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INNOVATIVE TECHNOLOGIES OF OIL AND GAS

APPLICATION OF GEOLOGICAL ENGINEERING INTEGRATION IN TIGHT SANDY CONGLOMERATE HORIZONTAL WELL

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In order to improve the recovery rate of tight glutenite horizontal wells in the Baikouquan Formation in Mahu Sag, geological models were constructed through three aspects: structural modeling, lithofacies modeling, and attribute modeling; through rock mechanics parameters, in-situ stress direction, and vertical direction. Stress, pore fluid pressure, maximum horizontal principal stress, minimum horizontal principal stress to construct a one-dimensional in-situ stress model, combined with imaging logging wellbore wall caving and induced fractures to determine the in-situ stress direction to simulate the three-dimensional stress direction in the study area, using finite element method to simulate and The objective function fits and inverses the distribution of the three-dimensional in-situ stress field. Finally, comprehensive reservoir parameter characteristics and engineering parameter characteristics are used to predict the "sweet spot" of the study area. The results show that there are three types of sweet spots in the glutenite in the Mahu Depression: Type I sweet spots are good reservoirs with good oil content, high oil well production, and good reservoir engineering compressibility; Type II sweet spots are followed by oiliness and oil well production; Type III The sweet reservoirs have just reached the lower limit of the oil layer standard, mainly poor oil layers. The research results provide a reference for the development of Baikouquan tight glutenite in Mahu Sag.

Keywords: geological integration; three-dimensional model; recovery factor; fracture network parameters; engineering parameters.

1. Introduction

The overall structural form of the Triassic Baikouquan Formation in Block Ma 131 is characterized by a southeast dipping monocline, with a northwest northeast high feature, and locally developed nose convex, groove, and platform structures. Affected by the late Hercynian and early Indosinian tectonic movements, Fengcheng and Xiazijie uplifted successively, and two sets of reverse faults in different directions developed in the work area, one set trending northeast and the other set trending northwest. The northeast trending fault is the main fault, and this group of faults is a deep source fault, which is the main reservoir controlling fault in this area. Among them, the Triassic Baikouquan is the main target layer, which mainly develops six main sedimentary microfacies: braided channels in the fan delta plain, sandy debris flows in the fan delta plain, front sandy debris flows, nearshore

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underwater distributary channels in the fan delta front, far shore underwater distributary channels, and river mouth bars. Relatively high-quality reservoirs are mainly distributed in the nearshore underwater distributary channel microfacies and a small amount of river mouth bar microfacies in the fan delta front. The lithology of the Baikouquan Formation oil reservoir in the Ma 131 well area is mainly composed of medium conglomerate, followed by small conglomerate and fine conglomerate. The porosity of the Baikouquan Formation oil reservoir is 2.2% to 13.2%, with an average of 7.87% and a permeability of 0.02 mD to 7.44 mD, with an average of 1.03 mD. It belongs to a low porosity and ultra-low permeability reservoir [1, 2].

The lithology of the Baikouquan Formation reservoir in the Ma 131 well area is complex, with strong heterogeneity. Currently, the completed drilling mainly consists of horizontal wells in the first and second sections, making it difficult to understand the three-dimensional structure and reservoir.

2. Reservoir geological modeling

Reservoir structure modeling. The Ma 131 well area belongs to a fault block oil reservoir, with an overall structure of high in the north and low in the south. The structure has good inheritance from deep to shallow, and is single. This time, four time domain 3D seismic interpretation layers were used, which were transformed into depth domain layers through time depth conversion. The Cokriging method was used to generate structural planes, which served as the trend control surface for the large layers of the structural model, generating the structural model for the large layers. Based on the layered data of directional and vertical wells, the thickness of each sand body and interlayer was calculated. Finally, under the control of the previous large layer structural model, the structural modeling of each sand layer group and interlayer was completed through small layer modeling based on the layer thickness map and the layered data of all wells. For horizontal wells, based on the actual drilling trajectory and stratification data of the horizontal well, structural correction was carried out on the drilled formation at the position of the horizontal well, ensuring the accuracy of the structure and formation where the horizontal well is located.

Petrographic modeling. This study mainly collected lithology data from 86 wells in the study area, and used a stochastic modeling method for lithology data. The sequential indicator simulation method was mainly used in this study. After multiple implementations, due to the uncertainty of stochastic modeling, each implementation was different. In order to simulate the underground rock storage properties more realistically, we compared the existing multiple implementations, selected the most reasonable model, and modified it layer by layer to obtain the final phase model (**Figure 1**).

Attribute modeling. The ultimate goal of reservoir 3D modeling is to establish a parameter model that can reflect the spatial distribution of underground reservoir properties (porosity, permeability, saturation). Due to the heterogeneity and anisotropy of the distribution of physical properties in underground reservoirs, conventional deterministic modeling with interpolation from a few observation points cannot reflect the spatial changes of physical properties [3-5]. This is because, on the one hand, the spatial distribution of reservoir physical parameters is stochastic, and on the other hand, the distribution of reservoir physical parameters is controlled by the genetic units of reservoir sand bodies, exhibiting the characteristics of regional variables. Therefore, the application of geostatistics and stochastic process controlled stochastic simulation methods is the best choice for quantitatively

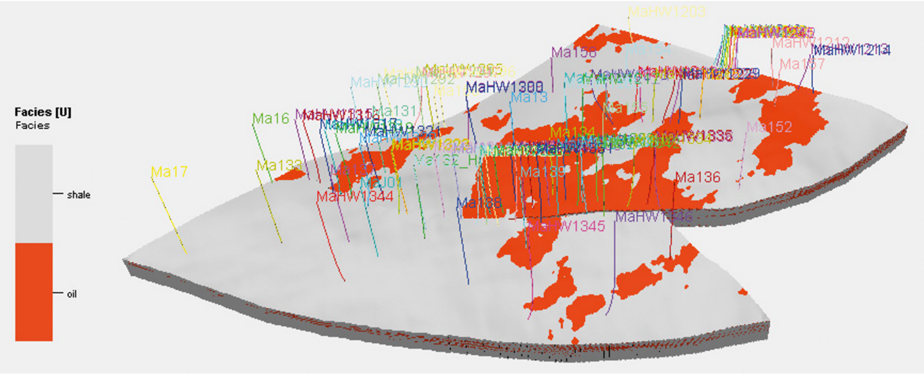

Fig. 1. Three-dimensional map of lithofacies properties of the Triassic Baikouquan Formation in the study area

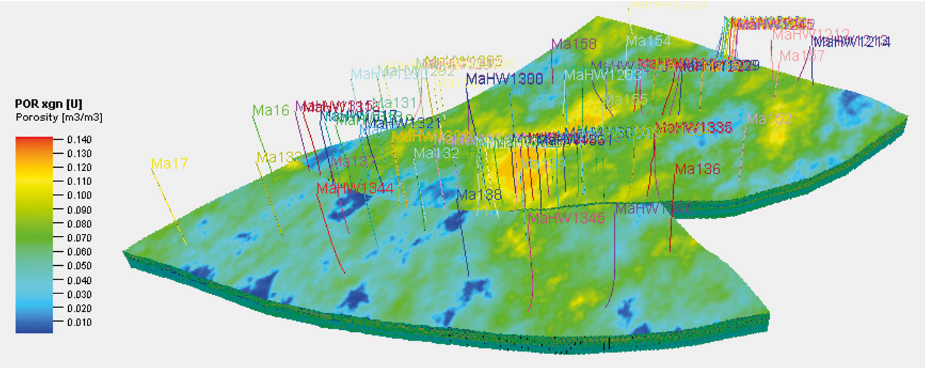

Fig. 2. Three-dimensional map of the porosity properties of the Triassic Baikouquan Formation in the study area

describing the spatial distribution of reservoir rock properties. The three-dimensional attribute modeling adopts a sequential Gaussian simulation algorithm under phase controlled conditions, and establishes models for porosity, permeability, and oil saturation respectively (**Figure 2**).

3. Rock mechanics parameter model

Including four mechanical parameters: Young's modulus, Poisson's ratio, shear modulus, and bulk modulus. The Young's modulus can be obtained through calculations of longitudinal and transverse waves and rock density. If there is no shear wave time difference in the study well section, a shear wave formula can be established by fitting curves such as longitudinal wave time difference, density, natural gamma, and resistivity to construct the required shear wave data for calculation.

$$E = \frac{\rho_b}{\Delta t_s^2} \cdot \frac{3\Delta t_s^2 - 4\Delta t_p^2}{\Delta t_s^2 - \Delta t_p^2} \cdot \beta = \rho_b \cdot V_s^2 \cdot \frac{3V_p^2 - 4V_s^2}{V_p^2 - V_s^2} \cdot \beta,$$

where, E is the Young's modulus of elasticity, GPa, ρ_b is the density of the rock, g/ cm^3; β is the unit conversion factor, $\beta = 9.290304 \cdot 10^7$.

4. Geostress calculation model

4.1. One-dimensional geostress

The calculation parameters of geostress are the actual elastic parameters of the formation, which are static parameters. The results calculated using logging data are dynamic elastic parameters. After converting the dynamic parameters to static parameters, subsequent geostress calculations can be carried out. The intersection of rock elastic parameters indicates (**Figures 3, 4**) that the correlation between dynamic and static Young's moduli is good, and the transformation relationship is a linear number function relationship; The correlation between dynamic and static Poisson's ratios is relatively poor, with scattered relationships and no unified rules, making it impossible to convert between dynamic and static. Therefore, in this study, the dynamic Poisson's ratio is used to approximate the static Poisson's ratio.

The direction of artificial fractures in the Ma 131 well area is the maximum horizontal principal stress direction (near east-west direction); Dipole acoustic waves and imaging logging show that the maximum horizontal principal stress direction is 90-105; The direction of artificial cracks detected by micro seismic waves is 96-104, and the maximum principal stress directions in the two work areas are close to east-west. By fitting the density curve trend near the wellhead, splicing the density logging curve to obtain the density curve of the entire well section, and using the overlying formation pressure calculation formula to calculate the vertical stress of the rock layer [6]. The calculation results indicate that as the depth increases, the vertical stress gradually increases. The vertical stress of the Baikouquan Formation in the Ma 131 well area is between 49 and 78 MPa.

According to the DC index analysis table (**Table 1**) of the Baikouquan Formation in the Ma 131 well area, it can be seen that the measured pore pressure gradient of the corresponding layer in the Baikouquan Formation in the Ma 131 well area is between

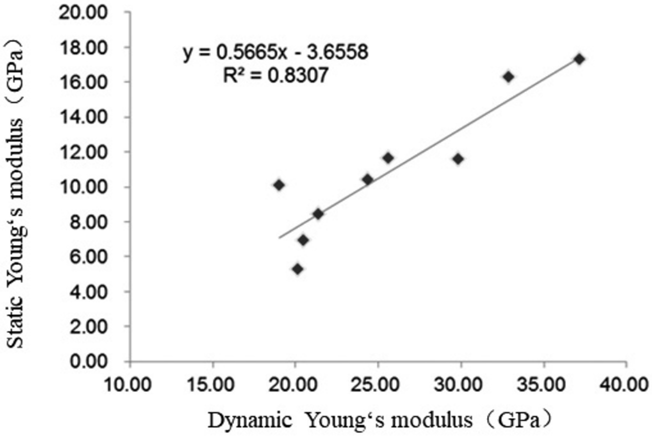

Fig. 3. Dynamic and static relationship diagram of Young's modulus in the study area

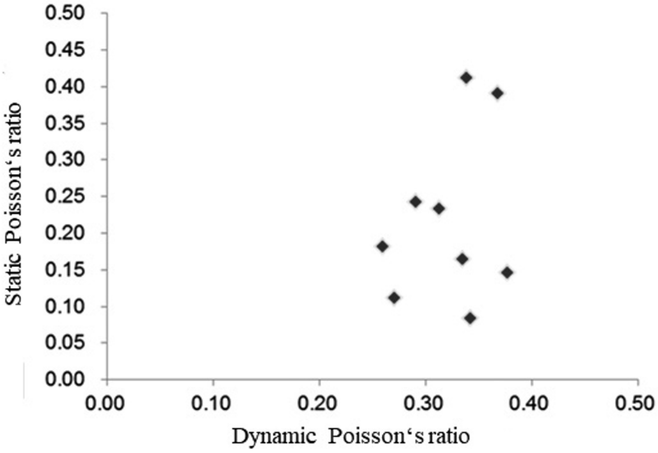

Fig. 4. The static relationship diagram of Poisson's ratio in the study area

Table 1. Monitoring and analysis table of DC index of Baikouquan Group in the study area

Well Name	Depth (m)	Pressure coefficient	Mud density
Ma131	500	1.03	1.14
	2460	1.03	1.22
	2460.3	1.1	1.22
	2785	1.1	1.23
	2785.1	1.05	1.23
	3430	1.05	1.28

1.05-1.25, which is the normal formation pressure. Through drilling and formation testing, it has been confirmed that the pore pressure gradient of the Baikouquan Formation in the Ma 13 well area is around 1.05-1.25. Through comparative analysis of mud density, it was found that the mud density is greater than the pore pressure. The Eaton acoustic trend line method (non reservoir section) was used to calculate the pore pressure. After multiple iterations in multiple wells, it has been shown that an equivalent mud specific gravity of around 1.2 for pore pressure is reasonable [7].

When using a porous elastic medium stress model to calculate the magnitude of horizontal geostress, first, based on stress experiments, minimum pump stop pressure parameters for fracturing, and imaging logging collapse points, calculate the maximum and minimum horizontal principal stress at the collapse point. Then, reverse calculate the structural stress coefficient, and after multiple well calculations, determine the maximum and minimum structural stress coefficients of the Baikouquan Formation in the study area, which are: ε H = 0.001193, ε H = 0.000206. After determining the structural stress coefficient, calculate the maximum and minimum horizontal geostress of a single well in the study area. The calculation results show that the maximum horizontal principal stress of a single well in the Baikouquan Formation of Ma 131 area is between 46-70 MPa, and the minimum horizontal principal stress is between 38-58 MPa.

4.2. 3D geostress

The three-dimensional stress direction of the Baikouquan Formation in the pilot test area of the Mahu Depression was simulated using the in-situ stress direction determined by imaging well wall collapse and induced fractures. The simulation results show that the maximum horizontal principal stress direction of the Baikouquan Formation in the study area is 85-95°, the minimum horizontal principal stress direction is -5~5°; -6~6°. The current design direction of the horizontal wells in the Baikouquan Formation in the pilot test area of Mahu Depression is north-south, and the prediction results are consistent with the regional geological understanding.

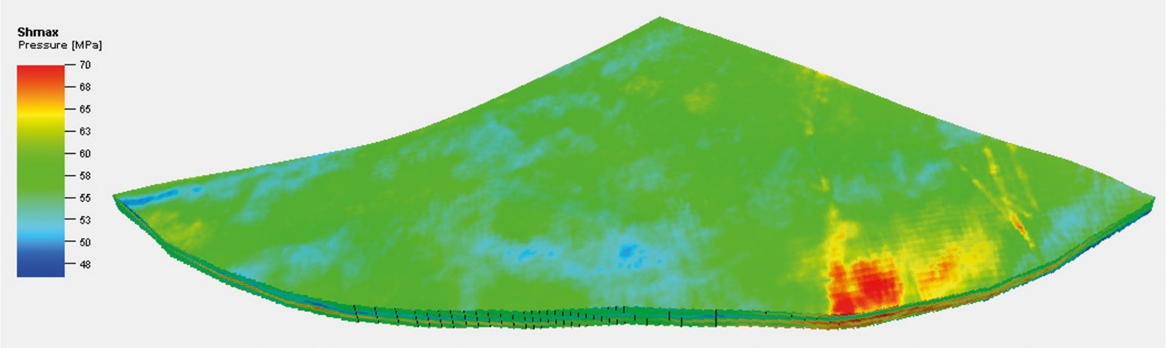

Fig. 5. Three-dimensional diagram of the maximum horizontal principal stress of the Baikouquan Formation in the studied well area

Finite element method simulation and objective function fitting inversion were used to predict the three-dimensional stress field of the Baikouquan Formation in the pilot test area of the Mahu Depression. The prediction results showed (**Figure 5**) that the maximum horizontal principal stress of a single well in the Baikouquan Formation in the study area was 46-70 MPa, and the minimum horizontal principal stress is between 38-58 MPa. Therefore, the Baikouquan Formation reservoir in the study area is not easy to be fractured and transformed to form a complex fracture network, and the main fracture shapes are single fractures. Studying the stress distribution rules of the Baikouquan Formation in the study area and obtaining the distribution rules of the in-situ stress field are of great significance for the subsequent simulation of horizontal well pressure fracture networks [8].

5. Dessert evaluation application in research area

The research area belongs to a tight conglomerate oil reservoir. In addition to including reservoir oil content, reservoir physical properties, reservoir energy and compressibility, and oil well production, the dessert classification should also include parameters such as lithology, electrical properties, acoustic wave impedance, Young's modulus, Poisson's ratio, etc. [9].

Reservoir characteristics. The main oil layers in the study area are distributed in the Baisan and Baier sections. The thickness of T_1b_3 oil layer is 5.62 m to 18.01 m, with an average of 11.89 m. The thickness of T_1b_3 oil layer is 3.12 m to 12.5 m, with an average of 8.31 m. The porosity of T1b3 reservoir ranges from 8.44% to 12.5%, with an average of 11.61%; The porosity of $T_1b_2^1$ reservoir ranges from 7.91% to 10.46%, with an average of 9.31%. T_1b_3 original oil saturation 0.540; The original oil saturation of $T_1b_2^1$ is 0.533. The dissolved gas oil ratio of T_1b_3 is 235 m^3/t, and the dissolved gas oil ratio of $T_1b_2^1$ is 140 m^3/t. According to the four properties of the reservoir, the resistivity of the oil layer Rt is ≥ 30 Ω. m. Reservoir temperature and pressure parameters (**Table 2**).

Engineering parameters. Rock mechanics parameters of Ma 131 block: Young's modulus 11-39 GPa, Poisson's ratio 0.21-0.38, brittleness index 13-40; The minimum principal stress of the geostress parameters is 38-58 MPa, and the difference in stress between the two directions is 11-23 MPa.

Oil well production. The initial production capacity of vertical and horizontal wells can be used as a basis for evaluating desserts [10]. In the initial stage of a vertical well, the daily oil production from self injection is 3.7 t/d to 12.6 t/d, while the

Table 2. The characteristic parameters of the reservoirs in the Baikouquan Formation in the study area

Interval	Reservoir mid-depth (m)	Reservoir mid-elevation (m)	Reservoir height (m)	Reservoir mid-pressure (MPa)	Pressure coefficient without factor	Saturation pressure (MPa)	Ground saturation pressure difference (MPa)	Saturation level (%)	Reservoir mid-temp (°C)	Factor
T_1b_3	3278	-2900	220	40.33	1.23	35.49	4.84	87.99	79.61	Lithology structure
	3047	-2650	270	38.78	1.27	33.93	4.85	87.51	74.87	Lithology structure
$T_1b_2^1$	3298	-2920	260	35.97	1.09	25.41	10.56	70.64	80.03	Lithology structure
	3097	-2700	280	34.53	1.11	23.97	10.56	69.41	75.9	Structure

Table 3. Sweet spot classification parameter table of the Baikouquan Formation in the study well area

Evaluation content	Evaluation parameters	Evaluating indicator		
		I	II	II
Oil content of reservoir	Lower limit of effective thickness (m)	8	10	12
	Effective porosity (%)	>11	9-11	7.5-9
	Oil saturation (%)	>65	55-65	45-55
Reservoir compressibility	Young's modulus (GPa)	>30	20-30	15-20
	Brittleness index (%)	>40	35-40	25-35
	Stress difference coefficient	<0.2	0.2-0.3	0.3-0.5
Reservoir properties	Formation pressure coefficient	>1.2	1.0-1.2	<1.0
	Original dissolved gas oil ratio (m^3/t)	>200	140-200	<140
	Ground saturation pressure difference (MPa)	>10	5-10	<5
Oil well production	Daily oil production during the initial stage of vertical well self injection (t/d)	>6	2-6	<2
	Average daily oil production of horizontal wells in the first year (t/d)	>25	15-25	8-15

average daily oil production from a horizontal well in the first year is 11.4 t/d to 35.3 t/d. The initial water content of a horizontal well is 4.87% to 29.54%.

The Baikouquan Formation in Well Ma 131 divides desserts into three categories based on four major categories and 11 items (**Table 3**). Type I desserts are good reservoirs with good oil content, high oil well production, and good compressibility in reservoir engineering. Type II desserts have lower oil content and oil well production. Type III dessert reservoir has just reached the lower limit of the oil layer standard, mainly consisting of poor oil layers.

6. Conclusions

On the basis of fully considering the geological model, geological integrated modeling takes into account engineering parameters such as rock physical parameters, geostress direction, vertical stress, pore fluid pressure, maximum horizontal principal stress, minimum horizontal principal stress, etc. It uses imaging logging to determine the direction of geostress determined by wellbore collapse and induced fractures, finite element simulation, and objective function fitting to invert the distribution of three-dimensional geostress field, and finally completes the three-dimensional geostress model. Integrated geological modeling greatly improves model accuracy and completes single well geostress calculation and three-dimensional geostress simulation of the Baikouquan Formation in the Ma 13 well area. The Young's modulus in the Ma 131 well area ranges from 11 GPa to 39 GPa, with an average value of 26 GPa; Poisson's ratio is 0.21 to 0.38, with an average value of 0.3; The brittleness index ranges from 13 to 40, with an average value of 25; The overlying strata pressure ranges from 57 MPa to 76 MPa, with an average value of 64 MPa; The pore pressure ranges from 28 MPa to 37 MPa, with an average value of 32 MPa; The minimum horizontal principal stress is 38-58MPa, with an average value of 48 MPa; The maximum horizontal principal stress is 46-70MPa, with an average value of 57 MPa; The minimum horizontal principal stress direction is between 5° and -5°, in a nearly north-south direction. Finally, based on geological engineering parameters such as oil content, thickness, physical properties, energy, compressibility, geostress, and single well productivity, desserts were classified to form a classification standard for tight conglomerate oil reservoirs in the study area. The Ma 131 well area was divided into three types of desserts, with Type I being the most advantageous area.

REFERENCE

1. Wu Zhongbao, Kang Lixia, Wang Gai'e. Research on remaining oil distribution law integrated with 3D geological modeling and reservoir numerical simulation[J]. Geology and Resources, 2006, 15(4):6.

2. Yu Jinbiao, Yang Yaozhong, Dai Tao, et al. Integrated application technology of reservoir geological modeling and numerical simulation[J]. Petroleum Geology and Recovery Efficiency, 2009, 16(5): 4.

3. Zou Caineng, Zhao Zhengzhang, Yang Hua, et al. The formation mechanism and distribution characteristics of deep-water sandy clastic flow in continental lake basin—taking the Ordos Basin as an example[J]. Acta Sedimentologica Sinica, 2009, 27(6): 1065-1075.

4. Li Xiangbo, Fu Jinhua, Chen Qilin, et al. The concept of sandy clastic flow and its application in deep-water sedimentation research of Yanchang Formation in Ordos Basin[J]. Advances in Earth Science, 2011, 26(3): 286-294.

5. Zou Caineng, Tao Shizhen, Yuan Xuanjun, et al. Formation conditions and distribution characteristics of continuous oil and gas reservoirs[J]. Acta Petrolei Sinica, 2009, 30(3): 324-331

6. Li Nan, Li Guohui, Wu Changjiang, et al. The significance of sandy clastic flow controlled by slope break zone to oil and gas exploration[J]. Journal of Sichuan Geology, 2014, 34(4): 504-509.

7. Li Xiangbo, Liu Huaqing, Chen Qilin, et al. The characteristics of sedimentary slope breaks in large depression lake basins and their control on sand bodies and oil and gas-Taking the Triassic Yanchang Formation in Ordos Basin as an example[J]. Acta Sedimentologica Sinica, 2010 , 28(4): 717-729.

8. Zhao Conghui. Discussion on the integration of horizontal well engineering geology[J]. China Petroleum & Petrochemical, 2017(03): 115-116.

9. Song Yang. Research and application of tight oil engineering geological integration technology in Leijia area[J]. China Petroleum and Chemical Standards and Quality, 2014, 000(014): 64-64.

10. Zhang Yuguang, Luo Yi, Zhang Hongtao, et al. Research on the “Engineering-Geology Integration” Technical System of Horizontal Well Production Increasing and Reforming[J]. Journal of Chongqing University of Science and Technology: Natural Science Edition, 2015(17): 44-49.