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Full Length Article

Pore structure of shale and its effects on gas storage and transmission capacity in well HD-1 eastern Sichuan Basin, China

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ABSTRACT

It is proved that the Wufeng-Longmaxi formation in Sichuan Basin is the key shale gas layer in China. Although the breakthrough of shale gas exploration had been gotten in it, the enrichment mechanism of it has not been well studied. To understand the enrichment mechanism of it, we will take the biggest total gas content layer (BTGC layer) and main production layer (MP layer) drilled in well HD-1 for example. A series of experiments were conducted on core samples, including total organic carbon (TOC) content, X-ray diffraction (XRD), scanning electron microscope (SEM), focused ion beam scanning electron microscope (FIB-SEM) and Micro-CT. Meanwhile, the aid tests (such as mud logging data, reservoir physical test, field desorption experiment data, mud gas logging data) were integrated to study the difference of the two sections in gas storage and transmission capacity too. The results show that although the field desorption gas content of BTGC layer is bigger than MP layer, the TOC of BTGC layer (3.45%) is smaller than it in MP layer (4.15%). The MP layer is dominated by the quartz with average value 87.3% which is obviously bigger than it in BTGC layer 37.5%. Although the helium porosity in BTGC layer (2.98%) is bigger than MP layer (2.68%), the permeability of it(0.005878mD) is smaller than MP layer(0.013950mD). Except the organic pores, to a certain type, the pores in the MP layer are bigger than them in BTGC layer, such as interparticle pores, dissolution pores, micro fractures. The connected pores are dominated by the pores in mm-scale and micro-scale. The difference of the enrichment mechanism in the two layers is dominated by the difference of pore structure. The MP layer provides a migration pathway to the gas enriched from nearby shale layer in km-scale. If the permeability and the overpressure of the layer are big enough, the shale gas would be exploited without hydraulic fracturing. In BTGC layer, the pores are scatted in the shale and isolated from each other. The gas storage ability of this type is commonly good, with high field desorption gas content, but it must be exploited with hydraulic fracturing for its low permeability. It is need to pay attention to the high permeability layer in shale strata in the further exploration of shale gas.

1. Introduction

Shale gas, as an alternative resource awaiting exploitation, has received much attention for large reserves [1,2]. In China, the exploration of it had started in 2005 [2]. The annual output of shale gas has gotten $78.82 \times 10^8\ m^3$ in 2016, which is the world's third. The production in Sichuan Basin occupies more than 95% of the shale gas production in China. It is verified that the Sichuan Basin and its surrounding area are the optimum areas for Paleozoic marine shale gas in China (Fig. 1a). Previous study shows that the Longmaxi formation in Sichuan Basin with over $10{,}000 \times 10^8\ m^3$ of shale gas in-place [4]. Meanwhile, the practices show that there are many similarities between the enrichment of shale gas and entrapment of hydrocarbon in China. The tectonic condition is the key factor for shale gas enrichment and to prolific production [3,4]. Up to January 9th, 2017, the well JY1-HF had product shale gas more than $9082 \times 10^4\ m^3$ with daily production about $6 \times 10^4\ m^3$ for more than four years. The per well output is more than twice the reserves($4024.8 \times 10^4\ m^3$) connected by this well and its hydraulic fractures [5]. Up to now, this phenomenon has not been well explained.

Compared to conventional reservoirs, shale was a tight reservoir characterized by abundant nano-pores [6]. It is widely believed that the reservoir characteristics of shale is essentially determined by the pore structure properties, including pore size distribution, surface area, pore volume and porosity parameters [6,7]. The pore system of gas shale are commonly characterized by, micropores (pore diameter < 2 nm),

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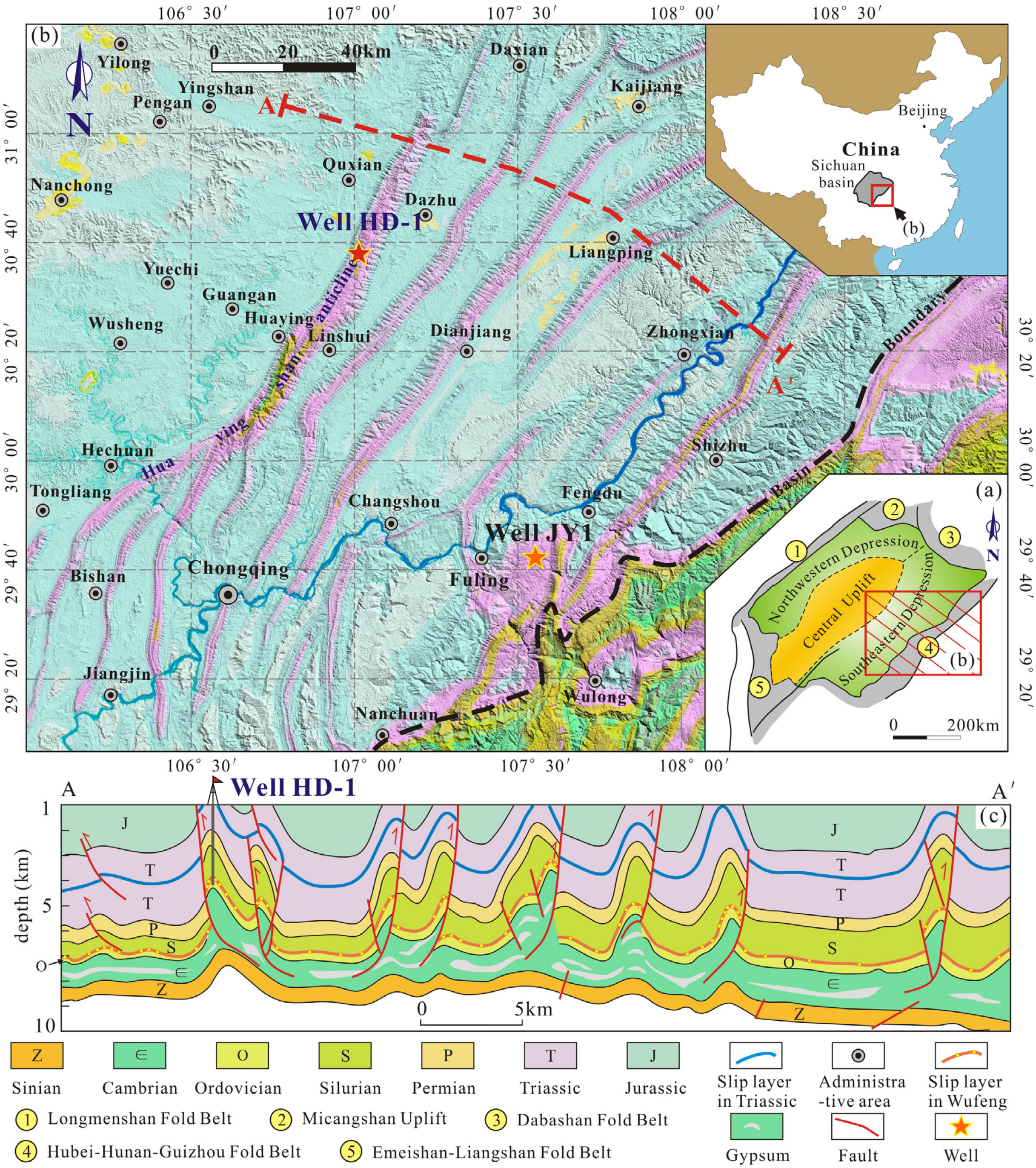

Fig. 1. (a) The shape and structure units of Sichuan Basin, (b) Map of the high and steep structural zones showing the geomorphological features in the study area and the location of well HD-1 and well JY-1, (c) The structural profile of the high and steep structural zones showing the structure style, the slip layer in Wufeng formation (MP layer) and the location of well HD-1.

mesopores (2–50 nm) and macropores (> 50 nm) [6,8,9]. Hence, previous studies are mainly focused on the micro-zone analysis for shale layer. The mm-scale fractures in shale gas are so rare that they are often been ignored. However, the permeability is bigger than 200 mD in the mm-scale fractures [3]. In well HD-1(Fig. 1b), the biggest total gas content layer (BTGC layer) at 1313.8–1321.5 m in depth is about 10 m shallower than the main production layer (MP layer) at 1331.8–1333.0 m in depth, which indicated that the productivity of shale gas in not only dominated by the gas content of shale layer but also the transmission of the gas in shale layer.

As mentioned above, the shale in Wufeng-Longmaxi formation is the key production layer of shale gas in China now. Although the breakthrough of shale gas exploration has been gotten in it [2], the enrichment mechanism of it has not been well studied. In the present work, we will take the BTGC and MP layer drilled in well HD-1 for example. The scanning electron microscope (SEM) is used to showing the 2D characterization of pore structure in them. Focused ion beam scanning electron microscope (FIB-SEM) and microscopic computed tomography (Micro-CT) measurements were used to showing the 3D characterization of pore structure in them. Meanwhile, the aid tests (such as mud logging data, mineralogical, reservoir physical test, field desorption experiment data, mud gas logging data) were integrated to study the difference of the two sections in gas storage and transmission capacity, which will benefit to understand the enrichment of shale gas