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Characteristics of depositional environment and evolution of Upper Cretaceous Mishrif Formation, Halfaya Oil field, Iraq based on sedimentary microfacies analysis

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ABSTRACT

As one of the most important carbonate targets in the Middle East, Upper Cretaceous Mishrif Formation has been highlighted for a long time. Although consensus has been reached on the overall sedimentary background, disputes still exist in understanding the sedimentary environment changes among sub-regions due to relatively limited research, rare outcrop, and incomplete drilled core, which hinders the analysis on sedimentary environment and thus the horizontal and vertical correlation. In this study, taking the Halfaya Oil Field as an example, the sedimentary microfacies analysis method was introduced to comprehensively characterize the cored interval of Mishrif Formation, including Single Layers MC1-1 to MA2. A total of 11 sedimentary microfacies are identified through system identification of sedimentary microfacies and environmental analysis, with reference to the standard microfacies classification in the rimmed carbonate platform. Then three kinds of environments are identified through microfacies assemblage analysis, namely restricted platform, open platform, and platform margin. Systematic analyses indicate that the deposits are mainly developed in the open platform and platform margin. Meanwhile, rock-electricity interpretation model is established according to the electricity response to cored intervals, and is then employed to interpret the uncored intervals, which finally helps build the sedimentary evolution pattern through horizontal and vertical correlation. It is proposed that the Single Layers MC1-1 to MB2-3 were deposited in the open platform featured by low water level, including sub-environments of low-energy shoal within platform and inter-shoal sea; Single Layers MB2-2 to MB1-2B were deposited in the open platform and platform margin, including sub-environments of high-energy shoal on the platform margin, low-energy shoal within platform, inter-shoal sea, and open sea; and Single Layers MB1-2A to MA2 were again deposited in the open platform with high water level, and the circumstance of open sea was dominant. The deposition of Single Layers MC1-1 to MA2 actually corresponded to a retrogradation-progradation process. Results of this study will not only provide significant guidance to the exploration and development of Mishrif Formation, Halfaya Oil Field, but also support that the theory of sedimentary environment correlation with adjacent areas is reliable.

1. Introduction

It is proposed that most of the grain shoal and bioherm-related reservoirs are distributed in the Persian Gulf Basin and Zagros Basin, Middle East (Mann et al., 2003; Bai, 2006; Jiang et al., 2008). Cretaceous reservoir rocks in the Middle East are featured by young age, shallow burial depth, and weak structural and diagenetic transformation. Since matrix pores with original structures are preserved to a large degree (Alsharhan, 1995; Volery et al., 2010), sedimentation plays an important role in the formation of the reservoir. As the most developed grain shoal reservoir, Upper Cretaceous Mishrif Formation in the Iraq is regarded as one of the

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most important targets in the Persian Gulf Basin, and even in the Middle East (Alsharhan, 1995; Aqrawi et al., 2010). The sedimentary environment of Mishrif Formation has been extensively studied, with the consensus of shallow marine carbonate deposition environment. Rudist contributed to the carbonate platform build-up (Volery et al., 2010; Mahdi et al., 2013; Al-Ekabi, 2015); Al-Dabbas et al. (2010) proposed the environment of Mishrif Formation in the southern Iraq consisted of basin, outer slope, and platform reef shoal; and Wang et al. (2016) suggested that the environment of Mishrif Formation in the Halfaya Oil field consisted of restricted platform, open platform, and platform margin.

Although previous researchers have reached consensus on the overall sedimentary background, namely the overall carbonate platform and rim, difficulties still are there in understanding sedimentary environment changes among sub-regions due to low research degree, absent outcrop, insufficient drilling well, and incomplete drilled core, which makes it difficult to correlate the sedimentary facies horizontally and vertically. Therefore, it hinders the fine research on the sedimentary environment.

In this study, the Mishrif Formation of Halfaya Oil Field in the southeast of Iraq is selected as target to conduct further sedimentary environment classification and analysis. Thin sections and cores are integrated to recognize and classify the microfacies and their assemblages with reference to the standard microfacies and rimmed carbonate platform sedimentary pattern by Wilson (1975) and Flügel (2004). Then electricity response to lithological variation in the cored interval is analysed to establish a model so as to identify the rock types of uncored intervals, which will greatly support the horizontal and vertical correlation of sedimentary facies as well as the evolutionary pattern. This study will not only provide significant guidance to the exploration and development of Mishrif Formation, Halfaya Oil field, but also provide strong theoretical support for sedimentary environment correlation with adjacent areas.

2. Geological setting

Halfaya Oil Field is located in the Maysan Province, Southeast Iraq, 400 km away from the Iraqi capital, Baghdad. It is tectonically on the instable continental shelf in the northern Persian Gulf Basin on the northern rim of Gondwanaland, and in the eastern instable continental shelf region, Mesopotamia main belt, and the southern part of Tigris sub-belt. This region is the most deeply buried in the Mesopotamia Basin, with thickest sediments, relatively stable tertiary tectonic units (Ameen, 1992; Azzam and Taher, 1993), and developed platform environment (Fig. 1). Affected by the Alps Movement, the study area is a gentle northwest-southeast anticline. Mishrif Formation was deposited during middle Cretaceous, with the sedimentary thickness of about 350–400 m which gradually thins to 150 m to the direction of southwest. It is stripe-shaped in the southeast-northwest direction in the Iraq-Iranian border and Basra Area (Dunnington, 1958; Owen and Nasr, 1958; Alkersan, 1975; Buday and Jassim, 1987; Aqrawi, 1998). It belongs to Qamchuqa Group, of which reservoir rocks were carbonate rocks with rudist deposited in the shallow marine platform. Pores are mainly intergranular pores, intragranular (dissolved) pores, and frame pores (Gao et al., 2013). As the most important oil-producing formation, Mishrif Formation can be as thick as 400 m, and be further divided into 15 single layers. The Laramide Orogeny in the late Cretaceous resulted in a regional unconformity surface on the top of Mishrif Formation (Aqrawi et al., 2010).

3. Materials and methods

This study is mainly based on four cored wells with thin sections, namely Wells N137, N195, Y115 and Y161. These four wells are distributed in the east-west direction in the northern part of the study area. The well space is moderate for horizontal microfacies comparison. Furthermore, these wells have more complete log data and richer core data available than the other wells, with respective cored Mishrif Formation intervals of 107.5m, 77m, 81m, and 45m. As cored intervals cover Single Layers MC1-1 to MA2, the overall sedimentary pattern could be reflected by cores and thin sections of these wells (Fig. 2). There are a total of 317 casting thin sections with the average sample spacing of 1 sample/m. Numbers of the samples from Wells N137, N195, Y115 and Y161 are 105, 87, 80 and 45, respectively. All the thin sections are provided by Research Institute of Petroleum Exploration and Development, CNPC, and analysed in the Sedimentary and Accumulation Department of Key Laboratory of Carbonate Reservoirs, CNPC. Specific attention has been paid to distinguish microfacies of Mishrif Formation in the cored interval in terms of biological types, abrasion degree, rock composition, grain size and other sedimentary features, with reference to the standard microfacies types and sedimentary environment model by Flügel (2004).

4. Microfacies types (MFT) and their assemblages

A total of 11 microfacies are recognized in the Mishrif Formation, and the component types and contents of each microfacies are shown in Fig. 3. Three assemblages can be correlated to three sedimentary environments, namely restricted platform, open platform, and platform margin (Table 1).

4.1. Description and interpretation of main microfacies types

4.1.1. MFT1 - Micritic limestone

Description—Rocks of this microfacies are generally tight on the macroscale. They are composed of clay-sized carbonate matrix with the grain diameter less than 0.01 mm. As observed under the microscope, biological or debris contents are hardly seen (Fig. 3). Matrix micro pores are developed, and fractures are occasionally observed (Fig. 4).

Interpretation—This microfacies generally reflects relatively low energy deep-water environment. Due to the rare bioclast content, it is very similar to the standard microfacies *SMF23*, *non-laminated homogenous micrite or microsparite without fossils*, but it lacks the minerals produced by the restricted or evaporation environment. Such rocks are also possibly found in the deep-water basins. According to previous studies, Mishrif Formation should be deposited in the rim carbonate platform environment, and thus basin environment assumption should be denied (Wang et al., 2016). Since there is no comparable standard microfacies, it is identified as the product of deep water deposition in the open sea environment according to the characteristics.

4.1.2. MFT2 - Biolithite wackestone

Description—As observed under the microscope, lime mud matrix dominates, accounting for over 70%. Grains are mainly biological grains and a small amount of bioclastic, including benthic foraminifera, gastropods, brachiopods, echinoderms, and so on (Fig. 3). The grain size varies from 0.1 to several millimetres. Biological grains are relatively intact. Pores are mainly biological body cavity holes and micro pores (Fig. 5).

Interpretation - This microfacies generally reflects a kind of relatively low-energy deep-water environment. Due to its relatively intact biological grains, it is analogous to the *SMF8, wackestones and floatstones with whole fossils and well-preserved endo- and epibiota*. It should form in the low energy environment under the wave base, mainly corresponding to the deep-water deposits in the open sea.