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Evaluation and Analysis of Engineering Geological Features Affecting Fracturing Effect in Block S

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Abstract: Reservoir evaluation and classification is an important content in oil and natural gas exploration and development. Reasonable and scientific evaluation of reservoirs has important guiding significance for the discovery of "sweet spots" in the later stage, the optimization of favorable areas and the optimization of fracturing stimulation measures in the later stage. , this paper evaluates and analyzes 6 engineering geological factors of reservoir rock compressibility, horizontal difference stress coefficient, reservoir interlayer stress difference, rupture pressure, closure stress and formation pressure coefficient in block S, and combines with the analysis of unimpeded flow after compression to find The favorable range value of each factor provides an important basis for the subsequent evaluation and analysis of other fracturing wells and the recommendation of fracturing process countermeasures. Based on the engineering geological factors that affect the fracturing effect, a new method for evaluating the geological quality of fracturing engineering is established, and the reservoirs with the comprehensive coefficient of fracturing engineering geological quality between 0.53 and 1 are regarded as high-quality A-level reservoirs. , the reservoirs with the comprehensive coefficient of fracturing engineering geological quality between 0.2 and 0.53 are regarded as the B-level general quality reservoirs, and the reservoirs with the comprehensive coefficient of fracturing engineering geological quality between 0 and 0.2 are regarded as the C-level poor quality reservoirs, which are selected for fracturing selection. Well selection provides an important basis.

Keywords: Tight sandstone, Engineering geological factors, Evaluation analysis, Fracturing effect.

1. Introduction

Block S in the Ordos Basin is a typical representative of tight sandstone gas reservoirs in my country. It has the characteristics of low permeability, low porosity, low pressure, and strong heterogeneity. Reservoir reconstruction measures such as hydraulic fracturing are necessary to obtain industrial productivity. The geological conditions in the area are complex. Not only are the low-geological sweetness reservoirs of class IV and V unsatisfactory after layering, but also the high-quality reservoirs of class I, II, and III often have gas test results that are lower than geological expectations. Therefore, combined with the characteristics of tight sandstone reservoirs in Block L, this paper takes into account 6 engineering geological factors including reservoir rock compressibility, horizontal difference stress coefficient, reservoir interlayer stress difference, fracture pressure, closure stress and formation pressure coefficient, and establishes The evaluation calculation model of each factor is used to analyze the influence of engineering geological factors on the open flow rate after fracturing, and then find the favorable range value of each engineering geological factor; establish a comprehensive evaluation method for the engineering geological quality of fracturing in Block S. It provides a reference for the evaluation and optimization of other fracturing wells.

2. Research Progress on Evaluation of Tight Sandstone Reservoirs

Tight sandstone reservoirs often have the characteristics of complex sand body distribution and strong heterogeneity. From the initial single parameter evaluation to multi-parameter comprehensive evaluation, many scholars have introduced complex mathematical methods to evaluate reservoirs.

2.1. Current Status of Research on Reservoir Evaluation and Classification

Scholars at home and abroad have carried out various evaluation and classification studies on tight sandstone reservoirs according to different standards. As early as 1985, Spencer studied tight sandstone reservoirs according to the classification of reservoir porosity. In 1987, Soeder[1] defined tight reservoir types according to the genetic types of interstitials. McCaffrey et al.[2] evaluated and analyzed the geological development potential of stratigraphic traps at the edge of turbidite deposits. In 2002, Law[3] established a method for classification of reservoirs according to the type of organic matter in source rocks. In 1997, Chinese scholar Yu Xinghe[4] proposed that the classification of low-permeability tight sandstone gas layers should take into account factors such as porosity, permeability and throat size. In 2006, Jiang Zhenxue et al.[5] classified tight sandstone gas reservoirs into two types: “tight first and then accumulation” and “first accumulation and then tight” according to the time sequence of sedimentary evolution. In 2009, Zou Caicai et al.[6] divided the reservoirs into two categories: primary sedimentary type and diagenetic transformation type, and further divided the reservoirs into finer classification based on the sedimentary background. In 2010, Bastia et al.[7] analyzed the history of stratigraphic sedimentary evolution and evaluated the development potential of deep-water reservoirs in the continental margin of northeastern India. In 2019, Gao Songyang [8] used the reservoir quality index and irreducible water saturation to classify and evaluate the Silurian tight sandstone reservoirs, which provided a good guide for reserve evaluation and oilfield development. In

2020, Zhao Jiarui et al. [9] made a fine description and classification of the microscopic pore structure of the tight sandstone in the Upper Paleozoic in Sulige.

2.2. Research Status of Application of Reservoir Evaluation and Classification Methods

As the reservoirs under study become more and more complex, it is relatively one-sided to analyze only a certain characteristic of the reservoir, and it is difficult to reflect the comprehensive quality of the reservoir. It is necessary to select more evaluation parameters to make the classification of the reservoir more refined and perfect..Therefore, many mathematical methods are applied to the study of reservoir classification, which reduces the influence of human subjective factors, and conducts comprehensive evaluation and classification of reservoirs in a more objective and scientific way.

In 2015, Chen Huanqing et al.[10] summarized the previous reservoir classification methods, and combined with their own scientific research practice, introduced 11 reservoir evaluation research methods and their advantages and disadvantages, including: geological experience method, weight analysis method, AHP method, fuzzy mathematics method, artificial neural network method, fractal geometry method, variogram method, cluster analysis method, grey relational method, various logging methods and seismic methods, etc. In 2015, Jia Peifeng et al. [11] studied typical tight reservoirs in Daqing and Changqing oilfields based on core experiments, and used statistical methods and numerical simulation methods to optimize 6 parameters for tight reservoir evaluation. In 2018, Zhao Yue [12] combined AHP and fuzzy mathematical evaluation to establish a fuzzy hierarchical comprehensive evaluation model for tight reservoirs, and predicted favorable blocks for tight reservoirs in the southwestern Ordos Basin. In 2018, Zhao Jun et al. [13] selected 4 parameters of porosity, sonic time difference, sonic permeability and reflection coefficient according to the characteristics of the reservoir, and introduced a method of multivariate membership functions based on fuzzy mathematics to distinguish the tight sandstone reservoirs clearly. into 4 categories. In 2019, Li Changxi et al. [14] used the bimodal log-normal distribution to fit the nuclear magnetic resonance T2 spectrum, obtained six parameters that characterize the reservoir, and applied the cluster analysis method to classify the tight sandstone reservoir, and achieved good application results. . In 2021, Wang Yan [15] et al. proposed a method for classifying tight sandstone reservoirs based on random forests to solve the problems of subjective experience and low efficiency in reservoir classification, which improved the efficiency and accuracy of reservoir classification.

3. Engineering Geological Factors Affecting Fracturing Effect

There are many engineering geological factors that affect the fracturing effect. In this paper, 6 engineering geological factors including reservoir rock compressibility, horizontal difference stress coefficient, reservoir interlayer stress difference, fracture pressure, closure stress and formation pressure coefficient are considered, and each factor is established. The evaluation calculation model is based on the statistical calculation of the distribution range value of each engineering geological factor in the S block.

3.1. Rock Compressibility

Rock compressibility is a key parameter in the development of tight sandstone gas reservoirs, which is reflected in the difficulty of achieving effective stimulation and stimulation of the reservoir. At present, most scholars use the brittleness index and fracture toughness of rock to comprehensively evaluate the compressibility of tight sandstone. Among them: brittleness index is one of the important mechanical properties of rock, which represents the difficulty of rock fracture to a certain extent. To judge the difficulty of fracturing fracture propagation, the smaller the value, the better the fracture propagation.

This paper adopts the traditional rock compressibility evaluation model as follows:

$$F_I = B_I * K_{\mathrm{IC}} * \tag{1}$$

$$B_I *= \frac{B_I - B_{\mathrm{Imin}}}{B_{\mathrm{Imax}} - B_{\mathrm{Imin}}} \tag{2}$$

$$K_{IC} *= \frac{KIC_{ICmax}}{KICmin_{ICmax}} \tag{3}$$

The calculation formula of rock brittleness index is as follows：

$$B_I = \frac{E* + v*}{2} \tag{4}$$

$$\begin{cases} E* = \dfrac{E - E_{\min}}{E_{\max} - E_{\min}} \\ v* = \dfrac{v - v_{\min}}{v_{\max} - v_{\min}} \end{cases} \tag{5}$$

Combined with previous fracture toughness test experiments, Chen Zhixi calculated the fracture toughness of rock under zero confining pressure, and Jin Yan introduced confining pressure on this basis to obtain the following fracture toughness calculation formula [16].

$$K_{IC} = 0.2176P_c + 0.59{S_t}^3 + 0.0923{S_t}^2 + 0.517S_t - 0.3322 \tag{6}$$

Table 1. Criteria for judging favorable range of rock compressibility

Evaluation indicators	Favorable	Unfavorable
Rock compressibility coefficient	＞0.257	≤0.257

3.2. Horizontal Difference Stress Coefficient

In-situ stress is an important parameter affecting the fracturing effect, and the smaller the difference between the two horizontal principal stresses in the reservoir, the more favorable it is to form a complex fracture network[72-73]. When the difference between the maximum principal stress and the minimum principal stress value in the horizontal direction is large, the main fracture in a single direction is extended during the fracturing process, and it appears as a single double-wing fracture after fracturing; when the difference between the horizontal stress is small, the fracture initiation direction and extension. During the process, it is easily affected by the weak point of formation stress, and the fracturing fracture communicates with the weak point of stress, which makes the fracture extension and diversion, and it is easy to form a complex fracture network. Therefore, the magnitude of the horizontal stress difference is very important for the formation of more complex fractures after fracturing.

At present, the horizontal difference stress coefficient is often used to characterize the difference in horizontal principal stress. The calculation formula is as follows:

$$K_h = \frac{\sigma_H - \sigma_h}{\sigma_h} \tag{7}$$

Table 2. Criteria for judging favorable range value of horizontal difference stress coefficient

Evaluation indicators	Favorable	Unfavorable
Horizontal difference stress factor	<0.236	≥0.236

3.3. Stress Difference Between Formation Reservoir and Interlayer

Usually, the stress of shale interlayer is larger than that of the reservoir section, and the larger stress difference between the reservoir and interlayer has a certain restriction on the longitudinal extension of fractures. The height of the fracturing fracture is controlled by the difference between the net pressure in the fracture and the stress between the reservoir and the interlayer. In general, when the main fracturing period is smaller than the fracture height, the fracture height can basically be controlled inside the reservoir; when the main fracturing period is longer than the main fracturing period, Then the vertical growth of cracks is basically uncontrolled. Therefore, it is very important to study the distribution of stress difference between reservoirs and interlayers in this block for the height of fracturing fractures.

Table 3. Criteria for judging favorable range values of reservoir stress difference

Evaluation indicators	Favorable	There is a risk of layer penetration	Unfavorable
Interlayer stress difference (MPa)	>4	2~4	≤2

3.4. Formation Fracture Pressure

In the bottom hole formation, when the pressure reaches a certain limit value, the formation will rupture, and this pressure limit value is the formation fracture pressure. A lower formation fracture pressure can effectively start fracturing and fracturing the formation during the fracturing operation, and the construction can be successfully completed; on the contrary, a higher formation fracture pressure may make the formation difficult to be fractured, and the fracturing fluid cannot be smoothly injected into the formation, resulting in construction failure. This situation requires the use of certain technical means.

Table 4. Judgment criteria for the favorable value range of rupture pressure

Evaluation indicators	Favorable	Unfavorable
Formation fracture pressure (MPa)	<55	≥55

3.5. Formation Closure Stress

Closing stress refers to the state of the fractures appearing to be closed but not closed after the pumping of the fracturing construction is stopped, and the fluid pressure at this time is the closing stress, also known as the closing pressure. Smaller closing stress is beneficial for fractures to obtain higher conductivity after compression. The closing stress can be approximately considered to be equal to the minimum horizontal principal stress of the formation, as shown in the following formula.

$$P_{\mathrm{cs}} = \sigma_h \tag{8}$$

Table 5. Criteria for judging the favorable value range of closing stress

Evaluation indicators	Favorable	Unfavorable
Formation closure stress (MPa)	<27	≥27

3.6. Formation Pressure Coefficient

The formation pressure coefficient refers to the ratio of the original formation pressure to the hydrostatic pressure at the same depth. Generally speaking, the normal pressure formation pressure coefficient is 1; when it is less than 1, it is called low abnormal formation pressure; when it is greater than 1, it is called high abnormal formation pressure.

$$\alpha = \frac{P_p}{\rho g h_0} \tag{9}$$

Table 6. Judgment criteria for favorable value range of formation pressure coefficient

Evaluation indicators	Favorable	Unfavorable
Formation pressure coefficient	>0.92	≤0.92

4. Comprehensive Evaluation of Engineering Geological Quality Affecting Fracturing Effect

Based on the single-factor evaluation criteria formed in the previous section, a comprehensive evaluation method for the geological quality of fracturing engineering in Block S is established. The evaluation of fracturing engineering geological quality integrates the above 6 engineering geological factors. The larger the value is, the better the fracture shape and stimulation effect can be obtained after fracturing. The evaluation idea and evaluation model are as follows.

(1) In order to make the geological factors of each fracturing engineering comparable, this paper normalizes the data. In the normalization process, it is necessary to distinguish between the bigger the better index and the smaller the better index. The parameters of rock compressibility, reservoir interlayer stress difference and formation pressure coefficient are the larger the better; the horizontal difference stress coefficient, fracture pressure and closure stress are the smaller the better parameters;

(2) When evaluating a single fracturing engineering geological factor, most of them use the division method of either high or low. The dividing point value divided by this method has great chance and randomness. In order to overcome this problem, this paper The idea of mathematical scaling is adopted to scale the boundary value into an interval, so the quality of the evaluation factor can be divided into three categories: excellent, general and poor.

$$\begin{cases} 0\sim\frac{2}{3}k_i & \text{bad range} \\ \frac{2}{3}k_i\sim\frac{2}{3}k_i+\frac{1}{3} & \text{general range} \\ \frac{2}{3}k_i+\frac{1}{3}\sim 1 & \text{good range} \end{cases}$$

According to the engineering geological characteristics of reservoir fracturing in Block S and the characteristics of the calculation model, the geological quality of fracturing engineering is divided into three grades. It is suggested that the tight sandstone reservoir fracturing in Block S is best selected in the well layer with the fracturing engineering geological quality greater than 0.53. If there is no such well layer, it should also be selected in the area with a large comprehensive coefficient of fracturing engineering geological quality. In addition, the difficulties in fracturing and stimulation of the reservoir can be judged according to the secondary geological index coefficient of each fracturing project, and then the fracturing countermeasures can be found in the fracturing process.

Table 7. Reservoir characteristics of different fracturing engineering geological qualities in Block S

level	Engineering Geological Factors Affecting Fracturing Effect						Comprehensive coefficient of geological quality of fracturing engineering	quality
	Rock compressibility normalization factor	Horizontal Difference Stress Coefficient Normalization Coefficient	Interlayer stress difference normalization factor	Normalized coefficient of rupture pressure	Closing stress normalization factor	Formation pressure coefficient normalization coefficient		
A	0.5~1	0.55~1	0.45~1	0.7~1	0.52~1	0.45~1	0.53~1	excellent
B	0.17~0.5	0.22~0.55	0.12~0.45	0.37~0.7	0.19~0.52	0.12~0.45	0.2~0.53	generally
C	0~0.17	0~0.22	0~0.12	0~0.37	0~0.19	0~0.12	0~0.2	Difference

5. Conclusions and Recommendations

(1) This paper evaluates and analyzes 6 engineering geological factors including rock compressibility, horizontal difference stress coefficient, reservoir interlayer stress difference, rupture pressure, closure stress and formation pressure coefficient in block L, combined with the unimpeded flow rate after compression. The favorable range value of each factor is analyzed and found, and the standard threshold value is formed to judge whether it is favorable for fracturing, which provides an important basis for the recommendation of fracturing process countermeasures. The favorable intervals for each factor are: rock compressibility coefficient greater than 0.2, horizontal difference stress coefficient less than 0.27, reservoir interlayer stress difference greater than 4MPa, formation fracture pressure less than 55MPa, closure stress less than 27MPa, and formation pressure coefficient greater than 0.92.

(2) Comprehensively affecting the engineering geological factors affecting the fracturing effect, a new method for the evaluation of fracturing engineering geological quality suitable for Block S was established, and the reservoirs with the comprehensive coefficient of fracturing engineering geological quality between 0.53 and 1 were regarded as Grade A. For high-quality reservoirs, the reservoirs with the comprehensive coefficient of fracturing engineering geological quality between 0.2 and 0.53 are considered as B-grade general-quality reservoirs, and the reservoirs with the comprehensive fracturing engineering geological quality coefficient between 0 and 0.2 are regarded as C-level poor quality reservoirs. High-quality reservoirs with a comprehensive coefficient of fracturing engineering geological quality greater than 0.53 are preferred. If such wells do not exist, they should be selected as far as possible in an area with a relatively large fracturing engineering geological quality comprehensive coefficient, which provides an important tool for fracturing well selection and layer selection. in accordance with.

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