Geological modeling of thin and poor reservoir based on well seismic multi-disciplinary

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Abstract. The reservoir physical properties of Tai X block are poor and the major development are thin and poor layers. The average porosity is 18.9% and the air permeability is $2.23 \times 10^{-3}$ μm$^2$, the Tai X block is a low-permeability reservoir. The block has the characteristics of large area, large number of faults, dense distribution of small faults and complex intersection conditions. It is difficult to obtain a high accurate geological model by using only logging data or seismic data, resulting in inaccurate stratigraphic interpretation results. Therefore, the joint well-seismic technique is used to combine logging data with seismic data to achieve the purpose of accurately identifying faults and establishing complete reservoir structure, and successfully deployed a horizontal well across the fault.

1. Introduction

3D geological modeling has always been a research hotspot of scholars at domestic and abroad in the process of oilfield development. By combining geological data, logging data, geophysical data and various logging interpretation results, a complete and accurate geological model can be formed by using reasonable modeling methods and software, which can specifically show the structural form, geological characteristics, fluid properties and distribution characteristics of the oilfield, which is very effective for studying the distribution of oil field reserves and making development plans [1-4].

Domestic scholars have made more in-depth research in multidisciplinary integrated geological modeling, and have made some achievements, more of which focus on well seismic joint modeling, or geological modeling based on phase control, etc[5-7]. However, although the above research breaks through the traditional modeling, with the improvement of oilfield development, the method is still difficult to meet the purpose of oilfield fine research. It is mainly manifested in the following aspects: ①It is difficult to accurately depict the thin difference reservoir sand body due to the limitations of data and technical methods; ②The combination of well seismic technology to identify faults can establish a simple geological model, without more complex and targeted application; ③It is highly dependent on drilling, but fails to achieve the purpose of accurate prediction between wells.

In order to depict the reservoir and improve the accuracy of reservoir prediction, this article, based on previous studies, takes Tai X block of Daqing Oilfield as an example, aiming at the characteristics of low permeability, thin difference, large number of faults and complex connection, explores the method of combining logging data and seismic data to carry out geological modeling (i.e. well seismic
combination), and establishes and obtains more than the traditional modeling method. It is a reliable geological model to provide technical support for subsequent remaining oil exploration.

2. Project overview
Tai X block is located in the periphery of Daqing Oilfield, adjacent to PUX Development Zone in the West and Tai X01 Development Zone in the East. It belongs to the inherited and developed depression syncline structure, with an area of 34.44 km². The average effective 3.0 m / 4.0 formation is drilled in a single well, with an average porosity of 18.9% and an air permeability of 22.3×10⁻³ μm². It is a low-permeability reservoir, with a wide range of lithology and physical property changes and strong heterogeneity. 153 faults are developed, and the fault connection is complex. The thickness of the reservoir is thin and the reservoir development is poor.

With the extension of development time and the adjustment of densification in 2011-2014, various development problems have become increasingly prominent. First, the production of oil wells is declining rapidly, the production of single wells is low; second, the proportion of oil-water wells is high, the degree of water drive control is low; third, Low degree of production of reserves in thin poor layer; fourth, with the annual workload of measures. It is difficult to select wells and layer; Fifth, the formation pressure is unbalanced.

3. Combined geological modeling of well and earthquake

3.1. The key technologies of modeling

3.1.1. Based on the structure modeling under the well earthquake condition. Three dimensional structural modeling is usually composed of fault model and layer model. The fault model mainly represents the fault plane of strata in three-dimensional space. The layer model reflects the three-dimensional distribution of the stratigraphic interface, which is the stratigraphic framework model.

3.1.2. Geological modeling based on facies control constraints. Based on the sedimentary characteristics and geological knowledge of block Tai X, the sedimentary facies map is digitized. Based on the theories and methods of geology, sedimentology and geostatistics, the sedimentary microfacies model is established by using reservoir prediction results and sedimentary microfacies characterization results of each small layer.

3.1.3. Attribute modeling based on well seismic dual control constraints. Generally speaking, the majority of geologists use the deterministic modeling method based on facies control to establish porosity model. The advantage of this method is that the interpolation and convergence of well data plane can be constrained by the spatial distribution of sand body, and the well data distribution can be controlled to be balanced, so that the model conforms to the conventional geological concept[8-11].However, there are some disadvantages in this method: first, both well data and sedimentary facies data are based on well information as starting point, which is difficult to achieve the effect of model inter well prediction; second, microfacies is a discrete type of data, porosity is a continuous type of data, microfacies type and porosity attribute are not directly related, this "hard constraint" based on facies control obviously not scientific and rigorous; Third, the mapping of sedimentary facies is based on the geological knowledge of geologists. Influenced by many factors, the porosity model based on facies control is bound to have certain subjectivity, and its porosity model often lacks the description of the real underground situation [12-13].

Generally speaking, wave impedance inversion data is the first choice of "soft constraint" modeling. This is because porosity and acoustic curve have a high correlation, and conventional single well porosity logging interpretation is generally based on the calculation of acoustic curve. Therefore, when choosing "soft constraint" background data, we should choose wave impedance inversion as "soft constraint" data. The purpose of establishing three-dimensional geological model based on well seismic
combination is to study the relationship among seismic attribute parameters, seismic inversion parameters and reservoir physical parameters, and use the seismic data to establish the model for simulation and prediction, which can give full play to the advantages of seismic data in describing the distribution law of sand bodies in the formation, improve the prediction accuracy of the model.

3.2. Structural model and sedimentary facies model

3.2.1. Fault model. There are 153 time domain faults in the block Tai X, which are densely distributed and have complex connection relationship. In order to accurately depict the structural form of thin difference reservoir, all faults in the study area have been successfully established and the accuracy and precision of the fault model have been guaranteed based on the multidisciplinary well seismic joint modeling technology through time depth conversion, as shown in Fig.1.

3.2.2. Layer model. After the fault model is processed, a layer model is built on this basis. In view of the thin reservoir in block Tai X, in order to accurately describe the reservoir and the distribution characteristics of remaining oil, each layer of the block reservoir is divided into 5 layers, with a total of 40 layers, as shown in Fig.2.

3.2.3. Sedimentary microfacies model. The sedimentary microfacies models of 8 small layers in the study area are established, including PI1 layer as shown in Fig.3 and PI2 layer as shown in Fig.4.
3.3. Attribute model under dual control constraint

On the basis of the completion of the well seismic joint structure modelling, according to the seismic attribute model body after resampling and sedimentary microfacies model, a porosity model establishment method with seismic data control as the "soft constraint" and sedimentary facies control as the "hard constraint", i.e., a double-control porosity model was proposed, and then the porosity model of Block X was completed by sequential Gaussian simulation algorithm (As shown in Fig. 5). Porosity is taken as the second variable in the permeability model and controlled by seismic data, as shown in Fig. 6.

![Figure 5. Porosity model based on dual control condition](image1)

![Figure 6. Permeability model](image2)

3.4. Three kinds of modeling comparative analysis

3.4.1. Analysis of modeling effect of logging data. Generally, the method of using logging data to interpret faults is called breakpoint projection method. Its operation is to project logging breakpoints onto meter paper. According to the plane coordinates and longitudinal depth of breakpoints, judge and speculate the spatial shape of faults in the formation. The higher the well pattern density is, the higher the interpretation accuracy is. However, this method of fault interpretation has the following three disadvantages:

(1) The interpretation accuracy decreases with the increase of well spacing. According to the interpretation results of a block in Daqing Oilfield, when the well spacing is greater than 200 m, more than half of the small faults extending less than 500 m will be missed.

(2) If there is a small fault with a small development scale and an extension length of no more than 500 m in the study block, it will generally only be drilled by one well. These breakpoints lack reliable research data in both horizontal and vertical directions, which are called as isolated breakpoints that are difficult to explain.

(3) Sometimes a well will encounter multiple breakpoints in the vertical direction at the same time. When such a situation occurs, it is difficult to determine which breakpoint belongs to which fault, which will bring difficulties to fault interpretation and cause fault combination errors.

3.4.2. Analysis of modeling effect of seismic data. Seismic data has high horizontal interpretation accuracy, good continuity and high reliability, which is beneficial to the combination of fault space, but its algorithm stability and vertical accuracy still need to be improved, and the seismic data is time domain, which cannot be directly used by oilfield development research, so it needs time depth conversion.

3.4.3. Analysis on the effect of well seismic joint multidisciplinary modelling. Combining the well logging data and seismic data in the study area, the seismic data in the time domain is transformed into the depth domain by using the time-depth conversion technology, and the comprehensive interpretation of the spatial shape of faults by ant body tracking technology can achieve the complementary advantages of well logging data and seismic data. The study block in this paper has the characteristics of large area, large number of faults, dense distribution of small faults and complex cross situation. Only using logging data or seismic data in 3D geological modeling is likely to miss small faults, or fault breakpoint combination is wrong, resulting in inaccurate formation interpretation results.
Therefore, for block of Tai X, the geological model established by well seismic joint multidisciplinary modeling technology has high interpretation accuracy in both horizontal and vertical directions, which can combine the advantages of well logging data and seismic data. The 3D geological model established by such technology has high accuracy in spatial plane, accurate spatial combination of faults and interpretation accuracy in vertical direction. It is also found that in the process of identifying and modeling faults in the study area, if only logging data is used for fault modelling, only 104 faults can be identified, and 49 small faults with extension length less than 500 are omitted, and the use of well seismic joint method for fault modeling, can avoid such problems, successful identification of logging data modeling missing small fault, fault identification increased by 47.12%.

3.5. Instance application

In the design of well pattern, not only the number of thin differential reservoir faults in the study area, but also the economic benefits of Oilfield development should be considered. After many demonstrations, horizontal wells are more suitable for well location deployment in the study area. Based on the results of geological understanding, the optimization method of "water well + oil well transfer injection" is adopted, the principle of "four injection and one production" well pattern is implemented, and finally a cross fault horizontal well is successfully deployed in the area.

The geological conditions of horizontal well X1 are relatively favourable, and the well is located at the south west side of well T66-91, and the target layer is small layer PI5. Single cross fault horizontal well is adopted. The trajectory parameters of horizontal well are shown in Table 1 and table 2, the elevation depth of target points at both ends of horizontal section is about -1295m. In order to improve the drilling rate of sandstone, the drilling track is drilled from the ascending wall to the descending wall (Fig. 7). The strike of horizontal section is 79° to the west by North, and the azimuth is set as 281°. After drilling 346m horizontally from target A along the top of PI5, drill through the fault, change the descending wall, and reach target B through 765m horizontally. The fault loss rate of the well is 14.12%. The well pattern adopts oil well T66-S83 transfer water injection well, water well T66-91 and two new wells. The single well of horizontal well has an effective control reserve of 4.26×10⁴t.

| Parameter | Target | Target layer | coordinate (X(m) Y(m)) | Direction (°) | Altitude depth (m) | Displacement (m) |
|-----------|--------|--------------|------------------------|--------------|------------------|-----------------|
|           | X1     | PI51         | 21640415.64 5062604.25 | 281          | -1195.6          |                 |
|           | A      | PI51         | 21639781.66 5062595.11 | 281          | -1206.3          |                 |
|           | B      | PI51         | 21638852.18 5062692.49 | 281          | -1206.1          |                 |

Table 1. Tai X block A1 horizontal well trajectory parameter table

| Target | Target layer | coordinate (X(m) Y(m)) | Structural depth (m) | Thickness of sandstone (m) |
|--------|--------------|------------------------|---------------------|---------------------------|
| X1     | PI51         | 2163901.56 5062701.89 | -1278.32            | -1195.6                   |
| A      | PI51         | 2163901.56 5062701.89 | -1295.62            | -1206.3                   |
| B      | PI51         | 2163901.56 5062701.89 | -1284.35            | -1206.1                   |

Table 2. Tai X block A1 horizontal well geologic parameter table

![Figure 7](image)
4. Conclusion
(1) Multidisciplinary well seismic joint modeling technology is a new technology in the field of fine 3D geological modeling and fault interpretation, which is gradually being studied and applied by various domestic oil fields. This technique combines the advantages of logging data and seismic data to achieve the required interpretation accuracy in both plane and longitudinal dimensions and accurate formation framing. (2) A porosity model based on seismic data control (soft constraint) and facies control (hard constraint) is proposed. (3) Through the combination of well seismic and multi-disciplinary geological model, the risk well location was successfully deployed. According to the result of geological understanding and the principle of "four injection and one production" well pattern, and finally a horizontal well across fault was successfully deployed in the area.

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