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Research paper

Impact of hydrocarbon expulsion efficiency of continental shale upon shale oil accumulations in eastern China

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ABSTRACT

Core samples were taken from two formations (the Qingshankou Formation in northern Songliao Basin and the third member of the Shahejie Formation of Zhanhua Sag) to carry out a study of impact of hydrocarbon expulsion from continental shale upon shale oil accumulations in eastern China. Total Organic Carbon (TOC) and pyrolysis data of these samples were used to establish an evaluation criterion with absolute and relative oil content indexes for determining oil potential of shale. As a result, a correspondence relationship between shale oil content and organic types was established. Factors that may affect oil content of shale were discussed through study of fractures, pore development, minerals and lithological assemblage of the samples. The results show that oil content of mature petroleum source rocks is firstly controlled by fracture growth and secondly by pore development. They played both negative and positive roles in hydrocarbon flow and accumulation in shale. Overpressure caused by hydrocarbon generation and existence of organic acid corrosion are two important factors affecting the formation of fractures and pores in shale, respectively. Intervals with type I organic matter are not favorable shale oil exploration targets because they contain little oil. Shale with type I organic matter tends to generate large amount of hydrocarbon, but these hydrocarbon will escape with a high efficiency through over-pressurized fractures caused by hydrocarbon generation and lack of pore space, which in turn is the result of absence of oxygen that is essential for forming organic acid to create secondary pores in shale. On the contrary, intervals with type II organic matters are potential shale oil exploration targets for that they offered just right conditions for oil to stay inside: higher content of oxygen that is helpful in forming organic acid, moderate hydrocarbon generation capacity that will not cause over-pressurized fractures in shale with secondary pores. While intervals with type III organic matter bear no exploration significance due to the fact that this type of kerogen produces less oil because of low hydrocarbon generation capacity and unfavorable molecular configuration. Shale intervals with thin sandstone interbeds provide favorable passageways for dissolved carbonate by organic acid to flow out, avoiding secondary precipitation. The pores left behind can be excellent space for generated hydrocarbon to linger around. These interbeds are also favorable for later reservoir stimulation measures such as hydraulic fracturing. Shale oil exploration shall be focused on finding sweet spots with greater pores, which are the main reservoir space.

1. Introduction

Shale oil and gas boom in the U.S. shows that commercial development of shale oil and gas is possible under certain geological conditions (Curtis, 2002; Bowker, 2007; Montgomery et al., 2005; Sonnenberg and Pramudito, 2009; Strąpoć et al., 2010). Before oil and gas production potential of shale being revealed by the boom, the organic-rich shale had always been taken as sources rocks in exploration and development of conventional oil and gas, which means that shale oil and gas are the left-behind hydrocarbon that failed to be expelled into adjacent conventional reservoirs. Based on this understanding, we believe that the accumulation of shale oil and gas is closely linked to efficiency of hydrocarbon expulsion. Although previous studies had been focused on either shale oil and gas accumulation (Bowker, 2007; Jarvie et al., 2008) or hydrocarbon expulsion (Hunt, 1990; Capuano, 1993; Robert et al., 1995; Xie et al., 1997), no one has ever

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attempted to establish a relationship between the two. In fact, a control study of accumulation and expulsion of shale oil and gas can help us to understand better the oil and gas potential of shale and accumulation pattern of shale oil and gas. However, shale oil in the US is produced from marine strata, which differ greatly from China's continental strata in oil and gas generation and preservation conditions. This means that we cannot simply copy the US experiences in its shale oil exploration and production but to find a new path suitable for the situation in China. Organic-rich continental mudstone in east China had been chosen as the study target as it is still within the 'oil-generation window'. This paper takes two petroliferous formations – the Qingshankou Formation in northern Songliao Basin (K_1qn) in Daqing Oilfield and the Shahejie Formation in Zhanhua Sag (Es_3) in Shengli Oilfield – as examples to study the impact of geological and geochemical factors, such as TOC, rock pyrolysis, porosity and etc., upon hydrocarbon expulsion and accumulation of shale oil and gas. The two oil fields are mature fields with more than 50 years of producing history and have been facing challenge of maintaining current production rates. Shale oil has been considered as a game changer ever since the US stroke the luck with the shale. We hope our work can shed some lights on shale oil exploration and production in continental oil-bearing basins.

2. Samples and experiment

About 1200 pieces of cores samples were taken from the Qingshankou Formation in northern Songliao Basin (995 samples) and the third member of the Shahejie Formation in Zhanhua Sag, Jiyang Depression (204 samples) to carry out the research. The basic geologic background of study areas is shown in Figures 1 and 2. These samples were then analyzed based on their TOC and pyrolysis data to indicate their oil-bearing potential, organic matter types and efficiency of hydrocarbon generation and expulsion. The factors that affect the expulsion efficiency of the shale from which the samples were taken were analyzed through a study of fractures and pore development, mineral composition and lithology of the samples.

Experimental instruments, such as CS cube, Rock-Eval pyrolysis, and XRD analyzer, were used to acquire data, like organic carbon contents, pyrolysis data and mineral composition, of the samples. The porosity of the shale in two locations were obtained through respective methods: cluster sampling and kerosene method were used to measure the porosity of the shale from the Zhanhua Sag; while in northern Songliao Basin, ten samples were taken and measured with the combination of CO_2, N_2 adsorption and the HPMI (high-Pressure-Mercury-Injection). All the samples from the two locations were scrubbed with dichloromethane and dried before the measuring processes. By applying the Kerosene method, we obtained pore volume of rock sample by dividing the difference between the weight of kerosene-saturated rock and that of kerosene-scrubbed and dried sample by the density of kerosene. The total volume of the rock sample can be calculated by dividing the difference between the weight of kerosene-saturated rock sample and the weight of kerosene-saturated rock sample in kerosene by the density of kerosene. CO_2 adsorption is a method based on DA equation and designed for measure pores with diameter less than 2 nm; while N_2 adsorption is based on BJH

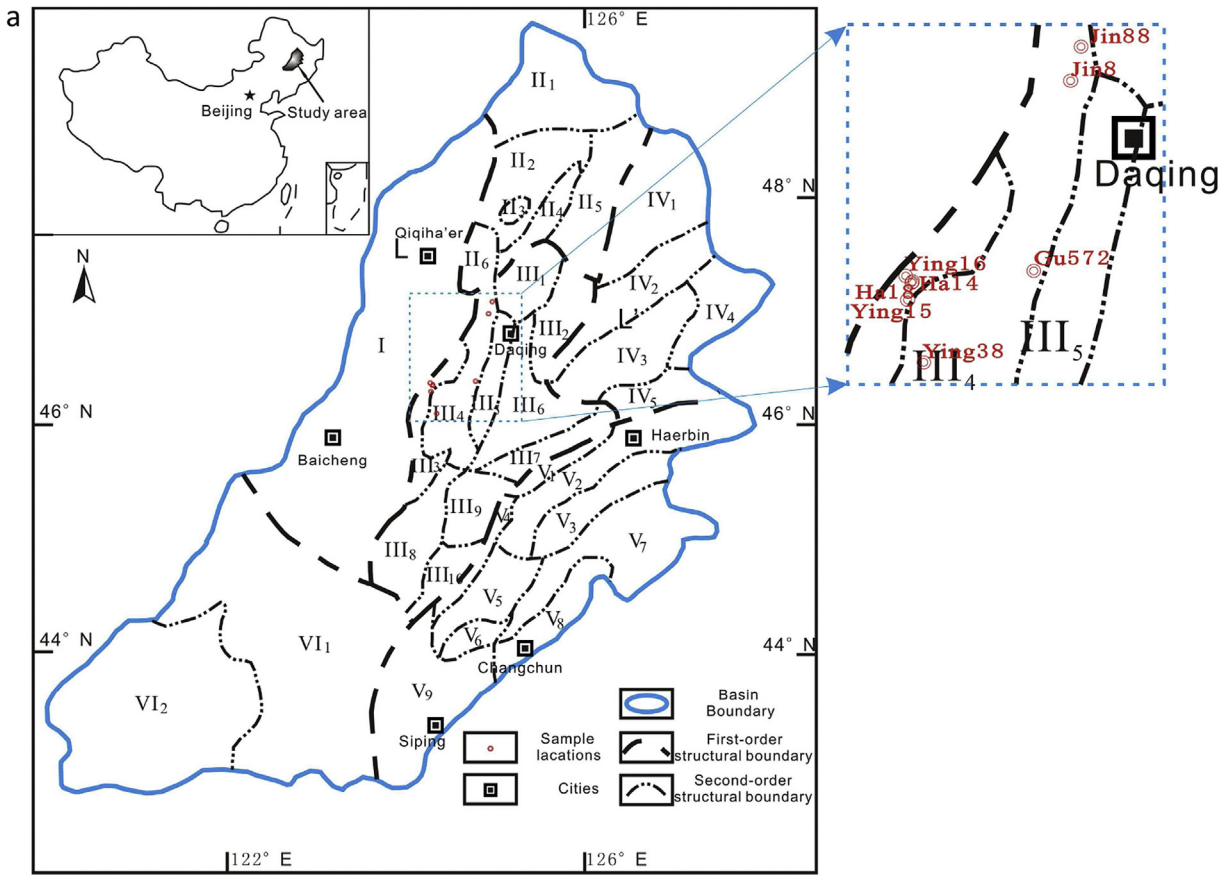

Figure 1. (a) Location and structural units (I, western slope zone; II, northern plunge zone; III, central downwarp zone; IV, northeastern uplift zone; V, southeastern uplift zone; VI, southwestern uplift zone) of the Songliao Basin; (b) generalized stratigraphic columns of the Songliao Basin (After Feng et al., 2008, 2010; Wang et al., 2011).