Field Research and Application of Tracking Adjustment Technology While Drilling for a Horizontal Well in Block A

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Abstract. A reservoir in Block A of an oil field is a new layer series in the new area, and a horizontal well has been deployed for the first time around the development of the target layer in the third section of the reservoir. Compared with the oil layers in the old area, the structure of the target layer in Block A is more complex, the reservoir changes rapidly, the prediction of sand-laden mud reservoir is difficult, and the tracking adjustment of horizontal wells while drilling is difficult. In view of the above problems, in order to ensure the drilling effect, we have carried out the basic geological research of the combination of well and earthquake, carried out the study of the correlation between rock and electricity and the combination of well and earthquake, carried out the multi-technology combination, innovatively formed the supporting technical methods of fine fault, micro-amplitude structure identification and reservoir prediction, established the fine three-dimensional geological model, optimized the well location and trajectory optimization design of favorable blocks, According to the technical process of "making plans before drilling, timely adjustment during drilling, and re-recognition after drilling", 7 horizontal wells have been tracked and adjusted while drilling, with an average oil reservoir drilling rate of 85.3%, which has achieved good drilling results and increased geological reserves and productivity.

Keywords: Horizontal well, Fine seismic interpretation, Geological modelling, Track optimization,Tracking while drilling

1. Introduction

A certain oil layer in Block A is a new layer series in the new area. In view of the characteristics of complex structure of the target layer, rapid change of the reservoir, and large thickness of the developed oil layer, a detailed geological study was carried out, the favorable area for well layout was optimized, and the horizontal well trajectory design was optimized. Through the technical process of "making a plan before drilling, adjusting in time while drilling, and recognizing again after drilling", the tracking adjustment mode while drilling is established. Completed the track design optimization and tracking adjustment while drilling of 7 horizontal wells, effectively improving the sandstone drilling rate, thus increasing the geological reserves and productivity.

The structure of a certain area from northwest to southeast presents a structural pattern of "two depressions and two uplifts, and the depressions and uplifts alternate". The fault zone is distributed in the northeast direction, cutting the central uplift zone. Block A is located in the central uplift zone, forming a fault anticline, fault nose, and fault block structure, which is a medium porosity and medium permeability reservoir. Affected by the sedimentary environment, from the southeast to the northwest, along the direction far from the provenance, the sedimentary microfacies are dominated by the core beach and the discernible channel, and gradually transited to dominated by the underwater distributary channel and sheet sand. In order to improve the drilling effect, 7 horizontal wells are designed and deployed on the basis of well-seismic and fine geological research and fine geological understanding.

2. Design and optimization of horizontal well trajectory combined with well and seismic

Based on the early horizontal well trajectory design and understanding, combined with the structure and reservoir characteristics of Block A, the technical process of block A trajectory design and optimization is established.

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2.1 Geological study combined with well and earthquake

In order to improve the accuracy of reservoir description, the existing well logging, core and seismic data of the block are comprehensively applied. Through conducting well seismic combined with fine geological research, fine sub-layer division, clear the block structure and reservoir development characteristics, clear the oil-water relationship, and provide the basis for deployment of favorable areas and target horizon optimization of horizontal wells.

2.1.1 Well seismic combined with fine stratigraphic correlation

A certain oil layer in Block A is a new series of strata in the new area. The subdivision standard of series layers has not been established before, and there is no unified marker layer in the whole area. Multiple cycles are developed in the three small layers of DII group, and the horizon correspondence is not clear. In view of the three difficulties in the correlation of a new layer system in Block A, one is that a new layer system has not established the correlation standard of the series, the other is that the three sub-layers of the DII group have developed multiple cycles, and the layer correspondence is not clear, which is not conducive to the adjustment work such as subdivided water injection, and the third is that the marker layers in each well area are not uniform, and the comparison of the series is difficult. The comprehensive use of core, electrical logging, seismic and other data has carried out the study of the rock and electrical correspondence and the combination of well and seismic, and five sets of 9 marker layers have been identified, The three sub-layers are subdivided into six sedimentary units to achieve the isochronous unification of the sedimentary units in the whole area, and the sub-layers are subdivided. A total of three oil layer groups, 17 sub-layers and 20 sedimentary units are subdivided.

2.1.2 Fine interpretation of well-seismic combination structure

The structural fault system of a certain oil layer in Block A is complex, the conjugate small faults are densely developed under the action of strike-slip, the lithological combination is complex and variable, the reflection characteristics are inconsistent, the waveform of the event axis changes rapidly, and the inter-well horizon tracking is difficult. On the basis of subdivision of small layers, aiming at the difficulties of "conjugate small fault development and difficult to trace the horizon" in the structural interpretation of the new series of strata in a new oil reservoir area, the identification methods are formulated respectively according to the difficulty of identifying the size of fault fault fault spacing in fault interpretation. The fault spacing is more than 10m, and the guided filtering+coherent orientation+3D visual inspection is applied to identify the fault; The fault spacing is less than 10m, and the application of dip scanning+body curvature identification+multi-directional observation+horizontal section interactive verification. In the aspect of horizon interpretation, first of all, multiple wavelet spectrum analysis, average wavelet determination of the best dominant frequency, improve the well seismic matching, and then adopt the method of "zoning calibration, block interpretation", first implement locally, then extend overall, improve the accuracy of structural interpretation, refine the trend change of each fault block layer, and improve the accuracy of target layer dip prediction, Guide the control of well deviation, and implement the development of small faults in the target layer in the horizontal well area to reduce the drilling risk. The accuracy of the climbing structure has reached 1.8 ‰, and 103 faults have been interpreted in the study area.

2.1.3 Reservoir prediction combined with well and earthquake

A certain oil layer has the characteristics of "wide dam-narrow river" in delta plain deposition and "narrow river-wide sheet" in underwater deposition. In combination with the response characteristics of sand body seismic profile, different well seismic combination technology methods are selected for different sedimentary environments. According to the sedimentary characteristics of the braided river delta plain, the 90 ° phase rotation is mainly applied to the corresponding reset reference sensitive seismic attribute prediction, combined with the logging facies control, and gradually optimized. The coincidence rate of the well is more than 70%, and the boundary and distribution direction of the sand body are basically clear; For the deposition of braided river delta front, seismic inversion is the main method, supplemented by seismic attributes, well logging is used to determine the area, and multiple inversion methods are compared and optimized. The coincidence rate of more than 2 meters is 75%, and the boundary and distribution characteristics of sand body are clear. Use the knowledge results to draw the well seismic combination phase zone map to improve the description accuracy of the sand body.

2.1.4 Well seismic combined with 3D geological modeling

On the basis of reservoir geological research, the fine structure and reservoir model are established according to the modeling idea of "well logging constraint, well seismic matching, facies controlled modeling" to guide the horizontal well trajectory design and adjustment while drilling.

2.2 Horizontal well trajectory design and optimization

2.2.1 Selection of favorable areas

The favorable areas of horizontal wells are selected in combination with geological knowledge and various achievement maps. In terms of structure, the area where the structure is relatively flat and the fault is clearly recognized is selected in combination with the well seismic profile and structural map; For the reservoir, refer to the inversion profile, well area sand body map, sedimentary facies zone map and other basic maps for the relatively stable area of reservoir sand body development; Finally, the target interval above the oil bottom is selected according to the distribution of oil and water.

2.2.2 Optimization of horizontal well parameters

Based on the experience of horizontal well trajectory design in other blocks, combined with the geological and surface characteristics of well block A, the optimization criteria of horizontal well parameters are established.
Optimization of horizontal section length: ① consider the development scale and structural development of the target sand body in the well distribution area; ② Maximize the use of geological reserves according to the economic benefits of numerical simulation; ③ At the same time, the coordination of the original well pattern should also be considered. According to the structural characteristics and the size of the sand body, considering the limitation of the surface well location, in order to maximize the utilization of reserves, the length of the horizontal section is optimized to be 500-600m.
Optimization of horizontal section direction: the development direction of sand body and the direction of maximum principal stress shall be comprehensively considered in the direction of horizontal section to achieve the best development effect. The following principles should be followed when designing the horizontal well extension direction: ① the horizontal well extension direction is perpendicular to the main seepage direction and parallel to the sand body direction; ② The extension direction of the horizontal well is perpendicular to the direction of the maximum principal stress.
③ The orientation of horizontal wells in the area sandwiched by faults shall be adjusted appropriately. Combined with the study on the influence of lateral extension of fractures on productivity, improve the fracture-controlled reserves and optimize the horizontal well orientation as NW260 °, near the vertical fracture direction.
Optimization of target location: ① ensure that the target location is stable and far away from the segment layer; ② The reservoir at the target location should be developed stably; ③ The bull's eye is preferably in the middle of the target layer; ④ It is better to have a control well near the target. During the selection of this area, the marker layer and the location of the target point are stable and far away from the fault position, so as to achieve "easy identification, comparison and adjustment".

2.3 Horizontal well deployment results

According to the principle of favorable area optimization and horizontal section parameter optimization, a total of 3 favorable areas are selected, 4 platforms and 8 horizontal wells are deployed, and the target layer is selected on DI group and DII. The average predicted effective sand body thickness is 4.0m, and the design average horizontal section length is 510m (Table 1).

Table 1 Statistics of design parameters of horizontal wells in Block A

Block	Well No.	Target	Predicted sandstone thickness（m）	Design horizontal section length（m）	Estimated altitude of target entry point（m）
A	1	DII1-DII2	11.1	504	-997
	2	DI6	3.8	565	-993.8
C	3	DI6	2.5	516	-1015.2
	4	DI3	2.3	493	-1011.1
B	5	DII2	2.2	469	-991.2
	6	DII2	3.2	522	-988.6
	7	DII2	2.8	506	-975.1
	8	DII1	3.8	502	-972.6
	Average		4	510	

3. Field application

3.1 Inclination section

Before deflection, check whether the trajectory to be drilled is reasonable, and adjust it in time if it exceeds the requirements of the drilling engineering. In combination with the latest understanding results of the block, re-identify the vertical depth of the target point, reasonably optimize the trajectory parameters, and ensure that there is enough adjustment space for the trajectory during the drilling process. According to the comparison of the actual drilling curve and the control well layer by layer, adjust the target depth in time to ensure accurate and smooth target entry.

Fine stratigraphic correlation is the key to accurately predict the vertical depth of the reservoir. For stratigraphic correlation, regional marker layer (large section contrast rough adjustment) or local marker layer (fine contrast fine adjustment) can be selected to find the oil and gas display that can be compared with the upper marker layer, select the adjacent wells that are relatively close or on the same river channel, and prepare the stratigraphic correlation map of the connected wells and the formation analysis while drilling of the geosteering wells in combination with the structural location. Selecting suitable and comparable marker beds is the key to accurate target entry. Different blocks and different oil formations deploy horizontal wells, and different marker beds are selected. The selection principle of general correlation marker layer is ① the development of surrounding control wells; ② Resistance and gamma curve have obvious characteristics; ③ It is close to the target horizon and has enough adjustment space; ④ Multiple marker layers can be selected. If there is a fault before drilling into the target, there must be a comparable marker layer after the fault.

3.2 Exploration interval

The selection of appropriate exploration distance and angle is the key to reduce the loss of horizontal section and improve the accuracy of target entry, which is mainly optimized from the following two aspects:

3.2.1 Optimization of exploration layer distance

When the stratum dips or is horizontal, the distance from the top of the probe to the target point is generally about 50m; Generally, about 30m is selected for the updip of the formation. The larger the updip amplitude, the shorter the distance from the top of the probe to the target.

3.2.2 Optimization of exploration angle

According to the principle of "not only can increase the vertical depth, but also can easily increase the inclination upward", when the oil layer is advanced, it can increase the inclination in time; When the oil layer lags behind, the vertical depth can be increased in time; According to the thickness of the target layer and the dip angle of the formation, the appropriate exploration angle is generally 2-4 degrees less than the dip angle of the formation.

3.3 Horizontal section

After entering the target, timely adjust to the appropriate angle to drill along the target interval. During the drilling process, accurately estimate the formation dip angle, judge the bit position, select the appropriate drilling angle, and ensure that the trajectory is drilled along the best position in the layer. In case of any new situation, or the drilling is not consistent with the previous prediction, timely analyze and adjust it, and re-predict and re-design the trajectory of the target reservoir depth according to the latest actual drilling situation. This process is a repeated geological steering process until the target is successfully hit. So as to improve the drilling rate.

3.3.1 Determine the bit position

The actual drilling curve, logging gas logging, cuttings, actual drilling trajectory and geological model are comprehensively used to predict the actual position of the bit relative to the reservoir and ensure that the trajectory is drilled along the formation.

3.3.2 Reasonable estimation of formation dip

Based on the comprehensive results of seismic, logging and logging data, accurate prediction and calculation of formation dip angle is the key to ensure the trajectory of drilling along the formation. Through experience, the following methods for calculating formation dip angle are summarized: ① estimate the formation dip angle according to the corresponding well depth and vertical depth of the same direction production point and the same direction entry point; ② Estimate the formation dip angle according to the vertical depth difference and horizontal displacement difference compared with the control vertical well horizon; ③ Calculate the stratum dip angle according to the difference between two tectonic lines and the distance between target points in the structural map; ④ Estimate the dip angle according to the difference of vertical depth and horizontal displacement of seismic profile in the time domain and depth domain of the marker layer; ⑤ Extract the dip body along the layer to estimate the dip; ⑥ Estimate the dip angle according to the waveform characteristics of the target sand body; ⑦ The dip angle is predicted according to the top of the three-dimensional sandstone model. In the actual application process, combined with the application conditions, multiple methods of interactive verification.

3.3.3 Reset the target

When the data shows deterioration or pinch-out during drilling, the well seismic and reservoir prediction shall be timely re-adjusted, the target depth shall be adjusted in time, or the horizon shall be adjusted up and down, and the target shall be re-set, guided according to the new target, to ensure the sandstone drilling rate.

3.4 Drilling completion effect

Seven horizontal wells have been drilled in Block A, with an average horizontal section length of 423.9m, sandstone drilling rate of 88.7%, oil reservoir drilling rate of 85.3%, producing area of 1.44km2 and producing reserves of 71.46 × 104t, built capacity 2.37 × 104t, see Table 2 for overall drilling conditions. According to the actual drilling trajectory curve after actual drilling, the actual horizontal well trajectory is highly consistent with the predicted trajectory, which proves the accuracy of well seismic and seismic interpretation.

Table 2 Statistics of completion effect of horizontal wells in Block A

Well No.	Target	Effective thickness (m)	Length of horizontal section(m)	Length of sandstone section(m)	Sandstone drilling rate(%)	Length of reservoir section(m)	Oil layer drilling rate(%)	Used area(km^2)	Producing reserves(104^t)
1	DII1-DII2	11.1	501	501	100	501	100	0.3	39.36
2	DI6	3.8	420	363	86.43	363	86.43	0.22	8.03
3	DI6	2	250	250	100	250	100	0.11	2.81
8	DII1	1.5	542	392	72.3	352.5	65	0.22	6.35
7	DII2	3.2	407	407	100	407	100	0.19	5.45
4	DI3	2	513	466	90.8	405	78.95	0.24	6.65
6	DII2	1.7	334	252	75.5	252	75.5	0.17	2.81
Total		3.6	423.9	375.9	88.7	361.5	85.3	1.44	71.46

3.5 Production effect

At present, seven completed horizontal wells have been put into production, and the average daily oil production of a single well at the initial stage is 13.8t, reaching the design level. As of February 2022, the average daily oil production of a single well is 8.6t, and the cumulative oil production is 2.9223 × 104t, achieving good drilling effect. See Table 4 for the overall production situation.

4. Conclusions

(1) Comprehensive application of seismic, logging and geological data to accurately predict the block structure and reservoir geological characteristics. The combination of well seismic and fine geological model is the key to the successful deployment and successful completion of horizontal wells, and the most important factor affecting the drilling rate of horizontal wells.
(2) Determining the bit position based on seismic, drilling while drilling, gas logging, lithology, logging and other information and accurately determining the unmeasured formation dip angle through different methods can effectively guide the tracking and adjustment process of horizontal wells while drilling.
(3) The application of horizontal well completion data can guide the re-recognition of the structure and reservoir in the horizontal well area, and guide the preparation of the next drilling and perforation fracturing plan. Provide basis for drilling sequence to be drilled in the next step.

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