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OPINION
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New Opinion of Development Potential of Carboniferous Volcanic Gas Reservoir: Taking the Kelameili Gas Filed as an Example

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INTRODUCTION

Volcanic rocks are widely distributed in many hydrocarbon-bearing basins in the word (Jin, 1998; Yi et al., 1998; Koning, 2003; Luo et al., 2003; Schutter, 2003; Jia et al., 2007). Although the volcanic reservoirs have been found in the United States, Brazil, China, Russia, and Egypt, etc., the research of the volcanic gas reservoirs are relatively rare. For example, the well-known volcanic gas reservoirs, Yoshii-Higashi-kashiwazaki and Minami-Nagaoka in Japan, but the research of them is still not enough. Therefore, the developing experience of carboniferous volcanic gas reservoirs has a significant effect.

In China, Xushen, Changling and Kelameli gas field were discovered from 2004 to 2008 and developed successively. However, due to the short exploration time and the late research of volcanic gas reservoirs, many problems and difficulties need to be further studied. Relevant literature shows that there are great differences in gas well performance characteristics and development effects in volcanic gas reservoirs, especially the nonlinear seepage characteristics. The main influencing factors of the development characteristics and effects of volcanic gas reservoirs are complex, involving many aspects, such as reservoir osmosis patterns, percolation mechanisms, and reservoir prediction, which need to be researched further. It is found that there are some obvious deficiencies in guiding the later rolling exploration and development (Hao et al., 2006; Yang and Lan, 2012; Shi et al., 2018). This paper summarizes the geological and development difficulties, taking the volcanic gas reservoirs in Kelameili gas field as an example. And new option are put forward to provide a reference for the efficient development of similar gas reservoirs.

DEVELOPMENT DIFFICULTIES

Kelameli gas field is the typical Carboniferous volcanic gas reservoir, which is located at the west end of Dinan uplift in the southeast of Luliang Uplift in Junggar basin, nearby Cainan Oilfield in the South and Wucaiwan gas field in the East. Kelameli gas field mainly includes four gas bearing areas: Dixi 17, Dixi 14, Dixi 18 and Dixi 10. Carboniferous volcanic rocks in Dixi 14 are mainly tuff and tuffaceous breccia, followed by basalt and rhyolite, and conventional clastic rocks are the least. The previous research recognized that the gas reservoir mainly includes five sets of reservoir rocks, with independent structure and boundary and unified gas-water system (Zhang et al., 2010; Wu et al., 2017). In 2008, the reported proved gas bearing area of natural gas was about 20 km^2, the geological reserves were about 350 × 108 m^3. In 2015, through the follow-up study on the adjustment scheme of Kelameili gas field, it was found that the rock mass structure changed again and the gas bearing area increased slightly. During the development and production of volcanic gas reservoirs in the well area,

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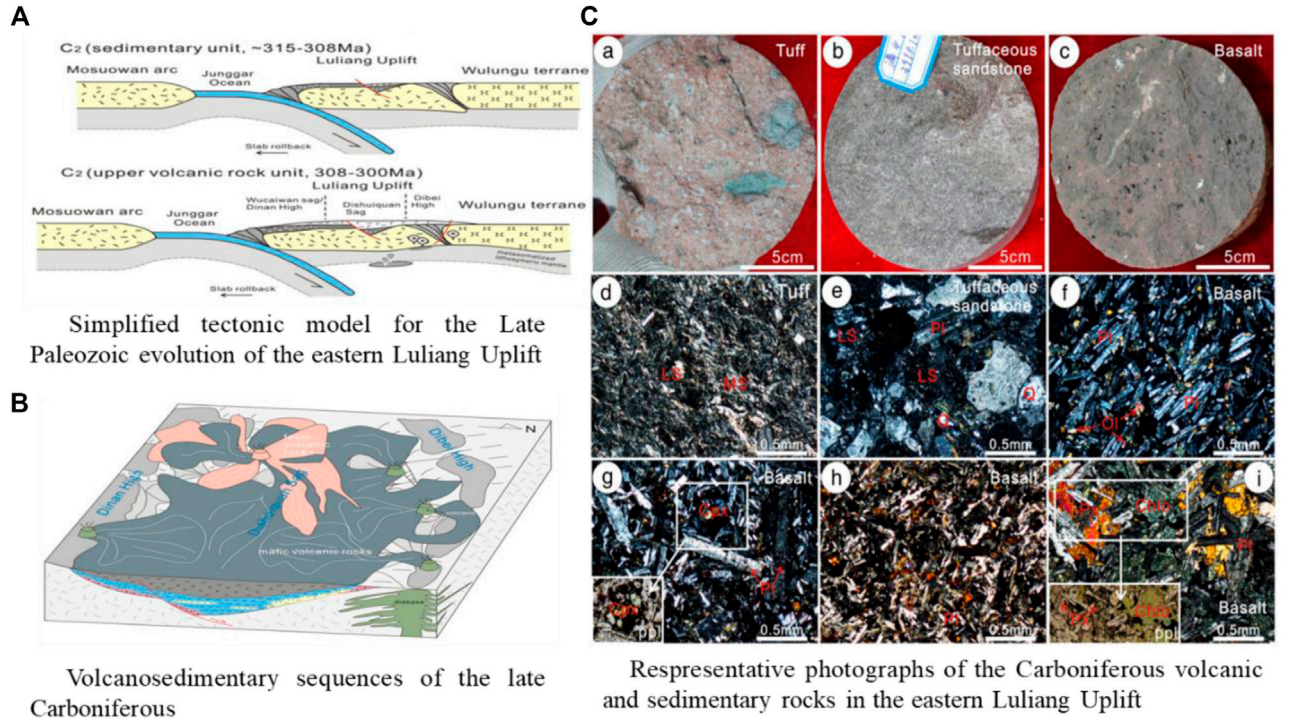

FIGURE 1 | Tectonic model, volcanosedimentary sequences and respresentative photographs of Carboniferous volcanic gas reservoir in Junggar Basin (Li et al., 2015a; Li et al., 2015b). **(A)** Simplified tectonic model for the Late Paleozoic evolution of the eastern Luliang Uplift. **(B)** Volcanosedimentary sequences of the late Carboniferous. **(C)** Respresentative photographs of the Carboniferous volcanic and sedimentary rocks in the eastern Luliang Uplift.

the understanding of rock mass structure and reservoir has been further. However, several problems are still not solved. For example, during the drilling process of the new well, the results are inconsistent with the original prediction of rock mass structure and lithology, and serious water generation in the production process of gas wells in some areas. Comprehensively considering the problems exposed in drilling, development and production, it can be shown in the following aspects:

(1) The rock mass structure in the well area is complex and needs further fine characterization.

Dixi 14 gas reservoir is mainly distributed in volcanic rock mass of explosive facies. The volcanic rock mass identified by 3D seismic data and combined with newly completed drilling data show that the structure and distribution range of rock mass often change to varying degrees as shown in **Figure 1A**. In the follow-up study on the adjustment scheme of Kelameili gas field completed in 2015, the Dixi 14 composite rock mass was recombed, and the rock mass expanded northeastward, increasing the area by 1.6 km^2.

(2) Volcanic rock facies and lithology are complex, diverse, and changing rapidly, which is difficult to predict.

Reservoir lithology in Dixi 14 well area is very complex, mainly consisting of Neutral-acidic volcanic tuff of volcaniclastics, accounting for 36%, followed by basalt, accounting for 15%. The lithological composition of each rock mass is quite different. Dixi 14 complex rock mass mainly develops volcanic eruption and overflow lithology, such as breccia, melted breccia, melted tuff and tuff, with fast lateral lithology change and strong inhomogeneity as shown in **Figure 1B**.

(3) The development potential of gas reservoirs and the distribution of remaining reserves need to be further realized.

After the implementation of several new wells in 2014 and 2015, Dixi 14 well area has achieved good production, increased rock mass area and expanded well-controlled reserves. In 2016 and later stages, several wells were planned to be implemented, development potential needs to be realized, and the well location deployment needs to be optimized.

RECOGNITION OF GAS RESERVOIR GEOLOGICAL CHARACTERISTICS

Kelamei gas field is located on the Dinan uplift in the southeast part of Luliang uplift in Junggar Basin. Carboniferous gas reservoir in Dixi 14 well area belongs to one of the four development blocks of Kelameili gas field. Dinan uplift was formed at the end of Carboniferous Period, reaching the Kelameili mountains in the east, Shixi uplift in the west, Haizi

depression in the East and Dishuiquan depression in the north. The regional tectonic position is very favorable.

The gas reservoirs in Dixi 14 well area are mainly composed of tuff breccia (15.9%), rhyolite tuff (12.4%), dacite (7.2%) and basalt (7.7%). The lithology is mainly acidic extrusive rock (51.6%), volcano sedimentary rock (26.9%) is relatively developed, and coal seam (0.8%) is locally developed as shown **Figure 1C**. The distribution interval of gas reservoir porosity is 7.1–22.2%, and the average value is 14.4%. Distribution interval of permeability is 0.005–836.000 mD with average value of 0.844 mD. Thus, the Dixi14 well area belongs to a medium-low pore and low-permeability gas reservoir. By checking the geological reserves of seven rock masses, the total reserves of condensate gas are about 18 billion cubic meter, natural gas 18 billion cubic meter and condensate oil 130 million tons.

NEW RECOGNITION OF GAS RESERVOIR DEVELOPMENT POTENTIAL

The gas produced by the Dixi14 well area from the complex rock mass is about 1.3 billion cubic meter and the recovery degree reaches 11%. The remaining gas reserves in the whole area remain at a high level. As gas reservoir belongs to natural energy elastic development, the change of gas saturation is not obvious. Therefore, the exploitation situation is mainly reflected in the degree of pressure drop. Petrographic rocks of volcanic rocks are highly variable, with poor connectivity of reservoirs and uneven pressure drop. The region of greater pressure drop for this pluton is largely centered to the east of the plutons, which were in earlier production. While higher formation pressures are retained in local wells at pluton sides as well as in areas of longitudinal use imperfections. New drilling has the potential to enhance the use of reserves in both the southern and northern mid lower reservoirs of plutons. At the end of 2017, twenty three gas wells were put into production, in which nineteen wells were open and produce more than 540 thousand cubic meter per day, and then the cumulative gas production reached more than 1.8 billion cubic meter.

Dixi 14 well area contains geological reserves about 17.6 billion cubic meter with an area of 12 km^2. As of now, the twenty three wells have controlled geological reserves about 9.8 billion cubic meter with an area of 7.0 km^2. The uncontrolled geological reserves of the producing wells are more than 7.8 billion cubic meter with an area of 5.0 km^2, there was still a large digging space. By the numerical simulation method, the gas recovery in 20 years is predicted to reach 6.7 billion cubic meter, and the recovery degree of geological reserves can reach 38.2%.

CONCLUSION

(1) Volcanic rock gas reservoir is one of the important targets of natural gas development. Under the background of rapid growth of current energy demand, rational development and utilization of the volcanic rock natural gas resources is of great significance for ensuring energy security, optimizing energy structure and improving environment in China.

(2) At present, the unutilized reserves of Dixi14 well area in Kelameili gas filed mainly exist in the areas with low reserve abundances of rock mass at the edge of the research area, as well as in the thin and poor reservoirs not affected by the edges and corners of main rock mass and between wells. Reserves controlled by drilling are mainly concentrated in the middle of rock mass. The zones are still well developed in the edge and interlayer of rock mass. New drilling and side drilling as well as combination of vertical and horizontal wells can be used to develop and adjust the reservoir so as to improve the degree of reserve production.

AUTHOR CONTRIBUTIONS

YH: Methodology. CW: Writing-original draft preparation. LC: Visualization. BX: Writing. LH: Reviewing. JQ: Editing.

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Conflict of Interest: YH, CW, LC, BX, LH, and JQ was employed by No.1 Gas Production Plant of XinJiang Oilfield Company.