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Upper Paleozoic Shale Gas Accumulation Conditions of the Tiemulike Formation in Yining Basin

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1 Introduction

Yining basin, an independent unit of the Yili-Zhongtianshan micro plate (Wang et al., 2007; Han et al., 2011), is an intermontane superimposed basin (Dai et al., 2015). Yining basin has well-developed Tiemulike dark shale with normal lake facies formed in late period of middle Permian, which has good foreground material conditions of shale gas reservoirs from the study of predecessors. Investigation for Paleozoic unconventional shale oil and gas of the basin has not been carried out. This study reviews the research status and advances of the shale gas in China and abroad, including geothermal chronology, shale nano-sized pore, the base of oil and gas geological exploration degree and geological structure in Yining basin, and analyzing the outcrops profile, drilling data, seismic data, sample test and analysis results, and previous research results. Basin simulation software "Basinmod" was used to restore burial history, and shale gas pool forming elements were also analyzed, involving source rock features, the reservoir characteristics of the shale, the condition of cap rocks development, the dynamics and way of reservoir formation. At last a comprehensive analysis and summary of the Yining basin shale gas accumulation conditions in upper Paleozoic was obtained.

2 Geological Setting

Tectonic framework of Yining basin contains three depressions with an uplift: Yining sag, Nileke sag, Gongnaisi sag and Awulale uplift (Li et al., 2011; Li et al., 2014) (Fig. 1). Yining Basin experienced four important evolution stages from late Archeozoic: the basement evolution stage (early South China age), the breakup of the super continent and ocean continent evolution stage (South China age-middle Devonian), the post-orogenic intraplate extensional stage (late Devonian-early Permian), and the intraplate evolution to the formation of the basin stage (middle Permian-present) (Xu et al., 2010; Liu et al., 2014). Judging from the change of the basin's nature from Permian, the intraplate evolution stage of Yining Basin can be divided into Permian intracontinental rift basin evolution stage and Meso-Cenozoic intracontinental fault subsidence basin evolution stage. From late stage of early Permian to late Permian, Yining basin had been lying in nonmarine lake basin phase of intracontinental rift. At the every period, Tiemulike Formation (P_2t) is main strata of Permian chromocratic argillutite in Yining basin.

Combining the structural feature of Yining basin: thermal evolution, erosion thickness restoration, paleogeothermal field restoration，subsidence history, drilling lithology and dark mudstone, shale geochemistry parameter and so on, this study restored the burial history and thermal evolutional history of the Ning 3 Well, Ning 4 Well. Yining basin had mainly experienced four subsidence stages and the erosion stages (Chen et al., 2008; Zhu et al., 2014). The maximal sedimentation extended from middle Permian to early Triassic, and basin uplifted in a short time in late Permian. The basin quickly deposited from early Triassic to late Cretaceous, what is more, it had experienced a large scale uplift and erosion in early Cretaceous, and sedimentation rate decreased from early stage of late Cretaceous to the end of Paleogene, in which the basin quickly uplifted due to the effect from the Himalayan movement. The basin slowly deposited from early Neogene to late Pleistocene, and it is in the erosion condition nowadays.

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3 Reservoir Forming Elements

3.1 Source rock characteristics

The Tiemulike Formation (P_2t) is mainly made up of black-deep grey calcareous mudstone, marl, black shale, mudstone (Feng, 2014) (Fig. 2). Flat bedding and low-amplitude wave bedding, and horizontally-laminated beds can be seen in limestone. The dark mudstone thickness is mostly 150-600 meters and its main sedimentary facies is deep lake and semi-deep lake. Terrestrial higher plants are its main source. The paleosalinity was higher, aqueous medium was alkaline and the depositional environments were strong reducing; its palynologic combination is featured by *Cordaitina-Crucisaccites-Protohap-Loxypinus*, the content of gymnospermous pollen was 80-90%, Spora Pteridophytae could hardly be seen, bivalve fossil formed *Palaeondonta-Palaeomutella-Neamnigenia* grouping. By multidisciplinary analysis, Tiemulike Formation was developing at a reducing environment with brackish and hypoxia water.

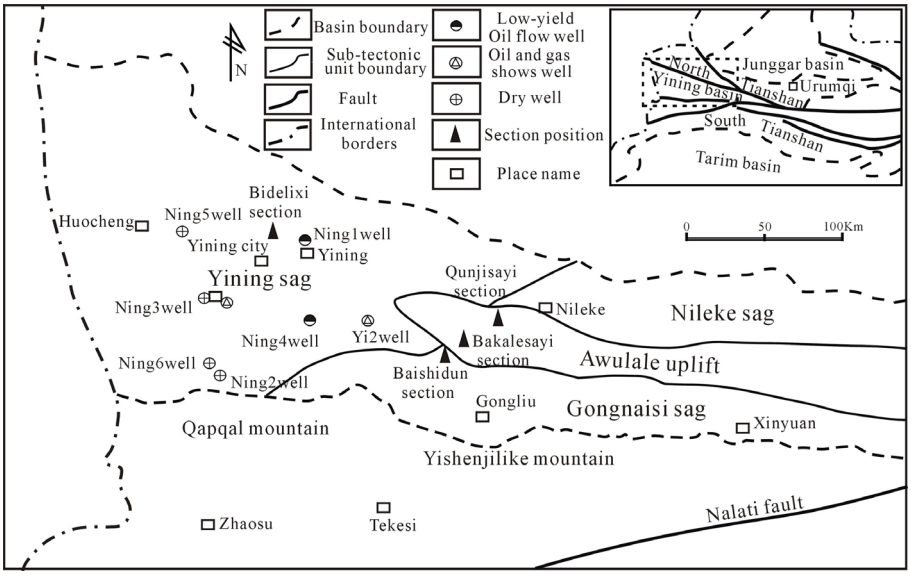

Fig. 1. Tectonic units of Yining Basin (modified after Li et al., 2011).

Organic matter abundance of hydrocarbon source rocks is high, with average content of organic carbon (TOC) 1.86%, and average potential hydrocarbon generation amount S_1+S_2 (mg/g) of 1.79 mg/g, and trend of organic matter abundance increases from the south to the north. The kerogen type is main III, and the same is II_2 (Fig. 3). The thermal evolution degree of Yining basin presents a trend of increase gradually from the basin edge to the basin center, with *R*o of about 0.8% at edge and weighted average value of *R*o being 1.29% at the central part.

3.2 Reservoir and seal characteristics

Average brittle mineral content of Tiemulike Formation mud shale is 68.8%, pore in mud shale is mainly micropore formed form volume reduction by organic matter hydrocarbon (Fig. 4A). Lots of micro-cracks developed during the process of organic matter generated hydrocarbon (Fig. 4B), high angle cracks, vertical mud shale formation, developed by tectonic stress are also visible. Porosity of shale is 2.3-3.1%, with an average value of 2.7%, and penetration rate is 0.002-0.008 md, with an average value of 0.005 md.

There are two regional seals of shale gas in the Tiemulike Formation of Yining basin: one is the Tiemulike Formation

Fig. 2. Photograph of Tiemulike Formation dark mudstone in the Qunjisayi section.

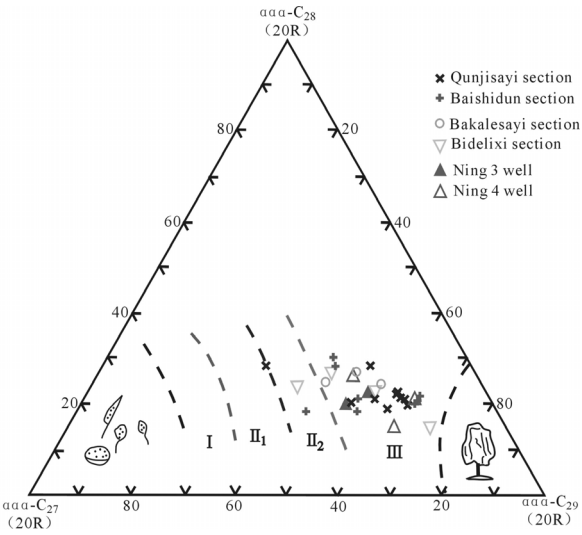

Fig. 3. Triangular diagram of organic matter type using the relative composition of sterane of Tiemulike Formation.

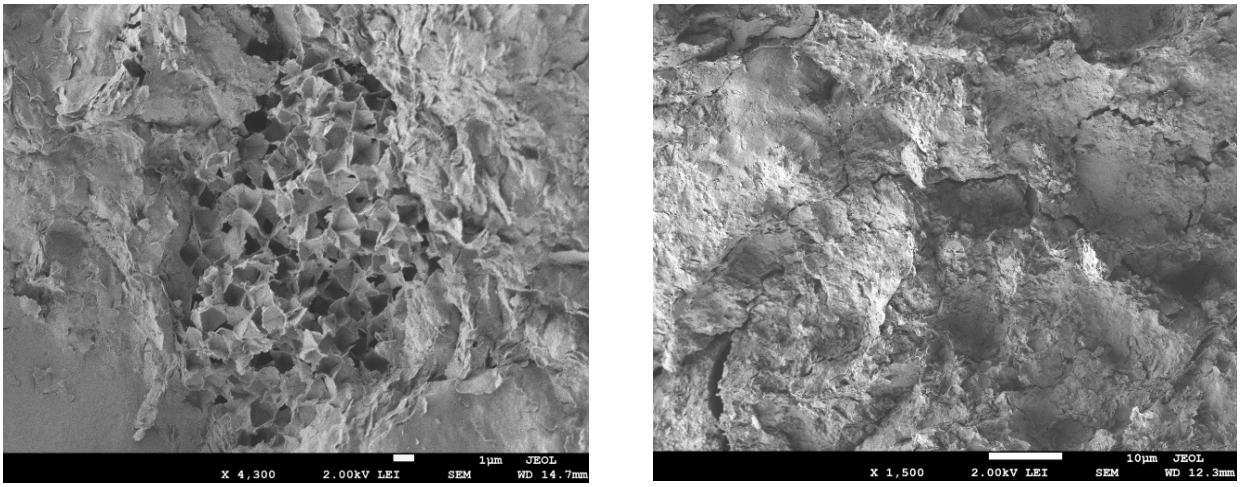

Fig. 4. A, Thermal evolution of organic matter formed honeycomb porous; B, Micro-fracture developed in black mudstone.

(P_2t) mainly made up of black-deep grey calcareous mudstone, marl, black shale, mudstone, developing at deep lake and semi-deep lake sedimentary environment; the other is the Xiaoquangou Group mainly made up of shallow lake mudstone and silty mudstone (Zhong, 2011).

3.3 Accumulation dynamics

There exists strong high abnormal excess pressure Mid-Permian Tiemulike Formation (Zhong, 2011). Early Paleozoic Yining basin was in stage of the large number of dry gas generation in Middle Jurassic, overpressure developed widely in mud shale. Because of thickened and pure dark mudstone layer with higher thermal evolution degree, some abnormal pressure suddenly increased zone are emergence in vertical. The higher excess abnormal pressure zones are with better transverse continuity, which formed a plurality of high abnormal fluid pressure compartment in central depression belt of Yining sag, and provided dynamic conditions for shale hydrocarbon expulsion and shale gas reservoirs.

4 Discussion of Accumulation Conditions and Conclusion

There are some outcrops of oil sand or asphaltic sand in the Tiemulike Formation of Yining basin (Hao, 2003). The hydrocarbon generation, expulsion and filling of dark shale of Tiemulike Formation in Yining basin is with episodic characteristics, and there are two times larger hydrocarbon generation and hydrocarbon filling process. Abnormal excess pressure was the main driving force of hydrocarbon expulsion from source rocks in Yining basin, when excess pressure value of hydrocarbon containing fluid reaches fracture pressure

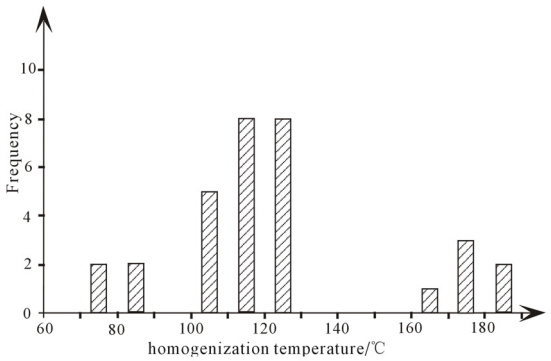

Fig. 5. Fluid inclusion homogenization temperature pattern of Tiemulike formation in Yining basin.

of formation or attained the opening pressure of pre-existing cracks, a large number of micro cracks in open state is produced in mud shale. High pressure hydrocarbon containing fluid transiently bleed off, and there exist multi-episodic process of hydrocarbon generation pressurization → formation breakdown → hydrocarbon export and reservoir discharge. Boiling fluid inclusions and secondary brine inclusion homogenization temperature display episodic reservoiring of Tiemulike Formation shale gas in Yining basin (Fig. 5), which reached hydrocarbon generating threshold at the early Triassic (Xiong et al., 2002), one peak temperature of homogenization temperature is from 80 to 130℃, on behalf of the Tiemulike Formation hydrocarbon source rocks rapidly warmed and generated oil due to high tectonic subsidence rate at early Triassic-middle Jurassic (Fig. 6); another peak temperature of homogenization temperature was from 160 to 180℃, standing for a large natural gas generated when Yining basin subsidence reached the maximum value at late Jurassic - early Cretaceous (Fig. 6). Petroliferous

systems related "four charts and a table" are made to systematicly analysis reservoir forming conditions of upper Paleozoic shale gas reservoirs in Yining basin. From clarification mentioned above, we can see that Permian Tiemulike Formation has bright shale gas exploration foreground, while we also should pay closely attention to exploration risk of Tiemulike Formation shale gas caused by strong reconstruction of Yining basin in Himalayan orogenic movement.

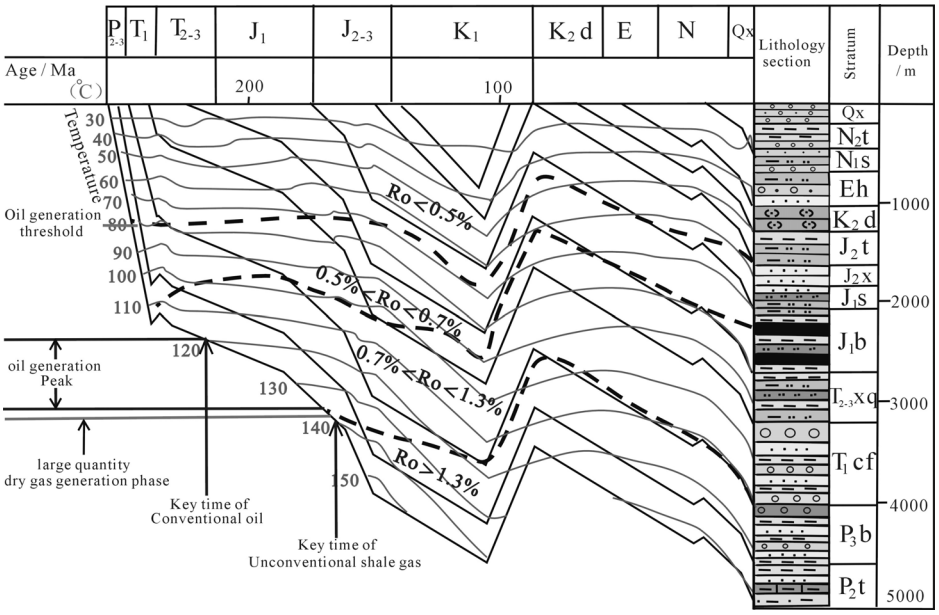

Fig. 6. Burial history at key time of Tiemulike Formation in Ning 4 well of Yining basin.

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References

Chen Zhengle, Li Li, Liu Jian, Gong Hongliang, Jiang Rongbao, Li Shengxiang, Zheng Enjiu, Han Xiaozhong, Li Xigeng, Wang Cheng, Wang Guorong, Wang Guo and Lu Kegai, 2008. Preliminary study on the uplifting-exhumation process of the western Tianshan range, northwestern China. *Acta Petrologica Sinica*, 24(4): 625-636 (in Chinese with English abstract).

Dai Shifeng, Yang Jianye, Ward Colin R, Hower James C., Liu Huidong, Garrison Trent M., French David and O'Keefe Jennifer M.K, 2015. Geochemical and mineralogical evidence for a coal-hosted uranium deposit in the Yili Basin, Xinjiang, northwestern China. *Ore Geology Reviews*, 70: 1-30.

Feng Yangwei, 2014. Depositional environment of Permian chromocratic argillutite and its shale gas exploration potential in Yining Basin. *Abstract collection of 1st CUGS*, 178-179.

Han Baofu, He Guoqi, Wang Xuechao and Guo Zhaojie, 2011. Late Carboniferous collision between the Tarim and Kazakhstan–Yili terranes in the western segment of the South Tian Shan Orogen, Central Asia, and implications for the Northern Xinjiang, western China. *Earth-Science Reviews*, 107: 74-93 .

Hao Jipeng , Yang Zhiyong , Shi Jianhong and Chen Guojun, 2003. The hydrocarbon potential of the Carboniferous-Permian strata in the Ili Basin, Xinjiang. *Sedimentary Geology and Tethyan Geology*, 23(1): 75-83 (in Chinese with English abstract).

Li Baoqing, Zhuang Xinguo, Li Jing and Zhao Shihua, 2014. Geological controls on coal quality of the Yili Basin, Xinjiang, Northwest China. *International Journal of Coal Geology*, 131: 186-199.

Li Yuwen, Yu Chaofeng, Xiong Shaoyun, Chen Nenggui and Qu Jianhua, 2011. Petroleum geology characteristics and exploration potential of Carboniferous rocks in Yili Basin. *Marine Origin Petroleum Geology*, 16(3): 30-37.

Liu Hongsheng, Wang Bo, Shu Liangshu, Jahn, B., and Lizuka, Y., 2014. Detrital zircon ages of Proterozoic meta-sedimentary rocks and Paleozoic sedimentary cover of the northern Yili Block: Implications for the tectonics of microcontinents in the Central Asian Orogenic belt. *Precambrian Research*, 252: 209-222.

Wang Bo, Chen Yan, Zhan Sheng, Shu Liangshu, Faure, M., Cluzel, D., Charvet, J., and Laurent-Charvet, S., 2007. Primary Carboniferous and Permian paleomagnetic results from the Yili Block (NW China) and their implications on the geodynamic evolution of Chinese Tianshan Belt. *Earth and Planetary Science Letters*, 263: 288-308.

Xiong Liping, Jiao Daqing, Liu Tiezhuang and Ma Fangxia, 2002. Evalution on Permian oil and gas bearing system in Yining depression. *Oil & Gas Geology*, 23(3): 293-299 (in Chinese with English abstract).

Xu Xueyi, Chen Junlu and Wang Hongliang, 2010. *Synthetic study on geological background of West Tianshan ore belt*. Research report of Xi'an Institute of Geology and Mineral Resources (in Chinese).

Zhong Hongli, 2011. *Tectono-sedimentary evolution and favorable exploration prediction of Ying depression*. Xi'an: Northwest University (in Chinese).

Zhu Jianjun, Lin Shuiqing, Zhang Hongjun, Zhang Gaoyuan, Ying Wenxi, Gu Chao and Wang Qi, 2014. Tectonic subsidence of Pining depression and its main controlling factors. *Natural Gas Geoscience*, 25(8): 1181-1187 (in Chinese with English abstract).