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The Micro-heterogeneity Characteristic of the Marine Shale Reservoirs and its Impacts on Water and Gas in Reservoir — a Case Study of Longmaxi Formation and Wufeng Formation Shales in Chongqing area

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Abstract This study presents the relationship between heterogeneity and migration/distribution of water and gas in shale reservoir of Longmaxi and Wufeng Formations. Shale reservoir heterogeneity characteristics of porosity, cracks, mineral composition, organic matter especially on micron/nano scale were observed by methods of mercury intrusion, field emission scanning electron microscopy experimental techniques, XRD and the effect on distribution and characteristics of internal moisture migration are discussed in this paper. The heterogeneity of porosity and microfractures are the main controlling factors on migration and distribution of water and gas. The fractal dimension can quantitatively evaluate the complexity and heterogeneity of pores.
Keywords shale reservoir, heterogeneity, pore structure, micro/nano-scale

Introduction

Shale gas is a kind of unconventional natural gas which exists in rich organic shales mainly stored in free and attached states (Zhang 2004). The research of shale reservoirs is focused on the porosity and permeability. Low porosity (less than 10%) and low permeability (μD-nD) are obvious characteristics of shale reservoir. Shale gas mainly stored in attached state in the shale reservoir with few free gas, oil-solution gas and water-soluble gas.

The heterogeneity of reservoir characteristics has been gradually paid attention to in the research of enrichment mechanisms and reservoir physical property of shale gas (Liu 2011,Hu 2013, Zhou 2013).In this study, heterogeneity characteristics and its impacts on water and gas are observed by methods of high pressure mercury intrusion, field emission scanning electron microscopy experimental techniques and XRD .

Heterogeneous characteristics

Changes of mineral components in the shale reservoirs are mainly controlled by the silty sedimentary laminae and interlayers. In Guanyinqiao profile, the silt content of Longmaxi Formation increased obviously for both appearing frequency and thickness. Many drillings nearby shows gas logging anomaly on the position of interlayers. The deposition surface and vertical surface shows a great difference in microstructure characteristics, reflecting the heterogeneity characteristics in different aspects in three dimensional space.

XRD experiment shows that the main mineral components of the reservoir consist of clay minerals, brittle minerals and other components (fig. 1).The Longmaxi formation shale reservoir mineral component changes significantly in vertical direction. Mineral components at the bottom of Guanyinqiao profile change little and are obviously different at the middle-upper part. Profile shows that the quartz content is higher at lower part and reducing upward .The content of calcite and some clay minerals including illite and chlorite increase upward. Changes of mineral components were reflected also in the lateral distribution. Source centers are different in the capability of providing detrital sediments. The shale reservoir

mineral types and content changed due to distance to the sedimentary center and source center.

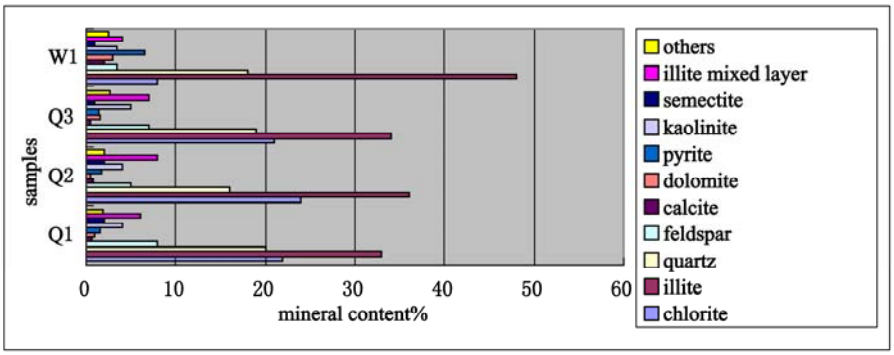


Fig.1 *Mineral components of samples ($Q_{1\sim3}$ from S_{1l}; W_1 from O_{3w})*

The pore size distribution of shale reservoir is extremely heterogeneous. The main pore size is under 120nm and a small amount of pores lies on micron size (fig. 2).

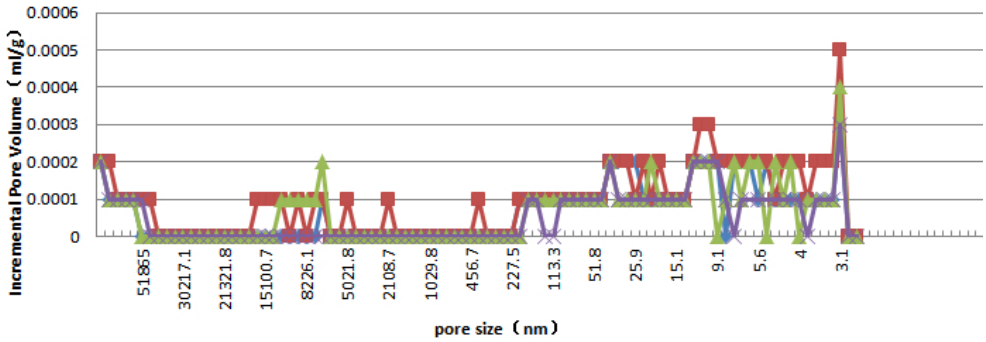


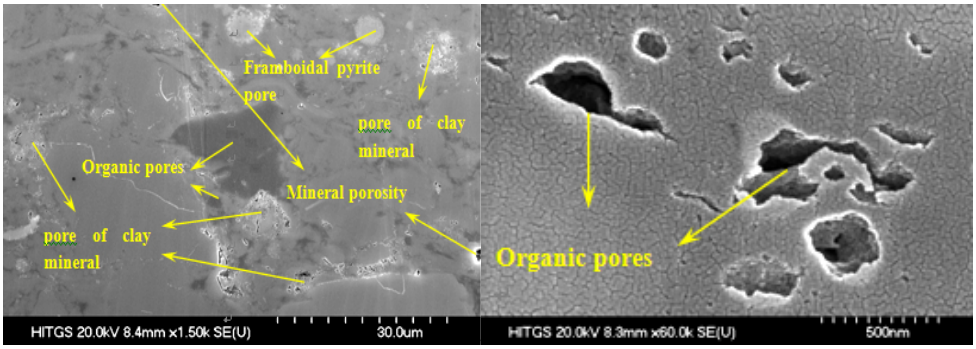
Fig. 2 *Distribution of shale pore size*

Compared with the conventional reservoir, shale reservoir has characteristics of pore size being on the nanoscale with pore structure more complex and micro heterogeneity more significant. The heterogeneity research of pores should correspond to the main aperture, and shale pores were observed on the nanoscale that the pore types are identified by the origin-morphology (fig. 3). Different pore types have different structure, main aperture and degree of heterogeneity in distribution.

The shale reservoir organic characteristics have strong heterogeneous features. Variation of vertical organic characteristic reflected (table 1) in kerogen type I at the bottom and upward II-1/II-2 appears. The average of TOC decreases upward: the average abundance at the bottom is higher than 2%(approaching 3%)and turned to be less than 1% on upper positions. There are changes on other organic characteristics, like organic matter maturity.

Table 1 *Organic characteristics of Longmaxi Formation*

Section of profile	Type of kerogen	Organic matter abundance	Organic maturity
Bottom	I	>2%	Over mature
Central section	I~II-1	1%~2%	High-over mature
Upper section	II-1~II-2	<1%	High-over mature



(a) Complex pore type *(b) Nano pores in organic matters*

Fig.3 *Recognition of shale reservoir*

Fractal model

Shale reservoir pore has fractal characteristics. Calculation formula of shale pore fractal model :

$$D=4+\ln(dV/dp)/\ln p \qquad (1)$$

Where:

D—fractal dimension;
V—Pore volume（mm^3/g）;
P—pressure（MPa）.

Fractal dimension of "3" means completely replacement. The higher the dimension is, the stronger the heterogeneity will be. Shale reservoir is kind of porous media with characteristics of developed reticular fracture and poor connectivity. By studying the fractal dimension (table 2) and adsorption characteristics, the pore structure of shale can be divided into three types: seepage pore, coagulating-absorption pore and absorption pore with boundaries of 285nm and 45nm which reflect the impaction of pore size on occurrence - flow state of gas.

Table 2 *Fractal dimension of pores*

Sample	Dimension(Low pressure)	Dimension(High pressure)
Q-1	2.93	3.09
Q-2	2.95	3.18
Q-6	2.94	2.91

Discussions

The impact of reservoir heterogeneity on distribution and characteristics of internal moisture migration are analyzed systemically, and the results are as follows:

① Porosity and permeability of homogeneous shale was so poor that internal fluid was unable to release. The heterogeneity caused by sedimentary laminae and interlayers was the foundation of the drilling of shale gas. Horizontal lamination directly affected the gas shale. Thin layers in shale have low porosity /permeability and large capillary pressure. It is easy to form a preferential seepage channel in the silty sedimentary laminae and interlayers (they are mechanical weak planes when fracturing). Organic matter with obvious stratification can also form seepage channel.

② The distribution of reservoir space has characteristics of strong microscopic heterogeneity, poor connectivity and nonuniform distribution. Porosity controls the distribution of shale gas and water. The release of gases need channels from the pores to microfractures. These microfractures have dominant flow direction which is easier for gas to flow. Relationship between molecular kinetic diameter and pore diameter controls the mechanism of storage and diffusion. The main aperture of shale(<50nm) is within the scope of absorption pore(<45nm) and this is the reason why shale gas is mainly stored in absorption state.

③ The linear relationship between permeability and porosity of the shale reservoir is not good. Diameter of most pores is smaller than the size of seepage channel. So pores make very little contribution to permeability. Microfissure developed well in high permeability part of the profile. The diameter of effective pores determined the transfusion way of the shale gas. The diffusion of shale gas through the pores was a comprehensive result of volume diffusion, Knudson diffusion and surface diffusion. When the aperture was bigger than the molecular free path, the methane molecular interaction will influence the diffusion most conspicuously. Otherwise,the Knudson diffusion was regarded as the main way. Gas transfuses in a state of attachment and when the gas transfuse into pores, microfractures and artificial/natural fracture more than 100 nm , it began to flow in darcy flow including laminar and turbulence.

Conclusions

The marine shale reservoirs shows great heterogeneous characteristics in mineral components, pore characteristics and organic characteristics. The heterogeneous characteristics is greater on micro-scale. The shale reservoir heterogeneity controlled the distribution and characteristi cs of internal moisture migration. The fractal dimension can quantitatively evaluate the compl exity and heterogeneity of reservoir pores.

Acknowledgements

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