Exploration and Suggestions on Continuous Optimization of Wellbore Structure of 8000m Ultra-deep Well in the Southern Margin of the Junggar Basin

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Abstract. In view of the complex formation pressure characteristics faced by the 8000 meter exploration in the middle section of the southern margin of the the Junggar Basin, the pore pressure, fracture pressure and collapse pressure of the formation were calculated by using the logging data and GMI software, and the calculation results were revised in combination with the drilling data and core mechanics test results, and the more accurate characteristics of the three pressure profile of the formation in the southern margin of the the Junggar Basin were obtained. In response to the pressure system characteristics of "three lows, two highs, and one narrowness", five necessary sealing points and one risk point were determined for the ultra-deep well in the middle section of the southern margin. Two sets of wellbore structures were optimized to support the completion of 8000 meter ultra-deep wells in the middle section of the southern margin. To further reduce drilling costs, based on research on international ultra-deep wells and domestic over ten thousand meters deep wells, the concepts and measures of tail pipe suspension, optimized casing clearance, and expansion while drilling have been proposed, which have reference value for continuously optimizing the wellbore structure at the southern edge.

Keywords: the Junggar Basin; southern edge; well structure; ultra-deep well; liner suspension; reaming while drilling

1 Foreword

Located at the northern foot of the Tianshan Mountains, the southern margin structure of the Junggar Basin is a large retroforeland basin since the Neogene. It has similar tectonic setting with the Kuqa Piedmont structure in the Tarim oil field, but the reservoir-forming conditions are quite different. The southern margin is a foreland overlap area of Permian, Middle and Late Jurassic and Neogene. It is the area with the most complete stratigraphic development and the largest burial depth. Three sets of regional cap beds are developed vertically, forming three sets of upper, middle and lower reservoir-forming association. The structure is divided into three sections in the east-west

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direction. The main source rock maturity is different, and it has the characteristics of "east-west oil and intermediate gas". The Sikeshu sag and Chepai zi bulge in the western section are independent reservoir-forming systems, mainly oil and relatively small in scale. The North Tianshan foreland depression in the middle section is mainly a natural gas exploration area with high maturity source focus and large anticline concentrated development. The eastern section is Fukang fault zone, which is highly efficient exploration field.

In the middle part of the southern margin of Junggar Basin, the fourth system (Xiyu Formation), Neogene system (Dushanzi Formation, Taxihe Formation, Shawan Formation), Paleogene system (Anji Haihe Formation, Ziniquanzi Formation), Cretaceous system (Donggou Formation, Lianmuqin Formation, Shengjinkou Formation, Hutubi Formation, Qingshuihe Formation) and Jurassic system (Kalaza Formation, Qigu Formation, Tousunhe Formation, etc.) have been drilled from top to bottom. The buried depth of the target layer is generally large, the buried depth of the main target layer (Qingshuihe Formation, Kalaza Formation) is greater than 7000m, and the buried depth of the potential target layer (Sangonghe Formation, Badaowan Formation) is 9000-10000m, and the lithologic structure, fault and pressure are complicated, resulting in the well structure of the exploration well.

Under the influence of undercompaction, fluid expansion and tectonic compression, there are differences in the pressure system between different transverse anticlines and different homologous anticlinal well locations, and the longitudinal whole presents the characteristics of "two high and three low". Anji Haihe Formation is an abnormal high pressure, the formation pressure in Ziniquanzi Formation gradually drops, the lower combination formation pressure reaches the highest in the lower part of Hutubihe Formation or Qingshuihe Formation, and the pressure in the Jurassic gradually drops[1-2].

The formation temperature in the southern margin is generally high. The measured temperature of well Letan 1 reaches 159°C, and that of well Tianwan 1 reaches 175°C. The high temperature has brought challenges to the temperature resistance of drilling fluid system and cementing cement slurry system in ultra-deep Wells. At the same time, higher requirements are also put forward for the use of downhole dynamic drilling tools in ultra-deep Wells.

2 Research Progress of Well Structure Scheme

2.1 Design Principles of Well Structure in the Middle Section of The South Margin

Optimization principle: According to the needs of completion, determine the completion string size, and then determine the completion casing size. On the basis of the existing cement slurry system, consider displacement efficiency, long-term sealing requirements, and whether the cementing process is leaking formation, and design reasonable annular clearance and non-standard casing joints. "Reverse design" borehole structure, reserve a layer of casing, and establish a borehole structure sequence[3] suitable for ultra-deep Wells in the middle section of the south margin.

Based on the above optimization principles, focusing on the requirements of "high efficiency, safety and speed", the formation pressure in the south margin region presents the characteristics of "three low, two low and one narrow" in the vertical direction. The formation in the middle part of the south margin is extremely deep, the formation under the Neogene paste rock mudstone is poor in stability and easy to collapse and collapse, and the Anjihai mudstone layer of the Paleogene system is highly water-sensitive and easy to collapse and shrink diameter. By using the drilling data and logging data that have been drilled in this oil and gas field, using geomechanical analysis and borehole stability evaluation technology, the formation three-pressure profile is established, the engineering sealing point is determined, and the structural design of the ultra-deep well of this oil and gas field is optimized from the aspects of "simplifying the well structure, optimizing the diameter of the hole and casing, and designing the unconventional well structure". In order to provide technical support for the efficient and economic development of oil and gas in the southern margin of Junggar.

2.2 Establishment of Formation Three-Pressure Profile

By using the well logging data of many Wells in the southern margin of Junggar Basin, the pore pressure, rupture pressure and collapse pressure of the formation were calculated by using GMI software, and the calculated results were modified in combination with the well drilling data and core mechanics test results, and a relatively accurate three-pressure profile[4] of the southern margin of Junggar Basin was obtained, as shown in Fig. 1.

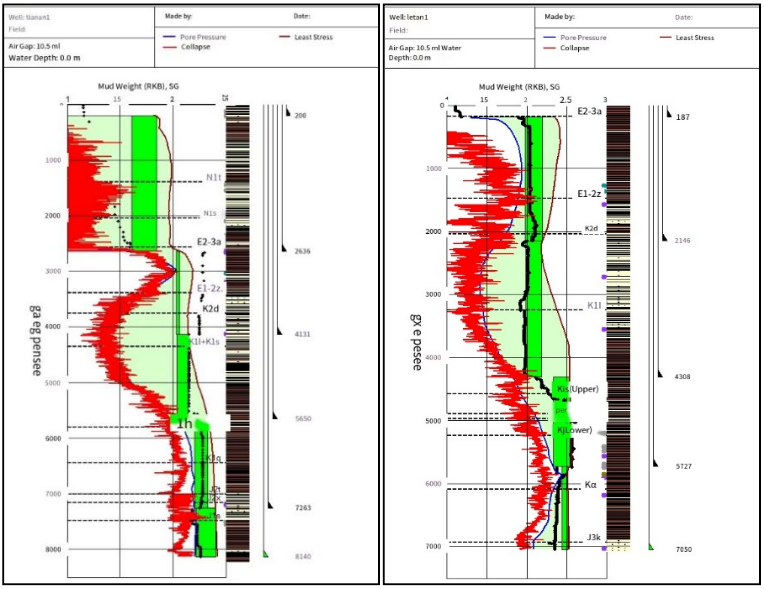

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Fig. 1. Three-pressure strata profile in the middle part of the south margin

It can be seen from the figure that the formation pressure in the south margin area presents the characteristics of "three low, two high and narrow" in the longitudinal direction. The high-pressure strata of the Haihe Formation in Anji, Hutubihe Formation or Qingshuihe Formation all face the problem of narrow safety density window.

2.3 Analysis of Must-Seal Points in Geological Engineering

By analyzing the three-pressure profile of the formation and the bearing capacity of the formation, considering the development of low-speed conglomerate in the upper strata of the fourth system in the southern margin, and in order to ensure the stability of the wellbore of the ultra-deep well, 5 geological engineering must seal points and 1 geological risk point are determined:

1) must seal point 1. In the middle part of the south margin, the low-speed conglomerate of the fourth system is developed, the surface is loose, and it is easy to leak and collapse layer, so the bottom of the fourth system is the bound point.

2) Must seal point 2, must seal point 3, must seal point 4, must seal point 5. There are several sets of vertical pressure systems in the middle part of the south margin, the distribution is complicated, it is difficult to describe accurately and quantitatively, but it can be qualitatively determined that there are two sets of abnormal high pressure layers in the Anji Haihe Formation, Hutubi Formation or Qingshuihe Formation. Combined with the upper and lower formation pressure system, it is necessary to add four sealing points in the well body structure design. The two required sealing points seal off the low-pressure strata (formation pressure coefficient 1.30 ~ 1.40) in the upper part of Anji Haihe Formation, creating conditions for the safe drilling of the lower strata with higher density (formation pressure coefficient 1.60 ~ 1.80). 3 must seal off high pressure formations of Anji Haihe Formation and Ziniquanzi Formation, creating conditions for safe drilling of Donggou Formation and its lower low pressure formations (formation pressure coefficient 1.50 ~ 1.70); Bifeng points 4 sealed off the Donggou Formation and its lower low pressure formations, creating conditions for the safe drilling of Shengjinkou Formation, Hutubihe Formation and Qingshuihe Formation high pressure formations (formation pressure coefficient 1.85 ~ 2.25); The five points of Bifeng isolated the high pressure strata of Shengjinkou, Hutubi and Qingshuihe formations, creating conditions for the safe drilling of the lower part of Qingshuihe Formation and the Jurassic relatively falling low pressure strata (formation pressure coefficient 1.90 ~ 2.10).

3) Geological risk points. The pressure drop of Jurassic system is large, the risk of drilling and leakage is large, and it can not be drilled in the same time with the upper Cretaceous formation, so it should be considered[5-6] in the design of well structure.

2.4 Evolution of Well Structure Design

The optimization of the lower south edge combination went through three phases as shown in Fig.2 to Fig. 4 [7]. The first phase was an exploratory phase prior to 2012, using either a conventional quad or unconventional quad configuration. The conventional quad configuration had ϕ660.4mm drilled at one open to the middle of the Neogene system as shown in Fig.2. The second with ϕ444.5mm bit to reach Shawan Formation of Neogene; Drilled through the complex formation of Taxihe Formation with ϕ311.15mm and entered the top of Shawan formation with ϕ311.15mm. To the full drilling depth with ϕ215.9mm in the quarter. First, the upper loose formation of Neogene was isolated; second, the Taxihe Formation with a thick gravel layer was isolated; third, the Ziniquan Formation of Paleogene was isolated and the low-pressure formation was isolated; and the fourth was sealed to the target well depth (high-pressure interval). The average drilling depth was 6,359m and the maximum drilling depth was 7,533m. The second stage is the 7,000-meter drilling stage from 2018 to 2020, which also adopts the conventional quad/extraordinary quad well structure with a maximum drilling depth of 7,601m. The third stage is the 7,000-meter drilling speed and 8,000-meter drilling stage after 2021. The main block is the middle part of the south margin, and the well structure of large five-open or six-open is adopted. The average well depth is 7,113m, and the maximum well depth is 8,166m. At one ϕ762.0mm drill bit to the lower part of the fourth system, the loose formation in the surface low-velocity conglomerate segment is sealed off. Drill through Shawan formation with ϕ571.5mm in the second area to seal off the low-pressure formation of Dushanzi and Shawan formations; The 3-ϕ 431.8mm bit penetrates the Ziniquan formation with ϕ431.8mm to seal off the Paleogene and middle and upper high-pressure formations in Donggou Formation, and the 4-ϕ 333.4mm bit reaches the top of Shengjinkou Formation to seal off the low pressure formation in Donggou Formation, as well as faults in Linmuqin Formation and Shengjinkou Formation. With ϕ241.3mm (reamed to ϕ260.4mm) drilled to the lower part of the Qingshuihe formation, the quinco has sealed off the Cretaceous-high pressure formation to ensure safe six-way drilling into the Jurassic, where a layer is reserved to prevent the pressure from falling too quickly. However, the lithology and combination of Lower Jurassic Sangonghe Formation and Badaowan Formation in the middle part of the south margin are not clear, the pressure system is more complex, the distribution of high-pressure water layer from Shengjinkou Formation to Hutubihe Formation is not clear, and the risk of uncertainty is high, so the well structure design needs to leave some room as shown in table 1 [8-9].

Table 1. Well structure optimization process of each structure in the south margin

Anticline	Well body structure	Evaluation results
High Springs	Regular quarto	Set
	Unconventional five-open (Hutubi 1)	
Hutubi	Big five open (call 6, call 101)	Continuous optimization
	Six open (call 102, call 9)	
Toguru	Unconventional Penta (Letan 1)	Increased opening Times
East Bay	Big Five Kai (Sky Bay 1)	Continuous optimization

Liukai (Tianwan 2, Qingbei 1)

Anjihai (Anjihai) Six Kai (Cheonan 1) Set

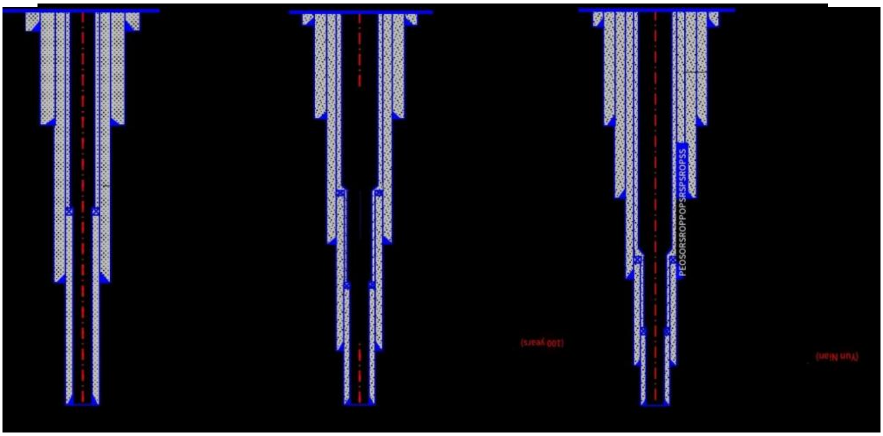

Fig. 2. Conventional quad body structure

Fig. 3. unconventional five-open well body structure

Fig. 4. Large five-open/six-open and seven-open well body structure

3 Exploration and Suggestion of Continuous Optimization of Well Structure

In view of the complex pressure system, high temperature and high pressure and other geological conditions, Xinjiang Oilfield Company carried out research on supporting technologies, and successively achieved the goal of "drilling" of 7,000 meters and "drilling" of 8,000 meters in ultra-deep Wells, and initially formed supporting technologies for safe drilling and completion of ultra-deep Wells, ensuring continuous breakthroughs in exploration, and gradually realizing the transformation from "drilling" to "well and fast" in ultra-deep Wells. However, with the further increase of drilling depth, the structure and pressure system of drilling strata become more complex, and the well structure needs to be further considered to optimize the safety, efficiency and economy of drilling.

In the 1990s, there were very few oil and gas Wells in the Gulf of Mexico with drilling depth (water depth) exceeding 8000m as shown in Fig.5. At the same time, because the pre-salt formation had not been uncovered, the downhole accidents were less complicated, and the five-cut to seven-cut well structure was mainly adopted [10-14]. After entering the 21st century, with the continuous increase of well depth, the number of Wells drilled gradually increased as shown in Fig.6. In order to reduce drilling cost, ensure oil and gas production and development benefits, based on the well structure design concept of "reducing casing gap to reduce upper and surface casing size under the premise of ensuring completion string size", the method of using downhole tools to expand open hole section size is proposed to ensure sufficient annular gap to facilitate rock carrying and cementing[10-12].

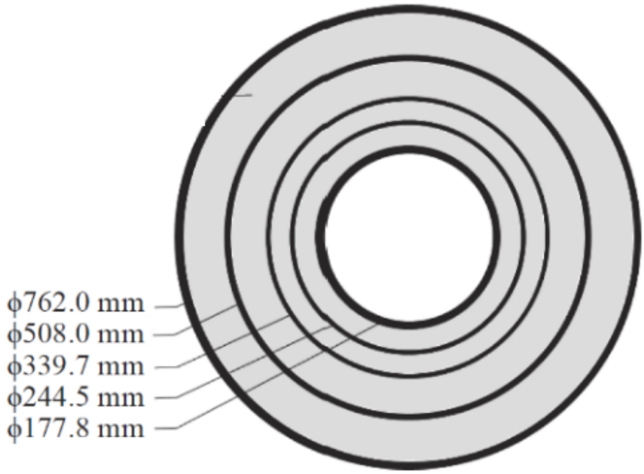

Fig. 5. Casing layers of compensated Wells in the Gulf of Mexico in the 1990s

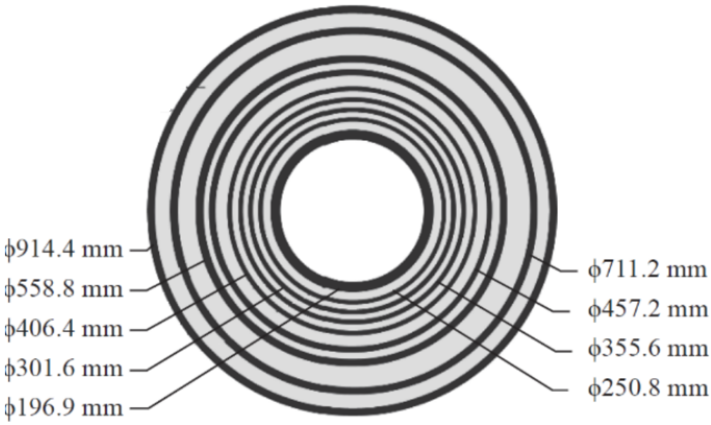

Fig. 6. Casing layers of ultra-deep Wells in the 21st century

Based on the above ideas, three optimization measures are proposed for the existing six-open well structure in the south margin as shown in Fig.6:

1) Change ϕ365.1mm casing into liner hanger to reduce casing weight;

2) Reamer ϕ333.4mm to ϕ368.3mm and run in ϕ295.3mm casing;

3) Drilled the quinqual hole from ϕ241.3mm to ϕ260.4mm directly without reaming in ϕ241.3mm.

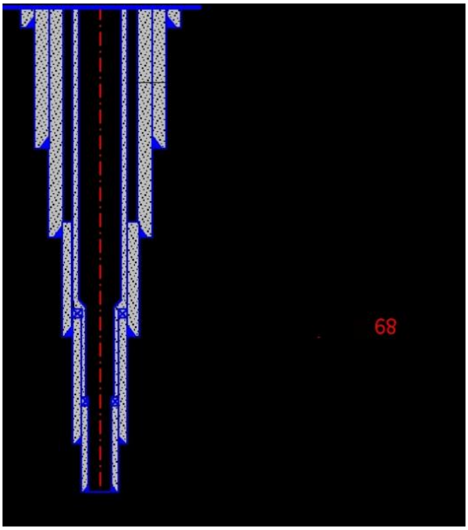

Fig. 7. Optimizes large pentaw/hexaw for seven-open

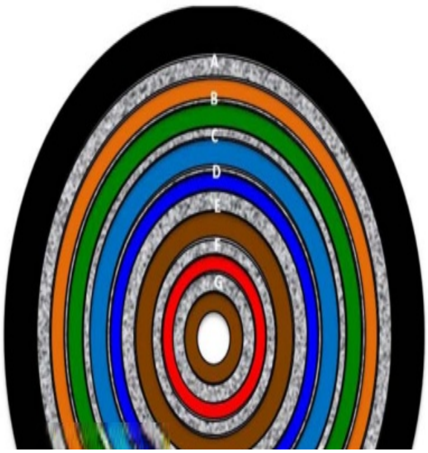

Fig. 8. Schematic diagram of optimizing annular clearance of well structure

The result of further optimization of well structure is shown in Fig.7, which has the following three advantages shown in Fig.8:

1) Reduce the drilling cost. The solution saves about 2600 m of large casing with over 300 tons in total weight (365.1mm, 13.88mm wall thickness, 122.33kg/m HS140V line weight) and reduces cement slurry usage, making cementing difficult for long borehole sections.

2) Reduced reaming difficulty. Adjusting the reaming interval from ϕ241.3mm in the lower difficult-to-drill formation to ϕ333.4mm in the upper well-drillable one is expected to save over 20 days of drilling time .

Table 2. Calculation of annular clearance for optimized well structure cementing

	The well structure is optimized		**Original well structure**	
Cementing annulus	Borehole x casing	Annulus clearance	Borehole x casing	Annulus clearance
A	Φ762mm xΦ609.6mm	The 76.2 mm	762 MMX Φ Φ 609.6 mm	The 76.2 mm
B	MMX Φ Φ 571.5 473.1 mm	The 49.2 mm	MMX Φ Φ 571.5 473.1 mm	The 49.2 mm
C	MMX Φ Φ 431.8 365.1 mm	The 33.3 mm	MMX Φ Φ 431.8 365.1 mm	The 33.3 mm
D	**Φ333.4mm(Φ368.3 mm) xΦ295.3mm**	**The 36.5 mm**	**MMX Φ Φ 333.4 273.1 mm**	**The 30.1 mm**
E	Φ260.4mm xΦ219.1mm	The 20.4 mm	Φ241.3mm(Φ260. 4mm) xΦ219.1mm	The 20.4 mm
F	Φ190.5mm xΦ139.7mm	The 25.4 mm	Φ190.5mm xΦ139.7mm	The 25.4 mm

Table 3. Optimal well structure drilling annular clearance calculation

	Optimize well structure		**Original well structure**	
Drilling annulus	Casing + bit size	Annular clearance	Casing + drill size	Annular clearance
Orange B	Φ 609.6 mm + Φ 508 mm	The 35.56 mm	Φ 609.6 mm + Φ 508 mm	The 35.56 mm
Green C	Φ 473.1 mm + 431.8 mm Φ	The 5.07 mm	Φ 473.1 mm + 431.8 mm Φ	The 5.07 mm
Blue D	Φ 365.1 mm + 333.4 mm Φ	The 1.97 mm	Φ 365.1 mm + 333.4 mm Φ	The 1.97 mm
Blue E	**Φ 295.3 mm + 260.4 mm Φ**	**The 3.62 mm**	**Φ 276.2 mm + 241.3 mm Φ**	**The 2.06 mm**
Brown F	Φ 219.1 mm + 190.5 mm Φ	The 1.58 mm	Φ 219.1 mm + 190.5 mm Φ	The 1.58 mm

3) Improve the cementing quality. As shown in Table 2, through the calculation results of drilling annular clearance and cementing annular clearance, the optimized well structure cementing annular clearance increases from 30.1mm to 36.5mm, which is

conducive to improving the displacement efficiency of annular cement slurry. As shown in Table 3, the annulus clearance after optimized well structure drilling increased from 2.06mm to 3.62mm, which improved the drilling safety.

Hanger design and Feasibility analysis: For the well structure shown in FIG. 7, the upper casing was reduced from Φ473.1mm to Φ431.8mm[13-14] by suspending 14⅜ casing. Table 4 calculates the existing liner hanger specifications of Φ339.7mm liner hung on Φ406.4mm casing. By enlarging liner and casing by 1 inch each, the fitting data of Φ365.1mm liner hung on Φ431.8mm casing is obtained. Calculation results in Table 4 show that, Φ431.8mm casing Φ365.1mm liner and Φ406.4mm casing Φ339.7mm liner series have the same clearance of 20.78mm and 20.77mm respectively. Therefore, it is theoretically feasible to design a liner hanger with specifications Φ365.1mm Φ431.8mm. According to the designed specification data of Φ431.8mm non-standard casing, casing verification is carried out by StressCheck software, which proves that the casing data meet the design requirements of borehole structure.

Table 4. Design of hanger (calculation of clearance between liner and upper casing)

	Φ 339.7 mm	**Φ 365.1 mm**	**Φ 406.4 mm**	**Φ 431.8 mm**	**Φ 339.7 mm + 406.4 mm Φ**	**Φ 365.1 mm + 431.8 mm Φ**
Outer diameter	The 339.72 mm	The 365.1 mm	The 406.4 mm	The 431.8 mm		
Inside diameter			The 381.26 mm	The 406.66 mm		
Gap					**The 20.77 mm**	**The 20.78 mm**

Analysis of borehole cleaning problem: insufficient annular return rate is a common problem in large-size borehole sections at home and abroad.

The analysis results show that when the upper Φ333.4mm borehole was drilled under the original well structure, the designed annular return velocity was 0.63m/s at a displacement of 45L/s. If the well structure is adjusted to liner suspension, the annular return velocity at 45L/s displacement is between 0.43m/s and 0.52m/s under different casing size and drill pipe size combination, which is slightly lower than that under the original well structure, which will bring hidden trouble to hole cleaning. This problem needs to be solved by upgrading the pump conditions and strengthening the displacement parameters.

4 Suggestions on Optimization of Supporting Technology for Reaming While Drilling

In order to expand the well structure, the reaming technology while drilling is adopted in the south margin ultra-deep well. In field application, there are often problems such as mismatch between reamer and bit drilling efficiency and large torque of reamer assembly. The main reason is that the power and energy applied on the reamer is not enough. To solve the above problems, we can try to install low-speed and high-torque screw power drilling tool (as shown in Table 5) in the upper part of the reamer to supplement the power and energy required by the reamer and improve the reamer efficiency. The above measures have several characteristics:

1) Can increase the reamer and drill speed, improve reaming efficiency.

2) Using the rubber characteristics of the screw to absorb the transverse vibration (vortex) of the reamer, it is more conducive to the stability of the BHA.

3) The quality and performance of the screw drill put forward higher requirements, requiring low speed, large torque screw, while improving the impact resistance of the rubber coating.

Table 5. Optimization of south edge reaming assembly

Current reaming assembly	**To optimize the drill assembly**
241.3 mPDC Φ	241.3 mPDC Φ
Φ238mm centralizer	Φ238mm centralizer
178mm float valve	178mm float valve
Non-magnetic drill collar	Non-magnetic drill collar
Suspension joints	Hanging joints
Converters	Converters
Φ238mm centralizer	Φ238mm centralizer
Φ1 178mm drill collar	Φ One 178mm drill collar
reamer	**Reamer**
	Φ197 Low speed high torque screw drill tool
Φ178mm drill collar 20 pieces	Φ178mm drill collar 20 pieces
Φ178mm jar	Φ178mm jar
Φ178mm drill collar 3 pieces	Φ Three 178mm drill collars
Adapter	Converters
Φ127mm weighted drill pipe 6 pieces	Φ127mm weighted drill pipe 6
Φ127mm sloping drill pipe	Φ127mm slope drill pipe
Converter joint	Converters
Φ184mm float valve	Φ184mm float valve
Φ149.2mm ramp drill pipe	Φ149.2mm slope drill pipe

5 Conclusions and Suggestions

With the development of exploration and development to the deep level, the problems of complex deep formation pressure system, high compaction degree, poor drillability and difficulty in accelerating speed of ultra-deep Wells in the southern margin of Junggar will become more and more prominent. Well structure optimization is the key and core to solve these problems, which can shorten the construction period of ultra-deep Wells in the southern margin, reduce the cost of construction, and increasingly reflect technological innovation and economic benefits.

1) The formation pore pressure, rupture pressure and collapse pressure profiles under strong structural stress in the south margin were established by using drilling and logging data, and the calculated results were revised in combination with drilling data and rock mechanics laboratory evaluation to obtain a relatively accurate formation three-pressure profile in the middle part of the south margin. Based on this, five geological engineering sealing points and one risk point were identified in the middle part of the south margin. The characteristics of the formation pressure system of "three low, two low and one narrow" in the south margin were determined.

2) According to the required sealing points of geological engineering and considering the needs of drilling, completion and cement projects, the unconventional five-open well structure and the unconventional six-open seven-open well structure were optimized, which solved the risk of unclear distribution of high-pressure water layer from Shengjinkou Formation to Hutubihe Formation and the uncertain fall back of the lower Jurassic pressure system, and supported the ultra-deep well drilling in the south margin of 8000 meters.

3) On the basis of the unconventional five-open and the unconventional six-open seven-open, in order to further save the drilling cost and shorten the drilling cycle, the well structure optimization has been continuously optimized and explored. It is proposed to change the Φ365.1mm casing into liner suspension and move the reaming section from Φ241.3mmh to Φ333.4mm, and the feasibility of engineering and tool implementation is analyzed.

4) While drilling reaming technology has become an effective means to expand well structure. In view of the large torque fluctuation and slow reaming speed in the field, the combination method of adding dynamic drilling tools is put forward.

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