Lacustrine Shale Gas Exploration in Yanchang Exploratory Block, China*

Xiangzeng Wang[1], Lixia Zhang[1], Chengfu Jiang[1], Binghua Sun[1], Chao Gao[1], Bojiang Fan[1], Chao Guo[1], Yongping Wan[1], Jianbo Sun[1], and H. Hu[1]

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[1]Shaanxi Yanchang Petroleum (Group) Co., LTD, Xi'an, China (sxycpcwxz@126.com)

Abstract

Shale gas has received widespread interest because of its emergence as a cheap and clean energy. For some parts of the world, such as North America, shale gas is being heavily developed (Montgomery et al., 2005; Loucks and Ruppel, 2007; Rowe et al., 2008; Ruppel and Loucks, 2008). At present, however, shale gas exploration is limited to the marine shale. Research on lacustrine shale is extremely poor. The Liuping 177 well, which is located in the Yanchang Exploratory Block, Ordos Basin, China, and is also the first shale gas well in China, was drilled in 2011; the initial production is 2350 m^3/d. The successful drilling of the Liuping 177 well indicates a breakthrough in lacustrine shale gas exploration. Analysis and understanding geological and geochemical characteristics of lacustrine shales provide us with critical information for an accurate assessment of shale gas potential, and consequently to select favorable exploration targets.

Geological Setting

The Ordos Basin is the second largest sedimentary basin in China. It lies in the central part of China and covers an area of 370,000 km^2 (Figure 1) (Wang et al., 2012; Zhang et al., 2012). The tectonic structure of Ordos Basin is characterized by a single western-dip monocline with undeveloped faults. The Triassic Yanchang Formation is composed of lacustrine deposits ranging from 100 m to 300 m thick. Yanchang Formation Chang-7 Member consists of interbedded dark shale, sandy shale, mudstone and oil shale with an area of 100,000 km^2, and total shale thickness ranging from 80 m to 130 m. The research area of the Yanchang Exploratory Block lies in the central part of the old lake which covers an area of 2000 km^2.

Burial and Distribution Characteristics

The burial depth of Chang-7 Member Shale ranges from 500 m to 2000 m, with the southwestern part deeper than 1400 m, and the northeastern part less than 1000 m. The total shale thickness of Chang-7 Member ranges from 5 m to 100 m. The total shale thickness decreases from more than 50 m in the southwestern part of the Block to less than 5 m in the northeastern part of the Block.

Geochemical Characteristics

Organic Matter Abundance

The content of total organic carbon (TOC) of Chang-7 Member Shale in the Yanchang Exploratory Block ranges from 1.76% to 5.88%, with an average value of 3.24%. The content of hydrocarbon potential ranges from 0.26 mg/g to 24.0 mg/g, with an average value of 11.2 mg/g. The content of chloroform bitumen "A" ranges from 0.31% to 1.72%, with an average value of 0.71%. Based on all the geochemical parameters above, the Chang-7 Member Shale is identified as a good source rock. The content of total organic carbon (TOC) shows an increasing trend from the east to the west part of the study area (Figure 2).

Organic Type

(1) Pyrolysis analysis
The hydrogen index of Chang-7 Member Shale in the Yanchang Exploratory Block ranges from 102 mg/g TOC to 289 mg/g TOC, with an average value of 192.8 mg/g TOC. The oxygen index ranges from 1 mg/g TOC to 30 mg/g TOC, with an average value of 8.3 mg/g TOC. The maximum pyrolysis temperature (Tmax) ranges from 339° C to 488° C, with an average value of 457° C. The degradation rate ranges from 5.8% to 42.0%, with an average value of 22.4%. Based on the geochemical parameters above, the main matrix type of the Chang-7 Member Shale in Yanchang Exploratory Block is type II kerogen, containing a small portion of type I and type III kerogen (Figure 3).

(2) Microscopic component analysis
Microscopic identification analysis shows that the components of kerogen in the Chang-7 Member Shale includes sapropelite, vitrinite and inertinite. Sapropelite is the most developed component and it accounts for more than 50% to the total weight. Vitrinite is the less developed component and accounts for 2% to 39% of the total weight, with an average value of 20%. Inertinite is the least developed component and accounts for 5% to 34% of the total weight, with an average value of 15%. Based on microscopic analysis, the main matrix type of the Chang-7 Member Shale is type II kerogen, including a small portion of type I kerogen.

Thermal Evolutionary Degree

The thermal evolutionary degree of the Chang-7 Member Shale in Yanchang Exploratory Block is relatively low. The measured Ro ranges from 0.52% to 1.25%, with an average value of 0.73%. The thermal degree analysis shows an increasing trend from the southeast to northwest within the Yanchang Exploratory Block (Figure 4).

Reservoir Characteristics

Mineral Composition

The content of clay minerals is relatively high and varies greatly among the Chang-7 Member Shale in the Yanchang Exploratory Block, with the content ranging from 37.4% to 72.8% (Figure 5). Among the clay minerals, illite/smectite-mixed mineral is relatively high, with the content ranging from 61.0% to 94.0%, and the average content being 80%; the content of illite ranges from 2.0% to 26.0%, and the average content is 9.1%; the content of chlorite ranges from 4.0% to 14.0%, and the average content is 9.4%; the content of kaolinite is relatively low, with an average content of 10%. The content of brittle minerals is very low also, with the content of quartz ranging from 20% to 30%, and the feldspar ranging from 10% to 33.9%.

Porosity and Permeability

Five types of reservoir were identified in the Chang-7 Member Shale, based on their origins and attitudes, and they are primary-pore, dissolved-pore, intercrystal-pore, micro-pore and fracture. The porosity and permeability of forty-two samples, which were collected from sandy interlayer, sandy shale and sheer shale, were measured using the impulse method. The result shows that, the porosity and permeability is favorable in the sandy interlayer, with an average porosity of 7%, an average vertical permeability of 0.000923 md, and an average horizontal permeability of 0.003583 md. The property of porosity and permeability is relatively poor for the shaly sandstone and sandy shale. The property of porosity and permeability is extremely poor in the sheer shale, with the porosity ranging from 1.69% to 3.54%, the vertical permeability ranging from 0.000058 md to 0.000091 md, the average horizontal permeability ranging from 0.000117 md to 0.000298 md. It is obvious that the lacustrine shale in this study is characterized by a highly heterogeneous nature.

Gas-Bearing Characteristics

Desorption Experiment

In order to observe the gas-bearing ability, the samples collected from the Chang-7 Member Shale were put into water, which is known as the desorption experiment. The test to the fresh samples collected from coring shows that there are a lot of gas bubbles adsorbing on the surface of core, some of which can float upward to the water surface (Figure 6). The gas bubbles distribute in succession at the micro-layers, which forms a shape of bubble beads. Among the test samples, the diameter of the largest bubble was 4 mm.

Methane Adsorption Experiment

Samples collected from six shale-gas wells were selected for the methane adsorption experiments. The result shows that the maximum CH_4 adsorption capacity of lacustrine shale can reach the lowest industrial standard ($1m^3/t$) even under the conditions of pressure being 1.5 MPa (Figure 7). With a pressure of 5 MPa, the maximum CH_4 adsorption capacities of most lacustrine shale can reach 2 m^3/t, which indicates a strong adsorbing ability. Comparing the two experiments, the adsorption capacity under the adsorption experiments is smaller than that under the desorption experiment, the reason of which is that the desorption gas is quantitatively more than the adsorption gas, for the desorption gas includes not only the residual free gas but also the dissolving gas and the adsorbing gas.

Conclusions

The relatively low thermal degree, diversified mineral composition, low content of brittle mineral, and low porosity and permeability are adverse factors for the formation of a shale-gas system. However, stable thickness of a single shale layer, high TOC content, abundant gas-prone matrixes, multiply sandy interbeds, developed fractures and high gas content are all favorable factors for the formation of a shale gas system. Understanding the above discussion on lacustrine shale, and weighing the favorable factors against adverse factors, provides us with a reference for selecting favorable exploration targets.

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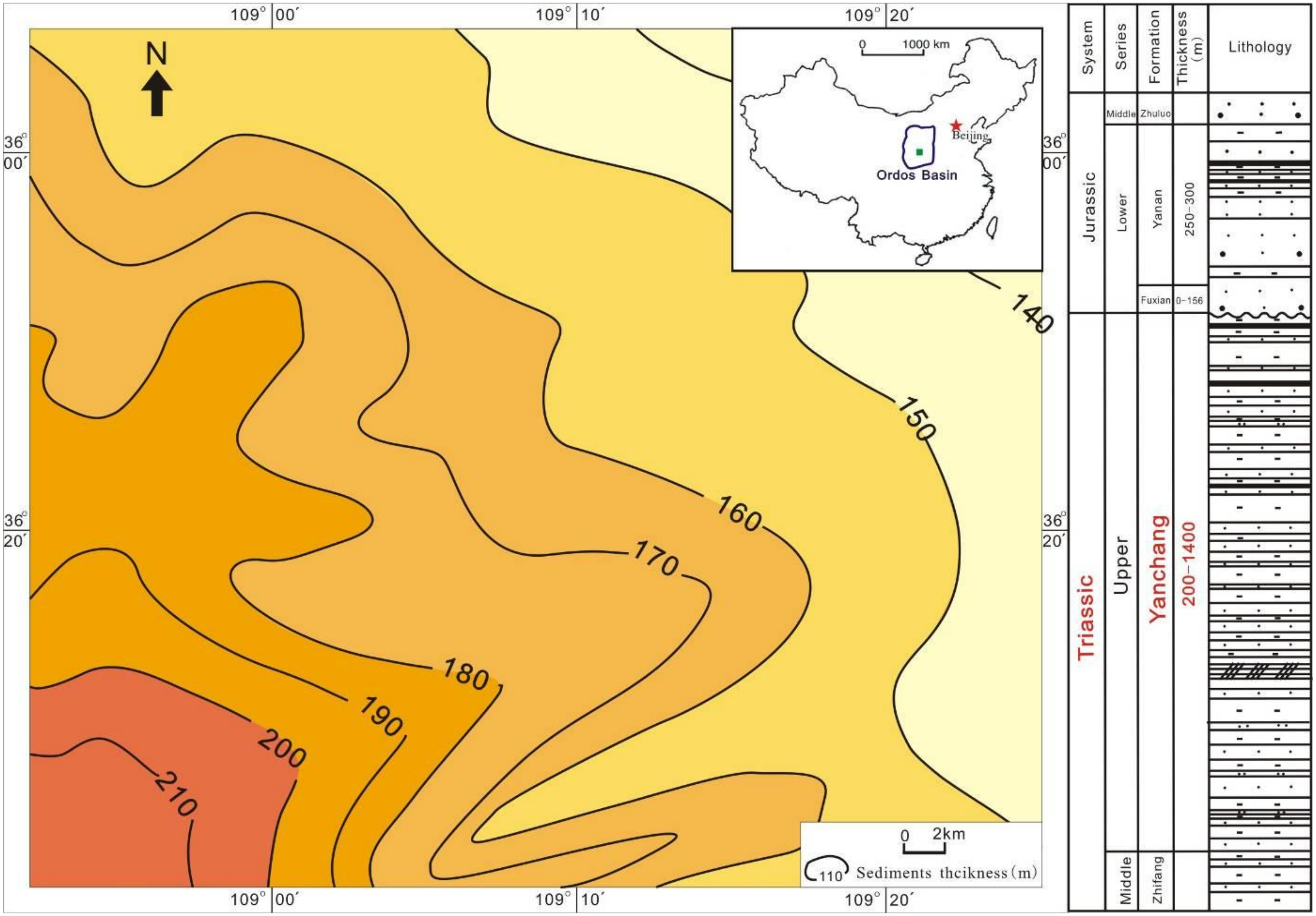

Figure 1. Distribution map of the Chang-7 Member in Yanchang Exploratory Block, China.

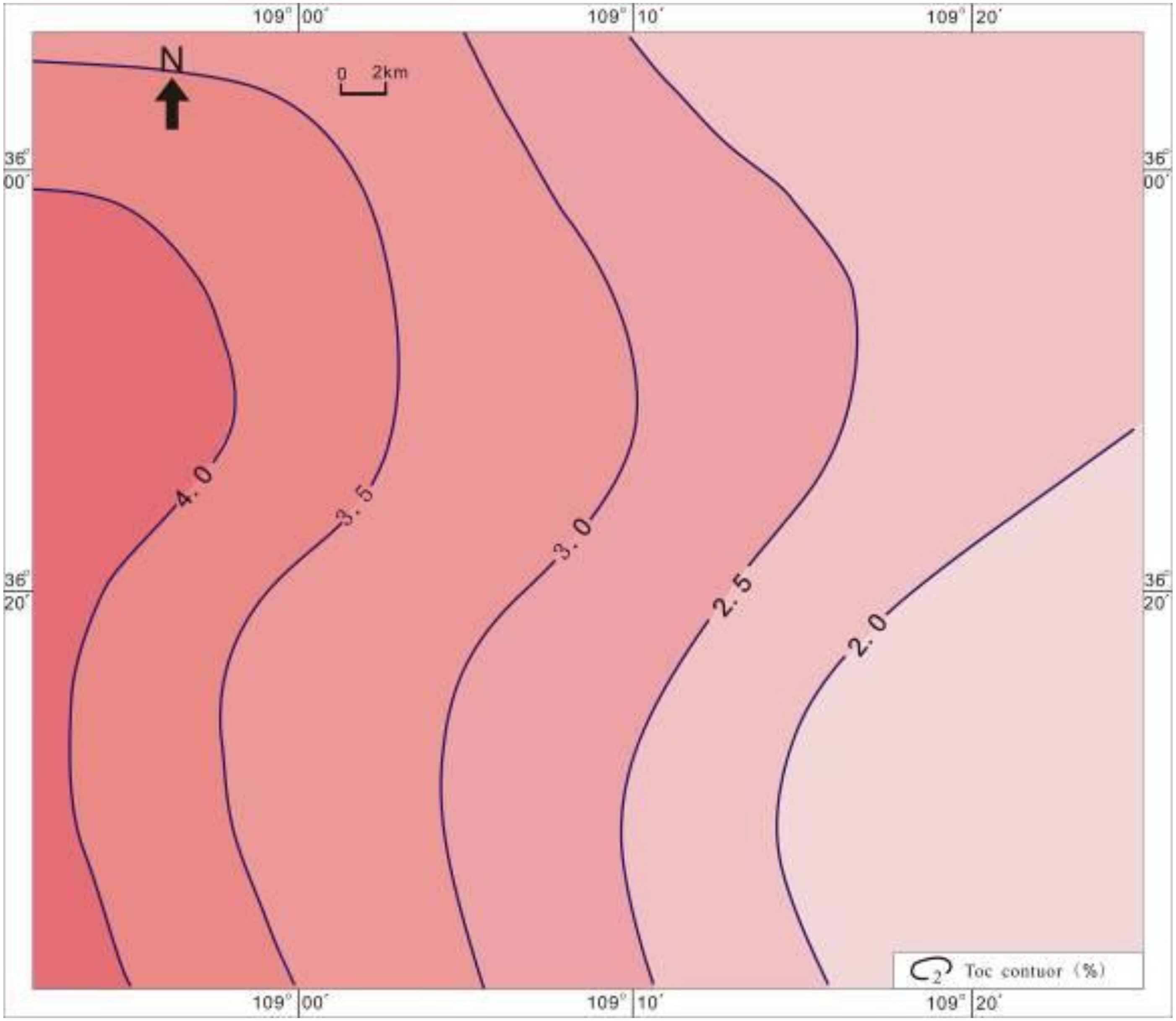

Figure 2. TOC distribution map of Chang-7 Member Shale in Yanchang Exploratory Block.

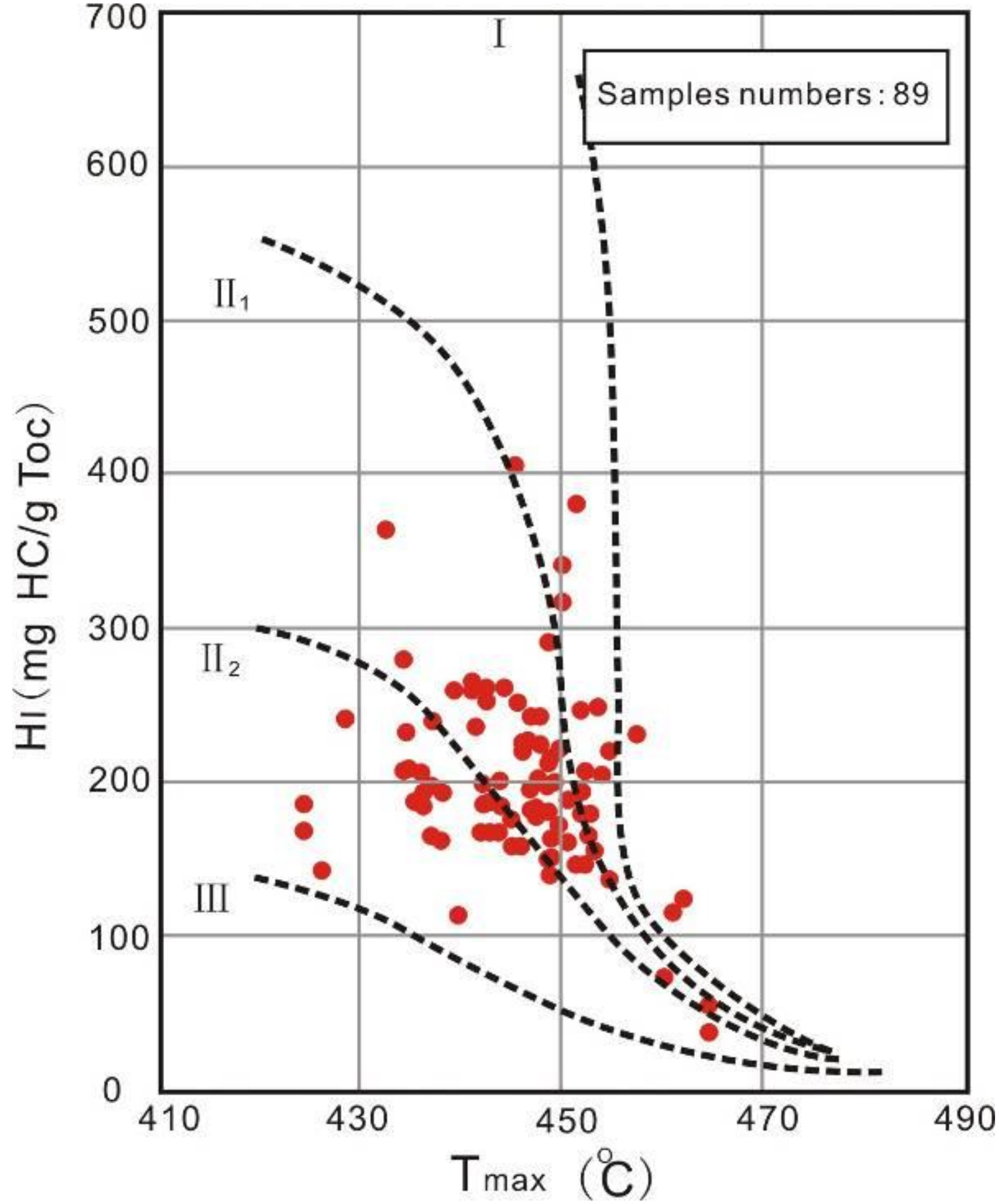

Figure 3. Classifying of kerogen types using hydrogen index with oxygen index.

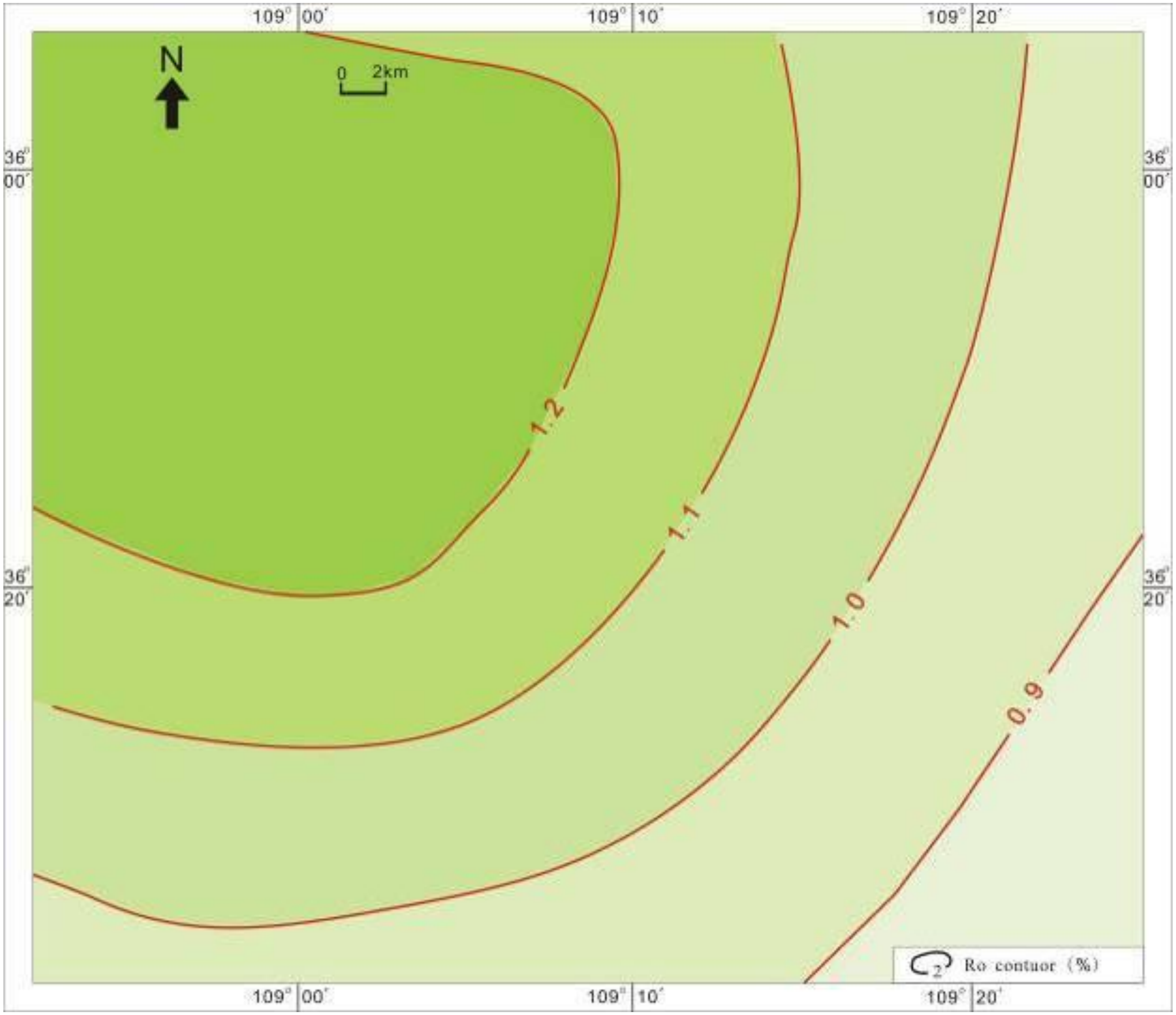

Figure 4. Ro distribution map of Chang-7 Member Shale in Yanchang Exploratory Block.

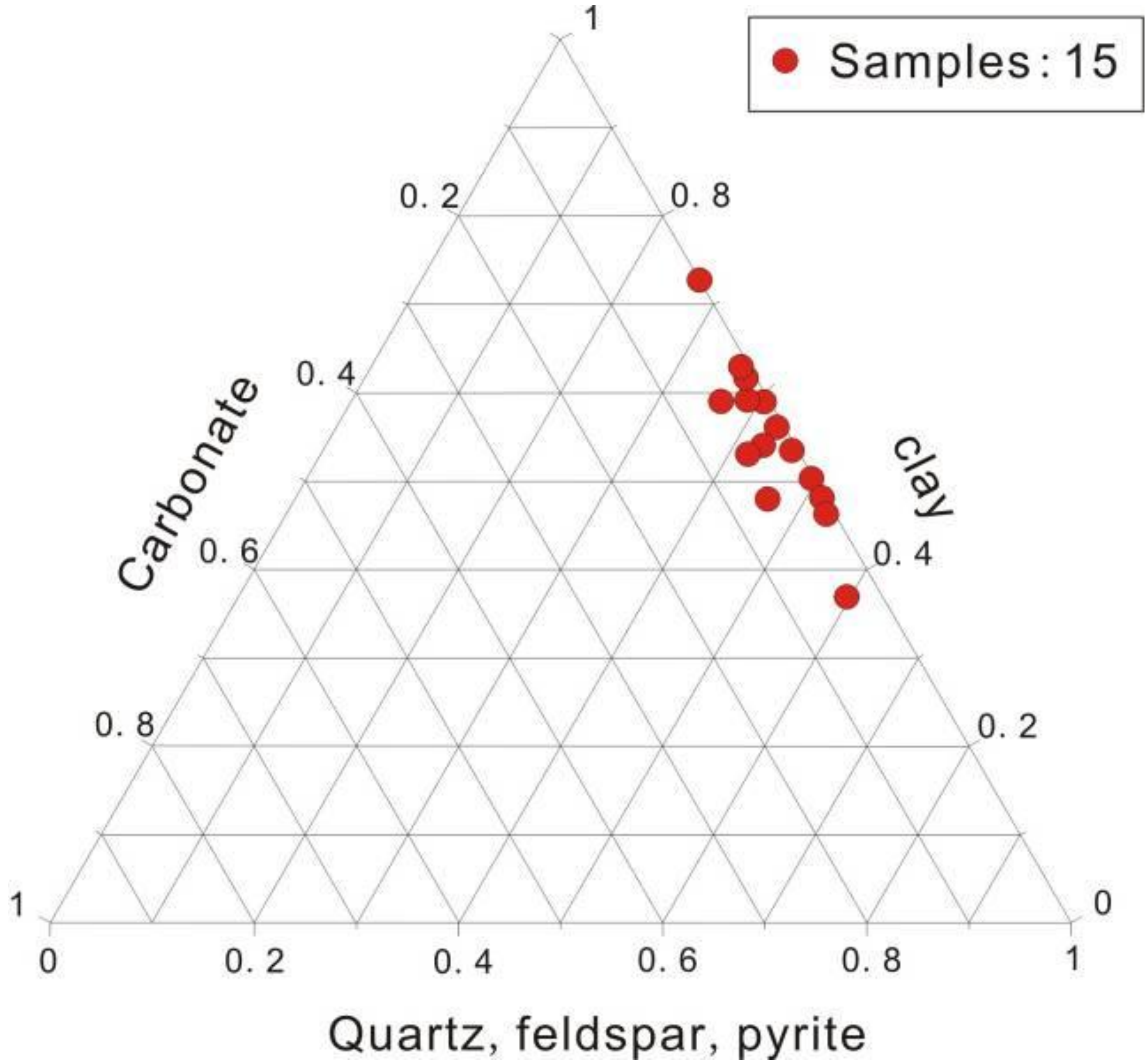

Figure 5. The mineral composition of the Chang-7 Member Shale in Yanchang Exploratory Block.

Figure 6. Desorption experiment of Chang-7 Member Shale from Yanye 4 well (1612.3 m).

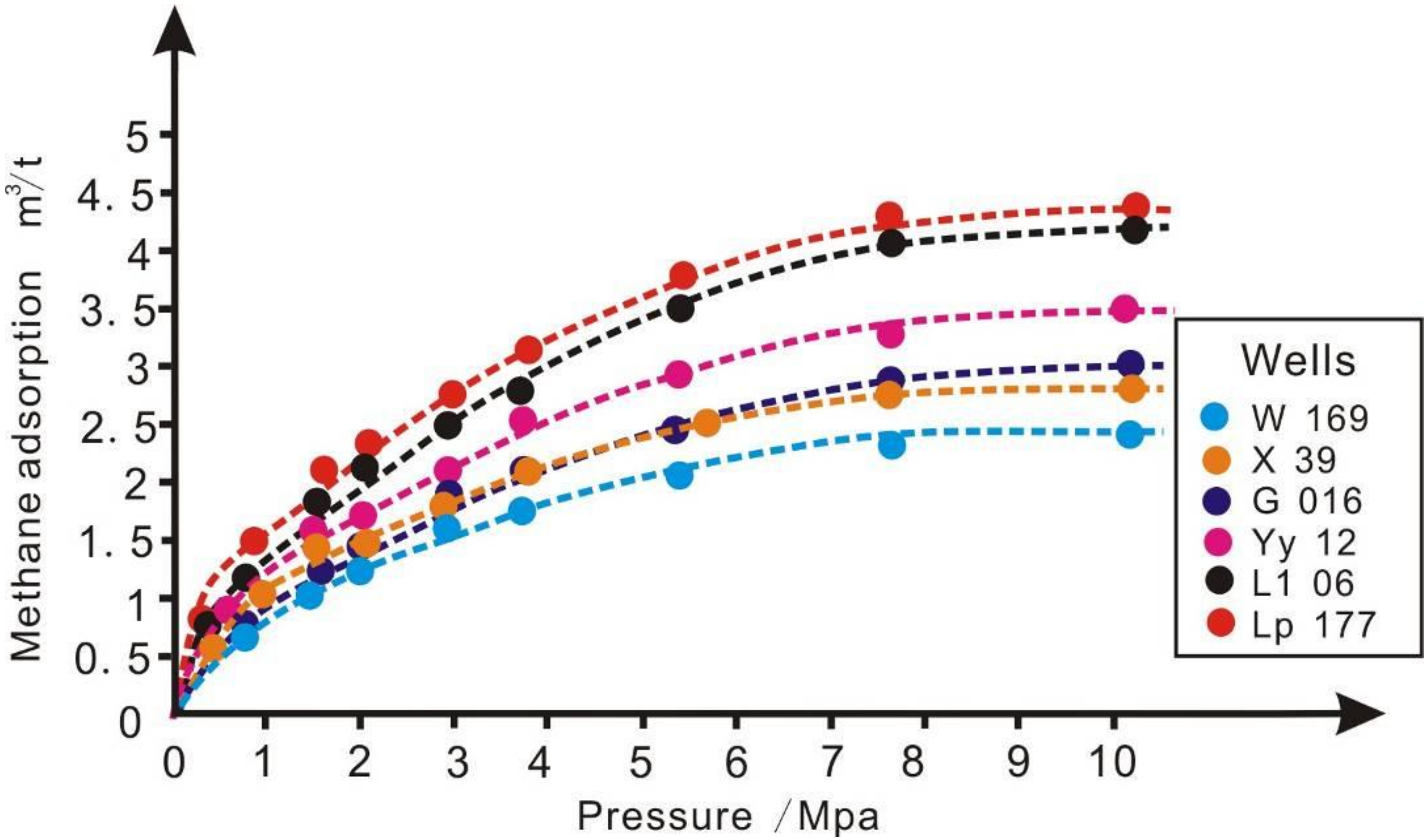

Figure 7. Methane adsorption isotherms of Chang-7 Member Shale collected from six wells.