PS Assessment of Shale Gas Potential of Lower Permian Transitional Shanxi-Taiyuan Shales in the Southern North China Basin*

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Abstract

The geological research and exploration evaluation of marine-continental transitional shale gas is lagging behind compared with the rapid development of marine and continental shale gas resource in China. To investigate the shale gas potential in the Lower Permian Shanxi and Taiyuan formations in the Southern North China Basin (SNCB), a series of measurements on representative core samples were conducted for characterizing the shale features, including their sedimentary environment, organic geochemistry, mineral composition, pore structure as well as gas-bearing capacity. The average total organic carbon (TOC) content of the Shanxi and Taiyuan shales reaches 1.68 and 2.26%, respectively and deposition took place in frequently changing depositional conditions, where predominantly gas-generating type III kerogen was preserved in the sediments. Regarding to the sedimentary environments, different microfacies can affect effective thickness, abundance of organic matter, mineral composition and gas content in the Shanxi and Taiyuan Formations. Besides the various microfacies, the TOC, inertinite, chlorite, thermal maturity and pyrite have a significant role on gas content to varying degree. Although the Shanxi-Taiyuan shales are not comparable to the known gas-producing shales in the U.S., there are some similarity in shale reservoir parameters such as the relatively higher organic richness (more than 2.0% TOC) and gas content (nearly 2.0 m^3/t) compared with the well-developed Longmaxi and Yanchang shales. Consequently, the Shanxi-Taiyuan shales could be classified as potential shale gas targets due to their relatively favorable reservoir properties and gas accumulation as well. However, some complex geological conditions such as the greater burial depth (>3500 m), higher clay content (more than 45%), rather deficiency of organic-matter-hosted pores whereas well-developed other types of pore-microfracture, extremely high thermal maturity (>3.0% R_o), several large unsealed faults, etc. in study areas might have important influence on gas production. Therefore, transitional shale gas exploration and exploitation in the SNCB should be undertaken according to the local geological conditions.

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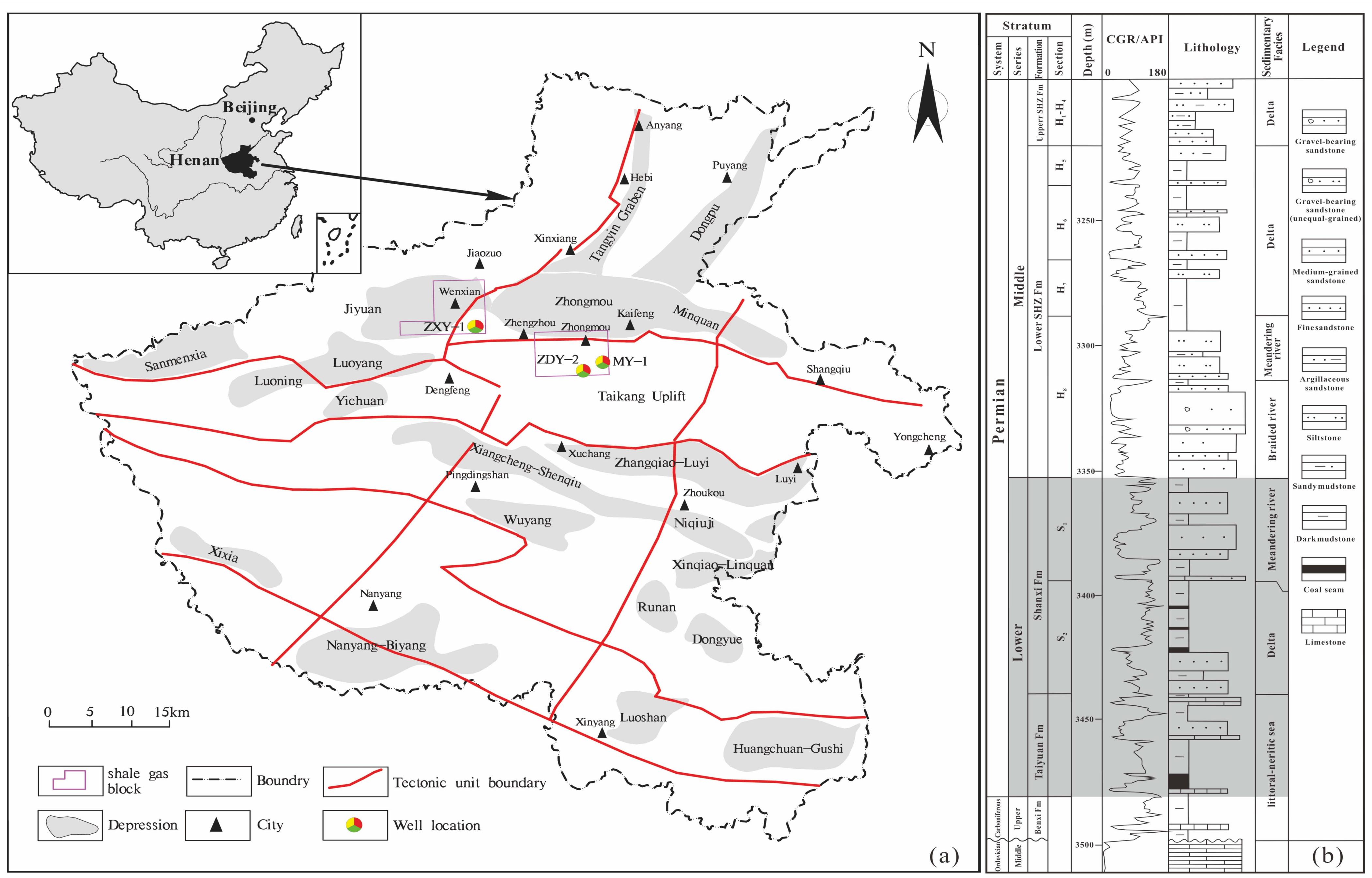
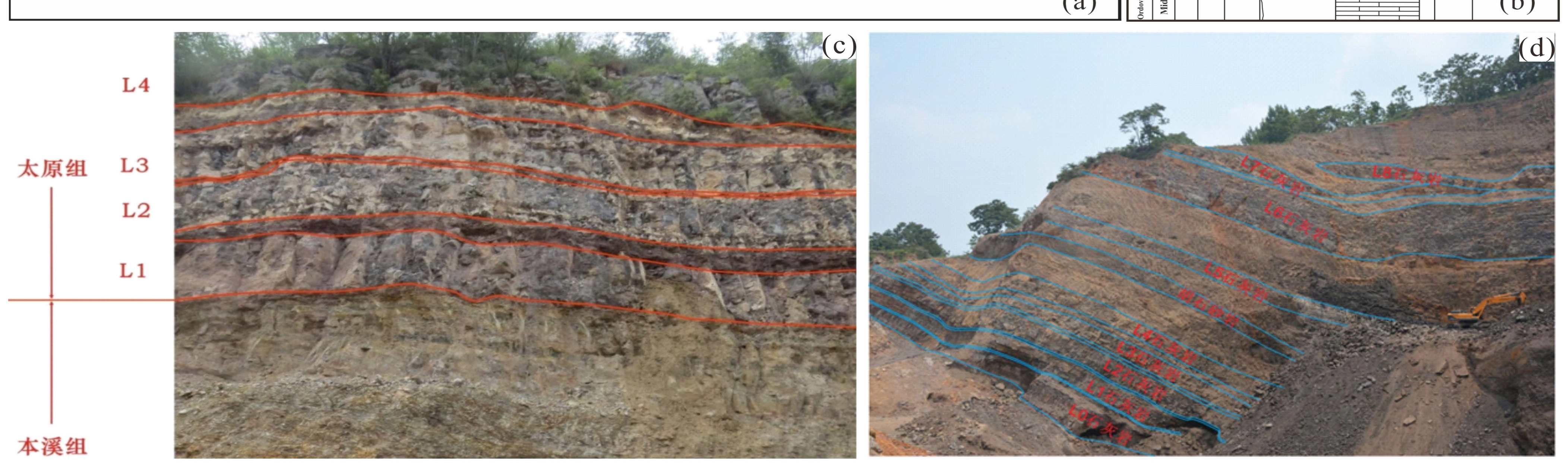
Abstract:

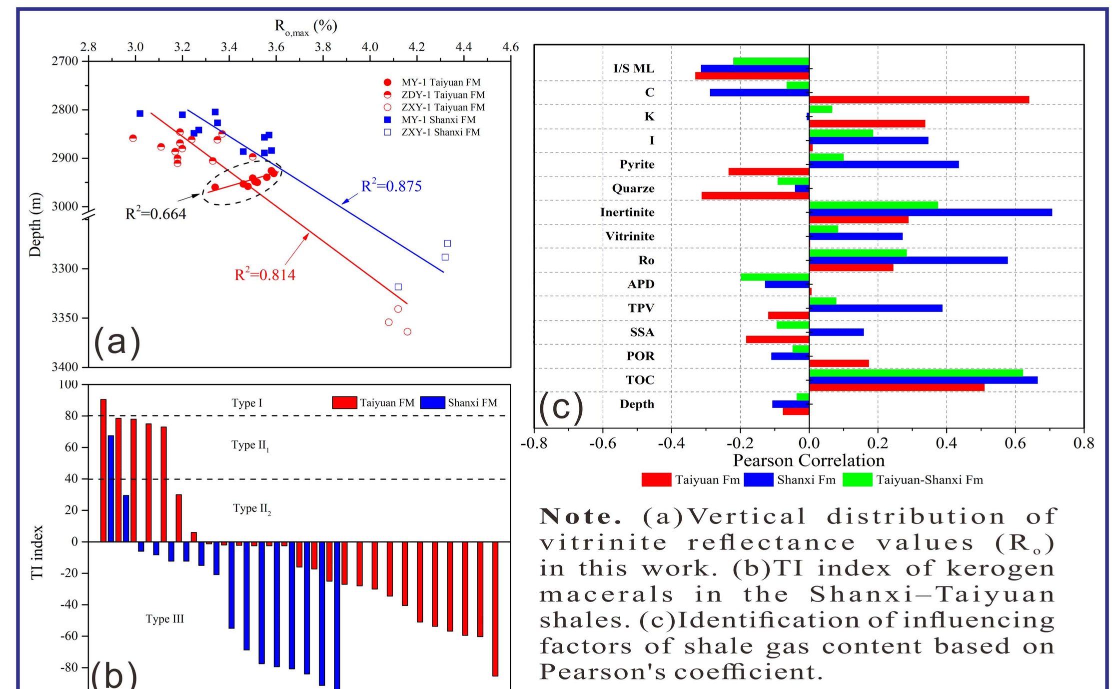
The geological research and exploration evaluation of marine–continental transitional shale gas is lagging behind compared with the rapid development of marine and continental shale gas resource in China. To investigate the shale gas potential in the Lower Permian Shanxi and Taiyuan formations in the Southern North China Basin (SNCB), a series of measurements on representative core samples were conducted for characterizing the shale features, including their sedimentary environment, organic geochemistry, mineral composition, pore structure as well as gas–bearing capacity. The average total organic carbon (TOC) content of the Shanxi and Taiyuan shales reaches 1.68% and 2.26%, respectively and deposition took place in frequently changing depositional conditions, where predominantly gas–generating type III kerogen was preserved in the sediments. Regarding to the sedimentary environments, different microfacies can affect effective thickness, abundance of organic matter, mineral composition and gas content in the Shanxi and Taiyuan Formations. Besides the various microfacies, the TOC, inertinite, chlorite, thermal maturity and pyrite have a significant role on gas content to varying degree. Although the Shanxi–Taiyuan shales are not comparable to the known gas–producing shales in the US, there are some similarity in shale reservoir parameters such as the relatively higher organic richness (more than 2.0% TOC) and gas content (nearly 2.0 m^3/t) compared with the well-developed Longmaxi and Yanchang shales. Consequently, the Shanxi–Taiyuan shales could be classified as potential shale gas targets due to their relatively favorable reservoir properties and gas accumulation as well. However, some complex geological conditions such as the greater burial depth (>3500 m), higher clay content (more than 45%), rather deficiency of OM–hosted pores whereas well–developed other types of pore–microfracture, extremely high thermal maturity (>3.0% R_o), several large unsealed faults, etc. in study areas might have important influence on gas production. Therefore, transitional shale gas exploration and exploitation in the SNCB should be undertaken according to the local geological conditions.



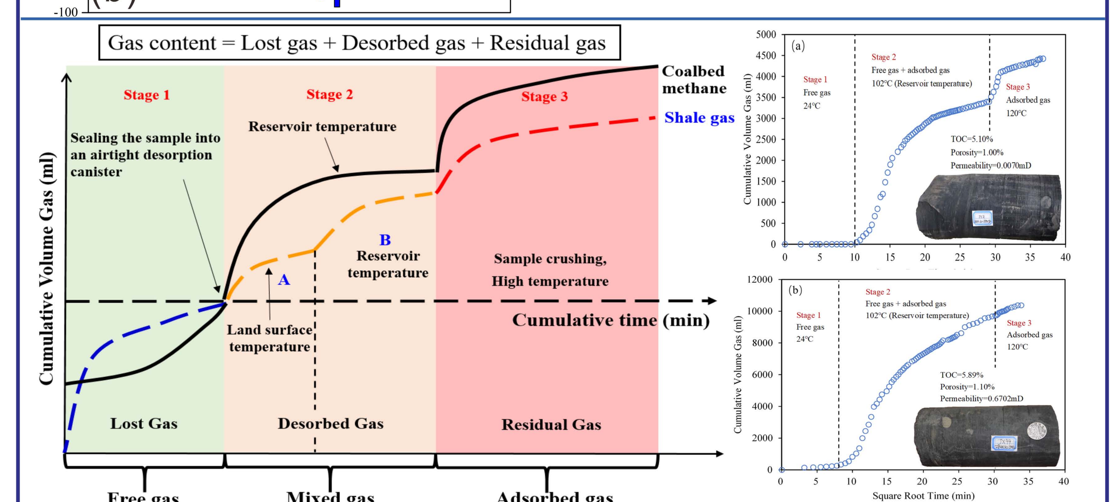


Note. (a) Geological setting of studied region, and (b) generalized stratigraphic column map of Upper Paleozoic strata in the SNCB, showing more details of lithology and depositional environments. Gray area represents research target formations. (c) and (d) Field outcorp picture of Taiyuan Formation (N: 35° 11' 53.99'', E: 113° 21' 17.46''), mainly including the limestone L1-L4. Other lithologies are mainly composed of limestone, sandstone, sandy mudstone and coal seam, with a small amount of siliceous rock.

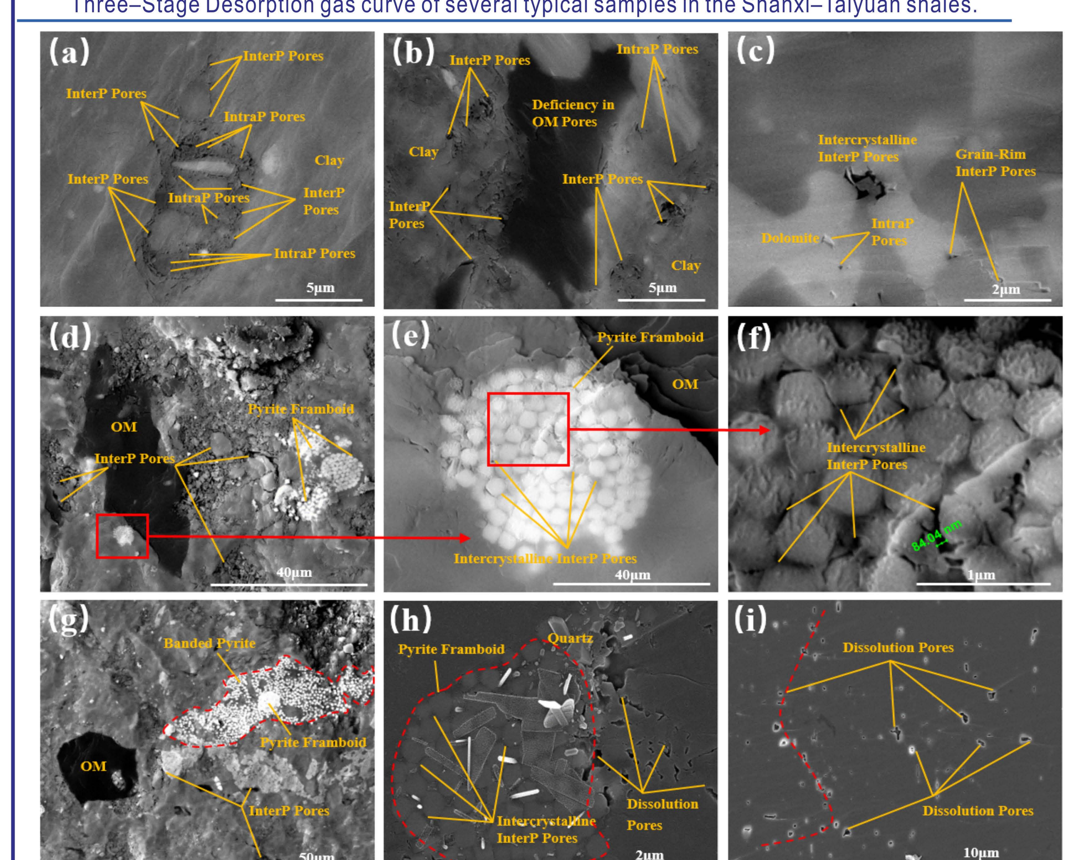
The depositional environment of Taiyuan Fm and Shanxi Fm during the Lower Permian are mainly barrier coastal facies and delta facies, respectively. The former, characterized by transgressive retrogradation sequence, is mostly composed of three sets of limestone interlayered with two sets of black shale and coal seam, in which the shale section is primarily lagoon facies and the limestone section is restricted platform facies. While the latter, the lower part of Shanxi Fm, is mainly black shale interbedded with coal seam, and the upper part is generally sandstone, which generally represented the typical regressive progradation sequence. From deep to shallow, the sedimentary environment gradually changed from the prodelta to the delta front, and finally developed into the delta plain facies.

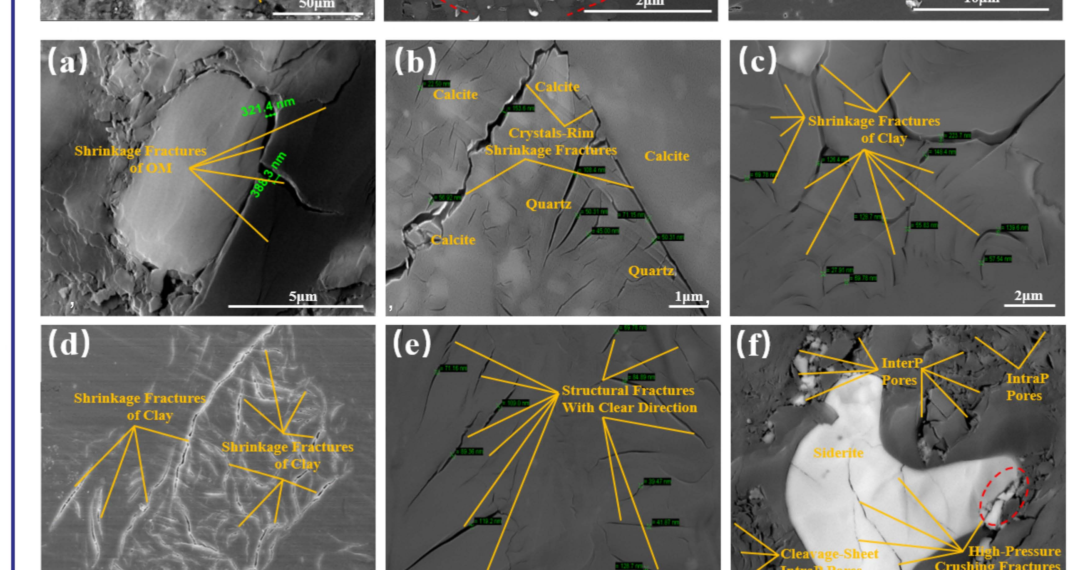


Note. (a)Vertical distribution of vitrinite reflectance values (R_o) in this work. (b)TI index of kerogen macerals in the Shanxi–Taiyuan shales. (c)Identification of influencing factors of shale gas content based on Pearson's coefficient.



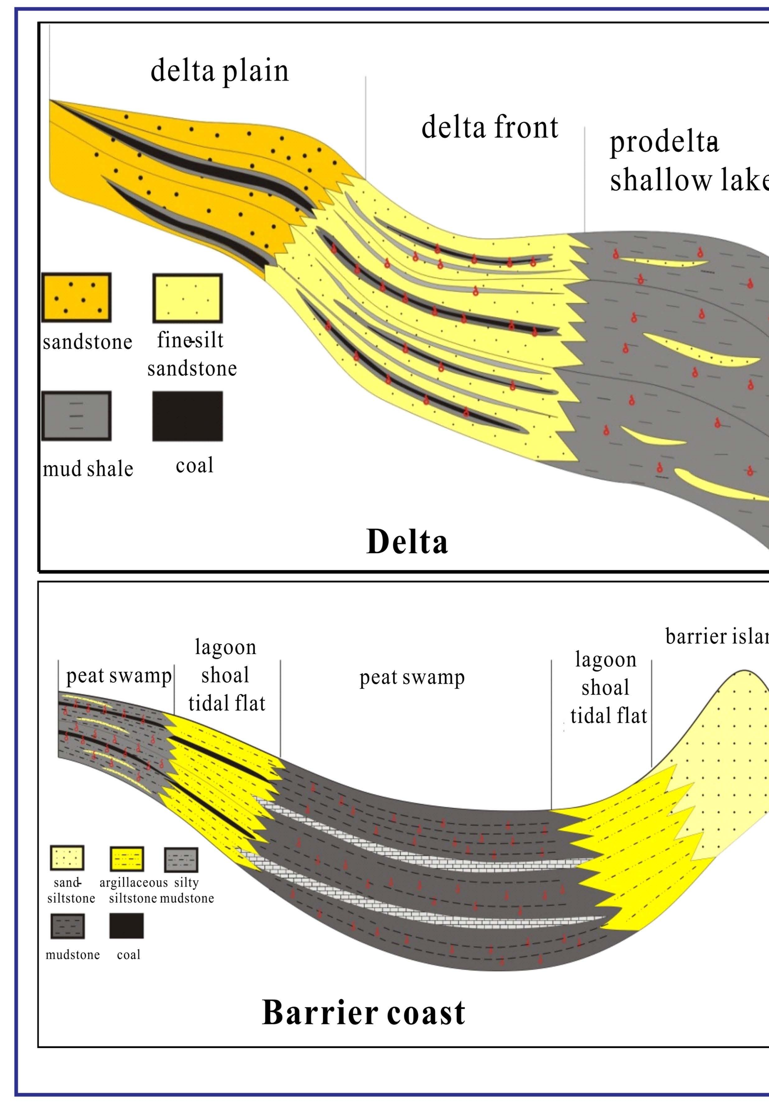
Three-Stage Desorption gas curve of several typical samples in the Shanxi–Taiyuan shales.

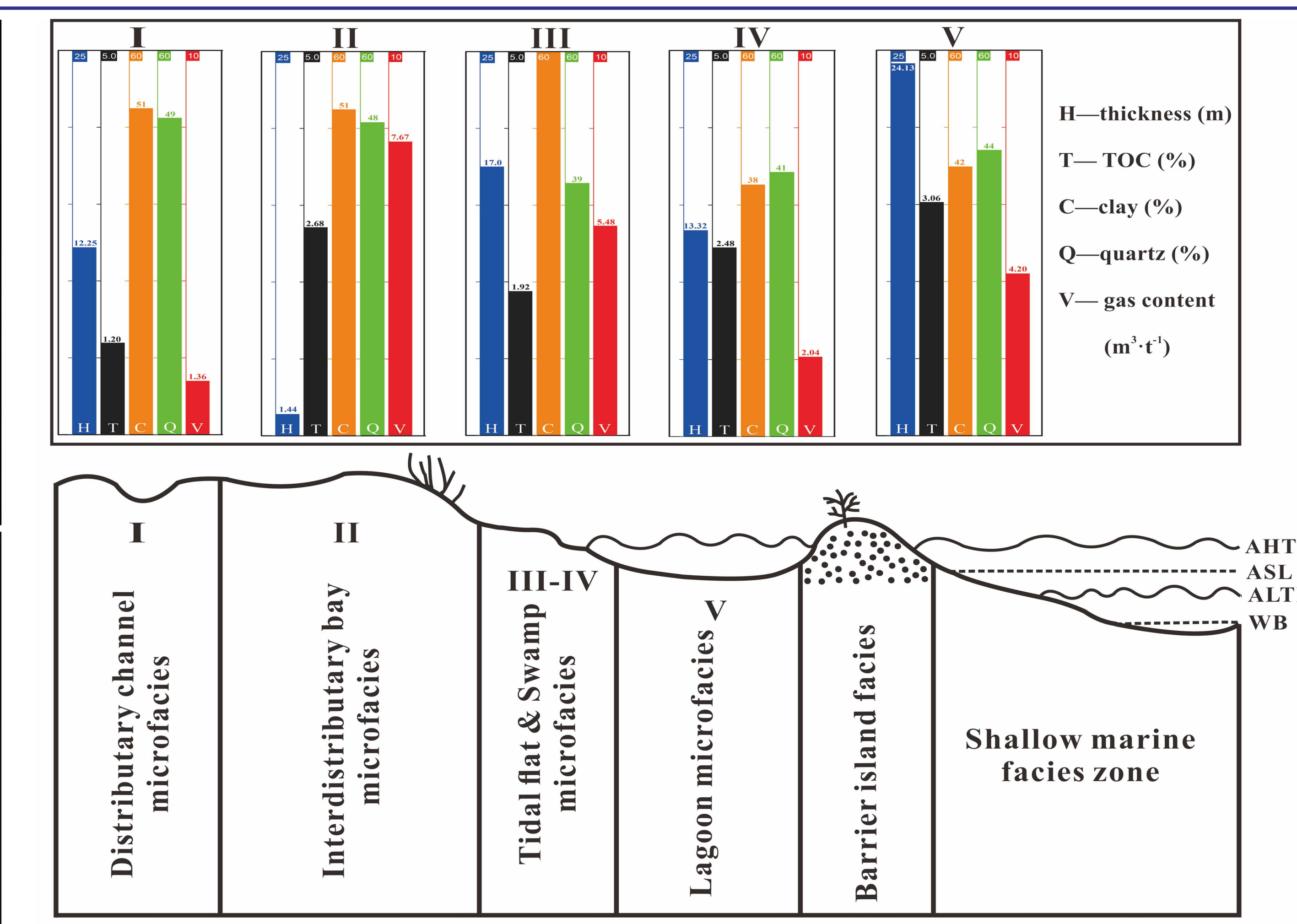




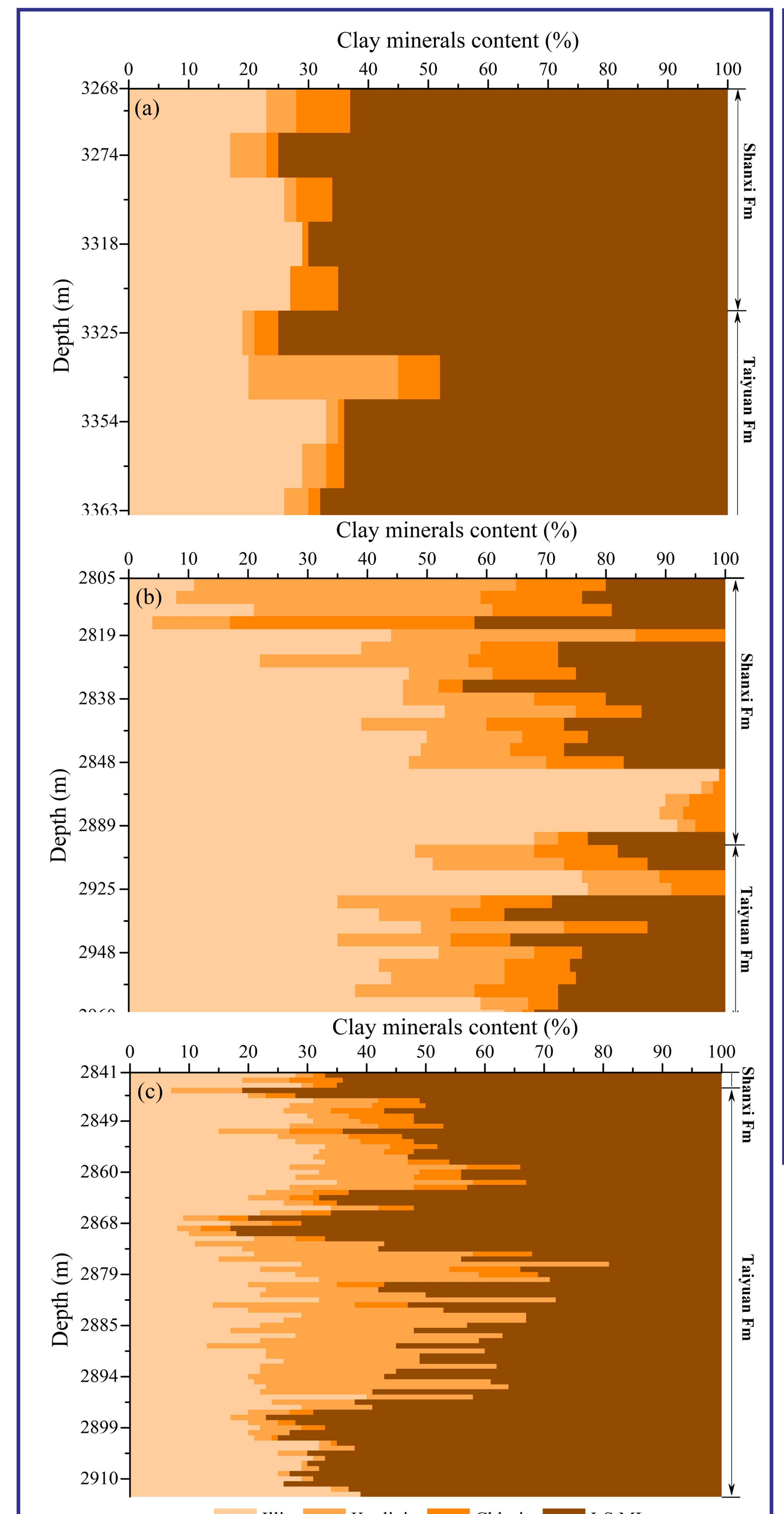
Note. Example of different pore types in the Shanxi–Taiyuan shales. (a) and (b) InterP pores and intraP pores, while OM pores are poorly developed. (c) Intercrystalline pores in carbonate minerals, and interP pores in grain–rim. (d) InterP pores between grains and intercrystalline pores in pyrite framboid . (e-f) Intercrystalline intraP pores within a pyrite framboid; (g) Pyrite framboid, banded pyrite, and interP pores. (h) Dissolution pores and intercrystalline intraP pores within a pyrite framboid. (i) Dissolution pores in carbonate minerals.

Example of different fractures in the Shanxi–Taiyuan shales. (a') Shrinkage fractures of OM. (b') Diagenetic fractures between quartz and calcite crystals. (c') Shrinkage fractures of clay minerals. (d') Shrinkage fractures in the interior of clay minerals. (e') Structural fractures with the clear direction. (f') Internal fractures in siderite, interP pores and clearage–sheet intraP pores.





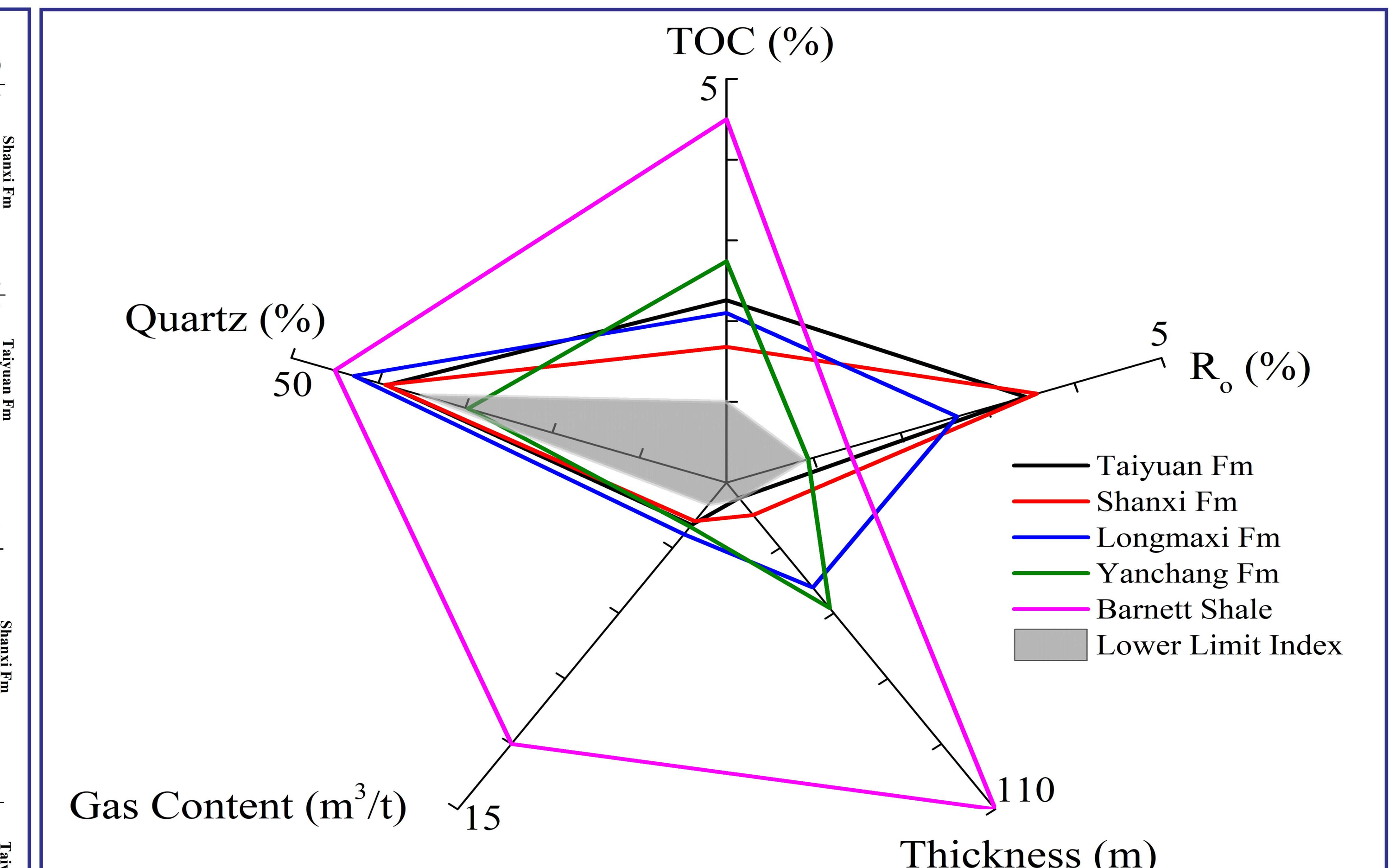
Sedimentary types and parameter distribution characteristic of Taiyuan-Shanxi Fm.



Note. Distribution of clay mineral composition in the Shanxi–Taiyuan shales: (a) Well ZXY–1; (b) Well MY–1; (c) Well ZDY–2.

Abbreviations

C—Chlorite; K—kaolinite; I—illite; APD— Average pore diameter; TPV— Total pore volume; SSA— Specific surface area; POR—Porosity. According to the Pearson's correlation coefficient,81,82 0.8–1.0 strong correlation extremely; 0.6–0.8, strong correlation; 0.4–0.6 moderate correlation; 0.2–0.4 weak correlation; 0.0–0.2 weak correlation extremely or no correlation.



Note. Important shale gas reservoir parameters that determine shale gas potential of Shanxi–Taiyuan shales in the SNCB compared with other typical shale reservoirs. The lower range index includes 1.0% TOC, 0.9% R_o, 5.0 m thickness, 1.0 m^3/t gas content, and 35% quartz, following the Chinese National Standard GB/T 31483–2015 (Geological evaluation methods for shale gas).

Discussion and Conclusion:

The Shanxi–Taiyuan shales have the obvious poorer shale reservoir if compared to known commercially gas–producing shales from the US such as Marcellus, Barnett and Woodford Shales. Nevertheless, their main reservoir parameters basically satisfy the lower range criteria of transitional shale in China, and even some of them are close to the gas–producing shales in China such as Longmaxi and Yanchang shales. Consequently, the Shanxi–Taiyuan shales could be classified as potential shale gas target candidate due to their favorable reservoir properties and gas accumulation conditions as well. Because of the advantages of thickness, TOC content, gas–bearing capacity and brittle minerals content in the here studied intervals as well, the Taiyuan shale has better reservoir quality compared with the Shanxi shale, allowing us to draw conclusions that the Taiyuan shale is more favorable for gas accumulation and exploitation.

Additionally, there are still some uncertainties and challenges in gas exploration and development such as the greater burial depth (>3500 m), extremely high thermal maturity (>3.0% R_o), several large unsealed faults, etc. in study areas. Therefore, transitional shale gas exploration and exploitation in the SNCB should be undertaken according to the local geological conditions.