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Research paper

Hydrocarbon potential and depositional environment of the Lower Cretaceous black mudstones and shales in the coastal Guangdong Province, China

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ABSTRACT

The Mesozoic (especially the Cretaceous) sequences in the northern South China Sea (SCS) are important potential targets of oil and gas exploration; however, they are currently poorly understood. We use organic petrology and geochemistry to evaluate the hydrocarbon potential and study depositional environment of the Cretaceous black mudstones and shales from the Dayawan Section in the Guangdong Province, China. These mudstones and shales yield total organic carbon (TOC) contents of 0.63%–2.76% and most samples meet the requirement for higher TOC source rocks. Organic matters in the mudstones and shales were sourced mainly from higher plants as well as subordinate benthic macroalgae. Organic petrology and geochemical data suggested that the organic matters were dominated by Type-III and minor Type-II, and generally have low thermal maturity. Thus, we evaluated the black mudstones and shales have a potential for hydrocarbon generation (especially gas prone). Pr/Ph, trace elements, and mixture source of organic matter suggested that these black mudstones and shales formed in a coastal–lacustrine environment, characterized by weakly oxidizing – weakly reducing conditions and low-salinity. A marine transgression developing in the middle part of the section was recognized. Generally, the northern SCS, which exhibits the more marine influence, likely contains source rocks with higher TOC contents and better organic matter types. The Cretaceous source rocks with higher liquid hydrocarbon generation potential may occur locally in the Pearl River Mouth Basin.

1. Introduction

As one of the largest epicontinental basin of the world, the South China Sea (SCS) is bordered by the Chinese mainland to the north, the Palawan Trough to the south, the Indo-China Peninsula to the east, and the Manila Trench to the west (Su et al., 1989). The SCS hosts abundant oil and gas reserves and has therefore been well studied (Huang and Chen, 1987; Metcalfe, 1996; Xia and Huang, 2000; Zhou et al., 2008). The SCS is located in the Tethys tectonic domain which contains the most oil and gas of the Cretaceous reservoirs (Zhang et al., 2003; He et al., 2007; Zhang, 2012). The main targets for hydrocarbon in the Tethys tectonic domain are the Cretaceous (Klemme and Ulmishek, 1991); however, in the SCS, the targets are the Paleogene and Neogene (Chen et al., 1997; He et al., 2017; Quan et al., 2017). There should be different in development of source rock and hydrocarbon accumulation between the Cretaceous and Paleogene and Neogene.

In fact, the Mesozoic sequences have been encountered during the early stages of oil and gas drilling in several basins within the SCS. Many wells showed that the thick Cretaceous occur along the northern margin of the SCS and have a potential for oil and gas. However, economic oil and gas discoveries were restricted due to technical and exploration limitations (Qiu and Wen, 2004; He et al., 2007; Hao et al., 2009; Yao et al., 2009). As so far, the hydrocarbon potential of the Mesozoic in the northern SCS is poorly understood.

A set of black mudstones and shales has recently been discovered interbedded in pyroclastic rocks in the Dayawan area near Huizhou

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City, Guangdong Province, China (Hu et al., 2017a). Previous studies suggested that these mudstones and shales formed during the Early Cretaceous and may correlate with terrestrial–marine transitional-facies shales in Fujian Province and elsewhere (Hu et al., 2012, 2017b). Therefore, Hu et al. (2012) inferred that the shales are related to the Cretaceous transgression that occurred in the northern SCS and adjacent areas. Field studies indicated that these black mudstones and shales are rich in organic matter, and should be appropriate material for hydrocarbon potential study of the Cretaceous source rocks in SCS. In this paper, we systematically study the petrology and geochemistry of the black mudstones and shales, determine their depositional environment and hydrocarbon potential, and discuss their significance for the Cretaceous oil and gas exploration in the northern SCS.

2. Geological setting

Guangdong Province in south China covers an area of ~180,000 km^2 and is located in the southwest South China Fold Belts (Guangdong Geology and Mineral Resources Bureau, 1988). Four NE–SW-trending faults go through Guangdong Province, referred to, from west to east, as the Wuchuan–Sihui, Enping–Xinfeng, Heyuan–Shaowu, and Lianhuashan fault belts. Together with other minor faults, the faults divide Guangdong Province into six stratigraphic regions referred to as the Guixianggan, Yunkai, Dongjiang, Wuyi, Leiqiong, and coastal subareas (Guangdong Geology and Mineral Resources Bureau, 1996) (Fig. 1). Twenty-four Mesozoic–Cenozoic sedimentary basins retain in the region and cover an area of 32,100 km^2; coastal sedimentary basins located in the Dongjiang and costal subareas. Volcanism mainly developed in the east of the Zhenghe–Dapu Fault (also known as the Lianhua Mountain Fault), similar to volcanism in the eastern Fujian and Zhejiang areas, was more extensive than that in the Dongjiang subarea (Hu et al., 2011). We focus on the Lower Cretaceous in the Dongjiang subarea which contains relatively scarce volcanism and therefore best preserves the source rocks. Two subordinate stratigraphic areas were divided within the Dongjiang Subarea, referred to as the Central and Northeastern Guangdong subareas (Fig. 2).

The Indosinian Movement resulted in the cessation of carbonate deposition in coastal areas of Guangdong Province and the development of clastic rocks on an active continental margin (Guangdong Geology and Mineral Resources Bureau, 1988). During the early Late Triassic, the western and northwestern Guangdong areas were uplifted, whereas the eastern Guangdong area became a depression and acted as a seawater invasion channel (Zhong et al., 2007). Seawater from the Pacific Ocean entered the central and northeastern Guangdong from the south-southwest, depositing marine and terrigenous facies coal-bearing clastic rocks, referred to as the Genkou Group, as well as estuarine-facies deposits in the Eastern Guangdong area. A transgression occurred during the Early Jurassic resulted in the deposition of shallow-marine, coastal, and deltaic facies deposits of the Jinji Formation. Subsequent regression during the late Early Jurassic resulted in coastal lacustrine, tidal-flat, and deltaic facies clastic deposits of the Qiaoyuan Formation, which overlies the Jinji Formation (Guangdong Geology and Mineral Resources Bureau, 1988; Xu et al., 2015).

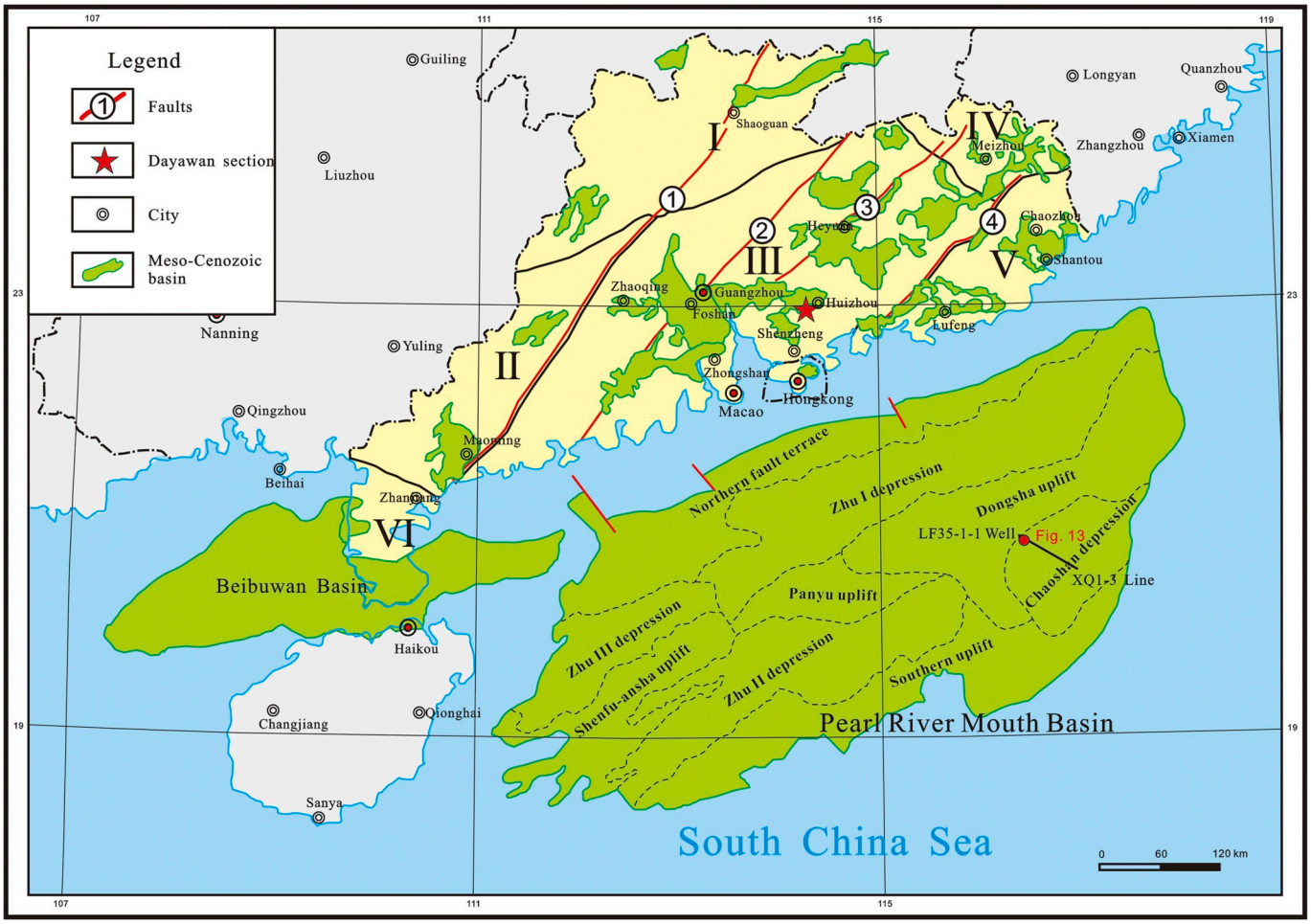

Fig. 1. The Meso-Cenozoic petroliferous basin in Guangdong Province and Coastal China. (Modified from Guangdong Geology and Mineral Resources Bureau, 1996; Li and Lyu, 2002). Faults: 1. Wuchuan-Sihui fault; 2. Enping-Xingfeng fault; 3. Heyuan-Shaowu fault; 4. Lianhuashan fault; Stratigraphic subarea: I. Guixianggan subarea; II. Yunkai subarea; III. Dongjiang sub area; IV. Wuyi sun area; V. Coastal subarea; VI. Leiqiong subarea.