Reservoir forming conditions and risk exploration techniques of bedrock in the central paleouplift of the northern Songliao Basin

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Abstract. Bedrock in the central paleouplift of the northern Songliao Basin presents favorable conditions for forming natural gas reservoirs, high-yield industrial gas was produced from the weathered crust of bedrock by risk exploration well Lp1, which means a great breakthrough in the exploration of bedrock gas reservoirs. In order to evaluate the exploration potential of bedrock gas reservoirs in the northern Songliao Basin, this paper systematically summarizes the exploration history, accumulation conditions and main controlling factors of bedrock gas reservoirs, and a set of technical methods for bedrock gas risk exploration has been established. Research results show that the major exploration breakthrough of the bedrock weathering crust proves that the bedrock in the basin has great potential for oil and gas exploration, and has strengthened the determination and confidence in the transformation of exploration ideas and the expansion of new exploration fields.

1. Introduction
Many fault depression groups in the northern Songliao Basin have complex geological structures of fault uplift alternation. The deeply buried depth of strata is large and diagenesis is strong. Therefore, it is difficult to predict exploration targets and identify and evaluate special lithologic reservoirs. Deep gas exploration has become a world-class problem[1]. In the past ten years, the proven reserves of deep volcanic gas reservoirs have exceeded 2000×10^8m^3. The tight gas of Shahezi Formation and peripheral fault depression have made breakthroughs, showing a good exploration prospect of deep natural gas[2-4]. Looking back on the exploration results of deep natural gas in the northern Songliao Basin, as of 2015, the discovered oil and gas resources are mainly attached to volcanic rocks and tight sandstone gas. Except for well Z1 and w902 deployed in 1973 and 1995, the weathered crust of bedrock in well Z1 and W902 respectively obtained a production of 1.1×10^4m^3/d and 3.4×10^4m^3/d respectively, no significant oil and gas exploration has been made in bedrock[5-8]. A high-yield gas flow of 11.5×10^4m^3/d was obtained in the weathering crust test of bedrock in risk exploration well Lp1, which opened the veil of bedrock exploration, and provided guidance and reference for bedrock gas exploration in Songliao Basin and other areas.

2. The geological conditions
The central paleouplift belt in northern Songliao basin is a long-term inherited paleouplift, which is located between Xujiaweizi fault depression and Gulong fault depression. It is bounded by depression
controlling faults in the East and West, it is distributed in the north-south direction, high in the north and low in the south, wide in the South and narrow in the north, 9-34km wide in the east-west, 110km long in the South and the area is 2400km² (Fig.1). There are 43 bedrock exploration wells drilled into the central paleouplift zone and its surrounding areas. 14 wells are shown to be gas wells. The research focus shifted from Denglouku formation to bedrock. A new round of overall evaluation research was carried out by using 3D seismic contiguous data in this place. Focusing on the distribution of dominant lithology of granite and metamorphic rock, prediction of weathering crust thickness and distribution, the description of the geological structure inside bedrock, and the prediction of hydrocarbon supply conditions and favorable area, a series of studies have been carried out. The favorable exploration zones are defined and the risk drilling targets are optimized. The first batch of L1, L2 and LX3 risk wells were deployed. The granite weathering crust of well L2 obtained 2.43×10⁴m³/d industrial gas flow. In order to improve the productivity of weathering crust, horizontal well Lp1 was deployed, and 11.5×10⁴m³/d high-yield gas flow was obtained by large-scale volume fracturing. The trial production is stable, obtained a major breakthrough in bedrock exploration in the central paleouplift zone of the northern Songliao Basin, showing bedrock natural gas in the northern Songliao basin Exploration potential and good exploration prospect.

![Figure 1. Bedrock distribution and Stratigraphic column of the Paleocentral Uplift Belt in Northern Songliao Basin](image)

3. Basic characteristics of bedrock gas reservoir and its main controlling factors

According to the identification marks of weathering crust, the comprehensive analysis from point (single well) - line (well connection) - surface shows that the weathering crust of bedrock in central paleouplift zone has the characteristics of vertical zoning. The profile structure of weathering crust is vertically divided into three layers: weathering accumulation layer, weathering leaching layer and fracture layer (Fig.2), with thickness up to 300 m. The weathering accumulation layer is mainly composed of weathered clay and sandy gravel, with broken core and gravel on fracture surface; the
logging curve shows high gamma ray, low resistivity, and sudden increase of acoustic; the imaging shows that the gravel is distributed unevenly; the weathered clay layer is rich in clay minerals such as kaolinite, and the pores and fractures are not developed, and it is combined with the overlying mudstone, which has good sealing ability, the logging porosity is 1.2% ~ 5.9%, with an average of 2.7%, but the thickness is relatively thin. Weathering leaching layer has strong dissolution, clay mineral filling and metasomatic filling are weak. Core observation is mostly high angle open fractures, fracture density is about 13-46 pieces/m, multiple groups of fractures are distributed in network and connected with each other, developed catacaustic intergranular pores, dissolution pores in feldspar crystal, iron oxide surface can be seen, and gas bearing property is continuous and stable; well logging curve shows that gamma value is distributed between high and low phases, and supplement The logging porosity is 0.4% ~ 6%.

Figure 2. Structural diagram of longitudinal zoning of weathering crust

Aiming at the poor quality of bedrock seismic data, in order to improve the weak signal, signal-to-noise ratio and highlight the characteristics of wave group, the key technologies of seismic data processing were developed. Five matching technologies of fidelity processing for bedrock interior seismic imaging, including wavelet frequency division noise attenuation, were established. The signal-to-noise ratio, imaging quality of complex structures and imaging accuracy of fault system of new data were greatly improved. The weathering crust reservoir and internal structure are well imaged. According to the characteristics of weathering crust with one strong (continuous, medium strong amplitude) and three low (low density, low velocity and low wave impedance) characteristics in seismic, the bottom interface of weathered crust is traced and interpreted. The comprehensive attribute analysis such as petrophysical analysis, wave impedance inversion profile and spectrum inversion is used to predict the reservoir thickness of 90~330m.

4. Major discoveries and technical methods of bedrock exploration
Lp1 well has obtained high-yield industrial gas flow in bedrock weathering crust, and its trial production has stable production capacity with cumulative gas production of 1.69 million cubic meters.
It has opened the prelude of bedrock gas risk exploration and has great strategic significance. It is not only an important milestone in bedrock natural gas exploration in northern Songliao Basin, but also has an important enlightenment for promoting natural gas exploration in new areas and new fields of the basin. The exploration of bedrock natural gas in northern Songliao basin has just started, and the overall research understanding and exploration degree are at a low level, which needs continuous research. The exploration breakthrough of Lp1 well has strengthened the determination and confidence to change exploration ideas and expand new exploration fields (Fig.3).

In the process of risk exploration, according to the practical results of bedrock exploration in the central paleouplift belt in recent years, the successful experience of other basins, combined with the characteristics of bedrock gas reservoir in central paleouplift belt, a set of technical methods suitable for bedrock reservoir exploration in central paleouplift belt are preliminarily summarized. Fidelity seismic imaging technology: in order to improve weak signal, signal-to-noise ratio and imaging quality, and highlight wave group characteristics, bedrock seismic processing technology has been carried out to form fidelity seismic imaging technology. The signal-to-noise ratio, imaging quality of complex structures and imaging accuracy of fault system have been greatly improved, which has laid a foundation for the recognition of paleo uplift structure and lithologic control reservoir.

**Figure 3. Seismic reflection characteristics of weathering crust**

Bedrock weathering crust structure model and reservoir prediction technology: combined with core, logging, imaging and seismic attribute data, combined with macro and micro, starting from point, line and surface, the weathering crust structure model and reservoir prediction technology are established. It is clear that weathering and leaching layer is an important exploration direction, and the thickness of weathering crust is expanded from less than 100 m to 300 m, which changes the previous ideas that weathering crust surface content gas, which has effectively guided the deployment of horizontal wells to increase production. The Lp1 well has obtained $11.5 \times 10^4$ m$^3$ of industrial gas flow, and the bedrock weathering crust has made a major exploration breakthrough.

Comprehensive evaluation technology of bedrock gas reservoir: according to the reservoir forming mode of new bedrock ancient reservoir in central paleouplift belt, the comprehensive evaluation technology of bedrock gas reservoir was established, and the new understanding of ‘lateral hydrocarbon supply, overall gas content, unconformity and fault dredging, reservoir control was put forward, and the reservoir forming mode of new bedrock ancient reservoir and lateral migration was
established. The resource amount was $113.35 \times 10^8$ m$^3$, and five risk exploration wells were deployed. There are 2 commercial gas wells and 2 low production gas wells, which effectively support the exploration deployment.

5. Conclusion
The bedrock has the conditions to form large-scale gas reservoirs. The relationship between source and reservoir determines that the bedrock has a 'new bedrock ancient reservoir, lateral migration reservoir forming mode. The hydrocarbon supply window and transport system control the formation of bedrock oil and gas reservoir. Unconformity surface and fault connect the reservoir and source rock. This understanding shows that gas reservoir can be formed not only in weathering crust near source rock, but also inside of bedrock and bedrock block far away from hydrocarbon generating centre. In order to obtain a larger discovery, a set of suitable technical methods is needed to guide exploration. The application of fidelity seismic imaging technology, bedrock weathering crust structure model and reservoir prediction technology, bedrock gas reservoir comprehensive evaluation technology and horizontal well large-scale volume fracturing technology are the key technologies for bedrock exploration in central paleo uplift belt. Applying these technologies and methods will help to make greater breakthroughs in the exploration of bedrocks and lay a solid theoretical foundation for the breakthrough of risk exploration.

6. Reference
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