Brittle-Plastic Properties Evaluation of Rock based on Element Logging

Li Yi¹, Zhang Yanqi¹, Hu Zongmin¹, Geng Changxi¹, Yuan Baiyan¹, Li Hao², Ligang Zhang²

¹Daqing No.1 Geo-logging company, Daqing Drilling & Exploration Engineering corporation, Daqing, 163411, China
²Institute of Petroleum Engineering, Northeast Petroleum University, Daqing, 163318, China
*Corresponding author’s e-mail: 18565369823@163.com

Abstract. Rock brittle-plasticity is an important factor which can influence the selection of rock breaking method and fracturing layers. It is very important to build up an appropriate brittle-plasticity characterization method and prediction method. In this paper, the point load method was used to test the deep rock load-displacement curve in Songliao basin, calculate the plasticity coefficient and the brittle-plasticity. Then the element content of the corresponding rock samples was tested. The relationship between plasticity coefficient and element content were estimated, and the influence of elements on brittle-plasticity of rocks was revealed. Finally, the calculation model of rock plastic coefficient based on element contents was built up. The research results can be used to evaluate the real-time brittle-plasticity of formation by using element logging data.

1. Introduction
Brittle-plasticity of rock refers to the deformation and failure characteristics of rock under different stress states [1]. There is no obvious plastic deformation when brittle rock is subjected to stress failure. Plastic rock has large plastic deformation before failure [2]. Brittle-plasticity of rock is the important criterion for optimization of crushing methods and selection of fracturing layers. It directly affects crushing efficiency, volume reconstruction efficiency and productivity of fractured wells [3]. At present, there is no unified characterization method and evaluation criteria for rock brittle-plasticity. There are two kinds of evaluation methods: rock mechanics characteristic method and rock mineral composition method [4]. The rock mechanics characteristic method evaluates the rock brittle-plasticity degree through various mechanical experiments based on the rock deformation failure mechanism. The mineral composition method is used to characterize the brittle-plasticity degree based on the contents of different minerals such as quartz, feldspar, calcite, gypsum, clay and so on [5]. Both of the evaluation methods have the problem of discontinuous sampling and high cost. It is very important to build up a real-time continuous method for evaluating rock brittle-plasticity. Therefore, this paper studies the relationship between element logging and plasticity coefficient, and forms a real-time continuous evaluation method of rock brittle-plasticity based on element logging data.

2. Rock plasticity coefficient
The evaluation of rock brittle-plasticity by mechanical characteristics method is mostly based on the characteristics of load-deformation curve. One of the typical methods is hardness test, the plasticity
coefficient is determined according to the load-penetration curve. The test is done by pressing a flat cylinder of a certain diameter into the rock surface, with the increasing load, the penetration depth increases, until the cuttings occur the first volumetric fracture. The typical load-penetration curve is shown in figure 1.

![Load-penetration curve](image)

The rock plasticity coefficient can be derived by equation (1):

\[
K = \frac{A_F}{A_E} = \frac{S_{OABC}}{S_{ODE}}
\]

(1)

The plasticity coefficient is the ratio of the total work consumed by crushing to the work of elastic deformation during the first volume fracturing of rock. The rock brittle-plasticity is graded according to the plasticity coefficient, shown in table 1.

Tab. 1. Classification criteria of rock plasticity coefficient

| Category            | brittle | Brittle-plasticity | Plastic |
|---------------------|---------|--------------------|---------|
| Grade               | 1       | 2                  | 3-4     | 5-6     | 6 |
| Plasticity coefficient | <1     | 1-2                | 2-3     | 3-4     | 4-6 >6-∞ |

3. Rock-forming mineral elements

Minerals are composed of elements and compounds that are relatively stable in the crust. Different petrogenic minerals have their own chemical element types. Common elements in minerals are shown in table 2.

Tab. 2. General Petroleum Formation Minerals contain chemical elements

| Mineral    | Molecular formula | Major elements       |
|------------|-------------------|----------------------|
| Quartz     | SiO₂              | O, Si                |
| Calcite    | Ca[CO₃]           | O, Ca, C             |
| Dolomite   | CaMg[CO₃]₂        | O, Ca, Mg, C         |
| Orthoclase | (K, Na)[AlSi₃O₈] | O, Si, Al, K, Na     |
| Muscovite  | KAl₂[AlSi₃O₁₀](OH)₂ | O, Si, Al, H, K     |
| Illite     | K₀.₇₅(Al₁.₇₅,Mg,Fe)[Si₁.₅Al₀.₅O₁₀](OH)₂ | O, Si, Al, K, Mg, Fe |
Different minerals have different elements, the contents of different minerals can be estimated by the contents of elements. Therefore, the element contents can reflect the rock brittle-plasticity by the mineral contents.

4. Relationship between element content and plasticity coefficient

This paper focuses on the deep rocks of Songliao basin, rock plasticity coefficient is measured by point load method, the content of rock elements is determined by X-ray fluorescence analysis, then analysis the relationship in between. Si, K, Na element content vs. Plasticity coefficient is shown in figure 2. Silicon has the highest content in rock sample, which is distributed at 43%-72%, it mainly reflects the content of quartz. As the content of silicon increases, the plasticity coefficient decreases obviously, and the brittleness increases. Potassium mainly exists in orthoclase and muscovite, sodium exists in pyroxene, amphibole and feldspar minerals. With the increase of sodium and potassium, the plasticity coefficient decreases and brittleness increases.

Al, Fe, Mg, Ti element content vs. Plasticity coefficient is shown in figure 3. Aluminum is widely exists in minerals, which is distributed at 10%-17%, as the content of aluminum increases, the coefficient increases obviously, is a typical plastic element. Iron is often found in dark minerals, the higher iron content, the greater plasticity of the rock. Magnesium and titanium content are very low, with the increase of the content of magnesium and titanium, the plasticity coefficient tends to increase.

5. Conclusion

The point load method and X-ray fluorescence analysis method are used to measure the plasticity coefficient and element content in deep layer rocks of Songliao basin which has a correlation between each other. With the increase of silicon, sodium and potassium, the plasticity coefficient decreased and...
brittleness enhanced. With the increase of the content of aluminum, iron, magnesium and titanium, the plasticity coefficient tended to increase, and plastic enhanced.

Acknowledgments
This work was supported by Youth Science Fund of Northeast Petroleum University (Grant No. 15011030105).

Reference
[1] Qinghui L, Mian C, Yan J, et al. Rock Mechanical Properties and Brittleness Evaluation of Shale Gas Reservoir[J]. Petroleum Drilling Techniques, 2012.
[2] Lawn B R, Marshall D B. Hardness, Toughness, and Brittleness: An Indentation Analysis[J]. Journal of the American Ceramic Society, 1979, 62(7-8):347-350.
[3] Cong G, Chong Z, Lin-Qi Z, et al. Method and Application of Shale Brittleness Evaluation Based on Elemental Capture Spectroscopy Logging[J]. Bulletin of Mineralogy Petrology & Geochemistry, 2017, 6(36):1040-1047.
[4] Liu X G, Sun J M, Guo Y F. Application of Elemental Capture Spectroscopy to Reservoir Evaluation[J]. Well Logging Technology, 2005, 29(3):236-239.
[5] Feng Z, Li X T, Wu H L, et al. Multimineral optimization processing method based on elemental capture spectroscopy logging[J]. Applied Geophysics, 2014, 11(1):41-49.