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Geological mechanisms of the accumulation of coalbed methane induced by hydrothermal fluids in the western Guizhou and eastern Yunnan regions

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ABSTRACT

Based on the geological characteristics of hydrothermal fluid in the western Guizhou and eastern Yunnan regions, this paper discusses the geological mechanisms of hydrothermal fluid on the coalbed methane (CBM) system. From the perspective of hydrothermal fluid activity in the regional strata, we analyze the geological processes by which coalbed methane is enriched and accumulated in this region. Our results demonstrate that two stages of regional thermal fluid activity occurred in the western Guizhou and eastern Yunnan regions. In the earlier stage, calcium fluid acted as the carrier, but in the later stage, it was replaced by siliceous fluid with a small amount of calcium fluid. The former resulted from thermal cycling of fluid through the strata, and the latter was caused by injection of deeply sourced high temperature fluids. We propose three geological mechanisms by which hydrothermal fluid affected coalbed methane accumulation: stimulation for hydrocarbon generation, transformation for physical properties and fluid supercharging. The hydrothermal fluid impels coalbed methane to generate and migrate at high intensity; it also produces dense swarms of tubular pores that coincide with tectonic stress. As a result, the coal body is broken, and there are changes to the porosity and permeability of the coal. Pressure development in the regional gas reservoir depends on the intensity of the fluid effect and the differential leakage of fluid pressure in the coal reservoir. The relatively closed and stranded hydrothermal fluid environment of coal measure strata tends to lead to a high pressure coalbed methane system. The platform uplift in northwestern Guizhou is one such environment, in which the geological configuration of the high temperature fluid provided favorable conditions for the enrichment and accumulation of coalbed methane.

1. Introduction

Western Guizhou and eastern Yunnan are part of an important region in China that has highly abundant coalbed methane (CBM) resources (Tian et al., 2008; Gao et al., 2009). Previous studies in the area have largely focused on describing the sedimentary environment and the coal accumulating characteristics of coal bearing strata, the origins of coalbed methane, the physical characteristics of the coal reservoir, and the evolution of heat accumulation; they have also evaluated potential coalbed methane resources (Gui, 1999; Tao et al., 2010; Li et al., 2014a, 2014b). Research has shown that the development of coal measure strata has unique geological features. Coal bearing strata mainly occur in Longtan Formation, the Late Permian to Late Paleozoic. The tectonic evolution of these strata included multiphase development, strong differentiation and late stereotypia. The sediment has features indicative of interacting marine and terrestrial facies, ground plan divergence and frequent vertical change. These features lead to weak aquosity, varied coal strata and tectonic type of controlling gas. In addition, there is very high gas content, resource abundance, reservoir pressure and stress. Finally, there is large vertical variation in coalbed methane resources, coal rank and permeability and geologic conditions (Gu et al., 2002; Qin et al., 2008; Li et al., 2015).

Many researchers have shown that hydrothermal deposits are widely distributed in this area, suggesting that formation of hydrothermal fluids may have had a significant effect on the enrichment and accumulation of coalbed methane (Yang et al., 1982; Zhou et al., 2000; Song et al., 2005; Qin et al., 2008; Li et al., 2014a,

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2014b). However, the mechanism by which hydrothermal fluids would affect the accumulation of coalbed methane has not been characterized. Hydrothermal fluids not only stimulate coalbed methane generating, but can also directly or indirectly control the storage capacity of the coal reservoir and the accumulation and dispersion characteristics of coalbed methane. They can also alter the dynamic balance of the CBM energy system via changes to the coal composition, thermal physics, and fluid pressure. Fluid inclusions contain geological and geochemical information that reflects the properties, composition, physicochemical conditions and geodynamic characteristics of the paleo-fluid in an ancient basin (Jones et al., 1977; Tobin and Claxton, 2000; Kelly et al., 2000; Marfil et al., 2002; Sun, 2003; Dubessy et al., 2004). In this study, we combine basin evolution simulation and fluid inclusion analysis to characterize hydrothermal fluid activity and discuss the contribution of hydrothermal fluids to the dynamic balance of the coalbed methane energy system. We also propose three mechanisms by which hydrothermal fluids affect the accumulation of coalbed methane. Taking into account the division between the areas of plutonic metamorphism and superposed thermal metamorphism in the western Guizhou and eastern Yunnan regions, we clarify the process and influencing factors of coalbed methane accumulation in this complex geological setting.

2. Geologic setting

The region spanning western Guizhou and eastern Yunnan Provinces is a famous coal industry base south of the Yangtze River. It is an ideal area for commercial exploration and development of industrial coalbed methane in China. Because of Yanshan and Himalayan movement, the region is divided into various intermontane downwarped and downfaulted basins. Following later tectonic movement, these prototypical basins were mostly destroyed. The preservation of some residual basins is the basis for the present tectonic system, which is mainly composed of synclinoria and synclines (Fig. 1).

Early in the Late Permian, controlled by a northeast tectonic framework, an inclined terrain formed from north to south and from northwest to east. Three sedimentary facies were also deposited (marine, terrestrial and interacting marine and terrestrial facies), and these controlled the coal formation in the Late Permian. From the end of the Early Permian to the Late Permian, multi-stage eruptions of Emeishan basalt magma constructed positive tectonic factor and topographic conditions. In negative tectonic activity center, the Ziyun aulacogen and the Luoping aulacogen, associated with the ancient Kangdian terrain, controlled the process of forming, developing and filling coal accumulating basins. Due to Yanshan movement, the strata preceding the Cretaceous and the coal measure strata of the coal accumulating period are strongly faulted and folded, forming the later tectonic framework. As a result, the coal bearing strata were divided and exist in many independent secondary syncline units, which generally present the tectonic characteristics of syncline controlling gas (Gui and Wang, 2000; Cromie and Khin, 2003; Tao et al., 2010; Bercovici et al., 2015).

In western Guizhou and eastern Yunnan, there are large differences in coal quality and the coal metamorphism is uneven. The maximum vitrinite reflectance is low in the central part of the region but high to the northeast and southwest. Fig. 1 shows a ring belt distribution in which the coal rank increases from the Panguan syncline to the rim. Coal metamorphism in the area is controlled by a variety of factors, including sedimentary depth, magmatic hydrothermal fluids and tectonic movement.

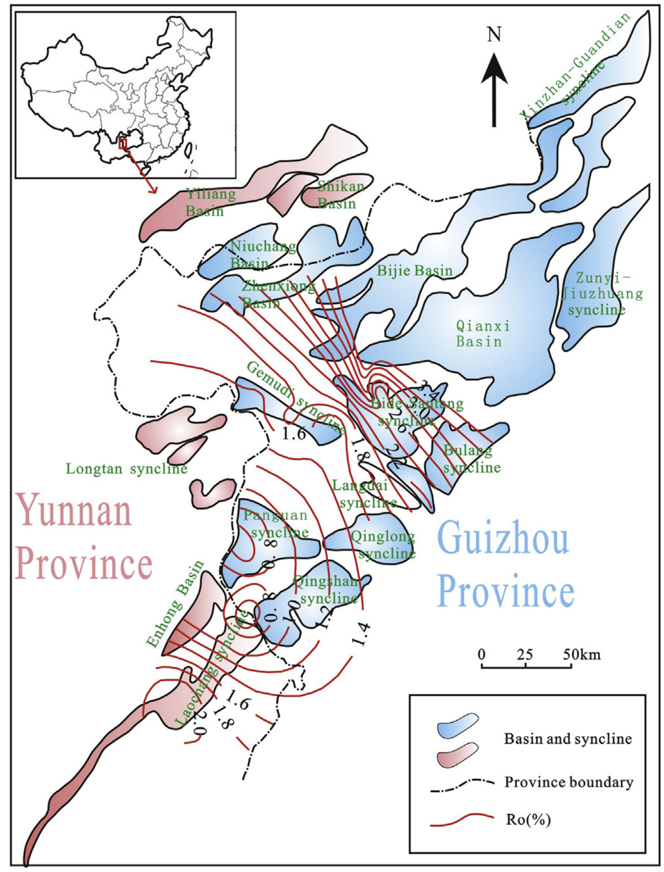

Fig. 1. Distribution of coalbed methane basins in the western Guizhou and eastern Yunnan regions.

3. Samples and methods

Given the high hydrothermal fluid activity in the western Guizhou and eastern Yunnan regions, it is important to characterize the thermal fluid's history through fluid inclusion analysis. To investigate hydrothermal fluid activity in the region, 40 coal and rock samples were collected from drilling (Fig. 2, Table 1). We conducted a series of experiments to test the homogenization temperature, salinity and components of the fluid inclusions; we also measured the physical properties of the coal.

In total, 16 rock samples collected by drilling (from roof and floor of coal seam) in the study area were used to measure the components of the fluid inclusions: these included inorganic components, anions and cations, and carbon and hydrogen isotopes. All the samples were first ground to 0.2–0.5 mm and both sides were polished under preparation temperatures below 80 °C. The measurements were made using the Laser Raman Spectroscopic Analysis Method described by Irmer, 2002 and Lascola et al., 2004. We used a LABHRVIS LABRAM HR800 Micro Laser Raman Spectrometer manufactured in France, which is capable of nondestructive analysis. Next, the same samples were analyzed to determine their homogenization temperature and salinity. Based on the Temperature Measurement Standard of Mineral Fluid Inclusion (EJ/T1105-1999) and established homogenization methods, the homogenization temperature of the fluid inclusions was measured on a LINKAM THMS 600 Cooling-Heating Equipment at 20 °C and 30% humidity. Finally, the salinity (as wt % NaCl) was calculated using the Data Conversion Table of Freezing Temperature-Salinity.

The coal rank of the study area was determined from 24 coal