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Full Length Article

Discovery of Precambrian thick black mudstones and its implication for hydrocarbon exploration in the southwest Tarim Basin

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ABSTRACT

Due to deep burial of Precambrian in Tarim Basin, no breakthrough in the hydrocarbon exploration has been achieved from these strata, and development of high-quality source rocks is also uncertain. More than 30 exploratory wells have been drilled in the southwest Tarim Basin and the pediment region of Kunlun Mountains with a total area of more than 100×10^3 km^2. Though some marine oil/gas fields such as Hetianhe, Bashituopu, Yubei and Luosi 2 have been discovered, the Cambrian or Ordovician source rocks have not been drilled, and hydrocarbon source still remain controversial. Recently, a set of thick black shales and mudstones has been found in the southwest Tarim Basin. The total thickness of mudstones is more than 140 m, and the total organic carbon mainly ranges from 0.6% to 1.9% with an average of 1.0%. T_{max} is from 490 °C to 520 °C, equivalent to R_o from 1.99% to 2.99%. Pyrites are very rich in mudstone. According to stratigraphic contact relationship and isotopic chronology, this mudstone may have the age of more than 517 Ma, and is tentatively named as the "Western Kunlun black rock series". Through the plate tectonic analysis, this set of thick black mudstones is possibly distributed widely in the southwest Tarim Basin, and its formation may be controlled by the aulacogen. This set of black mudstones may be an important source rocks in the southwest Tarim Basin, which suggest that the Precambrian-Cambrian strata in Tarim Basin has geological conditions for hydrocarbon accumulations. This discovery of the black thick mudstones in the southwest Tarim Basin will promote hydrocarbon exploration in the deep and ultra-deep strata of the Tarim Basin.

1. Introduction

As the petroleum exploration extends to deep and ultra-deep strata, the ancient strata are getting more and more attention (Zhu and Zhang, 2009; Wang and Han, 2011; Zhao and Cawood, 2012; Zhao and Guo, 2012; Zhang et al., 2015a), particularly, the Cambrian and even Proterozoic in the deep part of the basin gradually become hot spots of research and exploration (Wu et al., 2016, 2017a, 2017b; Guan et al., 2017; Ren et al., 2017; Zhao et al., 2017; Zhu et al., 2017). The Precambrian (especially Mesoproterozoic and Neoproterozoic) contains diverse life forms and develops excellent source rocks and reservoirs (Murray et al., 1980; Klemme and Ulmishek, 1991; Kaufman and Knoll, 1995; Bazhenova and Apefyev, 1996; Dutkiewicz et al., 2004; Galushkin et al., 2004; Kontorvich et al., 2005). Recently, the giant Anyue Gas Field in the Sichuan Basin is discovered (Wei et al., 2013; Zou et al., 2014; Du et al., 2016), it is the largest marine gas field in China so far, and has the gas reserves of more than one trillion cubic meters, the Sinian-Cambrian strata are source rocks (Zhu et al., 2015a) and reservoirs. Thus, the discovery of Anyue Gas Field opens a new exploration prospect in the deep Proterozoic strata.

In Tarim Basin, successive breakthroughs and discoveries are made in marine carbonates in recent years (Zhu et al., 2012a, 2013; Zhang et al., 2013, 2015b; Wang et al., 2013; Yang et al., 2014; Du and Pan., 2016; Sun et al., 2016; Han et al., 2017). For example, the deepest Paleozoic marine reservoir (7710 m) in the world is discovered in the Ordovician (Zhu et al., 2018), thereby a new viewpoint that the liquid petroleum can be preserved as deep as 9000 m under conditions of low geothermal gradient and rapid burial in late stage is proposed (Zhu et al., 2012b; c), which greatly expand exploration range and potential of deep liquid petroleum, and strongly promote drilling and exploration in slope zones and deep strata (Zhu et al., 2018). Industrial oil/gas flows are found in

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the pre-salt dolomite formations in the Cambrian (Wang et al., 2014), the natural gas has high content of H_2S, and the condensate is rich in sulfocompounds such as thioadamanes, indicating that hydrocarbons are originated from the Cambrian (Zhu et al., 2015b, 2016a; Cai et al., 2016), thus, the exploration target of the Lower Cambrian Xiaoerbulake Formation is expanded. In the southwest Tarim Basin and the pediment region of Kunlun Mountains, over the past three decades, more than 30 exploratory wells were drilled, mainly to Carboniferous and Ordovician, and some marine oil/gas fields (such as Hetian, Tuoputai, Luosi 2 and Yubei) were discovered but did not contain large-scale reserves, except the Hetian gas field (Dai et al., 2003), and the Cambrian or Ordovician source rocks were not encountered. Therefore, many researchers think that there is little potential for hydrocarbon exploration in the southwest Tarim Basin, because the Cambrian and Ordovician source rocks are not developed. In 2015, the Cambrian Yuertusi Formation high-quality source rocks were discovered in the Aksu area in Xinjiang (Zhu et al., 2016b), it brought about widespread attention of the internal academic circles. In the past three years, based on the general survey of more than 20 outcrops and drilling data in the periphery of the Tarim Basin, combined with experimental studies and seismic tracing, this set of Cambrian Yuertusi Formation high-quality source rocks was well investigated, and it mainly was developed in the north, central and east of the basin (the equivalent formation of the Xidashan Formation and Xishanbulake Formation in the east of the basin), and the oil-source correlation demonstrated that this set of source rocks was the major contributor to marine hydrocarbons in the north and central Tarim Basin; however, this set of source rocks might not be developed in the Bachu uplift and Maigaiti slope in the west Tarim Basin, so that the source of marine hydrocarbons in the southwest Tarim Basin was still unknown. In July 2017, a set of very thick black shale was found in the west Kunlun Mountains. The sample analysis indicates that this black rock series is distributed widely, and has stable lithology and high TOC. In the west Kunlun area, the stratigraphic distribution is very complicated due to tectonic activities, thus, the exact age of this rock series is still being determined (maybe Sinian or Nanhua period). Therefore, this set of source rocks is temporarily named as "Western Kunlun black rock series", and is speculated to widely distribute in the aulacogen in the southwest Tarim Basin, indicating that an important reservoir forming assemblage might be in the Precambrian-Cambrian strata in the southwest Tarim Basin.

2. Outcrop characteristics

The "Western Kunlun black rock series" lies to the north of the Kegang fault of the Western Kunlun Mountains and the southern margin of the Tiekelike microblock in the Tarim Basin (Lu et al., 2008), it belongs to Yecheng County administratively (Fig. 1).

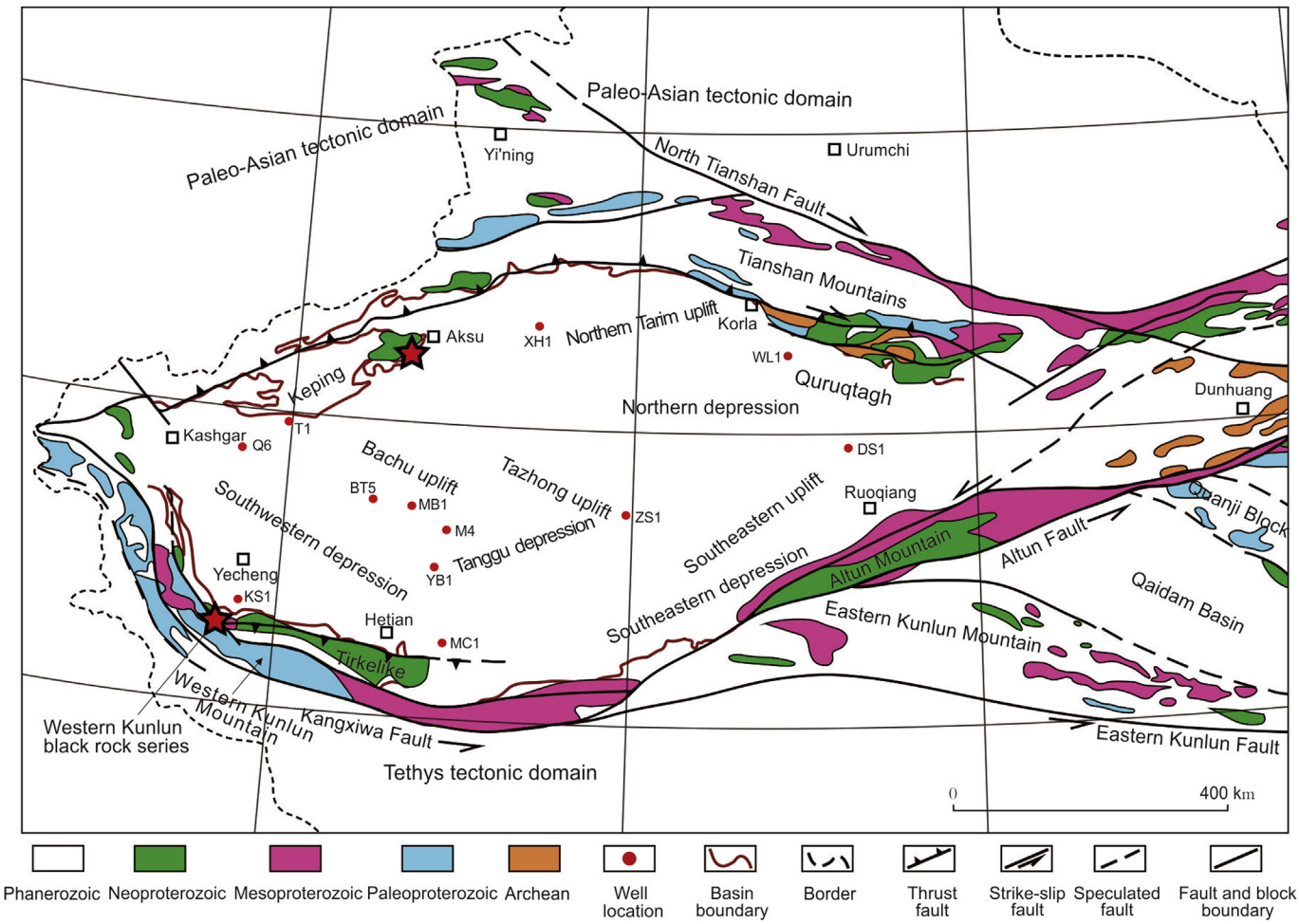

Fig. 1. Tectonic units of the Tarim Basin and the location of the Western Kunlun black rock series showing that the "Western Kunlun black rock series" lies to the north of the Kegang fault of the Western Kunlun Mountains and is located at the southern margin of the Tiekelike microblock in the Tarim Basin. The base map is modified according to Dutkiewicz et al. (2004) and Lu et al. (2008).

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