Mineral composition and brittleness evaluation of shale gas reservoir in the early Cambrian Qiongzhusi formation of Huize area, Eastern Yunnan Province

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Abstract. The brittleness of shale gas reservoir determines the effect of fracturing reconstruction, which is of great significance for improving shale productivity. The study of shale brittleness evaluation can provide basic data for fracturing design. The mineral composition characteristics of shale gas reservoir in the early Cambrian Qiongzhusi formation of Huize area, Eastern Yunnan Province are reported in this paper, and the brittleness is evaluated according to the proportion of brittle minerals in total minerals. The results show that the mineral composition of the reservoir is complex. After comparing the brittleness index calculated by different formulas, it is considered that the minerals with high young's modulus and low poisson's ratio should be considered as brittle minerals, which is conducive to the universality of the brittleness index formula and the objectivity of reservoir brittleness evaluation. Shale gas reservoir of Qiongzhusi formation is obviously divided into two sections: the layers of 1 to 7 with a large brittleness index (77.60% on average) on the lower part are beneficial to reservoir fracturing reconstruction, while the layers of 8 to 14 with a small brittleness index (37.78% on average) on the upper part are not conducive to reservoir fracturing reconstruction. This study is conducive to guiding further exploration and development of shale gas in the research area.

1. Introduction

Brittleness is a comprehensive characteristic of materials, and it is the ability to generate internal non-uniform stress under its own natural heterogeneity and external specific loading conditions, and lead to local failure, thus forming a multi-dimensional fracture surface[1]. Shale gas reservoir has typical characteristics of low porosity and ultra-low permeability, and basically has no productivity in the natural state. Only through horizontal well drilling and fracturing reconstruction technology can shale gas be economically and effectively extracted[2]. The study found that the brittleness of shale can significantly affect the fracturing effect and the stability of the well wall[3, 4], which is an important basis for target selection, reservoir mechanics evaluation, selection of perforation modification interval and design of fracturing scale[5].
At present, there are mainly three methods for predicting brittle mineral index: (1) brittle mineral index evaluation method based on rock elastic parameters[6-10]; (2) evaluation methods based on strength, hardness and robustness of laboratory rock mechanics tests [1]; and (3) brittle mineral index method based on experimental analysis of mineral composition[11-16]. The brittleness of reservoir can be evaluated by calculating the percentage of brittle mineral content in the total mineral volume. Although the plane prediction of the underground brittleness index cannot be achieved, the results can be relatively objective and accurate.

The early Cambrian Qiongzhusi formation (Є1q) and late Ordovician Wufeng formation - early Silurian longmaxi formation (ò3w-S1l) are widely developed in southern China, with high organic matter abundance and maturation, and geological conditions for shale gas formation[17]. Shale gas in Wufeng formation - longmaxi formation has made a major breakthrough and successfully achieved industrial development, becoming the main production layer of shale gas in China[18]. Shale gas in Qiongzhusi formation has achieved little exploration results, and only a few Wells have obtained industrial gas flow[19]. The reservoir characteristics, gas-bearing characteristics, geochemical characteristics and genesis of Qiongzhusi formation shale have been exploratory reports by predecessors[20-23], which is not enough to guide shale gas exploration and development in this area in the next step. On the basis of previous studies, whole-rock X-ray diffraction (XRD) analysis of Qiongzhusi formation shale in huize area, east yunnan province, was performed to study its mineral composition and brittleness characteristics, providing basic data for subsequent exploration of favorable targets.

2. Geological setting
Yunnan province is located at the junction of the Tethys-Himalayan tectonic domain and the Circum Pacific tectonic domain, and to the east of the collision zone between the Indian plate and the Eurasian plate. Huize area in eastern yunnan belongs to the southwest margin of the Yangtze block and is located in the northwest of Mile fault and the east of Xiaojiang fault. This area belonged to platform or quasi-platform from sinian to jurassic, and uplifted and denuded in yanshanian and xishanian, so the proterozoic-cenozoic strata were developed, with a dual structure composed of folded basement and sedimentary cover. During qiongzhusi stage in early Cambrian, the depocenter of eastern yunnan was located in the area of huize - qujing - Malone, and the black rock series composed of black-grey-green shale, silty shale, carbonaceous shale and argillaceous siltstone were deposited[21, 23].

3. Samples and experiments
Samples were collected from Laolin village, Dahai township, Huize county. The Qiongzhusi formation outcrop section is well developed with few overhangs. 21 samples were taken from bottom to top, depending on the color, structure and structure of the rock. In the sampling process, fresh rocks with weak weathering alteration should be selected to minimize or eliminate the influence of sampling difference and mechanical differentiation on the mineral composition of sediments.

According to the standard (SY/T 5163-2010), these samples have completed X-ray diffraction (XRD) experiments in Henan Polytechnic University (HPU): experimental method was XRD full spectrum fitting; qualitative recognition software was HighScore Plus; quantitative analysis system was Rockjack; experimental instrument was bruker D8 advance diffractometer (Germany); and whit the experimental conditions of 5°-65° scanning angle, 1°/min scanning speed, 40 kv voltage and 40 mA electric current.

4. Results and discussion
4.1 Mineral composition
The rock mineral composition of the reservoir is relatively complex (table 1), mainly including clastic minerals such as quartz, plagioclase and potassium feldspar, carbonate minerals such as calcite and dolomite, and clay minerals. The content of quartz ranged from 5.30% to 59.34%, with an average of
29.48%. The content of plagioclase ranged from 0 to 22.11%, with an average of 7.84%. The potassium

Table 1. Mineral composition of shale gas reservoir in the early Cambrian Qiongzhusi Formation of Huize area, Eastern Yunnan Province

| Samples | Detrital minerals | Carbonate minerals | Clay mineral | Other minerals |
|---------|------------------|-------------------|-------------|--------------|
|         | Quartz           | Potash feldspar   | Plagioclase | Calcite       |
| Dh1     | 33.41            | 4.32              | 0.57        | 48.46        |
| Dh2     | 59.34            | -                 | 2.89        | 16.92        |
| Dh3     | 5.30             | -                 | 85.44       | 4.33         |
| Dh4     | 53.71            | 0.34              | 2.27        | 2.13         |
| Dh5     | 21.02            | 1.18              | 15.54       | 56.60        |
| Dh6     | 46.31            | 2.89              | 0.89        | 38.02        |
| Dh7     | 18.03            | 6.50              | 1.88        | 47.28        |
| Dh8     | 30.64            | 11.84             | 0.78        | 0.56         |
| Dh9     | 25.63            | 11.85             | 8.73        | 5.21         |
| Dh10    | 25.82            | 19.51             | 2.14        | 1.48         |
| Dh11    | 30.76            | 15.52             | 0.57        | 28.61        |
| Dh12    | 35.96            | 0.04              | 3.98        | 0.20         |
| Dh13    | 25.13            | 0.18              | 6.11        | 1.32         |
| Dh14    | 22.69            | -                 | 4.82        | 2.77         |
| Dh15    | 29.08            | 0.27              | 5.12        | 1.53         |
| Dh16    | 20.20            | 1.16              | 3.96        | 4.76         |
| Dh17    | 25.55            | -                 | 4.26        | 3.29         |
| Dh18    | 26.47            | 0.12              | 3.53        | 6.50         |
| Dh19    | 26.75            | -                 | 4.69        | 4.15         |
| Dh20    | 23.48            | -                 | 2.53        | 1.77         |
| Dh21    | 33.87            | 0.34              | 3.94        | 0.73         |

Note: The symbol “-” indicates undetected.

Figure 1. The variation characteristics of main mineral content and brittleness index in longitudinal direction
feldspar content ranged from 0 to 19.51%, with an average of 5.41%. The content of calcite ranged from 0 to 85.44%, with an average of 7.36%. The content of dolomite ranged from 0 to 56.60%, with an average of 12.56%. The clay minerals ranged from 3.29% to 64.55%, with an average of 38.35%. In addition, it contains a small amount of rock salt, gypsum, anatase and the jarosite, which is oxidized from pyrite.

4.2 Brittleness Evaluation

At present, when evaluating the brittleness of shale reservoirs according to the proportion of brittle minerals in total minerals, different scholars all regard quartz as a brittle mineral, but there is a big difference on whether other minerals belong to brittle minerals [16]. According to formula (1) ~ (5), the brittleness index of reservoir is calculated and compared.

\[
BI_1 = \frac{W_{\text{quartz}}}{W_{\text{total}}} \times 100\% \quad (1)
\]

\[
BI_2 = \frac{W_{\text{quartz}} + W_{\text{feldspar}}}{W_{\text{total}}} \times 100\% \quad (2)
\]

\[
BI_3 = \frac{W_{\text{quartz}} + W_{\text{carbonate}}}{W_{\text{total}}} \times 100\% \quad (3)
\]

\[
BI_4 = \frac{W_{\text{quartz}} + W_{\text{carbonate}} + W_{\text{feldspar}}}{W_{\text{total}}} \times 100\% \quad (4)
\]

\[
BI_5 = \frac{W_{\text{quartz}} + W_{\text{carbonate}} + W_{\text{feldspar}} + W_{\text{pyrite}}}{W_{\text{total}}} \times 100\% \quad (5)
\]

In the formula, BI represents the mineral brittleness index, and W represents the mass fraction of each mineral component. The calculation results of each formula show that (jarosite stands for pyrite, because it is the weathering product of pyrite), the brittleness index has great difference (figure 1), but BI$_3$, BI$_4$ and BI$_5$ have the same change in section, which is due to the complex mineral composition of the whole rock of the reservoir. Therefore, for the universality of brittleness index formula and the objectivity of reservoir brittleness evaluation, all minerals with high brittleness degree with high young's modulus and low poisson's ratio should be regarded as brittle minerals. In this regard, BI$_5$ is the optimal formula to calculate the brittleness index. BI$_5$ value is between 32.90% and 95.35%, with an average of 58.64%. It is obviously that shale gas reservoir of Qiongzhusi formation is obviously divided into two sections: the brittleness index of layers 1 to 7 is large, with an average of 77.60%, which is conducive to reservoir fracturing and reconstruction; and layers 8 to 14 have a small brittleness index, with an average of 37.78%, which is not conducive to reservoir fracturing and reconstruction.

5. Conclusion

For the universality of brittleness index and the objectivity of reservoir brittleness evaluation, all minerals with high young's modulus and low poisson's ratio and high brittleness degree, such as quartz, feldspar, calcite, dolomite and pyrite, should be considered as brittle minerals. Shale gas reservoir of Qiongzhusi formation is obviously divided into two sections: the layers of 1 to 7 with a large brittleness index (77.60% on average) on the lower part are beneficial to reservoir fracturing reconstruction, while the layers of 8 to 14 with a small brittleness index (37.78% on average) on the upper part are not conducive to reservoir fracturing reconstruction.

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