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Geochemical identification of marine and terrigenous condensates—A case study from the Sichuan Basin, SW China

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ABSTRACT

Condensates are extensively produced from the marine Lower Permian Maokou Formation and the Lower Triassic Jialingjiang Formation (the main marine condensate-producing strata) in southern Sichuan Basin, and also in the terrigenous Upper Triassic Xujiahe Formation in the central and southern Sichuan Basin. Based on the analyses of light hydrocarbons, biomarkers and stable carbon isotopic compositions of marine and terrigenous condensates and the light hydrocarbon composition of natural gases in the Jialingjiang Fm and Xujiahe Fm in the Sichuan Basin, the following conclusions are drawn: (a) condensates produced from the carbonate reservoirs of Jialingjiang Fm and the Maokou Fm (marine condensates) belong to a single oil family, and the condensates from the terrigenous Xujiahe Fm (terrigenous condensates) belong to another family; (b) marine condensates, were generated from sapropelic organic matter in the late stage of high maturation, and the biomarker composition indicates that they were derived from the Lower Silurian shale and the Lower Permian carbonate, while the terrigenous condensates were generated from mature humic source rocks; (c) most of the marine condensates and gases encountered in the Lower Permian Maokou Fm and Lower Triassic Jialingjiang Fm were generated from the same source, and a few of the gases in the Jialingjiang Fm contain admixtures of coal-derived gas, while terrigenous condensates and gases were generated from the Xujiahe Fm humic source rocks; (d) effects that could be related to evaporative migration and biodegradation are not evident in the examined condensates.

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1. Introduction

Condensates, consisting of low molecular mass (C_5–C_8) hydrocarbons, are always produced together with natural gas, and a close relationship exists between the condensates and the corresponding gases. They occur in a gaseous or supercritical state underground in condensate-gas pools; on reaching the surface, liquid hydrocarbon separates from this mixture by retrograde condensation due to the decrease of pressure and temperature (Tissot and Welte, 1984; Dai et al., 1993; Dzou and Hughes, 1993; Curiale and Bromley, 1996; Hunt, 1996; Huang, 1997; Li et al., 1999; Zhang et al., 1999). Light hydrocarbons constitute a major portion of crude oils, and their proportion is much higher in condensates (Hunt, 1984). Light hydrocarbon parameters can reflect the original type, thermal maturity and secondary changes (such as the biodegradation, water washing and evaporative migration) of oils and gases; hence, they have been proved to be a powerful tool for understanding the geochemistry of a suite of oils and gases (Jonathan et al., 1975; Leythaeuser et al., 1979a,b; Thompson, 1979, 1983, 1987; Mango, 1990a,b, 1997; Dai, 1992; Halpern, 1995; Ten Haven, 1996; Carrigan et al., 1998; Odden et al., 1998; Wever, 2000; Jarvie, 2001; Akinlua et al., 2006). Low molecular weight compounds (light hydrocarbons, C_6–C_{14}) should be used in combination with the higher molecular weight ones (biomarkers, such as Ts, Tm, and steranes) to study the geochemical characteristics of oil to arrive at reliable and correct conclusions (Dai et al., 1992; Jarvie, 2001; Cañipa-Morales et al., 2003).

The Sichuan Basin is one of the most important gas producing provinces in China, with crude oil being produced only from Jurassic formations in the central area. Condensates are produced in the Upper Triassic Xujiahe Fm (terrigenous strata) in the central Sichuan Basin and the Lower Permian Maokou Fm and Lower Triassic Jialingjiang Fm (marine strata) in the southern Sichuan Basin. Among the marine strata, the Jialingjiang Fm is the most important because it has the highest productivity. In recent years, significant advancements have been made in the exploration of the Xujiahe Fm pool in the central Sichuan Basin, and large gas fields with

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proved reserves of more than 100×10^9 m^3 have been discovered successively, such as the Guang'an, Hechuan and Anyue gas fields. The unanimous view that the Xujiahe gas pools are self-generated and self-reservoired pools has been reported by several previous studies (Dai et al., 2009, 2012; Zou et al., 2009; Zhao et al., 2010; Hu et al., 2012). Geochemical characteristics of condensates in the Xujiahe Fm in the western Sichuan Basin have been studied by several researchers (Wang T. et al., 1989; Wang S. et al., 1994; Wang and Wang, 1990; Huang, 1997). However, few studies have investigated the geochemistry of marine condensates (condensates from the marine carbonates reservoirs, Maokou and Jialingjiang formations); the original relationship between marine and terrigenous condensates and gases present in the Sichuan Basin has not been understood clearly in the literature. Although the condensates in the Jialingjiang Fm were found in the 1950s, views regarding their genetic type and source are controversial. The views held by different scholars can be categorized into three groups: (a) self-generated and self-reservoired (Wang et al., 1989); (b) sourced from the Lower Permian Qixia Fm carbonate (An, 1996); and (c) mainly generated from the Lower Silurian shale, with a small part being sourced from the Upper Longtan Formation coal, such as the condensate in the Shengongshan gas field (Li Y. et al., 2005; Li Q. et al., 2005). The objective of this study is to investigate the oil–oil correlation and distinguish between the oil families of the marine and terrigenous condensates in the Sichuan Basin, to study the thermal maturity of condensates, kerogen types, depositional environment of the source rocks and oil–gas correlation, and to determine the original relationship between condensates and associated gases. This could be of great significance to the oil and gas exploration in the central and southern Sichuan Basin.

2. Geological setting

The Sichuan Basin is a large superimposed basin that is a congruence of the Palaeozoic marine craton basin and the foreland to intra-continental down-warped basin in the Mesozoic–Cenozoic period (Zhao et al., 2011). The basin, covering an area of 180×10^3 km^2, is located in the northwest of the Yangtze craton, with a diamond shape and northeast trend. The Sichuan Basin is

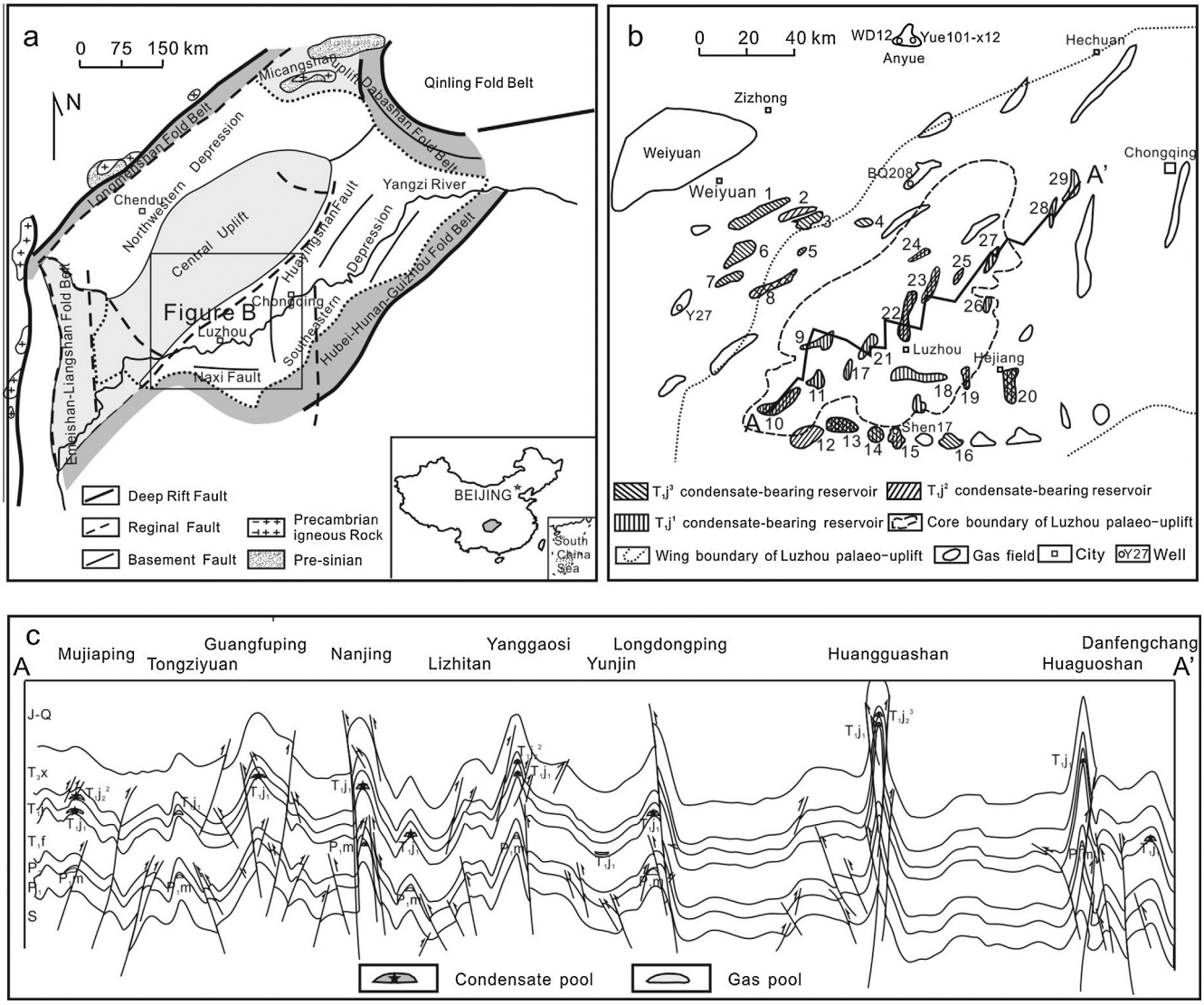

Fig. 1. Structural subdivision of the Sichuan Basin and the study area (a); distribution of the Jialingjiang Fm condensate reservoirs (b), and NE section (A–A') of the southern Sichuan Basin (c) (a: modified from Ma et al., 2007; c: modified from Yang and Li, 2004). 1. Ziliujing; 2. Lingyinsi; 3. Huangjiachang; 4. Longchang; 5. Yangjiachang; 6. Xinglongchang; 7. Kongtan; 8. Dengjingguan; 9. Guangfuping; 10. Mujiaping; 11. Tongziyuan; 12. Laowengchang; 13. Fujiamiao; 14. Changhuanba; 15. Shengongshan; 16. Wutongchang; 17. Nanjing; 18. Naxi; 19. Miaogaosi; 20. Hejiang; 21. Lizhitan; 22. Yanggaosi; 23. Jiukuishan; 24. Gufoshan; 25. Longdongping; 26. Yong'anchang; 27. Huangguashan; 28. Huaguoshan; 29. Danfengchang.

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