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The Palaeoclimate and Microscopic Reservoir Characteristics of Shanxi Formation Shales from Lower Permian in Qinshui Basin

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1 Introduction

Qinshui Basin is the major coal bearing basin in China. And the main exploration target layer is Carboniferous-Permian. In recent years, not only in the coal-bed methane has made great progress, and also in the tight gas. Besides, shale gas in the Carboniferous-Permian has showed a good exploration prospect. Although Carboniferous-Permian shale in Qinshui Basin is thin of a single layer, the cumulated is large, with high organic carbon content, high-over mature stage, and good gas bearing property. What's more, data of shale gas resources in China 2011 from the Oil and Gas Resources Strategic Research Center of Ministry of Land Resources has shown that transitional facies formations occupy a certain proportion.

Main exploration in the Qinshui Basin has been focused on CBM in the past, with Carboniferous-Permian coal distribution, depositional setting, physical property ,gas-bearing ,etc, been most studied.. But in recent years, with the domestic shale gas exploration and development in full swing, Gu (2011) et al., amounted the geological resources to be $8607\times10^8 m^3$ by assessing Carboniferous-Permian shale gas resource potential of the Qinshui Basin, and it has shown a certain resource potential. Due to the low degree of exploration, there are only few literatures studied on shale gas geological characteristics in the Carboniferous-Permian of Qinshui Basin. Presently, less research has been put on paleoclimate environment of shale forming and shale reservoir microscope characteristics.

Through the analysis of lower permian Shanxi formation shale trace elements, rare earth elements, shale pore types and oil and gas occurrence methods in Xiao Donggou outcrops of the southern Qinshui Basin (sectional position shown in Fig. 1), and research results of the previous this article, studied the shale forming paleoclimate and microscopic characteristics as well other aspects in the Qinshui Basin. Finally, obtained some understandings, which will provide evidence to Carboniferous-Permian shale gas exploration development in the Qinshui Basin.

2 Rare-earth Element Features of Shanxi Formation Shale in Xiao Donggou Outcrop

The rare earth element abundances vary widely of Shanxi formation shales in Xiao Donggou outcrops, abundance between 249.96–326.00ppm, with 278.90ppm as the mean. When chondrite standardized (meteorite data standarded from Sun & McDonough, 1989), the Shanxi Formation shales are characterized enrichment of light rare earth elements and unsmooth heavy rare earth elements. As the REE distribution patterns and the upper and lower crust is completely different (Fig. 2a), indicated that deposits may not be from the earth's crust. $(La/Sm)_N$ and $(Gd/Yb)_N$ indicating light and heavy rare earth elements differentiation degree change little. Eu and Ce are significantly negative anomaly, and the values are higher than that of the PAAS Eu anomaly value (0.66). The Eu abnormal value is small between 1.12–1.61,with 1.40 as the mean ,which shows the oxygen reduction environment of the shale in the study area. The Ce anomaly value is also small, with the average 0.87, which indicats a humid climatic condition of the study area shale and a certain depth of the water.

3 Palaeoclimate Analysis of Shanxi Formation Shale in Xiao Donggou Outcrop

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Table 1 The paleoclimate indicative parameters of Shanxi argillutites in Xiao Donggou outcrop of Qinshui Basin

Outcrop site	Layer	Lithology	Sample tag	Major and trace element ratio					
				Sr/Cu	Sr/Ba	m(100*MgO/Al_2O_3)	CIA	Fe/Mn	Mg/Ca
Xiao Donggou	P_1s	greyblack shale	SX-JC-XDG-016	6.76	0.28	0.88	83.81	0.44	0.81
	P_1s	greyblack shale	SX-JC-XDG-018	5.74	0.3	0.62	86.58	0.28	0.53
	P_1s	grey mudstone	SX-JC-XDG-022	1.84	0.22	3.76	84.73	2.68	2.24
			Upper crust	11.43	0.51				
			Lower crust	13.38	1.34				

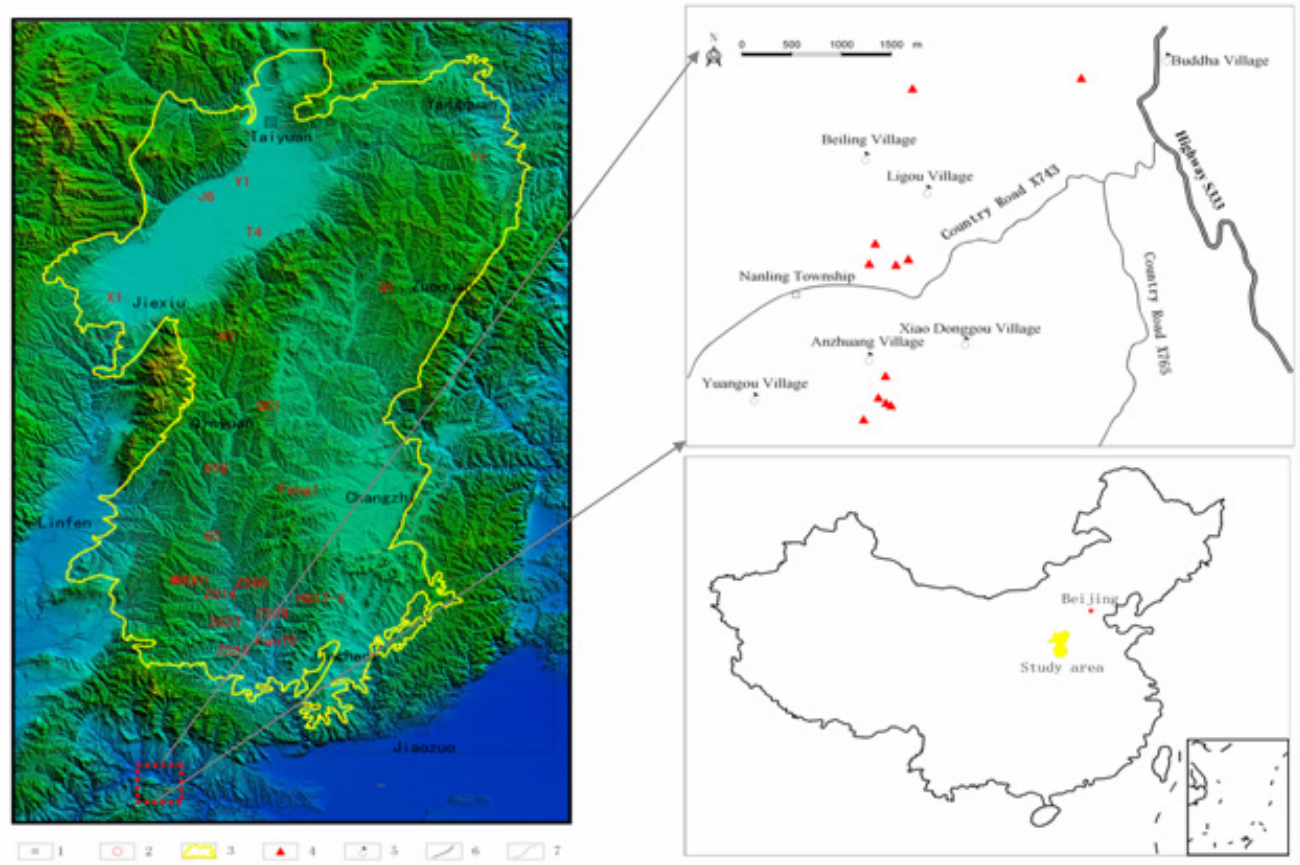

Fig. 1. Topographic map of the Qinshui Basin showing the locations of Xiao Donggou outcrops.
1, Provincial Capital, City and County; 2, wells; 3, basin boundary; 4, outcrops; 5, villages; 6, Highway; 7, Country Road.

There ara many parameters indicating paleoclimate characteristic in the element geochemistry, with Sr/Cu, Sr/Ba, m(100*MgO/Al_2O_3), Fe/Mn, Mg/Ca and Chemical modification indices(CIA) as the common ones. Constant element magnesium aluminum content ratio m (m=100*MgO/Al_2O_3) not only can be used as a judge environment indicators, but also can be a instructor on the climate action. Xerothermic climate limits the activity of magnesium. And it has low Al_2O_3 content, high water PH value and high m value. Warm humid climate improved the magnesium activity. And it has high Al_2O_3 content, low water PH value and low m value . The m value of Shanxi formation shale in Xiao Donggou outcrops is low, ranging from 0.62 to 3.77, the mean 1.75,thus reflecting the sediment deposition of humid climate (Table 1).

Paleoclimate evolution affects the distribution of elements and the change of the ratio in sediments to some extent. The Sr/Cu ratio change has become an important means to judge the paleoclimate. The Sr/Cu ratio indicates a humid climate, between 1.3 and 5.0,while greater than 5.0 shows xerothermic climate. The Sr/Cu ratio of Shanxi formation mud in Xiao Donggou section is 1.84, showing an warm humid depositional setting. And the ratio in shales is between 5.74–6.76, indicating dry, and hot depositional environment (Table 1).

Fe/Mn and Mg/Ca ratio can also indicate the ancient climate. Generally, high ratio Fe/Mn and low ratio Mg/Ca indicate humid climate. The ratio of Fe/Mn in Shanxi

formation shale of Xiao Donggou outcrops varies widely, ranging from 0.44 to 2.68, 0.53 to 2.24, respectively, thus indicating warm humid climate (Table 1).

Chemical weathering is often affected by ancient climatic conditions. Through the study of ancient weathering can instruct the ancient climate change. The CIA value of Shanxi formation shale in Xiao Donggou outcrops is between 83.81 and 86.58 (Table 1).According to Nesbitt (1982) , chemical alteration index (CIA) can be used to distinguish the degree of chemical weathering, we can see that the study area suffered strong chemical weathering.

From triangular diagram Al_2O_3-(Na_2O+CaO*)-K_2O (Fig. 2b), Shanxi formation shale samples in Xiao Donggou outcrop are at the end of dashed arrow direction ,and the angle is small between the solid and dashed line, which indicated that the study area suffered mainly chemical weathering, and then was less affected by potassium metasomatism. Therefore, it can be inferred provenance may be in a period of warm and humid weather conditions during the Shanxi formation sedimentation.

In summary, the anomalous value Eu and Ce of the rare earth elements, indicated Shanxi formation shale formed under warm and humid climatic conditions, and the water has a certain depth of sedimentary environments. The provenance of sediments is warm and humid weather conditions, which is conducive to hydrocarbon source rocks. But the study area suffered strong chemical weathering during the deposition of the Shanxi formation. In addition, the analysis of rock thin section also shows that the Shanxi formation shales are subjected to intense weathering (Fig. 3B).

4 Microscopic Characteristic of Shale Reservoirs

Rock slice analysis showed in Shanxi formation shale of Xiao Donggou outcrops rock compositions are mainly clay minerals, containing higher fine-siltstones (Figure3A). In addition, clay minerals and organic matter oriented irregular strip development, and the Shanxi formation shales have high organic matter content (Figure3A,C). The Shanxi formation shale reservoirs are overall dense. By the environmental scanning electron microscope, a lot of intercrystalline pores in clay minerals are seen (Figure3D,E,F). The micron-nanometer pores and secondary dissolution pores are often found in fine sandstones interbedded Shanxi formation shale (Fig. 3F). And the fine sandstones have high organic matter content (Fig. 3C). Gu et al., (2011) thought that the Shanxi formation shales have high TOC content in Qinshui Basin, and the organic matter abundance of the Shanxi formation shales is substantially above 2.0, up to 8.0.According to field analytical gas quantity of the Carboniferous-Permian shale gas, the Shanxi formation shale gas in Qinshui Basin has certain resource exploration prospects.

5 Conclusions

1) The abnormal value of the Eu and Ce in rare earth elements indicated Shanxi formation shales formed under warm and humid climatic conditions, and the water has a certain depth. The provenance of sediments is located in warm and humid weather conditions, which was conducive to hydrocarbon source rocks. But the study area suffered strong chemical weathering during the deposition of the Shanxi formation. In addition, the analysis of rock thin section also shows that the Shanxi formation shales are subjected to intense weathering.

2) Rock slice analysis showed rock compositions are mainly clay minerals in Shanxi formation shale of Xiao Donggou outcrops, also containing higher fine-silt sandstones. In addition, clay minerals and organic matters were irregular strip directional arrangement, and the Shanxi formation shales have high organic matter content.

3) The Shanxi formation shale reservoirs are dense. By observing the environmental scanning electron microscope, a lot of intercrystalline pores in clay minerals are found. The micron-nanometer pores and secondary dissolution pores are often seen in fine sandstones interbedded Shanxi formation shales. And the fine sandstones also have high organic matter content.

4) The Shanxi formation shales of the Xiao Donggou outcrops formed in warm and humid weather conditions, in which high abundance shales are developed. And the gas-bearing properties of the shales are better. A large number of micron-nanometer pores and secondary dissolution pores in shales are observed by the scanning electron microscope, which indicated good shale reservoir conditions. This further confirms Shanxi formation shale gas have certain resource prospects in Qinshui Basin.

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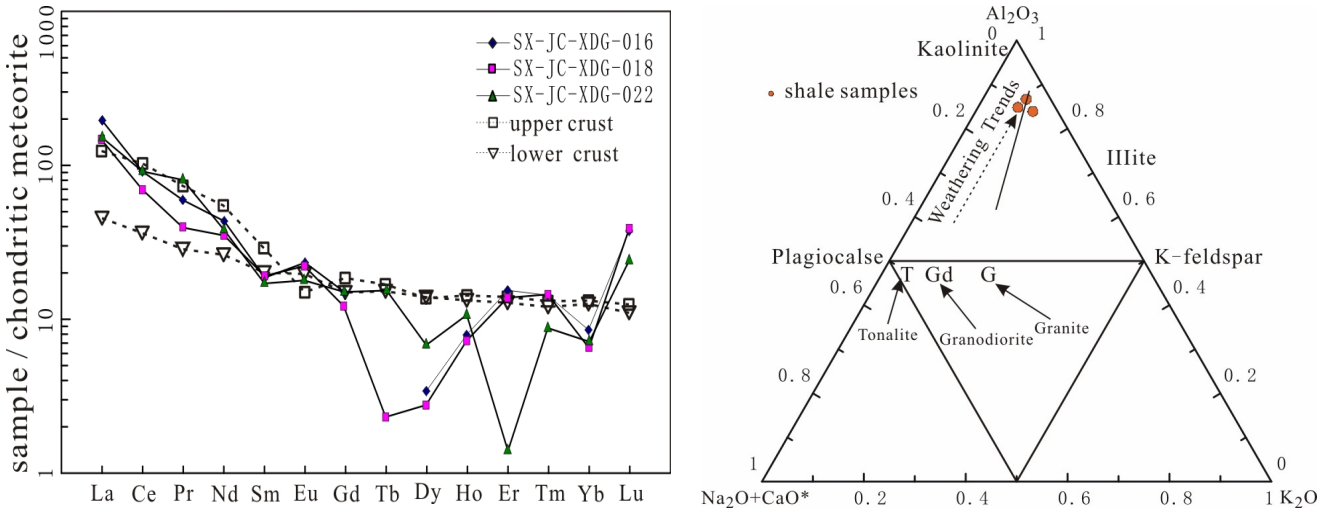

Fig. 2. Chondrite-normalized REE distribution patterns of Shanxi shales in Xiao Donggou outcrop of Qinshui Basin (a) and The Al_2O_3 -(Na_2O+CaO*)-K_2O plot of shales in Shanxi formation of the Xiao Donggou outcrops (b).

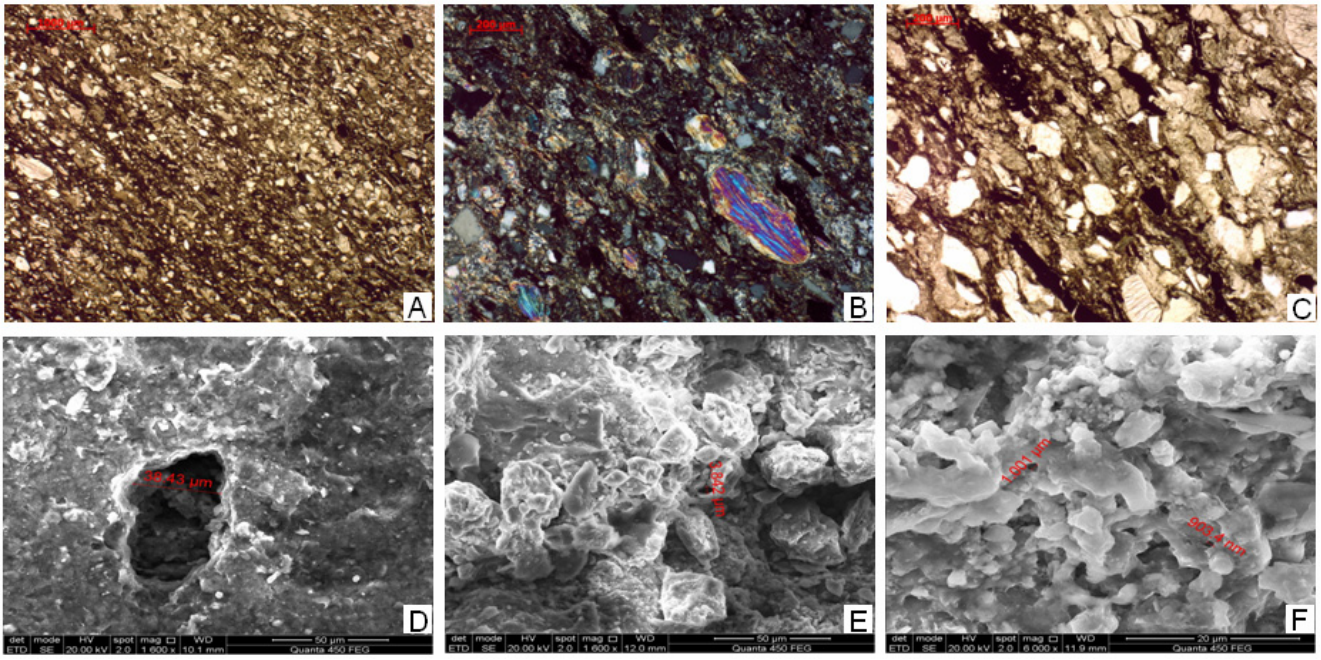

Fig. 3. Photos showing different pores features in the lower permian Shanxi formation shales of Xiao Donggou outcrops.
(A) clay minerals and organic matters oriented irregular strip development in thin-sections. (B) Samples weathering strong and high muscovite content in thin-sections. (C) high silt-fine sand contents in shales, and visible organic matter. (D) many intragranular pores are seen in smectite by environmental scanning electron microscope(ESEM). (E) Intracrystalline pores development among illite mixed layers by ESEM. (F) Intracrystalline pores development in chlorites by ESEM.

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