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Research Article

Mineral composition of the Lower Cambrian black shale in the Upper Yangtze region and its significance in oil and gas exploration

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Abstract

The Lower Cambrian is one of the important exploration strata of marine shale gas reservoirs in the Upper Yangtze region, but its exploration is geologically impacted by multiple factors such as deep burial depth, fewer wells and unsatisfactory exploration results. In this paper, the mineral composition of the Lower Cambrian black shale in the Upper Yangtze region was investigated using the data of X-ray diffraction, rock thin section, scanning electron microscope (SEM) and argon ion polishing-electron microscope, and its significance in oil and gas exploration was also analyzed. The following findings were made. First, shale in this region is mainly composed of clay minerals and quartz, and secondarily of carbonate minerals and feldspar. The average content of quartz in shale is 44.6%, and two types of quartz are developed, i.e. terrigenous quartz and biogenic silica. The average content of clay minerals is 33.32%, with illite (I) content being the highest, illite/smectite (I/S) layer content uneven, the mixed layer ratio lower, generally 5%, and chlorite (C) and kaolinite (K) locally distributed. Second, four types of clay mineral assemblages are identified, including I + I/S + C, transition from I + I/S + C to I + C, I + C, and I, indicating that diagenetic environments of shale are different in different areas. Third, the disordered arrangement of mineral grains is favorable for the survival of intergranular pores, indicating that in the diagenetic alteration process of feldspar into clay minerals, linear pores can be generated. It is concluded that the brittleness index of shale in this region is generally above 40%, indicating a good fragility. The fragility of shale in SE Guizhou is better than that in SW Sichuan Basin.

Keywords: Upper Yangtze region; Early Cambrian; Shale; Mineral composition; Clay minerals; Assemblage type; Brittleness index; Pore characteristic

1. Introduction

Lately, a significant progress in study on the Lower Silurian Longmaxi Fm shale in the Sichuan Basin has been successively achieved in terms of its lithofacies identification, geochemistry, micro-pores, gas content and fracturability etc. [1–6]. The Lower Cambrian shale in the Upper Yangtze region also has high organic abundance, great thickness and large scale. In recent years, some shale gas discoveries have been made in this region. For example, low gas production was obtained in some wells after fracturing in the shale interval, such as Qiongzhusi Fm in Well W201 and Well JY1 in SW Sichuan Basin, Jiumenchong Fm in Well HY1 in southern Guizhou, and Niutitang Fm in Well TX1 in SE Guizhou (Fig. 1). However, the shale gas reservoirs are still less explored due to large burial depth, few drilling wells, and unsatisfactory exploration results, as well as geological constraints. Under this background, the authors made a comprehensive study on the mineral composition of Lower Cambrian

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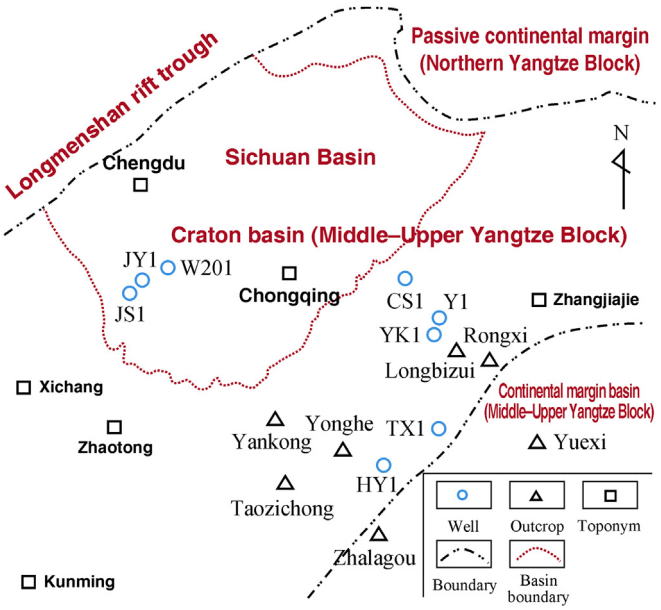

Fig. 1. A location map of the Lower Cambrian shale gas wells and outcrops in the Upper Yangtze region.

shale through outcrop observation, drilling core description, thin section analysis, whole-rock analysis, X-ray diffraction of clay minerals, analysis under scanning electron microscope (SEM) and argon ion polishing-electron microscope, and mineral energy spectrum, and investigated its impact on the diagenetic environment, pore formation and fracturing, thus providing a geological support for future exploration and development of the Lower Cambrian shale gas.

2. Mineral composition

Whole-rock analysis suggests that Lower Cambrian shale is mainly composed of quartz and clay minerals, followed by carbonate minerals and feldspar, as well as collophanite and pyrite locally (Fig. 2). Further analysis with the whole-rock thin section and X-ray diffraction of clay minerals indicates that siliceous primarily comes from detrital quartz particles and biogenic silica. Illite is the main clay mineral – over 90%, followed by illite/smectite (I/S) and chlorite. Generally, compared with the Lower Silurian Longmaxi Fm shale in the Sichuan Basin, the Lower Cambrian shale in the Upper Yangtze region contains more complex minerals and has a wider range of end-member contents on a triangular map, suggesting a greater variety of rock types. According to the mineral composition, texture/structure and organic contents, six types of lithologies were identified, including siliceous shale, carbonaceous shale, carbonaceous shale with calcareous lamination, micrite carbonaceous shale, lamellar argillaceous shale, and lamellar carbonaceous-silty shale. Specifically, siliceous shale, carbonaceous shale and lamellar carbonaceous-silty shale have higher gas contents, having favorable lithologies for shale gas exploration.

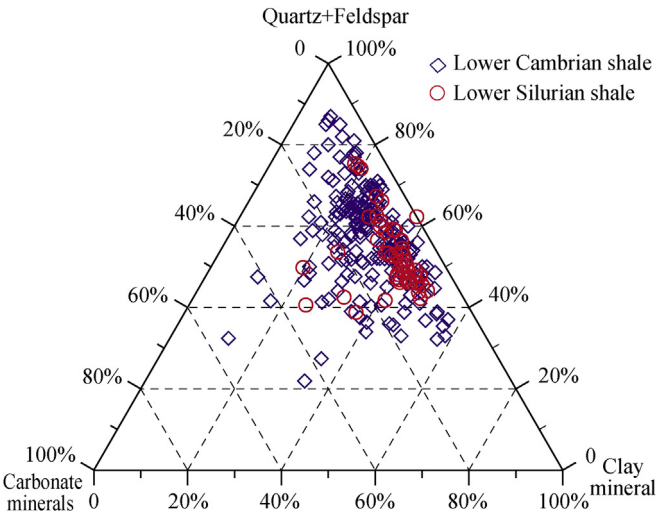

Fig. 2. Whole-rock mineral composition of the Lower Cambrian shale in the Upper Yangtze region.

2.1. Clay minerals

Shale is chiefly composed of clay minerals that represent a generic term of ultrafine-grained silicate minerals with sheet-like or ribbon-like structure and water-trapped lamellar structure, and water-trapped amorphous silicate minerals [7]. Different clay minerals are observed to have various interior structures and forms under SEM. Smectite has irregular fine granulars with a low crystalline degree and ambiguous outline. It has the capability of absorbing large amount of water to gain volume expansion [8]. Illite has complicated constitutions, and its crystal is coarser than smectite and of solid lattice, which indicates no swelling and low plasticity [9]. It is usually as bended sheet and fiber single crystal, with directional alignment, which is transformed to be like cellular, hair and floc after polymerized [10]. I/S normally wrap other particles or fills pores in a disorder manner, as a combined form of smectite and illite. The single crystal of chlorite is mostly needle-like and of thin hexagonal sheet, whose aggregation appears like flower, pompon, cellular and folded. The kaolinite crystal is usually as hexagonal plates, aggregated into clusters of plates and wormlike [10], which is a two-layered silicate mineral. This two parallel layered structure has a weak binding force, which means that it would be easily fractured and slipped. The X-ray diffraction results show that the clay minerals are chiefly composed of illite (I), illite/smectite (I/S), chlorite (C) and kaolinite (K). The content of illite is the highest (34–100%, or 77.07% on average). I/S distributes unevenly from 0 to 55% (12.47% on average), and its ratio is normally 5% or 10%. The content of chlorite (C) ranges from 0 to 45% with an average of 8.09%. The content of kaolinite (K) is low in 0–19% with 2.22% on average. The clay mineral content of shale is different depending on regions. The average content of illite, the highest, is 92% in the central–north Guizhou. In SE Chongqing, the average illite is 76%, while the content of I/S and C is 11% and 13%, respectively. In the Pengshui area, the average content of illite, I/S and C is 58%, 21% and 17%, respectively. In the Jingyan–Jianwei area, illite and I/S are dominant, with an average content of 44% and

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