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Contact metamorphism of shales intruded by a granite dike: Implications for shale gas preservation

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ABSTRACT

Contact metamorphism will lead to significant changes in mineralogy, organic geochemistry and microstructure (e.g., microcracks, pore size and shape) of shales. In order to investigate the influence of granite intrusion on shale gas preservation, we selected the Luocun section in South China, where the early Cambrian shales (i.e., the Hetang Formation) were intruded by an early Cretaceous granite dike. Compared with silty mudstones from the Mufushan section without any intrusion, the siliceous shales in the Luocun section have been silicified and contain some banded black carbonaceous residues, with less clay minerals when closer to the dike. The equivalent vitrinite reflectance is 2.6% at a distance of 50 m to the dike and raises to 3.7% next to the dike, suggesting that the granite dike has enhanced the thermal maturity of organic matter. The variation of vitrinite reflectance along the Luocun section reveals that the aureole width is ~37% of the dike width. However, there is no evident correlation between total organic carbon content of shales and their distance to the dike. Pores in shales from the Luocun section include interparticle pores, intraparticle pores, and a few large (>50 nm) intraparticle organic matter pores. With decreasing distance to the dike, the specific surface area of shale samples reduces from 5.22 to 0.16 m^2/g due to decreasing pore volume of mesopores and micropores. However, thermal expansion of shales and thermal reaction products of organic matter have produced macropores and microcracks in shales, which will enhance permeability of shales and result in fast escape of shale gas during intrusion of granites. Therefore heat and siliceous fluids from granites will modify composition and pore structure of shales and hinder preservation of shale gas within the contact aureole.

1. Introduction

The effects of magmatic intrusions on physical properties, evolution of organic matter and hydrocarbon generation process of mudstones and shales have received much attention (e.g., Li, 2000; Othman et al., 2001; Wang and Jin, 2003; Zhu et al., 2007; Svensen et al., 2007; Aarnes et al., 2010, 2011a, 2011b; Agirrezabala et al., 2014). Contact metamorphism by magmatic intrusions in mudstones and shales often results in the occurrence of graphitic and coke particles (Agirrezabala et al., 2014) and mineral dehydration reactions (Aarnes et al., 2010, 2011b). This process will create a progressive increase in vitrinite reflectance (VRo) (e.g., Othman et al., 2001) and bitumen reflectance (BRo) (e.g., Barker and Bone, 1995) in shales and mudstones. Bishop and Abbott (1995) found the loss of organic carbon concentration due to intrusion of Tertiary dykes. However, the residual organic carbon content in wall rocks may increase gradually with a decreasing distance to a diabase intrusion (Liu et al., 2011). The influence of such contact metamorphism on shales depends on the distance to the intrusion, the width and initial temperature of the intrusion, and the initial temperature of wall rocks (Raymond and Murchison, 1988; Wang et al., 2007a; Mastalerz et al., 2009). So far most studies focus on thermal evolution of organic matter and organic geochemistry of shales and mudstones. Our knowledge about the correlation between composition and microstructure (e.g., grain size, pore size and shape) of shales is still limited, which has strong implication on shale gas quality and preservation.

Due to large thickness, wide distribution, and high content of organic matter, Paleozoic mudstones and shales in the Yangtze Block have been targeted for shale gas exploration in South China. The Upper Yangtze region mainly covers the western Yangtze Block, while the Lower Yangtze region is located in the northeastern Yangtze Block. In the Upper Yangtze region, commercial shale gas has been obtained from organic-rich Silurian Longmaxi Formation in the Fulin area, Chongqing City. In contrast, the Lower Yangtze region experienced significant magmatism in the Cretaceous (Sun, 2006; Zhou et al., 2006). So far the shale gas exploration in the Lower Yangtze region has not obtained commercial wells, which has been attributed to multistage deformation and magmatic activities (Pan et al., 2011; Zhang et al., 2013). Some critical questions include: (i) How magmatic activities affect the thermal evolution of organic matter and microstructure of mudstones and shales? (ii) What is the influence of contact metamorphism on preservation of shale gas?

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To answer the above questions, we selected the Luocun section in the Lower Yangtze region (Zhejiang province), where the early Cambrian shales (i.e., the Hetang Formation) were intruded by an early Cretaceous granite dike. To reveal thermal and mechanical effects of granite intrusion on shales, we systematically investigated geochemical and microstructural features of the Hetang Formation along the Luocun section, as well as an original sample of the Hetang Formation from the Mufushan area for comparison. The results provide new insights on shale gas preservation in basins with magmatic activities.

2. Geological setting

The South China Block was formed by assemblage of the Yangtze and Cathaysia Blocks along the Jiang-Shao fault in the Neoproterozoic (Wang et al., 2007b; Shu, 2012). It was subducted beneath the North China Block along the Dabie-Sulu orogenic belt during the Triassic (Xu et al., 2009; Zheng, 2008) (Fig. 1a). The basement of the Lower Yangtze region is overlain by over 10-km-thick marine sedimentary strata from the early Paleozoic to middle Triassic, and terrestrial sedimentary strata from the late Triassic to early Cretaceous (Guo, 1996). It was subjected to significant Mesozoic deformation and Cretaceous granitic intrusion, and Cenozoic volcanism (Deng et al., 1992; Chen, 2002).

According to the thickness of shales and the total organic carbon (TOC) content, the early Cambrian Hetang Formation and the late Permian Longtan Formation are the most favorable strata for shale gas exploration in the Lower Yangtze region (Pan et al., 2011). The Hetang Formation widely distribute in southern and northern Jiangsu province, southern Anhui province and western Zhejiang province. The Hetang Formation in southern Anhui and western Zhejiang provinces is characterized by Type-I kerogen and the average TOC content of 3.09 wt%. In contrast, the Hetang Formation in Jiangsu province contains Type-I and Type-II kerogen, and has the average TOC content of 2.93 wt% (Pan et al., 2011).

3. Sampling

The Luocun section (N30°31′46″, E119°33′41″) is located in the depositional center of the Hetang Formation in the Lower Yangtze region (Fig. 1b). It has a thickness of 230–560 m, mainly consists of black shales, silicalites, and carbonaceous shales with high-ash anthracite seams (Fig. 1c) (Yu et al., 1995). A granite dike of 48 m wide intruded into the 126 m-thick siliceous shales of the Hetang Formation (Figs. 1c and 2a). The siliceous shales to southeast of the granite dike is about 49.85 m thick and well exposed, while the other side of siliceous shales is about 28.75 m thick (Fig. 2a). The granite sample shows porphyritic texture with microlite feldspar as matrix. The phenocrysts include quartz with embayment margins, and altered plagioclase due to argillation, carbonization, chloritization and sericitization (Fig. 3). Zircon U-Pb geochronology study yields the age of this granite dike as 131.8 ± 1.5 Ma (Zhang et al., in preparation), which is consistent with massive early Cretaceous magmatism in South China (Zhou et al., 2006).

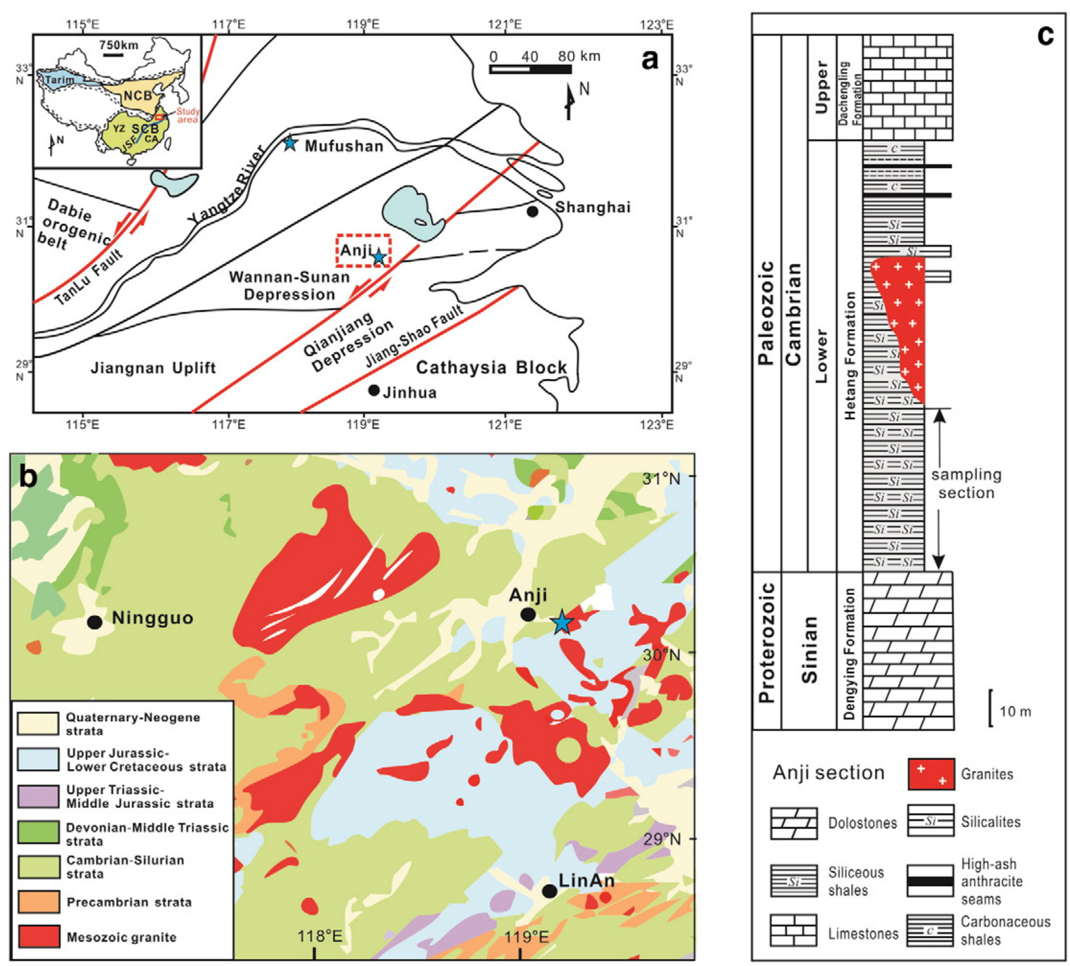

Fig. 1. (a) Simplified geological map of Lower Yangtze region, showing the study region (red square) near Anji, Zhejiang province, China. Blue stars indicate the sampling locations at the Luocun section in Anji area and the Mufushan section in Nanjing area. Abbreviations: NCB: North China Block; YZ: Yangtze Block; CA: Cathaysia Block; SCB: South China Block; JSF: Jiang-Shao Fault. (b) Geological map of the Anji area (modified after Zhang et al., 2013). (c) Stratigraphic column of the Luocun section.