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Research paper

New insights about petroleum geology and exploration of Qiangtang Basin, northern Tibet, China: A model for low-degree exploration

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ABSTRACT

The Qiangtang Basin is the biggest petroleum-bearing basin in the Qinghai-Tibet Plateau. This basin experienced a foreland basin evolution during the Early- Middle Triassic and a rift basin evolution during the Late Triassic-Early Cretaceous. Triassic and Jurassic hydrocarbon source rocks were widely distributed throughout the basin. The Triassic Tumen Gela Formation coal-bearing mudstones represent the best source rocks because of high total organic carbon (TOC) content (1.25–3.45%) and HI values (2.8–123 mg/g Toc), and the Xiali Formation mudstones are moderately-good source rocks with an average TOC content ranging from 0.55 to 7.30% and HI values ranging from 7.0 to 165 mg/g Toc. The Jurassic Buqu Formation and Suowa Formation carbonates, however, exhibit poor-to fair-quality as hydrocarbon source rocks. Excellent dolomite and paleokarst reservoirs and mudstones and bearing-evaporite marl cap rocks, together with well-developed structural traps are recognized in the basin. Additionally, a large paleo-oil-reservoir zone has also been discovered.

Based on an integrated petroleum systems analysis, nine favorable hydrocarbon exploration areas are proposed, of which the Tuonamu area and Badaohu area are selected as the potential targets for the exploration for oil and gas resources in the basin. Good reservoir quality dolomites in the Buqu Formation are considered to have a significant exploration potential.

1. Introduction

The Qinghai-Tibet Plateau, covering an area about 2.6×10^6 km^2 (Xiong et al., 2009), is located in the middle part of the Tethyan tectonic domain within which concentrates over two-thirds of global petroleum reserves (Klemme and Ulmishek, 1991). More than twenty marine basins and sixty-eight continental basins have been found in this region, of which the Qiangtang Basin is the largest (about 220×10^3 km^2), with favorable conditions for petroleum generation and entrapment (Zhao and Li., 2000).

The exploration history of the Qinghai-Tibet Plateau started in the 1950s. The main drilling activities were concentrated in the Lunpola Basin, where two small oil fields had been discovered from the 1960s–1980s. Since 1993, large-scale oil and gas reconnaissance and exploration have been carried out in the Qiangtang Basin by PetroChina (Zhao and Li., 2000). In 2001, new oil and gas reconnaissance and exploration actives were undertaken by the Chengdu Institute of Geology and Mineral Resources. According to the regional survey for oil and gas, more than 200 surface oil and gas shows have been found in Mesozoic formations (Wang et al., 2004b; Fu et al., 2008; Zeng et al., 2013). However, the exploration level of oil and gas in the Qinghai-Tibet Plateau is the lowest in China due to complicated tectonic evolution (Kapp et al., 2003; Yin and Harrison, 2000) and poor natural environmental conditions (e.g., extreme altitude, lower levels of oxygen, and severe climatic conditions).

In recent years, updated analytical techniques and concepts, such as seismic stratigraphy and petroleum system studies, were applied to more fully evaluate the hydrocarbon exploration potential of the Qiangtang Basin. A large paleo-oil-reservoir zone was discovered in the basin (Wang et al., 2004b), and gas show was also found by mud volcano investigation (Fu et al., 2013). Our new data also reveal that thick Mesozoic marine sediments were well developed in the Qiangtang Basin, and a total thickness of Paleozoic

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(6500 m), Mesozoic (6000 m), and Cenozoic (1500 m) strata is more than 13, 000 m (Wang et al., 2009). The Qiangtang Basin, therefore, is an area of potential future exploration, and oil and gas exploration will likely intensify in the near future.

In the present study, we integrate previous research with new data obtained from outcrop and subsurface studies including 1430 samples, 735 km seismic lines, and 12 shallow wells (Fig. 1b) to: (1) summarize the petroleum geology of the Qiangtang Basin; (2) proposes nine favorable hydrocarbon exploration areas and two key targets for the future; and (3) discuses the exploration potential of the basin.

2. Geologic settings

2.1. Tectonic evolution

From north to south, the Tibetan plateau consists of the Kunlun-Qaidam terrane, Songpan-Ganzi flysch complex, Qiangtang and Lhasa terranes, which are separated by the Hoh Xil-Jinsha River and Bangong Lake-Nujiang River suture zones, respectively (Fig. 1a). It is generally accepted that the Paleo-Tethys, represented at the present-day by the Hoh Xil-Jinsha River suture, opened probably in the Early Carboniferous time and was closed by the Permian to Late Triassic time (Dewey et al., 1988; Pearce and Mei, 1988; Nie et al., 1994; Kapp et al., 2003; Zhang et al., 2013). The Meso-Tethyan seaway between the Lhasa and Qiangtang terranes was open by the Late Triassci to Early Jurassic time and closed along the Bangong Lake-Nujiang River suture during the Late Jurassic time (Pearce and Mei, 1988; Yin and Harrison, 2000; Kapp et al., 2003; Wang et al., 2009; Liang et al., 2012).

The Qiangtang terrane, bounded by the Bangong Lake-Nujiang River suture zone to the south and the Hoh Xil-Jinsha River suture zone to the north, respectively, consists of the North Qiangtang depression, the Central uplift and the South Qiangtang depression (Figs. 1b and 2). It is considered to have undergone a two-stage evolution during the Mesozoic time, i.e., the Early-Middle Triassic evolution and the Late Triassic (or late middle Triassic)-Early Cretaceous evolution (Fig. 3). According to the study by Wang et al. (2004a, 2009), the Qiangtang Basin experienced a foreland basin evolution during the Early- Middle Triassic. In this interval, the South Qiangtang depression and Central uplift were uplifted entirely (Wang et al., 2004a), whereas the North Qiangtang depression was still a depositional area. During the Late Triassic (ca. 220–201 Ma), large-scale volcanic-eruption and volcanic-sedimentary events took place in the Qiangtang Basin, indicating a new history of tectonic and sedimentary evolution (i.e. rifting evolution, Fu et al., 2010a).

2.2. Stratigraphic and sedimentary characteristics

The early sedimentary successions of the Mesozoic Qiangtang Basin consist of alluvial and fluvial volcanoclastic deposits associated with continental explosive volcanic facies of the Nadi Kangri Formation (Wang et al., 2004a; Fu et al., 2010a), which are overlain by littoral to shallow-marine facies. Subsequently, a carbonate-platform facies association developed as a result of rapid differential subsidence and the consequent sea-level rise and transgression (Fu et al., 2010a). Therefore, the early sedimentary history of the Mesozoic Qiangtang Basin is characterized by a progradational sequence of transition from continental to marine facies, suggesting a progressive rift extension (Fu et al., 2010a).

2.2.1. The upper Triassic Nadi Kangri and Tumen Gela Formations

The Late Triassic Nadi Kangri volcanic rocks, with nearly east-west trending outcrops within the Qiangtang Basin along the northern Tibet, China, are composed largely of acidic tuff, dacite, rhyolite and minor basic volcanic rocks with a thickness of 217 to 1571 m (Fig. 4). The pre-Nadi Kangri paleo-weathered crusts are overlain unconformably by the Nadi Kangri volcanic rocks (Fu et al., 2010a). Therefore, the Nadi Kangri volcanic rocks represent the beginning of Mesozoic fill of the basin. These volcanic rocks are dated at the Late Triassic (about 205–220 Ma) (Fu et al., 2010a). In this interval, the explosive center was located in the northern and southern parts of the North Qiangtang depression (Fig. 5), where are continental-margin near-shore lacustrine deposits (Wang et al., 2004a) (Fig. 5). Sedimentary structures such as flow and

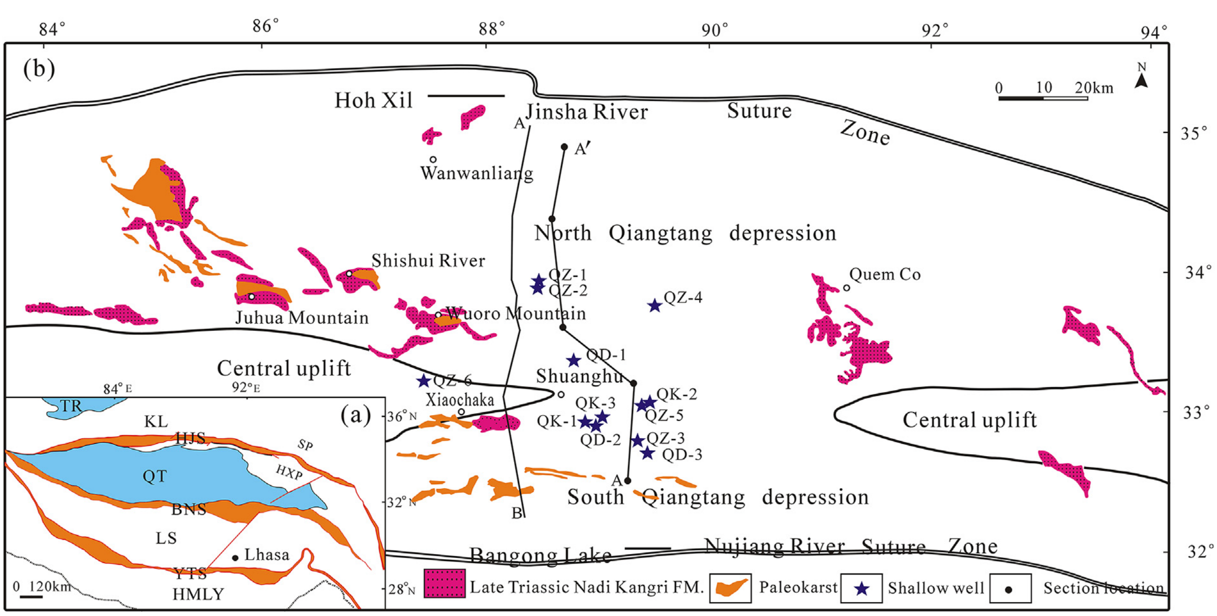

Fig. 1. (a) Map of the Tibetan plateau showing major Terranes. (b) Simplified tectonic map of the Qiangtang Basin, showing wells, main seismic lines, major structural elements, and late Triassic strata and paleokarst (modified from Fu et al., 2010a, b). TR-Tarim Basin; KL-Kunlun terrane; SP-Songpan-Ganzi flysch complex; HJS- Hoh Xil-Jinsha River suture; HXP-Hoh Xili piedmont zone; QT-Qiagtang Basin; BNS– Bangong Lake-Nujiang River suture; LS-Lhasa terrane; YTS–Yarlung Tsangpo suture; HMLY-Himalayas.