Discovery of Marine-terrestrial Transitional Facies Shale Gas in Taiyuan Formation of Zhenjia 1 Well, Northern Shaanxi, Ordos basin

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Objective

At present, there is controversy regarding the existence of marine-terrestrial transitional facies that can act as a source of shale gas. This detailed study of Carboniferous-Permian age geological data from the northern Shaanxi area (China) provides new insight for this type of shale gas. In addition, a new deposition and accumulation pattern for this type of shale gas is established. Thus, the objectives of this study were to identify high quality gas-bearing shale intervals in the lithological column of the marine-terrestrial transitional facies from the Zhenjia 1 well (ZJ-1) and obtain high-yield shale gas. We hope these results can give a direction of a new field and strata for shale gas surveys in northern China.

Methods

The detection logging data of ZJ-1, as well as organic petrology and rock physical data of adjacent wells and regional paleogeographic information, were used to predict a series of gas-bearing shale strata of ZJ-1 and select high-quality shale intervals for fracturing and gas tests, under the direction for the new deposition-accumulation pattern of "lagoon" shale gas with proto-generation and proto-preservation of marine-terrestrial transitional facies (Fig. 1). New techniques for reforming transitional facies of shale reservoirs, such as the adoption of "fracturing by small displacement, carrying proppant through low viscosity fluid by high displacement and with medium transformation level, liquid nitrogen injection in the whole process, and rapid flowback", were used to fracture the shale intervals. To obtain daily production data from a single interval of ZJ-1, the "one point method" was used to calculate yield, according to the "Interpretation standard for oil and gas test of exploratory well" (SY/T 6292-2008).

Results

In the middle of the eastern Ordos Basin, Carboniferous-Permian dark shales with some thin interbedded sand layers or lenses (sweet spots) are widely developed in lagoon facies that are rich in brittle terrestrial clastic mineral grains. An abundance of organic matter was present in the saline lagoon environment during deposition. The kerogen is mainly humic (type III) with high gas generation potential. Thus, it is likely there is large resource potential in the lagoon facies, which means that a new deposition-accumulation pattern for "lagoon" shale gas with proto-generation and proto-preservation of marine-terrestrial transitional facies in the middle of the eastern Ordos Basin can be established (Fig. 1). As a result, two new lagoon strata containing shale gas (Fig. 2) are found in ZJ-1: 2365–2421 m of the Benxi-Taiyuan Formation (56-m-thick) with an average gas logging value of 11.31%, and the lower Shanxi Formation (2267–2317 m, 50-m-thick) with an average gas logging value of 9.09%. The Tai-2 member (2365–2390 m, 25-m-thick, Fig. 2) contains the best conditions for shale gas production. The lithology is mainly gray-black sand-bearing or sandy shales with entrained black carbonaceous shales, coal, thin sandstones or lenses. The net thickness of sand-bearing or sandy shales is 18 m with a mud ratio of 72%. The Taiyuan Formation dark shales, measured from adjacent wells, contain about 33.5%–45% brittle particles, 1.71%–4.8% total organic carbon (TOC), and have vitrinite reflectance values (Ro) of 0.5%–2.51% (average of 1.5%). These data indicated that the Tai-2 member reached shale gas economic exploitation standards, and so it was the preferred target interval for fracturing and gas tests.

Vertical well and single interval fracturing and gas tests were carried out on the selected high-quality dark shale
Fig. 1. The new deposition-accumulation pattern for "lagoon" shale gas with proto-generation and proto-preservation of marine-terrestrial transitional facies in the middle-east part of Ordos Basin.

Fig. 2. Comprehensive logging map showing the fracture and gas test intervals, and ignition of the Zhenjia 1 well.

section in Tai-2 member. At 3:00 a.m. on 12 November 2016 when the fracturing fluid flowback rate was about 17%, ignition was successful and the stable height of the flame was 6–8 m (Fig. 2). The production was measured normatively for a continuous 24-hr period on 20–21 November. As a result, the wellhead production was $5.66 \times 10^4$ m$^3$/d and the open flow value was $11.35 \times 10^4$ m$^3$/d, which indicated that high-yield industrial shale gas flow in this new field was obtained for the first time. Ignition and blowout lasted for 53 days with the gas increasing from the first ignition on 12 November to the artificial pressure and plugging of the well on the afternoon of 5 January 2017.

Conclusions

This paper presents new insight for the great potential resource of shale gas in marine-terrestrial transitional facies. Through the exploration practice guided by theoretical innovation, the major breakthrough of obtaining shale gas in a new field of marine-terrestrial transitional facies was realized for the first time. The breakthrough of ZJ-1 well not only sets an important example for the exploitation of the shale gas from marine-terrestrial transitional facies in Ordos basin, but also indicates the direction of expansion for shale gas surveys into new type, new areas and new strata in northern China.

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