

Cenozoic volcanic rocks in the Pearl River Mouth and Southeast Hainan Basins of South China Sea and their implications for petroleum geology

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Abstract: Drilling, gravity, magnetic observation and seismic facies are combined to identify the Cenozoic volcanic rocks in the Pearl River Mouth Basin and the Southeast Hainan Basin in the northern South China Sea, and to analyze how their lithology, distribution characteristics and volcanic activity influence on hydrocarbon accumulation. As a result, more than 70 volcanic bodies are ascertained. They are divided into two types: (1) laminated lava and pyroclastic rocks in the Cenozoic sedimentary sequence; and (2) conoid, mounded or wedged basalt with rigid basement under the Cenozoic sedimentary sequence. In the early Cenozoic (E₁-E₂), the acidic, neutral and basic volcanic rocks developed, while in the mid-late Cenozoic (E₃-Q), single basic rocks existed intensively. The volcanic lithofacies mainly include the lower and middle effusive subfacies and the pyroclastic flow deposit explosive subfacies. Spatially, from the Southeast Hainan Basin to the Pearl River Mouth Basin, the Cenozoic volcanic activity gradually enhances; from shallow water area to the Central Basin of the South China Sea, the scale of Cenozoic volcanic rocks increases gradually, and the age tends to be younger. These activities improve the formation temperature, reduce the hydrocarbon generation threshold, and promote the hydrocarbon accumulation. Volcanic rocks in Wenchang Formation (E_{2w}) to Zhujiang Formation (N_{1z}) provide favorable conditions for hydrocarbon accumulation, so they are important targets in the deep exploration.

Key words: northern South China Sea; Pearl River Mouth Basin; Southeast Hainan Basin; Cenozoic; volcanic rocks; lava; pyroclastic rocks; hydrocarbon accumulation

1 Overview of study area

The continental margin basin of northern South China Sea experienced Himalayan tectonic movement of marginal expansion in the Cenozoic^[1-2], which led to development of a large number of Cenozoic volcanic rocks. The distribution area of the Cenozoic volcanic rocks in northern South China Sea and periphery land regions includes the southern coastal area of Fujian, Leiqiong peninsula of Guangdong, north of Hainan Island, the Northern Gulf Basin, Weizhou island of Guangxi Beihai, Vietnam and the South China Sea^[3-10], among them most are intermediate-basic rocks (basalt). The Paleogene volcanic activity mainly occurred in the Sanshui, Heyuan and Lianping basins. The Neogene-Quaternary volcanic activities mainly occurred in Leizhou-qiongzhou region, Baiyun Sag of the Pearl River Mouth Basin, the south of Dongsha uplift to the sea and land boundary, spreading ridge

of the South China Sea Basin, southern Vietnam and Taiwan-Luzon arc^[11].

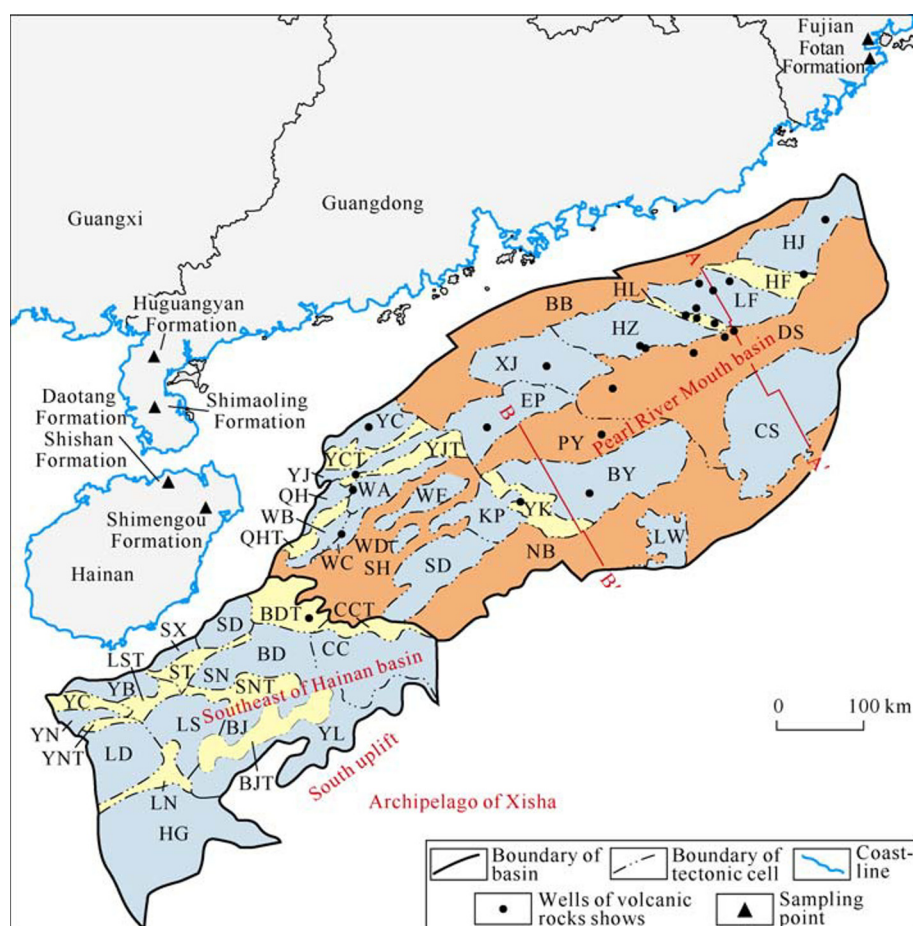
The formation time, spatial distribution, eruption times and causes of the Cenozoic volcanic rocks in the northern South China Sea have been studied for many times. Based on the drilling and dating data, the Cenozoic volcanic activity was divided into 8 stages by Zou Heping^[12]; according to the formation time and spatial distribution of volcanic rocks, Li Pinglu^[13] supposed that the Paleogene volcanic rocks of the Pearl River Mouth Basin are intermediate-acid and basic rocks with crevasse type eruption, the Neogene volcanic rocks are basic rocks with central-crevasse and central type eruption; Wu Jingfu^[14] analyzed the relationship between tectonic and volcanic events in the Pearl River Mouth Basin systematically, and supposed that the eruption of massive basaltic magma with single component increased gradually before 23.8 Ma (boundary of the Paleogene and Neogene), and then weakened.

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YB: Yabei sag; SX: Songxi sag; SD: Songdong sag; BDT: Baodao uplift; YC: Yacheng uplift; YN: Yanan sag; YNT: Yanan low uplift; LST: Lingshui low uplift; ST: Songtao uplift; LD: Ledong sag; LS: Lingshui sag; SNT: Songnan low uplift; SN: Songnan sag; BD: Baodao sag; LN: Lingnan low uplift; HG: Huaguang sag; YL: Yongle sag; BJ: Beijiao sag; BJT: Beijiao uplift; CC: Changchang sag; CCT: Changchang uplift; SH: Shenhu uplift; QHT: Qionghai uplift; WB: Wenchang B sag; WC: Wenchang C sag; QH: Qionghai sag; WA: Wenchang A sag; YJ: Yangjiang sag; YCT: Yangchun duplift; YC: Yangchun sag; YJT: Yangjiang low uplift; WD: Wenchang D sag; WE: Wenchang E sag; KP: Kaiping sag; SD: Shunde sag; NB: South uplift; YK: Yunkai low uplift; BB: North uplift; EP: Enping sag; XJ: Xijiang sag; HZ: Huizhou sag; HL: Huilu low uplift; LF: Lufeng sag; HF: Haifeng uplift; HJ: Hanjiang sag; PY: Panyu low uplift; DS: Dongsha uplift; BY: Baiyun sag; LW: Liwan sag; CS: Chaoshan sag

Fig. 1 Location of interpreted seismic profiles and wells drilled to the Cenozoic volcanic rocks in the northern South China Sea and rock samples along the southeast coast of China

The tectonic movements and magmatic activities of northern South China Sea are active and frequent, but in the Pearl River Mouth and Southeast Hainan Basin (hereinafter called Pearl-Qiong Basins), nearly $26.28 \times 10^4 \text{ km}^2$, the Cenozoic volcanic rocks only emerged in 25 drilled wells by 2010 (Figure 1). Previous studies were conducted in this region, but the cognition of volcanic activities in this area is still insufficient, the effect of hydrocarbon accumulation by volcanic activities is unclear. According to the latest seismic data, gravity and magnetic data, drilling and onshore outcrops, we synthesize geological and geophysical methods to discuss the characteristics of the Cenozoic volcanic rocks in the Pearl-Qiong Basins and the petroleum geological significance.

2 Comprehensive identification of Cenozoic volcanic rocks

2.1 Drilling shows

By 2010, 25 wells have encountered Cenozoic volcanic rocks, 24 in the Pearl River Mouth Basin, 1 in the Southeast

Hainan Basin (Table 1). From the perspective of distribution, volcanic rocks were drilled in Zhu I sag, Zhu III sag and Dongsha uplift. According to the classification scheme of volcanic rocks by Wang Pujun, et al.^[15], the Cenozoic volcanic rocks in northern South China Sea can be divided into four categories, which are volcanic lava, pyroclastic lava, pyroclastic rocks and sedimentary pyroclastic rocks (Table 2). Among them, the majority are volcanic lava (52.8%) and pyroclastic rocks (40.6%), followed by pyroclastic lava (6%) and sedimentary pyroclastic rocks (0.6%).

Acidic, neutral and basic volcanic rocks were showed up in drilling wells, with the major type being basic basalt (36.7%) which has the highest occurrence frequency (10 wells), followed by tuff, and other types of rocks (Table 1). The petrographic characteristics of many pyroclastic rocks (tuff, breccia, agglomerate) have not yet been identified according to original drilling data. Therefore, further studies are needed.

The sorting of volcanic facies mainly depends on lithological data which comes from logging data and curves. Accord-

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