The Fast and Optimized Drilling Technology for Sub-salt Horizontal Wells in Fault-Block JQ

Yu-hao Wei[1], Dong-jie Li[2(✉)], Wu-qiang Song[3], Nai-xu Gao[4], Hongyu Gong[5], Shan Gao[1], Peng-fei Lei[1], and Lu Yin[6]

[1] Engineering Technology Research Institute, PetroChina Huabei Oilfield Company, Renqiu, China
cyy_weiyh@petrochina.com.cn

[2] Development Department, PetroChina Huabei Oilfield Company, Renqiu, China
cyy_lidj@petrochina.com.cn

[3] Directional Drilling Technology Service Branch Company, Petrochina Bohai Drilling Engineering Company, Tianjin, China

[4] Department of Science, Technology and Information, PetroChina Huabei Oilfield Company, Renqiu, China

[5] NO. 3 Exploit Factory, PetroChina Huabei Oilfield Company, Renqiu, China

[6] NO. 1 Cementing Branch Company, Petrochina Bohai Drilling Engineering Company, Tianjin, China

Abstract. The fault-block JQ, in the Shulusag of the Jizhong depression, has complex congenital geological conditions. A large section of salt-gypsum rock develops at the bottom of the first section of the Shahejie Formation, which has a fast creep rate and a large creep non-uniform stress, which seriously pollutes the working fluid in the wellbore. The lower part of the salt paste layer is close to the reservoir of the second member of Shahejie. The occurrence of this reservoir changes rapidly, and the thickness of each sand group is relatively thin. In response to the above complex geological conditions, research work such as well trajectory design, well trajectory control in the reservoir, prevention of casing deformation and cementing quality have begun. Technical measures such as double six-section profile with double build-up, geology-engineering integration, double-layer combined casing and salt-resistant cement were proposed. Through on-site application and improvement of 4 horizontal wells, the matching drilling technology for sub-salt horizontal well has formed in fault-block JQ.

Keywords: Salt-gypsum rock · Horizontal well · Trajectory design · Geology-engineering integration · Double-layer combined casing

1 Introduction

The JQ fault block is located in the east wing of the Shulu Sag in Jizhong depression. It is a nose-like structural oil reservoir controlled by Jingqiu, which is trending from east to west. The strata encountered from top to bottom are Quaternary, Neogene, Paleogene,

J. Lin (Ed.): IFEDC 2021, SSGG, pp. 1766–1777, 2022.
https://doi.org/10.1007/978-981-19-2149-0_162

Carboniferous, Permian and Ordovician. The main oil layers are the Es_2 and Es_3 members. The Es_3 member is in the later development period with super-high water-cut, and the Es_2 member is in an unused state. As the regional caprock, the lower part of the Es1 member is deposited with a special set of rock, salt rock, gypsum mudstone, argillaceous and salt argillaceous dolomite. The buried depth of Es_1 is 2750–3000 m, the thickness is between 30–165 m, and the average thickness is 118 m. The Es_2 formation, 40–130 m away from the bottom of the salt-gypsum layer, deposited a set of medium porosity and low permeability reservoirs. The four sand groups in the Es_2 section all have independent oil-water interfaces. The oil layers are mainly developed in sand groups I & IV, but the physical properties of sand groups I & III are poor, and the oil-bearing area of sand groups I & II is small. Therefore, sand group IV is currently the main production layer. The average thickness of the IV sand group is 8m, and it contains two small layers of No. 9 & No. 10, and a set of 1.5–2 m thick mudstone interbeds developed between the two layers (see Fig. 1). In summary, there is a stable overall distribution and a wide range in the IV sand group, but the effective oil layer thickness is small, and the occurrence state changes quickly in the horizontal and vertical directions. Due to low natural production capacity, fracturing is needed. Therefore, the reservoir has the conditions for horizontal well development. It was decided to deploy horizontal wells in the sand group IV of Es_2 in the south where the reserves are highly realized.

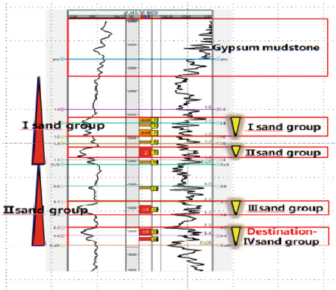


Fig. 1. Reservoir group division of Es_2 Formation

The sand group IV in Es_2, as the target layer, is adjacent to the upper part of the salt-gypsum layer, and its occurrence distribution is unstable. There are difficulties in wellbore trajectory design, reservoir trajectory control, casing damage prevention and cementing quality assurance. This article analyzes the difficulties in drilling sub-salt horizontal wells in the JQ fault block, and proposes a series of targeted technical measures. Field application shows that these measures realize the safe and rapid drilling of the salt-gypsum layer, improve the cementing quality of the long-sealed section of horizontal wells, prevent the occurrence of casing damage in the salt-gypsum layer, and establish the regional stratum change law.

2 Analysis of Drilling Difficulties

2.1 Well Trajectory Design

Due to the creep characteristics of the salt-gypsum layer, the borehole is easy to lose stability, which will cause complex downhole conditions such as Borehole shrinkage and stuck. Studies have shown that the creep rate of the salt-gypsum layer increases with the increase of the well inclination when the density of the drilling fluid is constant. This shows that the well inclination should not be too large in the salt-gypsum layer. Actual drilling data show that the distance between the lower reservoir and the upper salt-gypsum layer is only 40–200 m. The top of the IV sand group of Es_2, as the target layer, is only 120 m away from the salt-gypsum layer. This leads to an increase in the directional build rate and a reduction in the adjustment margin before entering the target, which makes the design of the well trajectory more difficult.

2.2 Well Trajectory Control

The stratum of Es_2 in block JQ dips along the east, south and west directions. The stratum of Es_2 in block JQ is slumped along three directions of east, south and west. The top is relatively gentle, with an inclination angle of 4–6°. The wing is relatively steep, with the inclination angle of the east wing being about 18° and the inclination angle of the west wing being about 7–8°. The overall reservoir occurrence is characterized by instability and rapid change [1]. The effective thickness of the reservoir in the IV sand group of Es_2 is relatively thin, which will increase the frequency of well trajectory control. In addition, logging and mud logging data show that the natural gamma characteristics of the mudstone at the top, bottom and middle of the reservoir are similar, and their color is unstable. If lubricants with fluorescent are used in horizontal wells, it will be more difficult to identify reservoirs and determine landing sites. On-site wellbore trajectory control space is at risk of further compression.

2.3 Casing Design

Non-uniform load caused by peristalsis of the salt paste layer at the bottom of Es_1 segment affected by the non-uniform load, the number of variable wells and abandoned wells has been increasing, and the well pattern has been seriously damaged. According to statistics, the casings of 97 of the 141 wells in the early stage were damaged or deformed, including 71 wells with severely deformed casings, which caused problems such as channeling, stuck tubing strings, and even scrapped. Through statistics, it is found that 41% of the casing deformation occurred within 6 months, indicating that the salt paste layer has the characteristics of fast plastic creep speed and strong stress, so the casing anti-extrusion strength design needs to be strengthened [2].

2.4 Cementing Quality

The dissolved salt paste will cause cement slurry pollution and cement stone corrosion, which will increase the risk of cement slurry flocculation and cement stone strength failure. If the salt rock in the sand and mudstone interlayer is dissolved, the wellbore will collapse, which will increase the volume of the annulus, reduce the cement slurry displacement efficiency, and affect the cementing quality. Because the salt paste layer also has strong water absorption, there are risks of cement slurry flashing and cement stone shrinkage, which cause problems such as sausage filling and poor cementing quality [3].

3 Key Technical Countermeasures for Drilling

3.1 Optimized Design of Well Trajectory

Due to the restrictions of the ground environment, the wellhead and the target box are not in the same straight line, and there is an offset. When designing the trajectory, a small azimuth twist of 5–10° is required. In theory, these horizontal well trajectories are three-dimensional. Taking into account the difficulties mentioned above, the double-building profile is preferred for trajectory design. At present, there are mainly three types of double-building profiles, including the five-section (hold-build-hold-build-turn & build), the six-section (hold-build-hold-turn & build-build-hold) and the seven-section (hold-build-hold-turn-hold-build-hold) [4]. The inclination angle of the target layer is predicted to be between 75 and 85°. The dip angle of the formation is relatively steep when entering the target. There is no pressure to increase the well inclination in the lower section. The six-section (hold-build-hold-turn & build-build-hold) can meet the requirements, as shown in Fig. 2.

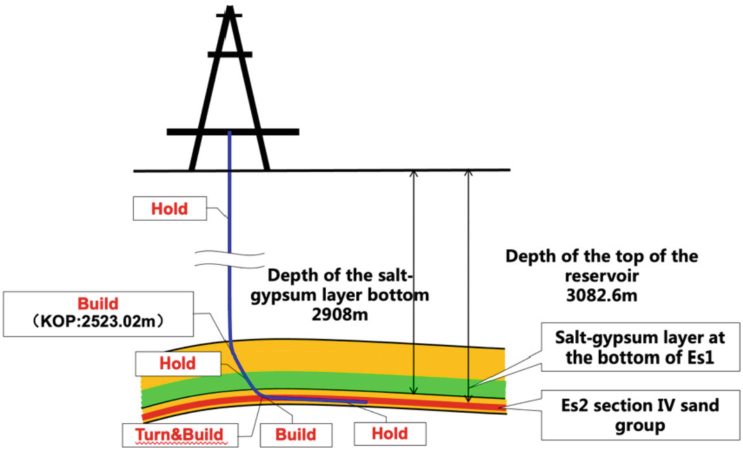


Fig. 2. Well trajectory vertical profile of well JQ-P2

Take the JQ-P2 well as an example (see Table 1). First of all, considering the prevention of eccentric wear between the sucker rod and the tubing, the KOP should be below the pump's running depth (average 1703 m). At the same time, the wellbore trajectory should reach 20–30° at 50 m above the salt-gypsum layer, with a moderate build-up rate

(≤4°/30 m). This can avoid the risk of building in the salt-gypsum layer. After passing through 50 m below the salt-gypsum layer steadily, the trajectory is increased twice to the reservoir dip with a high build rate (≤8°/30 m) to complete targeting. Finally, the trajectory continues to the bottom of the well with a certain inclination.

The second building inclination can be divided into two stages. The first is to build inclination while turning azimuth. While the inclination of the well is rapidly increased to 60–70° with a high build rate, the azimuth angle is turned to the final design azimuth. This can avoid a situation when the azimuth is not turned to the design level due to the early appearance of the reservoir, the azimuth is obtained at the expense of the build rate, which is easy to cause insufficient build rate and out of control of the trajectory; The second is to build inclination only. Before entering the target layer, the build rate is slightly reduced, and the geo-steering tool is run in advance. The use of a moderate build rate can provide adjustment space for the advance entry of reservoir and the uncertainty of the build rate of new tools.

This trajectory design scheme converts the 3D profile into two 2D profiles, greatly reducing the difficulty of horizontal well drilling engineering caused by offset.

Table 1. Well trajectory profile of well JQ-P2.

Well section		MD/m	Inc/°	Azi/°	TVD/m	Build rate /°/30 m	V.sec/m	CL/m
Hold		2523.02	0.00	/	2523.02	0.00	0.00	2523.02
Turn		2740.52	29.00	166.75	2731.35	4.00	53.88	217.50
Hold	Salt-gypsum rock layer	2793.00	29.00	166.75	2777.27	0.00	79.33	52.48
		2940.00	29.00	166.75	2908.46	0.00	152.05	147.00
	Hold	2990.52	29.00	166.75	2950.01	0.00	175.08	250.00
Build & turn		3126.01	60.00	176.10	3045.57	7.00	268.37	135.49
Build (Target A)		3249.58	84.84	176.10	3082.60	6.00	384.59	123.57
Hold (Target B)		4016.47	84.84	176.10	3151.60	0.00	1147.37	766.88

3.2 Guiding Technology Based on Geology-Engineering Integration

Precise Reservoir Prediction. Through the analysis of 3D seismic and logging data, some special rocks, such as I sand group, II sand group and III sand group, are used as the mark layer of stratigraphic contrast when the target layer is landed. After drilling through the mark layer—the bottom of the III sand group, the vertical depth and occurrence of the target layer are estimated by the equal thickness method. The location of the landing point will be predicted. The actual design compliance rate is proved to be high.

Real-Time Formation Recognition. When drilling in the horizontal section, MWD+GR or NWD tools can be used for reservoir identification [5]. NWD tool has the advantages of smaller measurement blind areas and more measurement parameters. As the preferred technology for geosteering, it can identify the strata in the first time, which is conducive to the rapid adjustment of the trajectory. By collecting the real-time gamma curve, the cutting relationship between the actual drilling trajectory and the formation can be judged. The well trajectory is controlled within the range of the designed target box.

Accurate Lithology Analysis. Using XRD and RoqScan technology, the lithology of cuttings returned while drilling can be analyzed. The changing laws of minerals in the formation can be obtained from a microscopic point of view. RoqScan technology is used to scan cuttings while drilling, which can quantitatively analyze the mineral composition, content and pore structure of the formation. The technology starts 50 m before entering the target layer, and the sampling interval is every 2 m. At the same time, three-dimensional quantitative fluorescence technology is applied to representative cuttings while drilling. When cuttings are contaminated by drilling fluid, it can still accurately identify oil and gas.

Efficient Trajectory Control. The design section of the horizontal well in this block has an average length of 600 m and a longest length of 767 m. With the extension of the horizontal section, the friction torque increases during the drilling process, which is easy to support pressure. If the trajectory cannot quickly re-enter the target layer, the reservoir-encountered rate will decrease. Therefore, while optimizing geosteering tools and shortening the response time of the reservoir, the optimization of friction and torque reduction tools should be strengthened to improve the efficiency of trajectory control.

As an economical tool for reducing friction and torque, hydraulic oscillators are widely used [6]. The model and location of the hydraulic oscillator must be designed according to its vibration power, range and use parameters. Finally, the distance between the tool and the bottom hole must be smaller than its vibration transmission range. According to parameters such as BHA, well inclination and displacement, the installation position of the hydraulic oscillator is calculated to be 150–200 m away from the drill bit. When drilling in the reservoir, the formation deflection trend should be used as much as possible to reduce slip drilling and increase the ROP. At the same time, the build rate should be kept within 4°/30 m as far as possible to make the well trajectory smooth.

Salt-Resistant Cement Slurry System. In order to solve the problem of salt & paste pollution of cement slurry, a set of salt-resistant cement slurry system was formed by optimizing additives such as salt-resistant filtrate reducer, drag reduction agent, retarder, etc., and reasonably adjusting the salt concentration of the slurry water. We choose cement slurry additives containing water-soluble AMPS molecules. AMPS molecules contain active functional groups such as sulfonate groups, amide groups and carbon-carbon double bonds. Since sulfonate does not react with salt, the additive has salt resistance and high temperature resistance. Due to the amide group, the additive has good hydrolytic stability, acid and alkali resistance and thermal stability, and the internal carbon-carbon double bond makes it easy to copolymerize with other molecules. In addition, the expansion agent can improve the deformability of the cement stone and keep the volume of the cement stone stable at different stages.

We must improve the cementing quality of the entire long well section, especially the lower reservoir section, in order to meet the needs of effectively sealing oil and water layers. The double-density & dual-setting toughness cement slurry system was optimized through indoor experiments.

The leading slurry formula: Grade D cement + 15%Y12000 + 2%TW-100S + 1%TW-401 + 1.2%ZH-2 + 10%NaCl + water". Tail slurry formula: Grade G cement + 2.5%TW-100S + 0.8%TW-401 + 3%microsilica + 3.5%G401 + 5%plugging agent + 9%NaCl + water.

It can be seen from the experimental results of Table 2 that the system has the following characteristics: low fluid loss, good rheology, no free water, adjustable thickening time and high early strength of cement.

Table 2. Conventional properties of salt-resistant cement.

Cement slurry	Density/g·cm^{-3}	Degree of fluidity/Cm	t/min	FL/mL	Free water/mL	$p_{24\ h}$/MPa
Leading slurry	1.70	23	220	150	0	13.6
Tail slurry	1.85	22	110	40	0	16.3

Note: The initial temperature of the experiment is 28 °C, the final temperature is 80 °C, and the heating time is 35 min; The initial pressure of the experiment is 5 MPa, and the final pressure is 42 MPa

3.3 Double-Layer Combined Casing

In preventing the deformation of the casing in the salt-gypsum layer, a variety of methods have been used in the JQ block [7] (see Fig. 3). Among them, the most mature technology is the double-layer combined casing technology, which theoretically can withstand 200 MPa external squeezing force. At present, no casing deformation has been found in the application wells of this technology. Double-layer combined casing technology can also be used in the design of horizontal well casings. In the second spud, the Φ241.3 mm drill bit is drilled to 50 m below the salt-gypsum layer, and then the Φ215.9 mm drill bit is drilled to the bottom of the well. This reduces the broken rock volume of the wellbore, increases the ROP, and reduces the drilling cycle. After drilling, the double-layer composite casing is run into the salt-gypsum layer. The annulus between the inner and outer casing is filled with machine oil and sealed.

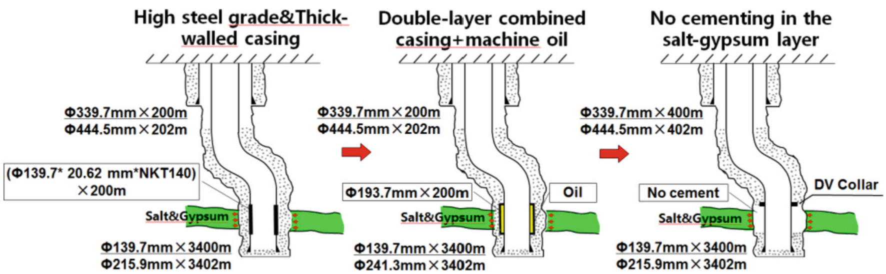


Fig. 3. Evolution of the technology of preventing casing deformation in the salt-gypsum layer

4 Field Application

Aiming at the development of the IV sand group of the second member of Shahejie Formation in the JQ fault block, a total of 4 horizontal wells were designed to be drilled in the initial stage. The average well depth is 3883 m, the average horizontal section length is 541.3 m, the longest horizontal section length is 858 m, the reservoir drilling rate is 94.5%, the average drilling speed is 11.1 m/h, the average drilling period is 33.9 d, and the accident complex time effect is 0.

4.1 Guiding Technology Based on Geology-Engineering Integration

Geosteering Application. Taking Well JQ-P2 as an example (see Fig. 4), three main marker layers are selected according to the data of adjacent wells, before the target layer is landed. Combined with cuttings logging, NWD tools are used to obtain real-time formation curves. Then, a fine stratum comparison is carried out on the ground, and the depth of the target layer is continuously corrected using the equal thickness method to ensure a reasonable landing angle [8–10]. As shown in Fig. 4, the well is predicted to land at an measured depth of 3176 m, that is, a vertical depth of 3066.40 m, with a landing angle of 70.05°. The actual reservoir landing point is at a measured depth of 3 169 m, that is, a vertical depth of 3 063.44 m, and the landing angle is 68.14°. This shows that the vertical depth prediction coincidence rate is as high as 99.9%. After entering the reservoir, we continue to explore the mudstone interbed and floor positions according to geological requirements. When the trajectory exits the reservoir, the well inclination is increased rapidly to re-enter the reservoir. When the trajectory enters the reservoir again, it starts to drill steadily until it penetrates the interlayer for the second time. Finally, the inclination was lowered to 82–83°, and the trajectory was drilled along the reservoir with a steady slope. Due to the slowing of the formation dip, the trajectory encountered the interlayer for the third time, and it was decided to drill down through the interlayer. Then the inclination increased from 80° to 87.3°, and the trajectory encountered the interlayer for the fourth time. The trajectory continued to drill with increasing inclination until the top of the interlayer. In the end, the drilling depth was 4027 m, and the final well inclination was 90.0°.

Engineering Steering Application. When the directional angle is built, the 1.5° screw with stronger ability to increase the inclination is used in the lower Φ215.9 mm wellbore, and the 1.25° screw is used in the upper Φ241 mm wellbore for directional construction. When the trajectory enters the horizontal section, the hydraulic oscillator and the wellbore cleaner are used to reduce the friction torque, destroy the cuttings bed, improve the drilling efficiency, and reduce the risk of stuck drilling; Before landing in the horizontal section, the landing angle is maintained at about 70° to solve the uncertainty of the reservoir vertical depth; When drilling in the reservoir, the formation deflection trend should be used as much as possible to reduce slip drilling and increase the ROP. At the same time, the build rate should be kept within 4°/30 m as far as possible to make the well trajectory smooth.

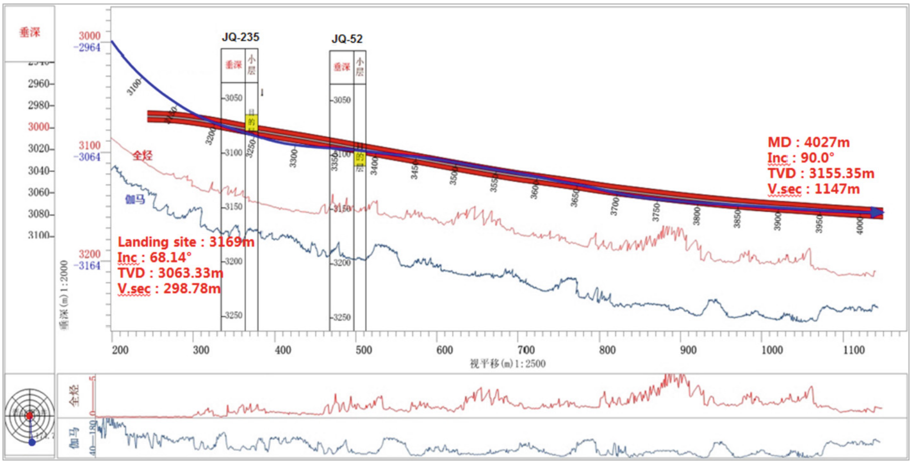


Fig. 4. Geosteering process in the reservoir of well JQ-P2

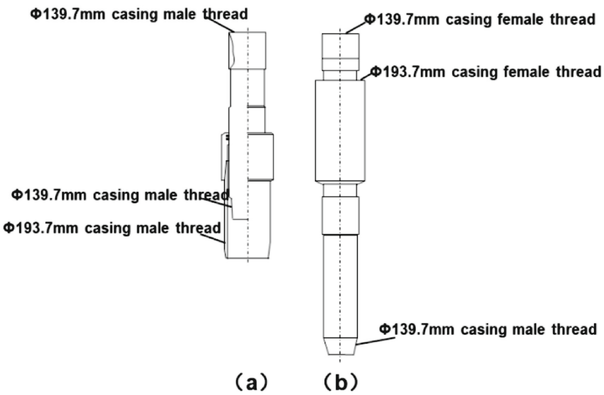
4.2 Application of Casing Deformation Prevention Technology

The 4 horizontal wells in the JQ block encountered a salt-gypsum layer of 151.5 m on average, with a maximum length of 220 m. In order to prevent casing deformation in the salt-gypsum layer, the position of the salt-gypsum layer is first determined according to logging data. Then when the casing is run in, the conventional casing string is replaced with a double-layer combined casing string 30 m (2700–2980 m) above and below the salt-gypsum section. Finally, the annulus between the inner and outer casing is filled with machine oil and sealed. The outer casing size of the salt-gypsum double-layer casing is Φ193.7 mm × 12.7 mm, the inner casing size is Φ139.7 mm × 10.54 mm, and the casing size of the remaining well sections is Φ139.7 mm × 9.17 mm casing. All casing steel grades are P110. Through software simulation, the anti-extrusion of the double-layer combined casing is greater than 250 MPa. The predicted maximum abnormal high pressure of the salt-gypsum layer in this fault block is 189 MPa [11], so it meets the requirements of anti-extrusion.

Compared with the conventional casing string, the key tool of the double-layer composite casing string is a pair of special oil injection valves (see Fig. 5), which is responsible for connecting the conventional casing with the double-layer combined casing and sealing the machine oil in the annulus [12]. At present, no casing damage and casing deformation have been found in the application wells of this technology.

4.3 Cementing Technology in Salt-Gypsum Formation

The average cement sealing length of horizontal wells in JQ block is 2855 m. High-quality cementing quality has been achieved, through continuous improvement of cementing technology, casing centering, wellbore cleaning, cement slurry system, and flushing & spacer fluid optimization. Well JQ-P1 uses two-stage cementing technology. The first-stage cementing uses conventional density & salt-resistant cement slurry to seal the well section below the salt-gypsum layer, and the second-stage cementing uses



(a)Upper valve for machine oil filling (b)Lower valve for machine oil filling

Fig. 5. Machine oil injection valve device. (a) Upper valve for machine oil filling. (b) Lower valve for machine oil filling

low-density & high-strength cement slurry to sealing the well section above the gypsum rock layer. Logging data shows that the cementing quality above the salt-gypsum layer is good, while the cementing quality below the salt-gypsum layer is poor.

Well JQ-P2 was changed to one-time back-up cementing, including low-density cement slurry in the upper part and salt-resistant toughness cement slurry in the lower part. This method can improve the cementing quality at the grading collar and ensure the casing tightness during volume fracturing. The size of the rigid centralizer is increased from Φ205 mm to Φ216 mm. During cementing, the casing above 60° is filled with clean water, which increases the buoyancy of the cement slurry on the casing and improves the casing centering. Logging data show that the cementing quality of the reservoir section has been greatly improved, but the cementing quality of the upper filling section is poor, and continuous optimization is still needed.

Before cementing in the J45-P3 well, 20 m^3 of fibrous thick slurry was injected into the open hole to carry mud and sand in the irregular wellbore to enhance the cleaning of the wellbore. During cementing, the high-temperature and high-viscosity spacer fluid is injected to improve the hydrophilicity of the contact interface and improve the cementing quality of the cement. After accurate calculation of the annulus static pressure difference, the density of the cement slurry in the upper filling section is increased to 1.70 g/cm^3. The final logging data showed that the overall cementing quality was greatly improved. The cementing quality of the upper part of the gypsum-salt layer was high, and the quality rate of the lower reservoir section reached 79% (see Fig. 6).

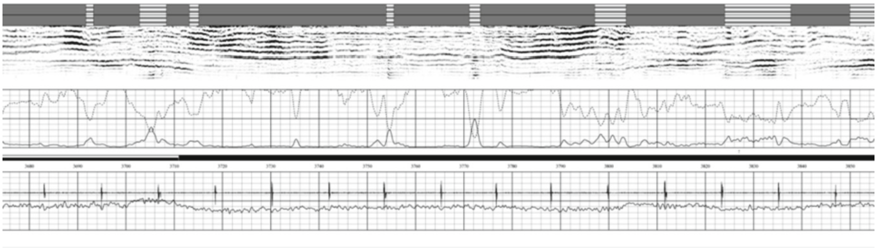


Fig. 6. Partial cementing quality in the reservoir of well JQ-P3

5 Conclusion

a. A large section of salt-gypsum rock is developed at the bottom of Es_1 member close to the lower Es_2 member reservoir. The reservoir occurrence has the characteristics of rapid horizontal and vertical changes. The salt paste layer has a fast creep rate and high stress. All of these have provided the geological foundation for the formation of the unique sub-salt horizontal well drilling technology in the JQ fault block. The technology, represented by double six-section profile with double build-up, geology-engineering integration, double-layer combined casing and salt-resistant cement, has become the key technology for JQ fault block sub-salt horizontal well drilling.

b. Due to the complex stratum characteristics of the JQ fault block, there are difficulties in reservoir prediction, identification and well trajectory control. Reservoir depth and occurrence are accurately predicted, and the landing angle of the reservoir is reasonably controlled through the comprehensive application of multiple technologies, such as formation comparison, structural analysis, geological logging and logging while drilling, and the auxiliary application of new technologies, such as 3D quantitative fluorescence logging, XRD and RoqScan. A set of fine geosteering analysis system was formed. At the same time, special tools, such as hydraulic oscillators and wellbore cleaners, are optimized to improve orientation efficiency and reduce downhole risks. A set of economical well trajectory control technology was formed.

c. At present, the most effective measures to prevent casing deformation in JQ fault block is double-layer combined casing (Φ193.7 mm + Φ139.7 mm) oil-filled. However, it still faces the problem that the upper Φ241.3 mm borehole is large in size, which is not conducive to the speed of drilling. Composite wellbore (Φ241.3 mm + Φ215.9 mm) is easy to produce steps, which is not conducive to the problem of drilling safety. Therefore, it is recommended to develop high anti-extrusion Φ139.7 mm casing, which can resist the non-uniform creep stress of the salt paste layer.

Acknowledgments. The project is supported by the Science and Technology Major Project of PetroChina Co Ltd. (2017E-1505), and the Long-term research project of PetroChina Huabei Oilfield Company (2021-HB-D13 & 2021-HB-D14).

References

1. Yang, W., Zhao, L., Hou, S., et al.: Preliminary application of fine reservoir description to development of Jingqiu oilfield. Petrol. Geol. Exp. **04**, 375–381 (2000)
2. Wang, H., Xue, Y., Sun, B.: Completion technology in gypsolith and salt formation to prevent collapsing casing in Jinqiu oilfield. Oil Drill. Prod. Technol. **16**(6), 034–039 (1994)
3. Yu, J., Le, S.: Cementing technology and application in gypsum salt bed of the right bank block of the Amu Darya **33**(S1), 22–24+7 (2010)
4. Xu, H., Niu, H., Niu, S., et al.: Optimization design and application of six-stage 3D horizontal well trajectory. Oil Drill. Prod. Technol. **39**(5), 564–569 (2017)
5. Li, D., Wang, Y., Wei, Y., et al.: Latest shale gas drilling technological development. Oil Forum **36**(01), 49–56 (2017)
6. Shi, P., Lin, J., Mi, N., et al.: Horizontal geosteering and its application in Yanchang oilfield. Unconventonal Oil Gas **1**(03), 29–36 (2014)
7. Zhang, X., Lian, Z., Wang, G., et al.: Deformation mechanism and prevention of casing in Jingqiu Oil field. Oil Drill. Prod. Technol. **16**(2), 001–009 (1994)
8. Tian, S.: Research on horizontal drilling technology and application in oil sheet. Drill. Prod. Technol. **2004**(03), 15–17+1 (2004)
9. Zhang, Z.: Research on control technology of reservoir encountering rate in horizontal wells. J. Shengli Coll. Chin. Univ. Petrol. **03**, 10–12 (2014)
10. Dong, S., Zhang, X., Chen, J.: Scheme design and performance evaluation of double-layer combined casing. J. Southwest Petrol. Inst. **19**(4), 85–90 (1997)
11. Lian, Z., Zhao, G., Dong, F., et al.: Mechanics analysis of liquid medium filled in double-layer combined casing. Oil Drill. Prod. Technol. **19**(5), 001–005 (1997)
12. Wang, F., Lan, Y., Huang, X., et al.: Double casing cementing in gypsum salt layer of Shulujingqiu structure. Drill. Prod. Technol. **42**(5), 27–30 (2019)