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Research Article

Modeling Method of Braided River Delta Reservoir Configuration Based on Flow Unit

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Abstract

The complex fault block oilfield in Weixinan Sag is gradually entering the middle and late development stage and the middle and high water cut stage. The complex contradictions among layers, within layers and in the plane result in low efficiency of injection water waves, complex distribution of oil and water, and difficult to accurately predict the distribution of remaining oil. The fine characterization of the internal configuration of the reservoir was carried out to characterize the strong heterogeneity of the continental sedimentary complex fault block reservoir, and the flow unit was subdivided to qualitatively characterize the differences in the reservoir quality of sand bodies at different stages in the vertical direction of the reservoir, which brought new challenges to the fine geological modeling of the reservoir. In view of the lack of well data in offshore oil fields, sedimentary laws and geological knowledge base summarized in previous studies are used to constrain the modeling of braided river delta reservoir configuration. Taking Weizhou C Oilfield as an example, sequential indication, object, truncated Gauss Multipoint geostatistics isophase modeling method is preferred to establish underwater distributary channel model based on target method. The truncated Gaussian simulation method can effectively characterize the characteristics of the transition zone, establish the flow unit model, use the flow unit constraint attribute model to establish, further calculate the reservoir heterogeneity coefficient, accurately characterize the reservoir heterogeneity, and lay a good foundation for the next step of reservoir numerical simulation and tapping the potential of remaining oil.

Keywords

Complex Fault, Truncate, Flow Unit, Configuration, Modeling

1. Preface

The braided river delta sedimentation is the main reservoir in the Weixinan Depression. As the complex fault block oil fields gradually enter the middle and high water cut stages of development, the interlayer, intra layer, and planar contradictions are complex and increasingly prominent. In response to the poor quality of seismic data and limited drilling data in offshore oil fields, a detailed characterization of the internal configuration of the reservoir has been carried out to characterize the strong heterogeneity of terrestrial sedimentary complex fault block reservoirs [1-8]. Combined with the understanding of production dynamics [9], the flow units have been subdivided to qualitatively characterize the differences in the quality of sand bodies in different stages of the reservoir vertically [10]. At the same time, it also brings new challenges to the fine geological modeling of reservoirs.

During the formation of a delta, the underwater distributary

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channels frequently migrate laterally, resulting in the vertical stacking of multi-stage rhythmic sand bodies. The composite sand body of underwater distributary channels is formed by the vertical accumulation or lateral stacking of four level structural units (such as underwater distributary channels) with multiple stages and a single genesis [11-17]. In depth research has been conducted both domestically and internationally on the configuration modeling of braided river delta reservoirs. Professors Wu Shenghe, Li Shaohua, Yin Yanshu, and others have improved and innovated their modeling methods and algorithms for delta sedimentary reservoirs [18-21]. They mainly apply target based, multi-point geostatistics, or process based modeling methods to simulate the morphology and spatial distribution of reservoirs such as underwater distributary channels and river mouth dams, study interlayer distribution, and characterize seepage channels or barriers [22, 23].

Offshore oil fields mainly utilize sedimentary laws and geological knowledge bases summarized from previous research to constrain the modeling of braided river delta reservoir configurations. Taking the Weizhou C oilfield as an example, this study explored modeling methods such as sequential indication, target based, truncated Gaussian, and multi-point geostatistics, and optimized the target based method to establish an underwater distributary channel model. On this basis, a truncated Gaussian simulation method was used to establish a flow element model, and a flow element constrained attribute model was used to further calculate the reservoir heterogeneity coefficient, accurately characterizing the reservoir heterogeneity and laying a good foundation for the next step of reservoir numerical simulation and residual oil tapping.

2. Overview of Oilfield

The Beibu Gulf Basin is located on the northern continental margin of the South China Sea. It is a fault basin developed on the basement of the Pre Paleogene and mainly composed of Cenozoic sediments. The reservoirs are mainly braided river delta plain braided distributary channels. The braided river delta sedimentary underwater distributary channels frequently migrate laterally, and the stacking relationship of sand bodies is complex. The stacking relationship of sand bodies in this area mainly includes three types: shear stacking formed in the early stage of river channel erosion and transformation, lateral stacking between different river channels, and isolated stacking, with shear stacking as the main type. The driving energy for the development of C oilfield is mainly natural energy and water injection drive. Each oil group in each block is an independent oil-water system, which is a layered edge water reservoir.

3. Modeling Technology Based on Target Braided River Configuration

Modeling methods can be divided into two categories: deterministic modeling and stochastic modeling. Stochastic modeling is a method that applies stochastic simulation methods to generate multiple optional and equally probabilistic reservoir models. It can perform uncertainty analysis on heterogeneous reservoirs and is more suitable for offshore oil fields with limited data. Random modeling can be divided into two categories: target based and pixel based. The target based method mainly involves the process of punctuation, simulating the spatial distribution of spatial objects based on their geometric shapes such as sedimentary facies, cracks, flow units, etc.

The application of traditional sequential indicator random modeling methods or deterministic modeling methods is difficult to depict the complex geometric shape and superposition of waterways, and cannot reflect the unreasonable continuity and connectivity of sand bodies, resulting in a lot of noise. This traditional geostatistical modeling method, which uses a variation function as a tool, can only reflect the correlation between two points in space and cannot characterize the spatial contact relationship and connectivity of complex geometric sand bodies (such as river side deposits and point dams). Based on the comprehensive research on reservoir configuration modeling methods at home and abroad, this study explores phase modeling methods such as sequential indication, target based, truncated Gaussian, and multi-point geostatistics. Comparing several methods, the target based stochastic modeling method is flexible in use, and some new qualified geological data can be easily added to the model as conditional information, such as phase percentages, sand body width to thickness ratios, sand body morphology, and various phase spatial distribution patterns.

This simulation is based on the discretization of single well facies data to a grid, customizing the shape of the simulated target body through statistical analysis of the size of the target body data, combining its spatial distribution orientation, planar distribution length and width, profile thickness and other parameters [24], as well as the vertical probability curve of single well statistics and the sedimentary facies map of previous geological understanding. Under the constraints of these parameters and planar distribution laws, the final model is obtained using a target based stochastic simulation method.

3.1. Principles and Ideas Based on Target Modeling Methods

The principle of target random modeling method is: let Y be a vector of spatial coordinates, and Xk be a random variable describing the geometric dimensions (shape, size, direction) of type k. Using the joint distribution of Xk (u), Ik (u, k) (k=1,2,..., K), the geometric shape, size, and other attributes of the center point at this location are determined. Ik (u, k) is a random function representing whether the k-th geometric attribute appears or not at position u. When u belongs to Xk, it is 1, otherwise it is 0. Simulate the position of the target first, and then simulate its related attributes. The punctuation process method of discrete random simulation with the target as the simulation unit is based on the probability law of point process, which generates the spatial distribution of the center points of these objects according to the distribution law of geometric objects in space, and then labels the properties of the objects (such as geometric shape, size, direction, etc.) on each point. The punctuation process is a gradual approximation process, using various parameter lines for multiple combinations and iterations until it is appropriate.

3.2. Modeling Based on Target Phase

Configuration modeling defines the basic morphological characteristics of the simulated target body from three perspectives: longitudinal section, transverse section, and plane. Based on the basic morphology of the underwater distributary channel in the delta, an axisymmetric shape is selected as the final simulation of the basic morphology of a single channel. The morphology of the underwater distributary channel in this area is braided and interwoven in a strip shape on the plane, with a uniformly thick tapered convex lens shape in the longitudinal section and a top flat bottom convex shape in the transverse section.

The skeletal sand bodies of braided river delta sediments are mainly channels or river mouth bars. Channel sand bodies differ significantly from lacustrine mudstone sediments. Domestic scholars mainly analyze the internal configuration of delta composite sand bodies from the perspective of a single sedimentary facies belt (underwater distributary channels or river mouth bars). There are three stacking modes of composite channel sand bodies: isolated, lateral stacking, and shear stacking (Figure 1).

According to the geological knowledge base obtained from previous configuration research, the thickness of single sand layers in Weizhou C oilfield is mainly distributed in the range of 5m to 20m. The width to thickness ratio of this area ranges from 51:1 to 72:1. Calculation width: mainly distributed between 300m and 1100m, combined with the distribution of composite sand bodies studied in sedimentary facies, it is predicted that the width of the composite waterway should be around one kilometer. The sand body along the source is relatively continuous, and the long range in the direction of the source is set to 3000m. Short range selection of composite river channel with a main frequency width of 1000m. The main frequency thickness of a single sand body used for longitudinal range variation is 9m.

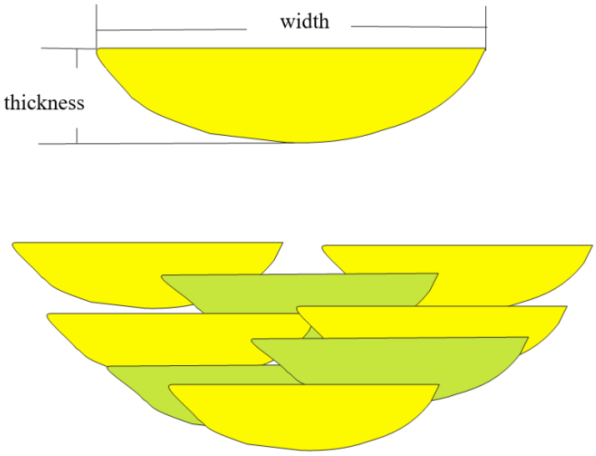
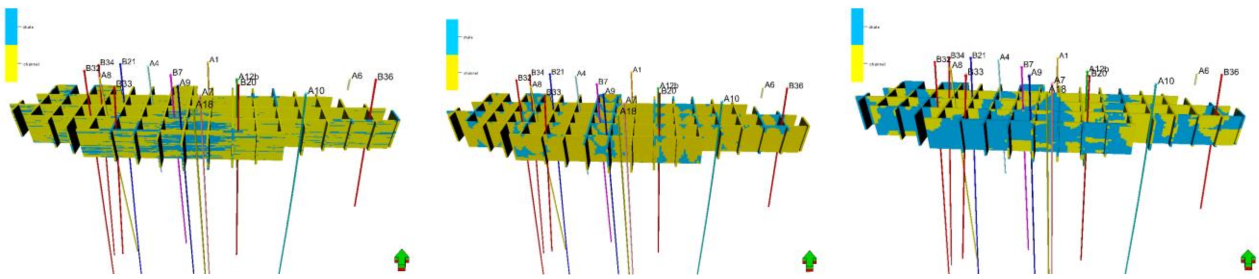


Figure 1. *Channel profile and sand overlay mode.*

Using mudstone as the background phase, the underwater distributary channel sand body is used as the simulated target body. The shape of the underwater distributary channel sand body is a semi ellipsoid on the profile, and its main range, source direction, width, and thickness are set according to the configuration research results. Using the proportion of a single well's underwater diversion channel, draw a plane proportion diagram of the channel phase, and control the simulation of the underwater diversion channel model to randomly simulate the phase model.



a sequential indication b object c multipoint

Figure 2. *Three modeling methods effect comparison.*

Compared with sequential indication and multi-point geostatistical modeling methods, target based simulation results have the weakest random interference, followed by multi-point geostatistical simulation, and sequential indication simulation has the strongest random interference [25-27]. The target based method can better reflect the contact relationship between different sedimentary microfacies and the sedimentary process of underwater distributary channels; The simulation results of multi-point geological statistics do not match the actual geological understanding; The sequential indication simulation is too mechanical in terms of matching the boundaries of digital facies and has poor consistency with sedimentary laws (Figure 2).

3.3. Braided River Delta Underwater Diversion Channel Model

Taking the W3 IV oil formation in the Weisan section as an example, the long axis direction (source direction) is set as the northeast direction, and the underwater distributary channel model is simulated using a target based method under the same constraint as the underwater distributary channel plane by using the proportion of a single well underwater distributary channel. Extracting the channel skeleton profile from the channel facies model, according to the configuration model skeleton profile (Figure 3), the results show that the proportion of underwater distributary channels in the western part of the W3 IV oil formation is small, and the channels are mostly isolated or side stacked. The eastern part where underwater distributary channels are more developed is mostly cut and stacked.

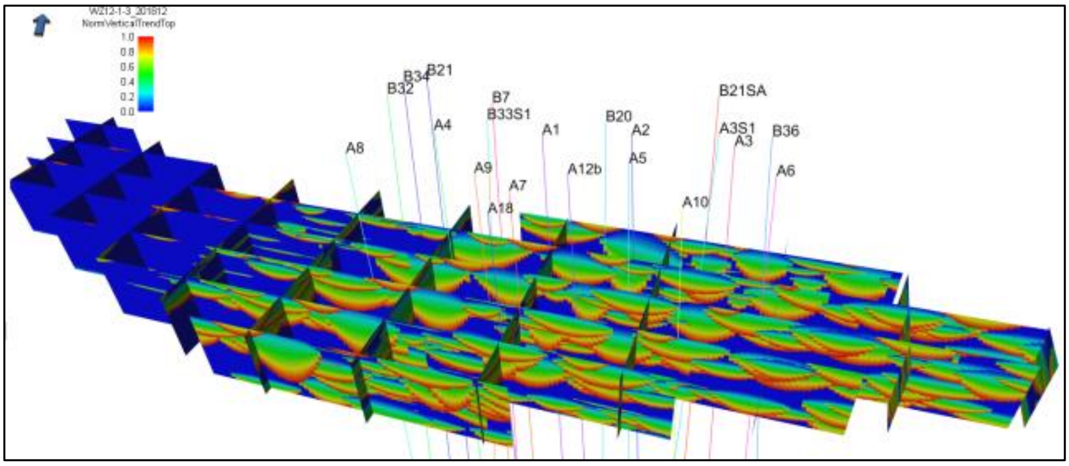


Figure 3. *Profile of river channel configuration model framework of W3 Ⅳ oil formation.*

4. Flow Unit Simulation

The study of flow units can qualitatively characterize the differences in reservoir quality between different stages of sand bodies in the vertical direction of the reservoir, and can effectively distinguish the changes in vertical reservoir quality within the same stage of sand bodies. Based on configuration based flow unit research and fine 3D geological modeling, we conduct precise characterization research on reservoir heterogeneity, analyze the impact of sand body stacking relationships on connectivity, accurately characterize flow units in the model, and guide oilfield adjustment and potential tapping.

4.1. Research on Flow Units

Flow unit research is one of the important means for reservoir quality evaluation. Flow unit division can not only qualitatively characterize the differences in reservoir quality between different stages of sand bodies in the vertical direction of the reservoir, but also effectively distinguish the changes in vertical reservoir quality within the same stage of sand bodies. Flow units are influenced by multiple factors, and a single parameter is difficult to accurately classify. Therefore, in the early stage, multiple parameters such as porosity, permeability, and sand body thickness (mainly physical property parameters) were used to classify flow units into four categories. Type I and II flow units have better physical properties and are mainly distributed in the axial part of the composite waterway sand body, while Type III and IV flow units have relatively poor physical properties and are mainly distributed on the side or edge of the composite waterway sand body (Figure 4).

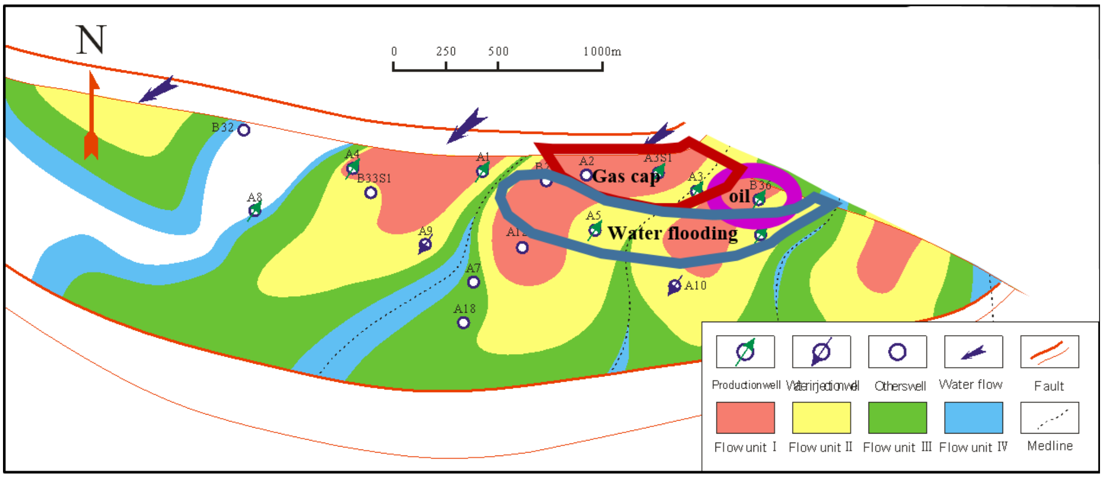


Figure 4*. Plan Distribution of Flow Units in W3 Ⅳ Oil Formation.*

4.2. Flow Unit Simulation

Matron et al. first proposed the truncated Gaussian simulation method, which is a pixel based approach. This method is applied to the simulation of sedimentary facies, which can reflect the spatial variation of facies sequence. It mainly involves truncating and discretizing Gaussian random functions to obtain discrete variables. Truncated Gaussian simulation is mainly suitable for simulating rock physics phases that are spatially interconnected and belong to the same category in terms of physical properties. It is more suitable to apply it to the simulation of "flow unit" in Weizhou C oilfield.

By utilizing the distribution pattern of flow elements on a plane and employing truncated Gaussian simulation method to constrain the simulation of flow elements, a flow element model is ultimately established. The cross-sectional profile (Figure 5) of the W3 IV oil formation passing through the A4 to A6 well models shows that the flow unit is relatively continuous, following the distribution pattern of good in the middle, poor on both sides, and good in the near source and poor in the far source. The simulation results are relatively accurate.

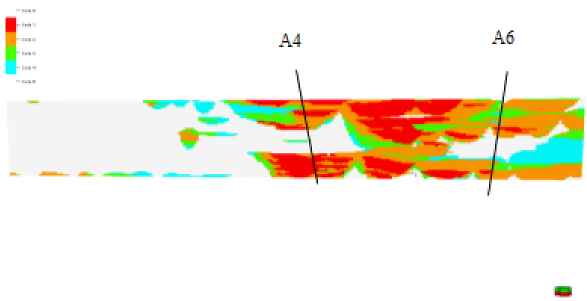


Figure 5*. Intersection of flow unit model of W3 Ⅳ oil formation passing well A4-A6.*

4.3. Permeability Modeling

The equivalent permeability model can be based on equivalent conversion of sedimentary trends, such as bedding, rhythm, and other laws [28]. The target area has established a porosity model constraint trend body based on the distribution pattern of good bottom and poor top properties of the river channel using a composite river channel model. Based on the analysis of the variation function, a permeability model was established with the main direction (235 °), main range (3000 m), secondary range (1000 m), and longitudinal range (5 m) given for porosity simulation. The permeability model of W3 IV oil group (Figure 6) shows that the permeability distribution range is wide, ranging from 0.01 to 8000, and the permeability value at the bottom of the river channel is relatively high.

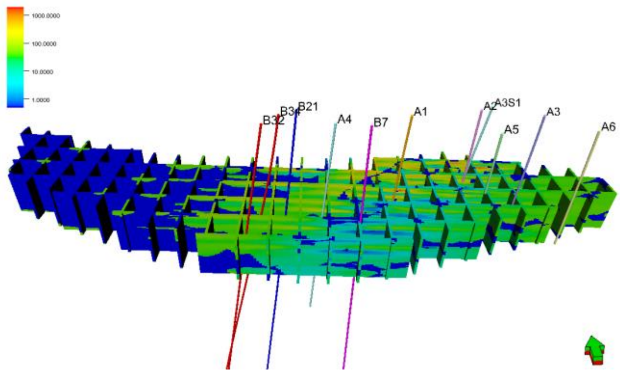


Figure 6*. Profile of permeability model framework of W3 Ⅳ oil formation.*

4.4. Study on Reservoir Heterogeneity

The main method used to characterize reservoir heterogeneity in this study is to use the coefficient of variation of heterogeneous parameters (V_k) to describe the heterogeneity characteristics of the reservoir. The coefficient of variation characterizes the degree of dispersion of permeability within a sand layer, which is represented by the ratio of the standard deviation of permeability of each individual sand layer in a certain well section to its average value. In the model, the ratio of the standard deviation of permeability between a single grid and its six adjacent grids to its mean value.

The coefficient of variation characterizes the degree of dispersion of permeability, which can be obtained by using the ratio of the standard deviation of permeability (V_k) of a single grcid connected to its surrounding six grids to its average value ($\bar{k}$). Namely:

$$V_k = \sqrt{\sum_{i=1}^{7}\left(k_i - \bar{k}\right)^2 / 6} \; / \; \bar{k}$$

A coefficient of variation model was established based on the permeability model. The coefficient of variation model of W3 IV oil group shows that the distribution range of coefficient of variation values is 0 to 0.77, and the mutation positions of coefficient of variation are mostly at the river boundary or the bay between tributaries, which conforms to the strong heterogeneity and rapid changes in physical properties at the river boundary and bay between tributaries. On the cross-section of the coefficient of variation model passing through wells A9 and A7 perpendicular to the source direction (J direction) (Figure 7), it can be seen that there is a sudden change in the coefficient of variation at the edges, bottom, and distributary bays of the river channel, further indicating that the physical properties of the sediment at the bottom of the river channel change rapidly and have strong heterogeneity.

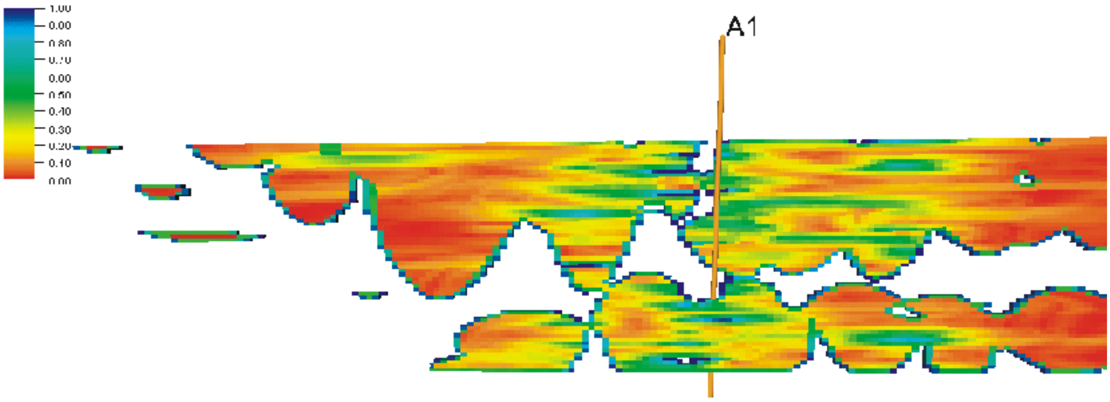


Figure 7. *Profile of W3 Ⅳ Oil Formation Variation Coefficient Crosscutting Material Source Direction.*

5. Application Effects

The planar distribution of remaining oil is mainly formed by the imperfect injection production well network on the configuration unit, followed by a small amount of remaining oil retained due to poor seepage at the configuration interface between underwater distributary channel units. The water injection effect of the production wells in the W3IV oil group is good, and the overall water flooding effect is good. The remaining oil is only distributed in the gas cap area of the high structure or between the injection and production well groups.

The deployment and implementation of 8 adjustment wells (6 in operation) and 22 measures (8 in operation) in areas where the underwater diversion channel of Weizhou C oilfield has not been affected by water injection, based on the research results of remaining oil, has resulted in a cumulative increase of over 1.7 million cubic meters of oil and an average increase of over 5% in recovery rates in three blocks. The implementation effect is good and the economic benefits are significant.

The research results of C oilfield have laid the foundation for the development adjustment plan, which is of great significance for guiding the potential evaluation of old oilfields and guiding the design of the next development plan.

6. Conclusion

For complex fault block oil and gas fields, such as the 3 well area of Weizhou 12-1 oilfield, a systematic summary of the process, methods, and key technologies for modeling complex structures and complex facies was conducted. Based on the interpretation results of low sequence faults, the "Y" -shaped fault modeling technology and fault stepped grid method were used to establish a regular grid model, solving the problem of structural modeling of complex faults.

In response to the serious heterogeneity of reservoirs and unclear oil-water relationships in the later stages of development, comprehensive data is used to conduct configuration modeling research, depicting the direct stacking and connectivity relationships of reservoirs, and even further dividing reservoir flow units, laying a good foundation for the next step of numerical simulation. The research results of C oilfield have laid the foundation for the development adjustment plan, which is of great significance for guiding the potential evaluation of old oilfields and guiding the design of the next development plan.

Conflicts of Interest

The authors declare no conflicts of interest.

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