Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal
of Earth Sciences
and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 02

April 2016, P.P.759-766

Gas-Bearing System Classification and Gas Reservoir Formation Characteristics for Unconventional Natural Gas of Upper Paleozoic in Ordos Basin

HAIPENG YAO[1,2,3] AND YANMING ZHU[1,2]

[1]*School of Resource and Geosciences, CUMT, Xuzhou, Jiangsu 221008, China*

[2]*Key Laboratory of Coalbed Methane Resources and Reservoir Formation Process, CUMT, Xuzhou, Jiangsu 221116, China*

[3]*Coal Geological Bureau of the Inner Mongolia Autonomous Region, Hohhot 010010, China*

***Email:** yaohp_cumt@sina.com*

Abstract: Coal seams, organic shale, and sandstones undergo vertical interbedded development in coal-bearing strata of Upper Paleozoic in Ordos Basin. Based on the sedimentary background analysis of research areas, and in combination with comparison of gas isotope, gas measurement and hydrology, the paper comprehensively analyzed the gas-bearing system classification for unconventional natural gas of Upper Paleozoic in Ordos Basin. Through an in-depth analysis of gas-bearing property and reservoir physical property of various gas-bearing systems, the paper also expounded gas reservoir formation characteristics for unconventional natural gas of Upper Paleozoic in the research areas. Results showed that the gas-bearing systems of Upper Paleozoic in Ordos Basin were divided into the shale gas-bearing system in Member 1 of Taiyuan Formation and the mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation. The shale was the type of gas source rock of the shale gas-bearing system in Member 1 of Taiyuan Formation, with an average organic matter content of 3.3% and an average gas amount of $5m^3/t$. There was a high content of brittle minerals in the reservoir and a relatively developed micro-fracture. It was characterized by “low porosity, low permeability, and low gas saturation” on the whole. Coal seams and shale were the main types of gas source rock of the gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation, of which the coal seams had an organic matter content of 22.32%～81.51% and a gas amount of 17 m^3/t, and the shale had an organic matter content of 0.04%～2.73% and an average gas amount of 3 m^3/t. The main reservoir contained coal seams, dark shale, and tight sandstones, and was characterized by “low porosity and low permeability” on the whole. The shale in Member 2 of Xiashihezi Formation and in Shangshihezi Formation presented itself as regional cap rock that had a continuous planar distribution and a good sealing ability, and whose thickness was from 50m to 200m. The unconventional natural gas reservoirs in the research areas were mainly divided into the in-source combination gas reservoir in Member 1 of Taiyuan Formation and the mixed-source combination gas reservoir in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation.

***Keywords:** Unconventional natural gas; gas-bearing system; gas reservoir formation characteristics; Ordos Basin*

1. Introduction

The shale gas reservoirs of coal measures, the coal seam gas reservoirs, and the tight sandstone gas reservoirs are subordinate to continuous gas accumulations [1] that are characterized by in-source or near-source gas accumulations, vague boundaries of traps, and development in large-area unconventional reservoir systems as well. The Ordos Basin is one of the crucial bases for exploration and development of energy mineral sources (such as petroleum and coal) in China. Among state energy basins, the Ordos Basin has the maximum amount and highest degree of exploration and research in terms of coals, coal measures and other unconventional natural gas reservoir. However, such problems still exist in the northern areas of the Ordos Basin that there is great heterogeneity in present exploration degrees and geological recognition degrees and that the distribution rules and exploration directions of unconventional natural gas remain unclear. In light of previous studies and the author’s preliminary studies, a great deal of research work has been conducted on unconventional natural gas reservoirs in northern areas of the Ordos Basin [2-8], which emphasizes on analysis of typical tight sandstone’s gas reservoir formation characteristics, gas reservoir formation conditions, and predominant factors of gas reservoir formation, and on resource potential evaluation of shale gas and coalbed gas. However, there still lacks comprehensive research on the shale gas reservoirs, the coal seam gas reservoirs, and the tight sandstone gas reservoirs as a whole according to the characteristics that the three of them are considered as one continuous gas accumulation. Therefore, on the basis of existing exploration discovery and the in-depth research on the gas reservoir formation conditions and gas accumulation processes for unconventional natural gas, the paper undertook systematic analysis and summarization on both the development intervals and gas reservoir formation characteristics of unconventional natural gas in northern areas of the Ordos Basin. This is of great significance to deep recognition of distribution rules of unconventional natural gas in the research area and to identification of the next advantageous exploration direction as well [9].

2. Geological background:

The integrity of asymmetric and monoclinal structure and formation of the northern areas of the Ordos Basin has a nearly SN trend and a W tendency. The main bases of the research in the paper are relative experimental data (Organic carbon content test, Organic matter maturity test, High pressure mercury intrusion test, Low temperature liquid nitrogen test, Scanning electron microscope test, Water quality analysis test), borehole logging (SY/T°6161-2009), and logging data (SY/T°5788.2-2008) from EY-1 Well that is located at Yishan Slope in the northern areas of the Ordos Basin (Figure 1). The borehole logging reveals that the main developments of the research areas from bottom to top are in Ordovician, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and the Quaternary period, when the development of coal seams is mainly in Permian-Carboniferous and Jurassic. The research objective in the paper is coal measures and adjacent to the oil and gas storage set layer in Permian-Carboniferous.

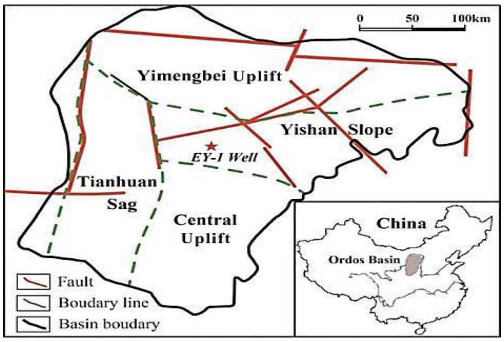

Figure 1: *Location and regional structures of the north of Ordos Basin*

The coal-bearing strata of Permian & Carboniferous in research areas have a stable development and a continuous planar distribution. Taiyuan Formation has a depth of 40～80m and a burial depth interval of 2800~3500m; the depth of Shanxi Formation is 50~100m and the depth of Xiashihezi Formation 40.7~71m. The three groups of reservoir have complicated lithologic components, the main of which are pebbly sandstone, grit, fine sandstone, silt mudstone, mudstone, and interbedded coal seal compositions with different thickness. With No.9 coal seal floor as the boundary, Taiyuan Formation was divided from bottom to top into Member 1 of Taiyuan Formation (C_2t^1) and Member 2 of Taiyuan Formation (C_2t^2). With No.5 coal roof mudstone as the boundary, Shanxi Formation was divided from bottom to top into Member 1 of Shanxi Formation (P_1s^1) and Member 2 of Shanxi Formation (P_1s^2). The marker bed that was characterized by the combination of the bottom pebble sandstone with the thickness of 10m and the top mudstone with the same thickness, the Xiashihezi Formation was divided from bottom to top into Member 1 of Xiashihezi Formation (P_2x^1) and Member 2 of Xiashihezi Formation (P_2x^2) (Figure 2).

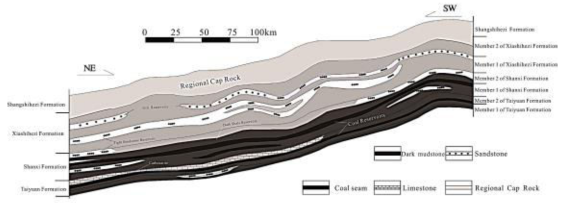

Figure 2: *The sketch map of the lithologic combination in Permian-Carboniferous in the north of Ordos Basin*

3. Unconventional gas-bearing system partition of coal measures:

Based on the concept of independent petroleum system that was proposed by Ulmishek in 1986 [10], Qin Yong et al. put forward the concept and connotation of multiple superimposed CBM system [11]. Conditions were good for source rocks, reservoir rocks, traps, and regional cap rock composition of the coal strata in Permian-Carboniferous in the research areas [12-14]. Controlled by multi-phase tectonics and lithologic combination, the generated unconventional natural gas under such conditions was trapped effectively by the regional cap rock in Member 2 of Xiashihezi Formation and the bottom of Xiashihezi Formation and thus formed a gas-bearing system with multi-layer coupling gas reservoir [15].

From the perspective of sedimentary environment, Taiyuan Formation in the research areas was a set of marine-terrestrial depositional system, where Member 1 of Taiyuan Formation was a tidal-flat depositional system of dark shale and sandstone. As seawater continued to regress out of the research areas, the depositional environment transited gradually from marine-terrestrial transitional facies to continental facies. This was the reason why the delta-plain facies depositional system was the main feature of Member 2 of Taiyuan Formation ~ Member 2 of Shanxi Formation, with a development of coal seams, dark shale, and sandstone. Till middle Permian, the research areas were mainly featured by continental facies depositional system, and the Xiashihezi Formation was the braided delta-plain facies depositional system with an interbedded development of thick mudstone and sandstone (Figure 3).

From the perspective of gas carbon isotope, the abundance of gaseous methane carbon isotope in

Member 1 of Taiyuan Formation was -15.453‰; the abundance of gaseous methane carbon isotope in the bottom of Member 1 of Taiyuan Formation was -35.11; and the abundance of gaseous methane carbon isotope in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation was -31.517‰~-43.929‰ (Figure 3). Due to the difference of prominent between the abundance of gaseous methane carbon isotope and depositional environment in Member 1 of Taiyuan Formation and that in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation, it was considered that Member 1 of Taiyuan Formation and Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation were two independent gas-bearing systems [22, 23].

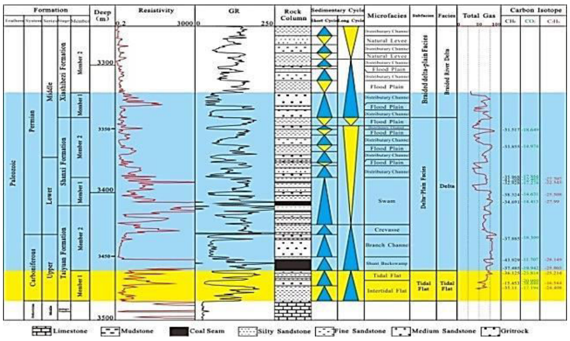

***Figure 3:** Gas-bearing system partition and characteristics in EY-1 Well*

In the research areas, for Member 1 of Taiyuan Formation, the PH value was 7.2, the concentration of Cl^- 1690 mg/L, the concentration of K^++Na^+ 3213 mg/L, the concentration of Ca^{2+} 371 mg/L, the concentration of HCO_3^- 21.66 mg/L, and the total degree of mineralization 0.93 g/L; for Shanxi Formation ~ Xiashihezi Formation, the PH value was 5.0~6.0, the general concentration of Cl^- between 18200~41109 mg/L, the concentration of K^++Na^+ 4540~9592 mg/L, the concentration of Ca^{2+} 5780~13911 mg/L, the concentration of HCO_3^- 76.9~201 mg/L, and the total degree of mineralization 29.12~65.34 g/L; For Majiagou Formation, the PH value was 6.0, the general concentration of Cl^- between 31376~32603 mg/L, the concentration of K^++Na^+ 9075~9114 mg/L, the concentration of Ca^{2+} 6814~7615 mg/L, the concentration of HCO_3^- 578~1115 mg/L, and the total degree of mineralization 50.99~54.92 g/L (Table 1). On the whole, the PH value of Member 1 of Taiyuan Formation was larger than that of the aquifer systems in upper and lower reservoirs, but the total degree of mineralization and other ions concentration of Member 1 of Taiyuan Formation were lower than that of the aquifer systems in upper and lower reservoirs. Therefore, it could be seen that Member 1 of Taiyuan Formation, Shanxi Formation ~ Xiashihezi Formation, and Majiagou Formation were subordinate to different underground aquifer systems.

***Table 1:** Summary sheet of underground water quality characteristics of Upper Paleozoic in the research areas [16]*

Well No.	Layer position	PH	K^++Na^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Ba^{2+} (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	total mineralization g/L)
E11	P_2x	6.0	6151	12115	60	207	31134	0	107	49.77
E6	P_2x	5.0	9592	13911	612	0	41109	0	115	65.34
S57	P_2x	6.0	8400	11900	110	326	34500	0	76.9	55.31
E12	P_1s	6.0	7879	10058	484	0	30102	1531	201	50.26
S164	P_1s	6.0	8340	10271	603	0	31536	1588	127	52.47
S43	P_1s	6.0	4540	5780	334	100	18200	0	165	29.12
EY-1	C_2t^1	7.2	3213	371	54.77	0	1690	3968	21.66	0.93
S2	O_2m	6.0	9114	7615	2473	0	32603	2001	1115	54.92
S2	O_2m	6.0	9075	6814	2189	0	31376	961	578	50.99

Through a comprehensive analysis of the sedimentary environment, the gaseous carbon isotope characteristics in EY-1 Well, and the regional underground water quality characteristics in the research areas, it could be found that Member 1 of Taiyuan Formation was an independent underground energy system with distinct characteristics from the upper and lower reservoirs. Meanwhile, according to the gas logging total hydrocarbon curve of EY-1 Well, Upper Paleozoic in the research areas showed apparent gas logging characteristics, denoting that there was exceptionally abundant unconventional natural gas resources. Therefore, the paper held it that the unconventional natural gas system of Upper Paleozoic in the research areas should be divided into two independent systems: the shale gas-bearing system in Member 1 of Taiyuan Formation and the mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation.

4. Characteristics of the unconventional gas-bearing system in coal measures:

4.1. The shale gas-bearing system in Member 1 of Taiyuan Formation:

(1) Gas source rock

The organic shale constituted the gas source rock in the shale gas-bearing system in Member 1 of Taiyuan Formation. Vertically, it was located at the bottom of No.9 coal seam floor of Taiyuan Formation, with the maximum single-floor thickness of 14m and the accumulated thickness of 30m. According to the test results of EY-1 Well, the general type of Kerogen in dark shale was Type III; the vitrinite reflectivity (R_o%) was between 1.30%~1.66%, with the average value of 1.52% [17-19] (Figure 4), denoting that the vitrinite was at the mature ~ highly-mature stage; the organic carbon content of dark shale was between 1.45%~7.33%, with the average value of 4.73% (Figure 5). The gas logging results showed that there was a high hydrocarbon gas content, and that the measured total hydrocarbon value was between 2.6%~ 12.1% under the coring state, whose value was generally above 7% [20]. The on-site desorption test showed that the gas content of dark shale was between 3.8~6.9m^3/t, with the average value of 5m^3/t.

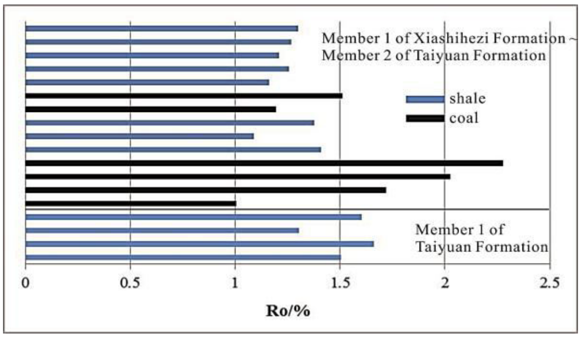

Figure 4: *Thermal evolution characteristics of the organic matter in the gas source rock*

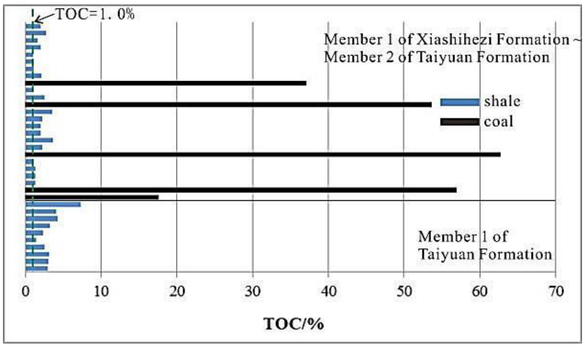

Figure 5: *Characteristics of the organic matter content of the gas source rock*

(2) Reservoirs

The organic shale is both the gas source rock and the reservoir, where the gas occurs in the shale mainly at the absorption state and the Free State but slightly at the dissolved state; and the gas occurs in the tight sandstone mainly at the Free State. The reservoir lithologic composition is a set of black carbonaceous shale, black silt sandstone, and siltstone, with a local mixture of pebbly sandstone. Brittle minerals in the shale are in high content: the content of quartz is 6.4%~55%, with an average value of 25.79%; the content of clay minerals is around 42.44%~84%, with an average value of 62.63%（Figure 6）, where illite and kaolinite account for 76%~83% as the predominant components, with an average value of 80% (Figure 7). According to the results of mercury intrusion porosimetry [21], the main pore sizes for this formation in the research areas are either less than 100nm or above 10000nm to the advantage of gas occurrence at the absorption state and the free state [22, 23] (Figure 8). The average porosity of the reservoir is 0.45%~0.92%; the fairly developed micro crack has a width of about 175.0~439.1nm; the main types of micro pores contain intercrystalline pores, corrosion pores, and organic pores [24, 25], at the pore size of 64.35~375nm (Figure 6). The permeability is 0.02×10^{-3}~0.41×10^{-3} μm^2. The general gas saturation is between 1%~ 52.5%, with the average value of 21.9%. The reservoirs in this formation in the research areas are characterized by “low porosity, low permeability, and low gas saturation” on the whole [26].

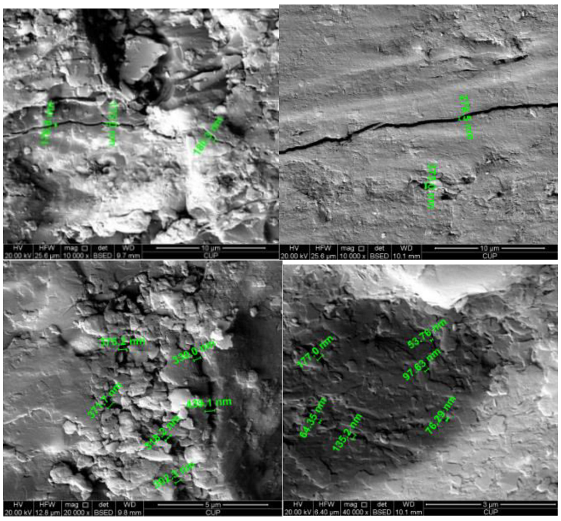

Figure 6: *The development characteristics of shale pores in the research areas*

(3) Cap rock

The 10-meter-thick shale at the upper areas of Member 1 of Taiyuan Formation was integrated by gas source, reservoirs and cap rock typically. The fact that the gas carbon isotope values in this formation (namely $\delta^{13}C_1$ at -15.453‰ and $\delta^{13}C_2$ at -16.544‰) are different from those at the upper areas of Member 2 of the Taiyuan Formation (namely $\delta^{13}C_1$ at -36.125‰ and $\delta^{13}C_2$ at 25.124‰) demonstrates that there is strong sealing ability for the top shale in Member 1 of Taiyuan Formation.

4.2. The mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation:

There is general isotopic reversal of ethane and propane carbon in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation in the research areas, namely $\delta^{13}C_2$>$\delta^{13}C_3$, from which it can be deducted that natural gas in this formation is characterized by mixed sources [27, 28]. This shows that the poor sealing ability for thin mudstone in this formation fails to help form effective separate blockage, thus different reservoirs connecting to each other and becoming a unified gas-bearing system [29].

(1) Gas source rock

Gas strata in Member 2 of Taiyuan Formation have a wide and stable distribution across the research areas. There are generally 4~10 coal seams, all of which are medium-to-high-rank metamorphic coals with the total thickness of above 12m. The maximum thickness for a single seam is 7.8m. There are 1~3 coal seams in Shanxi Formation with the thickness of between 4.5~10m. The maturity of organic matters in gas source rock is between 1.00%~2.28%, with the average value of 1.42% (Figure 4), and most of the organic matters have entered the mature ~ highly-mature stage; the content of organic matters in gas source rock is between 1.00%~62.71%, with the average value of 10.36% (Figure 5), where the main gas source rock is organic carbon in the coals with the content as high as 62.71%. The gas logging results showed that there was a high hydrocarbon gas content, and that the general measured total hydrocarbon value was above 10% under the coring state. The on-site desorption test showed that the content of coal seam gas was between 11.4~26m^3/t, with the average value of 17m^3/t, and that the content of shale gas was between 1.2~5.5m^3/t, with the average value of 3m^3/t.

(2) Reservoirs

The main reservoir types for this formation include coal seams, dark shale, and adjacent tight sandstone. There are two combination patterns for the reservoirs, namely the pattern of "self-generation and self-accumulation" and the pattern of "lower-generation and upper-accumulation". Lithologic combinations for the reservoirs are dark carbonaceous shale, sandstone, and coal seams. For mineral components in the reservoirs, the content of clay minerals is between 18.7%~67.7%, with the average value of 48.7%, where illite and kaolinite account for 47%~97% as the predominant components, with an average value of 73% (Figure 8); the content of quartz is between 30.5%~79.2%, with the average value of 46.6% (Figure 7). The main pore size in coal reservoirs is less than 100m to the advantage of gas occurrence at the absorption state. There are also general pore developments at the size of 1000nm or above 10000nm to the advantage of gas occurrence at the Free State. The porosity of the reservoir is 1.00%~6.79%, with the average value of 3.17%. The main pore sizes in shale are either less than 100m or above 10000nm; there is basically no pore at the size of between 100 ~ 1000nm (Figure 9). The porosity is between 0.51%~1.51%, with the average value of 1.02%. The general pore size for sandstone is between 5~15μm. Overall, the porosity of the reservoirs in this formation in the research areas is between 1.3%~20%, and the permeability 0.01×10^{-3}~42.7×10^{-3}μm^2. The reservoirs in this formation in the research areas are characterized by "low porosity and low permeability".

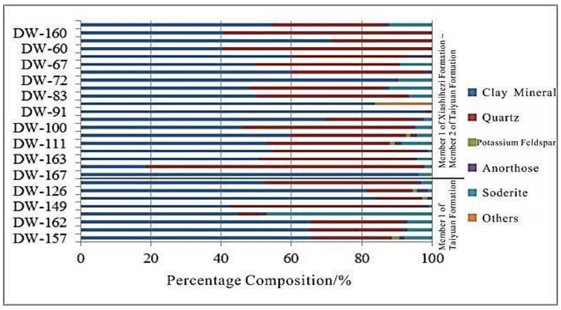

Figure 7: *Rock mineral component characteristics for the reservoirs in this formation (DW-167:coal)*

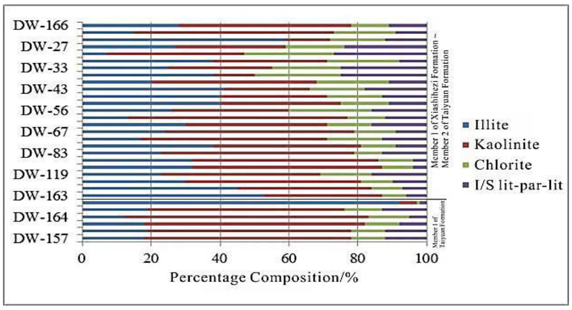

Figure 8: *Clay mineral component characteristics for the reservoirs in this formation*

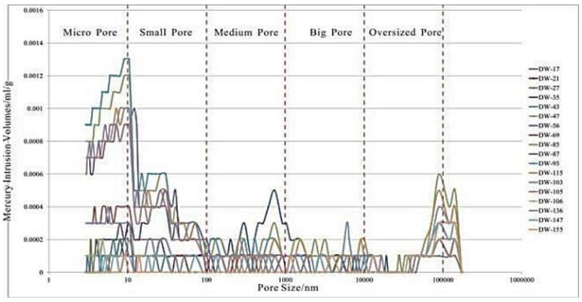

Figure 9: *Relation map between mercury intrusion volumes and pore sizes for the reservoirs in this formation in the research areas [30]*

(3) Cap rock

The main regional cap rock of the unconventional natural gas system in coal-bearing strata in Permian-Carboniferous is found to be the continuously distributed regional shale in Member 2 of Xiashihezi Formation and in Shangshihezi Formation, whose thickness is between 50~200m. According to measured data in EY-1 Well, the specific surface area of the shale in this formation is between 2.06~8.74m^2/g and the breakthrough pressure between 9.01~10.61Mpa. During the drilling, gas logging characteristics in the strata above this formation are insignificant. After breaking through the regional cap rock, the gas logging value increases rapidly, and the total hydrocarbon value/ basic value rises from 1 to above 60, demonstrating strong sealing ability.

5. Gas reservoir formation characteristics of the three types of gas reservoirs:

Given the wide and large-area hydrocarbon generation of Upper Paleozoic in the northern areas of the Ordos

Basin, it is inevitable that there is planar difference in terms of hydrocarbon generation strength. With the low permeability of lithologic strata, it is mainly the distribution of source rock that controls the distribution of unconventional natural gas [31]. In combination with such characteristics as geological structures in the research areas develop poorly, the paper conducted comprehensive analysis and research on gas reservoir formation characteristics on the basis of the shale gas-bearing system in Member 1 of Taiyuan Formation and of the characteristics of gas source rock, reservoirs, and cap rock in the mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation. On the foundation of the relations between lithologic trapping of the two gas-bearing systems and spatial positions of source rock, the coal-bearing strata of Upper Paleozoic can be divided into two types of gas reservoir characteristics: the in-source one and the near-source one. Both of them demonstrate longitudinal spatial positions and characteristics on the one hand, and the distribution relations between lithologic strata and source rock on the plane on the other hand.

Overall, gas reservoir formation combination characteristics for unconventional natural gas in the research areas can be divided into the in-source combination characteristics of “self-generation and self-accumulation” in Member 1 of Taiyuan Formation and the mixed-source combination characteristics of both “self-generation and self-accumulation” and “lower-generation and upper-accumulation” in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation. The organic shale is the hydrocarbon source rock of the shale gas-bearing system in Member 1 of Taiyuan Formation in the research areas. Most of the hydrocarbon gas that is generated by the organic shale occurs in situ at the absorption state and the free state, thus forming in-source unconventional natural gas reservoirs. Coal seams and the organic shale are the hydrocarbon source rock of the mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation. A part of the hydrocarbon gas that is generated by the organic shale occurs in situ at the absorption state and the free state, thus forming in-source unconventional natural gas reservoirs. This kind of gas reservoir combination has high gas saturation in areas such as Member 2 of Taiyuan Formation ~ Member 2 of Shanxi Formation in the research areas. With substantial increase of quantity of generated hydrocarbon by organic matters, the rest of the generated hydrocarbon gas occurs in the sandstone system in this formation at the free state, thus forming near-source unconventional natural gas reservoirs. This kind of gas reservoir combination has low gas saturation in areas such as Member 1 of Xiashihezi Formation in the research areas (Figure 10).

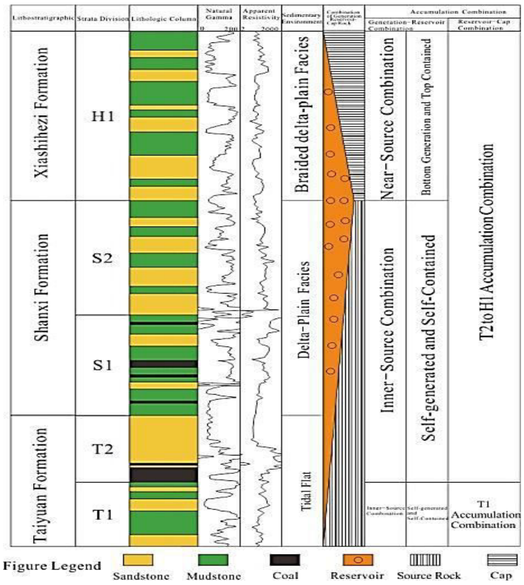

Figure 10: *Gas reservoir formation combination characteristics in Permian-Carboniferous*

6. Conclusion:

(1) Through comprehensive analysis of the sedimentary environment, the gaseous carbon isotope characteristics, and the regional underground water quality characteristics in the research areas, the paper divided the unconventional natural gas system of Upper Paleozoic in the research areas into two independent systems: the shale gas-bearing system in Member 1 of Taiyuan Formation and the mixed-source gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation.

(2) Organic shale constituted the gas source rock of shale gas-bearing system in Member 1 of Taiyuan Formation, with the maximum single-floor thickness of 14m. The organic carbon is of high content at the mature ~ highly-mature stage. There was a high content of brittle minerals in the reservoir and a relatively developed micro-fracture. It was characterized by “low porosity, low permeability, and low gas saturation” on the whole. The 10-meter-thick shale at the upper areas of Member 1 of Taiyuan Formation was integrated by gas source, reservoirs and cap rock typically.

(3) Gas source rock in the gas-bearing system in Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation is mainly coal seams and organic shale. The organic carbon in the gas source rock is of as high content as an average of 10.36%, whose organic matters are highly mature. Main components of the reservoirs in this formation in the research areas are dark carbonaceous shale, sandstone, and coal seams, being characterized by “low porosity and low permeability”. The shale in Member 2 of Xiashihezi Formation and Shangshihezi Formation is regional cap rock with strong sealing ability.

(4) The main unconventional natural gas reservoirs of Upper Paleozoic in Ordos Basin can be divided into in-source natural gas reservoirs and near-source

natural gas reservoirs. Member 1 of Taiyuan Formation has in-source combination gas reservoirs with the pattern of "self-generation and self-accumulation"; while Member 2 of Taiyuan Formation ~ Member 1 of Xiashihezi Formation has mixed-source combination gas reservoirs with the patterns of "self-generation and self-accumulation" and "lower-generation and upper-accumulation".

References

[1]Zhang S., Chen Y.J., Lv L.X., "Reservoir Characteristics of Unconventional Gas". Complex Hydrocarbon Reservoirs, 5(4): 14-18, 2012.

[2]He Z.X., Fu J.H., Xi S.L., Fu S.T., Bao H.P., "Geological Features of Reservoir Formation of Sulige Gas Field". Acta Petrolei Sinica, 24(2): 7-12, 2003.

[3]Li X.Q., Feng S.B., Li J., Wang M., Huang X.B., Wang K.D., Kong L.X., "Geochemistry of Natural Gas Accumulation in Sulige Large Field in Ordos Basin". Acta Petrologica Sinica, 28(3): 836-846, 2012.

[4]Liu S.L., Li J.M., Sun F.J., Xiao H.P., Liu R.E., "Reservoiring Mechanism of Sulige Gas Field in Ordos Basin". Natural Gas Industry, 25(3): 4-6, 2005.

[5]Wang K.D., Li X.Q., Feng S.B., Kong L.X., Xu F., Cao H.L., "Characteristics of Fluid Inclusions and Natural Gas Pool-Forming Significance of the Upper Paleozoic Reservoirs in Sulige Gas Field". Natural Gas Geoscience, 22(6): 961-968, 2011.

[6]Yang H., Fu J.H., Liu X.S., Fan L.Y., "Formation Conditions and Exploration Technology of Large-Scale Tight Sandstone Gas Reservoirs in Sulige". Acta Petrolei Sinica, 33(1): 27-36, 2012.

[7]Kang Y.L., Zhang H., Chen Y.J., Li Q.G., You L.J., Cheng Q.J., "Comprehensive Research of Tight Sandstones Gas Reservoirs Stress Sensitivity in Daniudi Gas Field in Ordos Basin". Natural Gas Geoscience, 17(3):335-338, 2006.

[8]Ma Z.G., Zhang J.Q., Cai Y.H., Li C.C., "Study on Gas Identification Factor of Tight Sandstones Reservoirs in Lower Shihezi Formation From Daniudi Gas Field in Ordos Basin". Geophysical Prospecting for Petroleum, 51(4): 414-418, 2012.

[9]Zhao M.J., Lu X.S., Zhuo Q.G., Li Y., Song Y., Lei G.L., Wang Y., "Characteristics and Distribution Law of Hydrocarbon Accumulation in Kuqa Foreland Basin". Acta Petrolei Sinica, 36(4): 395-404, 2015.

[10]Ulmishek G. "Stratigraphic aspects of petroleum resource assessment [A]. In: Rice D D, ed. Oil and gas assessment-methods and applications". AAPG Studies in Geology, 21: 59-68, 1986.

[11]Qin Y., Xiong M.H., Yi T.S., Yang Z.B., Wu C.F., "On Unattached Multiple Superposed Coalbed-Methane System: in a Case of the Shuigonghe Syncline, Zhijin-Nayong Coal Field in Guizhou". Geological Review, 54(2): 65-69, 2008.

[12]Wang S.C., Zhou Q.F., "Origin and Intension of Concept in Petroleum System". Oil and Gas Geology, 21(3): 279-282, 2000.

[13]Li Y.Y., Lin W.C., "Generation and Evolution of Carboniferous Petroleum System in Eastern Sichuan Basin". Journal of Southwest Petroleum Institute, 21(1): 35-38, 1999.

[14]Zhu H.Q., Meng X.L., "Analyzing the Characteristics of Petroleum System in Yancheng Sag". Natural Gas Industry, 24(2): 18-21, 2004.

[15]Qin Y., Shen J., Wang B.W., Yang S., Zhao L.J., "Accumulation Effects and Relationship of Deep Coalbed Methane". Acta Petrolei Sinica, 33(2): 48-54, 2012.

[16]Dou W.C., Liu X.S., Wang T., "The Origin of Formation Water and the Regularity of Gas and Water Distribution for the Sulige Gs Field in Ordos Basin". Acta Petrolei Sinica, 31(5): 767-773, 2010.

[17]M. Gnaneswara Reddy. "Effects of thermophoresis, Viscous dissipation and joule heating on steady mhd heat and mass transfer flow over an inclined radiative isothermal permeable surface with variable thermal counductivity", International journal of heat and technology, 30(1):99-108, 2012.

[18]N.T. Eldabe, E.M.A. Elbashbeshy, T.G. Emam, E.M. Elsaid. "Effect of thermal radiation on heat transfer over an unsteady stretching surface in a micropolar fluid with variable heat flux", International journal of heat and technology, 30(1):93-98, 2012.

[19]Wang X.H., Jiao Y.L., Niu Y.C., Yang J., "Study on enhanced heat transfer features of nano-magnetic fluid heat pipe under magnetic field", International journal of heat and technology, 33(1):137-144, 2015.

[20]Dong Y., Wu C.S., Lv Q.H., Li H.K., Guo H.M., "Study of CO2 fluid density calculation model based on grayscale image". International journal of heat and technology, 33(1):161-166, 2015.

[21]Xie X.Y., Tang H.M., Wang C.H., "Contrast of nitrogen adsorption method and mercury porosimetry method in analysis of shale pore size distribution". Natural Gas Industry, 26(12): 100-102, 2006.

[22]Chalmers, G R L, Bustin, R M. "The organic matter distribution and methane capacity of the Lower Cretaceous strata of northeastern British Columbia", International Journal of Coal Geology, 70(1-3), 223-239, 2004.

[23]Zhong L.W., Zhang H., Yuan Z.R., Lei C.L., "Influence of specific pore area and pore volume of coal on adsorption capacity". Coal Geology & Exploration, 30(3): 26-29, 2002.

[24]Choquette P W, Pray L C. "Geologic nomenclature and classification of porosity in sedimentary carbonates". AAPG Bulletin, 54(2): 207-244, 1970.
[25]Pittman E D., "Diagenesis and productive capability of sandstone reservoirs". AAPG Bulletin, 26: 159-173, 1979.
[26]Samuel O. Adesanya. "Steady magnetohyrodynamic visco-elastic heat generating/absorbing slip flow through porous medium with radiation effect", International journal of heat and technology, 30(1):69-74, 2012.
[27]Hong F., Song Y., Zhao L., "Controlling Factors of Gas Reservoir Formation in the North of Ordos Basin". Natural Gas Industry, 18(5): 22-25, 1998.
[28]Wang M.J., He D.F., Bao H.P., Lu R.Q., Gui B.L., "Upper Paleozoic Gas Accumulations of the Yimeng Uplift in Ordos Basin". Petroleum Exploration and Development, 38(1): 30-39, 2011.
[29]Shen Y.L., Qin Y., Guo Y.H., Ren H.Y., Wei Z.H., Xie G.L. "The Upper Permian Coalbed Methane Bearing System and its Sedimentary Control in Western Guizhou". Geological Journal of China Universities, 18(3): 427-432, 2012.
[30]Zhong T.X., "Characteristics of pore structure of marine shales in South China". Natural Gas Industry, 32(9): 1-4, 2012.
[31]Feng Q.H., "The Characteristics of Sandstone Reservoir and Gas Accumulation in Yulin Gas Field", Xi-an: Northwestern University, 2006.