Research on variogram analysis method for 3D modeling of sandstone reservoir

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Abstract: Analysis of variogram is a necessary step in 3D stochastic modeling, and different settings of variograms can directly affect the final distribution of model attribute. How to optimize the setting of variogram parameters by unit and facies type has become a key step in geological modeling. This article focuses on the reservoir within sedimentary background of fluvial-deltas in the layer SII7+8 which develops multiple sedimentary microfacies, such as fluvial channels, abandoned fluvial channels, flood plains, and natural levee with strong heterogeneity, so as to study the impact of changes of the variogram parameters on the simulation results of reservoir properties, in order to explore the analysis method of the variogram. On this basis, the reservoir is divided into 3 types of sand bodies and 11 types of sedimentary microfacies based on net pay thickness, sedimentary environment, and main sand scale and morphology. The distribution characteristics and extension scale of different facies types on the plane are classified and studied, in order to determine the characteristic parameters of the variogram of different types of sand bodies, accurately simulate the distribution characteristics of reservoir physical property, and further improve the accuracy of the 3D attribute model.

1. Introduction

Oilfield A has developed three sets of oil zones, namely Saertu, Putaohua, and Gaotaizi Formation, which develop 3 types of sand bodies and 11 types of sedimentary microfacies. The three-dimensional spatial characterization of reservoir attribute parameters adopts the method of facies -controlled stochastic three-dimensional geological modeling. However, due to the limitations of geological concept and data, there is often great uncertainty in the prediction of reservoir attribute parameters. In order to reduce this uncertainty in the process of attribute prediction, by optimizing the feature parameter settings of the variogram through the differentiation of facies types, the prediction accuracy of the 3D attribute model has been further improved.

2. Variogram setting

In the analysis of the variogram, the characteristic parameters of the variogram are obtained by setting parameters such as the major, minor, and vertical directions, bandwidth, search radius, step size, and tolerance[1]. These values include the sill, nugget, and range. Sill refers to the difference between two unrelated data samples, indicating the spatial trend of parameter changes. After normal transformation, the sill value of the data is within 1 ± 0.3. The nugget C0 reflects the randomness of the parameters, and the larger the C0 value, the greater the randomness of the parameter distribution. Range α describe the spatial correlation of data, where the sample data is correlated within the range, while the sample data is not correlated outside the range. Due to the fact that normal transformation is a general step in data analysis, the nugget and range in the analysis results of the variogram have a direct impact on the simulation results. In order to analyze the influencing factors of nugget and range and their impact on simulation results, a spherical model was used to explore the setting method of variogram analysis using the permeability parameters of the layer SII7+8b, and the sequential Gaussian simulation algorithm was applied.

2.1 The influence of nugget and range of the characteristic parameters of the variogram on the simulation results.

When the major direction, tolerance, bandwidth, and other parameters remain unchanged, the variance analysis results and simulation results when only the search range is changed are shown in Table 1 (the property coefficient Q=C0/(C+C0) represents the distribution characteristics of the parameters under a certain variance setting, with Q less than 0.5 being mainly structural, and Q greater than 0.5 being mainly random)[2].
From the results, it can be seen that, while other parameters remain unchanged, nugget, range, and property coefficient in the major direction all show an increasing trend with the increase of search radius, but the

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simulation results do not improve with the increase of range or randomness. The simulation results can only distinguish the approximate trend of parameter distribution when the search range is below 500m and above 1500m. If the range is too large or too small, good simulation results cannot be obtained. The characteristic of the best simulation effect of the variogram is that the range is 233m, and the search radius is 750m. The reservoir property coefficient is 0.69. Under such parameter settings, the parameter distribution is mainly random, and the search radius is consistent with the main band size of the parameter distribution.

Table 1 Analysis of characteristic parameters and results for different variance of layer SII7+8b

Search radius (m)	Variogram of major direction				Analysis of simulation results
	Nugget	Sill	property coefficient	Range（m）	
200	0.21	0.87	0.24	62.2	The parameters are randomly distributed, and the direction and trend of the sediment provenance cannot be distinguished irregularly
500	0.49	0.87	0.57	113	The main strip, non-main strip, and extreme value zone can be distinguished, but the simulation effect with a search radius of 750m and a range of 233m is the best, and the parameter distribution area matches best with the distribution of sedimentary microfacies and high permeability strips
750	0.62	0.90	0.69	233	
1000	0.75	0.96	0.78	833	
1500	0.75	1.07	0.70	1400	The parameters can be distinguished along the general trend of the main channel sand, and the distribution of non-main strip parameters is irregular

2.2 Factors on the variogram parameters

In the modeling software Petrel, the parameters that can be set in the analysis of the variogram include the major direction, bandwidth, search radius, tolerance, and other main parameters. In order to understand the impact of these parameters on the characteristic parameters of the variogram, the permeability parameters of the layer SII7+8b were taken as the object to analyze the impact of changes in these parameters on the values of range α and C0. Heterogeneity coefficient $p = 10 \times \sqrt{C_0 / \alpha(C + C_0)}$ was introduced when evaluating the distribution characteristics of parameters. The smaller the p value, the weaker the homogeneity.

Table 2: The influence of major direction and tolerance on the results of variogram Analysis

Major direction (degree）	Nugget	Sill	Range (m)	property coefficient	heterogeneity	tolerance	Nugget	Sill	Range (m)	property coefficient	heterogeneity
0	0.38	0.93	156	0.41	0.51	20	0.20	0.89	128	0.22	0.42
30	0.7	0.95	579	0.74	0.36	30	0.41	0.90	123	0.45	0.61
40	0.62	0.90	233	0.69	0.55	40	0.71	0.93	544	0.77	0.38
60	0.62	0.91	233	0.68	0.54	50	0.62	0.90	233	0.69	0.55
90	0.3	0.96	174	0.32	0.43	60	0.61	0.90	190	0.67	0.60

The analysis results of variance under the condition of only changing the major direction with other parameters unchanged are shown in Table 2. From the table, it can be seen that the property coefficients of the parameter distribution in the major direction of search along different variance vary greatly, ranging from 156m to 579m, and the analysis results at 40º and 60º are relatively close. From the distribution map of sedimentary microfacies, it can be seen that the extension direction of the high permeability strip is about 45º. Therefore, when setting the variogram, the extension direction of the high permeability strip should be used as the basis for setting the major search direction.

Tolerance is the angle range allowed to search based on the major direction axis, set within the range of 0-90º, and should depend on the size of the main strip. The range does not increase with the increase of tolerance. When the tolerance of layer SII7+8b is 40, the analysis results show a larger range and weaker heterogeneity.

Bandwidth is the maximum cutting width to prevent the search area from becoming too large. It should not be too large or too small, and should also be consistent with the distribution range of the main high permeability strip. The scale of the high permeability strip in the layer SII7+8b is between 500-1500m, so the analysis results with a bandwidth of around 200 are better (Table 3).

From Table 1, it can be seen that as the search range increases, the characteristic parameters of the variogram gradually increase. However, the simulation results show that the setting effect is best when the search radius is consistent with the scale of the main sand and high permeability strip.

Table 3 Impact of bandwidth on the analysis results of the variogram

Bandwidth（m）	Nugget	Sill	Range(m)	Property coefficient	Heterogeneity
40	0.742	0.91	544	0.815	0.387
50	0.592	0.88	156	0.673	0.657
100	0.603	0.888	174	0.679	0.625
200	0.623	0.9	233	0.692	0.545
300	0.652	0.916	311	0.712	0.478
400	0.654	0.929	389	0.704	0.425

Based on the influence of the above variance parameters on the analysis results, it can be concluded that when setting the variogram, it is necessary to take the distribution characteristics of reservoir parameters as the basis, and set and analyze the variogram according to the scale and extension direction of the main strip distribution, to obtain characteristic parameters consistent with the reservoir parameter distribution, in order to establish a more accurate three-dimensional geological model.

3. Method for setting the variogram of different facies types of sand bodies

Block M is located in the west of A oilfield, under the control of the LaXi River system, with 91 sedimentary units. According to different sedimentary environments, sand bodies, scales, and distribution characteristics, the single sand layer in the entire area is divided into three categories: channel sand bodies, inner delta-front sand bodies, and outer delta -front sand bodies, with 11 types of sand body (Table 4). The characteristics of each type of sand body are analyzed in details, and the main parameters of the variogram are set based on the sedimentary characteristics of various reservoirs, in order to conduct attribute modeling.

Table 4 Reservoir description and main parameters setting of variogram in Block M

Sedimentary facies		Sedimentary characteristics	Zone	Major direction (degree)	Search range（m)
Fluvial sandstone	Large-middle fluvial sandstone	a large scale river, thick oil layers, high permeability, a width of up to 3-4km, a thickness of mostly 5-9m, a width to thickness ratio greater than 400	9 sedimentary units	0-30	Channel: 2000 Interdistributory bay: 500
	Small fluvial sandstone	The scale of a single channel sand body is relatively narrow, with a curved strip on the plane, a width of 500-1000m, and a thickness of 3-6m.	3 sedimentary units	0-30	Channel: 500 Non-channel: 500
Inner delta-front sand bodies	Dendritic delta sand bodies	The river channel is irregularly striped and intermittently distributed, with a small scale and a width mostly within 500-600m.	12 sedimentary units	0-40	Channel: 500-800 Non-channel: 500-800
	Dendritic-lobe delta sand bodies	The sand bodies of fluvial channels are narrower north-south strips, with relatively small scale and thickness. 90% of fluvial sand bodies have a width of less than 120m and a thickness between 1.5m and 2.5m.	26 sedimentary units	0-30	Channel: 500 Non-channel: 600-1000

4. Model evaluation

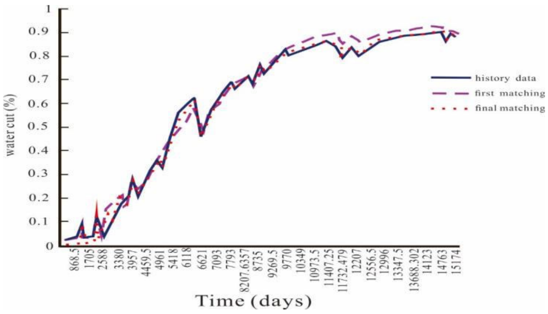

Figure 1 Water cut matching curve of Block Beierxi

The 3D geological model of the Block M is upscaled and exported, and model evaluation and dynamic history matching is performed by Eclipse. The water cut curve calculated by the first matching of the water cut in the entire area is highly consistent with the actual water cut curve shape (Figure 1), and the matching result is significantly better than the first water cut matching result of Block N which is studied in multi-disciplinary research (Figure 2). It indicates that the established three-dimensional geological model is in line with the actual development status of the reservoir, and the accuracy of the geological model meets the requirements of fine modeling.

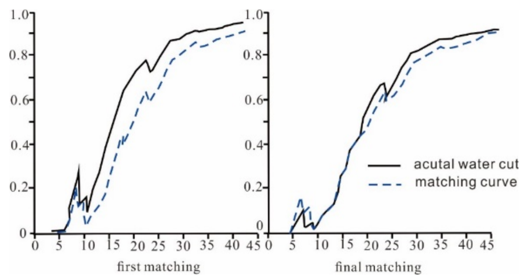

Figure 2 Water cut matching curve of Block N

5. Conclusions

The distribution of reservoir physical property is controlled by sedimentary microfacies. Within the control range of microfacies, the parameter distribution is mainly structural, and the randomness of parameter distribution becomes stronger as the search range for variation increases;

The random simulation results under different ranges indicate that range is the main factor affecting the simulation results, but the simulation results do not change with the increase or decrease of range. The simulation effect is best only when the setting of the variogram is consistent with the main strip of parameter distribution;

When setting the variogram, the determination of parameters such as major direction, bandwidth, search radius, and tolerance must be based on the study of sedimentary facies;

The study of sedimentary facies and variogram characteristics is a prerequisite for three-dimensional geological modeling. Describing sedimentary facies of reservoir based on reservoir thickness, sedimentary facies, and sand body of main strip is a fast and effective method for setting variogram parameters. Numerical simulation results have shown that the established model is in good agreement with the actual development status of the reservoir.

References

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