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RESEARCH PAPER

Geological features of grain bank reservoirs and the main controlling factors: A case study on Cretaceous Mishrif Formation, Halfaya Oilfield, Iraq

WANG Jun[1, 2, *], GUO Rui[2], ZHAO Limin[2], LI Wenke[2], ZHOU Wen[3], DUAN Tianxiang[2]

1. School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China;
2. PetroChina Research Institute of Petroleum Exploration & Development, Beijing 100083, China;
3. College of Energy Resources, Chengdu University of Technology, Chengdu 610059, China

Abstract: The geological features and distribution regularity of the grain shoal reservoirs of the Cretaceous Mishrif Formation in Halfaya Oilfield and their main controlling factors were analyzed based on cored data, 302 pieces of thin sections and 2507 experiment data points. Various types and multiple phases of grain shoal reservoirs are developed in Mishrif Formation, which are dominated by grainstone, followed by wackestone packstone. The formation and distribution of grain shoal reservoirs are mainly controlled by relative sea level change, paleogeomorpholoy and contemporaneous-penecontemporaneous dissolution. Relative sea level change controls the types and development phases of grain shoals. When the sea level falls, rudists, coquina, arene and pelletoids are extensively deposited, among which, rudists clastic shoal and coquina shoal that are deposited at the lowest sea level have the best reservoir properties, with a maximum porosity of 33.94%, maximum permeability of 764.571×10^{-3} μm^2 and an average permeability of 45.81×10^{-3} μm^2. Paleogeomorpholoy controls high-energy facies belt and the dissolution of meteoric water. The submarine paleohigh controls the formation and distribution of high-energy facies belt during depositional period. However, during uplifting and denudation period, the reservoirs in paleohigh are intensively dissolved and represent good reservoir properties, with an average porosity of 14.78% and permeability of 7.849×10^{-3} μm^2. Contemporaneous-penecontemporaneous dissolution results in the formation of most effective pores, which is the key factor for the formation of grain shoal reservoirs in the study area.

Key words: grain shoal reservoirs; main controlling factor; relative sea level change; paleogeomorpholoy; dissolution; Mishrif Formation; Halfaya Oilfield; Mesopotamia basin

Introduction

There are 46 grain shoal reservoirs and 52 bioherm reservoirs among the 226 large and medium carbonate reservoirs worldwide, accounting for 43.4% of the total. Most of them are in the Persian Gulf Basin and Zagros Basin of Middle East[1–2], with Cretaceous grain shoal limestone as the main producing zone and production accounting for 50% of the total area[3–5]. The grain shoal reservoir of Cretaceous Mishrif Formation, the most developed reservoir in Halfaya Oilfield, Iraq is one of the major reservoir units in the Persian Gulf Basin, even the entire Middle East[6–8]. Previous scholars have carried out in-depth study on the pore types, structure and genesis of the reservoirs of Mishrif Formation in Middle East[9–14], which effectively guides the exploration and development of the oilfields in this region. The Cretaceous reservoirs in the Middle East with new age and shallow buried depth have stratified distribution and good petrophysical property due to the weak tectonic and diagenetic reformation of late stage, within which, a large amount of primary matrix pores are preserved[6, 15]. Sedimentation has the greatest impact on the reservoirs, one of the distinctive manifestation is that sedimentary microfacies controls the formation and distribution of favorable reservoirs. But influenced by metharmosis, the porosity and permeability of the grain shoal reservoirs of different types are apparently different, showing strong heterogeneity[16–17].

Based on coring data, casting thin section observation results and petrophysical property test results, the grain shoal reservoir features of the Mishrif Formation in Halfaya Oilfield and their main controlling factors were studied in terms of petrology, sedimentary distribution and reservoir space types, in order to provide a reliable geological basis for the heterogeneity characterization and 3-D geological modeling of the grain shoal reservoirs.

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*** Corresponding author.** E-mail: wangjun121@petrochina.com.cn
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1. Geological features

Halfaya Oilfield, a giant oilfield with bioclastic limestone as the main producing zone, is located in Missan Province in southeastern Iraq (Fig. 1), 400 km away from Iraqi capital, Baghdad. Structurally, it is located in the foredeep belt of southern Mesopotamian Basin, appearing as a wide and gentle long-axis anticline of NW-SE trending formed during Neogene Zagros orogenic movement. The basement is composed of Precambrian crystalline metamorphic rock, Lower Cambrian metamorphic rock and pyroclastic rock. Since the Cambrian Period, Halfaya Oilfield has been in the northern margin of Gugangwanaland for a long time, where platform deposits mainly develop. During the Cretaceous Period, shallow shelf carbonate developed due to weak tectonic movement, especially large-scale bioclastic limestone. There are seven sets of oil-bearing strata in vertical there, among which, the limestone of Lower Cretaceous Sadi Formation and Middle Cretaceous Mishrif Formation are the main oil-producing zones, contributing 80% of the total production. The Mishrif Formation, the most important producing zone in Halfaya Oilfield, 400 m thick is characterized by development of grain shoal reservoirs, which can be further divided into 15 sublayers. Its top surface is a regional unconformity surface formed in Late Cretaceous Laramide orogeny, with obvious truncation in the southeast part of the study area[8]; its bottom surface is weathering crust residual breccias of 20 m thick, mainly composed of limy gravel and gray-green mudstone, with grain size fining downward from unconformity surface to tight cementation zone. Currently, the entire study area is covered by 496 km^2 3-D seismic data and has a total of 127 drilled wells, including 14 coring wells. The coring data of M208 well is the most complete (continuous coring from Middle Cretaceous Mishrif Formation to Tertiary Jeribe Formation).

1.1. Petrological feature

The observation results of cores from the seven coring wells and 302 pieces of thin sections show that the reservoirs of Mishrif Formation are dominated by grainstone, followed by wackestone and packstone. Grainstone comprises bioclastic grainstone, psammitic grainstone and pelletoid grainstone, with skeletal fragment grains of echinoderm, benthic foraminifera and rudist and non-skeletal fragment grains of sand cuttings, oolite and peloid. Sand cuttings are generally bioclasts with a certain roundness, containing fairly intact echinoderms fossils. Peloid is generally fossil fragment in pelletoid shape. The platform margin shoal of MC1-MB2 Member is dominated by bioclastic grainstone, pelletoid bioclasticgrainstone/packstone and bioclastic wackestone. The grains are mainly rudist bivalve, foraminifera and echinoderms, with content of 75%–90%. The intra-platform shoal of MA2 Member-lower MA1 Member and MC3-MC2 Member is dominated by bioclastic grainstone, bioclastic pelletoid packstone, bioclastic wackestone and wackestone, with grain content of generally 50%–85%. The bioclast is composed of benthic foraminifera, bivalves and minor sand cuttings (allochemical grains of foraminifera carrying and rounding).

1.2. Sedimentological features

Two types of grain shoals with quite different geological features are developed in the Mishrif Formation of Halfaya Oilfield, namely platform margin shoal and intraplatform shoal, in which, platform margin shoal predominates in MC1-MB2 Member, whereas, intraplatform margin shoal predominates in MA2-MA1 Member and MC3-MC2 Member (Table 1).

1.2.1. Vertical sedimentary evolution

Vertically, controlled by relative sea level eustacy, multiple phases of grain shoal deposits are developed in Mishrif Formation (Fig. 2). According to lithology, well logs and physical properties, Mishrif Formation can be divided into two sedimentary cycles. The first cycle evolved from open platform to platform margin. With the rise of sea level, a set of bioclastic shoal of 25 m thick deposited in MC3-3 Member, whereas, a set of thin marlstone of intraplatform depression facies deposited in MC3-2 Member. Subsequently, then the depositional environment evolved into open platform. MC3-1 Member is dominated by bioclastic shoal. MC2 Member is dominated by psammitic shoal in the middle-lower part, but a set of marlstone and argillaceous limestone of limy flat facies in the upper part. Then, with the cyclical drop of sea level, the study area entered platform margin environment, when thick platform margin shoal deposited in MC1-MB2 Member (Fig. 3a). Two phases of stacked shoals deposited in MC1-4 Member, which are pelletoid shoal and bio-fragmental shoal from bottom to top. Six phases of aggradation shoals deposited in the MC1-2, MC1-1, MB2-3 and MB2-1 Members, which are bioclastic shoal, psammitic shoal, bioclastic shoal, rudists

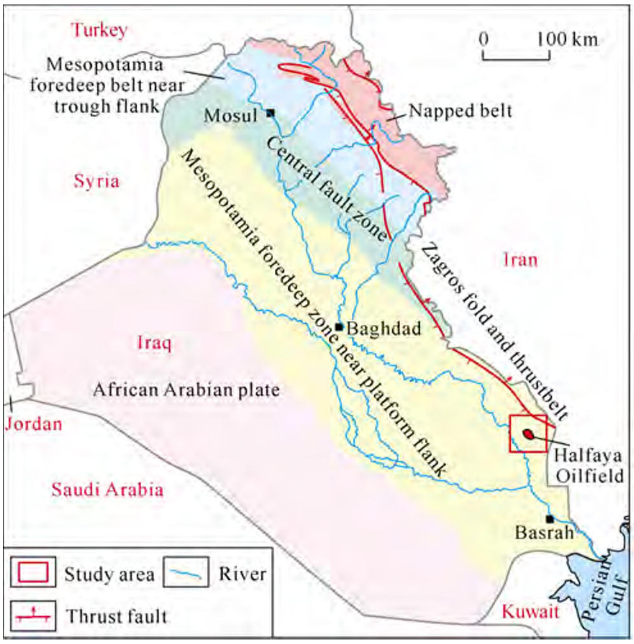

Fig. 1. Regional structural location of Halfaya Oilfield.