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Full Length Article

Bitumen formation of Cambrian Longwangmiao Formation in the central Sichuan and its implication for hydrocarbon accumulation

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ABSTRACT

Based on organic petrology, organic geochemistry and SEM method, type, formation period and source of bitumens in the Cambrian Longwangmiao Formation in the central Sichuan Basin were well investigated, and combined with fluid inclusions and tectonic evolution characteristics, the hydrocarbon accumulation history of the gas reservoir of the Longwangmiao Formation in the Anyue gasfield was also studied. The result shows that all bitumens in the Longwangmiao Formation was from the Lower Cambrian source rocks, it had multiple genetic types which was dominated by the pyrolysis genetic type; the bitumens were formed into three stages, i.e., the bitumen of the oxidized water-washing type in the first stage, the bitumen of the precipitated type in the second stage, and the bitumen of the pyrolyzed type in the third stage; the gas reservoir in the Anyue gasfield experienced five stages of hydrocarbon charging, including two stages of liquid hydrocarbon charging, charging of the kerogen pyrolysis gas in the Late Triassic-Early Jurassic, charging of the crude oil pyrolysis gas in the Late Jurassic-Early Cretaceous and charging of the dry gas charging in the Himalayan trap reformation and adjustment process.

1. Introduction

The discovery of the Anyue gasfield in the Sichuan Basin is a new historic breakthrough in China's natural gas exploration. Especially the gas reservoir of Longwangmiao Formation has proved the geological reserve of natural gas of over 440.38×10^9 m^3, and is the largest integral gas reservoir discovered in China by now (Zou et al., 2014; Wei et al., 2015a). Drilling data show that a lot of solid bitumens are developed in reservoirs of the Longwangmiao Formation. As a solid-state derivative accompanying the whole process from hydrocarbon generation to termination, the bitumen records various geological and geochemical actions since the hydrocarbon generation (Wang et al., 2008), and studies on formation of the bitumen is of special significance to understand the accumulation process of the Longwangmiao gas reservoirs. However, current studies only show that it is the residue after pyrolysis of the paleoreservoirs in general terms (Zou et al., 2014), and the systematic analysis are not yet carried out. Since the accumulation process of Sinian-Lower Paleozoic natural gas in the Sichuan Basin is characterized by difference of hydrocarbon generation and expulsion, multi-stage hydrocarbon migration and accumulation, and early accumulation and reservoir (Liu et al., 2009b), most of gas reservoirs experience a complicated accumulation history; therefore, the bitumen in gas reservoirs may not only be the pyrobitumen from the pyrolysis, but also be the aggregation of various genetic type bitumen. Based on above understanding, in this study, the bitumen formation is analyzed comprehensively, and the hydrocarbon accumulation process of the Longwangmiao Formation in the Anyue gasfield are recovered in combination with fluid inclusions.

2. Geological background

The Anyue gasfield is located at the central Sichuan Basin and tectonically at the east of the axis of the Central Sichuan paleo-uplift (Fig. 1), including the Gaoshiti, Moxi and Longnvsi structures. Researches show that, the Central Sichuan paleo-uplift began to take shape in the depositional period of the Ediacaran Dengying Formation, and a palaeogeographic pattern showed that high in the

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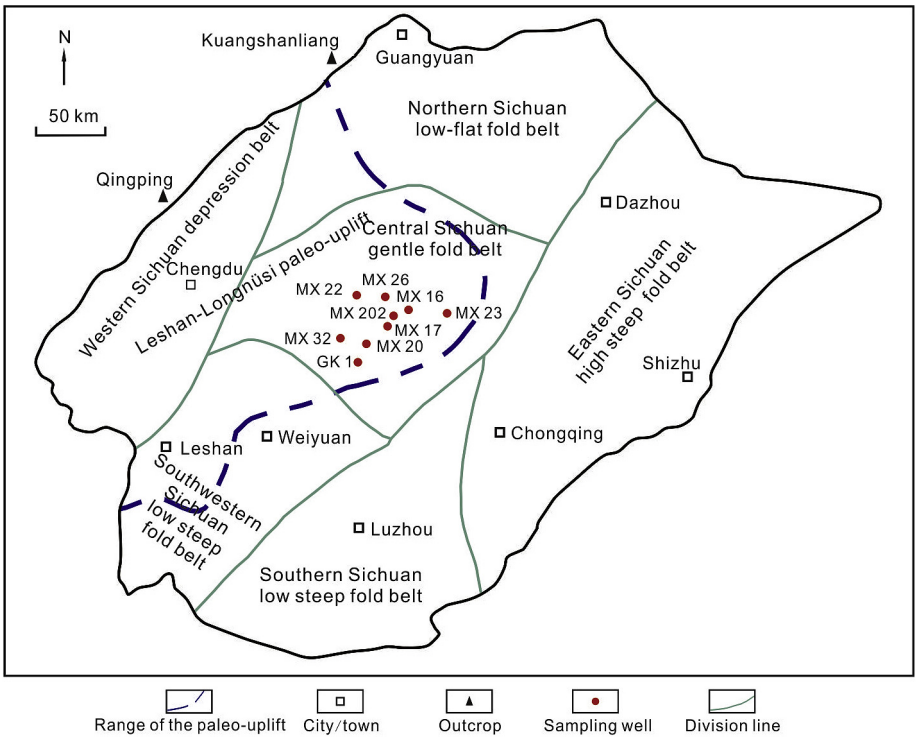

Fig. 1. Location of the Anyue gasfield and well location in the Sichuan Basin showing that the Anyue gasfield is located at the central Sichuan Basin and tectonically at the east of the axis of the Central Sichuan paleo-uplift.

west and south, as well as low in the east and north (Li et al., 2015a); in the depositional period of the Early Cambrian Canglangpu Formation, it showed an underwater paleo-uplift, and its core was located at the area of the Longmen Mountain (Zou et al., 2014); at the end of the Silurian, the Caledonian Movement sharply made the stable base uplifted and the shape of the Central Sichuan paleo-uplift was basically finalized as a large asymmetric and nose-like structure with a narrow and steep wing in the southeast and a wide and mild wing in the northwest; subsequently, development of the paleo-uplift was in the stable burial stage and adjustment stage (Xu et al., 2012), and the Gaoshiti-Moxi area was still in the relatively stable tectonic area and at a the structural high (Li et al., 2014), that is quite favorable for large-scale hydrocarbon accumulation.

In the study area, the Ediacaran Doushantuo Formation and Dengying Formation, the Cambrian Maidiping Formation, Qiongzhusi Formation, Canglangpu Formation, Longwangmiao Formation, Gaotai Formation and Xixiangchi Formation, the Ordovician system and the Silurian system are well developed from bottom to top. The main reservoirs are the Ediacaran Dengying Formation and the Cambrian Longwangmiao Formation, the source rocks are mudstone in the Ediacaran Doushantuo Formation, mudstone in Member 3 of the Dengying Formation, argillaceous dolomite in the Ediacaran Dengying Formation and shale in the Cambrian Qiongzhusi Formation (Zou et al., 2014), and several favorable source-reservoir-caprock assemblages are formed. Source comparison shows that the natural gas in the Longwangmiao Formation is mainly from the Lower Cambrian Qiongzhusi Formation (Wei et al., 2015b).

3. Methods

In terms of the study on bitumen genesis, bitumen samples in the reservoirs are all collected from the Longwangmiao Formation of the Gaoshiti-Moxi structural belt in the Sichuan Basin. The bitumens mainly are in the dolomite intercrystalline pores, intergranular pores, dissolution pores and fractures and it occur in the black solid substance. Over 310 samples were collected from 15 wells, of which the bitumen content of 7 wells (such as Well MX 16, Well MX 17, Well MX 202 and Well MX 32) is relatively high, and samples for analysis of reflectivity, carbon isotope, elemental composition and chromatography-mass spectrometry of the bitumen are all from these 7 wells (Table 1 and Fig. 1); other samples are mainly used for SEM and microscope observation and content of the bitumen. The bitumen reflectivity is analyzed with the MPV-SP microphotometer. The elemental composition is analyzed through the vario MICRO cube elemental analyzer. The carbon isotope of the bitumen is analyzed through the SerconGeo 20-20 in accordance with the VPDB standard. The chloroform bitumen “A” is obtained by the chloroform extraction of the grinding samples, after the asphalt is precipitated with n-hexane, the saturated hydrocarbon, aromatic hydrocarbon and colloid components are separated from the filtered liquid through the silicone alumina chromatographic columns and the solvent with different polarities. The Trace GCUltra-DSQII produced by Thermo Scientific Company is used to carry out the chromatography-mass spectrometry analysis of the saturated hydrocarbon; the chromatography-mass spectrometry analysis condition is that the chromatographic column is the HP-5MS elastic capillary column (60 m × 0.25 mm × 0.25 mm), the initial temperature is 100 °C (constant temperature for 5 min) and then the temperature rises to 320 °C at the rate of 3 °C/min and keep stable for 20 min, the carrier gas is 99.999% helium and injected at a constant rate of 1 mL/min, the inlet temperature is 280 °C and the temperature of the transmission line is 300 °C. The EI electronic bombardment (70eV) is used with the filament current of 100 mA and the ion source temperature of 250 °C.

Over 30 samples are collected for inclusion analysis, especially

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