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Research paper

Enhanced effects of large-scale CO_2 transportation on oil accumulation in oil-gas-bearing basins — Implications from supercritical CO_2 extraction of source rocks and a typical case study

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ABSTRACT

Large-scale mantle-derived CO_2 emplacement and co-accumulation of CO_2 and crude oil have been discovered in oil-gas bearing basins in eastern China and many other areas worldwide. To investigate the effect of the natural supercritical CO_2 on the migration of crude oil as well as on the formation of oil reservoirs, experiments on supercritical CO_2 extraction (SCE) and traditional chloroform extraction (CE) of hydrocarbon source rocks were carried out and the geochemical characteristics of the Huangqiao CO_2-oil reservoir in the Subei Basin, eastern China were investigated. The SCE yielded a large proportion of the hydrocarbons in the Permian mudstone source rocks at 110 °C under 30 MPa. Compared with the traditional chloroform extraction (CE), the SCE-retrieved organic compounds are dominated by saturated hydrocarbons and contain a relatively higher concentration of small molecular mass compounds. Many wells in the Huangqiao reservoir yielded large amounts of CO_2 from several formations, such as the Triassic Qinglong Formation (T_1q) and the Permian Longtang Formation (P_2l). Accompanying the CO_2 flow, a certain amount of oil is commonly recovered. The oil is mainly light oil or condensate oil with a relative density of 0.7933–0.8308, and it contains 90.06–97.37% saturated hydrocarbons. Compared with hydrocarbons in the Permian source rocks, the oil accompanying the CO_2 in the Huangqiao reservoir contains more C_{20-} hydrocarbons and less C_{21+} hydrocarbons. The oil accompanying the CO_2 has a similar composition to the SCE extracts from the source rocks, namely, both contain a relatively high concentration of low molecular mass hydrocarbons. Therefore, it can be concluded that, in the Huangqiao area, during movement upward along deep faults and fractures or flow through source rocks, the deep supercritical CO_2 naturally extracted hydrocarbons, especially small molecular hydrocarbons, from the source rocks, and then brought them to the shallow strata to form the CO_2-oil coupling reservoirs.

1. Introduction

Accumulations of large volumes of CO_2 related to mantle degassing, metamorphic reactions or magmatic processes have been found in many oil-gas bearing basins around the world (Lawrence and Cornford, 1995; Palcsu et al., 2014; Wycherley et al., 1999). In some of these basins, such as Otway Basin in Australia (McKirdy and Chivas, 1992), the continental margin basins of the northern South China Sea (Huang et al., 2015), Shabwa Basin in Yemen (Worden, 2006) and Santos Basin in Brazil (Ma et al., 2015), oil co-accumulates with CO_2 in reservoirs.

Multiple CO_2 gas reservoirs with CO_2 contents up to 99% have also been found in many oil-gas bearing basins in eastern China, such as the Songliao, Bohai Bay, Subei and Sanshui Basins (Fig. 1). Numerous studies have shown that the CO_2 in these basins mainly originated from the mantle (Dai et al., 1996; Huang et al., 2015; Zhang et al., 2008a; Zheng et al., 2001) and was related to volcanic activity occurring since the Cenozoic (Qu et al., 2016; Wang et al., 2012b; Xu et al., 1995), and only a small amount of the CO_2 originated from thermal decomposition of carbonate rocks or was derived from organic matter (Zhang et al., 2008a). Many CO_2 reservoirs in eastern China, such as the Changling reservoir in the Changling depression of Songliao Basin, Pingfangwang reservoir in the Jiyang sag of Bohai Bay, and the Huangqiao reservoir in the Subei Basin, also produce oil along with CO_2 gas (Figs. 1 and 2).

In the CO_2 reservoirs, the interaction between CO_2 and reservoir rocks has been studied in detail. In general, CO_2 with high partial pressure heavily altered feldspar grains in the sandstone reservoirs, leading to the formation of dawsonite (Gao et al., 2009; Worden, 2006; Yu et al., 2014), kaolinite, calcite and ankerite (Liu et al., 2011). The

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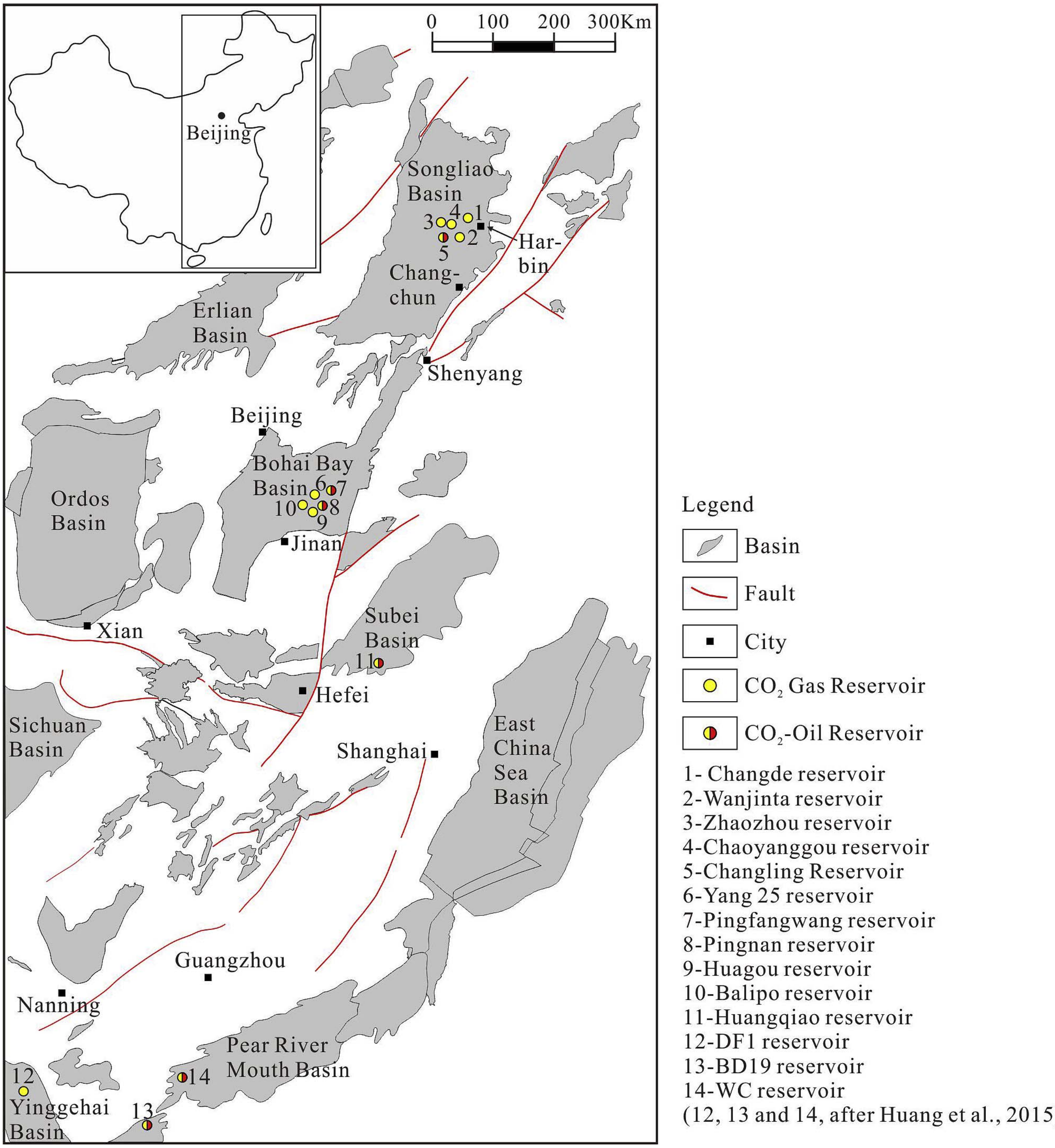

Fig. 1. Location of CO_2 and CO_2-oil reservoirs in oil-gas bearing basins in eastern China.

reservoir quality (porosity and permeability) was highly enhanced by the CO_2-rich fluids due to dissolution of sandstone reservoirs (Higgs et al., 2013; Yang et al., 2014).

The critical temperature and pressure of CO_2 are 30.98 °C and 7.38 MPa, respectively (Lu et al., 2004). Under geological conditions where the pressure gradient of static water is 10 MPa/km and the geothermal gradient is 30 °C/km, CO_2 is in the supercritical state at depth more than 800 m below the surface (Varma et al., 2009). Supercritical CO_2 has a strong ability to dissolve a variety of organic compounds (Hyatt, 1984). Supercritical CO_2 extraction has received significant attention as an analytical tool for the extraction of hydrocarbons from geological samples. Some scholars found experimentally that supercritical CO_2 fluid could effectively extract hydrocarbons from sedimentary rocks (Bondar and Koel, 1998; Monin et al., 1988), and this has been used for source rock quality evaluation in gas, oil (Jaffé et al., 2000) and shale oil exploration (Jarboe et al., 2015; Middleton et al., 2014; Wang et al., 2012a).

However, some questions concerning the effects of mantle-derived supercritical CO_2 on petroleum migration and accumulation under natural reservoir conditions are less discussed. The process and mechanism that supercritical CO_2 extracts hydrocarbons dispersed in deep sediments and then enhances them to migrate towards shallow strata to form CO_2-oil reservoirs are unclear.

In the present work, (1) experiments of supercritical CO_2 extraction for hydrocarbon source rocks were carried out to simulate interactions between mantle-derived CO_2 and crude oil in the reservoir, (2) the