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Research paper

Multiple-stage migration and accumulation of Permian lacustrine mixed oils in the central Junggar Basin (NW China)

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ABSTRACT

The Permian lacustrine petroleum system in the central Junggar Basin, northwest China, has recently obtained exploration success. These accumulations are characterized by mixed oils and multiple-stage migration and accumulation. This process, however, has not been well constrained, limiting the understanding of the general laws of hydrocarbon migration and accumulation and making it difficult to define exploration strategies. Here, we reconstruct this process mainly based on oil-bearing fluid inclusion analyses including petrography, homogenization temperature and sequential extraction. Inclusion petrography shows that petroleum inclusions dominantly display yellow fluorescence, while intergranular free oils mostly display strong blue green fluorescence. This implies that the reservoirs seem to have experienced at least two stages of hydrocarbon charge from different sources and/or maturities. The sources/maturities are determined through reservoir sequential extraction analyses. The free oils are mixed and sourced from the Lower Permian Fengcheng Formation (P_1f) and the Middle Permian Lower Wuerhe Formation (P_2w), while the inclusion oils are also mixed and derived mainly from the P_1f source. Both oils are characterized by moderate maturity. Homogenization temperature measurements of oil-bearing fluid inclusions, combined with reconstruction of reservoir burial and thermal history, not only further verify multiple hydrocarbon charging events but also characterize the timing, which indicates a three-stage petroleum charging model. During the first stage of the Late Triassic, Carboniferous reservoirs were charged by P_1f-sourced oils, which were dysmigrated or remigrated to Jurassic reservoirs during the second stage (i.e., the Early Cretaceous). In contrast, the third stage from the Late Cretaceous represents another hydrocarbon charge event that is the primary oil accumulation sourced from the P_2w rocks. According to this model, both primary and secondary oil accumulations contribute to the current region's exploration success, and provide future exploration targets.

1. Introduction

China's tectonically superimposed basins, especially in northwest China, have abundant hydrocarbon accumulations due to the development of multiple petroleum systems (e.g., the Junggar and Tarim basins) (Watson et al., 1987; Carroll et al., 1990; Li et al., 1996; Jia et al., 1998; Koopmans et al., 2002; Jin and Wang, 2004). It is the development of multiple petroleum systems that causes the hydrocarbon migration and accumulation history to be very complex. Reservoirs may be charged by multiple source rocks and/or different reservoirs may be mono-sourced (Lu et al., 2004; Cao et al., 2005; Hao et al., 2011; Zhu et al., 2013; Zhang et al., 2014). Restoring the mixed-sourced petroleum system is always challenging, as isotopic and molecular geochemical methods on bulk oils are ineffective due to the mixing effects of hydrocarbons (Ladwein, 1988; Graham et al., 1990; Li et al., 1996; Hanson et al., 2000; He et al., 2000; Chen et al., 2003a, 2003b; Jin and Wang, 2004). However, oil-bearing fluid inclusion analyses can provide good clues to solve this issue (Karlsen et al., 1993; George et al., 2007). Fluid inclusions can preserve the original characteristics of hydrocarbon fluids and the diagenetic environment and thus are not affected by later alteration, such as hydrocarbon mixing, thermal maturation and biodegradation (Watson and Brenan, 1987; McLimans, 1987; England et al., 1987; Prezbindowski and Tapp, 1991; Head et al., 2003). Therefore, hydrocarbons in fluid

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inclusions can provide valuable information for tracking multiple-stage fluids, and deciphering hydrocarbon sources and migration in superimposed petroliferous basins (Bodnar, 1990; Isaksen et al., 1998; Cao et al., 2006).

The Junggar Basin is a typical superimposed petroliferous basin in northwest China with the central basin surrounding the Penyijingxi sag (Fig. 1) being a current exploration highlight (Hao et al., 2011; Cao et al., 2012). Beginning in 1992, three regional oil fields namely Shixi, Mobei and Mosuowan have been found in the eastern band of the sag, reflecting promising exploration prospects. They yield approximately two million tons of oils each year, making a significant contribution to the petroleum industry in the Xinjiang Autonomous Region of northwest China (Kuang et al., 2005; Zhou et al., 2005; Shi et al., 2010). The discovered hydrocarbons mainly accumulate in the deeply buried Carboniferous and shallowly buried Jurassic reservoirs, and are generally believed to be mixed sourced (Xiao et al., 2010; Hao et al., 2011; Cao et al., 2012) as there are two sets of source sequences that have generated hydrocarbons present in the study area (Wang, 2001). However, the process and mechanism of this mixing have not been well constrained as conventional geochemical studies on bulk oil show negligible differences in general physical and geochemical properties, making the modeling of petroleum migration and accumulation elusive (Xiao et al., 2010; Hao et al., 2011; Cao et al., 2012). As a consequence, the general laws of hydrocarbon migration and accumulation are not sufficiently known, thus limiting exploration strategies. In this paper, we seek to reconstruct and model hydrocarbon migration/accumulation in this area mainly employing fluid inclusion analyses. It aims to provide new data on the regional characteristics and laws of oil enrichment, expand hydrocarbon exploration, as well as provide references to similar studies at home and abroad.

2. Geological setting

2.1. Tectonics

Covering an area of about 1.3×10^5 km^2, the Junggar Basin is located in the northern part of Xinjiang Uygur Autonomous Region, northwest China. The triangle-shape basin is bounded by the Qinggelidi-Kelameili Mountains to the east, the Zhayier Mountains to the west, the Tianshan Mountains to the south and the Altai Mountains to the north (Fig. 1a). It is a late Paleozoic, Mesozoic and Cenozoic superimposed basin developed on the Junggar basement (Wang, 1996; Li et al., 2006) (Fig. 1a).

The basin underwent pre-Carboniferous folding and basement metamorphism (Coleman, 1989; Chen et al., 2002). From the Devonian to the Carboniferous, the basin is a platform basin in the Xingmeng Ocean surrounded by deep troughs (Coleman, 1989; Chen and Wang, 2004; Wu et al., 2005). Later during the Late Carboniferous, the basin transformed from an open marine basin to a closed continental basin and stepped into a basin-

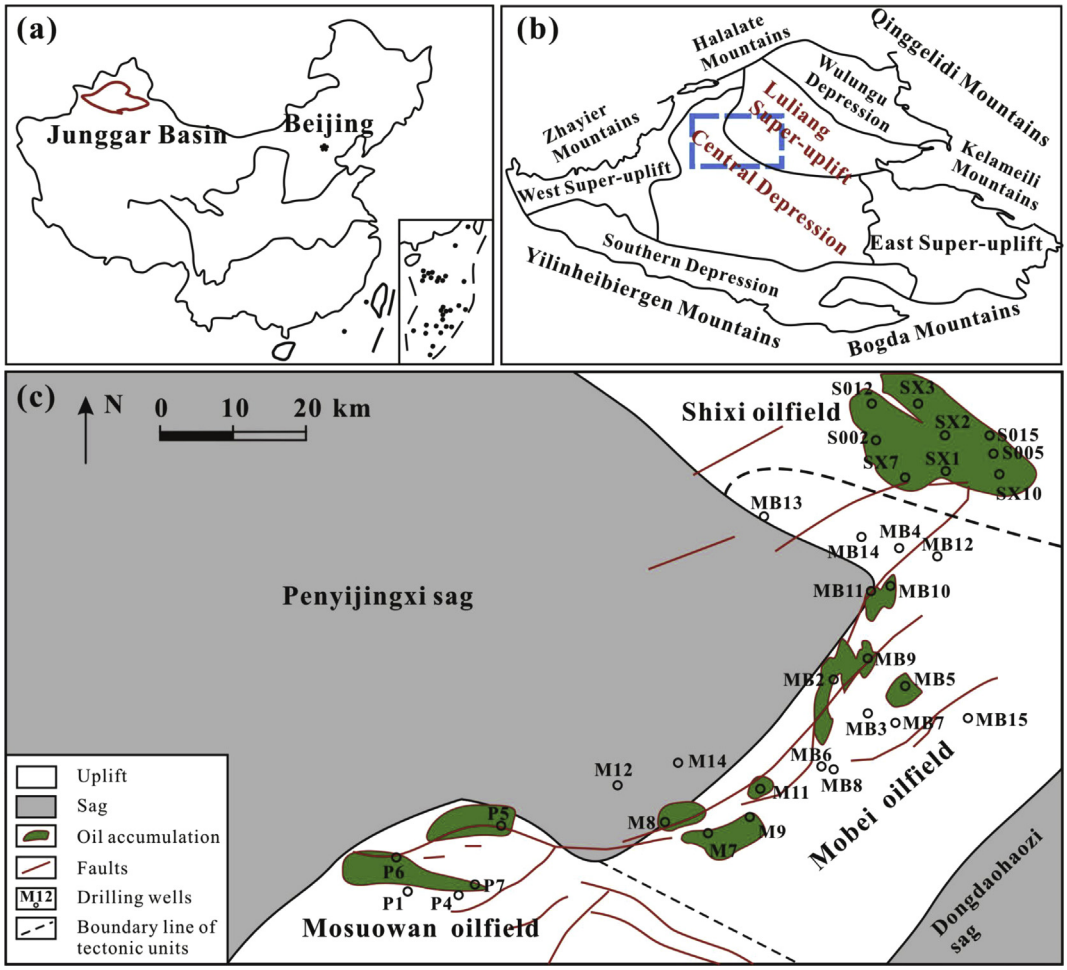

Figure 1. Sketch map showing the locations of the main oil and gas accumulations in the study area. (a) the geographic location of the Junggar Basin in China; (b) tectonic units in the Junggar Basin, insert rectangular represents area shown in Figure 1c; (c) current results of oil and gas exploration in the study area.