FACIES ARCHITECTURE, DIAGENESIS AND PALEOCEANOGRAPHY OF MISHRIF (LATE CRETACEOUS) IN SELECTED WELLS OF WEST QURNA OIL FIELD, SOUTHERN IRAQ

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ABSTRACT

The Cretaceous is consider as very substantial period especially in middle and south of Iraq inasmuch of hydrocarbon content along his rock succession. In present work, the Mishrif Formation was studied in well 220 and well 280 of West Qurna oil field, Southern Iraq, the examination of the hand specimens of the formation rocks indicates recrystallized vuggy limestone in well 220 and recrystallized limestone in well 280. Twenty-four core samples distributed equally over the two wells were collected and prepared for microscope examination. Six main types of microfacies were found in both wells, these are: lime mudstone, wackestone, packstone, grainstone, rudstone and grapestone; and four submicrofacies these are: bioclast wackestone, benthic forams wackestone, bioclast packstone and peloidal packstone. The diagenetic processes include: cementation, dolomitization, compaction, dissolution and porosity. The microfacies examination reflect facies zone (7, 8 and 9A) which indicate deposition in the (evaporitic to the open marine) platform interior environment.

Keywords: Cretaceous, Diagenesis, Foraminifera, Microfacies, Mishrif

INTRODUCTION

Mishrif Formation (late Cretaceous) represents a substantial hydrocarbon reservoir in southern Iraq and has an ample distribution in the Middle East and widespread in the Arabian Gulf region, it’s a carbonate reservoir in the south and center of Iraq, and considers as a part of the Wasia Group, (Al-Kilaby, 2009). (Rabanit, 1952) was first who described the formation in unpublished report, later; the type locality and full description is by (Owen and Nasr, 1958) in well Zubair 3 south of Iraq, the lithology consists of: a fine-grained, limestone underlie by grey to white,
dense, algal limestone with stylolite and fossil debris, the lower part is shelly and foraminiferal limestone with rudist (Bellen et al., 1959). (Chatton and Hart, 1961) and (Buday, 1980) described the Mishrif Formation as detrital shallow marine carbonate of Cenomanian-Early Turonian. The description is same as above introduced by Jassim and Goff (2006). Mishrif Formation is a carbonate sequence precipitated in shallow open marine carbonates deposited in the Middle Cenomanian-Lower Turonian cycle. It is represented in many oil fields such as, West Qurna, Rumaila, Halfaya, Amara, Buzergan, Majnoon and Nasiriya (Jassim and Goff, 2006).

Mishrif Formation is due to progressive sedimentation on shoaly carbonate shelf that evolved through the Mid-Cretaceous in Southern Iraq. The lithology of the formation composed of different grains (skeletal and non-skeletal) and micrite. Non skeletal grains are intraclasts and peloids whereas skeletal grains consist of foraminifera (Benthonic, Planktonic), molluscs, ostracods and echinoderms, (Al-Kilaby, 2009). The formation under study represents about 35% of the total hydrocarbons in Iraq (Aqrawi et al. 2010). Mishrif Formation contains about 40% of Iraqi hydrocarbon of Cretaceous period (Aqrawi et al. 1998; Al-Dabbas et al., 2010).

Mid-Cretaceous succession south of Iraq contains two cycles, these are Mishrif and Rumaila formations (Buday 1980). A gradational contact separate Rumaila and Mishrif Formations. The Mishrif Formation in West Qurna oil field is overlain by Khasib Formation, and the Kifil Formation is missing (Aqrawi 1995; Al-Dabbas et al., 2010). The Thickness of the formation is 350 to 400 m in south-east close to the Iranian border and thinning out in the west and south-west (Ali-Siddiqi, 1978).

Mishrif Formation acquires special importance because it’s petrographic and petrophysical characteristics make it an oil reservoir. According to Al-Zaidy (2019) the microfacies of Mishrif Formation is bioclastic or foraminiferal bioclastic wackestones and packstones reflect shallow open marine and a very coarse-grained bioclastic rudstone and floatstone existed in the uppermost of the Mishrif Formation in the Rf-1and No-1 wells. In the present work, the Mishrif Formation is studied in wells West Qurna (WQ-220) (92 m) and (WQ-280) (98 m) of West Qurna oil field, Southern Iraq. The study area is located in West Qurna oil field, Basra Governorate, south of Iraq (map 1). According to Tectonic division of Iraq by Jassim and Goff (2006) the area is located in the Mesopotamian Zone which is part of the Stable Shelf, the coordinates of the two wells is (31°.03´.38´´) N; (47°.15´.19´´) E for WQ-220 and (30°.51´.39´´) N; (47°.17´.02´´) E for WQ-280. This work is aim to microfacies and diagenetic processes analysis and reconstruct the paleoceanography of Mishrif Formation.

DATA AND METHODS

There are 24 core samples collected from the South Oil Company (SOC) distributed equally along the two wells, these samples were used to prepare thin sections, the office work included a petrographic study under microscope type Leica (PN: DM 500) to examine the grains and groundmass in order to nomenclate the core sample, the microfacies are photographed using camera type Optika D9 (10 MP). Finally, three software were used; Arc GIS 10, Sedlog 3 and Corel 9 to draw the location map, plates and stratigraphic sections.
RESULTS

Microfacies analysis: Rock body with specified characteristics is called a facies. Ideally, facies are a unit of discriminated rock that deposited under special conditions sedimentation and indicate a specific process of the environment (Reading, 1996). The lithology, standard microfacies SMF, Facies zone FZ and environment of deposition of the studied sections are shown in the (figs. 1 and 2).
The modified classification of Dunham (1962) by Embry and Klovan (1971) were used figure (3) and the Cretaceous benthic foraminiferal distribution by BouDagher-Fadel (2008) figure (4) was also adopted to show the proper position of benthic foram. microfacies are matched with the models of standard microfacies and depositional environment zones of carbonate by (Flugel, 2010).

Skeletal grains

Skeletal grains represented the most dominant components within the Mishrif succession. These include: Foraminifera, Algae, bioclasts, and bivalve shells.

Foraminifera

Foraminifera are single-celled, protists where the cytoplasm is enclosed inside an organic or mineral shell called tests. The shells are composed of a single or multi chambers (Sen Gupta, 1999). Foraminifera were found in all marine environments and they are abundant and diverse in modern oceans They may be planktonic or benthonic in mode of life (Hemleben et al., 1989), therefore they are the most abundant in marine sediments and important as paleoecologic indicators (Imbrie and Kipp, 1971).
Map (1): Location of the studied wells
| Period   | Epoch | Age     | Formation | Depth (m) | Lithology | Facies type  | SMF | Facies Zone | Depositional environment [After Flügel, 2010] |
|----------|-------|---------|-----------|-----------|-----------|--------------|-----|-------------|---------------------------------------------|
| Cretaceous | Late  | Santonian | Marnifl  | 2550      | Bioclast  | wackestone   | 10  | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2575      | Bioclast  | wackestone   | 10  | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2600      | Bioclast  | wackestone   | 10  | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2550      | Bioclast  | packstone    | 6   | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2575      | Bioclast  | packstone    | 8   | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2600      | Bioclast  | packstone    | 8   | 7           | Platform interior (Open marine)            |
|          |       |         |           | 2600      | Rudist    | grainstone   | 12S | 8           | Platform interior (Restricted)             |
|          |       |         |           | 2600      | Rudist    | grainstone   | 12S | 8           | Platform interior (Restricted)             |

Figure (1): The lithology, SMF, FZ and environment of deposition of WQ-220
| Period  | Epoch | Age | Formation | Depth (m) | Lithology          | Facies type | SMF | Facies zone | Depositional environment (After Flügel, 2010) |
|---------|-------|-----|-----------|-----------|--------------------|-------------|-----|-------------|-----------------------------------------------|
| Cretaceous | Late | Santonian | Mishrif | 2475      | Lime mudstone      | 23          | 9A  | Platform interior (Evaporitic or Brackish)    |
|         |       |       |          | 2500      | Lime mudstone      | 23          | 9A  | Platform interior (Evaporitic or Brackish)    |
|         |       |       |          | 2525      | grapestone         | 17          | 8   | Platform interior (Restricted)                |
|         |       |       |          | 2550      | grapestone         | 17          | 8   | Platform interior (Restricted)                |
|         |       |       |          |           | Lime mudstone      | 23          | 9A  | Platform interior (Evaporitic or Brackish)    |
|         |       |       |          |           | Lithoclast rudstone| 24          | 8   | Platform interior (Restricted)                |
|         |       |       |          |           | Lime mudstone      | 23          | 9A  | Platform interior (Evaporitic or Brackish)    |
|         |       |       |          |           | Lime mudstone      | 23          | 9A  | Platform interior (Evaporitic or Brackish)    |
|         |       |       |          |           | peloidal packstone | 16-N        | 8   | Platform interior (Restricted)                |
|         |       |       |          |           | peloidal packstone | 16-N        | 8   | Platform interior (Restricted)                |
|         |       |       |          |           | peloidal packstone | 16-N        | 8   | Platform interior (Restricted)                |
|         |       |       |          |           | peloidal packstone | 16-N        | 8   | Platform interior (Restricted)                |

Figure (2): The lithology, SMF, FZ and environment of deposition of WQ-280
Benthonic Foraminifera

Benthonic Foraminifera are very abundant grains in Mishrif Formation indicating a shallow open marine environment and this abundance reflects shallow, well-lighted, temperate, little nutrition waters and suitable substrate with normal salinity (Hottinger, 1983; Murray, 1991; O’Connell et al., 2012). There are many types of benthic foraminifera recognized in the studied sections. These are *Orbitolina* sp. (Plt.1-A), *Miliolids* Pl. (1-B), *Cuneolina* sp. Pl.(1-C), *Lenticulina* Pl. (1-D), *Valvulammina* sp. Pl. (1-E), *Nezzazatinella* sp. Pl. (1-F), and *Maynsina* sp. Pl. (1-G).

Calcareous algae
The green Dasycladacean algae are also found in Well WQ-220 Plate (1-H). Calcareous algae exist in many kinds of environments; they are most abundant and varied in shoal, equatorial and subequatorial sediments (Flugel, 2010).

**Bioclasts**

Bioclast is the debris of organism results from transmission and robbing of fossils. The bioclast as an expression is applied for fossils under microscope, in any case alike the fossils are wrecked (broken shells) or biomorph (bivalves). Skeletal grain is equivalent to bioclast (Flugel, 2010). The main component of the bioclasts found in this study are clast of foraminifera, ostracods and shell fragments, Pl. (1-I).

**Non-skeletal grains**

**Peloids**

Peloids are subspherical grains without internal structure, composed of micrite and aquatic in origin, their size is very small (micron to millimeter) they are abundant in shoal, tidal and subtidal platform sediments and in reefs, and common in limestones of profound waters. Peloids are scarce or missing in non-equatorial cool water sediments. (Flugel, 2010), these particles reflect marine, hot and arid conditions (Reijers et al., 1983; Zeng et al., 1983., Moghadam and Khaksar, 2007). Pl. (1-J).

**Aggregate grains**

Aggregate grains are isolated ooids, bioclasts and other grains which linked with each other by organic envelope, its characterized by patchy form, they range between half and few millimeters (Flugel, 2010). They are abundant in shelf waters, and also in reef environment (Milliman, 1967) Pl. (1-K).

**Intraclast**

It is a lime fragments of consolidated or partly consolidated particles, came from the denudation of closely penecontemporaneous sediment from intraclast, extraclast, and Lithoclasts of a basin and reprecipitated inside the same basin, they existed in shoal ecosystem, but may move to inward water. The intraclasts are formed in shallow water environments which distinct by high energy system and tides which constantly rework lime sediments (Flugel, 2010) Pl. (1-L).

**Microfacies**

There are six main types of microfacies and four submicrofacies which distributed in the two wells, each type indicates deposition in a specific environment, these microfacies will discussed below:

**Lime mudstone microfacies**

This microfacies is distinct by non-laminated homogeneous micrite and occur only in the well WQ-280 at depths (2469-2477), (2506) and (2524-2533 m), it’s equivalent to SMF 23 and...
deposited in FZ 9A which indicates platform interior (evaporitic or brackish) depositional environment Pl. (2-A).

**Wackestone microfacies. This microfacies subdivided into two types:**

**A- bioclast wackestone submicrofacies**

This type of microfacies characterizes with bioclast abundant and some shell fragments, and found only in the well WQ-220 at depths (2510-2518 m), this microfacies corresponds standard microfacies SMF 10 according to (Flugel, 2010) and facies zone FZ 7 according to (Wilson, 1975) and indicates platform interior (open marine) depositional environment, this type of facies reflect quiet and low energy environment (Akinmosin and Osinowo, 2010).

**B- benthic forams wackestone submicrofacies**

This type of microfacies characterizes with abundance of benthic forams and little shell fragments, and found only in the well WQ-220 at depths (2587-2602 m), this microfacies corresponds SMF 10 and FZ 7 and indicates platform interior (open marine) depositional environment Pl. (2-B).

**Packstone microfacies. This microfacies subdivided into two types:**

**A- bioclast packstone submicrofacies**

This microfacies is occur in WQ-220 at depths (2525-2536 m) and (2561-2579 m) it characterized with shell fragments and few benthic forams Plate (2-C), and equivalent to SMF 8 and FZ 7 which indicates deposition in platform interior (open marine).

**B- peloidal packstone submicrofacies**

It’s occurred in WQ-280, at depths (2542-2567 m) and characterized by peloids abundance Plate (2-D), the exact SMF of this microfacies is 16-N and FZ 8 which indicates platform interior (restricted).

**Grainstone microfacies**

This microfacies occur only in well WQ-220 at depths (2547-2554 m) and characterized with abundant rudist and shell fragments and a few benthic forams and intraclasts Plate (2-E), it’s equal to SMF 12-S and deposited in FZ 8 which indicates platform interior (restricted) depositional environment.

**Rudstone microfacies**

This name is modified by (Embry and Klovan, 1971) to refer to grainstone with particle size more than 2 mm, in our case, the microfacies is characterized with intraclasts grains and very little of benthic forams Plate (1-L), it’s equivalent to SMF 24 and FZ 8, which was deposited in platform interior (restricted).

**Grapestone microfacies**
This microfacies is found only in well WQ-280 at depths (2488-2497 m) and characterized by abundance of aggregate grains distributed in lime and microspar matrix without any other grains like bioclast or biomorph Plate (1-K), the equivalent standard microfacies is 17 and facies zone 8 which indicate platform interior (restricted) depositional environment.

**Oceanographic reconstruction**

Using the model of benthic forams of Cretaceous by (BouDagher-Fadel, 2008) which depends on index fossils (benthic forams) distribution Figure (4) found in the two successions some of these benthic forams are prefer the platform ecosystem like *Orbitolina sp.*, which indicates back-reef towards the open sea, *Miliolids* reflect shallow shelf environment, *Cuneolina sp.*, and *Nezzazatinella* occupy the total shelf to the back-reef. All these benthic forams indicate shallow open water environment and good-lighted, temperate, oligotrophic water (Hottinger, 1983; Murray, 1991; O’Connell *et al.*, 2012).

The standard microfacies by Flugel (2010) and facies zones by Wilson (1975) which inferred from microfacies of the studied sections discriminate shallow waters of interior platform from the evaporitic or brackish water (FZ-9A) to back-reef (FZ-7).

**Diagenetic microfacies**

It indicates alteration during consolidation and history of rock, Diagenesis assigns to all biological, chemical and physical operations (Flugel, 2010).

The main diagenetic processes explained below and the percentage of the diagenesis in both wells illustrated in fig. (5).

1- **Cementation**

It is a post-depositional process including mineral growth within the pores of sediments (Selley, 2000), in this study the following types were recognized:

A- Drusy mosaic cement: This type of cement includes size growth of crystals from the outer margin of pores into the inner margin. It is precipitated in vadose and phreatic environments (Friedman, 1964). In present work, it’s occurred in WQ-220 at depth (2561 m) Pl. (2-F).

B- Blocky cement: increasing size of minute blocky cement which covers primary pore wall. Types A and B cements reflect burial diagenic environments (Flugel, 2010). It’s occurred in WQ-220 at depth (2579 m) and WQ-280 at depth (2469 m) Pl. (2-G).

C- Granular cement: It is characterized by equigranular or anhedral and/or subhedral crystals (Bathrust, 1975). in the present work it is occur in WQ-220 at depth (2587 m) Pl. (2-H).

2- **Dolomitization**

Dolomitization as a term may (1) refer that the process has changed CaCo$_3$ to MgCo$_3$ or limestone changes into dolomitic limestone, (2) 10% of dolomite included in the rock (Folk, 1959), according to (Randazzo and Zachos, 1984), the following types of dolomitization are found in the present work:
A- Nonplanar equigranular mosaic: Tightly to very linked packed anhedral crystals without pores and inter-grains generally lobate, bent, dentate, or unequal boundaries, it is found in the WQ-220, at depth (2561 m), Pl. (2-I).

B- Planar euhedral: Inequigranular Porphyrotopic: crystal of dolomite is big rhomb (euhedral form); the inter-grain area that supported the crystals are filled with different minerals or non, crystals enclosed in a finer-grained groundmass, in the WQ-220, at depth (2595 m), Pl. (2-J).

3- Compaction:
In the present work there is only a chemical compaction exited and indicates solution pressure, this type of compaction is related to fractures (Logan, 1984). The chemical compaction exited in WQ-280 only and represented by:
A- Low-Amplitude Peaks Stylolite at depth (2469 m) Pl. (2-K).
B- High-Amplitude Peaks Stylolite at depth (2477 m) Pl. (2-L).

4- Dissolution:
It is one of the destructive diageneses, Walter (1985) suggests that carbonate grains dissolution is rely on the volume of organic matter among grains. Dissolution of aragonite skeletal grains is the most diagenetic operations. Fossil shells which consist of aragonite subjected to total dissolution and remaining mold is filled by CaCO₃. At (CCD) Calcium carbonate compensation depth, the precipitation and dissolution of carbonates be in equal rate (Selley, 2000), in the present work, it is increased with increasing depth in both sections Pl. (2-M).

5- Porosity:
Represented the ratio of the pores connected or not, to the total volume of the rock. Bulk porosity should be discriminated from the effective porosity, which means the ratio interconnected porosity to the bulk volume of the rock (Flugel, 2010).
Sedimentary rocks porosity is divided into two main types:
1-The first one is formed before sedimentation and called primary porosity, for example, the porosity inside the internal structure of fossils and also formed through the sedimentation stage (inter-grains porosity).
2-The second type is formed by diagenetic processes later after sedimentation and called secondary porosity (Flugel, 2010). According to the time taken to form this type of porosity, Choquette and Pray (1970) divided the secondary porosity into three times called eogenetic, mesogenetic, and telogenetic. In the present work, the two types are recognized, primary porosity (Fabric-selective pores\intra-skeletal Porosity formed by the dissolution of weak calcified internal structure (Bachman, 1984) in WQ-220 at depth (2579 m) and WQ-280 at depth (2497 m) Plate (2-N); and secondary porosity (Non-fabric selective pores\Vuggy-porosity (Flugel, 2010) in WQ-220 at depth (2547 m) and WQ-280 at depth (2542 m) Pl. (2-O).
CONCLUSIONS

The authors are concluded the following:
- The lithology of well 220 is recrystallized vuggy limestone and recrystallized limestone in well 280.
- Six main types of microfacies were found in the sequence, these are: lime mudstone, wackestone, packstone, grainstone, rudstone and grapestone; and four submicrofacies these are: bioclast wackestone, benthic forams wackestone, bioclast packstone and peloidal packstone.
- The diagenetic processes in both wells are: cementation, dolomitization, compaction, dissolution and porosity, the dissolution is increasing in well 220 and less in well 280.
- The paleoecology is distributed in facies zone (7, 8 and 9A) which indicate deposition in the (evaporitic to the open marine) platform interior environment.

Plate 1

A- Orbitolina sp., B- Miliolids, C- Cuneolina sp., D- Lenticulina
E- Valvulammina sp., F- Nezzazatinella sp., G- Maynsina sp.
H- Dasycladacean algae, I- Shell fragments, J- Peloids K- Aggregate grains

Scale bar: 1000 micron
Plate 2: A- Lime mudstone microfacies, B- benthic forams wackestone submicrofacies, C- bioclast packstone submicrofacies, D- peloidal packstone submicrofacies, E- grainstone microfacies, F- Drusy mosaic cement, G- Blocky cement, H- Granular cement, I- Nonplanar equigranular mosaic, J- Planar-e (euhedral) Inequigranular, K- Low-Amplitude Peaks Stylolite, L- High-Amplitude Peaks Stylolite, M- Dissolution, N- intra-skeletal Porosity, O- Vuggy porosity
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