Advances in Geo-Energy Research

Vol. 2, No. 3, p. 282-291, 2018
www.astp-agr.com

Original article

Study on facies-controlled model of a reservoir in Xijiang 24-3 oilfield in the Northern Pearl River Mouth Basin

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(Received June 9, 2018; revised June 27, 2018; accepted June 28, 2018; available online July 5, 2018)

Citation:
Zheng, L., Chen, C., Lu, C., Cheng, M. Study on facies-controlled model of a reservoir in Xijiang 24-3 oilfield in the Northern Pearl River Mouth Basin. *Advances in Geo-Energy Research*, 2018, 2(3): 282-291, doi: 10.26804/ager.2018.03.06.

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Keywords:
Sedimentary facies
geological model
multi-point geostatistics
facies-controlled modeling
model verification

Abstract:
To better understand the internal structure of the Xijiang 24-3 Oilfield in the Northern Pearl River Mouth Basin, a reasonable and effective three-dimensional quantitative geological model is needed to characterize the distribution characteristics of the reservoir. Xijiang 24-3 Oilfield is a braided river delta deposition, which contains many sedimentary microfacies in three subfacies zones. The reservoir structure is complex and heterogeneous. The reservoir modeling research was conducted on the Xijiang 24-3 oilfield H3A reservoir. Analysis of the oilfield core, the well-logging, and seismic data, establish a regional structural model. The regional sedimentary microfacies model is simulated by multi-point geostatistics. The reservoir property model is established by using facies-controlled modeling technology with sedimentary microfacies as a constraint condition. A facies-controlled property model and a non-facies-controlled property model are established respectively. The facies-controlled model corresponds well with the sedimentary microfacies of the reservoir, and the variation trend of the model shows a higher coincidence rate with the distribution characteristics of the well. The facies-controlled model reflects the spatial distribution characteristics of the physical properties of the underground reservoir and is in accord with the actual geological understanding of the reservoir. This model also provides a reliable basis for the next stage of reservoir description and a basis for further exploration and development work.

1. Introduction

Three-dimensional models of reservoirs that accurately reproduce their geometric forms and internal properties provide reliable bases for using various geological core and well-logging data in their descriptions (Cheng et al., 2004). Reservoir property model involves an intuitionistic description of the property distribution of hydrocarbon formation (Luo et al., 2016). Geological modeling methods are divided into deterministic modeling and stochastic modeling (Wu and Li, 2007). With the continuous improvement in the accuracy of reservoir prediction, stochastic modeling or combinations of deterministic and stochastic modeling methods have become more common (Falivene et al., 2006). Traditional stochastic modeling is mainly divided into variogram-based and object-based methods (Dubrule, 1993). The object-based approach establishes a reservoir structure model by directly generating an overall target block, with a Boolean method and an indicator point process (Deutsch and Wang, 1996; Jones, 2001; Li et al., 2007). The theoretical basis of the variogram-based method relies on two-point geostatistics, the method is divided into many kinds, gaussian simulation and sequential indicator simulation is more commonly (Soares, 1998; Chen and Zhu, 2008). Traditional modeling methods based on variograms have limitations in characterizing spatial structures, and so it is difficult to reproduce the geometry of complex reservoirs using this methodology (Strebelle, 2002; Li et al., 2007). In order to overcome these problems, a multi-point geostatistical modeling method that uses a training image instead of a variogram to express the spatial structure of geological has beeen developed(Strebelle and Journel, 2001; Caers and Zhang, 2002; Krishnan and Journel, 2003). Facies-controlled modeling uses the planar distribution of the sedimentary microfacies and the superposition of vertical sand bodies to establish a model of the physical parameters of a reservoir (Yu et al., 2005; Zhang et al., 2008). The sequential Gaussian algorithm, in a facies-controlled model, simulates the three-dimensional spatial distribution of porosity and permeability parameters. This procedure often produces results which are more in line with actual geological conditions as compared with non-facies-controlled modeling.

https://doi.org/10.26804/ager.2018.03.06.

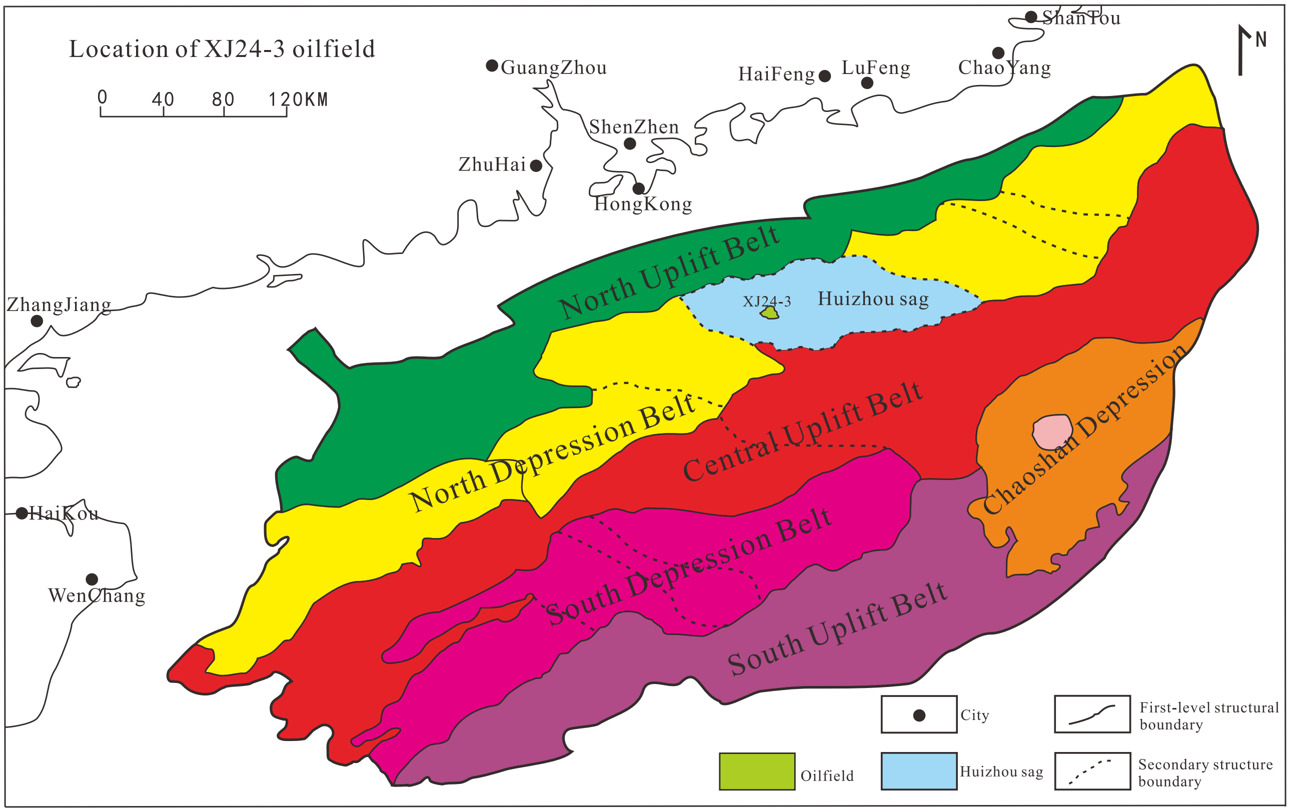

Fig. 1. Tectonic unit of the Pearl River Mouth Basin and the location of the Xijiang 24-3 Oilfield, modified from Liu (2011).

The Xijiang 24-3 oilfield has developed multiple sets of braided river delta deposits (Chen et al., 2009). The main reservoir facies zones in Xijiang 24-3 oilfield are the distributary channel and the distributary bar in the subfacies of the delta plain, the underwater distributary channel, the mouth bar, and the front sheet sand in the delta front (Zhou et al., 2011). To better understand the reservoir heterogeneity and to improve the recovery of the high water-cut period, we have developed a three-dimensional model of the microfacies distribution and physical parameters distribution of the main reservoir H3 oil group in the Xijiang 24-3 oilfield. Multi-point geostatistical modeling was used to establish sedimentary microfacies model. Then using the sequential Gaussian algorithm, we established a reasonable and effective geological property model of the H3A oil formation in Xijiang 24-3 oilfield with sedimentary microfacies as constraint conditions.

We use this model to delineate the distribution characteristics and variation rules for the geological space of the reservoir. This model then provides a reasonable geological basis for reservoir numerical simulation in the later stages of regional stratigraphy and thereby produces a solid geological foundation for predicting the remaining amount of oil in the reservoir.

2. The geological overview of the oilfield

Xijiang 24-3 oilfield is located on the tectonic belt in the south of Huizhou sag in the Pearl River Mouth Basin (Guo et al., 2000) (Fig. 1). The oilfield area is generally a low-amplitude dome anticline structure, which is complicated by faults at the top. One feature of anticline structure is that the south wing is relatively steep, with four low sides, and a thinning trend in the northwest to the southeast direction. Xijiang 24-3 oilfield is located at the junction of the ancient Pearl River delta plain and front. The oilfield is identified as a land-sea transitional braided river delta sediment (Liang et al., 2000; Fu et al., 2001; Chen et al., 2009), the sedimentary characteristics of the reservoir are mainly underwater distributary channels, mouth bar, and distal bar sand bodies on the delta front.

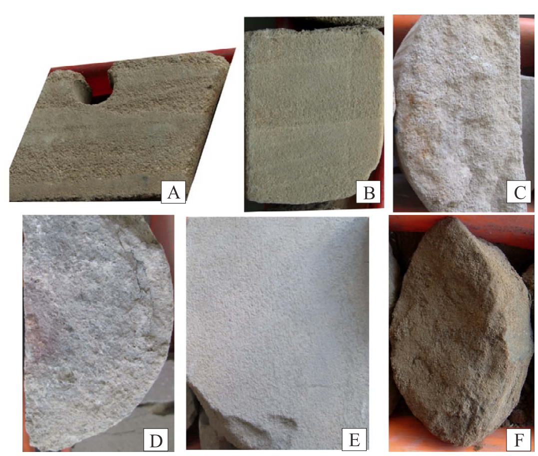

Fig. 2. A. Trough cross-bedding, gray-yellow conglomerate; B. Tabular cross-bedding, conglomeratic coarse sandstone; C. Coarse sandstone; D. Conglomeratic coarse sandstone; E. Medium sandstone; F. Fine sandstone.

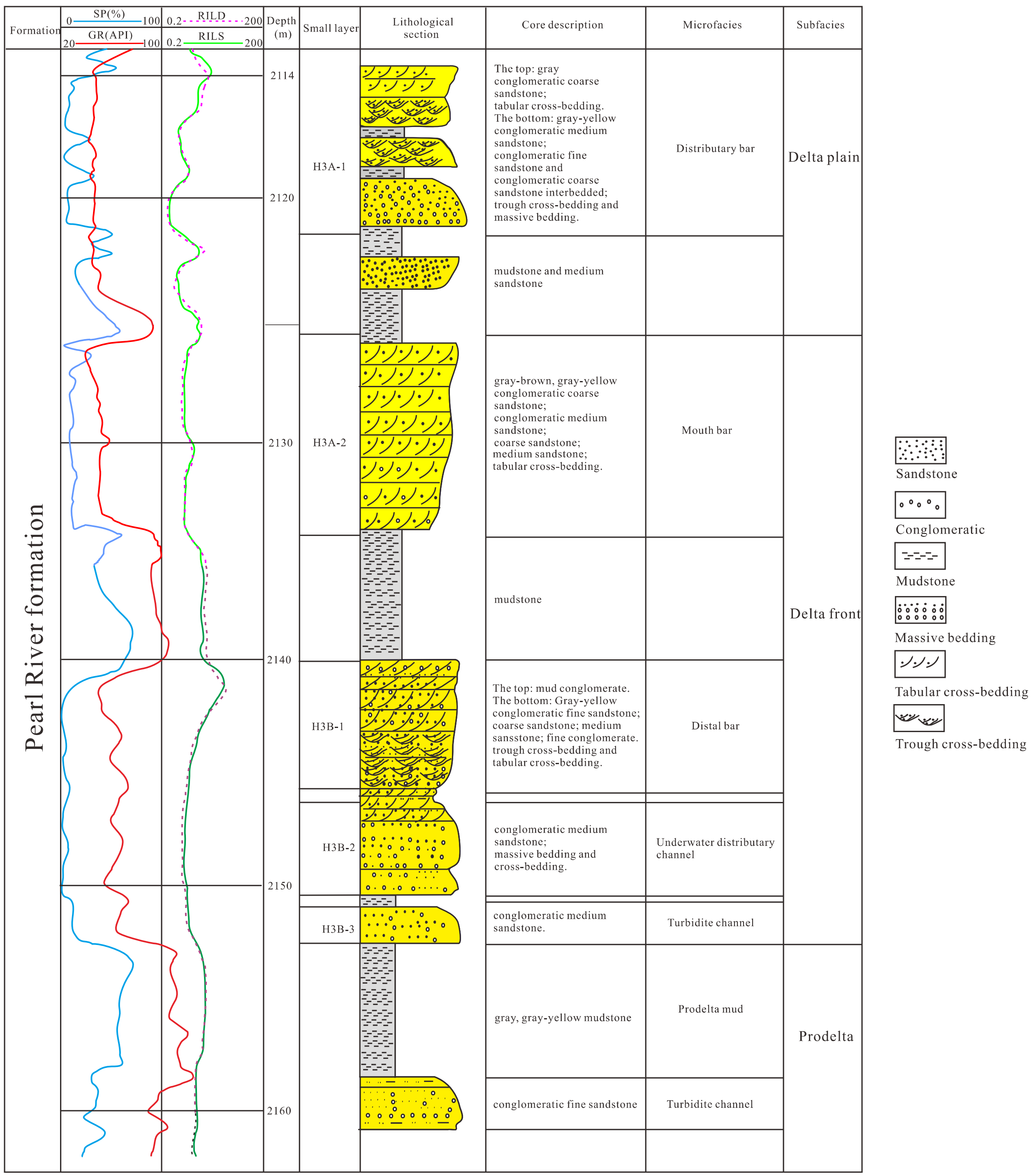

Fig. 3. The well-logging curve shape and the lithology features of well XJ24-3-2X.

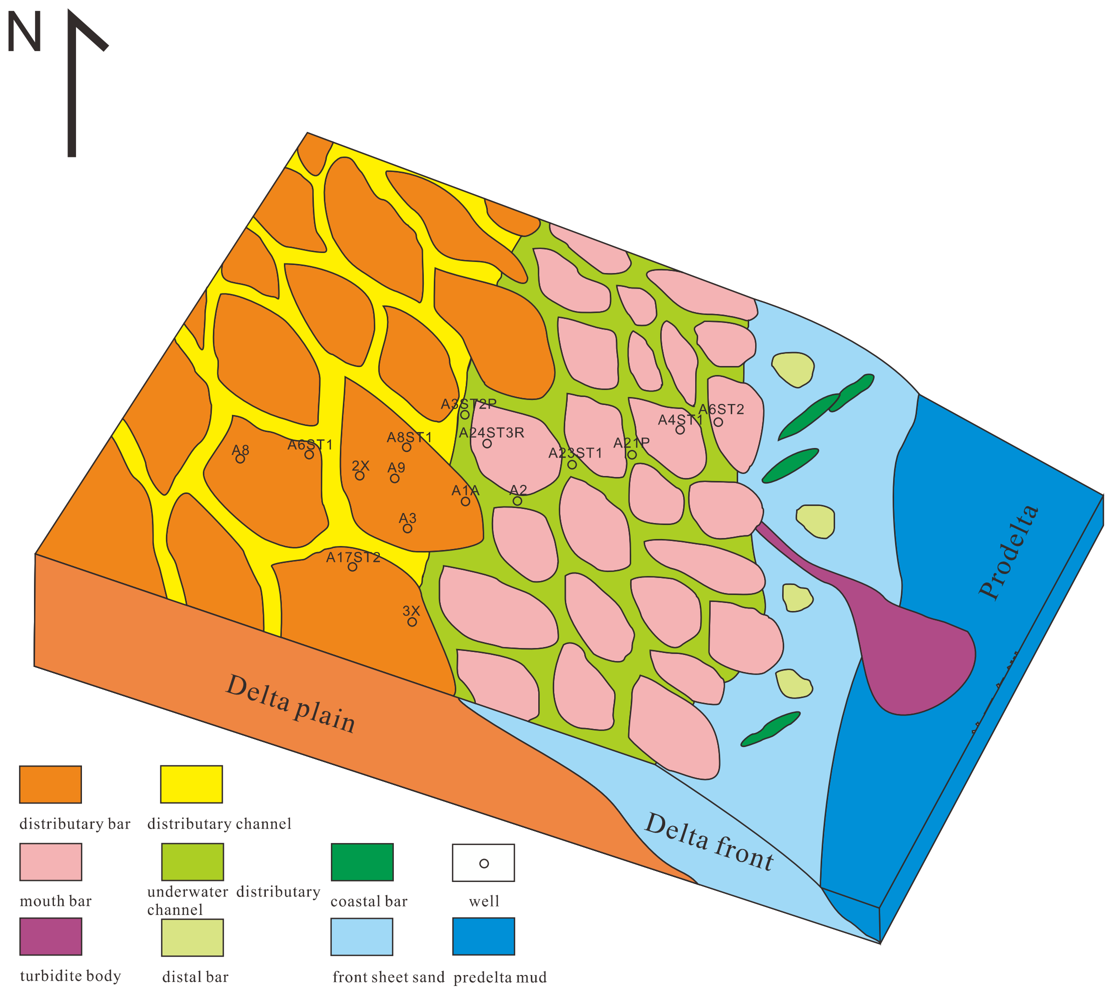

Fig. 4. Sedimentary model of Xijiang 24-3 oilfield.

In the study, we divided the oilfield into 4 oil groups: H1, H2, H3, and H4. The H3A reservoir in the Pearl River Formation of Miocene is the main oil layer of the oilfield. The distribution characteristics of sedimentary microfacies are obtained by analyzing reservoir geology, core Fig. 2 and well-logging data (Fig. 3). Fig. 3 shows the well logging curve shape and the lithology features, and it is the basis for the study of sedimentary facies. The braided delta plane often appears in the western area of the oilfield. This area is composed of distributary bar and distributary channels. The central oil-bearing area is the braided delta front which is made up of mouth bar and underwater distributary channel. The eastern part of the oilfield composes the outer edge of the braided delta front which is made up of the front sheet sand, turbidite body, and coastal sandbar (Fig. 4). The main body of the oilfield is located on the delta front close to the prodelta. The H3 oil group was generally at the stage of sea level decline during the deposition period, and the facies transitioned from the delta front to the delta plain. The H3 oil group was subdivided into 7 small layers, and the H3A layer belonged to the delta plain subfacies. Vertically, the thickness of its single sand layer increases upwards. The ratio of sand to mud also increases, and the lithology changes from fine to coarse, forming a set of progressive parasequence of reverse grain order all in the same upward direction. The H3A sand body is the main reservoir of the H3 oil group. The H3 oil group sand body has a single lithology, high maturity, and good reservoir performance.

3. Reservoir geological modelling

Reservoir geological modeling analyzes geological data and properties of known points to predict the properties of unknown areas. The key is to select a numerical calculation model that conforms to the observed spatial variation to get a reasonable reservoir parameter estimation value of the unknown area by interpolation and extrapolation of known control point data. The specific modeling methods are divided into deterministic modeling and stochastic modeling (Lv et al., 2000; Qiu and Jia, 2000; Hu et al., 2001; Chen et al., 2005). The technology of stochastic modeling is based on the known information and the theory of random function. Then stochastic simulation is applied to generate an optional, equal probability reservoir model (Liu et al., 2003; Gao et al., 2009).

The oilfield is in the late stages of development; however, due to offshore drilling, the well location distribution is not large. There are many horizontal wells. Stochastic modeling,

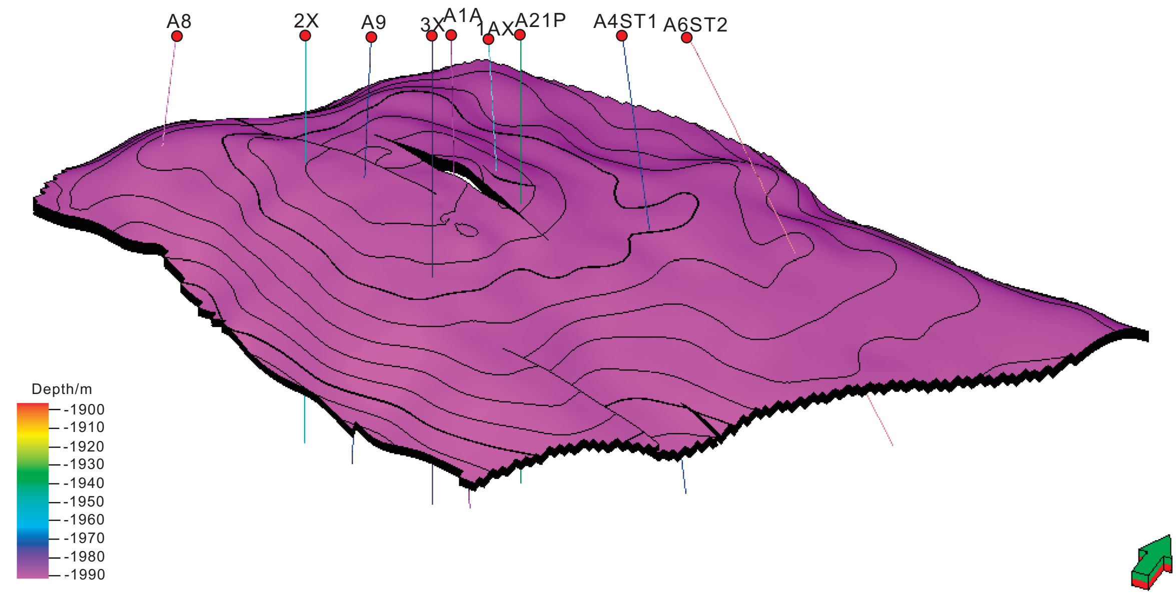

Fig. 5. The construction model of H3A oil group.

to accommodate existing deterministic information, reduces the uncertainty of the model as much as possible.

The structural model is the basis for establishing sedimentary facies models and property models which can provide an accurate stratigraphic framework for subsequent modeling (You et al., 2005; Wu et al., 2015). Consideration of the well spacing of the study leads to a model of H3A oil layer with a grid step size of 25 m × 25 m and a vertical grid step size of 0.5 m.

Study shows that there are many small faults in the H3A layer. A model based on the well logging data leads to a reservoir that is divided into small layers. The top and bottom of these layers become the level of the stratigraphic framework. A three-dimensional structural model is based on gridding the fault level to generate a fault model. Then using interpolation or random simulation methods, coordinate data, hierarchical data, and fracture data are applied to generate a reasonable model for each layer.

The model (Fig. 5) shows that the structure of the H3A layer is relatively smooth, with many faults. Faults run through all of the reservoirs, but the distance between faults is small. The high site of the reservoir structure is an anticline structure and should be a favorable well site deployment area. This model is in accord with the actual geological situation.

We used a multi-point geostatistical modeling method to establish sedimentary microfacies for H3A layer. The spatial multiple points combination mode of multi-point geostatistics is used to describe geological structural information and is more suitable for simulating geologic information with complex structures than traditional two-point geostatistics (Yin et al., 2011; Chen et al., 2012; Liu et al., 2015). It is difficult to obtain multi-point statistics from sparse well data in the modeling process. For this reason, multi-point geostatistical simulation methods need to use training images. The training image is a digital image that can express the actual reservoir structure, geometry, and its distribution pattern, which reflects a priori a geological concept (Khodabakhshi and Jafarpour, 2014; Høyer et al., 2016). The sedimentary background of the H3A layer in the study area is the braided river delta front subfacies, and various sedimentary microfacies, which are classified according to the lithology, logging, and seismic data. The distributary bar, distributary channel, mouth bar, and underwater distributary channel as the main microfacies are distributed throughout the entire study area. In this study, the microfacies map, obtained from prior geological work, was used as the training image to simulate the sedimentary microfacies. The multi-point statistical geological modeling method and the results of the H3A layer are shown in Fig. 6.

According to the distribution of microfacies shown in Fig. 6, the direction of the main sediment source can be accurately interpreted from the northwest, and the well point-facies data of the microfacies model is consistent with the actual microfacies of the plane. In addition, the microfacies morphology follows the distribution law and is also very similar to the microfacies map derived from previous geological work. There is also good continuity in the distribution of microfacies sand bodies in the vertical direction.

4. Facies-controlled property modeling

The property model of the reservoir is based on the sedimentary microfacies model, which shows the distribution characteristics of physical parameters such as porosity, permeability, and water (oil) saturation of the reservoir structure skeleton in three-dimensional space. Facies-controlled property modeling imposes sedimentary microfacies constraint to control the distribution of reservoir physical parameters. This approach also randomly simulates or interpolates inter-well

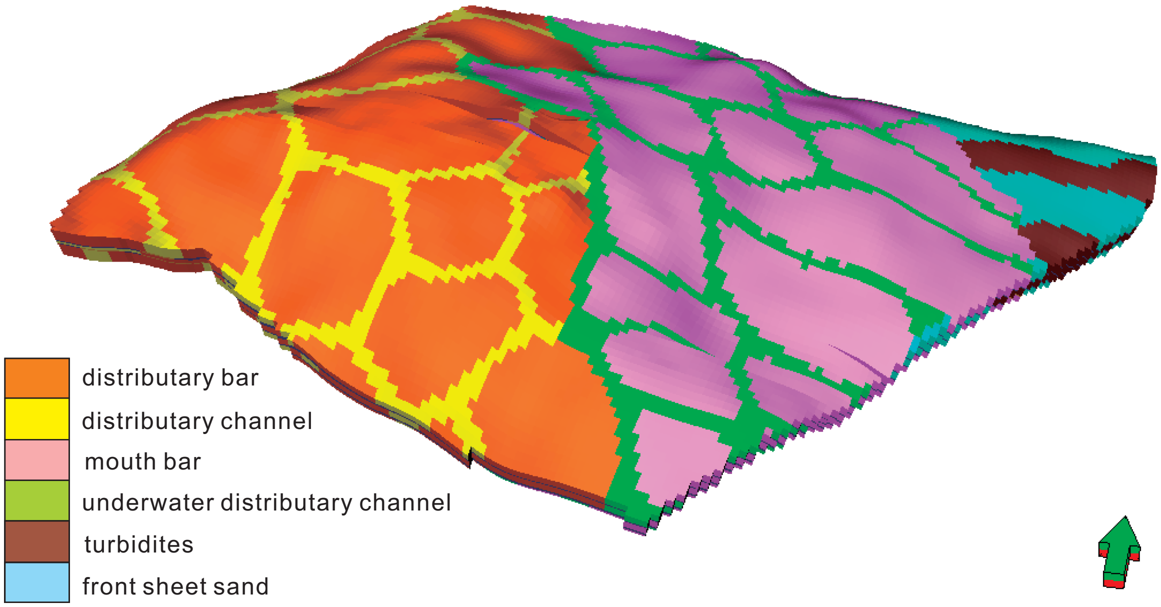

Fig. 6. Sedimentary microfacies model of H3A oil group.

Table 1. Porosity model simulation parameters.

Microfacies types	Function types	Azumith	Main range (m)	Second range (m)	Vertical range (m)
Distributary bar	Spherical	-46	202.8	167.4	18.9
Distributary channel	Spherical	-49	196.5	129.3	10
Mouth bar	Spherical	-45	238.4	161.1	10.3
Underwater distributary channel	Spherical	-47	199.8	86.4	7.8
Front sheet sand	Spherical	-49	152.5	99.1	6.6

parameters according to different microfacies types to produce an effective reservoir property model.

Our facies-controlled property model uses a sequential Gaussian simulation algorithm to simulate the H3A-1 single layer. First, the distribution characteristics of physical parameters in different microfacies of the H3A-1 layer are described statistically, then input data is tested, and finally, this data is truncated to produce the output. The normal distribution transformation and the elimination of outliers are carried out to satisfy the requirements of random simulation. The vertical and profile variograms of the physical parameters are calculated, and the logging-interpreted property data are coarsened into the established grid by an arithmetic averaging method that matches the simulated grid. The rational variogram is analyzed and selected. The fit of the variogram determines the major, minor and vertical variation ranges. Sequential Gaussian simulation of the different types of sedimentary microfacies produces the facies-controlled distribution model of physical parameters. (Yin and Wu, 2006; Shi, 2007).

4.1 Porosity model

Simulation of the H3A-1 reservoir porosity model, using the sedimentary microfacies model, describes the spatial distribution characteristics of the porosity and leads to the H3A-1 porosity model. The specific process is to set the property parameters of each layer according to the source direction, including each microfacies simulation parameter and variogram function fitting parameters (Table 1). Then calculate the variogram model and apply the sequential Gaussian function to simulation the porosity model (Fig. 7(a)). Fig. 7(a) shows that the overall porosity is high, and the high value spreads from northwest to southeast is consistent with the direction of source.

4.2 Permeability model

The permeability model of H3A-1 reservoir was constructed by comparing the porosity model. The property parameters of each layer were determined by analyzing and fitting the variogram of the permeability data to the sedimentary microfacies model (Table 2).

Calculation of the variogram model, using a sequential Gaussian function produces the permeability model. The simulation results are shown in the figure below (Fig. 7(b)). Fig. 7(b) shows the distribution of the high and low values of

Table 2. Penetration model simulation parameters.

Microfacies types	Function types	Azumith	Main range (m)	Second range (m)	Vertical range (m)
Distributary bar	Spherical	-53	152.4	66.9	17.8
Water distributary channel	Spherical	-49	196.5	129.3	10.7
Mouth bar	Spherical	-49	186.7	148.8	13
Underwater distributary channel	Spherical	-54	162.7	110.1	9.8
Front sheet sand	Spherical	-83	141.9	61.5	5

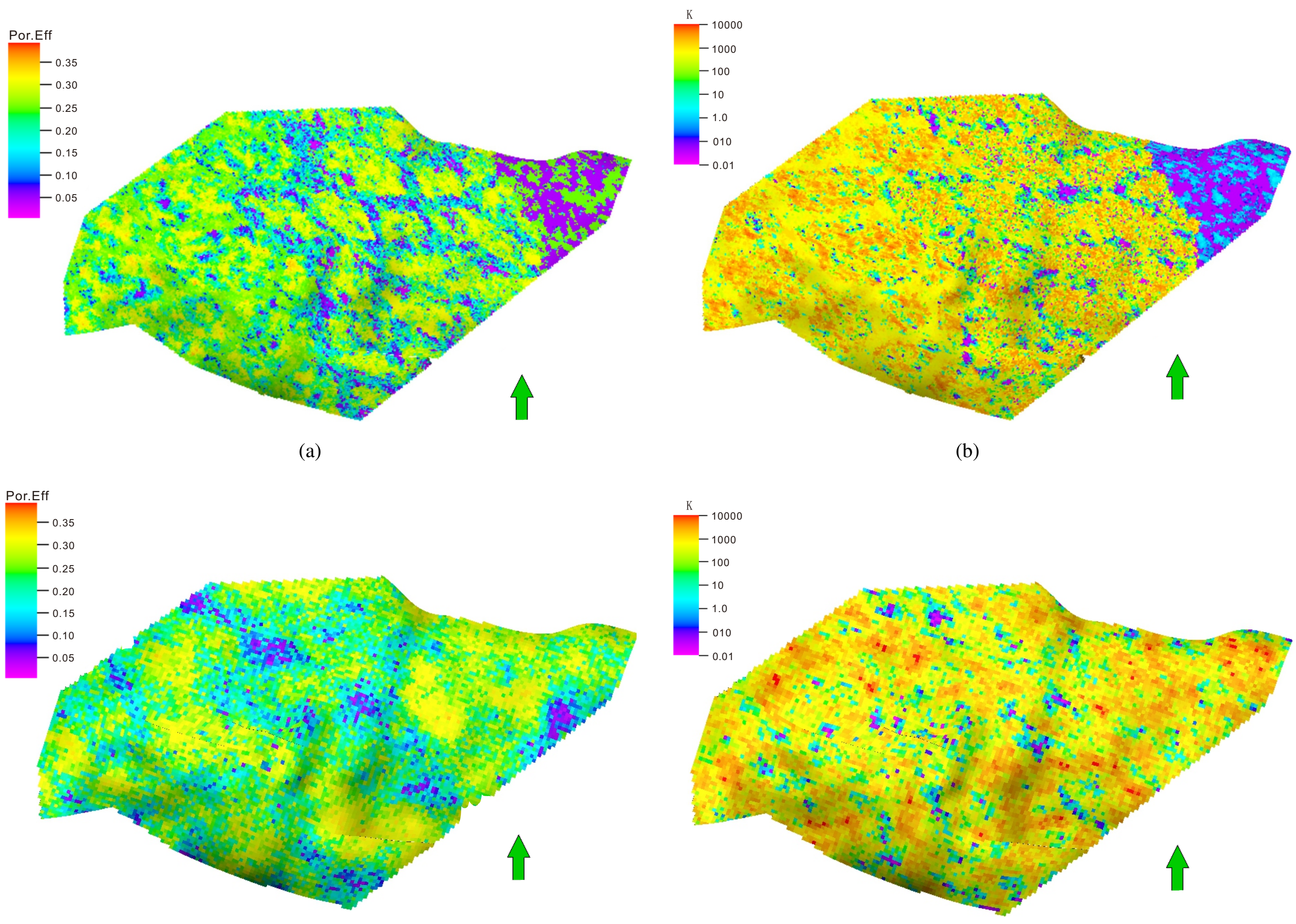

Fig. 7. Property model of H3A-1 oil group: (a). Facies-controlled porosity model of H3A-1 layer; (b). Facies-controlled permeability model of H3A-1 layer; (c). Unfacies-controlled porosity model of H3A-1 layer; (d). Unfacies-controlled permeability model of H3A-1 layer.

permeability and the large range.

The simulation results in Figs. 7(a) and 7(b) show that the porosity of the study layer is constrained by the sedimentary microfacies, and H3A-1 is a medium and high porosity reservoir in which most of the porosity is between 20% and 30%. The permeability model shows a much wider range of values than the porosity model. For the same small layer of the same sedimentary microfacies, the change in porosity is greater than the range of permeability which is mean the spatial continuity of the permeability is poor. In general, due to the constraints of sedimentary microfacies, the simulation results of porosity and permeability models show strong regularity that establishes the distribution of high and low values for these parameters. The characteristics of all of the high-value belts that spread from northwest to southeast reflect the distribution of various physical parameters in different sedimentary microfacies.

The geological model conforms better to the actual geological conditions when facies-controlled property modeling is used. Facies-controlled property modeling can accurately show the distribution of underground oil and gas reservoirs.

4.3 Model verification

Non-facies-controlled property modeling is a reservoir

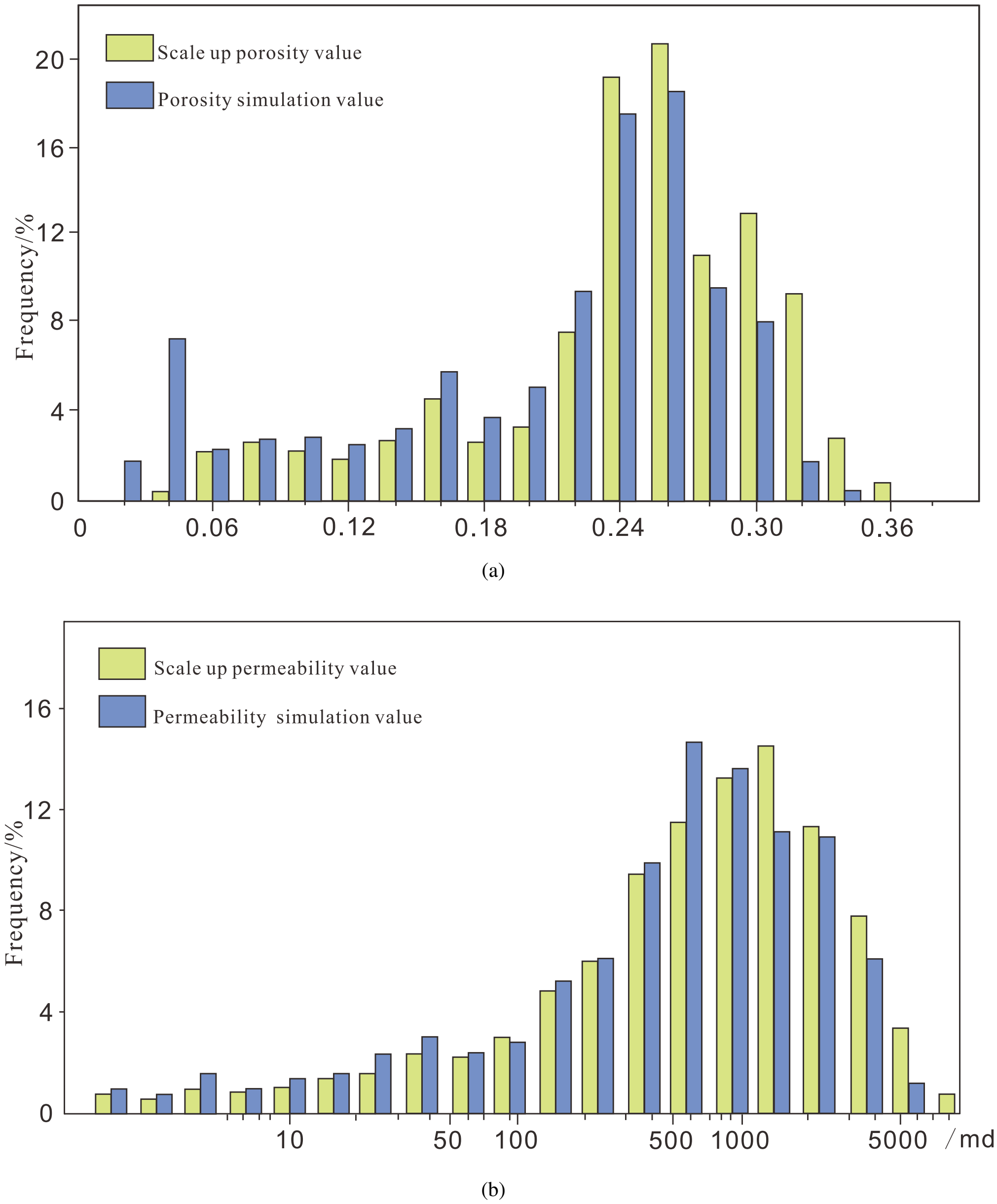

Fig. 8. Test of property simulation results: (a). Statistic of porosity; (b). Statistic of permeability.

model with optional equal probability that is based on both known information and random function with no sedimentary microfacies constraints. This model has strong randomness in-plane distribution and variation trends of the reservoir property. For different structural regions, the distribution characteristics of property have no obvious regularity or trend changes. There may be reservoirs with similar property values but different sedimentary microfacies in the plane. These reservoirs can be divided into the same origin units because there is no well-point control. The distribution characteristics of reservoir property and the sedimentary microfacies of the corresponding sand bodies are consistent with each other when facies-controlled property modeling is simulated. The established model approximates the actual geological conditions.

The non-facies-controlled property model of the H3A-1 layer is established in the study area (Figs. 7(c) and 7(d)). The distribution trend of reservoir porosity and permeability is not obvious. The high-value area is relatively concentrated, and there are some difference in the distributions of the sedimentary facies belts. Without well-point control, there is a discrepancy between the distribution characteristics of the property and the actual geological conditions in the area. Comparison of the non-facies-controlled property model with the facies-controlled property model shows that the distribution of porosity, permeability and the distribution of sedimentary microfacies are consistent. At the same time, the trend of the distributary channel from northwest to southeast coincides with the results of prior geological studies.

Under the control of facies to simulate the porosity and permeability parameters must conform to the prior probability distribution on the statistical rule that is the statistical characteristics of the data. Fig. 8 shows the simulation data and results from the inter-well scale up well logs. Comparison of the model's simulated values with the scale-up value of inter-well (Fig. 8) shows that the simulation values of the porosity and permeability are reliable because they are in good agreement with the distribution characteristics of the raw data on the well.

5. Conclusions

Xijiang 24-3 oilfield is a typical braided river delta facies. The simulation of the reservoir sedimentary microfacies model was performed by using a multi-point geostatistics method. The well-point data of the microfacies is consistent with the actual microfacies in the plane, and the microfacies pattern is very similar to the microfacies diagram of earlier geological work. In the vertical direction, the regular distribution of microfacies sand bodies shows good continuity.

Using sedimentary microfacies model as a constraint, the porosity model, and the permeability model are derived from a sequential Gaussian simulation method. The variation of the model is in good agreement with the distribution characteristics of the well.

Compared with the non-facies-controlled property model, it can better reflect the spatial distribution of the physical properties of the underground reservoir and provide a reliable geological basis for the next stage of reservoir description and further development.

Acknowledgments

The authors acknowledge Mr. Cheng Chen for his guidance and suggestions. The authors also thank the two anonymous reviewers for their careful work and thoughtful suggestions that have helped improve this paper substantially.

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