Drilling Fluid Technology for Strong water-sensitive and high-stress formations in Southern Margin of Junggar Basin

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Abstract. The southern margin of the Junggar Basin is a typical piedmont structure, which is characterized by complex structural types, large local differences, and fault fractures. The drilling engineering construction in this area is difficult, and downhole accidents are frequent, among which the Anjihaihe Formation and Ziniquanzi Formation are the most complex. In the early exploration, the potassium and calcium-based PRT drilling fluid system and organic salt drilling fluid system are used , and the oil-based drilling fluid is used in the later exploration and development. The collapse and stuck drilling accidents of the Anji Haihe Formation and Ziniquanzi Formation are significantly reduced, extremely prone to collapse. In this paper, the mechanical and chemical analysis of borehole instability is carried out in the case of Well Fengtan 1. According to the strong water-sensitive and high-stress formation in the southern margin of Junggar, the technical countermeasures of drilling fluid are formulated: it is recommended to use high-density oil-based drilling fluid, and the rheological performance of drilling fluid can be optimized by strengthening the plugging performance of drilling fluid, and reducing the water loss of drilling fluid at high temperature and high pressure, which can improve the stability of the wellbore. During the lateral drilling process of Well,Fengtan 1 good results were achieved by implementing this drilling fluid technology, and the well was successfully drilled to the mid completion depth.

Keywords: Southern margin of Junggar; strong water-sensitive and high-stress formation; Oil-based drilling fluid; countermeasures; mechanical and chemical analysis.

1 Introduction

The southern margin of Xinjiang Junggar Basin is located in the south of Junggar Basin and at the northern foot of Tianshan Mountain. It is 400km long from east to west and 40-70km wide from north to south. It is rich in oil and gas resources and has great exploration potential, making it an important strategic substitute area[1-2] for oil and gas

G. Zhao et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Architecture and Urban Engineering (ICCAUE 2024)*, Advances in Engineering Research 262,
https://doi.org/10.2991/978-94-6463-688-8_39

exploration in Junggar Basin. The southern margin of the Junggar Basin is a typical piedmont structure with complex structural types, large local differences, and developed faults and fractures. The drilling engineering in this area is very difficult, and the underground accidents are frequent. Among them, the Tertiary Anji Haihe Formation and Ziniquanzi Formation contain a large amount of paste mudstone and mudstone, and there are complex fracture zones, which are the main intervals[3] in which complex accidents such as obstruction, stuck drilling and leakage occur in the drilling process in this area.

2 Drilling Fluid Construction Situation of Block

In the early exploration, potassium-calcium based PRT drilling fluid system and organic salt drilling fluid system were used, which resulted in frequent drilling stuck accidents, frequent blockage of Huo 001 well and drilling tool stuck 5 times; Frequent blockage occurred in well Huo 002; 85 times of blockage occurred in well Huo 003, and 10 times of drilling tool stuck[4]. The whole well project was abandoned due to the serious collapse of well 1, Huo 10 and West 4. The performance of water-based drilling fluids could not meet the construction requirements of the strong water-sensitive and high-stress strata in the southern margin of Junggar Basin, Xinjiang. Oil-based drilling fluids were used in all the exploration and development in the later period, and the collapse and sticking accidents of Anjihaihe and Ziliquanzi formations were significantly reduced, and the drilling cycle was greatly reduced. For example, the third section of Well Huo 101 used high-density oil-based drilling fluids when drilling the Anjihaihe formation. Borehole stability was effectively ensured in the drilling process, and no other downhole faults occurred except for several times of blocking and sticking, realizing three-run drilling and one trip, which greatly shortened the drilling cycle[5].

The anti-collapsing effect of oil-based drilling fluid is significantly better than that of water-based drilling fluid. However, due to the superposition of undercompaction, fluid expansion and structural compression, the pressure systems of different transverse anticlinal Wells and different anticlinal Wells are different. The collapse pressure of high-stress strata in the southern margin of Junggar Basin in Xinjiang is difficult to predict, and the collapse sticking accidents of Haihe Formation and Ziniquanzi Formation still occur from time to time. It seriously restricts the speed and efficiency of drilling engineering and the benefit development of oil field companies.

3 Tracking and Analysis of Typical Accident Wells

Fengtanyi 1 well is a pre-exploration well deployed at the northern broken nose of Manas in the thrust belt of Huomatuback inclined belt in the southern margin of Junggar Basin. The well uses 431.8mm drill bit to drill to the Anjihaihe formation on the bottom plate of the main fault with a depth of 3978m. After drilling, the hole is redrawn to the bit position of 3833m. The rotary top drive drilling tool could not be turned away, and drilling stuck occurred. After the pump is stopped, the drilling tool is moved up and down, the pumping pressure is not decreased, the collapse of the drilling is stuck, the normal circulation is not possible, the drilling tool is unable to release the stuck for many times, and the explosive release is forced, the late fishing fails, and the well is forced to fill and sidetrack, causing major project losses. The chemical coupling analysis of wellbore instability force was carried out to find out the cause of formation instability and drilling stuck after the drilling stuck accident.

3.1 Formation Stress Analysis

3.1.1Second Opening Construction Situation.

The second opening of FT1 well was drilled to 3438m with a 517.5mm bit. The formation was Anji Haihe Formation and the drilling fluid was oil-based drilling fluid with a medium completion drilling fluid density of 2.0g/cm^3. The results of the second opening electric measurement of double well diameter were shown in Figure 1:

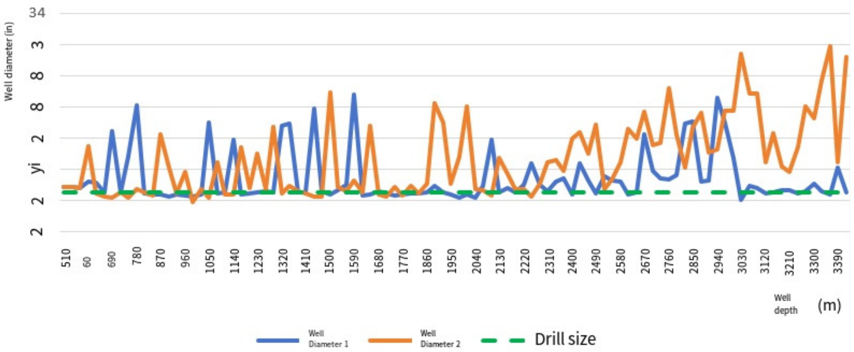

Fig. 1. Double Well Diameter Diagram of Fengtan 1 Well Second Open Electrical Measurement

Double diameter analysis of the second section shows that the regional stress has significant influence (caving ellipse principle), and the ground stress of the 3030-3438m section is the strongest.

3.1.2Construction of the Third Opening Section.

The depth of three openings is 3438m, the starting density is 1.70g/cm^3, the drilling depth is 3510m, the drilling depth is 3622m, and the drilling depth is 1.68g/cm^3. The drilling time is obviously faster, the drilling depth is 3645m and the single heel block is serious, the hole is not broken, the drilling simplifies the drilling tool, the density is increased to 1.85g/cm^3, and the drilling depth is 3656m and the single block block is connected. Block content 5%, in the shape of a long rib, shear failure state, judged as insufficient density, density increased to 2.00g/cm^3, drilling to the depth of 3670m, block content 3%, in the form of pieces, block content 3%, the single root was successfully lifted up, and the transmission encountered resistance, drilling to the depth of 3711m, single root appeared resistance, block content 1%, density increased to 2.03g/cm^3. After drilling to 3765m, the short lifting was smooth, drilling to 3896m, the card was raised, the drill tool was moved up and down 43 times, and the drilling was normal after redrawing the hole to the well depth of 3721m. It can be seen from the construction of the second and third openings that Anji Haihe Formation and Ziniquanzi formation belong to the strong water-sensitive and high-stress strata, which are easy to collapse and have high risk of drilling stuck as shown by Figure 2.

Fig. 2. Block Loss in Anjihaihe Formation

3.2 Drilling Fluid Performance Test

Oil-based drilling fluid system was used in the third opening of frontanyi Well 1. The drilling fluid properties measured on site after drilling stuck are shown in Table 1:

Table 1. Performance of On site Drilling Fluid

Density (g/cm3)	Funnel viscosity (s)	PV (mPa.s)	YP (Pa)	Initial cut/Final cut (Pa)	Oil-water ratio	Breaking voltage (V)	HTHP (ml)	Chloride ion (mg/l)	Alkalinity
2.09	84	69	7	3/9	88:12	940	1.8	27000	2.4

3.3 Rolling Recovery Experiment

Mudstone of Anji Haihe Formation has strong water sensitivity and becomes loose immediately after soaking in clean water. The rolling recovery rate of cuttings in pure oil medium and in-situ drilling fluid was determined by using the lumps of Anji Haihe Formation and Ziziquanzi Formation of Fengtan Well 1 according to the "Test Method for Physical and Chemical Properties of Mud Shale Tested by Drilling Fluid SY_T5613-2016", and the hot rolling condition was 120℃×16 hours. The experimental results are shown in Table 2:

Table 2. Rolling Recovery Rate Test Results

Drop block source	Media	Mass before hot rolling (g)	Mass after hot roll (g)	Recovery rate
Anjihaihe Formation	Diesel	50	48.29	96.6%
Purple mud Spring subgroup	Diesel	50	47.82	95.6%
Anji Haihe Formation	Well PULP	50	48.89	97.8%
Purple Mud Spring subgroup	Well Pulp	50	48.34	96.7%

It can be seen from the above experimental results that the inhibition of oil-based drilling fluids is very strong. The rolling recovery rate of cuttings in oil-based drilling fluids from Haihe Formation and Ziniquanzi Formation is slightly higher than that of pure oil medium, and the inhibition of water-in-oil drilling fluids is comparable to that of all-oil-based drilling fluids.

3.4 Immersion Experiment

The lost block (belonging to Anji Haihe Formation) returned during the process of drilling stuck in the field was collected, and the layer of mud attached to the surface was cut off with a blade to expose the inner layer. The soaking liquid was diesel oil, 26%CaCl222 aqueous solution, 50%CaCl aqueous solution and water-in-oil emulsion (diesel oil +4% main emulsifier +2% auxiliary emulsifier +2% wetting agent +26%CaCl aqueous solution, oil-water ratio 8:2, demulsification voltage 593V) for 24h. The experimental results are shown in Figure 3:

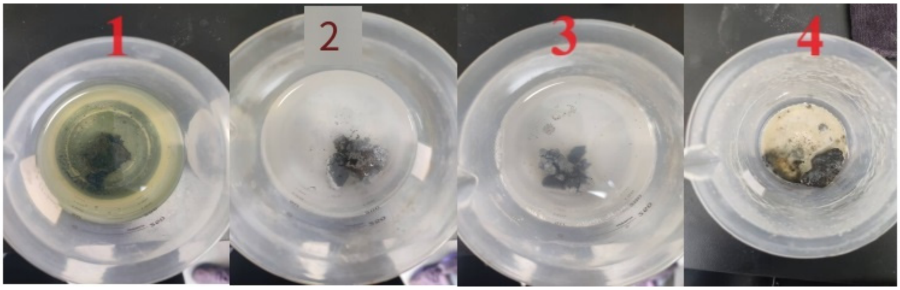

Fig. 3. Results of soaking for 24 hours
Note: Soaking liquids for grades 1-4 are diesel oil, 26%$CaCl_{22}$ aqueous solution, 50%CaCl aqueous solution and water-in-oil emulsion, respectively

The above experimental results show that the Anji Haihe formation is highly water-sensitive and will still hydrate and disperse in high concentration brine, but remain stable in pure oil medium and water-in-oil emulsion. The outer phase of oil-based drilling fluid is oil and the inner phase is high concentration brine, which can solve the strong water sensitive problem of Anji Haihe formation and Ziniquanzi formation well.

3.5 Mineral Component Analysis and Electron Microscope Scanning

After the site stuck drilling was collected, the lost block was returned, and the mineral component analysis and electron microscope scanning were carried out. The results were shown in Table 3 and Figure 4:

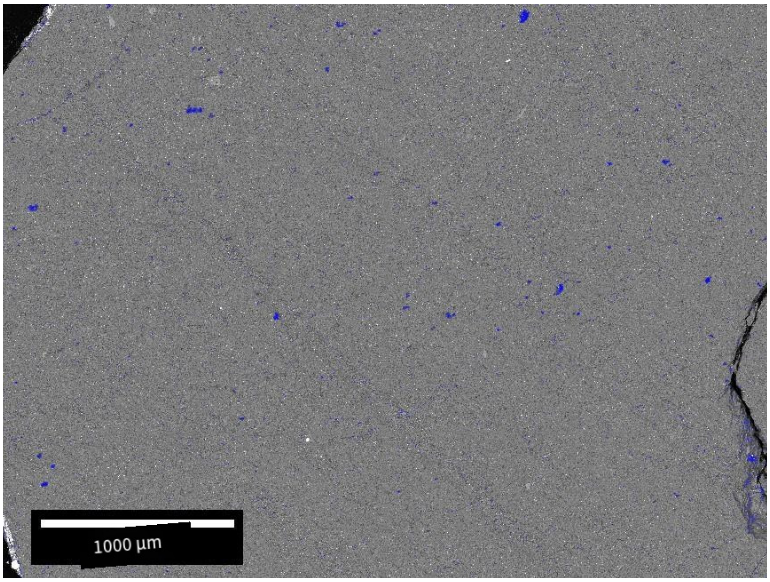

Fig. 4. Electron microscopy scanning image of the Anjihaihe Formation block

Table 3. Mineral components of lost block in Anji Haihe Formation

Quartz (%)	Potassium feldspar (%)	Plagioclase (%)	Illite/Muscovite (%)	Mixed clay (%)	Kaolinite (%)	Calcite (%)	Ferrodolomite (%)
3.12	0.17	1.55	1.81	90.75	0.15	0.80	0.65

From the above results, it can be seen that the Anjihaihe formation is dominated by clay minerals, and the micro-fractures are not developed.

4 Drilling Fluid Technology Strategy

1. The strong water sensitive and high stress strata in the southern margin of Junggar, represented by the Haihe Formation of Anji and Ziniquanzi Formation, are prone to collapse. When using water-based drilling fluids, they are mainly characterized by strong water sensitivity and chemical collapse. When using oil-based drilling fluid, it is mainly characterized by high stress and stress collapse. Therefore, it is recommended to use high density oil-based drilling fluid to maintain mud shale stability through the strong inhibition of oil-based drilling fluid, and balance high stress through high density.
2. Strengthen the plugging performance of drilling fluid, and improve the formation strength by plugging micro-cracks of formation through micro-nano materials, and play a role in stabilizing well wall.
3. The rheological property of drilling fluid was optimized, the reading value of drilling fluid Φ6 was appropriately improved, the carrying property of drilling fluid was strengthened, and the borehole was cleaned by using heavy thick slurry from time to time to minimize the residual annular mass and reduce the risk of blockage sticking.
4. Reduce the high temperature and high pressure water loss of drilling fluid, control the HTHP water loss <2ml, and reduce the influence of filtrate on the stability of borehole wall through dense low permeability mud cake.
5. Based on the wellbore digital technology, the formation water sensitivity index, brittleness index, drillability index and loss risk coefficient are retrieved, and the dynamic coupling borehole stability evaluation is carried out in time. The collapse pressure of the formation to be drilled is predicted by the drilled formation parameters, providing a basis for determining the appropriate drilling fluid density. Taking Fengtanyi 1 well as an example, the rock mechanics parameters were calculated using the empirical formula method, and the formation collapse pressure[3] in the 3200-3622m section was predicted by the PMI software with reference to the epitaxial trend of the unwell formation in the third open well shown in Figure 5 and the well in the second open well. And 2.40-2.50g/cm^3 in well section 3622-4630m.

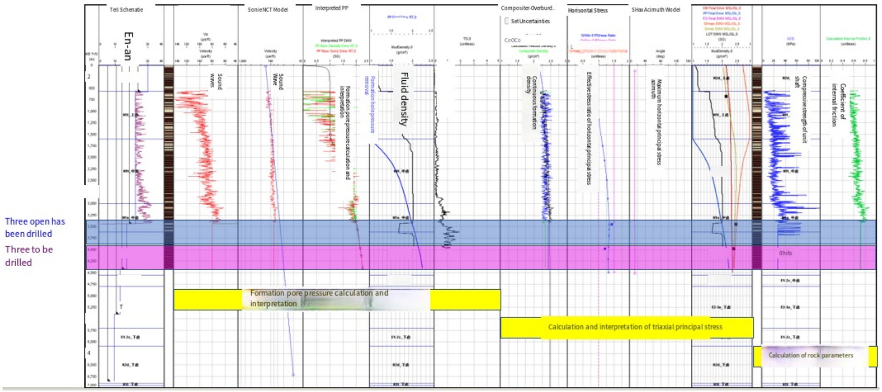

Fig. 5. Rock mechanics calculation of the third opening of Fengtan 1 well

5 Field Application Effect

Fig. 6. Large scale falling blocks in Anjihaihe Formation

Lateral drilling began on July 6, 2024, with the initial drilling fluid density of 2.20g /cm3, sidedrilling to 3580m, the drilling fluid density of up to 2.30g /cm3, and gradually increased to 2.45g /cm3 during drilling, and successfully drilled to the middle completion depth of 4755m on August 27, 2024. After optimizing the performance of oil-based drilling fluid and increasing the density of drilling fluid, the downhole conditions were significantly improved, and no stuck accident occurred. A large number of loose blocks with the maximum size of 29cm were returned during drilling to the bottom of the well washing process. The high-density drilling fluid was conducive to carrying large sized loose blocks through the buoyancy effect shown in Figure 6, which was conducive to ensuring downhole safety.

6 Conclusion

- The strong water-sensitive and high-stress strata in the southern margin of Junggar are prone to collapse, which is mainly manifested by chemical collapse when using water-based drilling fluid. When using oil-based drilling fluid, it mainly shows high stress, mainly stress collapse.
- It is recommended to use high-density oil-based drilling fluid. Strengthening the plugging performance of drilling fluid, optimizing the rheological property of drilling fluid, reducing the water loss of drilling fluid at high temperature and high pressure can improve the stability of borehole wall.
- Due to the complex pressure system, it is difficult to predict the collapse pressure of the strong water-sensitive and high-stress formation in the southern margin of Junggar Basin, Xinjiang. Therefore, the coupling analysis of borehole force and chemistry should be strengthened to determine the appropriate drilling fluid density.
- Good results have been achieved in the lateral drilling of front probe 1 well according to this drilling fluid technology strategy, and the formation collapse pressure coefficient obtained through the analysis of well force chemical coupling is in good agreement with the reality.

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