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RESEARCH PAPER

Differential Hydrocarbon Migration and Entrapment in the Karstified Carbonate Reservoir: A Case Study of the Well TZ83 Block of the Central Tarim Uplift Zone

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Abstract: The hydrocarbon migration and entrapment mechanism in the lower overlapped basins, occurring in the complex carbonate pore-fissure-fracture reservoirs, is one of the key problems that have to be solved for effective hydrocarbon exploration. The production, gas/oil ratio, and the composition of crude oils and natural gas in the TZ83 Well block are high at the intersection point of the NE and NW-strike faults and decrease gradually along the ridge of the structure. A basic model of the pore-fissure-fracture system is built according to the achievements in the research on carbonate karstification. Processes of hydrocarbon migration and entrapment in this system are analyzed, which indicate that an understanding of the complexness of differential hydrocarbon migration is the key to interpreting this phenomenon. The hydrocarbon must charge the nearest compartment before migrating further away to charge other compartments in its pathway in the complex pore-fissure-fracture system. As a result, the following two phenomena appear: (1) Gas is enriched near the hydrocarbon injection point and drives away the oil, which is enriched in the compartments farther from the injection point. (2) The complex gas–oil–water relationship is controlled by the lateral connecting networks. Based on this, this article shows that the fault intersection point is the injection point of the oil and gas, and the main pathway system is distributed along the ridge of the structure. The theory of deferential hydrocarbon migration in the pore-fissure-fracture system can be presented from two aspects: (1) In hydrocarbon exploration, the structure of the fissure-fracture system should be described first, and then the special distribution of gas–oil–water can be predicted according to the main charging point and the main pathway system. (2) Exploration should be confined to the hydrocarbon charging point and the main pathway systems. An explored area should not be abandoned merely due to failures in some wells.

Key Words: differential hydrocarbon migration and entrapment; karstification; pore-fissure-fracture reservoir; overlapped basin; central Tarim Uplift Zone

1 Introduction

A superimposed basin consists of two or more types of prototype basins overlapped or combined[1,2]. The characteristics of its accumulation generally include "multi-phase basin forming, multi-phase transformation, multi-assemblage source rocks, multi-period generation, and discharge of hydrocarbons and multi-phase migration, accumulation and dispersion"[1,3]. After petroleum exploration of an overlapped basin reaches the lower part of a structural formation, the exploration target shifts from the clastic reservoirs to the carbonate ones, from high-porosity and permeability reservoirs to the low- and even ultra-low porosity and permeability ones[4,5]. Due to low porosity and permeability, an intense capillary pressure is formed between the matrix and the reservoir pores, in an area with carbonate

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rocks, causing non-Darcy hydrocarbon migration. However, there exists in hydrocarbon migration a certain starting pressure gradient that belongs to the low-speed, non-Darcy seepage flow[6-8], thereby, lowering the speed of the horizontal migration of hydrocarbons even at the same potential gradient. As for the lower part of an overlapped basin, the presence of capillary pressure is an effective obstacle for material exchange, thus forming relatively independent pore-fissure-fracture units[9,10] or fluid compartments[11,12]. The two above-mentioned characteristics of low and ultra-low permeability reservoirs will inevitably cause hydrocarbon migration and entrapment to display some characteristics that become special scientific problems of hydrocarbon exploration in overlapped basins[13].

Principles of differential entrapment of oil and gas have been derived from the research work on the carbonate provinces[14] and have been further proved by Gill[15] during his research on oil and gas migration and accumulation in the Niagaran pinnacle-reef belt of Northern Michigan[15]. Gussow[14] has proposed that the principle of differential entrapment is based on the observation in a sequence of reefs in a single trend, in the Western Canada basin, where the deepest reefs only contain gas; while the shallowest only contain water; and there will be one deep reef with a gas/oil contact, and one shallow reef with an oil / water contact, but the others will be full, to the spill point. Gussow has named this characteristic distribution as differential entrapment. This principle has served as a key to analyzing the hydrocarbon migration and accumulation process in the anticlines[16,17] and faulted traps[17,18] that have developed in the clastic rocks. Loucks[10] has built an ideal model of the channel system developed in the karstified and fractured carbonate reservoir. We will further prove that there exists differential hydrocarbon migration and entrapment in that system, by an in-depth study of a good example from the Well tz83 block of the Central Tarim Uplift Zone.

2 Geologic setting

Well tz83 block is located in the middle section of the No. 1 slope break zone in central Tarim. It is bounded by the No. 1 slope break zone on the northeast, by the No. 10 structural belt on the southwest, and by the No. 82 NE-strike-slip fault on the northwest. Its southeast side is a gentle slope connected with the Well 16 block. Its depositional sequence is similar to that of the whole Tarim basin. The chief exploration target is the superficial karstification unconformity of the Yingshan formation of the lower Ordovician (Fig. 1). The top structure map of the Yingshan formation indicates that this area is a NW-dip nose structure, the peak- of which is near Well tz83 and Well tz721. The southeast of the structure is connected with the Well tz16 block. A distinct saddle structure is formed near Well tz722, where these two structures are connected.

The reservoir of the Yingshan formation is of low to ultra-low porosity (<5%) and permeability (<1 mD), controlled by superficial karstification. Mainly controlled by the horizontal seepage zone, petroleum resources are proven to be less in the vertical seepage and stagnant zones. The relationship between the porosity and permeability indicates that the reservoir quality is affected by fracturing, thus leading to high permeability, but low porosity. Therefore, reservoirs here are of a typical fracture-fissure-type (Fig. 2). The capillary pressure between high-porosity and permeability reservoirs, formed due to karstification and fracturing and ultra-low permeability host rocks, serves as an effective hindrance to the material exchange, forming a relatively independent pore-fissure-fracture unit[9,10] or a fluid compartment[11,12]. Its hydrocarbon accumulation effect is equivalent to that of an independent trap. Such pore-fissure-fracture units cause the bead-stringed shape in seismic reflection, which is the key target of hydrocarbon exploration.

The oil–gas–water relationship in Well tz83 block is complex, and can chiefly be shown in three aspects: (1) Water frequently appears in hydrocarbon exploration. Of the seven exploration wells and one developed well in this area, three of them have a high production of oil, one produces the same quantity of oil and water, and three produce only water. This shows that a good reservoir is only a prerequisite for hydrocarbon accumulation. (2) Unexpected and irregular water flushing during trial production. Even in a well with a high production of oil, there is water flushing. Taking Well tz722 in the Tarim Basin as an example, in the trial production, the content of water once reached as high as 50%. (3) The oil–water interface slants northward as a whole. This can be proved by two wells, Well tz83 and Well tz831. Both of them are structurally located in the down-dip direction of Well tz721, but the gas–oil ratio of the former is higher than that of the latter, showing that gas is not accumulated in the core of the structural nose and there is no gas cap with a uniform gas–water interface. Meanwhile, Well tz62–27c is structurally higher than Well tz83 and Well tz831, but the former is a dry hole and the latter two have a high production of gas, indicating once again that there is no uniform oil–water interface. The above three phenomena indicate that hydrocarbon accumulation is not a structural nose-controlled one, but a stratigraphic/lithologic-controlled one. The complex oil–water relationship calls for an urgent and rational explanation of the hydrocarbon accumulation mechanism, so as to guide further exploration and development in this area.

3 Tracing hydrocarbon migration

Analyzing hydrocarbon migration and accumulation mechanism is based on the accurate location of the direction and route of hydrocarbon accumulation. Systematic variations