Identifying coal structure using logging data

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Abstract. Coal structure, which is important for the mining of CBM, is closely related to the coal reservoir fracture characteristics. This paper calculates the integrity coefficient, stability coefficient and fracture coefficient of coal, and constructs a chart confirming the division standard of the coal structure in the study area. The research results show that coal mechanical parameters can effectively represent coal structure. The integrity and stability coefficients of undeformed coal are the highest, and its fracture coefficient is the lowest; the integrity and stability coefficients of fragmented coal, granulated coal and mylonitized coal gradually decrease, and their fracture coefficients gradually increase. The methods described in the paper can classify coal structure relatively accurately and provide an effective new method for the delimiting of coal structure.

1. Introduction

Coal structure has an important influence on the effect of fracturing during the exploitation of CBM. The degree of development of tectonic coal is the key factor for influencing the exploitation of CBM. It not only reduces the permeability of the coal seam, but it also resists technological measures such as fracturing [1]. Because of the characteristics of tectonic coal, such as low mechanical strength, loose coal structure and no brittle fracturing, it is difficult to develop fractures. With the formation of cracks during fracturing, the cracks will be blocked by collapsing coal, which will prevent the permeability of the coal seam from improving [2]. As a result, the degree of development is important for the classification of CBM reservoir quality and the optimization of fracturing layers when using logging data to make a reasonable classification of the coal structure of the CBM reservoir.

Because of the characteristics of coal, such as brittleness, frangibility and low mechanical strength, the coal is easily broken during drilling and coring, resulting in a low coring recovery rate and expensive coring cost. Identifying the coal structure by cores is limited by the degree of integrity and number of cores [3]. There is no doubt that logging data are very valuable and contain important physical information for identifying the coal structure [4]. Based on the idea that different coal
structures have different logging response characteristics, Fu Xuemei and other scholars used logging data, such as resistivity, GR, density and AC, to identify the coal structure, and obtained good results [5]. When the coal is under the influence of tectonic stress, the coal structure will transform from coal with a native structure to fragmented coal, granulated coal and mylonitized coal. Accordingly, the mechanical characteristics of coal also change [6]. That is, the mechanical parameters of coal associated with different coal structures have certain characteristics [7,8]. Based on the mechanical parameters of coal calculated by logging data, this paper systematically analyses the internal relationships between different coal structures and their mechanical parameters, which provide a new method for the identification of coal structure using logging data.

2. The construction of coal structure evaluation parameters

Based on the logging data calculation result of coal mechanical parameters, this paper determines the integrity coefficient, fracture coefficient and stability coefficient, which are used to construct the identification diagram of coal structure.

2.1 Integrity coefficient

The integrity coefficient of coal, which is used to represent the integrity characteristics of coal, is a function of acoustic time of skeleton and coal.

\[ K_v = \left( \frac{\Delta t_{ma}}{\Delta t} \right)^2 \]  

In the formula: \( K_v \) is the integrity coefficient of coal (non-dimensional), and \( \Delta t_{ma} \) is the acoustic time of the coal skeleton (\( \mu s/ft \)).

\( K_v \) reflects the integrity of the coal. When \( \Delta t \) is closer to \( \Delta t_{ma} \), the value of \( K_v \) increases, the fracture is less developed, and the coal structure is more integrated.

2.2 Fracture coefficient

The fracture coefficient, which is a function of the compressional wave slowness, shear wave slowness, the Young’s modulus calculated from logging data, and the Young’s modulus of the coal skeleton, is used to reflect the fracture degree of the coal:

\[ R_f = \frac{E_{ma} - E}{E_{ma}} \]  

In the formula: \( R_f \) is the fracture coefficient of coal (non-dimensional), and \( E_{ma} \) is the Young’s modulus value of the non-fractured coal (MPa).

Because the fracture degree of coal is closely related to the Young’s modulus, the more fractured the coal, the smaller the Young’s modulus. For one type of coal, the Young’s modulus of the coal skeleton is a constant; thus, when the coal is more fractured, the fracture coefficient calculated by Young’s modulus is larger. It is clear that using the fracture coefficient (which highlights the fracture degree of coal) to represent the fracture degree of the coal eliminates the influence of coal characteristics on Young’s modulus to some degree.

2.3 Stability Coefficient

The stability coefficient of coal can be obtained by the product of the volume modulus and shear modulus.

\[ R_g = K_v \times G \]  

In the formula: \( R_g \) is the stability coefficient of coal (non-dimensional).

When fractures are developed in the coal seam, the value of density obtained by logging will decrease to some degree, whereas the value of AC will increase. Thus, the Young’s modulus E and shear modulus G will decrease, which causes the stability coefficient of the coal to decrease.
3. Methods for coal structure identification
Based on the integrity coefficient, the fracture coefficient and the stability coefficient, which are calculated by the method above, this paper constructs a three-dimensional coal structure evaluation diagram using these three parameters as coordinates (shown in Fig.1). From the diagram, it is clear that the integrity coefficient and stability coefficient of coal gradually decrease, and the fracture coefficient gradually increases, with the transition from native structure coal to fragmented coal, granulated coal and mylonitized coal. In other words, the integrity and stability coefficients of coal with native structure are the highest, and its fracture coefficient is the smallest; when the integrity and stability coefficients of fragmented coal, granulated coal and mylonitized coal gradually decrease, the fracture coefficient gradually increases.

The coal structure division standards of the study area determined by Fig.1 are shown in Table 1. The quantitative identification of coal structure from logging data, which is based on coal mechanical parameters, can be achieved through this table.

![Figure 1. The crossplot of integrity coefficient, stability coefficient and fracture coefficient for coal](image)

| Coal Structure | Integrity Coefficient $K_v$ | Fracture Coefficient $R_f$ | Stability Coefficient $R_g$ |
|----------------|-----------------------------|-----------------------------|-----------------------------|
| Undeformed     | $\geq 0.65$                 | $0.3 \leq$                  | $\geq 0.2$                  |
| Fragmented     | $0.5 < K_v < 0.65$          | $0.3 < R_f < 0.55$          | $0.1 < R_g < 0.2$           |
| Granulated     | $0.38 < K_v \leq 0.5$       | $0.55 \leq R_f < 0.72$      | $0.05 \leq R_g < 0.1$       |
| Mylonitic      | $\leq 0.38$                 | $\leq 0.72$                | $\leq 0.05$                |

4. Analysis of the application example
The logging identification methods of coal structure, which are based on coal mechanical parameters, have been of practical use for CBM reservoirs. The results of the identification of the coal structure of the HS 10 Well are shown in Fig.2. The main CBM reservoir of this well is at 744.1-747.6 m, its thickness is 3.1 m, and there are no discernible partings in the layers.

The integrity coefficient of the 744.1-744.6 m section is 0.52, the fracture coefficient is 0.51 and the stability coefficient is 0.11, so it is identified as fragmented coal; the integrity coefficient of the
744.6-746.4 m section is 0.45, the fracture coefficient is 0.59, and the stability coefficient is 0.08, so it is identified as granulated coal; the integrity coefficient of the 746.4-747.6 m section is 0.55, the fracture coefficient is 0.31, and the stability coefficient is 0.19, so it is identified as fragmented coal. Comparing the results of coal structure identification of the 7th track in the figure with the coal core observations and descriptions of the 8th track, it is clear that the coal structure identified by the method described in the paper is identical to the coal structure of the coal core observation and description.

5. Conclusions

(1) Based on geophysical logging technology, this paper presents a coal structure identification method through coal mechanical parameters, which provides an effective method for the division of coal structure.

(2) The coal mechanical parameters can represent the coal structure. The integrity coefficient and stability coefficient of coal with native structure is the greatest, and its fracture is the lowest; whereas the integrity and stability coefficients of the fragmented coal, granulated coal and mylonitized coal will decrease gradually, and the fracture coefficient will increase gradually.

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