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Research paper

Sedimentology and organic properties of lower Tertiary lacustrine source rocks, Lunpola Basin, central Tibetan Plateau: Implications for hydrocarbon potential

Pengfei Ma [a], Chengshan Wang [a, *], Licheng Wang [b], Yalin Li [a], Jian Hu [c]

[a] State Key Laboratory of Biogeology and Environmental Geology, School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[b] MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[c] PetroChina Research Institute of Petroleum Exploration and Development, Beijing 100083, China

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ABSTRACT

The Tertiary lacustrine Niubao Formation is well exposed in the middle-western part of the Lunpola Basin, central Tibetan Plateau, where crude oil was once discovered during drilling campaigns. Sedimentological, organic petrographic and geochemical work was performed on the upper and middle members of this formation in order to investigate its hydrocarbon source rock potential.

Sedimentological analyses indicate that both members were deposited in relatively deep lake conditions away from the influence of big stream system, with the upper Niubao Formation (UNF) having higher sand content. The two members contain abundant high-quality Type I kerogen derived mainly from plankton, algae, and bacteria. Compared with samples of the middle Niubao Formation (MNF), UNF samples also contain more Type II and Type III kerogens of terrestrial origin. Biomarkers of source rock extracts suggest that a long-standing anoxic, stratified, and saline ancient lake occupid the basin during deposition of the two members, which was conducive to the preservation of organic matter. However, higher gammacerane content and the presence of β-carotane in MNF samples imply a more saline lake condition. Rock-Eval T_{max} and biomarker parameters reveal marginal maturity and immaturity for samples from MNF and UNF, respectively. Therefore, MNF has better source rocks of higher maturity might be the main hydrocarbon generating member of the basin; similar diagnostic biomarkers and biomarker parameters reported in the crude oil also imply its affiliation with the source rocks of MNF.

1. Introduction

Energy supply is becoming more and more important with the rapid economic development of China (Wang et al., 2011a). In 2013, 5.6 million barrels of crude oil were imported per day (EIA of U.S., 2013; Sun et al., 2014b), accounting for half of the oil consumption in China. In view of this situation, domestic energy exploration and exploitation have received much more attention than before, especially in the under-explored Tibetan Plateau (Wang et al., 2011a; Zhang et al., 2011), which covers nearly 20% of the territory of China, with probable reserves of more than 10.5 billion barrels (Zhao et al., 2006).

Recent studies involving oil and gas exploration of the Tibetan Plateau have mainly concentrated on the marine strata of the Qiangtang Basin (e.g., Ding et al., 2011; He et al., 2012a,b, Fig. 1B) and the oil shale layers of the upper Tertiary Dingqinghu Formation of the Lunpola Basin (e.g., Wang et al., 2011b; Fu et al., 2012; Sun et al., 2014c, Fig. 1B,C) and the Nima Basin (e.g., Li et al., 2010; Wang et al., 2011a, Fig. 1B). Considering the multi-episode tectonic evolution and widespread fault systems of the Qiangtang Basin (Zhao et al., 2006), and the immature and sporadic distribution of the Dingqinghu oil shale layers (Wang et al., 2011a,b; Sun et al., 2014c), the future prospects of these basins seem uncertain.

Another important target, the Niubao Formation, is widely distributed in all of the Cenozoic lake basins developed in the Bangong-Nujiang suture zone (BNSZ), and the crude oil was once extracted from reservoirs of this formation through the Zang-1 well

* Corresponding author.
E-mail address: chshwang@cugb.edu.cn (C. Wang).

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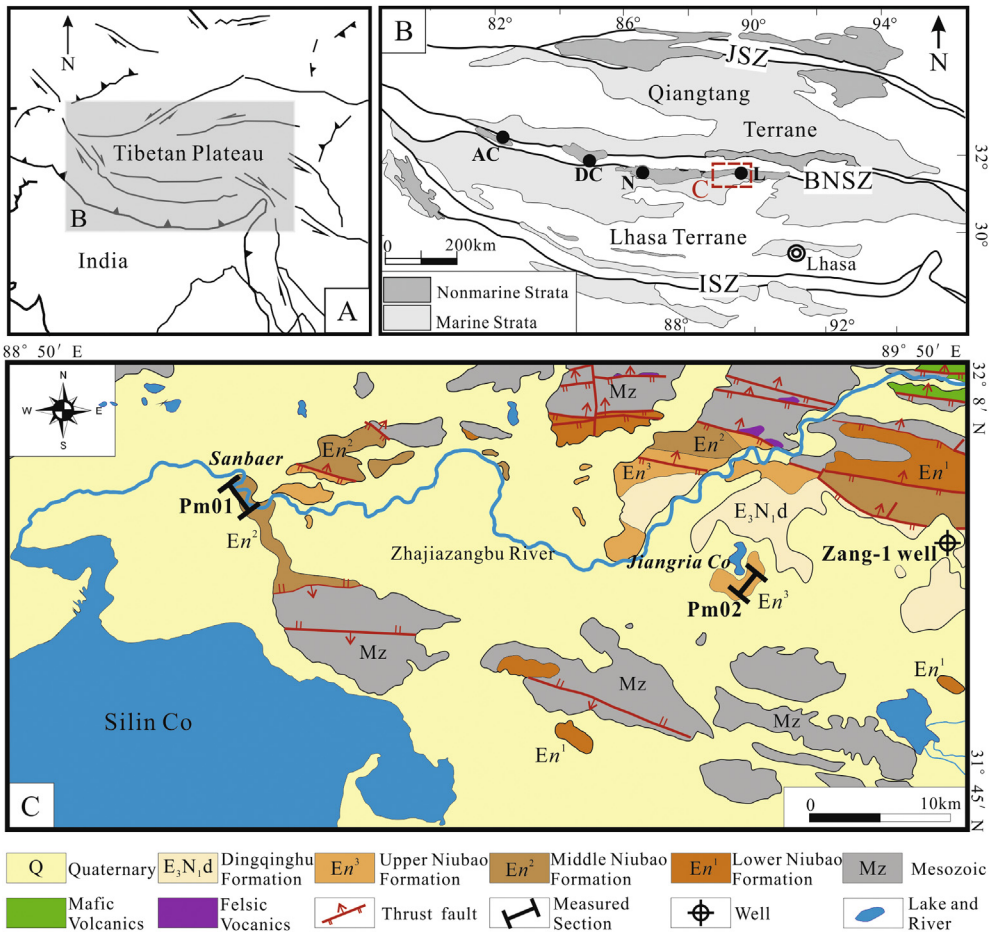

Fig. 1. (A) and (B) Schematic tectonic maps of the Tibetan Plateau and Cenozoic Lunpola Basin in the central part of the plateau (modified from Ma et al., 2013, 2015). (C) Geologic map showing the distribution of strata in the study area and the location of the measured sections (modified from Geological Survey Academy of Jilin (2003, 2006); Ma et al., 2013). ISZ: Indus-Yarlung suture zone; BNSZ: Bangong-Nujiang suture zone; JSZ: Jingsha suture zone; L: Lunpola Basin; N: Nima Basin: DC: Dongco Basin; AC: Avengco Basin.

in the Lunpola Basin (Lu et al., 1997; Fu and Zhang, 2005, Fig. 1C). But little information about it has been published in English language journals.

Herein, we report the source rocks from two sections of the lower Tertiary Niubao Formation of the Lunpola Basin. The purposes of this paper are: (1) to present the sedimentological and organic properties of the strata, and (2) to evaluate the hydrocarbon source potential of the Niubao Formation.

2. Geological setting

Located in the middle part of the BNSZ (Fig. 1B), that formed during the Cretaceous period (Gao et al., 2011), the Lunpola Basin is an east-west elongated basin covering an area of about 5000 km^2 (Wang et al., 2011b; Ma et al., 2013). Similar to other Cenozoic nonmarine basins like Nima, Dongco, and Avengco in the BNSZ (Fig. 1B), the Lunpola Basin was initiated by the regional extension during the early Cenozoic (Luo et al., 1996), and reformed and terminated by the north- and south-dipping thrusts bounding the north and south margins, respectively (DeCelles et al., 2007; Kapp et al., 2007; Sun et al., 2014a, Fig. 1C).

The structure and stratigraphy of the basin were established by geophysical studies and drilling campaigns during oil exploration (Cai, 1997; Rowley and Currie, 2006; Chen, 2011). From north to south, three structural belts: a northern nappe structure, a central depression, and a southern thrust uplift were identified (e.g. Xu et al., 1983; Gu et al., 1999; Wang et al., 2004). The basin received up to 4000 m of Tertiary sediments that could be divided into the Niubao Formation (NF) and the overlying Dingqinghu Formation (DF) (Xu and Lee, 1984; Ma et al., 2013; Sun et al., 2014a, Figs. 1–3).

The lacustrine DF is about 1600 m in thickness, and consists mainly of dark siltstones, mudstones, marls, and laminated shales. The DF is distinguished in the field by dark-brown paper-thin oil shales containing large amounts of fish, insect, and plant fossils (Wang et al., 2011b; Ma et al., 2015, Figs. 2A and 3). U–Pb zircon dates the formation at an age of late Oligocene to early Miocene (He et al., 2012a; Sun et al., 2014a). The underlying fluvial-lacustrine NF is about 2400 m thick and can be divided into three members (Luo et al., 1996, Figs. 2 and 3). The lower Niubao Formation (LNF) deposited in the northern part of the basin and is composed of brown-purple conglomerates and sandstones with green–gray mudstone interbeds (Luo et al., 1996, Figs. 2B and 3). The middle and upper Niubao Formation are exposed in the central and western parts of the basin and recovered by the Zang-1 well, drilled in the central depression (Figs. 1C and 3). The MNF is dominated by dark-gray homogeneous mudstones and laminated shales with brown sandstone intercalations (Ma et al., 1996, Figs. 2C and 3). Reservoirs containing crude oil are located in the middle-upper parts of this member (Lu et al., 1997, Fig. 3). The UNF is characterized by nested orders of sedimentary cycles marked by mudstones, alternating with sandstones and siltstones (Ma et al., 1996, Figs. 2D and 3). Unlike the Dingqinghu Formation, which has relatively