Reservoir characteristics and well-logging evaluation of the Lower Cambrian shales in southeast Chongqing, China

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Abstract: To accurately identify the reservoir characteristics and main controlling factors of the Cambrian Niutitang black shale in the southeast Chongqing, a series of systematic measurements were conducted on core samples from Well Yuke-1 and Well Youke-1. The measurements include clay mineral analysis, XRD analysis, petrophysical properties, specific surface area, pore diameter and TOC, as well as R_o and maceral compositions. The Niutitang shale reservoir contains detrital minerals and clay minerals averagely of 51.34% and 32.74%, respectively. The average effective porosity and permeability are 1.2% and 8.0×10^{-3}mD, respectively, typically of ultra-low porosity and permeability. Mesopores are dominant, accounting for approximately 73% of the total pore volume. The average BET specific surface area is 7.75m^2/g and the average pore diameter is 5.3nm. The average TOC is 2.29% and the average R_o is 3.12%, indicating that the organic matter is in over-maturity stage. Statistical analyses of the measurements show that the micropore volume is positively correlated with TOC but negatively correlated with the total content of clay minerals; the mesopore volume is positively correlated with TOC, the total content of clay minerals and the content of carbonate minerals; the macropore volume is positively correlated with TOC and the content of carbonate minerals, weakly positively correlated with the content of detrital minerals but negatively correlated with the total content of clay minerals. The porosity and TOC of the Niutitang shale are computed using the conventional well-logging method for the Yuke-1 and Youke-1 wells, and the porosities are quite consistent with the core analysis resultsr, but in the shallow reservoir that contains no oil and gas, the TOC exhibits no correlation with the core analysis results.

Key words: *shale; reservoir characteristics; well logging; multiple linear regression; Niutitang Formation*

1 Introduction

Shale gas in natural fractures and intergranular pores is generally in the form of free gas, or absorbed gas in kerogens and clay particles, or dissolved in kerogens asphalts (Curtis, 2002). These organic-rich shales are both source rocks and reservoirs (Martini et al., 1998). Shale gas resources are abundant on a global scale. In addition to North America, many countries including China, the UK, India and New Zealand also announced discoveries of shale gas (Dong et al., 2012). On March 1, 2012, the Chinese Ministry of Land and Resources disclosed for the first time that the geological and recoverable shale gas resources in mainland China excluding the Qinghai-Xizang region amounted to 134.4×10^{12} m^3 and 25.08×10^{12} m^3, respectively (Yu, 2012). According to Energy Information Administration (EIA, 2013), China possesses the most abundant shale gas resources in the world with a recoverable shale gas resource up to 31.57 $\times10^{12}$ m^3 and has great potentials in the exploitation and utiliza-

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tion of shale gas. Paleozoic marine shales are mainly distributed in South China, North China and Tarim Basin. Mesozoic and Cenozoic continental shales are mainly distributed in the Songliao Basin, Bohai Bay Basin and Ordos Basin, while the Carboniferous-Permian marine-continental transitional shales are mainly distributed in northern China (Dong et al., 2012; Li et al., 2012).

Currently, US have successfully exploited five shale gas-bearing basins commercially (Curtis, 2002). The geological accumulation theory of shale gas has been investigated deeply. The assessment technology for shale-gas reservoirs, perforation optimization technology, fracturing technology and horizontal-well drilling technology have been developed accordingly (Huang et al., 2009; Zhao and Yang, 2011).

China has recently made important progress in the basic geological theory and understandings regarding the geological features of organic-rich shales, the geological conditions for the formation and enrichment of shale gas and the optimal selection of shale-gas prospect zones, etc. The assessments on shale-gas reservoirs are mainly conducted in terms of five aspects including: distribution of organic-rich shale intervals, mineral compositions, characteristics of micro-nano pores in shale reservoirs, petrophysical properties and gas-bearing capacity of gas shales (Chen et al., 2010; Nie et al., 2011). In particular, the pore structures of shale-gas reservoirs have drawn a wide attention (Chen et al., 2011; Zou et al., 2012). Shale is an ultra-tight reservoir formation, of which the pore sizes may be down to several nanometers and are far smaller than those of sandstone and carbonate reservoirs (Yang et al., 2013). By means of Ar-ion milling and Field Emission Scanning Electron Microscopy (FE-SEM), a great number of micro- and nano-scale inorganic and organic pores can be detected and characterized in shales. The shale reservoir porosity can thus be quantitatively measured (Ross and Bustin, 2008; Nelson, 2009). The characteristics of shale-gas reservoirs are mainly investigated through isothermal adsorption experiments, analyses of specific surface area and pore diameters as well as scanning electron microscopy (Xue et al., 2013). Low-temperature nitrogen adsorption method is widely applied in measuring rocks with high contents of organic matter such as coal and shale (Clarkson and Bustin, 1999; Tian et al., 2012). However, less is known about the intrinsic relationships between the assessment parameters such as pore volume and methane adsorption capacity and the shale composition characteristics. It is clear that organic matter is a key factor, whose abundance is positively correlated with the specific surface area and adsorption capacity of gas shales (Xue et al., 2013). Accordingly, by using multiple linear regression method, this study investigates the relationships between the shale composition characteristics and the effective porosity, pore volume and BET specific surface area of shale reservoirs to determine the main controlling factors for the physical properties of reservoirs. On this basis, the reservoir assessment parameters can be indirectly calculated based on the shale composition characteristics.

2 Geological background

The southeastern part of Chongqing is located in the southeast margin of Sichuan Basin and on the northwestern side of the Daloushan Mountains. It lies within the Upper Yangtze Plate. The pre-Sinian basement is not found in this region. The cap rock covers from the Cambrian to the Jurassic, with a depositional thickness of up to 8951m (SPBG, 1977). Multi-phase tectonic movements occurred in this region, characterized by strong extrusions. Anticlines and fractures were mainly formed during the Yanshanian Orogeny of the Mesozoic Era, showing a NE-SW trend. These movements show apparent inheritance and significant modification to the previous geological structures. Afterwards, the geological structures in this region are basically established, and the whole region is uplifted to form the land (Xie et al., 2013).

The Lower Paleozoic marine shales are extensively developed in the southeast Chongqing area, mainly including the Lower Cambrian Niutitang Formation and the Lower Silurian Longmaxi Formation. These shales are featured by a wide distribution, shallow buried depth, a great thickness and a good fracture development (Zhang et al., 2009; Dong et al., 2010). The shales are collected from the Niutitang Formation in Well Yuke-1 and Well Youke-1 (Fig. 1).

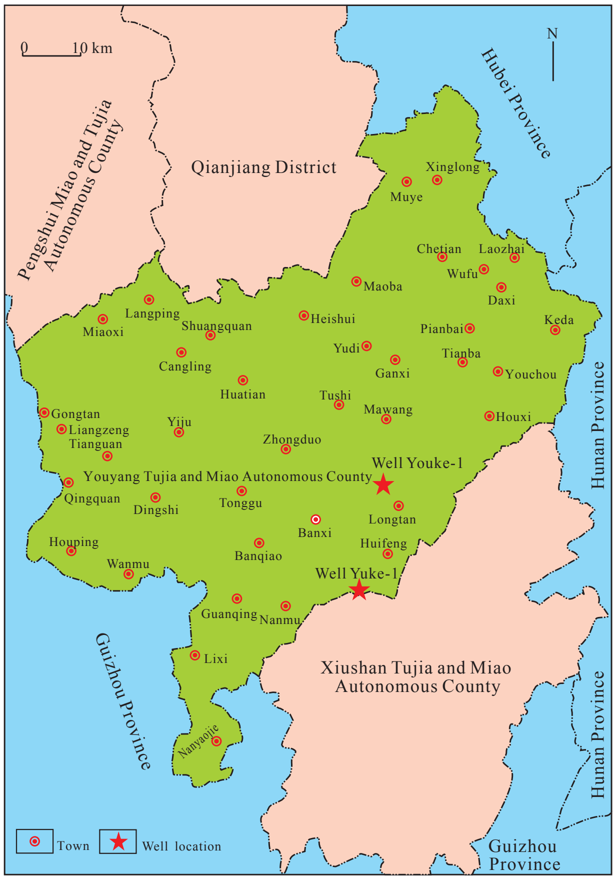

Fig. 1 Geographic locations of Well Yuke-1 and Well Youke-1