1516910 Lower Silurian Shale Gas Potential in Chongqing Southwest China: Geological Settings and Characteristics of Longmaxi Formation

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INTRODUCTION

In China, Upper Yangzi area, especially Chongqing and its periphery, is one of the most prolific areas that develop shale gas. Several suits of Paleozoic marine shales developed in Yangzi platform. Most part of Chongqing is in the northwest of the platform and well developed Silurian shales. Silurian Formation is a good hydrocarbon source rock deposited in static and anaerobic settings. Lower Silurian Longmaxi Formation has most developed dark shales. This shale mainly distributes in southeast and northeast of Chongqing. They are characterized by high thermal maturity and high organic content. However, there is no systematic analysis yet to characterize organic rich shales. The objectives of this paper are to study the reservoir characteristics of shale gas in this area. This work may help us to optimize the favorable area for shale gas exploration.

STUDY AREA

The shale gas development areas in China which are roughly divided into four, include South, North-Northeast, Northwest and Qinghai-Tibet (Zhang, 2008). At present our preliminary study and exploration for shale gas are focus on the basin in the Midwest, and Sichuan Basin is the main gas-bearing basin in Midwest China. Chongqing (32°10′-28°107′N, 105°15′-110°15′E), 82400 km^2, locates in southwest China, eastern edge of Sichuan Basin, and upper reaches of Yangtze river, According to the favorable development condition of shale gas, Chongqing can be divided into four, Northeast, Southeast, West and Middle (Fig.1).

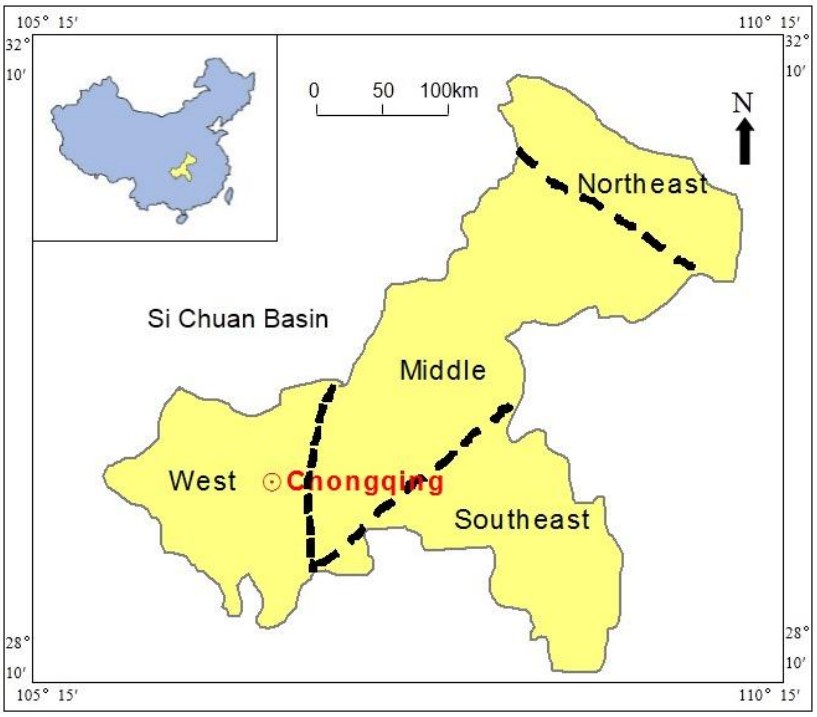

Fig.1 Location and Distribution Map of Chongqing

GEOLOGICAL SETTING

Most part of Chongqing is in the northwest of the Yangzi platform and generally suffered regional low-temperature dynamic epimetamorphism. Contact metamorphism and dynamic metamorphism also happened in invaded zone and fault zone (He et al., 1999; Pei, 2007).

Early Silurian, sea water invaded the area from south to north, presenting the shape of gulf, and the water was deep but not fluent, depositing prolific black shales, silica rocks and graptolite fossils. With the ocean basin expanding, it deposited shales, silt rocks, muddy limestone and so on in subtidal neritic sanidal environment. Middle Silurian, the depth of water increased in sediment trap. It mainly deposited shallow sanidal yellow-gray and sage green silty shales. Late Silurian, most of the area was uplifted to land, becoming a denuded area.

Silurian Formation is a good hydrocarbon source rock. Lower Silurian Longmaxi Formation has most developed dark shales. This shale mainly distributes in southeast and northeast of Chongqing. The thickness are about 25m-200m in northeast and 80m-200m in southeast, and the main lithology includes silty shales, carbonaceous shales, siliceous shales and prolific graptolite fossils (Fig.2).

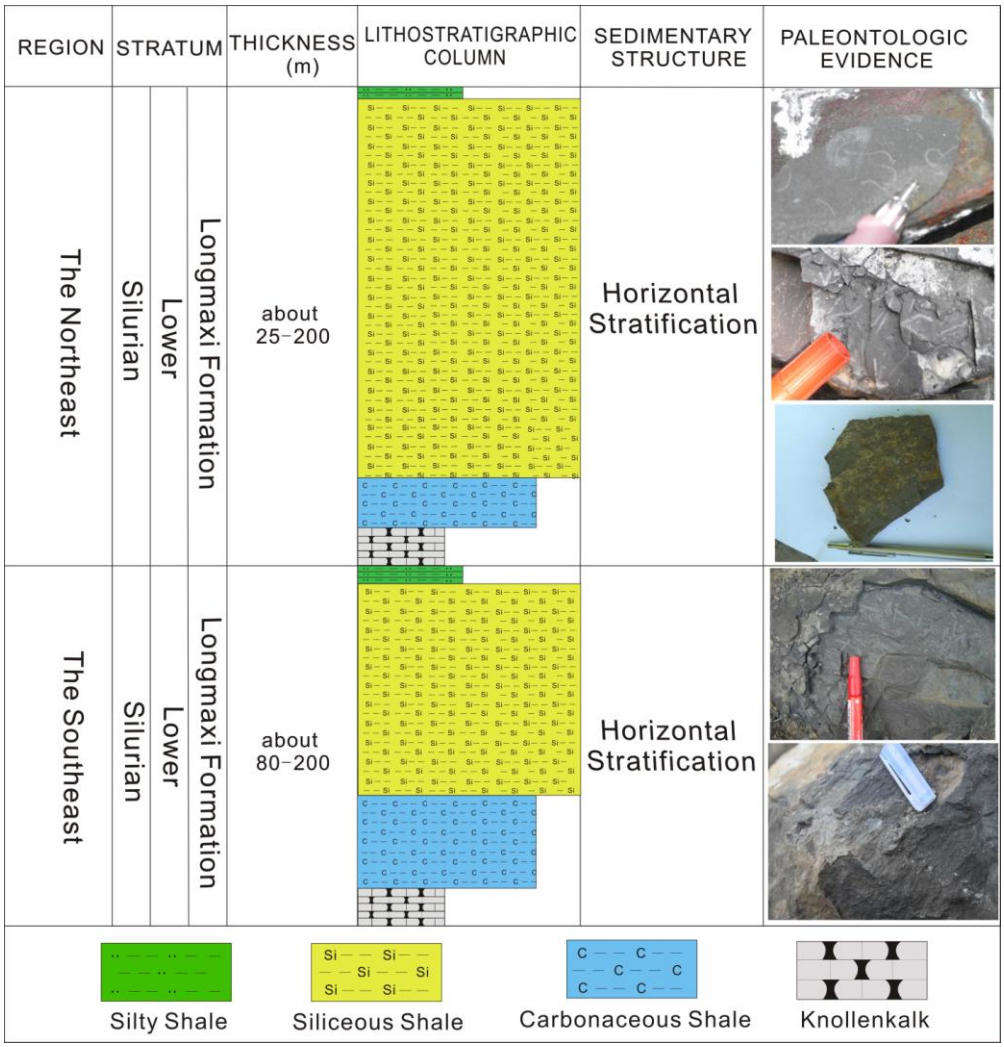

Fig.2 Lower Silurian Longmaxi Formation Stratigraphy in Northeast and Southeast of Chongqing

STRUCTURAL CHARACTERISTICS

Mainly locating in prolific shale gas accumulating zone in the southeast and east of Sichuan Basin, Chongqing is structurally in moderate-gentle slope of southeast structural belt and steep slope of east-northeast belt in Sichuan Basin. Experiencing multi-phases tectonic activities in evolvement, Chongqing is characterized with early subsidence, late uplifting, long subsidence period and short uplifting period (Liu et al., 2004; Wo et al., 2006).

Chongqing is across two tectonic units, Yangtze paraplatform and QinLing geosyncline, experiencing orogeny and tectonic activities in evolvement between Mesoproterozoic and Quaternary Period, and forms present geological tectonic framework. The area experienced multi-phases tectonic activities which named JinNing, ChengJiang, Jialidong, Hualixi, YinZhi, YanShan and XiShan.

According to positions of geotectonics and characteristics of tectonic deformation during different periods, the tectonic geological units of study area is divided into four levels (Fig.3).

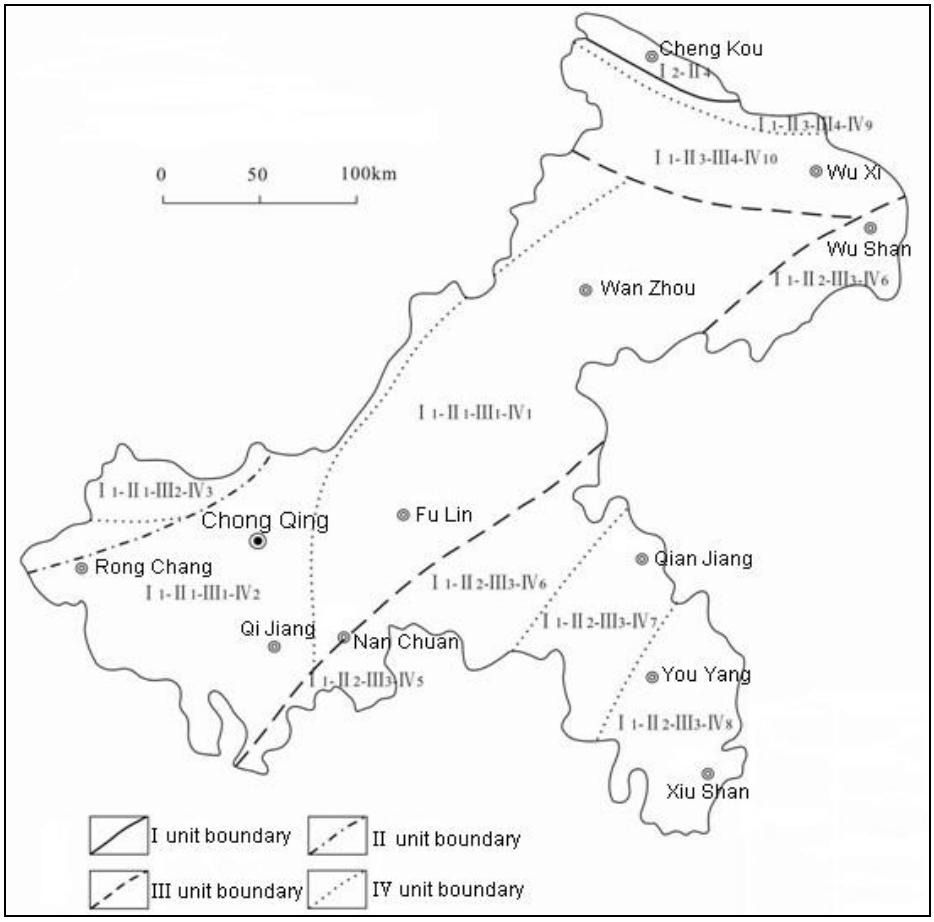

Fig.3 Structural Map of Chongqing

Level Ⅰ tectonic units: $Ⅰ_1$ Yangzi Metaplatform, $Ⅰ_2$ QinLing Geosynclinal Folded System
Level Ⅱ tectonic units: $Ⅱ_1$ Chongqing Syneclise, $Ⅱ_2$ Upper Yangzi Syneclise,
$Ⅱ_3$ DaBa Mountain Platform Edge Downwarp,
$Ⅱ_4$ DaBa Mountain North Miomagmatic Fold Zone
Level Ⅲ tectonic units: $Ⅲ_1$ Chongqing Seg-Fold Bunch, $Ⅲ_2$ Sichuan Middle Anteklise,
$Ⅲ_3$ Chongqing Southeast Seg-Fold Bunch, $Ⅲ_4$ DaBa Mountain Seg-Fold Bunch
Level Ⅳ tectonic units: $Ⅳ_1$ Wanzhou Seg-Fold Bunch, $Ⅳ_2$ HuaYing Mountain Quaquaversal Fold Bunch
$Ⅳ_3$ Longnvshi Platform Vault, $Ⅳ_4$ Zigong Platform Sag,
$Ⅳ_5$ JinFo Mountain Quaquaversal Fold Bunch,
$Ⅳ_6$ QiYao Mountain Quaquaversal Fold Bunch, $Ⅳ_7$ QianJiang Seg-Fold Bunch
$Ⅳ_8$ Xiu Mountain Quaquaversal Fold Bunch,
$Ⅳ_9$ ChengKou Seg-Fold-Fault Bunch
$Ⅳ_{10}$ DaBa Mountain South Seg-Fold Bunch

SEDIMENTARY FACIES

Forming in blocked and semi-blocked stagnant marine basin, Lower Silurian Longmaxi Formation is shallow-deep shelf deposit which controlled by gulf deep shelf deposit system. Through the sedimentary facies analysis of some profiles, the sedimentary facies of the study area mainly includes deep water continental shelf facies, shallow water continental shelf facies and sandy continental shelf facies (Fig.4 and Fig.5).

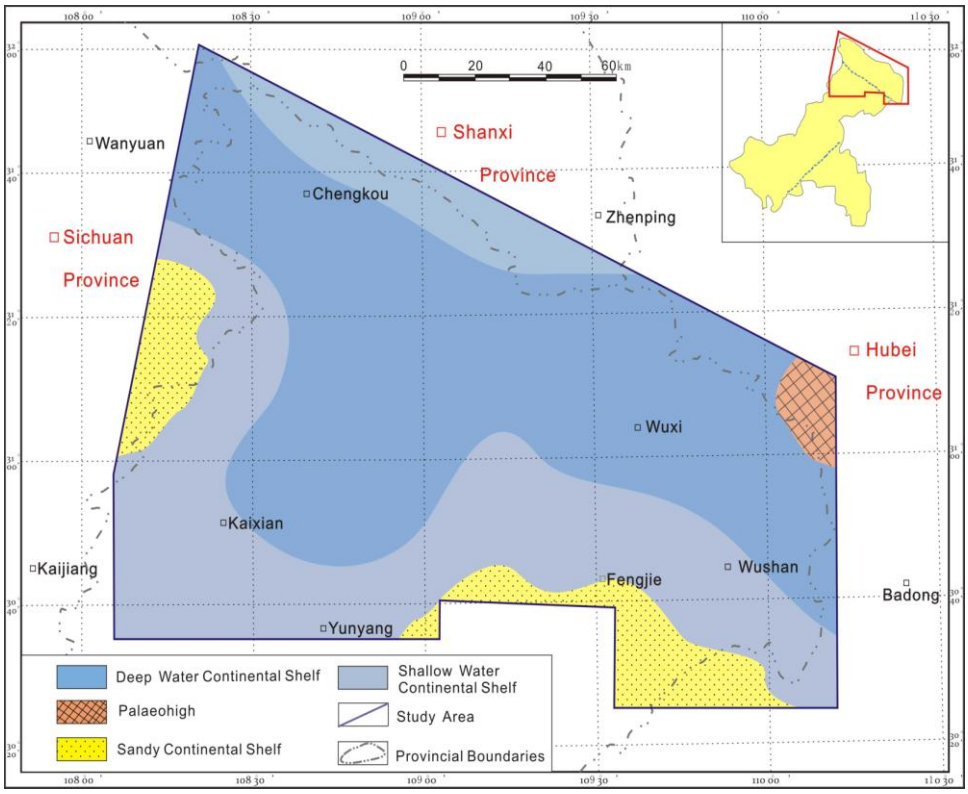

Fig.4 Sedimentary Facies map of organic-rich shale of Lower Silurian Longmaxi Formation in Northeast of Chongqing

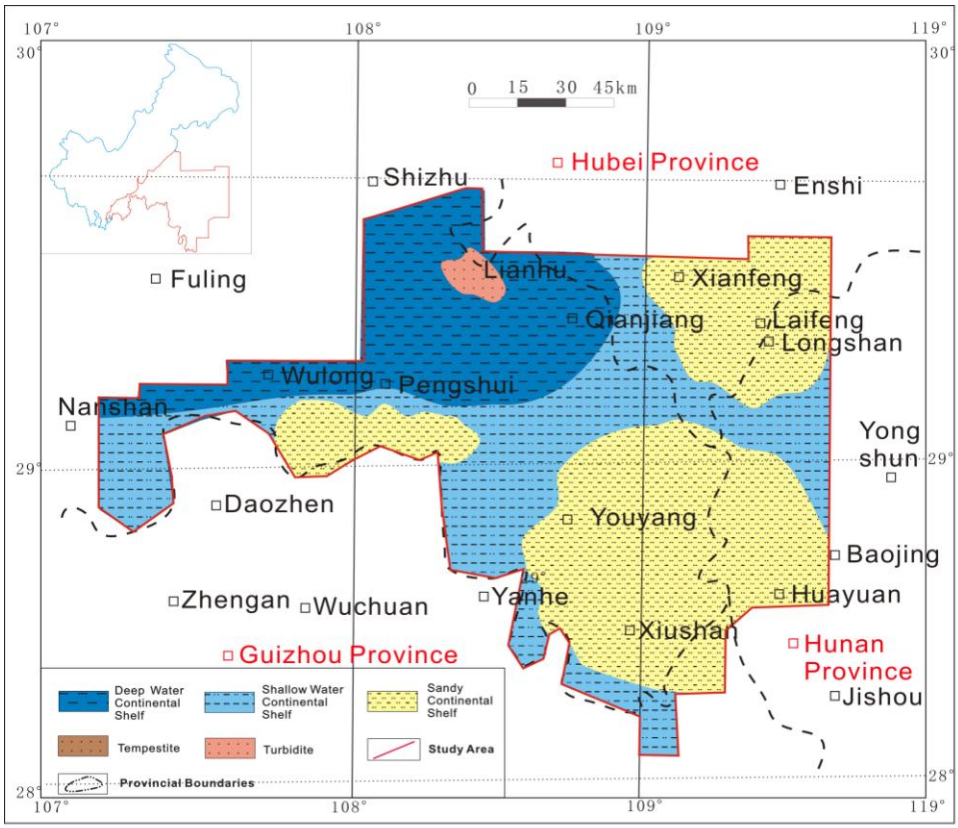

Fig.5 Sedimentary Facies map of organic-rich shale of Lower Silurian Longmaxi Formation in Southeast of Chongqing

(1) Deep water continental shelf facies

Deep water continental shelf developed in a hydrostatic strong reducing environment which is generally beneficial for the preservation of organic matter. Therefore, suspended sediment can form organic-rich dark shale after depositing, burying, compacting and diagenesis. The color of shale is usually dark gray or black and the organic content is relatively high. The lithology mainly includes black carbonaceous shale, silty shale, siliceous shale and some siltstone. In addition, a large number of graptolite fossils are contained in the shales (Fig.6, Fig.7).

(2) Shallow water continental shelf facies

Shallow water continental shelf developed in a weak oxidation-weak reducing environment. The color of shale gradually shallows, usually gray and the organic content obviously reduces. The silty content is relatively high and the lithology mainly includes gray shale, silty shale and calcareous shale (Fig.8, Fig.9).

(3) Sandy continental shelf facies

Sandy continental shelf deposited in Late Silurian, the color of shale is usually gray or light gray and the lithology mainly includes silty shale. The development of sedimentary structure is limited, which is usually horizontal stratification. Furthermore, it's almost hard to find plankton and graptolite fossils in this period (Fig.10, Fig.11).

Fig.6 Dark shale deposited in deep water continental shelf (Northeast of Chongqing)

Fig.7 Dark shale deposited in deep water continental shelf (Southeast of Chongqing)

Fig.8 Gray shale deposited in shallow water continental shelf (Northeast of Chongqing)

Fig.9 Gray shale deposited in shallow water continental shelf (Southeast of Chongqing)

Fig.10 Light gray shale deposited in sandy continental shelf (Northeast of Chongqing)

Fig.11 Light gray shale deposited in sandy continental shelf (Northeast of Chongqing)

RESERVOIR CHARACTERIZATION

The main control factors of hydrocarbon generation conditions of shale include kerogen type, micropetrological unit, TOC, Ro, pyrolysis parameters, hydrocarbon generation history and so on.

The organic composition of black shale in Lower Silurian Longmaxi Formation is mainly sapropel type kerogen. The types of kerogen in study area are mainly characterized by type Ⅰ-Ⅲ (Tab.1, Fig.12, and Fig.13).

Tab.1. Classification Standard of Kerogen Type $\delta^{13}C$

Kerogen Type	Classification Standard
Type Ⅰ	$\delta^{13}C$<-30‰
Type Ⅱ$_1$	$\delta^{13}C$=-30‰～-28‰
Type Ⅱ$_2$	$\delta^{13}C$=-28‰～-26‰
Type Ⅲ	$\delta^{13}C$≥-26‰

Fig.12 grey massive asphalt ×800 (Northeast of Chongqing)

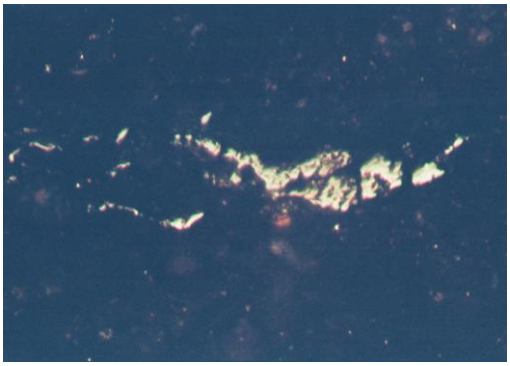

Fig.13 grey massive asphalt ×500 (Southeast of Chongqing)

Based on the measurement data of field sections and test results of samples in outcrops, the distribution range and isoline map of Ro and TOC of Lower Silurian Longmaxi Formation in

Northeast and Southeast of Chongqing (Fig.14, Fig.15, Fig.16, and Fig.17) were compiled. As seen from the four maps, Ro of shales are from about 1.8% to 5.4% and TOC are from about 2.1% to 3.7%, both mainly concentrating in the Midwest of Northeast and Southeast area.

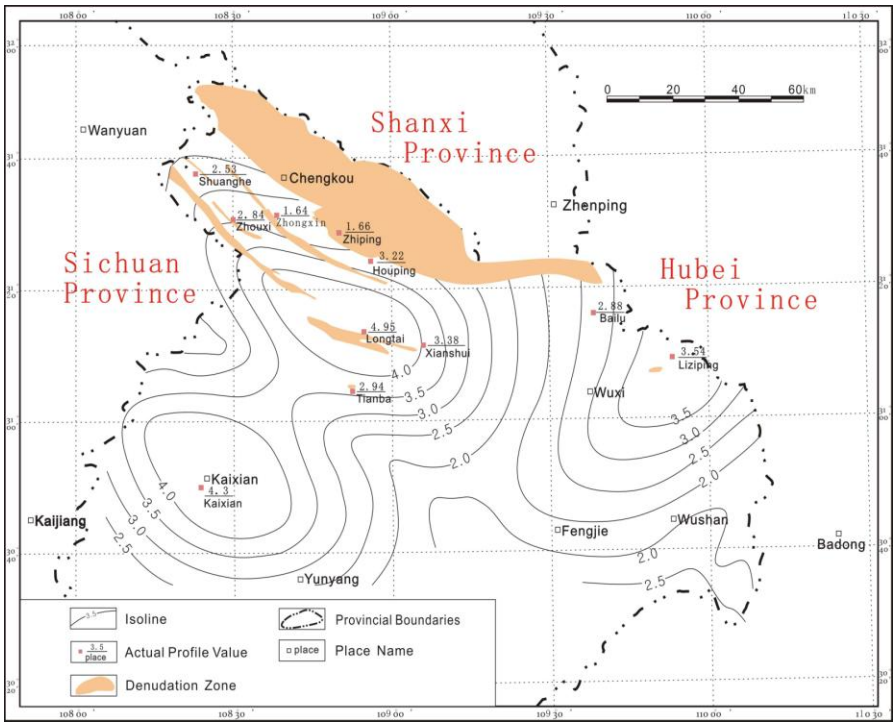

Fig.14 Distribution range and isoline map of Ro of Lower Silurian Longmaxi Formation in Northeast of Chongqing

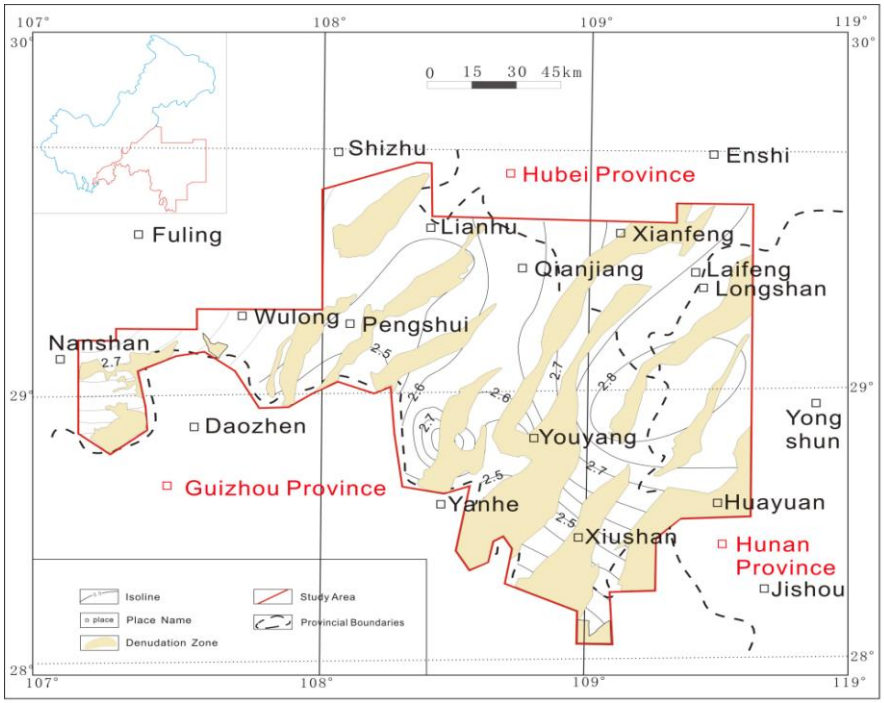

Fig.15 Distribution range and isoline map of Ro of Lower Silurian Longmaxi Formation in Southeast of Chongqing

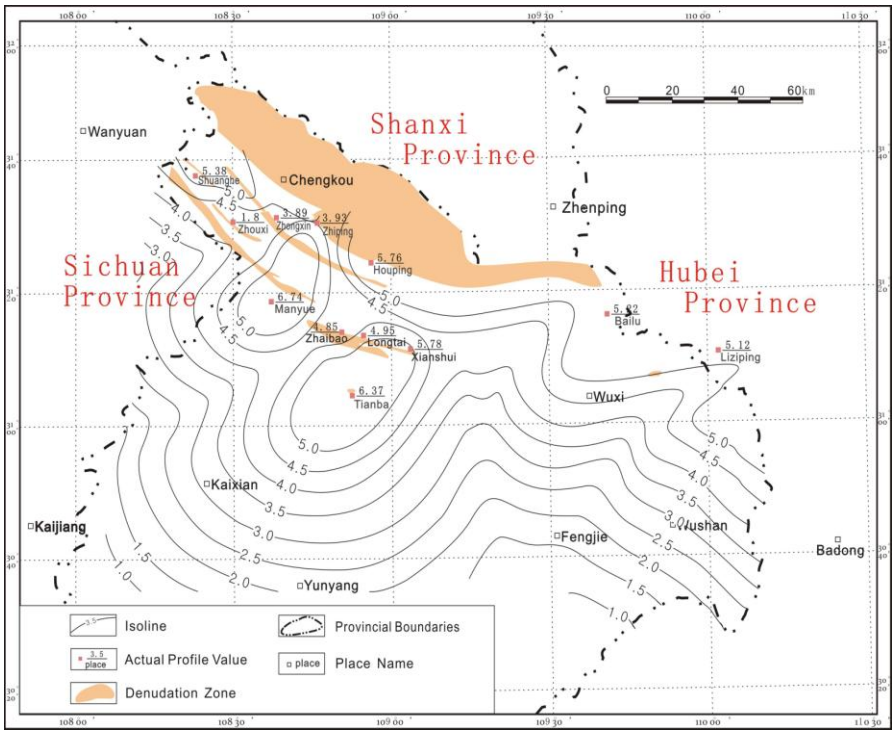

Fig.16 Distribution range and isoline map of TOC of Lower Silurian Longmaxi Formation in Northeast of Chongqing

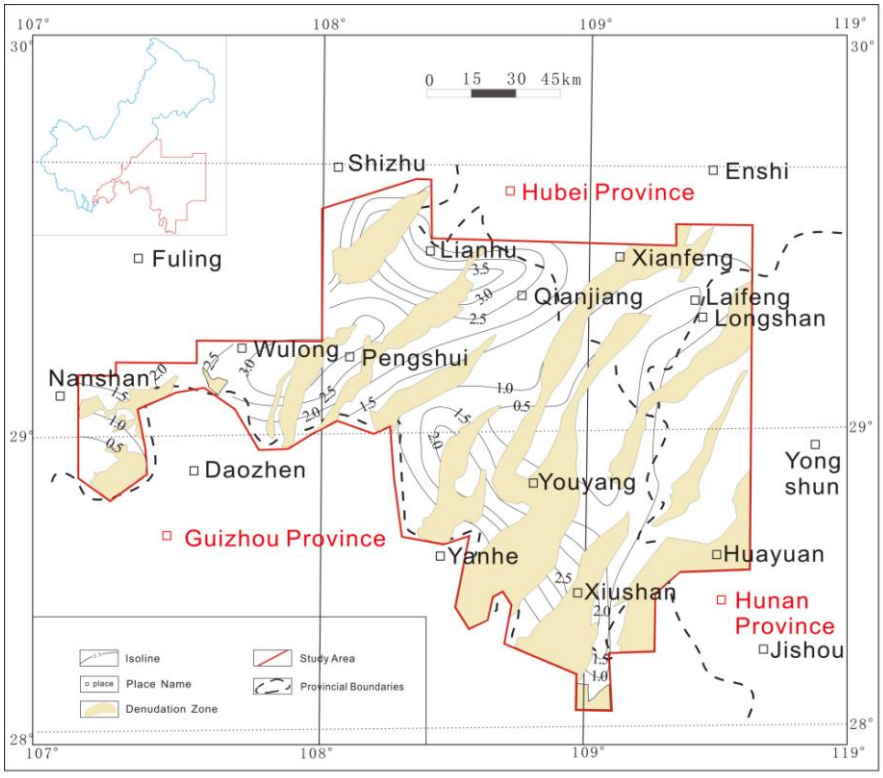

Fig.17 Distribution range and isoline map of TOC of Lower Silurian Longmaxi Formation in Southeast of Chongqing

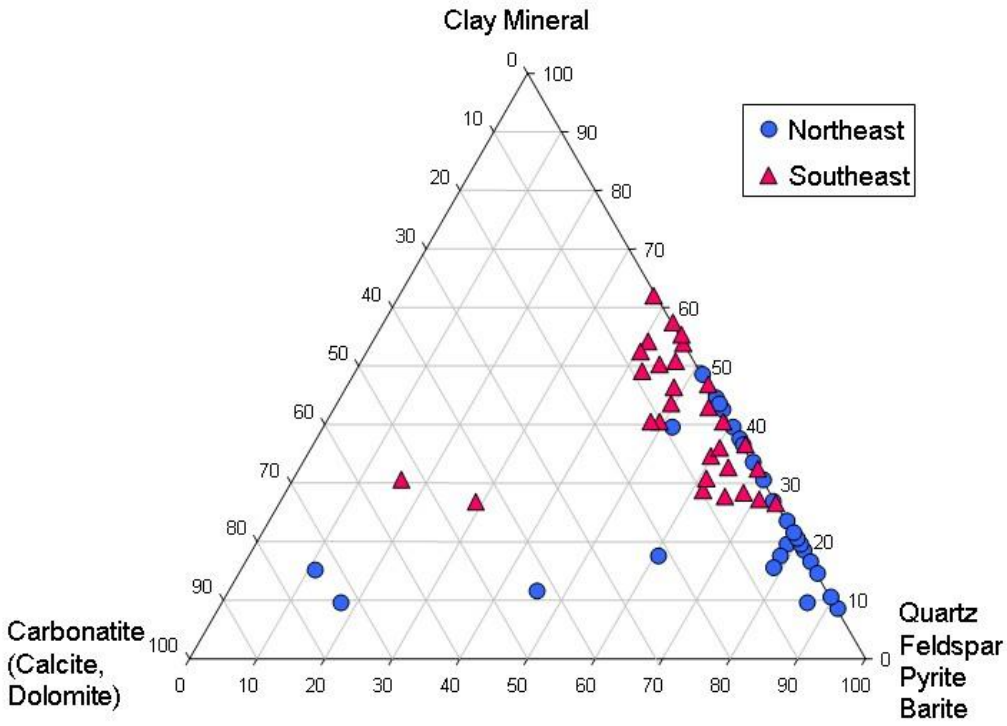

Fig.18 Distribution map of mineral composition of Lower Silurian Longmaxi Formation in study area

The main mineral compositions of black shale of Lower Silurian Longmaxi Formation are detrital mineral, clay mineral and a small number of carbonatite and pyrite (Fig.18).

In Northeast of Chongqing, the content of detrital mineral which mainly includes quartz and a small number of feldspar, is from 29% to 71% and average is about 48.7%. The content of clay mineral which mainly contains kaolinite, goeschwitzite, and andreattite, is from 27% to 62% and average is about 43.2%.

In Southeast of Chongqing, the content of quartz is from 7% to 95%, and average is about 58%. The content of clay mineral which mainly contains kaolinite, goeschwitzite, and andreattite, is from 5% to 50% and average content is about 27.5%. The content of carbonatite is from 0% to 40%

Thus it can be seen that the black shales are mainly characterized by high content of brittle mineral composition. The brittleness of rock is beneficial to engineering fracturing.

CONCLUSIONS

Most part of Chongqing is in the northwest of Yangzi platform where developed several suits of Paleozoic marine shales, and well developed Silurian shales.

Chongqing is across two tectonic units, Yangtze paraplatform and QinLing geosyncline, experiencing multi-phases orogeny and tectonic activities in evolvement between

Mesoproterozoic and Quaternary Period, and the tectonic geological units of study area is divided into four levels.

Forming in blocked and semi-blocked stagnant marine basin, Lower Silurian Longmaxi Formation is shallow-deep shelf deposit which controlled by gulf deep shelf deposit system. The types of sedimentary facies in study area mainly include deep water continental shelf facies, shallow water continental shelf facies and sandy continental shelf facies.

Test data of rock samples in outcrops confirm that the Lower Silurian Longmaxi Formation shales are mainly characterized by high organic content, high maturity, high content of brittle mineral composition, type Ⅰ- Ⅲkerogen, and have good hydrocarbon generation potential.

From the above, the Lower Silurian Longmaxi Formation in the stable area of southeast and northeast of Chongqing, are currently most prospective shale gas targets.

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ACKNOWLEDGEMENTS

We would like to thank the shale gas program, our leaders and our colleagues at Chongqing Institute of Geology & Mineral Resources and Schlumberger Zhongyu Shale Gas Technical Services (Chongqing) Co., Ltd. for financial and technical support, respectively.