Integration research of seismic data and logging for hydraulic fracturing in ultra-deep carbonate reservoirs with faults

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Abstract. Deep carbonate reservoir heterogeneity is serious, fault and fracture development, geology characteristic upper and lower horizontal well is uncertainty. The fracturing design scheme applicability is not strong based on the well logging data of guide well or adjoining well. Therefore, it is necessary to combine the engineering geology, construction technology and the optimized design of the scheme organically to solve the above problems. Based on the interpretation model of logging data, this paper discusses the prediction method of rock mechanics parameters combined with logging and seismic data. The plane distribution law of shear wave and rock density was obtained by the seismic inversion algorithm, and the plane law obtained by 3D seismic inversion was used as the prediction constraint conditions to carry out 3D geological modeling for the rock mechanics parameter field in SHB block, and on this basis, the local in-situ stress field simulation was figured out. According to the established geomechanical model, the section was cut along the direction of the horizontal well bore, and important information such as reservoir development status and geomechanical parameter distribution of the upper and lower sections of the horizontal well bore were analysed. A full three-dimensional model of asymmetric fractures was established. The research work in this paper is of great significance to improve the success rate of stage fracturing of ultra-deep horizontal well and the economic development of single well.

1. Introduction
Horizontal well fracturing technology is a key technological measure to accomplish the effective development of oil and gas reservoirs[1-3]. Conventional hydraulic fracturing models are usually calculated based on homogeneous reservoir models. With the development of oil reservoir in SHB block, the reservoir fractures are developed and the heterogeneity is serious. Due to the serious horizontal and longitudinal heterogeneity of the reservoir, it is difficult to predict the rock mechanical parameters and in-situ stress distribution in the horizontal fractured layer, and the fracturing pumping parameters are lack of pertinence. At present, based only on the geological data of the adjacent well or pilot section, using homogeneous model to calculate the hydraulic fracture propagation will bring large error[4-7]. In addition, according to well logging interpretation of guide hole parameters of rock and ground stress distribution is also unable to accurately describe the horizontal section of geological stress parameters[8-10]. Stress concentration due to local structure, sedimentary characteristics of reservoir and in-situ stress...
distribution law of rock mechanics parameters, often forms in the process of actual fracturing can form two asymmetrical artificial fracture\cite{11-13}. By strengthening the study of rock mechanics parameters and in-situ stress profiles, many scholars can optimize the perforation scheme, fluid pumping rate, fluid type and other pumping parameters\cite{14-16}, so as to improve the success rate of fracturing operation and better communicate with oil-gas enrichment areas\cite{17,18}. Therefore, in view of the above problems, in this paper, the geomechanical parameters are elaborated, a heterogeneous three-dimensional geomechanical model is established, and the full three-dimensional fracture simulation calculation method is used to calculate the extension features of artificial fractures in heterogeneous reservoirs, so as to optimize the pumping program and pumping parameters during hydraulic fracturing.

2. Interpretation of in-situ stress by logging

The mechanical parameters of rock mainly include Young's modulus, Poisson's ratio and density, which are the premise and foundation of in-situ stress research. According to the research idea of "logging-seismic data combination", the physical and mechanical parameters of a single well are firstly calculated based on logging data.

![Fig. 1. Interpretation diagram of rock mechanical parameters and in-situ stress parameters](image)

In the reservoir segments of Yijianfang and Yingshan formations, the overburden pressure is 165-170MPa. The minimum horizontal principal stress is about 152-157MPa. The formation breakdown pressure is about 165-170MPa. The stress and brittleness of the reservoir are not different from those of the upper and lower barrier layers.
The analysis shows that the elastic modulus of Silurian and Ordovician strata mainly varies between 40~60MPa due to the longitudinal difference of lithologic characteristics. Poisson's ratio mainly ranges from 0.20 to 0.25 (Figure 2). The calculated experimental results are close to the measured results of well SHB501 in this area.

3. Three-dimensional geomechanical model of seismic data and logging combination

3.1 Three-dimensional rock mechanics model
According to the interpretation results of seismic data volume, combined with the corresponding relationship between seismic horizon and stratum. The root mean square amplitude attribute is sampled into the three-dimensional geological grid through seismic data resampling. By selecting reasonable truncation value, the whole grid is divided into two parts, namely fault and background. On this basis, the time domain geological model is established.

![Fig. 4. Depth domain geological model including multiple geological elements](image)

The buried depth of SHB block varies widely from south to north. It can be seen from the seismic and geological model diagram established that the farther south, the greater the depth and the greater the average velocity. This is because the strata in the study area are high in the north and low in the south. According to the regional background data, the unified depth domain division of geological and seismic stratification is made. Based on the established time-depth conversion relation, the established time-domain geological model is transformed into a deep-domain geological model. At the same time, in the process of establishing the geological model, drilling trajectory and fault are loaded into the model according to the well location coordinates and fault distribution map.

### 3.2 3D in-situ stress model

After the formation of faults through multiple tectonic movements, the stress of the reservoir reaches a state of equilibrium. At present, the in-situ stress simulation mainly adopts two methods: parameter modeling and finite element simulation. Parametric modeling is to establish the prediction data body of the in-situ stress field between wells by using the Gaussian sequential statistical method and the previous interpretation results of the in-situ stress of a single well. Although the parameter modeling method refers to the in-situ stress parameters of a single well, but the stress effects of geological features such as fault distribution or tectonic movement cannot be simulated. At the same time, the rock mechanical parameters and in-situ stress of horizontal well can not be calculated because of the lack of logging curve in horizontal section.

Finite element simulation algorithm using the space geometric relations, the balance equations of force, the constitutive equation of rock area of in-situ stress simulation model is set up. However, due to the limitation of 3d modeling program, young's model, Poisson's ratio, compressive strength and other parameters can only be input average value, which does not reflect the influence of reservoir heterogeneity on in-situ stress parameters. Therefore, the reliability of computational simulation results is greatly reduced. 3D seismic data can be used to establish a regional stress field. However, the resolution of 3D seismic data is in the range of 10-15 m, while hydraulic fracturing operations require longitudinal accuracy of less than 1 m. Therefore, the 3d elastic parameter model and rock mechanics parameter model obtained by seismic method alone cannot meet the needs of optimization design of actual fracturing construction.
The horizontal maximum principal stress is closely related to the tectonic position. In the bedrock, the block is complete and the maximum principal stress varies in the range of 170-200MPa. Since the maximum principal stress direction is NE-trending, the NW-trending fault is compressed to produce stress concentration, and the distribution range is 10-20MPa higher than that of the bedrock. The strike of the NE trending fault is nearly parallel to the direction of the maximum principal stress. The rock mass in the core part is broken and the stress is released, which is 10-20MPa less than the normal stress. Stress concentration tends to occur at both ends of the fault. The minimum horizontal principal stress is 115-145MPa. In the extrusion fault development area, the stress is concentrated and the stress is 10-15MPa higher than the normal value. The stress decreases slightly in and around tensile and strike-slip faults. At the end of the fault, the stress increases in concentration.

In order to overcome the above problems, the idea of combining seismic data with logging data must be adopted. The advantages of both 3D seismic plane prediction and logging longitudinal prediction can be used to accurately describe the 3D elastic parameter model and rock mechanics parameters. Three-
dimensional rock elastic parameter model and rock mechanical parameter characterization are completed in three steps: discrete processing of logging data, data analysis and model realization. In order to meet the needs of fine stratification and longitudinal fracturing, the interval of logging data is 0.05 m. If the mesh is divided according to the longitudinal accuracy of 0.05 m, the mesh number of single parameter model will reach 1 billion mesh level, which is far beyond the processing capacity of existing computers. Therefore, it is necessary to carry out highly discrete processing of logging curves. After the completion of the discretization, the probability distribution law and variation function relationship are analyzed by using mathematical statistical formula, and the distribution law of discrete data body in plane and longitudinal is obtained. Combined with 3D seismic data, Gaussian sequential method is used to describe 3D rock elastic parameter model, strength parameter and rock mechanics parameter, and a better prediction effect is obtained. The prediction model can be used for real 3D hydraulic fracturing simulation, which solves problem of high heterogeneity in the upper and lower reservoir of horizontal well (Fig.6).

4. Field application and analysis
In the above three dimensional rock mechanics parameter and stress model, on the basis of the combination of well track profile, well X3 horizontal section parameters of rock mechanics and ground stress import fracturing software Gohfer software, as shown in Fig.7, reservoir porosity, permeability, poisson's ratio, heterogeneity of minimum horizontal stress distribution are well reflected in the numerical simulation of fracture. The actual fracture morphology of the formation can be simulated more truly. The grid structure calculation method is adopted to solve the linear fracture mechanics equation by using the finite element method, and the two-dimensional finite difference grid method is used to calculate the fluid flow. Combined with the full three-dimensional fracture propagation model, the geometry size of fracturing fractures under various formation conditions can be simulated (Fig. 8).

![Fig.7. Stress distribution around the well (left) and rock mechanics (right)](image-url)
It can be seen from the simulation results that the length and height of fracture calculated by the heterogeneous model are not symmetrical, and the simulation results are more in line with the actual geological conditions. Compared with the homogeneous model, the fracture on the side near the fault is obviously more fractured due to the effect of stress concentration near the fault. In addition, due to the development of natural fractures in the lower part of the reservoir, natural fractures are more likely to open and extend, making it easier for hydraulic fractures to communicate with the below of reservoir. The research results are of great significance for optimizing the hydraulic fracturing design of complex reservoirs, improving the success rate of horizontal well staged fracturing and improving the productivity of single well.

5. Conclusion
(1) In the ultra-deep carbonate reservoir, fractures and faults are well developed, the reservoir heterogeneity is strong, and the initiation and extension law of hydraulic fractures are uncertain. Only the geological data of the adjacent well or the guide hole section can not meet the needs of the actual horizontal well fracturing design. Through the combination of logging and seismic data, the actual artificial fracture propagation characteristics can be simulated to improve the reliability of hydraulic fracturing design.
(2) In the existing seismic acquisition, processing and interpretation technology conditions, improving the resolution of seismic data and geologic interpretation model precision three-dimensional rock mechanics and ground stress model, established the SHB block of structure model, rock and ground stress parameters such as elastic mechanics model, implements the rock mechanics parameters and ground stress explain three-dimensional display. At the same time, combining with single well logging data, the wellbore stress field is refined to provide support for the pumping design of horizontal well fracturing.
(3) On the basis of fine reservoir characteristics and stress field description of horizontal well, the position parameters of horizontal well stage fracturing can be optimized, and the fracturing design ideas can be adjusted according to the actual geological conditions of each stage.

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