1. Microfacies types of Bajawan and Baba formations: (a) Non-fossiliferous lime mudstone; Baba Formation; well BH-80 at depth of 1378 m. (b) Bioclastic wackestone; Bajawan Formation; well BH-194 at depth of 1380 m. (c,d) *Peneroplis*, miliolid wackestone submicrofacies; Bajawan Formation; well BH-193, at depth of 892 m. (e) Bioclastic packstone; Bajawan Formation; well BH-80 at a depth 1332 m. (f) Peloidal packstone; Baba Formation; well BH-80 at depth 1368 m

textures, consisting of abraded and fragmented skeletal grains of benthonic foraminifera like miliolids, along with dolomite and anhydrite. The dominant components, however, are bioclasts with sparry calcite cement. Based on these faunal elements, it was deposited in a lagoon-back reef environment (Hottinger, 2013). This microfacies closely corresponds to SMF10 and was deposited in lagoon-back reef setting (FZ7).

3.1.4.2. Miliolid grainstone submicrofacies

This microfacies was described in the lower part of the Bajawan Formation in well BH-194 at depths of 1386 and 1374 m (Plate 2.e). It is primarily characterized by grain-supported textures, with the main components of imperforated benthic foraminifera, specifically miliolids with *peneroplis*. The abundance of foraminifera suggests a reef-back reef environment, with very limited circulation and relatively hypersaline conditions (Romero et al., 2002). Based on these organisms, the facies was deposited in a lagoonal environment (Vecchio and Hottinger, 2007).

3.1.5. Coralline algal boundstone microfacies

This submicrofacies has been identified in the Baba Formation in well BH-194 at a depth of 1393 m and Bajawan Formation in well BH-80 at depths of 1324 and 1338 m (Plate 2.f). It is predominantly composed of coralline algae and occurs as patch reefs, which are typically found in open lagoons and/or barrier reefs that separate the open sea from restricted lagoons (Tucker et al., 1990). The deposition of this submicrofacies took place in a patch reef environment. This submicrofacies is comparable to the standard microfacies SMF7 outlined by Wilson (1975), associated with an organic buildup environment (FZ5).

3.2. Depositional Environment

3.2.1. Depositional environment of the Bajawan formation

The microfacies of the Bajawan Formation are primarily composed of benthic foraminifera such as Miliolids, *Austrotrillina*, *Peneroplis*, and different bioclasts. It also includes corals and fossil debris, which often suggest a back-reef (lagoonal) environment within an inner shelf setting. These conditions correspond to environments described by Brandano et al. (2008) and Flugel (2010). The high concentration of benthic foraminifera (Miliolids, *Austrotrillina*, *Peneroplis*, and bioclasts) indicates a normal saline lagoon environment, marked by moderate energy and semi-restricted conditions near a tidal flat, as described by Beavington-Penney and Racey (2004). Evidence based on the diverse types of microfacies identified in the Bajawan Formation, along with the presence of large foraminifera like Miliolids and *Austrotrillina* alongside *Peneroplis*, indicates a lagoon-back reef depositional environment, as noted by Hussain et al. (2021) and Geel (2000). These observations suggest a deposition in shallow marine waters within a lagoon-back reef setting for the Bajwan Formation.

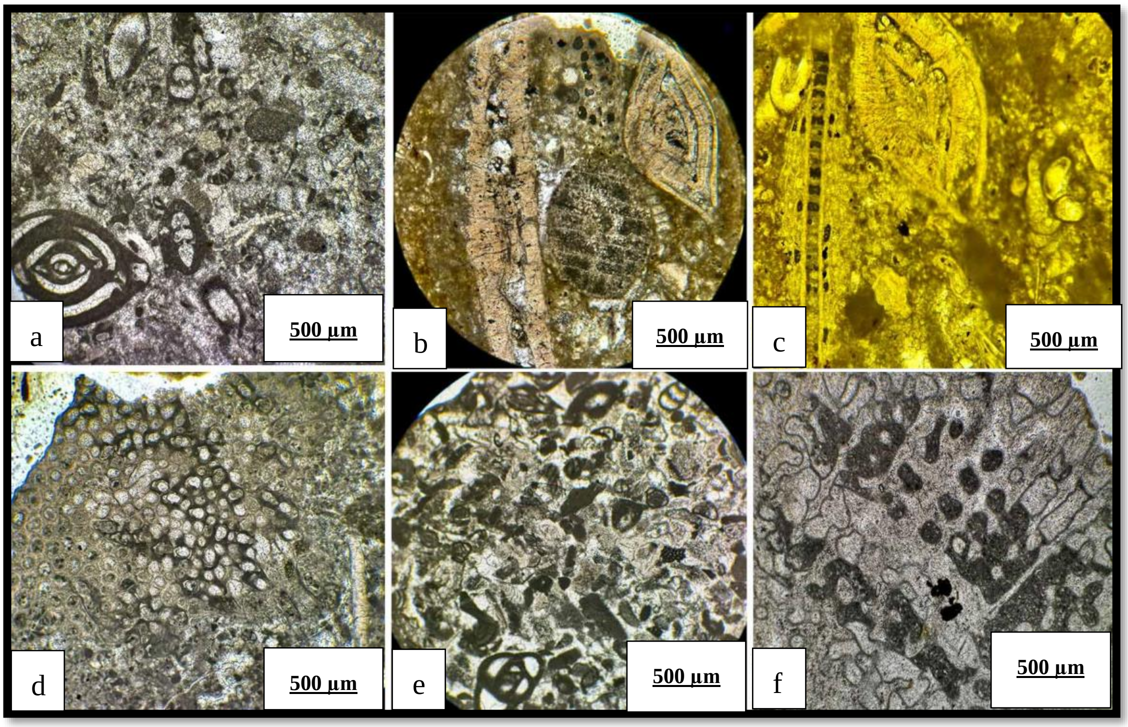

Plate 2. Microfacies types of Bajwan and Baba formations: (a) Miliolid packstone ; Bajawan Formation; well BH-194 at depth of 1384 m. (b),(c) *Lipidocyclina* packstone; Baba Formation ; well BH-80 at depth of 1425 m. (d) Bioclastic grainstone; Bajawan Formation; well BH-193 at depth of 884 m. (e) Miliolid grainstone; Bajawan Formation; well BH-194 at depth of 1374 m. (f) Coralline algae boundstone; Baba Formation; well BH-80 at depth of 1393 m

3.2.2. Depositional environment of Baba Formation

The depositional environment of the Baba Formation is primarily defined by microfacies dominated by large perforate benthic foraminifera, including species such as *Lepidocyclin*a, Nummulites intermedius, miliolids, and corals. These fauna suggest a deposition in calm, low-energy, deep, normal saline waters within back-reef (lagoonal), reef, and fore-reef environments (Buxton and Pedley, 1989*)*. *Lepidocyclina* flourished in warm, well-lit reef and fore-reef environments, providing habitats for diatoms (BouDagher-Fadel, 2008; BouDagher-Fadel and Price, 2013). In contrast, Nummulites adapted to various settings, potentially forming banks on raised areas; however, smaller to medium-sized Nummulites typically inhabited reef and fore-reef (mid-ramp) settings (Jorry et al., 2006). The presence of imperforate foraminifera, like miliolids, points to open shelf lagoon conditions (Romero et al., 2002; Amirshahkarami, 2013). Miliolids are found in various shallow environments, from hyposaline to hypersaline, including reef and fore-reef slope. They are often indicators of restricted lagoons or nutrient-rich environments in back-reef and reef areas (Murray, 1991; Geel, 2000). The foraminiferal assemblage, mainly comprising miliolids, *Lepidocyclina*, and bioclasts, indicates deposition in a high-light reef/fore-reef environment (Flugel, 2010). In Iran, Hatefi et al. (2018) observed that the prevalence of Lepidocyclinids and Nummulites indicates higher light intensity and wave energy, characteristic of a mid-shelf depositional environment. Large perforate foraminifera, such as *Lepidocyclina* and Nummulites, are commonly found in carbonate sediments of reef and fore-reef settings (Hottinger, 1983). In summary, the Baba Formation's depositional settings are primarily associated with lagoon and reef environments.

3.3. Diagenetic Processes

These are all the chemical, physical, and biological processes that occur in sediments, leading to changes in their texture and mineral composition under the influence of temperature and pressure from the time of deposition until transformation. Several factors affect diagenetic processes, including temperature, pressure, burial, tectonic forces, and the weight of the sedimentary cover (Friedman, 1964). Diagenetic processes are crucial because they induce changes in petrophysical properties such as permeability and porosity, which are of significant importance for oil reservoirs and aquifers.

3.3.1. Cementation

Cementation is an important constructive diagenetic process, involving the partial or complete filling of pore spaces with cementing materials, primarily derived from solutions saturated with calcite. Cementation is influenced by several factors, including the mineralogical and chemical composition of sediments, pressure, temperature, solution concentration, and pH (Tucker and Wright, 2001).

Longman (1980) noted that cementation occurs in all sedimentary environments, with each depositional environment exhibiting distinct diagenetic characteristics. The mineral composition of cement varies depending on the mineral content of solutions passing through the rocks; for example, in deep marine waters, cement is mainly composed of low-magnesium calcite, with minor amounts of high-magnesium calcite (Milliman, 1974).

3.3.1.1. Blocky cement

This type of cement is characterized by large, uniform calcite crystals that fill the voids in a blocky pattern. Blocky cement has clear, well-defined edges and nearly complete crystal faces, with no specific growth orientation. Crystal sizes range from coarse, around a few mm, to medium-sized, approximately tens of microns. This type of cement forms due to late diagenetic processes or after the dissolution of grains and carbonate cement (Flugel, 2004). This type of cement was identified in the lower part of the Bajawan Formation from well BH-194 and BH-193 (Plate 3.b).

3.3.1.2. Drusy cement

This type of cement consists of transparent, pure calcite crystals with irregular faces, characterized by crystal growth and size increase from the cavity wall towards the center. These cavities can be either vuggy (cavities) or moldic (Longman, 1980), a feature typical of early cementation. In the current study, this type of cement was observed in both formations and in the upper part of the Bajawan Formation in well BH-194 (Plate 3.a). Drusy cement is distinguished by smaller crystals adjacent to the outer walls of fossilized structures, which gradually increase in size towards the center of the void. This cement is commonly found in the vadose zone within freshwater environments in both deep and shallow marine settings (Friedman, 1964).

3.3.2. Dissolution

Dissolution is a process that generates voids within carbonate rocks through the dissolution of both skeletal and non-skeletal granular components, often driven by their low instability. Additional factors such as pressure, temperature, low pH, rock fracturing, and water composition also play a significant role (Milliman, 1974). This process can partially or entirely dissolve carbonate elements like grains and matrix, with the resulting voids often mirroring the shape of the dissolved material, which can vary depending on fossil type. These voids may remain unfilled or be filled by secondary cement. Dissolution is especially intense in grains composed of unstable minerals such as aragonite and high-magnesium calcite (Boggs, 2006). Features like vugs and pores suggest formation under conditions influenced by magnesium-rich waters (Garcia et al., 2023). Dissolution is crucial for enhancing reservoir properties by increasing both porosity and permeability. In the Baba Formation, dissolution was particularly evident in the shells of benthic foraminifera, which experienced partial or complete dissolution, resulting in moldic porosity. It was also observed in the micritic matrix, where it produced vuggy porosity in the formation rocks. This process was especially prominent in the upper and lower sections of well BH-80. The types of porosity were classified using the descriptive system by Choquette and Pray (1970).

3.3.2.1. Intraparticle porosity

This type of porosity forms within fossil cavities and is found in the lower parts of the Baba Formation in well BH-80 (Plate 3.c) and the lower parts of the Bajawan Formation in well BH-194 (Plate 3. c).

3.3.2.2. Channel porosity

This type of porosity is found in the upper part of the Bajawan Formation in well BH-193 and the lower part of the Baba Formation in well BH-80 (Plate 3.b). It consists of elongated voids within the rocks of varying sizes, ranging from large to small. These are secondary in origin and are sometimes filled with microspar cement.

3.3.2.3. Vuggy porosity

This is one of the most common types of porosity found throughout the sequences of both formations in wells BH-193 and BH-80m (Plate 3.e). It results from the irregular distribution of dissolution effects during early and late diagenetic stages. Vugs are present in varying sizes and shapes within the foundation of both formations.

3.3.2.4. Fracture porosity

This secondary porosity is distributed across various depths of the formation in wells BH-80 and BH-193 (Plate 3. f). It results from tectonic activities (Hussain and Ibrahim, 2023) and rock fracturing during different stages, in addition to compaction and dissolution processes (Selley, 1998).

3.3.3. Micritization

Micritization represents a late, heterogeneous chemical diagenetic process. According to Bathurst (1975), it occurs as grains are coated with a micritic layer that forms through the deposition of micrite in the pores on the external surfaces of grains, typically after the death of marine organisms. The micritization process can affect the entire grain, not only the external surface but also extending into the internal parts of the grain, giving it a texture resembling peloids. Micritization generally occurs due to the influence of algae and bacteria, which impact the surfaces of carbonate grains. This process is commonly observed in modern depositional environments and marine phreatic settings (Bathurst, 1975). This phenomenon has been observed on the upper surface of most fossil shells, especially in benthic foraminifera shells, in most parts of the Bajawan Formation from well BH-194 (Plate 4.a).

3.3.4. Dolomitization

Dolomitization is one of the most important and complex heterogeneous chemical diagenetic processes. It occurs as magnesium ions (Mg) replace calcium ions (Ca), partially or completely converting limestone to dolomite through interaction with Mg-rich waters. Dolomitization involves three stages: late, syn-depositional, and early stages (Kaldi and Gidman, 1982). Late-stage dolomitization occurs after sediment lithification and burial, but it may also occur concurrently with sedimentary processes or during early depositional stages. Dolomitization takes place in both continental and marine waters, as well as in mixed-water zones where meteoric waters blend with high-salinity waters (Warren, 2000). It is influenced by several factors, such as temperature, increased Mg/Ca ratio (Land, 1967), along with other factors like flowing solutions, pressure, rock permeability, and rock chemistry. Due to the diversity of natural dolomite textures, dolomitization lacks a unified explanation (Nader et al., 2004), and there is no single model to explain all types of dolomite (Zenger and Dunham., 1980; Dunham, 1962).

Dolomite rocks constitute about 50% of the world's petroleum reservoir rocks (Warren, 2000). Al-Sinawi et al. (2017) also indicated that dolomitization is a significant process affecting the characteristics of oil reservoir rocks. Ameen (2008) pointed out that dolomitization reduces sediment thickness by half, thereby increasing porosity. Dolomitization occurs extensively in limestone rocks with high organic content (Mazzullo, 2000). This process is one of the most influential on the studied rocks, as dolomitization was observed in the lower parts of the Baba Formation in well BH-80 (Plate 4. b and c).

3.3.5. Compaction

Compaction is a late-stage, chemically homogeneous diagenetic process that leads to the deformation of sedimentary components and the overall reduction in the volume of sediments. One of the main factors affecting compaction is the weight of the overlying sediments and the depth of burial, which causes the reduction in grain size from coarse to fine, thereby decreasing the thickness and primary porosity of the rocks (Chilingar et al., 1967). According to Flugel (1982, 2004), compaction decreases due to the early cementation of sediments.

Compaction can be either chemical, involving pressure solutions that dissolve parts of the components, or mechanical, which compresses grain size as a result of their reorganization and packing. These two types of compaction are common in deep marine environments, where fractures and dissolving solutions contribute to porosity reduction. At the points of contact between grains, zones of weakness form, leading to the development of stylolites (Flugel, 2004). Here is a brief description of these two types:

3.3.5.1. Mechanical compaction

This process involves the breaking and deformation of structural grains due to the weight of overlying sediments, leading to reduced permeability and porosity. Mechanical of compaction depends on the compressive force acting on the grains and void spaces (Taylor, 1950). In the current study, mechanical compaction was observed only in well BH-193 (Plate 4.d).

3.3.5.2. Chemical compaction

This is a diagenetic process in which pressure solution surfaces, known as stylolites, are formed. Several factors control this process, such as the chemical composition of the solutions, burial depth, tectonic stress, and vertical stress resulting from the weight of overlying sediments, in addition to the nature, size, and surface characteristics of the grains. Stylolites are considered one of the most prominent features of sediments subjected to chemical compaction, appearing as undulating, serrated surfaces where insoluble residue accumulates within the deposits. This process is considered late-stage because it only occurs after sedimentation and burial are complete. This phenomenon is commonly observed in micritic rocks, where it cuts through both grains and the matrix (Flugel, 1982). One type of stylolite has been identified in the studied wells based on the classification of Logan and Semeniuk (1976) and Flugel (2004).

3.3.5.2.1. Smooth stylolite

This type of stylolite is free of undulations. It was observed in the lower part of the Bajawan Formation in well BH-80 (Plate 4.e).

3.3.5.2.2. Low-amplitude peaks stylolite:

This type is characterized by low-amplitude undulations with low peaks. It was identified in the lower part of the Baba Formation in well BH-80 (Plate 4.f).

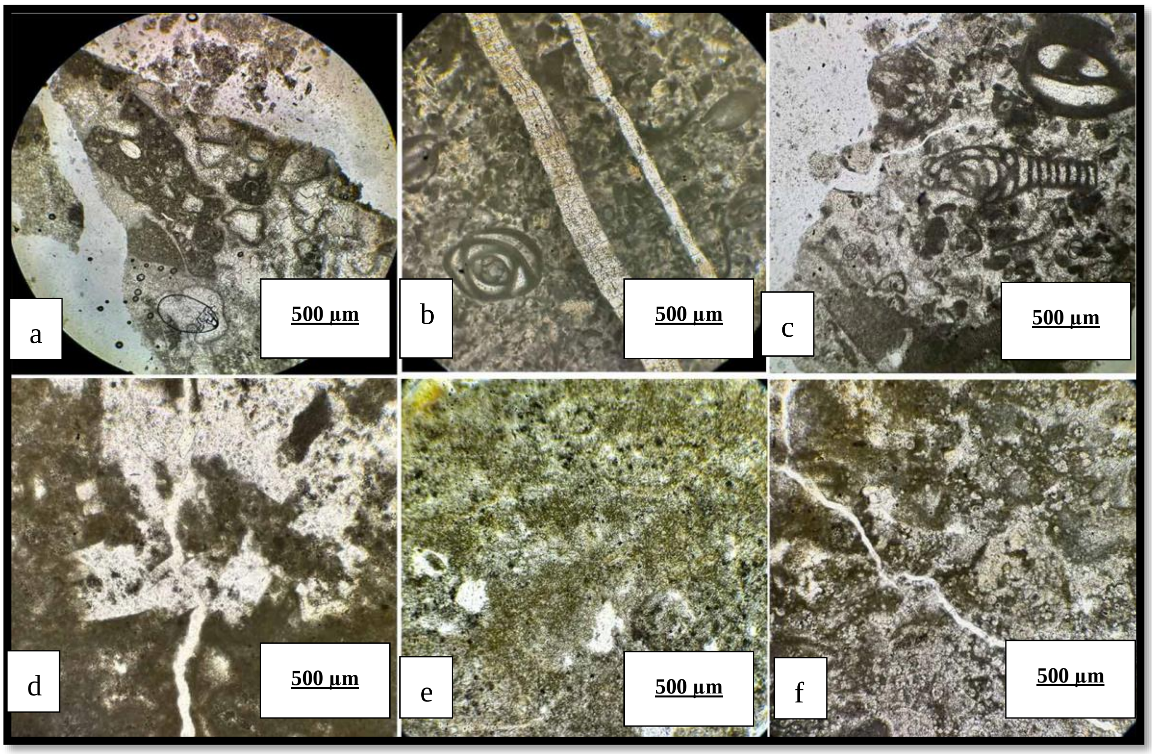

Plate 3. Diagenetic processes of Bajwan and Baba formations: (a) Drusy cement, well BH-194 at depth 1394 m. (b) Blocky cement , well BH-193 at depth 886 m. (c) Intraparticle porosity ،well BH-194 at depth 1382 m. (d) Channel porosity, well BH-80 at depth 1384 m. (e) Vuggy porosity, well BH-80 at depth 1360 m. (f) Fracture porosity, well BH-80 at depth 1348 m

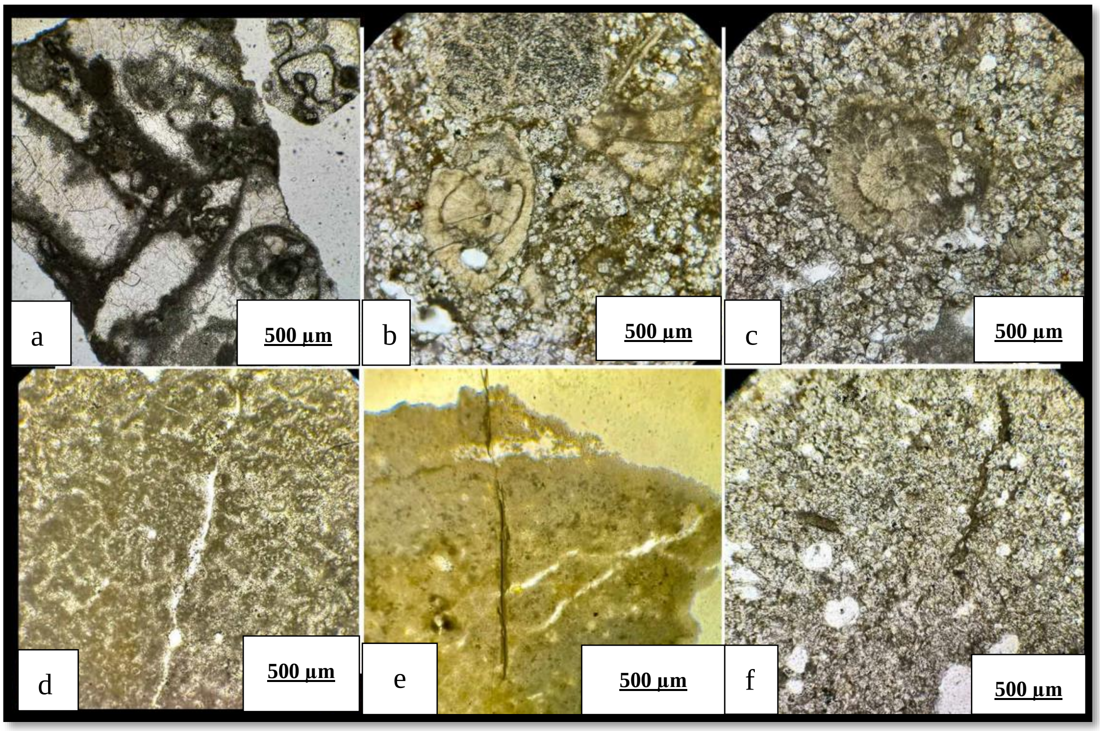

Plate 4 . Diagenetic processes of Bajwan and Baba formations: (a) Micritization, well BH-194 at depth 1374 m. (b) Dolomaitization, well BH-80 at depth 1418 m. (c) Dolomaitization, well BH-80 at depth 1416 m. (d) Mechanical compaction, well BH-193 at depth 912 m. (e) Smooth stylolite , well BH-80 at depth 1322 m. (f) Low-amplitude peak stylolite , well BH-80 at depth 1406 m

4. Conclusions

This study examines the Baba and Bajawan formations (Oligocene) in the northwest of Kirkuk City, northern Iraq, through the analysis of samples taken from three main wells: BH-80, BH-193, and BH-194. The Bajawan Formation, in the representative section of well BH-194, primarily consists of limestone that is rich in pyrite, marly, medium-hard, porous, and crystalline. The lower part, which interlaces with the Baba Formation, consists of gray limestone that is medium-hard, dolomitic, contains vugs, and is porous. On the other hand, the Baba Formation consists of porous dolomitic limestone that contains vugs. The Baba Formation lies above the Tarjil Formation, which is 12 m thick and composed of brown limestone that is medium-hard, crystalline, porous, and marly.

The study identified five main micofacies, homogeneous, non-fossiliferous lime mudstone, wackestone, packstone, grainstone and coralline algae boundstone. These microfacies were subdivided into eight secondary facies. Through the microfacies analysis of the studied sections, a significant presence of benthic foraminiferal such as Nummulites, Lepidocyclina, Miliolids, and corals was observed, indicating a shallow marine environment. Based on the identified microfacies, the Bajawan Formation is interpreted to have been deposited in shallow marine waters within lagoon-back reef environments with normal salinity, moderate energy, and semi-restricted conditions near tidal flats. In contrast, the Baba Formation was deposited in calm, low-energy waters with relative depths within back reef (shallow lagoons), reef, and fore-reef environments. The study revealed that both formations were affected by several diagenetic processes, including cementation, dissolution, compaction, dolomitization, and micritization.

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