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Full Length Article

Characteristics of the basement reformed volcanic edifice in Bohai Sea and its implication for hydrocarbon enrichment

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ABSTRACT

The intact volcanic edifice had been formed and finalized during the depositional stage of Mesozoic Yixian Formation in the Bohai Sea. The residual body of the intact volcanic edifice after reformation was defined as the basement reformed volcanic edifice. Based on drilling, seismic, well logging and microscopic data in the study area, characteristics of the basement reformed volcanic edifice were well discussed, and its control on oil and gas was also investigated. Results showed that the basement reformed volcanic edifice was jointly controlled by magmatic property, paleo-geomorphology and late reformation, and the late fault cutting and differential denudation were major reformation ways of the volcanic edifice; strong and weak volcanic eruption patterns developed in the study belonged to the inverted-sequence eruption, and the explosive facies and the intermediate-acidic or acidic effusive facies were the favorable reservoir facies; weathering, cycles and period boundaries controlled vertical distribution of high-quality lithofacies, and coupling between each periodic interface at different levels and residual high-quality lithofacies was the key to oil and gas enrichment. Major exploration targets of volcanic rocks were to find periodic interfaces in the volcanic edifice with the residual high-quality lithofacies within 150 m from the weathering crust or eruption surface.

1. Introduction

In recent years, with improvement of oil and gas exploration and transformation of research ideas, China significant breakthroughs had been achieved in exploration of volcanic rocks in Songliao Basin, Junggar Basin, Bohai Bay and other basins (Yang et al., 2006; Jin et al., 2012; Wang et al., 2013). Volcanic hydrocarbon reservoirs were expected to be another growth point of onshore hydrocarbon reserves in China. At present, significant achievements of volcanic rock exploration in China were achieved mainly in Songliao Basin and Junggar Basin (Feng et al., 2014). The in-situ volcanic edifices were developed in Songliao Basin (Feng et al., 2014) and were not damaged at the later stage, and distribution of high quality reservoir was mainly controlled by lithofacies and later diagenetic evolution (Meng et al., 2002; Luo et al., 2008; Sun et al., 2009). Volcanic rocks in Junggar Basin were distributed in the basement and were destroyed seriously at the later stage, previous studies mainly focused on controlling and reformation effects of lithofacies, weathering crust and late fault on reservoirs (Zhang et al., 2010; Wang et al., 2011; Wu et al., 2012). Controlled by volcanism, such the volcanic edifice that belonged to buried-hill structure was quite different from the in-situ volcanic edifices in Songliao Basin. So far, few studies have been carried out to expand targeted researchs on this kind of the volcanic edifice.

In the basement of continental rift basins in eastern China, this kind of the volcanic edifice was well developed, and had active oil and gas shows (Luo et al., 1996; Liang et al., 2000). In this article, for the first time, the residual body of the intact volcanic edifice after reformation was defined as the basement reformed volcanic edifice, which was located near the unconformity surface of the basin basement. This kind of the volcanic edifice experienced multi-episodic tectonism, thus the original volcanic pattern was destroyed, and spatial location of volcanic rock body was also changed, even leading to partial loss of volcanic rock body. Exploration of such volcanic bodies was different from the conventional weathering-crust buried hill and the complete volcanic edifice strictly controlled by lithofacies. Researches on distribution of high-quality reservoirs in the basement reformed volcanic edifice and factors controlling hydrocarbon enrichment were quite rare.

For a case study of Mesozoic in Bohai Sea, based on drilling, seismic and well logging data, controlling factors of the current

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reformed volcanic edifice were investigated by identification and characterization of the basement reformed volcanic edifice. Through analysis of relationship among interfaces of different levels (weathering crust, cycle interface and periodic interface), lithofacies and oil reservoirs, controlling effects of volcanic edifice, volcanic lithofacies, weathering, cycle and periodic interface on volcanic hydrocarbon accumulation were revealed. The purpose was to verify the reservoir controlling mechanism of the reformed volcanic edifice and different level interfaces, explore controlling factors of hydrocarbon accumulation in the basement volcanic rocks, and guide new discoveries of oil-gas exploration of basement volcanic rocks in eastern China.

2. Geological background

The Bohai Bay Basin in eastern China was a typical Cenozoic fault basin, it experienced continual tectonic activities in Mesozoic, such as the depression stage in the Cretaceous, the compression-flexure stage in the Early-Middle Jurassic, and the rift stage in the Late Jurassic-Early Cretaceous, but the depression stage again in the Late Cretaceous (Qi et al., 2004). The volcanic activities were intense during the rift stage in the Late Jurassic-Early Cretaceous, which was an important development period of volcanic rocks in eastern China (Qi et al., 2003). During the late Yanshanian period, the strata were whole uplifted, and the Mesozoic basin was strongly reformed, fracture and denudation of volcanic rock occurred. In the Cenozoic, faults were rejuvenated; the basin was rifted again to form the current structural framework. During the process of later uplifting and differential reformation of Mesozoic basement volcanic rocks, some corroded volcanic rocks were as the Cenozoic sedimentary sources, and some volcanic rocks were well preserved to form the basement reformed volcanic edifice.

The Bohai Sea located in the middle-east part of Bohai Bay Basin, was the sea area of Bohai Bay with exploration area of about 40×10^3 km^2 (Gong et al., 2007; Qi et al., 2008). Basement faults in the study area were principally controlled by the Tancheng-Lujiang fault zone, which was dominated by NNE-trend and NW-trend faults (conjugated faults). Distribution of volcanic rocks in the study area were controlled by trend and activity intensity of fault zone, of which volcanic rocks in the east controlled by the main faults were mainly distributed in NE trend, volcanic rocks in the west controlled by conjugated faults were mainly distributed in NW trend, and the main body of volcanic rocks were distributed adjacent to the Tancheng-Lujiang fault zone (Han et al., 2008) (Fig. 1a). The Jurassic Haifanggou Formation and Lanqi Formation, Cretaceous Yixian Formation, Jiufutang Formation, Shahai Formation, Fuxin Formation and Sunjiawan Formation were mainly developed from bottom to top of Mesozoic. The Haifanggou Formation was composed of coarse fragment glutinite intercalated with coal streaks; distribution range of igneous rocks was relatively small in Lanqi Formation, and the PL9-1 structure was drilled in the granite intrusion; volcanic rocks in Yixian Formation were the most developed, and were dominated by intermediate-basic volcanic rocks, including basalt, andesite, taff, volcanic breccia and so on (Ye et al., 2016); the Jiufotang Formation–Sunjiawan Formation was primarily composed of mudstone partially intercalated with thin-bedded sandstone, where volcanic rocks were not developed (Fig. 1b). In the study area, volcanic rocks were characterized by multi-cycle and multi-period eruption, and thus several sets of reservoir-cap assemblages were formed. Current discovered oil and gas was mainly from the Cenozoic source rocks; volcanic rocks in the Yixian Formation and granite in Lanqi Formation were the main reservoirs which were characterized by young source rocks in old reservoirs, the Oilfield 428W (Fig. 1c) and the Gasfield JZ20-2 as well as several hydrocarbon-bearing structures such as QHD30-1, PL7-1 and KL10-1N were discovered in volcanic extrusion rocks in Yixian Formation.

3. Characteristics of the basement reformed volcanic edifice

3.1. Morphology of the reformed volcanic edifice

Current volcanic edifice was controlled by tectonic activity, and its original morphology was changed. Lithofacies distribution of the volcanic edifice was different from the conventional intact volcanic facies distribution. Based on the drilling and seismic data, morphologies of key volcanic edifices in the study area were depicted. The results showed that morphologies of volcanic edifices were jointly controlled by magmatic property, paleo-geomorphology and late reformation.

The magmatic property controlled primitive morphology of the volcanic edifice. Different magmas had different viscosity and fluidity. Volcanic rocks of Yixian Formation in the study area were mainly formed in the extension-rift tectonic setting; during the basic magma upwelling along deep and large faults, mineral crystallization difference controlled magma evolve to high silicate minerals, and thus transit to intermediate andesite and acid rhyolite (a few magmas could evolve in this stage). During the magma evolution process, gradual increase of viscosity and gradual degradation of fluidity controlled difference of volcanic rock body in primitive morphology. The basic basalt was characterized by sheet shape with high length-width ratio, while the intermediate magma was characterized by mushroom shape and wedge shape with relative medium length-width ratio.

The paleo-morphology controlled difference in reformed degree of volcanic edifices at different tectonic positions. Volcanic rock body in the structural high near volcanic crater was corroded greatly with obvious truncation; volcanic rock body in the slope and the depression area was less or not eroded with obvious overlap (Fig. 2a).

After formation, the volcanic rock body underwent the uplift denudation in the late Yanshanain period and intense fault depression in the Paleogene. During the fault depression process, the warping effect resulted in reformation of volcanic rock body again, and a large number of the basement reformed volcanic edifices were formed in the study area. Well-to-seismic comparisons showed that formation pattern of the basement reformed volcanic edifices mainly was denudation and planation at the structural high, lateral fault cutting and combination of these two patterns (Fig. 2). On the one hand, the fault cutting could change spatial position of the original volcanic rock body, so that the volcanic rock body at the structural high was located at the low position after normal fault cutting (Fig. 2b). On the other hand, the fault cutting could lead to fracture and hiatus of the volcanic rock body, and this fault cutting pattern was mainly developed near the large-scale controlling-sag faults, the volcanic edifice on one side of fault was absent (Fig. 2a). The denudation and planation mainly affected the structural high of the volcanic edifice, and the volcanic rock body near the volcanic crater was eroded in different degrees (Fig. 2a); the combination pattern was a result of fault and denudation.

3.2. Lithofacies mode

The volcanic eruption mode was a comprehensive characteristic of volcanic eruption environment and spatial configuration of different rocks, and it determined vertical combination relation and distribution rules of different lithofacies. In Songliao Basin, volcanic rocks were dominated by acidic eruption, vertically, facies transition from volcanic channel facies, explosive facies and effusive facies at the bottom to extrusive facies on the top occurred,

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