Analysis on brittleness characteristics of tight oil siltstones

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SUMMARY

We obtain the basic parameters of the rocks of Qingshankou formation by performing the rock uniaxial and triaxial compression mechanics experiments. Different brittleness indexes are computed and we select the best brittleness index of B2 (E/υ, Young's modulus / Poisson's ratio) to evaluate rock brittleness characteristics. The coefficient of brittle stress drop is introduced to evaluate rock brittleness characteristics which coincide with the selected brittleness index. The relationships between brittleness indexes and rock parameters such as elastic parameters, mineral components and reservoir physical properties (porosity, and density) are analyzed. Results show that E and υ are the good indicators of rock brittleness, while shale content has no obviously influence on the elastic parameters. Quartz and carbonate minerals are considered as brittle components for evaluating rock brittleness. There is a good correlation between the brittleness index B2 and reservoir porosity, which is important for analyzing rock brittleness characteristics in the study area.

Key words: brittleness indexes, brittleness characteristics, rock parameters, elastic parameters, the coefficient of brittle stress drop

INTRODUCTION

The brittleness characteristic of rock is an important factor to estimate rock drillability and wellbore stability. It is also an important indicator for locating the high quality sweet-spots of tight oil/gas. Therefore, the studies on the brittle characteristics of tight oil and gas reservoirs are of great significance. Rock brittleness is a comprehensive characterization of the rock brittle properties. Jarvie, (2007) and Li et al. (2013) proposed several rock brittleness prediction models by analyzing the differences of mechanical properties of rock with different mineral components. The brittleness indexes were also established by Rickman et al. (2008), Guo et al. (2013) and Liu et al. (2015) based on the Young's modulus (E) and Poisson's ratio (υ). Some other researchers (Altindag, 2010; Tarasov and Potvin, 2013; Xia et al., 2016) evaluated the rock brittleness characteristics from the perspective of the rock failure strength, strain, and energy. However, there is no unified or standard evaluation criterion for rock brittleness in the academic and industrial communities.

We analyze the indicators and select the best brittleness indexes for the study area. The coefficient of brittle stress drop is introduced for investigating rock brittleness characteristics and its applicability is discussed. We then investigate the relationships between the rock brittleness and mineral components, elastic parameters, and reservoir properties.

Experimental measurement

We perform uniaxial and triaxial compression mechanics experiments to obtain the basic physical parameters of the rocks such as elastic parameters, peak strain, peak strength, residual stress, residual strain, which can provide the necessary basic parameters for brittleness characteristics analysis in the tight oil siltstones. By performing rock uniaxial compression experiments on the 5 samples collected from the well, we measure deviator stress, axial strain, and radial strain and obtain the complete stress-strain curves (as is shown in figure 1). We also obtain the elastic parameters, peak strains, peak strengths, residual stresses, and residual strains. Under a single confining pressure (20MPa), and by increasing the axial pressure up to 60 (MPa), we adopt the rock triaxial test for the 22 samples to obtain the parameters such as Young's modulus (E) and Poisson's ratio (υ).

Experimental results

Figure 1 shows that the complete stress-strain curves of the 5 samples from the wells. According to the factors that the rock with the lower peak strain has a higher brittleness, the order about rock brittleness of the 5 samples from high to low is *96H-113-H*, *21-T-1*, *21-H*, *113H-83-H*, *21-T-2*.

On the basis of the previous brittleness index studies, we calculate the 6 different brittleness indicators. As is shown in Table 1, B1 (Rickman et al. 2008) and B2 (Guo et al. 2015) are proposed according to Young's modulus (E) and Poisson's ratio (υ), *B*3 (Altindag, 2010) is a brittleness indicator which consider the post-peak stress state, and B4, B5 (Tarasov and Potvin, 2013) and *B*6 (Xia et al. 2016) consider both pre-peak and post-peak state of the complete stress-strain curves. It is shown in Figure 2 that B2 of the 5 samples is consistent with the conclusions from the figure 1. It is suggested that B2 (E/υ) is better than the other indexes by analyzing rock brittleness characteristics in the target formation.

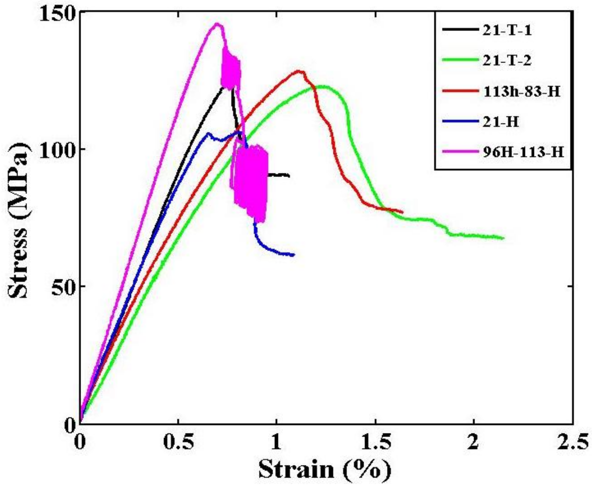

Figure 1: Complete stress-strain curve of the 5 sample from the well.

Table 1: The six brittleness indexes

B1-B6 Brittleness Indexes
$E_{\mathrm{BI}} = (E - E_{\min}) / (E_{\max} - E_{\min})$, $\upsilon_{\mathrm{BI}} = (\upsilon - \upsilon_{\max}) / (\upsilon_{\max} - \upsilon_{\min})$,
$\mathrm{B1} = (E_{\mathrm{BI}} + \upsilon_{\mathrm{BI}}) / 2$,
$\mathrm{B2} = E / \upsilon$,
$\mathrm{B3} = (\sigma_{\mathrm{p}} - \sigma_{\mathrm{r}}) / \sigma_{\mathrm{p}}$,
$\mathrm{B4} = (M - E) / M$,
$\mathrm{B5} = E / M$,
$\mathrm{B6} = (\sigma_{\mathrm{p}} - \sigma_{\mathrm{r}})(\varepsilon_{\mathrm{p}} - \varepsilon_{\mathrm{r}}) / \sigma_{\mathrm{p}}\varepsilon_{\mathrm{p}} + M$,

Where E is the Young's modulus, $E_{\max}$ (or $E_{\min}$) is the maximum (or minimum) value of the Young's modulus, υ is the Poisson's ratio, $\upsilon_{\max}$ (or $\upsilon_{\min}$) is the maximum (or minimum) value of the Poisson's ratio, σ_{p} is the peak strength, σ_{r} is the residual strength, and ε_{r} is the residual strain, ε_{p} is the peak strain, M is the post-peak modulus.

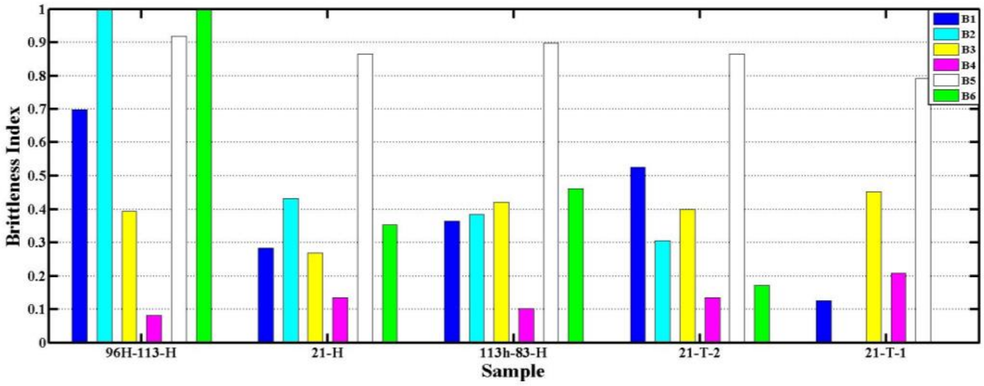

Figure 2: The different brittleness indexes of the 5 samples.

Coefficient of brittle stress drop

According to the brittle-plastic model of the natural rocks, the sudden stress drop part of the brittle section on stress-strain curve is considered after the peak stress. We calculate the coefficients of brittle stress drop by using the rock uniaxial and triaxial compression experiments. The coefficients of brittle stress drop can indicate the steep degree of stress drop in the constitutive curve and reflect the difficulty of brittle failure. The greater the stress drop coefficient is, the gentler stress drop of the constitutive curve can be, vice versa (Ge, 1997).

The equation for calculating the coefficient of brittle stress drop is as

$$\lambda = \left(\varepsilon_r - \varepsilon_s\right) / \left(\varepsilon_s - \varepsilon_m\right) \tag{1}$$

Where ε_r is the residual strain, ε_s is the peak strain, ε_m is the pre-peak characteristic strain which is usually calculated by using the ratio of residual stress and elastic modulus E. When λ =0, it corresponds to an ideal brittle-plastic model.

We calculate the coefficients of brittle stress drop for the 5 samples. Figure 3 shows that coefficients of brittle stress drop of the 5 samples increase from left to right, and the brittleness of samples decrease in turn. Figure 4 also shows that the variations of the coefficient of brittle stress drop are highly consistent with those of brittleness B2 in the samples. The coefficients of brittle stress drop can effectively evaluate brittle characteristics of rock since it is consistent with the conclusions from B2 analysis.

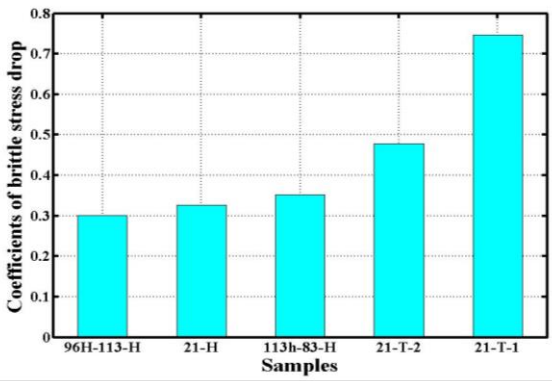

Figure 3: Coefficients of the brittle stress drop of different samples.

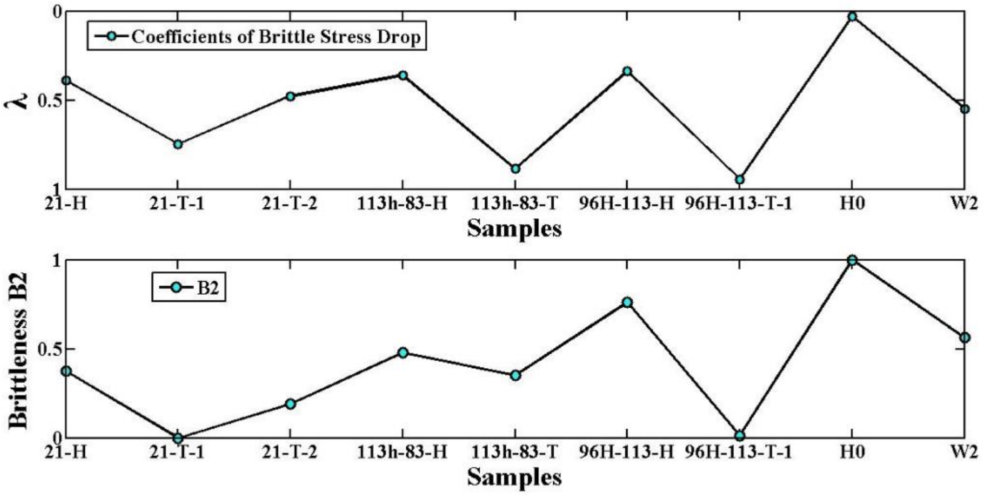

Figure 4: Comparison between the brittle stress drop and the brittleness B2 in different samples.

Analysis on the relationships between rock brittleness and elastic parameters, reservoir physical properties, and mineral components

In figure 5, it is shown that higher *E* and lower *υ* correspond to higher brittleness index. Meanwhile, in Figure 6, shale content shows no obvious effect on Young's modulus (*E*) and Poisson's ratio (*υ*) and there is a poor correlation between shale content and *E* (or υ). Figure 7 shows that tight oil siltstones with higher density and lower porosity have higher values of B2. Generally, quartz is usually considered as a brittle mineral and carbonate minerals and feldspar minerals may also play an important role in contributing to brittleness index in shale.

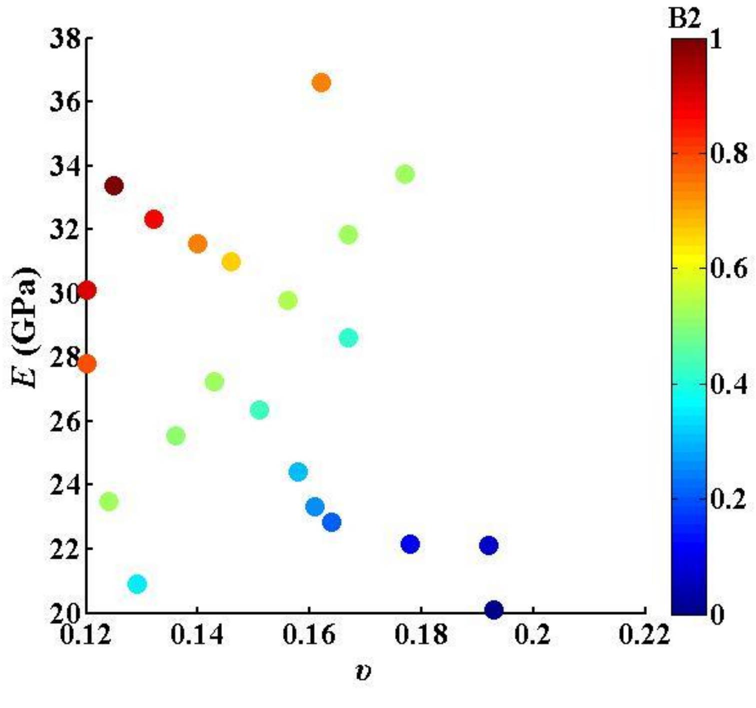

Figure 5: Cross-plot of *E* and υ. Color bar indicates the brittleness value B2 of the 22 samples.

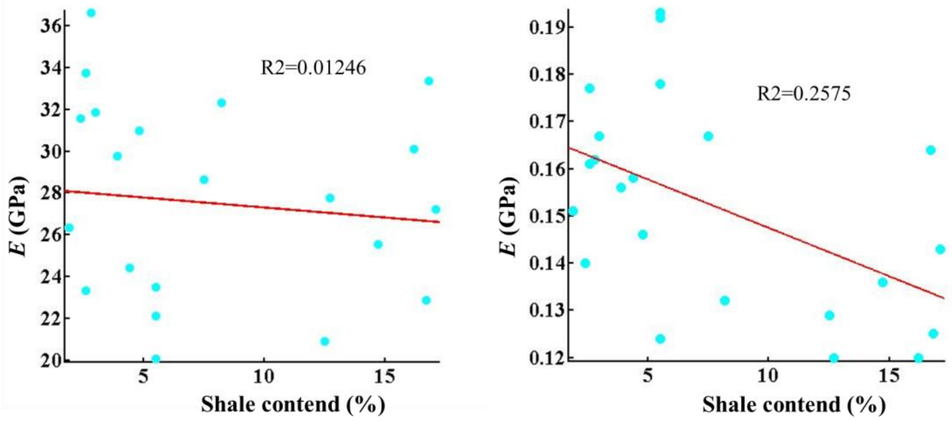

Figure 6: The fitting curve of shale content versus *E* (a) and the fitting curve of shale content versus υ (b).

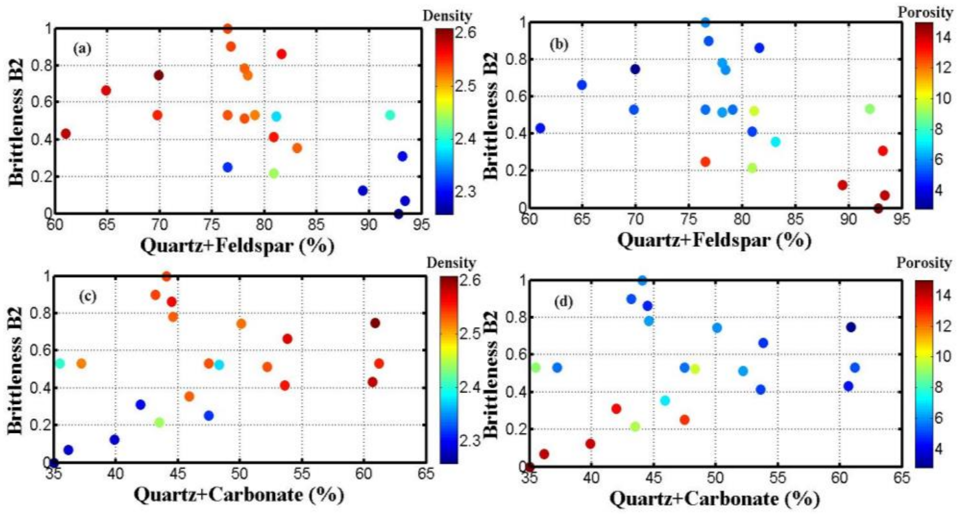

Figure 7: Cross-plots of different mineral component contents and the brittleness indexes. Color bars of (a) and (c) stand for density (ρ), and those of (b) and (d) stand for porosity (φ)

In Figure 7 (a) and 7 (b), it is shown that the content including both quartz and carbonate has a clearer positive correlation with B2. In 7 (c) and 7 (d), it is shown that the content including both quartz and feldspar has a clearer negative correlation with B2. Quartz and carbonate minerals are better than feldspar minerals to be considered as brittle minerals to evaluate tight oil and gas reservoir brittleness.

CONCLUSIONS

We introduce the coefficient of brittle stress drop to evaluate rock brittleness characteristics. It is consistent with B2 which is selected from the brittleness indexes in the existing literatures. The results show that the Young's modulus (E) and Poisson's ratio (υ) are good indicators of rock brittleness and shale content has no obviously influence on the elastic parameters. Both quartz and carbonate minerals can be regarded as brittle minerals to evaluate rock brittleness. Reservoir physical properties such as porosity and density have a good correlation with rock brittleness indexes B2 which is effective in estimating rock brittleness. It is important to evaluate the rock brittleness characteristics comprehensively by considering all the different methods and factors mentioned above.

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