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RESEARCH PAPER

Geological features and exploration fields of tight oil in the Cenozoic of western Qaidam Basin, NW China

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Abstract: Using a large amount of drilling and experimental analysis data, this paper evaluates four potential fields of tight oil exploration in western Qaidam Basin from comprehensive analysis of geological conditions such as sedimentary environments, source rock evaluations, reservoir characteristics, and source-reservoir relationships. Influenced by continuous uplift of Tibet Plateau since Paleogene, the sedimentary environment of the western Qaidam Basin exibits three characteristics: (1) a paleo-topographic configuration consisted of inherited slopes, depressions and paleohighs; (2) frequent alternation of relative humid and arid paleoclimate; and (3) oscillation of salinity and level of the paleo-lake water. Preferential paleo-environment resulted in two sets of large-scale source rocks with high efficiency and two types of large-scale tight reservoir rocks (siliclastic and carbonate), deposited during the late Paleogene to early Neogene. The above source and reservoir rocks form favorable spatial relationships which can be classified into three categories: symbiotic, inter and lateral. Based on sedimentary environments and reservoir types, tight oil resource in western Qaidam Basin can be divided into four types, corresponding to four exploration fields: salty lacustrine carbonate tight oil, shallow lake beach-bar sandstone tight oil, delta-front-sandstone tight oil and deep lake gravity-flow-sandstone tight oil. The temporal and spatial distribution of tight oil has characteristics of layer concentration, strong regularity and large favorable area, in which the saline lacustrine carbonate and shallow lake beach-bar sandstone tight oil are the best exploration targets in the western Qaidam Basin.

Key words: tight oil; geological features; exploration fields; Qaidam Basin; tight reservoir

Introduction

Low porosity and permeability reservoirs are widely distributed in Qaidam Basin as a result of special geological conditions[1]. Since the introduction of the new theory of tight hydrocarbon exploration in 2011, there has been a new understanding on the tight oil resources in the basin. The discovery of the beach-bar sandstone tight oil in the Shangganchaigou Formation (N_1) of the Neogene in Well Zha2 of the Zhahaquan area has opened the prelude of tight oil exploration in western Qaidam Basin. By the end of 2015, a total of more than 40 exploratory wells were deployed there, in which about 30 wells had oil and gas shows in the tight reservoir layers, and more than 20 wells achieved industrial oil flow, showing good prospects for tight oil exploration[2–3].

Although the tight oil exploration has achieved initial success in western Qaidam Basin, as the reservoirs are diverse in type, and mostly characterized by thin layer thickness (1–8 m), multiple layers and discontinuous lateral distribution, it is difficult to find out geological sweet spots there. This paper, based on previous understanding, uses a large amount of drilling and experimental analysis data, starts from the analysis of depositional environment, further elaborates the source, reservoir and assemblage and geological characteristics of the formation of tight oil in this area. Finally, it makes a classification and evaluation of tight oil within the study area from the view of sedimentary environment and reservoir type, so as to provide some geological basis for the next exploration of tight oil.

1. Geological setting

With an exploration area of about 3×10^4 km^2, stretching from the Altun Mountains in the west to Eboliang-Gansen line in the east, western Qaidam Basin can be divided into four secondary tectonic units from south to north: Kunbei fault terrace, Mangya sag, Dafengshan salient and Yiliping sag[3-4]. The stratigraphic division of the Cenozoic in western Qaidam Basin is shown in Fig. 1, it can be seen that the Cenozoic consists of Lulehe Formation (E_{1+2}), lower member of

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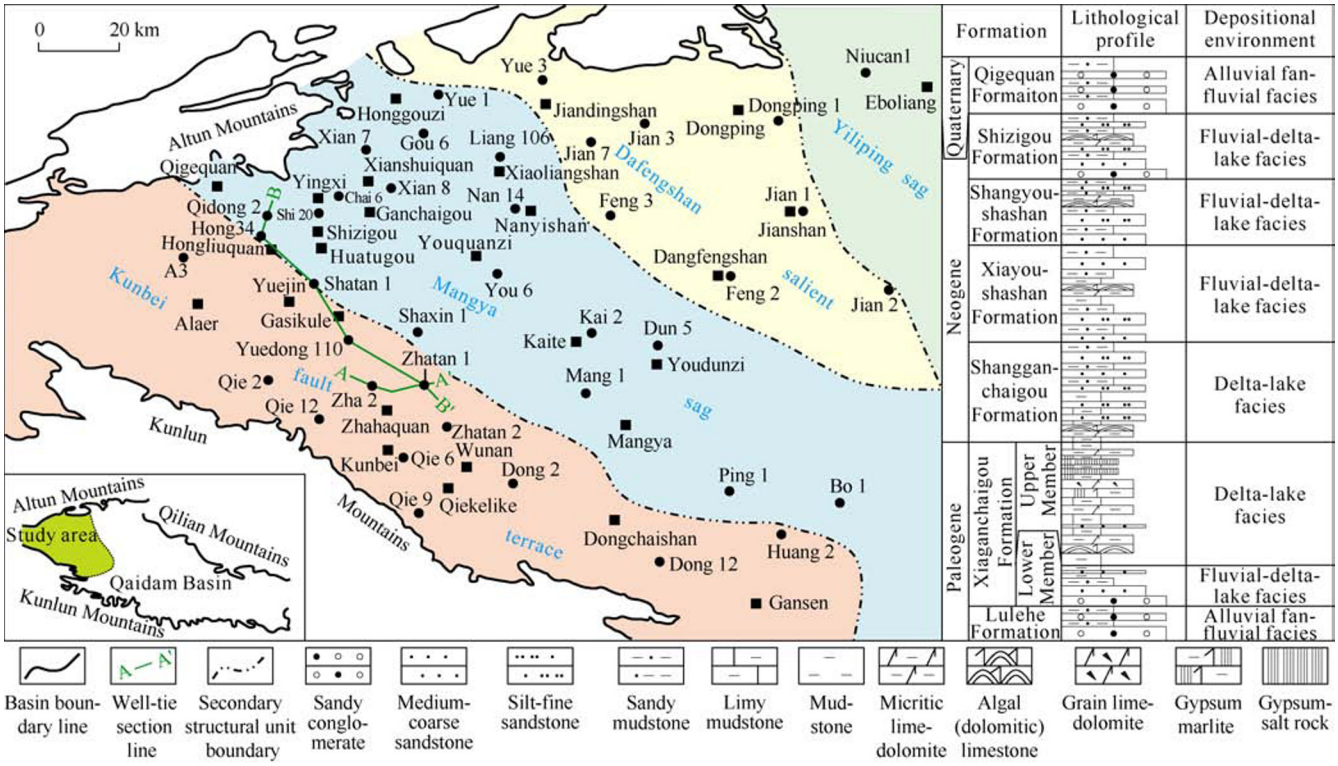

Fig. 1. Structural units and stratigraphic characteristics of western Qaidam Basin.

Xiaganchaigou Formation (E_3^1), upper member of Xiaganchaigou Formation (E_3^2), Shangganchaigou Formation(N_1), Xiayoushashan Formation (N_2^1), Shang youshashan Formation (N_2^2), Shizigou Formation (N_2^3) and Qigequan Formation (Q).

2. Geological characteristics of tight oil

2.1. Sedimentary environment

Paleostructure restoration shows that during the late Paleogene to early Neogene, a series of synsedimentary reverse faults[5] developed in western Qaidam Basin under the influence of the constant uplifting and compression of the Tibetan Plateau, and consequently inherited paleoslope and paleogeomorphologic framework with alternating uplifts and depressions formed in the area under the control of the faults. The paleo-slopes at the basin margin are composed of the Kunbei step-fault zone, the gentle slope of Dafengshan and the piedmont steep slope of Altun Mountain[6]. The paleo-depression area mainly developed in the present Mangya sag, including five sedimentary paleo-subsags: Hongliuquan-Shizigou, Zhahaquan-Qiekelike, Nanyishan-XiaoLiangshan, West Mangya and East Mangya[1] separated by paleoslopes and paleohighs. At the same time, the basin saw a constant increase of altitude[7–9], and constant shift of paleo-latitude northward[10]. The pollen of fossil plants, clay minerals and sedimentary rock types reveal the paleo-climate of Western Qaidam Basin featured frequent alternation between relative humid and drought climates, and prevalent northwesterly wind since Paleogene[11–13]. Under the control of paleo-climate, the basin water salinity and lake level experienced high-frequency fluctuations[14–15]. Under the joint control of paleo-structure, paleoclimate and paleo-lake water, favorable combinations of hydrocarbon sources and tight reservoirs came about from the late Paleogene to Neogene in the western Qaidam Basin.

During the E_3^1 depositional period, the paleoclimate was relatively wet, the source material supply was sufficient, the lake level rose steadily, and the sag center was mainly located in Hongliuquan-Shizigou area, near the subsag center. Large-scale braided river delta front sandbodies contact with source rocks like crossed fingers in the Hongliuquan gentle slope, while the thick nearshore turbidite fan sandbodies in the Qigequan-Honggouzi steep slope area are wrapped inside hydrocarbon source rocks, forming two kinds of favorable tight oil reservoirs, the delta front and deep lake gravity flow sands.

In the early stage of E_3^2-N_1, the favorable tight oil sources, reservoirs, and their combinations in western Qaidam Basin were in the full swing of development. Vertically, it can be divided into 3 cycles: the period of lake level rise-weak salinization, the period of lake initial fall-semi salinization and the period of lake level rapid fall- salinization, the three cycles made up multi-classes of tight oil reservoir and source superimposed combinations. In the lake level rise-weak salinization period, with sufficient provenance supply, high quality hydrocarbon source rock developed extensively in the paleoslope, paleohigh and subsag areas, and nearshore subaqueous fan and turbidite fan sandbodies developed in the steep slope area and the synsedimentary fault footwall, forming tight oil source reservoir combinations of deep lake gravity flow sandstone primarily. In the lake level initial fall-semi-