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RESEARCH PAPER

Shale lithofacies and reservoir space of the Wufeng–Longmaxi Formation, Sichuan Basin, China

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Abstract: Based on observation of the outcrops and cores of the Late Ordovician to the Early Silurian Wufeng–Longmaxi shale, developed in the deep water shelf environment, in the southeast of the Sichuan Basin, the mineralogical features, lithofacies characteristics and reservoir space types were studied and the factors affecting reservoir capacity were analyzed by observation of eletron microscope and analysis of mineral content. The mineral composition is dominantly clastic quartz and clay minerals, with feldspar, calcite, dolomite, pyrite and so on. Five lithofacies, i.e. carbonaceous shale, siliceous shale, silty shale, calcareous shale and ordinary shale, were identified in the Wufeng–Longmaxi shale. Seven types of reservoir space, including structural tension fracture, structural shear fracture, interlayer lamellation fracture, pyrite pore, the inter-crystal micro-pore and micro-crack in clay mineral, the edge micro-crack around quartz grains and organic matter pore, were found in the Wufeng–Longmaxi shale. The development of reservoir space is strongly controlled by the mineral composition, lithofacies, organic carbon content, organic matter maturity and diagenesis.

Key words: Sichuan Basin; Wufeng–Longmaxi Formation; shale lithofacies; reservoir space; shale gas

Introduction

Shale gas has become a new bright spot in the global unconventional oil and gas exploration and development. In China, a series of regional basic researches show a huge potential of shale gas resources [1–4].

Predecessors mostly studied shale as source rock, but researches taking shale as reservoir rock were relatively few. Some scholars studied the reservoir characteristics, types and formation conditions, proposing reservoir evaluation parameters for shale gas [5–9]. In China, Zou et al [6] first discovered nano-pores utilizing nano-CT technology, opening a prelude to study nano-scale pores of oil and gas reservoir.

This study starting from the analysis of outcrops and drilling cores, focused on the lithology characteristics, lithofacies types and reservoir space of Wufeng-Longmaxi shale, southeast of Sichuan Basin, and discussed the controlling factors of shale reservoir properties, in hope of guiding shale gas exploration in the study area.

1 Geological setting

The study area is located in the Chuandong high-steep tectonic belt and Chuannan low-gentle tectonic belt at the southeastern edge of Sichuan Basin (Fig. 1). Since the Sinian, the Sichuang Basin has experienced multiple stages of tectonic movements, forming the tectonic framework nowadays. The study area inherited the tectonic evolution of the Sichuan Basin [7–9], forming a series of NE-SW echelon folds. At the late Ordovician, Xuefeng uplift, Chuanzhong uplift and Qianzhong uplift exposed, transforming the open sea environment into a confined sea, which served as low energy, under-compensated anoxia environment [10–11]. There were two large global transgressions at late Ordovician and early Silurian. Wufeng-Longmaxi shale is the sedimentary reaction to the two global transgressions [12–13].

Affected by tectonic movement and transgression in late Ordivician, the Wufeng Formation received a set of deep water fine deposit, mainly siliceous shale, sliceous rock and carbonate; in the depositional stage of early Silurian Longmaxi Formation, a set of fine clastic rocks, primarily black shale, settled.

Well developed outcrops can be seen in the study area, with mainly black massive shale in central and lower part (Fig. 1), rich in pyrite and grapholite; and mainly silty shale in the upper (Fig. 2, a-d). Silty shale and turbidite silt interbeds can be found in the upper part, with slump deformation and flute cast structures (Fig. 2, e and f). The thickness of shale is relatively large, ranging from 20 to 200 m. Besides, Wufeng-

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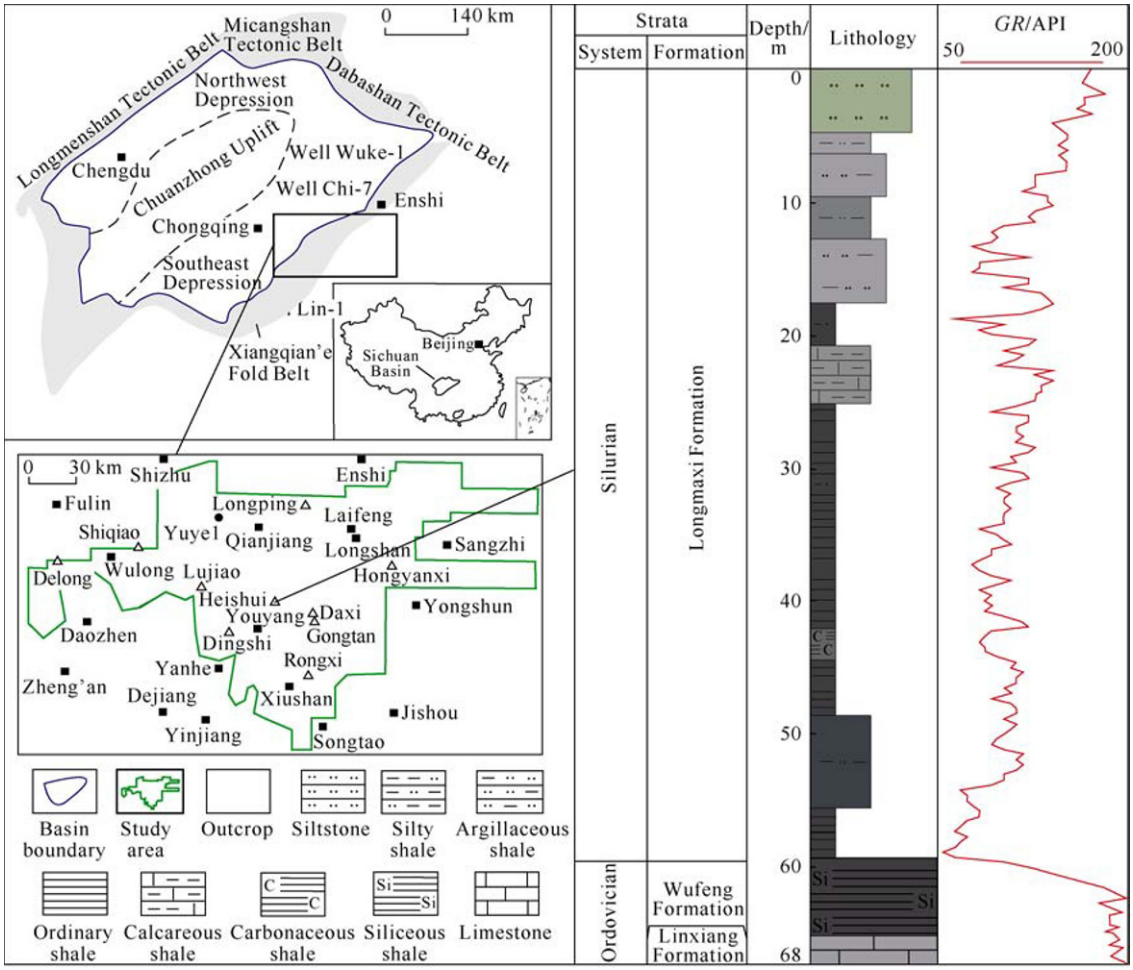

Fig. 1 Sketch map of study area and lithology of Wufeng-Longmaxi formations

Longmaxi shale is rich in organic matter and acts as an important source rock layer and the key exploration target of shale gas in the study area.

2 Lithofacies

2.1 Minerals composition

Shale in the Wufeng-Longmaxi Formation is dominantly composed of clay minerals and quartz (Fig. 3), with a little plagioclase, potassium feldspar, calcite, dolomite and pyrite. The content of clay minerals ranges from 24.7% to 65.7%, with an average of 47.6%; the content of quartz is between 25% and 65%, with an average of 42.4%; carbonate component is rare, ranging from 2% to 20%, with an average of 3.2%. Clay mineral is mainly illite, with a little kaolinite and chlorite. The relative content of illite ranges from 75% to 91%, while the content of kaolinite is rare, ranging from 2% to 5%. Quartz is mainly terrigenous, and the particle size is mainly silt-clay, layered or floating distributed in the shale. The carbonate mainly exists in the form of crack fillings and cement. Deposited in deep water environment, the interval in study is relatively rich in pyrite. Lenticular pyrite can be seen in cores of Well Yuye1, with intergranular pores filled by calcite (Fig. 2c). In addition, some endogenous biogenic silicon can be identified in local area. Siliceous microorganisms, mainly siliceous sponges are found in black siliceous shale of Lujiao outcrops; and are also found in Well Lin1, Wuke1 and Chi7, accounting for about 0.1%–3.5% [14].

2.2 Lithofacies division

Based on outcrops, cores and microscopic observation, according to the mineral composition, five lithofacies can be identified in Wufeng-Longmaxi shale: carbonaceous shale, siliceous shale, silty shale, calcareous shale and ordinary shale.

In the study area, mudstone and shale in traditional concept can't be well identified and compared across the region, therefore mudstone and shale both can be called shale here. Ordinary shale here means the shale whose clay minerals content is more than 90%. Grapholites can be enriched in siliceous shale, silty shale and ordinary shale, so grapholite shale is not divided individually.

2.3 Lithofacies

2.3.1 Carbonaceous shale

Carbonaceous shale contains plenty of carbonized organic matters, with organic carbon content ranging from 3% to 15%. Carbonaceous shale is black and gray, stained hands in hand specimens. Carbonaceous shale is mainly composed of clay