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Prediction of Sedimentary Microfacies Distribution by Coupling Stochastic Modeling Method in Oil and Gas Energy Resource Exploitation

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Abstract

In view of the problem that a single modeling method cannot predict the distribution of microfacies, a new idea of coupling modeling method to comprehensively predict the distribution of sedimentary microfacies was proposed, breaking the tradition that different sedimentary microfacies used the same modeling method in the past. Because different sedimentary microfacies have different distribution characteristics and geometric shapes, it is more accurate to select different simulation methods for prediction. In this paper, the coupling modeling method was to establish the distribution of sedimentary microfacies with simple geometry through the point indicating process simulation, and then predict the microfacies with complex spatial distribution through the sequential indicator simulation method. Taking the DC block of Bohai basin as an example, a high-precision reservoir sedimentary microfacies model was established by the above coupling modeling method, and the model verification results showed that the sedimentary microfacies model had a high consistency with the underground. The coupling microfacies modeling method had higher accuracy and reliability than the traditional modeling method, which provided a new idea for the prediction of sedimentary microfacies.

Keywords

Coupling Modeling, Oil and Gas Energy Resource, Sedimentary Microfacies, Seological Model, Reservoir Prediction

1. Introduction

The establishment of a reservoir geological model in oil and gas energy resource exploitation is the key to reservoir description, and is also the core content and front of current oil and gas reservoir geology research [1]. Reservoir geological modeling refers to the shape, scale, direction and superposition relationship of the formation units of different levels of reservoirs. Since the development of the concept and method of geological modeling, reservoir modeling technology has become a popular research direction. At present, scholars have established rich qualitative and quantitative models of reservoirs through outcrops, modern sedimentation, and flume experiments. These models have guided the fine configuration anatomy of reservoirs in many old oil fields with dense well patterns, and have played a significant role in the comprehensive adjustment in the later stage of oilfield development and in tapping the potential of remaining oil [2]. In recent years, with the gradual quantitative development of geological research, how to quantitatively characterize the results of fine reservoir analysis in the three-dimensional geological model has become a research hotspot, and has formed some practical technical methods, which has played a good role in promoting the application of the results of geological model research in the actual oilfield development. The stochastic modeling method of oil and gas reservoir is a new oil and gas prediction technology developed in recent years. It is based on the known information, takes the stochastic function as the theory, and uses the stochastic simulation method to generate an optional, equal probability reservoir model method. This method has been rapidly developed [3] [4]. Traditional 3D modeling generally only reaches the microfacies level, while random modeling refers to the 3D quantitative simulation of the internal configuration interface and configuration unit of a single microfacies sand body. Its essence is to refine the interface level of the model, and bring the internal secondary interface of the reservoir into the quantitative characterization category of heterogeneity [5] [6]. Only by accurately characterizing it in the model and improving the prediction accuracy of the remaining oil distribution can it better guide the later adjustment and tapping of the potential of the oilfield. At present, most modeling engineers usually choose only one optimal random modeling method for reservoir sedimentary microfacies prediction [7] [8]. However, because the distribution characteristics and geometric morphology of different sedimentary microfacies have different laws, it is difficult to simulate the distribution of microfacies with different morphological characteristics by a random reservoir modeling method, so the accuracy of the geological model established is not high. For this reason, the author proposed a coupling stochastic geological modeling method to comprehensively predict the distribution law of reservoir sedimentary microfacies, that is, to combine the goal based point indicating process modeling method with the pixel-based sequential indicator simulation method to establish a reservoir microfacies geological model, which provided a new idea for predicting sedimentary microfacies.

2. Simulation Principle of Two Modeling Methods

2.1. Principle of Point Indicating Process Simulation

Pointing process simulation method is a simulation method based on target body, which belongs to random modeling method [9]. Unlike other methods, pointing process simulation method can define the geometric shape of target body according to the content of known geological knowledge base, and directly generate target body in the modeling process by studying the shape of target (such as length, width, thickness and their quantitative relationship), define different geometric shape parameters of the target, and truly reproduce the three-dimensional shape of the reservoir.

Pointing process assigns a feature or attribute to each point of the process [10]. Its basic idea is to generate the spatial distribution of the central points of these objects according to the distribution law of geometric objects in space according to the probability law of the point process, and then mark the physical properties (such as physical geometric shape, size, direction, etc.) on each discrete point. Therefore, random sequences can be used $\psi = \left| X_n,\ m\left(X_n\right) \right|$, $\{X_n\}$ is a point process, and $\{m\left(X_n\right)\}$ is the corresponding attribute. The attribute $\{m\left(X_n\right)\}$ corresponds to a specified attribute space M. The distribution of geological sedimentary facies is usually described by discrete random field $\{L(x): x \in D\}$, where x is the point in reference domain D, which represents the spatial distribution range of reservoirs, and $L(x)$ represents the type of facies at location x, which is often taken as {11, 12, ..., l_n}.

It can be seen that the simulation process of the point indicating process is based on the geological knowledge of the target, and some prior geological knowledge about the target is added to the model as constraints, so that the random simulation results can be as close to the geological reality as possible. In the process of random simulation, it is necessary to apply optimization algorithms (such as iterative algorithms or simulated annealing) to "gradually approximate" the target distribution, that is, use multiple combinations of various parameter distributions and interactions to iterate until a satisfactory random simulation result is finally obtained.

2.2. Principle of Sequential Indication Simulation

Sequential indicator simulation is a simulation method based on pixel [11] [12] [13]. By calculating the variation function of spatial attribute parameters, a stochastic reservoir model based on the variation function is established. Suppose that there are k codes for sedimentary microfacies, $k = 1, 2, 3, \ldots K$. Any point in the model belongs to and can only belong to [1, K], which is represented by the binary indicator variable $I(u)$, then:

$$I_k\left(u\right) = \begin{cases} 1 u \in \left[1,\ K\right] \\ 0 u \notin \left[1,\ K\right] \end{cases}$$

Hypothesis $I_k\left(u\right) \times I_{k'}\left(u\right) = 0, \forall k \neq k'$

$$\sum_{k=1}^{k} I_k\left(u\right) = 1$$

When simple Kriging is used for estimation, the probability estimation of the relative position u provided by the variable is:

$$\mathrm{Prob}\left\{I_k(u)=1\middle|(n)\right\}=p_k+\sum\nolimits_{\alpha=1}^{n}\lambda_\alpha\left[I_k(u_\alpha)-p_k\right]$$

where $p_k = E\{I_k(u)\} \in [0, 1]$ is the marginal probability of simple Kriging inferred, λ_a is the weight coefficient, which is obtained from the simple Kriging equations. After the conditional probability at position u is calculated, the sedimentary microfacies code at the node can be obtained by Monte Carlo sampling method. When all nodes are simulated, a realization is completed.

3. Coupling Modeling Solutions and Technical Ideas

In view of the problem that "single modeling method cannot better predict the distribution of microfacies", a "coupling modeling method" was proposed to comprehensively predict the distribution of sedimentary microfacies. The idea is as follows:

First of all, when selecting a random geological modeling method, only the microfacies suitable for this method are simulated, and other sedimentary microfacies are used as background facies. At the end of the simulation, the simulation phase retains the simulation value at the grid node. For the background phase, if the node is conditional data, the conditional data is reserved. If the node is non-conditional data, its value is set to null, that is, no simulation is performed. Secondly, select an appropriate random modeling method to simulate the nodes not simulated in the background phase in the first step, and the process is the same as that in the first step. In this way, different random geological modeling methods can be coupled, and the simulation of each microfacies is based on its characteristics to select appropriate modeling methods for prediction, so as to truly reproduce the geometric shape and spatial distribution of various reservoirs, which greatly improves the prediction accuracy of reservoir microfacies.

In this study, the pixel-based sequential indication simulation method and the target-based point-to-point process simulation method are combined. The process is as follows:

1) The distribution of sedimentary microfacies with simple geometric shape is established by using the method of point indicating process simulation. At this time, in order to distinguish the background facies from other microfacies, a separate code is set for the background facies.

2) Extract the code value of the grid node. If the code is not equal to the background phase code, keep its value; otherwise, set it to null.

3) Sequential indication simulation for null value nodes. At this time, only the micro phases of non-simulated nodes are considered, the probabilities of different micro phase types of non-simulated nodes are calculated, and the micro phase types of non-simulated nodes are determined and simulated through Monte Carlo sampling.

4. Case Study

4.1. Regional Overview

The DC block is located on the front uplift structural belt in the east of the Bohai

Basin in China, with a gentle structure. Some high-angle normal faults dipping eastward from northeast to the southwest are developed. The formation of traps is related to these normal faults. The types of traps developed include fault anticlines, fault noses, etc. The trap area is small and the amplitude is low. Drilling confirmed that the distribution of oil and gas reservoirs is jointly controlled by the structure and sand body distribution. The discovered oil and gas production layers include the sandstone reservoirs of C7, C5 and C3 members of the Paleogene Oligocene Carbonera Formation. Among them, the main reservoir, C5, develops delta front and pre-delta transitional deposits, which can identify multiple delta front lobe bodies. The lobe body development includes the sand mudstone interbedding deposits of underwater distributary channels and microfacies between underwater distributary channels. Oil and gas are accumulated in the higher part of these sand bodies. The reservoir lithology is mainly sandstone and siltstone, with porosity of 17% - 35.6% and permeability of 500 - 3900 mD, belonging to high porosity and permeability reservoir.

4.2. Coupling Stochastic Modeling Process

1) Establishment of construction model

The structural model is the basis of all reservoir modelling. In this study, two types of data are mainly used to establish the structural plane model: one is the top surface structural map and fault polygon of seismic fine structure interpretation, and the other is the stratigraphic division and small layer correlation results of drilled wells. The stratum interface in the model is constrained by the structural trend of the seismic interpretation horizon and corrected by the sub layer correlation results, which not only makes the structure of the model completely conform to the drilling data, but also shows the correct superposition shape of the structure in the plane and vertical. The structural model of the study area is shown in **Figure 1**. The boundary of the model is the boundary of the commercial

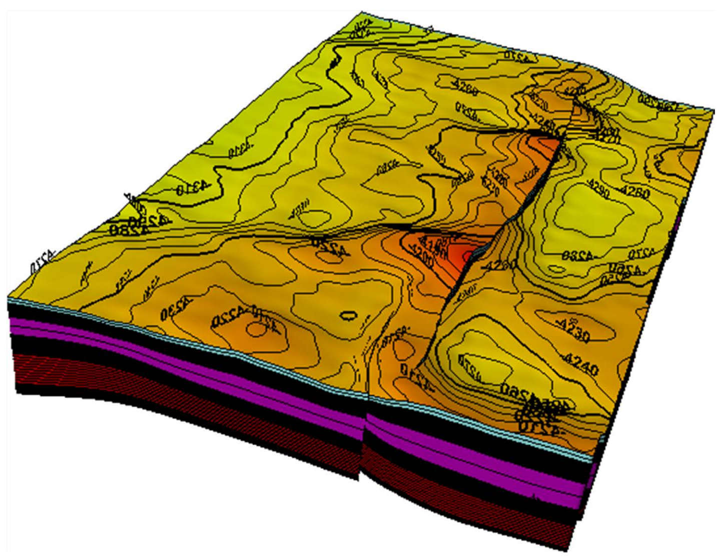

Figure 1. Structure model of the study area.

development area. A high angle normal fault with nearly north-south direction is developed in the study area.

2) Establishment of sedimentary microfacies

Through observation of coring wells and analysis of logging curves, delta and shelf sedimentary facies can be identified in C5 section of DC block. Three subfacies of delta plain, delta front and pre-delta are developed in the delta. The shelf develops inner shelf subfacies. The delta front mainly develops underwater distributary channels dominated by sandy sediments and underwater distributary channels dominated by muddy sediments. The front delta mainly develops two microfacies: sheet sand dominated by sandy deposits and front delta mud dominated by argillaceous deposits. The shelf mud and sheet sand are mainly developed on the shelf. The underwater distributary channel has an obvious geometric shape, which can be predicted using the point indicating process simulation method. Other microfacies have a complex morphology, which can be predicted using the pixel-based sequential indicating simulation method.

Using the logging data of 22 wells in the whole area, combined with the geological research results, the required modelling data can be obtained through data analysis.

For the point indicating process simulation method, it is required to input the channel length and extension direction, channel width, channel thickness, channel meander wavelength and channel percentage. For the sequential indication simulation method, it is required to input statistical analysis parameters of variation function characteristics, including the direction and size of primary and secondary range, vertical range, etc.

According to the single well microfacies interpretation data and geological research results, the following parameters are obtained for the C5 reservoir in DC block: the proportion of channel microfacies is 32%, the extension distance of the channel from north to south is about 1500m, the channel width is 400 m, and the thickness is 6 m. For other microfacies used for sequential indication simulation, the variation function analysis results are shown in **Table 1**.

4.3. Coupling Modeling Results

Using the above methods, a 3D geological model of reservoir microfacies in C5 section of DC block is established. **Figure 2** and **Figure 3** are the three-dimensional and north-south profiles of sedimentary microfacies of C5 reservoir in DC block.

Table 1. Transition function analysis results of different microphases.

Microfacies name	Interchannel	Sheet sand	Shelf mud
Main range direction	30	30	45
Main range/m	700	1200	1500
Secondary range/m	300	700	800
Vertical range/m	3	2	5

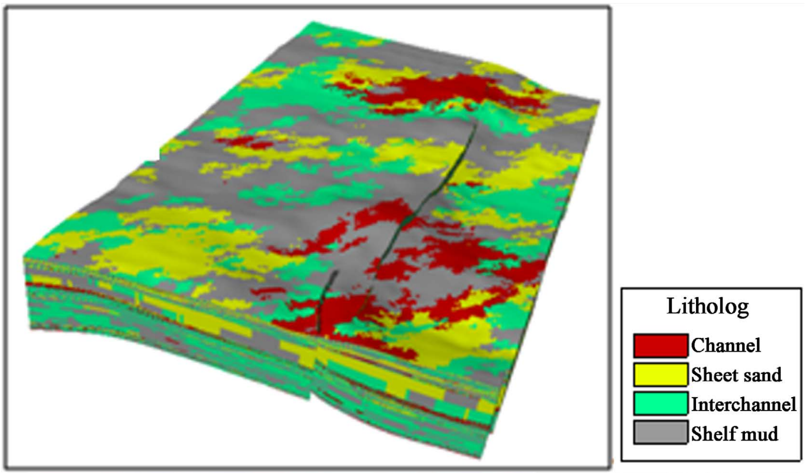

Figure 2. Sedimentary microfacies 3D map of C5 reservoir DC block.

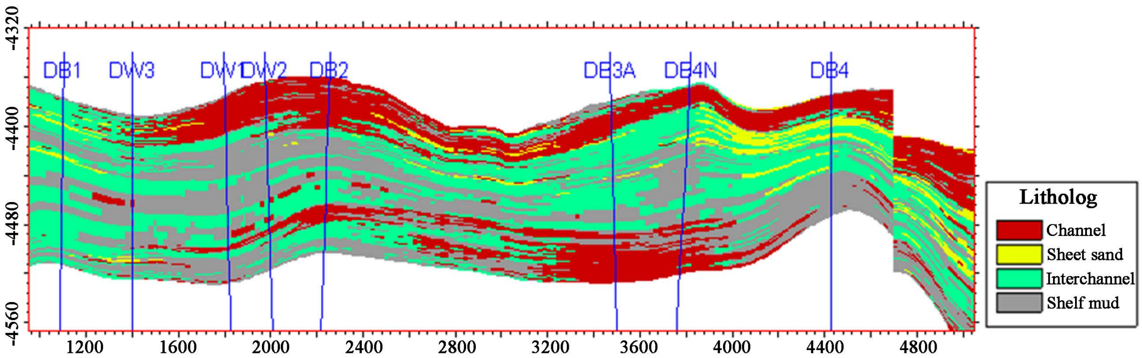

Figure 3. Sedimentary microfacies profile map C5 reservoir DC block.

The simulation results reproduce the underground spatial distribution of channel, interchannel, sheet sand and shelf mud.

4.4. Model Accuracy Inspection

In order to verify whether the design modeling method is reasonable, the modeling results are diluted and verified. Dilution verification is to dilute a part of the wells, and then only use the remaining wells as conditional data for simulation prediction to check whether the simulation results at the diluted wells are consistent with the actual drilling data.

Well DB4S is randomly selected as the thin pumping well in the work area. Figure 4 shows the results of three realizations taken at different times after pumping near the pumping well, and Figure 5 shows the logging curve of the pumping well. It can be seen from Figure 4 that a thicker river channel is developed in the upper part of the reservoir, sheet sand is developed in the lower part of the river channel, and some smaller branch rivers are developed at the bottom of the reservoir, which is in line with the situation reflected in the actual drilling logging curve (Figure 5), which indicates that the coupling modeling results more truly reflect the distribution of sedimentary microfacies of the underground reservoir.

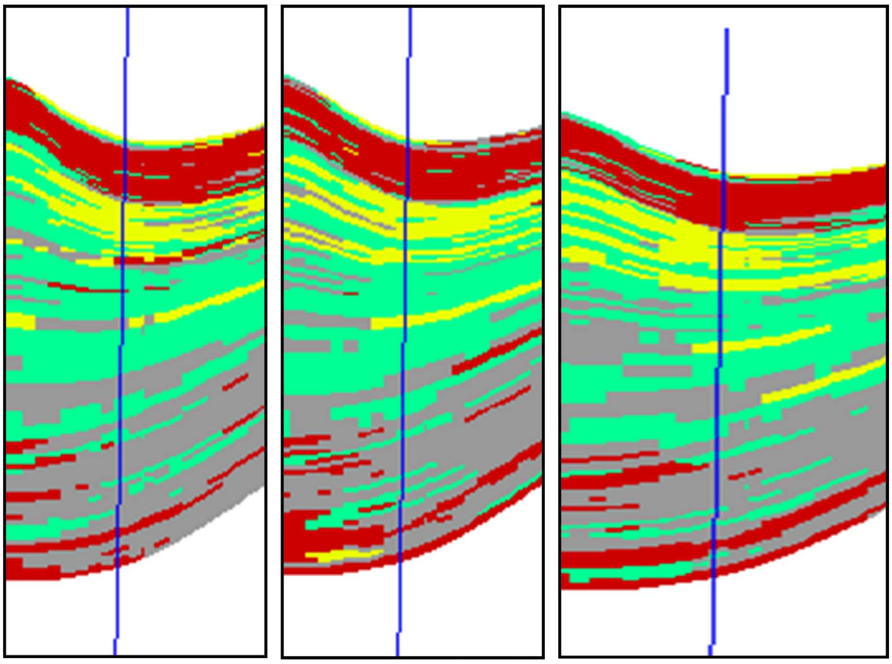

Figure 4. Microfacies simulation results of DB4S.

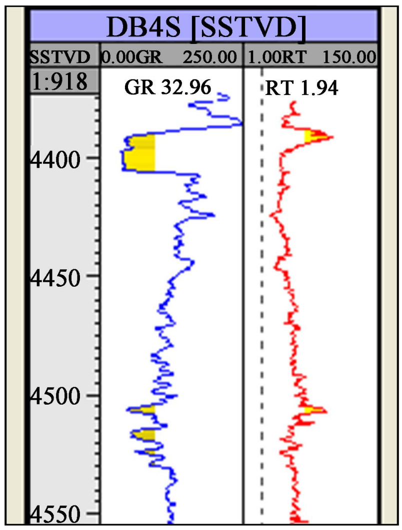

Figure 5. Drilling well logging curve of DB4S (GR & RT).

The sedimentary microfacies established by this method are used as constraint conditions to model facies controlled reservoir parameters and conduct numerical simulations. The numerical simulation results are in good agreement with the actual production history of the well, greatly reducing the workload and difficulty of history matching, and the reliability of single well production prediction and scheme design is higher.

5. Conclusions

1) According to the different distribution characteristics and geometric shapes of different sedimentary microfacies, the idea of coupling modeling with differ-

ent simulation methods is proposed, which breaks the tradition of using the same modeling method for different sedimentary microfacies.

2) Taking full advantage of the characteristics and principles of point indicating process simulation and sequential indicator simulation, the sedimentary microfacies model of C5 reservoir in DC block has been established through the idea of coupling the two. Through dilution verification, the sedimentary microfacies model has a high consistency with the underground. The coupling microfacies modeling method has higher accuracy and reliability than the traditional modeling method, which provides a new idea for the prediction of sedimentary microfacies.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zhao, B., Hou, J., *et al.* (2011) Modeling Method of Carbonate Fractured Reservoir Based on Point Indicating Process Simulation. *Science and Technology Bulletin*, **29**, 39-43.

[2] Hu, J., Feng, F., *et al.* (2015) Identification of Channel Sand in W Oilfield of Llanos Basin. *Journal of Southwest Petroleum University* (*Science & Technology Edition*), **37**, 30-38.

[3] Lv, Z.B., Zhao, C.M., Huo, C.L., *et al.* (2010) Application of Fine Facies-Constrained Geological Modeling Technology in Adjustment and Tapping Oil Potential of Old Oilfields: An Example from Suizhong 36-1 Oilfield. *Lithologic Reservoirs*, **22**, 100-105.

[4] Liu, Y. and Zhang, C. (2011) Petroleum Geology and Exploration in Colombia. *Petroleum Geology & Experiment*, **33**, 226-232.

[5] Feng, F., Wang, X., Hu, J., *et al.* (2015) Exploration and Development Technology for Lithologic-Structural Reservoir in Dorotea Block of Llanos Basin in South America. *China Petroleum Exploration*, **20**, 79-88.

[6] Zhu, Y.-X., Liu, L.-F. and Jin, J. (2004) Llarno Basin Oil and Gas Geological Characteristics and Predict Favorable Zones. *Xinjiang Petroleum Geology*, No. 1, 110.

[7] Sun, Y., Guo, S.B. and Shao, Y. (2010) Application of Pre-Stack Inversion Technology to Tracing Sand Body: A Case Study from Huagang Formation in Pinghu Oil and Gas Field. *Lithologic Reservoirs*, **22**, 27-30.

[8] Chen, J.-Y., Yu, X.-H., Li, S.-L., *et al.* (2008) Multiple Seismic Attributes with a Synergy of Reservoir Geological Modeling Method. *Xinjiang Petroleum Geology*, **29**, 106-108.

[9] Wang, Z., Bi, J.-J. and Bao, F. (2009) The Application of Well Seismic Joint Stochastic Modeling in AoNa Region. *Daqing Petroleum Geology and Development*, **28**,

37-39.

[10] Li, G. and Sha, X.-M. (2011) Description of Devonian Oil Reservoirs in Algerian BEL Structure. *Lithologic Reservoir*, **23**, 24-29.

[11] Zhang, J., Yan, A., Liu, W., *et al.* (2019) Hydrocarbon Accumulation Characteristics of Cabiona Block in Llanos Basin. Petroleum Geology and Recovery Efficiency, **19**, 24-26.

[12] Thornton, J.M., Mariethoz, G. and Brunner, P. (2018) A 3D Geological Model of a Structurally Complex Alpine Region as a Basis for Interdisciplinary Research. *Scientific Data*, 5, Article No. 180238. https://doi.org/10.1038/sdata.2018.238

[13] Kim, J., Lee, J.Y., Ahn, T.W., *et al.* (2021) Validation of Strongly Coupled Geomechanics and Gas Hydrate Reservoir Simulation with Multiscale Laboratory Tests. *International Journal of Rock Mechanics and Mining Sciences*, **149**, Article ID: 104958. https://doi.org/10.1016/j.ijrmms.2021.104958