Microfacies Analysis and Depositional Environment of the Mishrif Formation at Selected Wells in E Oilfield, Southern Iraq

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Abstract

The Mishrif Formation is an important succession that was deposited during the Cenomanian–Early Turonian. More than 79 thin sections of core in addition to well log data for the Mishrif Formation from 2 boreholes within the E oilfield (E-1, and E- 2) were used to determine the different associations facies to interpret the depositional environment of the Mishrif Formation. Six major microfacies were diagnosed the Mishrif Formation, Mudstone, Wackestone, Packstone, Grainstone, Boundedstone, and Rudstone and ten submicrofacies include: Bioclastic Packstone submicrofacies with rich Echinodermat, Coral and Rudist fragment and high Dolomitization, Rudstone submicrofacies with large Rudist fragment and vug porosity, Boundstone submicrofacies with very large coral, Plankton Foraminiferal Packstone submicrofacies with the Globigerinellinoides and Calcispheres, Bioclastic Wackestone to Packstone submicrofacies with dolomite and calcareous algae, Peloidal Packstone with coral, pillows, pieces of Rudist and Separate-Vug pore, Bioclastic Packstone to Grainstone submicrofacies, Peloidal to Bioclastic Packstone submicrofacies, Benthonic Foraminiferal Mudstone submicrofacies, Rudist fragmented Mudstone. These microfacies were deposited in restricted, shoal, shallow open marine, rudist bioherm, and deep marine environments.

Keywords: Microfacies analysis; Depositional environment; Mishrif Formation; Southern Iraq

1. Introduction

The Cretaceous rocks in Iraq and the Middle East which represent a distinguished location within the stratigraphic column, so the formations of this period represent rocks with good oil potential, some of them are source rocks that generate hydrocarbons, and others are oil reservoirs, many researchers are interested in studying the formations of this period in Iraq in view of the oil potential and the good quality of the rocks of the Cretaceous period in general and the rocks of the Mishrif Formation in particular. This study came to complement the previous studies in the E oilfield and is one of the new oilfields in southern Iraq. The Mishrif Formation is one of the formations of the sedimentary cycle Late Cenomanian–Early Turonian and one of the most important reservoirs in the Mesopotamian basin in central and southern Iraq (Al-Nagib, 1967).

The E oilfield is located in the southwestern part within the administrative wells of Al-Muthanna Governorate, 35 km southeast from the center of Samawah City and 50 km from the center of Nasiriya City (Fig. 1). The Block-10 contract area has never been drill tested. In this study, two oil wells were selected for the Mishrif Formation in the E oilfield in southern Iraq, which is considered one of the main
reservoirs in the oilfield to study the paleontology and diagenetic processes to deduce the sedimentary environment of the formation.

The first to describe the Mishrif Formation is Rabanit (1952) where it is described in the type section of Zb-3 within the upper part of what was called the Khutiah Formation within the Wesea Group, which includes the Ahmadi, Rumaila and Mishrif formations. Al-Zaidy and Al-Shwaliy (2018) described the microfacies analysis and basin development of the Cenomanian- Early Turonian Sequence in the Rafai, Noor and Halfaya oilfields. Mishrif was mainly interpreted as the seal and the reservoir; in southern Iraq, it is represented by a shallow environment, mostly by rudist reef facies, which marks the regression (Al-Mimar et al., 2018).

In Iraq, the Mishrif Formation was formed as a result of both tectonism and eustasy. The Mishrif Formation fits within the Albain- Early Turonian Supersequence IV of Iraq's Cretaceous sequence-stratigraphic framework, according to Aqrawi et al. (2010). This refers to Megasequence AP8, which was deposited on the Arabian Plate's passive (Sharland et al., 2001).

Each of these subzones may be identified by structural highs and lows with different trends that were created during the deformation of the northern Tethyan border of the Arabian Plate between the Cenomanian and Early Turonian (Jassim and Goff, 2006). Negative gravity residuals are found under a number of supergiant oilfield formations, including Zubair, Rumaila, and Nahr Umr, indicating that salt diapirism is the source of numerous structures in southern Iraq (Jassim and Goff, 2006; Aqrawi et al., 2010). Early Jurassic time is when some of these structures first started to emerge (e.g., Al-Sakini, 1992; Sadooni and Aqrawi, 2000).

The Mishrif Formation was deposited in the Early Cenomanian cycle, the second depositional cycle of strata previously known as the Middle Cretaceous, in the Mesopotamian Basin and southern and central Iraq. Buday (1980) divided the sequence into two sedimentary cycles. The Cenomanian-Early Turonian cycle begins with the deposition of the Rumaila Formation during the period of marine transgression in the cycle and is topped by the deposition of the Rumaila Formation, which consists of limestone and chalky, graduating in turn upwards to the Mishrif Formation during the period of marine regression in the Late Cenomanian-Early–Turonian. The gradient, in turn, leads upwards to the Khasib Formation containing high evaporites, which overhangs the Mishrif Formation. Awadees et al. (2018) divided the Cenomanian-Early–Turonian mega-sequence into seven 4 order genetic - meso sequences , each containing 5 order lithofacies cycles.

Where the Mishrif Formation takes its stratigraphic position between the Khasib Formations from above and is bordered by the Rumaila Formation from the lower, where the contact between them is gradual, it may sometimes be difficult to distinguish between the rock units of these two formations. It should be noted that the anhydrite facies of the Kifil Formation symmetrically cover the facies of the Mishrif Formation in some wells in southern and central Iraq, which in turn represents the last stage of marine retreat and the end of the sedimentary cycle (Chatton and Hart, 1962).

This study aims to analysis facies and depositional environmental interpretation aiming towards a better understanding of the depositional setting, and determine digenesis processes that effect on the Mishrif Formation.

2. Methodology

The current study was carried out by collecting 79 core rock samples from Mishrif Formation from the Oil Exploration Company's laboratories to the studied wells. Where a large number of rock slides were examined by polarizing light microscope, 39 thin sections from E-1 and 40 from E-2 were examined, and describing the samples under the microscope. Followed by the collection of preliminary information from the final reports of the wells of the study area, and using the application of microfacies analysis to interpret the stratigraphic analysis determine the sedimentary environment of Mishrif
Formation and studying the different types of porous and diagenetic processes under the microscope. It was investigated to what extent major and minor microfacies, diagenetic processes variables, porosity types, and evolution existed. To further aid in the identification and correlation of facies, well logs, GR, and sonic logs were combined with microfacies. The gamma ray and sonic logs that were accessible, together with stratigraphic correlation, were used to anticipate and correlate the lithological units, reservoir units, and sedimentary facies.

Fig. 1. Tectonic map of Iraq with the location of E oilfield, Cenomanian-Early Turonian Palaeogeography (Aqrawi, 2010).

3. Results and Discussion

3.1 Petrography

The succession of the Mishrif Formation was subjected to a facies study through the study of microfacies because of its special importance in giving a clear picture of the sedimentary environments and diagenetic processes of any calcareous formation. A sedimentary facies is defined as a rocky body with certain lithological characteristics, such as granular size, mineral composition, sedimentary structures, etc., that distinguish it from other facies.
Therefore, the current study tended to study the fine facies under the microscope to show the type of microfacies, the effective transformational processes, and to identify the sedimentary environments and the facies discovered in this study were traced vertically using well logs (Sonic and Gamma ray). The classification used in this study is the Dunham (1962), Wilson (1975), and Flugel (2010), for its ease of application on the facies of the study area and for its usefulness in showing different types of sedimentary texture depending on the clay or granular support. Their characteristic skeletal and non-skeletal grain types in Mishrif Formation. Skeletal grains are one of the most important and widespread constituents of the Mishrif Formation. They consist of whole fossilized organism’s foraminifera, bioclasts, or fragments encased in varying degrees of abrasiveness (Boggs, 2009).

In recent years, oil and gas scientists have achieved particularly outstanding results in the search for oil and gas, helping to more clearly define the Cretaceous succession and its evolution in various palaeogeographical domains. Rudists and their derived bioclasts play an important role as the main fossil constituents of many sedimentary reservoirs found in Cretaceous carbonate rocks (Cestari and sartario, 1995).

Rudist represents an important fossil index and contributes to the construction of the Mishrif strata. It is clearly visible in the E-I well. Fragments ranging from small to large were found. Foraminifera is a marine protozoan. Some genera are found in hypersaline or subsaline marginal waters, where they are abundant but species diversity is low (Scholle and Ulmer-Scholle, 2003) (plates1-C and 2-E).

Benthic foraminifera are the main constituents of the rocks of the Mishrif Formation and are present in front and back reefs as well as in slope and shoal environments. It frequently occurs with corals, algae, Textularia, Nezzazata, and Milliode are examples of common benthic foraminifera found in the thin sections analyzed. Planktonic foraminifera were abundant in the lower Mishrif Formation, and they were restricted to specific depths within the formation as the depositional environment deepened such as Calcispheres, Echinoderms, Globigerinelloides, Heterohelix, and Hedbergella (plats 2-B and 3-E).

The Mishrif Formation is rich in calcareous algae, especially in the form of green algae. Corals are very common in the Mishrif succession and, together with corals, have made an important contribution to the construction of the Mishrif carbonate platform. The emergence of corals was almost related to the high effect of recrystallization and cementation, destroying the porosity within the corals (plate 2-F).

Non-skeletonized grains are those that do not appear to have been derived from microbial skeletal material. They are less dominant in the Mishrif Formation, represented by spheroids and oolitics. Peloid is in the form of spherical or oval particles and is widely used in most studies. It is composed of microcrystalline calcite with a diameter of 0.2-1 mm and internal structures of other shapes (Tuker, 1990; Flugel, 1982), and is distributed in shallow coral reefs and silt mounds on carbonate ledges in tropical and subtropical seas (Flugel, 2004), they have multiple origins and may be the result of bioclastic aversive processes or bioclastic feces (plates 1-D and 1-E).

Fine-Grained Carbonate Matrix (Groundmass) The floor consists mainly of fine-crystalline calcite called micrites, which is small crystals whose diameter does not exceed (4) microns and often appears opaque under the microscope. If its diameter exceeds (5) microns, it is called sparry calcite. The (Micrites) is deposited in an environment with calm sedimentation energy, while Sparry Calicite is deposited in an environment with high sedimentation energy (Flugel, 1982).
Plate 1. A: Boundstone microfacies with coral (E-1 depth 1841.15 m) B: Fossiliferous Wackestone with Dissolution (E-2 depth 1837.05 m) C: Rudstone with rudist fragment (E-1 depth 1814.30 m) D: Peloidal Packstone with pieces of Foraminiferal and Dolomitization (E-2 depth 1838.95 m) E: Bioclastic packstone to Grainstone with peloidal and coral fragment (E-2 depth 1843.4 m) F: Bioclastic wackestone to Packstone (E-2 depth 1855.40 m)

3.2. Diagenetic processes

Physical, chemical, and biological processes refer to diagenesis. Carbonate minerals generally are more sensitive than most silicate minerals to diagenesis changes, such as dissolution, recrystallization, and replacement. Therefore, the petrophysical properties of the diagenetic processes and their impacts clarify the Mishrif Formation rocks.

Types of porosity in Mishrif Formation consisting of Interpartical Porosity It is what gives porosity to the groundmass of the rock, depending on the size and sorting of the grains or crystals and their degree of crystallization. It has been observed in the study area within some packstone facies and the wackstone, but in a small amount, Vuggy Porosity this type of porosity is the result of dissolution that is
irregular in shape and size, and in turn is divided into two main types: Separate-Vug pore space, and Vug pore space.

Plate 2. A: Channel Porosity (E-2 depth 1868.50 m) B: Nezzazata (E-2 depth 1881.81 m) C: Globigerinelloides and Calcspheres (E-2 depth 1909.3 m) D: Algae (E-2 depth 1888.8m) E: Rudist Fragmented mudstone with Intrafossils Porosity (E-2 depth 1866.30m) F: Echinoderma and Calcareous alga (E-2 depth 1891.90 m)

The first type consists of moldic porosity and intrafossils porosity. The second type consists of solution enlarged fracture porosity and fracture porosity, intercrystalline porosity and channel porosity. This process (porosity and canal porosity) was diagnosed in the lower part and to a lesser extent in the upper part of the Mishrif Formation (panel 1-b) (plates 2-E, 3-A and 4-F).

There are many important diagenetic processes observed in this study. After the carbonate deposits are deposited, the organisms decompose the solid particles and other carbonaceous materials. This process micritization results in fine-grained precipitation. However, decomposition has been included here as a very early action because it causes changes in previously formed sediments. The most important type of biological modification of sediments results from the grazing activities of organisms. Drilling by algae, fungi, and bacteria is a particularly important process for the modification of structural materials and carbonate grains (Boggs, 2009). In the upper part of the Mishrif Formation and to a lesser degree in the lower part, this process (micritization) was identified (plate 4-D).
Compaction represents the mechanical and chemical reactions that occur due to increased silt loading and increased temperature and pressure conditions during maintenance. A suture is a suture thread whose surface is usually covered with an insoluble material such as clay or organic debris. Sutures are usually parallel to the sediment, but may also occur as bedding at different angles, thus generating reticular or nodular confinement patterns (Ahr, 2008) (plate 3-D).

Dissolution and insufficient saturation of carbonate pores leads to dissociation of metastable carbonate grains and cements in shallow atmospheric environments, deep ocean and cold water (Steinsund and Hald, 1994; Berelson et al., 1994). The obvious result of this process is in the middle part in the Mishrif Formation (plate 1-B).

Plate 3. A: Bioclastic Packstone with Intergranular porosity (E-2 depth1888.80m) B: Rudstone (E-1 depth 1783 m) C: Bioclastic Wackestone to Packstone (E-2 depth 1904.20m) D: Mudstone with Compaction (E-2 depth 1901.01 m) E:Benthonic foraminifera mudstone (E-2 depth 1847.95 m) F: Dolomitization (E-2 depth 1783.95 m)

Recrystallization this refers to changes in crystal size, crystal shape, and crystal lattice orientation without changes in mineralogy (Flugel, 2004; Alsultan et al., 2022). This process affects the evolution of some parts of micrites to microsparite in the Mishrif Formation. This process was characterized in the lower parts of the Mishrif Formation within the studied wells (plate 4-C).

Dolomitization is the conversion of limestone to dolomite, which takes place when magnesium carbonate replaces the initial calcium carbonate by the action of magnesium-bearing water (Flugel,
2004). When compaction and cementation processes are absent, late diagenetic dolomitization enhances the porosity of the rocks, improving reservoir quality (Moore, 2001). Within the studied wells, dolomitization was identified in the upper and middle parts of the Mishrif Formation (plates 1-D, 3-F and 4-A).

Cementation this process is defined according to Flugel (1982) as the process of chemical precipitation of calcium carbonate from a saturated solution present in the primary pores between the structural grains or secondary fractures created by the solution during the solution process, thus it leads to the growth of calcite crystals, thereby affecting the coagulation and consolidation of sediments, thereby reducing porosity and permeability. Awadh et al. (2018) showed that the salinity of the brines in Mishref is six times higher than the current sea water, as the highest salinity was recorded in the MJ field and the lowest in the WQ field. Flugel (1982) divided cement to equivalent granular cement, drusy mosaic cement, blocky cement, spary calcite cement. The obvious result of this process is in the Lower part in the Mishrif Formation (plates 4-B, 4-C and 4-E).

Plate 4. A: Dolomitization with rudist fragment (E-1 depth 1775.5 m) B: Equivalent granular cement (E-1 depth 1810.75 m) C: Recrystallization- blocky cement (E-2 depth 1904.2 m) D: Micritization (E-1 depth 1807.8 m) E: Blocky cement (E-2 depth 1833.35 m) F: Vugs porosity (E-2 depth 1837.05 m)

3.3. Depositional Environment

A depositional environment is defined as a specific portion of the Earth's surface geographical environment in which sediments are deposited, characterized by complex physical, chemical, and living
conditions that distinguish them from other environments (Selley, 1978). Facies are associated with each facies the overlapping of others, their vertical and lateral succession is the result of lateral changes in the depositional environment, so what is the difference. Except those sediments, especially carbonate rocks, are affected by depositional environmental conditions, such as water energy, salinity, temperature and other factors. As well as the influence of climate, these factors play a fundamental role in the generation and distribution of carbonate rock deposits (Alsultan et al., 2022). It can be seen from the above that the depositional environment of the core-containing borehole can be identified by delineating the core and preparing rock thin sections to identify the primary and secondary microfacies, and then linking these microfacies with the depositional environment for identification (Alsultan et al., 2021). Five association facies were distinguished: Deep Marine, Shallow open marine, Rudist Biosstone, Shoal and Restricted Marine. Each of these faces represents a different sedimentary environment. The vertical stacking of these correlations with their descriptions in the study wells is shown in Figs. 2 and 3.

3.3.1. Deep marine Environment

The facies of this environment consist of the Wackestone containing the crumbs of the neighborhoods located between the facies of the open sea and the facies of the shoal environment. The facies of this environment are characterized by a small thickness and intermittent extension. The facies of this environments are Planktonic Foraminiferal Packstone, Bioclastic Wackestone to Packstone, Fossiliferous Wackestone with dissolution and the carrying planktonic foraminifera such us Calcispheres, Echinoderms, Globigerinelloides, Heterohelix, Hedbergella and Bioclastic Packstone (plates 1-B, 1-F and 3-C) (Figs. 2 and 3). When comparing this facies with the standard microfacies (Flugel, 1982), they resemble the facies deposited within the FZ-1 facies range.

3.3.2. Shallow open marine environment

It represents a transitional environment between the facies of the Mishrif formation, as sediments abound in the deep regions. Among the microfacies characteristic of this sedimentary environment are the Bioclastic Packstone, Peloidal to Bioclastic packstone (plate 3-A), Peloidal packstone facies, and the carrying benthonic foraminifera such us Textularia, Nezzazata, Milliode and bioclastic crumbs. It is distinctively downslope and seaward of the rudist biostrome habitat. Mostly bioclastic wackestones and packstones make up its texture. A particular form of bioclast may regionally predominate at different stages within the succession, particularly the rudist bioclasts (plates 4-A and B), which appear as well-worn (sand-size or coarser) angular or tabular grains. The bioclasts range in size from silt to sand and, in some circumstances, are even coarser. Benthonic foraminifera like Dicyclina and Praevalveolina, calcareous green algae, coral and coralline algae, echinoderms (plate 2-F), and gastropods are some of the more significant fossils. Less often found were brachiopods and pelagic foraminifera. The shallow open marine facies association was formed on the foreslope portion of the Mishrif carbonate platform, and its sediments are mostly made up of bioclasts that were created when rudist biostromes were destroyed by tidal currents or storms. In the Mishrif Formation, the shallow open marine facies is one of the more prevalent facies in the wells studied (Figs. 2 and 3).

3.3.3. Shoal Environment

The shoal environment is characterized by significant tidal current and wave activity near the seaward border of the carbonate substrate. Deposition depths are less than 5-10 meters above wave-base in this environment (Tucker, 1985). This environment is characterized by the facies of of Grainston to Packstone rich in pieces of bioclastic fragments (plate 1-D), and the facies of Peloidal Packstone (plate 1-E) that bears Peloids with the standard (Flugel, 1982) we find that it falls within the facies of SMF- 13 within the range FZ- 6.
Fig. 2. Microfacies succession and depositional environment of Mishrif Formation in E-1 well

3.3.4. Rudist Bioherm Environment

The facies of this environment are characterized by the presence of large sized pieces of rudest fragments deposited in facies ranging from Rudstone with a few algae and corals. The facies of the Boundstone facies it has a high initial porosity affected by the secondary dissolution process leading to the development of primary porosity, and when comparing the facies of this environment with the
standard (Flugel, 1982) we find that it falls within the facies of SMF- 7 within the range FZ- 5 (plates 1-A, 1-C and 2-E) (Figs. 2 and 3).

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Fig. 3. Microfacies succession and depositional environment of Mishrif Formation in E-2 well

3.3.5. Restricted marine environment

Benthic foraminiferal mudstone constitutes the main body of this facies relationship, *Nezzazata*, *Textularia* and many more benthic foraminifera are diverse. Other fossils found include coral fragments and red coral fragments. The matrix is basically fine mudstone, in some cases containing a large amount of argillaceous material. In lagoon environments, this pattern can be observed by comparing the facies
of that environment with facies (Flugel, 1982) we find that it falls within the facies of SMF-23 and SMF-16 within the range FZ-8 (plates 3-D and 3-E) (Figs. 2 and 3).

4. Conclusions

Six major microfacies and ten secondary microfacies were identified for the Mishrif Formation in the E oilfield. They are Bioclastic Packstone, Rudstone, Boundstone large Rudist fragment, Plankton Foraminiferal Packstone, Bioclastic Wackestone to Packstone, Peloidal Packstone, Bioclastic Packstone to Grainstone, Peloidal to Bioclastic Packstone, Benthonic Foraminiferal Mudstone Packstone, Bioclastic Packstone to Grainstone, Peloidal to Bioclastic Packstone, Benthonic Foraminiferal Mudstone, and Rudist fragmented Mudstone. These microfacies were deposited in restricted, shoal, shallow open marine, rudist biocerm, and deep marine environments, which indicates a clear variation in sea level and tectonic activity that accompanied the sedimentation process.

There are six diagenetic processes affected by the configuration of the Mishrif Formation: micritization, dissolution, compaction, recrystallization, dolomitization, cementation. Different types of pores in the thin section (rock slides) have been distinguished: interpartical Porosity, Vuggy Porosity, intercrystallite porosity, Channel Porosity.

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References


