Rockmass mechanics parameter prediction and application in tight sandstone reservoirs

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Summary

The rock mechanic features mean significantly to predicting tight-sand’s “engineering sweet spots”, where the engineering benefit. Therefore, before using elastic rock properties to predict the rock mechanics, brittleness index, compressive strength and compressibility, it is necessary to consider the application conditions of petrophysics and logging analyses, as well as the applicability and accuracy of rock mechanic parameters. This paper proposes a calculation for computing floating brittleness index and the lithoface-restricted compressibility, in which the floating brittleness index and the compressibility are expressed as a function of P, S-impedance and velocity, and the density is implicit, improving the stability of solution. The comparison of its application to the logging data and regional structural conditions shows the floating brittleness index and the lithoface-restricted compressibility can indicate the sweet spots within tight reservoir.

Introduction

As the petroleum resources decreasing, tight sand reservoirs are taken more seriously in recent years and their portions in petroleum reserves and productions have increased. Up to now, most of China’s tight reservoirs are gathered in the Ordos Basin, and the studies of rock mechanics are critical for detecting the reservoirs’ “sweet spots” and fracturing strategies within this basin. The reservoirs’ rock mechanics are comprised of brittleness index, compressive strength and compressibility. Effectively using seismic data to predict the rock mechanics before the drillings kick off is a hot topic in this field. It can not only help detect the “sweet spots” within the tight reservoirs, and also provide useful drilling information to support engineering.

Currently, there are few articles about using seismic data to calculate rock mechanic parameters, and most of them lack fixed theoretical system and are still in a exploratory stage, for their applications are transferred to tight reservoirs from shale petroleum, while some other papers are focused on rock mechanic features and researches of cracks and geostress based on rock mechanic parameters\cite{1,2}. Yet, there are no application cases of using the seismic data to calculate the brittleness index, though the article 3\cite{3} gives out the method of using Yang’s modulus and the Poisson’s ratio to calculate brittleness index, and the Schlumberger brings out a calculating formula for compressive strength.

This paper studies the rock mechanic features of tight reservoirs and their seismic prediction methods in the Ordos Basin. Based on others’ previous studies, we have made important improvements to the seismic prediction of brittleness index, and as the first one to propose seismic prediction methods of compressive strength restricted by lithofacies; the first one to apply the compressibility to “engineering sweet spots” prediction. The results reveal the prospect of rock mechanic parameters in tight reservoirs in the Ordos Basin.
Methods  Seismic prediction method of rock mechanics parameter

2.1 Calculations of brittleness index

The rock’s stress-strain experiment shows that when the stress load from a certain initial elastic state to peak strength, the strain will mutate and quickly fall to residual strength. Rock stress drop of this feature is known as the coefficient of brittle stress drop or brittleness index.

At present, the calculations of rock brittleness from well log data are mainly used the rock mechanic method (Young's modulus and Poisson's ratio) and rock mineral analysis method.

The crossplot of core data of 39 samples from 7 wells shows us a linear relationship between brittleness index and rock mechanic parameters (Young's modulus and Poisson's ratio). With the Poisson's ratio increases, brittleness index decreased; with the increase of the Young's modulus, brittleness index tended to increase.

We found that both the weight of Young's modulus and Poisson's ratio are 0.5, when using the rock mechanic method. However, the error between this form and the brittleness index is large. In order to get a reasonable result, we rewrote the formula as follows:

\[ BI = a \cdot \Delta E + b \cdot \Delta \sigma \]

where: \( a + b = 1 \)  \( \text{(1)} \)

Then we can change the weights of Young's modulus and Poisson's ratio by adjusting the values of a and b. As a consequence, the calculated BI fit better with the brittleness index (Figure 1). The ordinate of Fig. 1 is measured brittleness index (True BI), while the abscissa is the calculated brittleness index.

In Fig. 1b, the weights of Young's modulus and Poisson's ratio are 0.81 and 0.19 when using equation (1). Fig. 1a is the crossplot of True BI versus calculated BI, of which the weights are both 0.5. Obviously, the adjustable formula gives a better result in our research area.

![Figure 1 comparision of BI with two methods](image)

(a) computation with equal weight  \hspace{1cm} (b) computation with variable weight

We can get P-wave velocity, S-wave velocity and density from pre-stack seismic inversion. Then Young's modulus and Poisson's ratio formulas are as follows:

\[ E = 2\rho \cdot V_s^2 \left( 1 + \frac{V_p^2 - 2V_s^2}{2V_p^2 - 2V_s^2} \right) \]

\[ \sigma = \frac{0.5 \left( \frac{V_p}{V_s} \right)^2 - 1}{\left( \frac{V_p}{V_s} \right)^2 - 1} \]

where: \( \rho \) is density, \( V_p \) is P-wave velocity, \( V_s \) is S-wave velocity.

It can be seen that Young's modulus is related to density, however, the magnitude of density is so small that it is different to get an accurate and stable solution from seismic data. Therefore, we can replace density with velocity and impedance, of which the magnitude are large. As a result, the stability of the calculation of brittleness index can be improved after the transform of the calculation of Young’s modulus.
so Young's modulus can be rewritten to this:

$$E = 2SI \cdot Vs \left(1 + \frac{AL^2 - 2SI^2}{2AI^2 - 2SI^2}\right)$$

(3)

### 2.2 Compression coefficient (Cc) calculation

The compression coefficient shows that the meaning of compressibility and compressive strength of the rock are just the opposite, but their computing don’t require the participation of mud content, so compression coefficient can be defined as the reciprocal of bulk modulus:

$$Cc = \frac{1}{K}$$

(4)

The bulk modulus calculation formula is:

$$K = \rho Vp^2 - \frac{4}{3}\rho Vs^2$$

(5)

Because of density can’t be accurately obtain from seismic data, in order to improve the stability of the compression coefficient, we don't let the density directly involved in the calculation but use the impedance and velocity(stable inversion parameters), bulk modulus of the formula becomes:

$$K = AI * Vp - \frac{4}{3} SI * Vs$$

(6)

In practical application, firstly we identify the tight reservoir facies in seismic sections by using the crossplot of p-wave (Figure 2), then, calculate the elastic parameters and rock mechanics parameters from tight sandstone under the control of sedimentary facies mode\(^{(i)}\) (Figure 3).
Result

The practical application compared with drilling data and geological conditions, the brittleness index with variable coefficient and the compressibility under the control of tight reservoir facies can indicate the "sweet spots" development area of tight reservoir. The brittleness index parameter is suitable for the Chang7 tight oil reservoir of the Mesozoic Yanchang formation in the central lake basin of the Ordos basin, brittleness index of the Chang7 tight sandstone is bigger than brittleness index of mudstone. If the reservoir is tight sandstone, the reservoir brittleness is higher, the chance of communication “sweet spots” by engineering fracturing is greater, however, compression coefficient has a more significant effect in the study of the He8 tight gas reservoir in the upper Shihezi formation Palaeozoic in Surig area of the Ordos basin. When the He8 tight sandstone contain gas, the rule of compression coefficient is: the poor gas-bearing sandstone > gas sandstone > water-bearing sandstone > dry sandstone. Popularized the tight reservoir "sweet spots” prediction technology, we optimize the Chang7 tight oil enrichment region of Mesozoic group, optimize the horizontal well experimental zone and Submit the Chang7 tight oil in the Ordos basin which becomes China's largest production base of tight oil in 2013, and builds a huge capacity. Water prediction is the bottleneck which restricts the development of the Surig gas field. Petrophysical analysis shows that in range of high gas saturation (40%-80%), the change of compression coefficient is the most obvious, the relative change rate is twice the Poisson's ratio as well as Vp/Vs.

Conclusions

On the basis of digging the tiny difference in gas-water response from joint inversion and the independent variable crossplot analysis, this study optimizes bulk modulus with the larger fluid detection window to calculate compressibility under the control of facies (excluding shale content), and effectively predict the distribution of the gas and water (figure 3). In the Surig gas field, application shows that such technology can benefit for reserve and improve production, and recovery efficiency.

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