Sequence stratigraphy and sedimentary study on Mishrif formation of Fauqi Oilfield of Missan in south east Iraq

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Abstract. The reservoir of Mishrif formation has a large scale distribution of marine facies carbonate sediments in great thickness in central and south east Iraq. Rudist reef and shoal facies limestones of the Mishrif Formation (Late Cenomanian - Middle Turonian) form a great potential reservoir rocks at oilfields and structures of Iraq. Facies modelling was applied to predict the relationship between facies distribution and reservoir characteristics to construct a predictive geologic model which will assist future exploration and development in south east Iraq. Microfacies analysis and electrofacies identification and correlations indicate that the limestone of the Mishrif Formation were mainly deposited in open platform setting. Sequence stratigraphic analyses of the Mishrif Formation indicate 3 third order depositional sequences.

1. Introduction
The Missan Oilfields are located to the south east of Iraq, adjacent to the border of Iraq and Iran, the transitional zone between Zagros Mountain and Arabian Plate, the southern Mesopotamian basin, which is about 350km of the southeast of Baghdad and approximately 175km to the north-north east of Bashra. It includes 3 on production oilfields: Buzurgan, Fauqi and Abu Ghirab. The target Fauqi oilfield across the border of Iraq and Iran. (Figure 1.1) There are two oil-bearing sequences: the upper is Tertiary Asmari formation and the lower is Cretaceous Mishrif formation. The Mishrif formation is a typical reef and shoal facies carbonate reservoir with a huge thickness. Geological and geophysical studies indicated that the sedimentary landform here is almost flat, the carbonate deposition is sustained and steady. Vertically it was devided into 3 oilgroups which is named as MA, MB, MC (the Abb. of oilgroup A, B and C of Mishrif formation). Sedimentary studies shows a facies characteristics of intra-platform of shoal and open sub-tidal deposits vertically, Especially the intra-platform of shoal and open sub-tidal deposits were mainly deposited in MC2 (the Abb. of oilgroup C; layer 2 of Mishrif) and MB21 (the abb. of oilgroup B; layer 2 sublayer 1 of Mishrif), which are the two enriched and much thicker reservoirs compare with MA and other sub-oilgroups. Especially, The bioclastic shoal reservoirs of upper to middle interval of MB21 have good vertical connection and lateral extension, with such a stable and huge thickness of about 80m across the area, and is easily to do lateral tracing and comparision. It is the main target reservoir and oil-produced pay in Mishirf formation of Fauqi oilfield.
2. Regional Geological Setting

Figure 1.1 Location map of Missan Oilfield

Figure 2.1 Structural Location Map of Missan Oilfields
Missan oilfield is located in the transitional zone between Zagros Mountain and Arabian Plate, the southern Mesopotamian basin (Figure 2.1). More than 3500m of Cretaceous sediments were deposited in this basin under the influence of tectonic, eustatic and climatic controls. During Cretaceous period, the basin formed part of a larger-scale carbonate platform located on the NE passive margin of the Arabian Plate.

There are two anticlines with NW-SE orientation developed in the Missan Oilfields, which namely eastern anticlinal belts and western anticlinal belts. Fauqi oilfields rest on the eastern anticlinal belt which dipped southward gradually. The Formation develops inherently from Asmari Formation to Mishrif Formation.

A thick carbonate succession was deposited varying from pelagic basinal facies to grain-rich reef and foraminifera-rich lagoonal facies. The Mishrif group was deposited during generally high sea levels of the late Cenomanian to middle Turonian. Sedimentary background of Mishrif formation is mainly open marine carbonate platform deposits. This kind of epicontinental deposit featured as a steady reservoir distribution with good continuity.

3. Reservoir Characteristics

The Mishrif Formation was dominated by limestone. The main reservoir lithology of interval MB21 consists mainly of bioclastic (mainly rudists; grainstone) limestone, micrite, chalky limestone and etc. It was divided into 3 members of MA, MB and MC, which can be subdivided into 6 zones and 6 subzones as well as 7 layers.

The three main pore types of Mishrif formation are dissolved vug, matrix pore and micro fracture-pore. Base on the fracture study, Due to low density of the fractures, the pore type remains as the major storage space for oil while the fractures act as an important conduction that is the key to improve permeability. Fractures, especially the high angle fractures, are less developed and mainly made up of filled fractures in Mishrif reservoir. Microfractures zone only serves as a communication channel between the upper and lower layers.

The reservoir of main oil intervals MB21 and MC in Buzurgan oilfield is characterized by middle high porosity and low to middle permeability, whereas that in Fauqi oilfield is middle porosity and extreme low to low permeability.

The OWC (Oil & Water Contact) of MB21 sub-zone have not been drilled, but it was confirmed in southern block of MB22 sub zone and both southern and northern block of MC sub zone, which is 4125mSS. Since the net pay thickness of Mishrif is over 100m, the faults could not be the barriers of the oil flow. According to the analyses above, the reservoir trap type of Fauqi area is defined as anticline–structure trap.

The reservoir quality was mainly controlled by facies and diagenesis. The best reef shoal reservoir was deposited at the high energy area where the relative sea level decrease (Drain1, Drain2 & Drain3, the three high perm zones of MB21). The influence of diagenesis to reservoir growth and heterogeneity mainly is differential dissolution and differential cementation, which has close correspondence to the relative sea level changes. [1, 2]

4. Sequence Stratigraphy

The Cretaceous succession in the Mesopotamian basin can be divided into six super sequences or so-called 2nd order sequences, each of these super sequence is separated by regional-scale unconformities and maximum flooding surfaces which are related to regional-scale tectonic deformation and eustatic sea-level changes. According to this division, Mishrif group is considered to be part of the fourth super sequence. The Mishrif group represents the uppermost part of this super sequence and overlain by the Khasib formation with a sharp contact corresponding to an early-middle Turonian unconformity. By contrast at its lower boundary, the Mishrif group passes gradually into the underlying Rumaila formation, and the two formations cannot be easily distinguished in many wells in Missan oilfield and even across the southern Mesopotamian basin [3, 4].
The Mishrif group has an age gap of about 6 Ma, and the carbonates are heterogeneous and include rudistids, bioclastics, alge and foraminifera-rich facies deposited in setting ranging from shallow open marine to lagoonal facies. Reulet (1982) and Aqrawi et al. (1998) suggested that the formation should be divided into two long-term sequences or so-called 3rd order sequences. This division is based on facies evolution and their identification of a regional-scale intra-formational disconformity surface separating the two sequences (Figure 4.1).

However, according to change trend of the fine grains, here it is preferred here that the Mishrif group be divided into three 3rd order sequences. They are named SQ1, SQ2 and SQ3 from the bottom up (Figure 4.2). It should be pointed out that the part of the lowest sequence SQ1 is included in the Rumaila group, precisely, the maximum flooding surface MFS1 is located in Rumaila group. Stratigraphically, the Mishrif and Rumaila group together consist of three 3rd order sequences. Each of them is composed of a lower transgressive hemi-cycle and an upper regressive hemi-cycle. Each of the 3rd order sequences is separated by a disconformity and/or a conformity surface, and all the maximum flooding surfaces are characterized by relatively finer grain, which is mudstone and wackestone. The boundary between SQ1 and SQ2 is the conformity surface on top of MC11, and sequence boundary SB1 is not recognizable on some wells in Fauqi and Buzurgan oilfield. The sequence boundary between SQ2 and SQ3, which is SB2, is the disconformity on top of MB21. It can be evidently identified on cores and well logs, and is marked by the leaching vugs observed on the cores. At present sequence boundary SB2 is thought to be a shortly exposed surface after deposition. Sequence boundary SB3 is Mishrif-Khasib regional unconformity and has an obvious log response. SB3 is underlied by the Mishrif carbonate and overlain by Khasib greenish shale. On the seismic profiles, SB2 and SB3 are identified as MB21 top and MA top respectively, but SB1 cannot be recognized.
Figure 4.2 The 3rd order sequence division of the Mishrif formation in Fauqi oilfield

The division above could be correlated regionally (Figure 4.3, Figure 4.4). According to the tripartite division, the Mishrif group of Amara oilfield in Iraq and Dehluran oilfield can be correlated to that of Missan. Some authors, including Ali Asghar Taghavi (2006) and T. A. Mahdi (2014), have adapted this tripartite division to Mishrif group in Mesopotamian basin before.

Figure 4.3 Third order sequence correlation profile of Mishrif group across Amara, Fauqi, Buzurgan and Dehluran oilfield
The division and correlation of the 3rd order sequence would provide general guide and be useful to analyze the sedimentary facies evolution within the whole Mishrif formation. But it will not be enough when the main production zone (sub-member MB21) is studied in details. Therefore, the 4th and 5th order sequence division and correlation should be carried out.

Based on the 3rd order sequence division, the Mishrif group is divided into five 4th order sequences. Sub-member MB21 just takes up one whole 4th order sequence. Consequently, three 5th order sequences S1, S2 and S3 are divided within sub-member MB21 (Figure 4.5). S1 consists of a relative sea-level rising hemi-cycle and a falling one. The relative sea-level rising or water-deepening hemi-
cycle is common on all the wells of Fauqi and Buzurgan oilfield. However, the falling or water-shoaling one is not obvious on some wells. This indicates that the 5th order sequence is likely to be autogenetic cycle. On the contrary, the 3rd sequence is allochthonous because of its regional correlation across Missan oilfield and even the southern Mesopotamian basin [5, 6]. Different from sequence S1, the 5th order sequence S2 and S3 merely includes a relative sea-level falling hemi-cycle respectively. Both the core and log data shows evident upwards water-shoaling and grain-coarsening trend. In particular, the lithology changes gradationally from wackestone to peloidal packstone or even grainstone within each cycle. As a result, it can be concluded that MB21 is dominantly made up of three upwards water-shoaling and grain-coarsening cycle’s stratigraphically (Figure 4.6).

The 5th sequence division of Mishrif group has been carried out in Fauqi and Buzurgan oilfield, even though the relative sea-level rising hemi-cycle does not always show an obvious upwards grain-finishing trend.

Figure 4.6 The 5th order sequence correlation profile of the Mishrif group in Fauqi oilfield

5. Sedimentary Facies Identification

Lots of literatures has discussed the sedimentary model in the southern Mesopotamian basin, and two different types could be summarized: the reef-rimmed carbonate platform and the carbonate ramp. Some authors like James and Macintyre (1985) and T. A. Mahdi and and A.A.M. Aqrawi (2014) recommend the reef-rimmed carbonate platform. In this depositional model, rudist congregations occupied the platform margin without forming a continuous rim, and may pass laterally into or be replaced by shoal facies, depending on the precise palaeo geographical location within the southern Mesopotamian Basin. The ancient slope break is the important evident characteristic for the reef-rimmed carbonate platform. However, after precisely interpreting the 2D and 3D seismic data which collecting grid covered almost the whole Missan oilfield, no such break have been observed on the seismic profile. The carbonate ramp depositional model for the Mishrif group in Iraq or the upper Sarvak formation in Iran, which was comprehensively discussed by Trevor P. Burchette(1993), A.A.M. Aqrawi(1998) and Ali Asghar Taghavi(2006), is adapted here (Figure 5.1).

The paleo-environment varied from open platform to restricted platform during the Cenomanian–early Turonian Mishrif formation period. Four principal facies are recognized corresponding to palaeo-depositional settings ranging from shallow open marine to lagoon deposit. These facies are summarized as below (Figure 5.2).
**Figure 5.1** Proposed ramp carbonate platform model for the Mishrif formation

**Figure 5.2** Characteristics of sedimentary facies of Mishrif group in Fauqi oilfield

5.1. *Shallow Open Marine Facies*

Shallow open marine facies comprising massive, thick limestone units consist of bioclastic packstones and wackestones. Bioclasts include mixed debris of rudists, green algae, echinoids and bivalves, together with benthonic and planktonic foraminifera (Figure 5.2). Colonial corals and algae also occur.

Shallow open marine facies become more grain-rich and rudist-rich upwards within the studied well successions. Grain-rich bioclastic limestones in this facies have high porosities and typical blocky motifs on the porosity logs, although stylolites and cementation zones may cause local irregularities in log pattern.
5.2. Shoal Facies

Shoal facies composed predominantly of grain-dominated grainstones and packstones (Figure 5.2). Bioclasts include rudists, echinoderms and algae together with pellets. Allochthonous molluscs and small benthonic foraminifera also occur locally, although these latter components are poorly preserved indicating long transport.

The shoal facies deposits are interpreted to have been deposited in high energy settings above fair-weather wave base, and as a result contain only little clay. Therefore gamma-ray signatures show only minor deflections, although porosity logs indicate the occurrence of high porosity intervals.

5.3. Rudist Biostromes or Reef Facies

Rudist biostromes are dominated by autochthonous rudists within grainstones and packstones (Figure 5.2). Rudist bioclasts are poorly sorted, frequently broken but hardly rounded, and are often highly compacted.

Within the Mishrif group, rudists do not show features characteristic of reefs. According to Gili et al. (1995), rudist-rich rock units here are referred to as lithosomes and the dense faunal associations as congregations. Intact rudist congregations in the Mishrif group are volumetrically less extensive than the rudist-dominated debris found in slope and shoal locations.

5.4. Lagoon Facies

Lagoon facies were deposited in restricted areas within the Mishrif platform, and are characterized by a diverse benthonic foraminifera fauna including miliolids, alveolinids and textulariids (Figure 5.2). Gastropods, ostracods, rudist fragments and sponge spicules occur locally, showing little breakage indicating short transport distances. Lagoon facies deposits may be more than 30m thick in Fauqi oilfield.

Figure 5.3 The 3rd order sequence division and sedimentary facies of the Mishrif formation
Within the lagoonal successions, thin beds of peloidal and rudistid-packstones and grainstones may occur, interpreted as small-scale shoals and biostromes which developed within the lagoonal environment. Log responses for lagoon are characterized by high gamma-ray reflections and relatively low porosity readings compared with shoal facies.

6. Conclusion
The rock type of Mishrif formation especially MB21 are mainly bioclastic rudist limestone, bioclastic grainstone, bioclastic peloidal packstone. The reservoir space type is primary intergranular pore, secondary intergranular dissolved pore, moldic pore, matrix micropore, a few small dissolved pore and micro-fracture. The sedimentary environment is carbonate open platform facies, which include intra-platform of reef, intra-platform of shoal and open sub-tidal deposits. The reservoir quality was mainly controlled by facies and diagenesis. The Mishrif formation was divided into two long-term sequences or so-called 3rd order sequences. This division is based on facies evolution and their identification of a regional-scale intra-formational disconformity surface separating the two sequences. Based on the 3rd order sequence division, the Mishrif group is divided into five 4th order sequences. Sub-member MB21 just takes up one whole 4th order sequence. Consequently, three 5th order sequences S1, S2 and S3 are divided within sub-member MB21.

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