

Three-dimensional geological modeling study of Block A of the Hailar Basin

Jin'ang Wang^{1,2}

¹ Unconventional Oil and Gas Research Institute, Daqing, Heilongjiang, 163000, China

² College of Earth Sciences, Northeast Petroleum University, Daqing, Heilongjiang, 163000, China

Abstract: At present, the Beier Depression requires more detailed quantitative research. To numerically represent the actual reservoir, and to compare and interpret the seemingly unrelated data, this study is based on the geological and logging data of each well within the study area, combined with the spatial configuration relationship of sedimentary facies, and guided by the theory of geostatistics, a multi-parameter collaborative geological attribute spatial distribution model has been established. Through Kriging interpolation and random simulation algorithms, quantitative predictions of geological parameters of the three-dimensional grid cells have been achieved. This study has constructed a three-dimensional geological model system including structural model, sand body framework model, physical property parameter model and hydrocarbon-water distribution model, and realized the integrated representation of reservoir structure, attributes and fluid distribution.

Keywords: Hailar Basin; Beier Depression; Sedimentary Facies; Three-dimensional Geological Modeling.

1. Overview of the Study Area

This block is structurally located in the central part of the Sudert structural belt of the Beier Lake Depression. Overall, it is a syncline structure controlled by a north-eastward major fault.

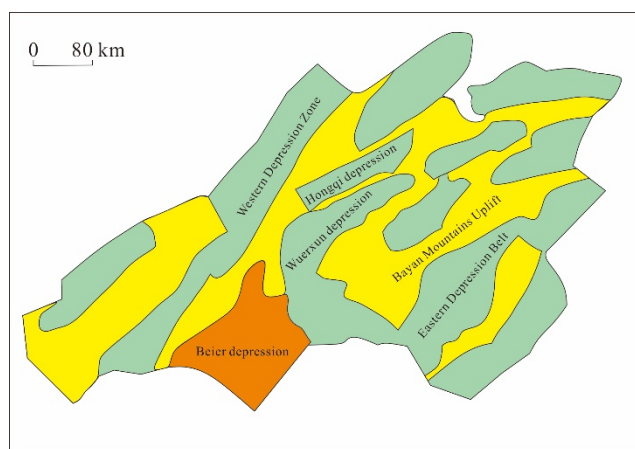


Fig 1. Beier Depression Location Map

The central area has undergone uplift and erosion. The faults in the area are extremely developed, with a density of 4.5 faults per square kilometer. The fault blocks are highly fractured, and 80% of the blocks have an area ranging from 0.5 to 2.0 km². On average, each well encounters 2 fault points. The fault gap varies between 17 and 286 meters. The main fault blocks are cut into 3 irregularly strip-shaped fault terraces, with a stratigraphic dip angle of approximately 11°. The analysis of the regional sedimentary environment indicates that the target layer section belongs to a coastal shallow lake - fan delta sedimentary system. The sediment source mainly comes from the southwest and the south. The fan body formed by the southern sediment source extends northward, while the fan body controlled by the southerly-easterly sediment source advances in the north-northwest direction. Different sediment source directions significantly affect the size and spatial distribution characteristics of the

fan delta.

2. Current State of Three-Dimensional Geological Modeling Research

Reservoir description technology originated in the 1980s. In recent years, the development of reservoir description technology can be summarized as "precision" and "detail". "Precision" means to enhance the quantitative degree and prediction accuracy of reservoir description; "detail" refers to the increasingly detailed content and scale of description, that is, to improve resolution[1]. Currently, more and more international scholars are using "Reservoir Characterization" to replace the original "Reservoir Description", which largely reflects the development trend of reservoir description technology[2].

2.1. Three-dimensional Detailed Structural Model

Based on the grid data of the structural layer and the fault data obtained from well data and seismic information, combined with the well-spacing network logging data, a structural model was established using the Petrel software.

Given the complex geological structure and the presence of numerous faults in the target area, this study adopts a modeling approach that combines hierarchical control, multi-data collaboration, and three-dimensional visualization. The following three key technologies are mainly applied:

Firstly, based on the principle of hierarchical control, the spatial cutting relationship between derived small fault segments and the main controlling large faults is systematically integrated. Through comprehensive analysis of factors such as the planar distribution pattern of fault points, the variation law of fault distances, the dip attitude of fault planes, the nature of faults, and the height difference of strata between the two sides[3-4], the small fault segments are identified and combined from the main fault to the derived faults, from large to small, ensuring that there are no unassigned well points within the planar distribution area and guaranteeing the rationality of the fault system;

Secondly, the data of fault points in the dense well network area is fully utilized to conduct dynamic matching analysis of the three-dimensional spatial fault points and fault planes. The relationship of fault point attribution is preliminarily determined, and combined with the well positions, fault points, and fault distribution characteristics in the two-dimensional plane, the extension range of faults and the matching relationship of fault points are comprehensively determined. Through multiple iterations of spatial and plane verification, the optimal combination of fault points and the

spatial consistency of the fault system are achieved; Thirdly, based on the detailed interpretation of faults, by establishing planar fault polygons, conducting high-precision simulation of fault planes, and carrying out interactive picking and combination of structural planes under the constraint of section and stratum intersection lines, the three-dimensional structural framework consistent with geological laws is systematically reconstructed. Finally, a high-precision three-dimensional structural model is completed[5-6].

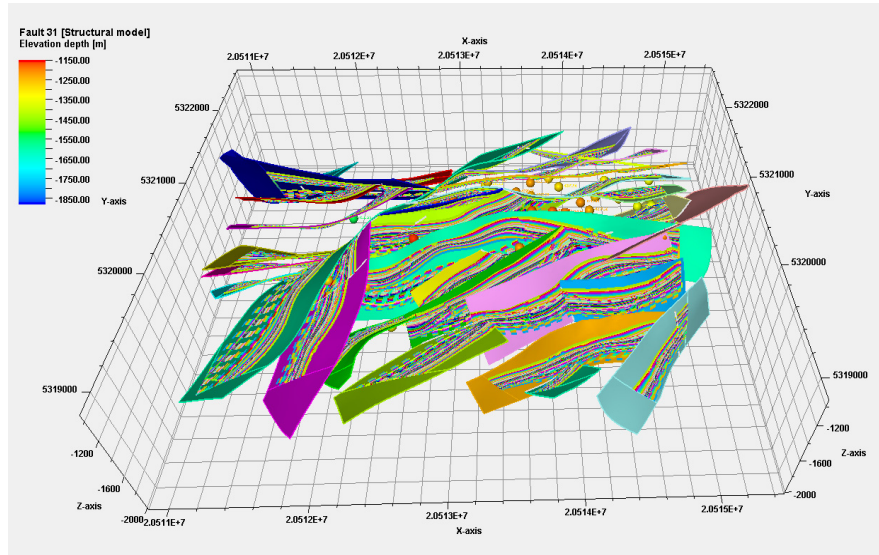


Fig 2. Beier depression final fault model

2.2. Depositional Facies Modeling

This modeling adopts the random modeling method based on phased attributes, treating the same micro-phase as a geological body with statistical homogeneity. Based on this, a three-dimensional phased attribute model is constructed. Under the condition that the sedimentary facies belt map has been completed in the previous stage, this study uses the assignment method to establish the sedimentary facies model of the study area[7-8].

Based on the discrete phase point data derived from the detailed description of the working area, the nearest neighbor point interpolation algorithm is used to generate the sedimentary facies distribution map. This method can effectively maintain the discrete characteristics of the original data and ensure that the constructed facies model strictly follows the facies type control at the well points, thereby providing reliable geological constraints for the subsequent attribute modeling.

2.3. Establishment of three-dimensional phased attribute model

The core objective of reservoir three-dimensional modeling is to construct a structured model that can accurately represent the spatial distribution of the physical parameters of the underground reservoir. Due to the strong heterogeneity and anisotropy of reservoir physical properties in space[9], traditional deterministic modeling methods rely solely on limited observation points for interpolation, which is difficult to effectively depict their complex change patterns. The reasons for this are as follows: on the one hand, the physical parameter values of the reservoir have a random distribution characteristic; on the other hand, their spatial

variation is strictly controlled by geological causal units such as sedimentary microfacies and diagenesis, demonstrating significant regionalized variable attributes.

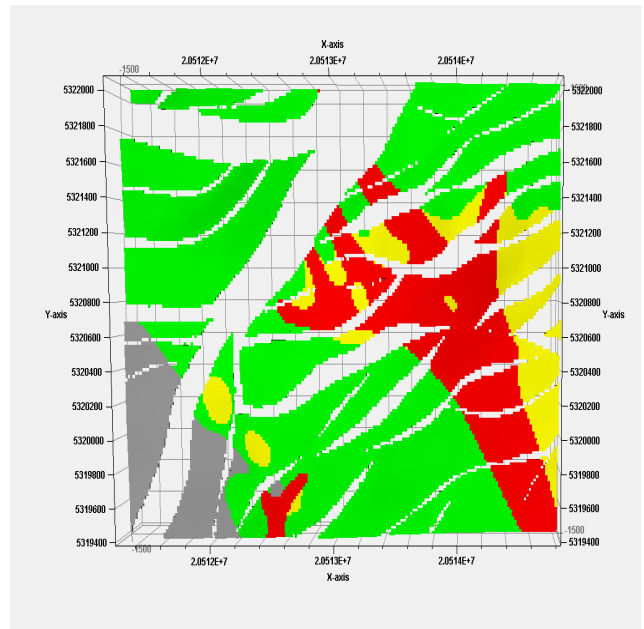


Fig 3. Unit sedimentary facies model

Therefore, on the basis of establishing a high-precision sedimentary microfacies model, conducting random simulation of physical parameters under phased conditions has become a key approach to truly reflect the heterogeneity of the reservoir. By using the phased random simulation method based on geostatistics and random process theory, it can effectively integrate geological cognition and random

uncertainty, and is the optimal strategy for achieving quantitative representation of the spatial distribution of

reservoir physical parameters.

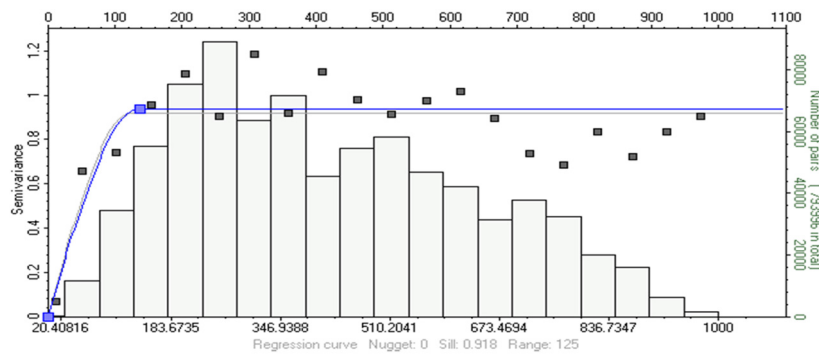


Fig 4. Main transformation fitting

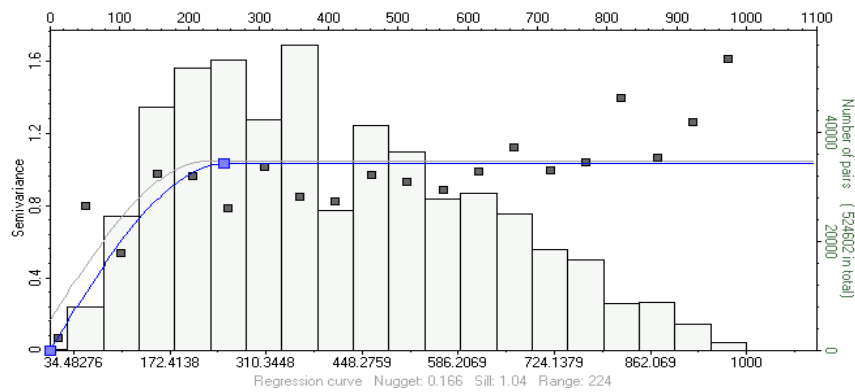


Fig 5. Secondary variable fitting

Reservoir property modeling focuses on permeability, porosity and oil saturation as the core modeling parameters, and uses sequential Gaussian simulation method for random modeling. The specific process is as follows: Firstly, based on the established sedimentary facies model, the quantitative distribution laws of reservoir parameters within different sedimentary facies are identified; on this basis, random simulation interpolation is carried out for each facies zone to generate an attribute model that conforms to the geological

statistical characteristics. During the facies-based modeling process, different statistical parameters are adopted for different sedimentary facies to characterize the Gaussian field model. This method effectively utilizes the control effect of sedimentary facies on rock properties, making the parameters such as porosity and permeability show stronger regularity in spatial distribution, reducing randomness, and significantly improving the credibility and certainty of the attribute model.

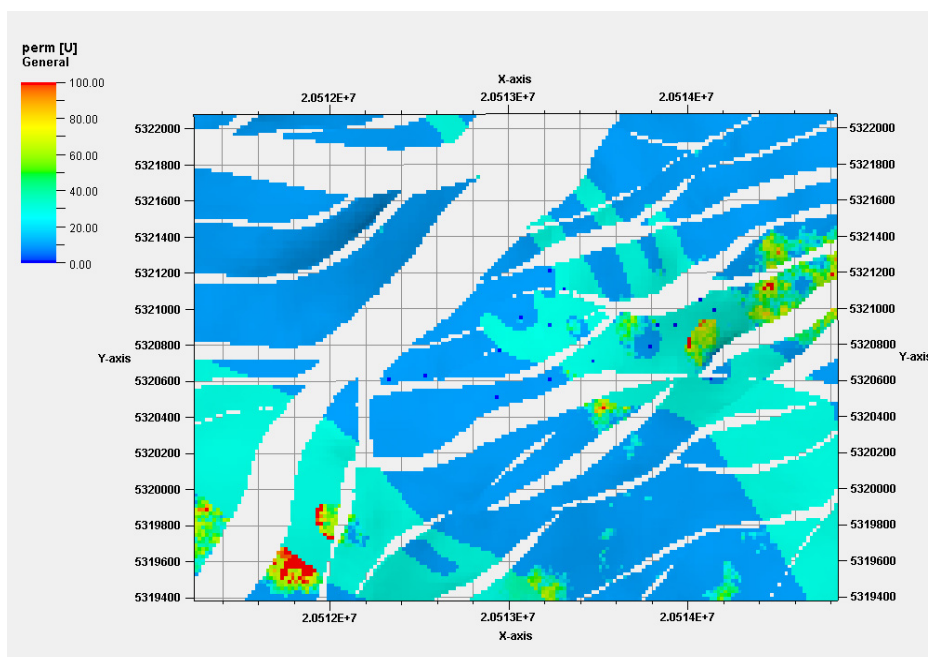


Fig 6. Unit permeability model

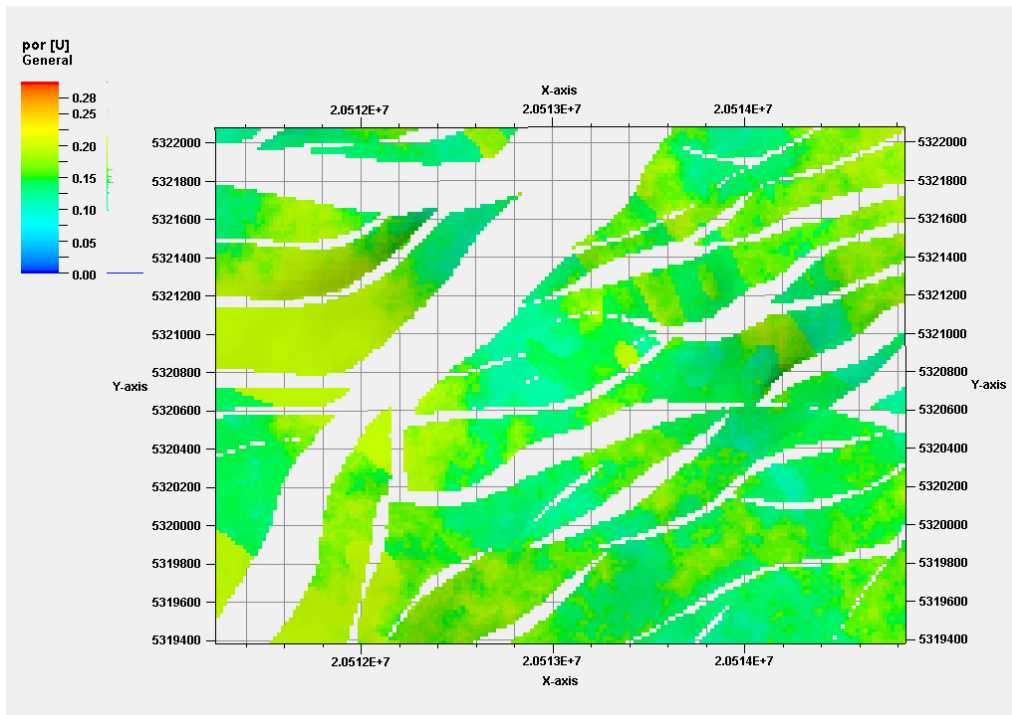


Fig 7. Unit porosity model

3. Conclusion

In this study, the combined method of well seismic data was applied to establish detailed fault models and structural models. Quality checks of the structural models were conducted, and the trend of sedimentary facies was utilized to constrain the establishment of the phased reservoir parameter distribution model. The distribution of attributes such as porosity in this block was quantitatively characterized. The phased parameter modeling and the distribution of rock physical parameters have a very regular pattern, and the randomness of parameter distribution has been greatly reduced, thereby improving the accuracy of attribute quantitative characterization. This lays a foundation for subsequent numerical simulations and other work.

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