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Research paper

Hydrocarbon migration and accumulation of the Suqiao buried-hill zone in Wen'an Slope, Jizhong Subbasin, Bohai Bay Basin, China

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ABSTRACT

The hydrocarbon migration and accumulation of the Suqiao deep buried-hill zone, in the Jizhong Subbasin, the Bohai Bay Basin, eastern China, was investigated from the perspective of paleo-fluid evidence by using fluid inclusions, quantitative fluorescence techniques (QGF), total scanning fluorescence method (TSF) and organic geochemical analysis. Results show that the current condensate oil-gas reservoirs in the study area once were paleo-oil reservoirs. In addition, the reservoirs have experienced at least two stages of hydrocarbon charge from different sources and/or maturities. During the deposition of the Oligocene Dongying Formation (Ed), the deep Ordovician reservoirs were first charged by mature oils sourced from the lacustrine shale source rocks in the fourth member of Shahejie and Kongdian Formations (Es_4+Ek), and then adjusted at the end of Ed period subsequently by virtue of the tectonic movement. Since the deposition of the Neogene Minghuazhen Formation (Nm), the reservoirs were mainly charged by the gas that consisted of moderate to high-maturity condensate and wet gas sourced from the Es_4+Ek lacustrine shale source rocks and mature coal-derived gas sourced from the Carboniferous-Permian (C-P) coal-bearing source rocks. Meanwhile, the early charged oil was subjected to gas flushing and deasphalting by the late intrusion of gas. The widely distributed hydrocarbon inclusions, the higher QGF Index, and FOI (the frequency of oil inclusions) values in both gas-oil and water zone, are indicative of early oil charge. In addition, combined with the homogenization temperatures of the fluid inclusions (<160 °C) and the existence of solid-bitumen bearing inclusions, significant loss of the *n*-alkanes with low carbon numbers, enrichments of heavier components in crude oils, and the precipitation of asphaltene in the residual pores suggest that gas flushing may have played an important role in the reservoir formation.

1. Introduction

The petroleum exploration and development in marine strata is becoming more and more important in China in recent years. However, in most regions of China, marine strata are deeply buried, thermally overmature, and have experienced multiple-stage tectonic deformation (Ma et al., 2004). The reservoirs may have experienced complex physicochemical processes, such as alteration, leakage, remigration and reaccumulation, making exploration in marine sequences a great challenge. Understanding the hydrocarbon migration and accumulation during the complex evolution histories has become a prerequisite for successful petroleum exploration in marine strata.

The fluid inclusions trapped in petroleum reservoirs or along oil migration pathways by mineral diagenesis can preserve essential information on the P-T conditions and compositions of the fluids at the time of trapping (Parnell, 2010). Therefore, hydrocarbons in fluid inclusions can provide valuable information for reconstructing paleo-temperature and pressure of the reservoirs (Burruss, 1989; Swarbrick, 1994; Aplin et al., 1999; Tseng and Pottorf, 2002; Ferket et al., 2011), and for determining hydrocarbon migration and charging time (Burley et al., 1989; Jiang et al., 2015; Guo et al.,

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2016), PVT modeling (liu et al., 2003a; Bourdet et al., 2010), as well as the fluid evolution within a reservoir (Bourdet et al., 2012; Xiang et al., 2015). In addition, quantitative grain fluorescence technique (QGF) has become an effective approach in the analysis of hydrocarbon evolution process recently. Not only is the technique non-destructive, rapid and cost-effective, but also can consecutively collect samples at different depths in several wells for the system spectral analysis (Liu et al., 2003b; 2007; Liu and Eadington, 2005). QGF data have been used to identify oil-bearing reservoir, hydrocarbon migration path and the current and paleo-water-oil contact. Moreover, total scanning fluorescence technique (TSF) can be used to test the three-dimensional fluorescence spectrums of reservoir extracts, crude oil and hydrocarbon inclusions in the reservoir and reflect the information of hydrocarbon compositions more comprehensively, which can be used to analyze hydrocarbon property and make detailed oil-source correlation (Liu et al., 2003b, 2007; 2014; Liu and Eadington, 2003, 2005).

Suqiao deep buried-hill zone (Fig. 1), located in the north of the Wen'an Slope, Jizhong Subbasin, Bohai Bay Basin, is one of the important oil-gas area found in marine strata in China. The discovery of Well S1, with a high production rate of approximately 59 tons (433.65 bbl)/d of crude oil and 6.3×10^4 m^3/d of gas in the Ordovician reservoirs in November 1982, opened the prelude of the petroleum exploration in this area (Du et al., 2002). Then two regional oil-gas fields namely Suqiao (SQ) and Xinanzhen (XAZ) have been found in the area, reflecting promising exploration prospects. The discovered hydrocarbons mainly accumulate in the deep buried Ordovician carbonate reservoirs, and are generally believed to be mixed sourced (Qin et al., 2000; Liu et al., 1990; Yang and Li, 1991) as there are two sets of source sequences that have generated hydrocarbons present in the study area (Jin et al., 2014; Zhang et al., 2014a). However, the process and mechanism of this mixing have not been well investigated. Only some preliminary oil- and gas-correlation and fluid inclusion studies, mainly based on geochemistry have been conducted. As a consequence, the general laws of hydrocarbon migration and accumulation are not sufficiently known, thus limiting exploration strategies. In this paper, we attempt to reconstruct the hydrocarbon migration and accumulation process from the perspective of paleo-fluid evidence using an integrated analysis of fluid inclusions, quantitative fluorescence techniques, total scanning fluorescence method and hydrocarbon geochemistry as they have been suggested to be effective approaches of investigating complex, multiple-stage hydrocarbon migration and accumulation histories.

2. Geological setting

The Wen'an Slope is an NNE-trending, NW-dipping gentle slope in the Jizhong Subbasin, which is one of the most petroliferous zones in the Bohai Bay Basin (Fig. 1A). It is bounded by the Dacheng Uplift to the east, the Baxian Depression to the west, the Yangcun Slope to the north, and the Raoyang Depression to the south. The Suqiao buried-hill zone, which includes Suqiao (SQ) and Xinanzhen (XAZ) buried-hills, is the key area of oil and gas exploration in Wen'an Slope. The study area belongs to the northern section of Wen'an Slope and is a faulted buried-hill tectonic belt developed in NW-dipping slope (Fig. 1B). From Paleozoic to Cenozoic, the study area has experienced multiple tectonic stages characterizing by a "seesaw" tectonic movement from regional east-dipping to west-dipping. Furthermore, the multiple tectonic stages can be divided into four different stage (Du et al., 2002; Kong et al., 2011): regional subsidence and uplift stage (Paleozoic), differential subsidence and uplift stage (Mesozoic), synrift stage (Paleogene), and postrift stage (Neogene). Since the late Ordovician, the study area underwent about 150 million years of tectonic uplift. As a result, the Devonian, Silurian, and even part of Ordovician strata were eroded resulting in the most important unconformity at the top of Ordovician (Du et al., 2002). In addition, this area mainly develops NNE and NWW dipping faults which have an important effect on the development, formation and hydrocarbon migration of fault-block

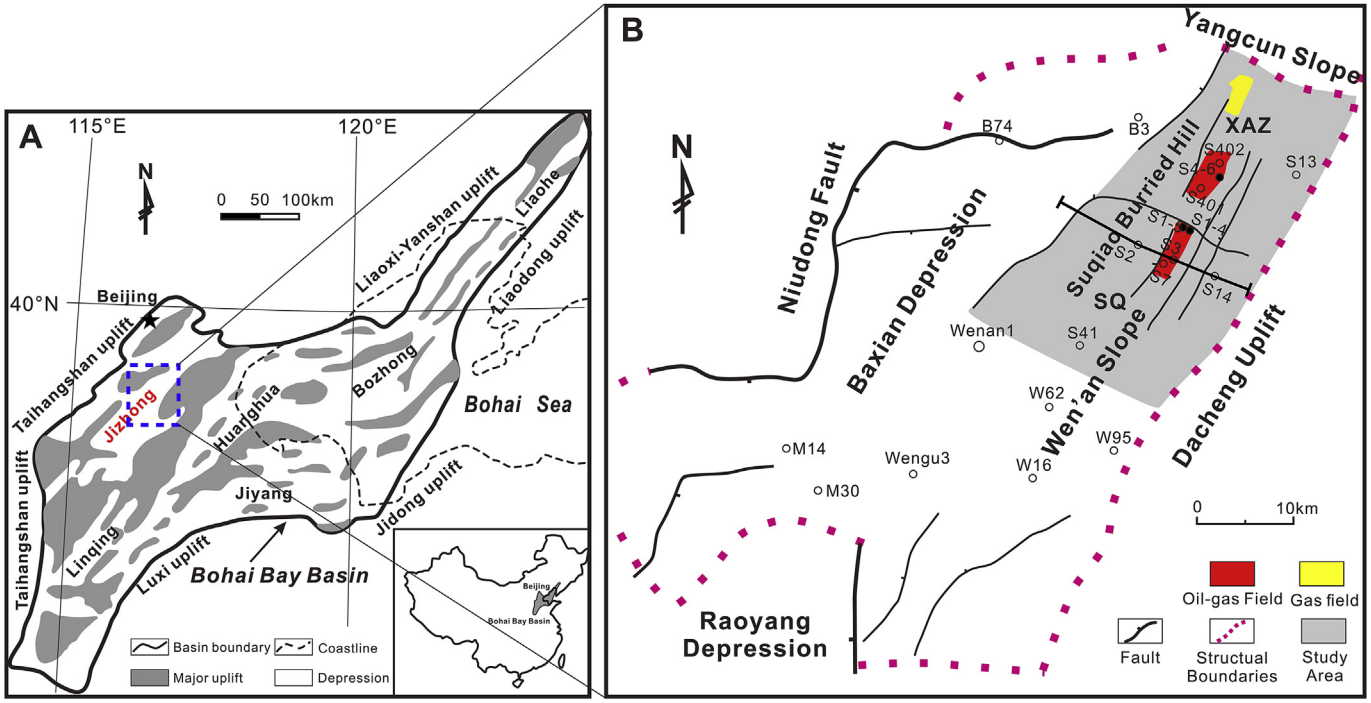

Fig. 1. A. simplified structural map illustrating the regional setting of the Bohai Bay Basin. The Jizhong subbasin is in the north-west part of Bohai Bay Basin. B. the shadow outlines the Suqiao buried-hill zone in the Baxian Depression (Zhao et al., 2013). SQ = Suqiao hills, XAZ = Xinanzhen hills.