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Application of Pressure Data Analysis in Tapping the Potential of Complex Fault Block Oilfield

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Abstract
The B oilfield in Bohai Bay Basin is the fluvial facies sedimentary, reservoir thickness varies rapidly in lateral direction, and what is worse the fracture system is very developed, petroleum reserves are small within a single block. Due to the poor quality of seismic data, the sealing of fault and reservoir connectivity is unclear which directly affect the understanding of reserves and adjusting injection-production well pattern. This paper introduces the working principle of StethoScope, and use formation pressure testing by StethoScope analyzing the fluid system and reserve scale, which can indirectly judge the sealing of fault and reservoir connectivity. This method provides a reliable basis for well pattern deployment.

Key words: Formation pressure testing; Fault and reservoir connectivity; Bohai Bay Basin; StethoScope

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INTRODUCTION

The B oilfield in Bohai Bay Basin is the fluvial facies sedimentary, reservoir thickness varies rapidly in lateral, and what is worse the fracture system is very developed, the distribution of fluid system is complex[1-2], and the shallow gas develops, thus the quality of seismic data is poor, the sealing of fault and reservoir connectivity are difficult to understand. As the continuous development of the B oilfield, the dynamic reserves of some fault districts are much larger than the proved reserves. Whether the faults are closed will directly affect the reserves scale of adjacent potential fault district. As the reservoir distribution and connectivity is unclear, part of the fault districts well pattern is imperfect, the reservoir pressure drop largely to need to be adjusted. In view of the problem, the oilfield introduces the formation pressure testing by StethoScope in the process of design and drilling of the well. By grasping the pressure distribution of the reservoir in time, it indirectly judges the fault sealing between the undeveloped fault district and the developed fault district and the reservoir layer connectivity, timely optimizing well pattern, improving oil field development effect[3]. This paper mainly focuses on the principle, operation process and application effect of formation pressure testing while Drilling.

1. INTRODUCTION TO PRESSURE TESTING WHILE DRILLING

The StethoScope tool is part of Schlumberger's range while drilling (Figure 1) to obtain accurate formation pressure and formation mobility during the drilling phase[4]. Today's drilling and completion of oil and gas wells is increasingly challenging and costly, and the use of formation pressure testing while Drilling by StethoScope services, especially in high-gradient wells and horizontal wells[5], can reduce formation-related pressure uncertainty associated with drilling, thus reduce risk and costs.

The StethoScope tool mainly tests the formation pressure and formation fluidity (near-well zone permeability and mud filtrate ratio) at a certain depth, andtimelytransmit the measurement result to the ground through the mud signal to provide data support for decision.

Figure 1
The Schematic Diagram of StethoScope

The StethoScope tool performs reservoir pressure testing by pressing the gasket containing the probe against the borehole wall (Figure 2). A small amount of formation fluid (up to 25 cc) is pumped through the probe sealed pre-test container (Often referred to as pressure drop), and pre-test begins. At the end of the pressure drop period, the pressure recovery period begins. The difference in pressure drop depends on the fluidity of the flowing fluid[6-7]. As the fluid flows from the unconfined pressure zone in the formation to the low pressure region near the probe[8], the pressure disturbance will continue in a similar pattern to the pressure drop period. The pressure measured by the final probe will always rise to the formation pressure. According to the data analysis, the formation pressure, the pressure drop and pressure recovery flow can be obtained (Figure 3).

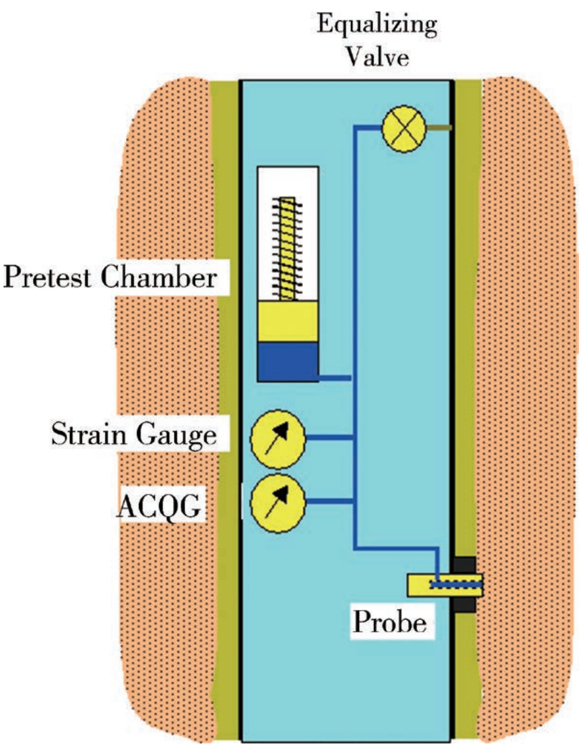
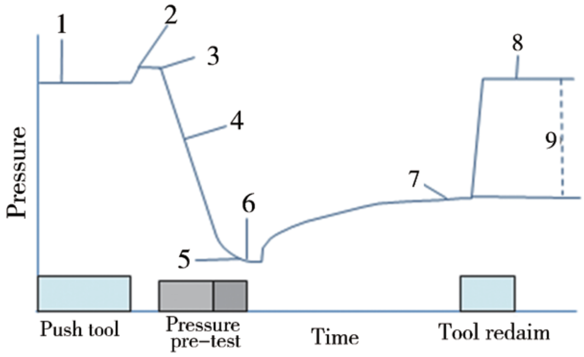


Figure 2
The Operating Principle of StethoScope Tool



(1- The mud column pressure before testing; 2- The pressure response of the probe to the borehole wall; 3- The pressure starts to fall; 4- Fluid expansion of the tool line; 5- The formation fluid begins to flow into the tool; 6- Pressure starts to recover; 7- Pressure recovers over; 8- The mud column pressure after testing; 9- Wellbore and formation pressure difference)

Figure 3
The Schematic Diagram of Pressure Pre-Test

According to the pre-test pressure and time, the corresponding data processing and analysis can becarried out to obtain drawdown mobility[9].

$$\frac{k}{\mu} = C \times \frac{q}{\Delta P_{SS}}.$$

$\frac{k}{\mu}$ - Formation drawdown mobility, mD/cP; C- Tool form factor; q- Pressure drop flow, cc; ΔP_{SS}- Pressure drop in steady state, MPa.

If the viscosity of the mud filtrate is known, the formation permeability can be calculated based on the formation pressure drop. As the pressure while drilling pressure is shorter, the pressure wave cannot be spread far away from the wellbore, so the permeability based on pressure while drilling data results can only represent the average value of the near borehole.

2. PRE-TEST OF TIME OPTIMIZATION MODE

In order to better solve the complex situation of downhole, the StethoScope tool is embedded in a certain automated system, under the circumstance of total test time of 5 minutes, and the volume of the test fluid and Velocity, etc. can be determined according to the permeability of the stratum to obtain a relatively stable formation pressure testing.

When the time optimization mode is used for the test[10], the tool calculates the formation fluidity based on the Investigation Pretest to select the appropriate test flow rate and pump volume for the subsequent measurement phase. Good effect can also be got in the actual application process. The time optimization mode also has four combinations, the stress test time is 5 minutes. The

Investigation Pretest determines that the pressure falls below the formation pressure and the pressure recovery time is short[11], but the range of formation mobility can be obtained. This ensures that there is sufficient time for the next pre-test to stabilize the formation pressure.

In the time optimization mode, there are two ways to determine whether the cake is broken, that is, whether connected with the formation and dropping to the formation pressure. Type 1 (Figure 4, left), if the pressure drop curve deviates from the volume expansion law of the fixed streamline, it is judged that the fluid is replenished from the formation into the streamline to judge the breakage of the cake. Type 2 (Figure 4, right), a series of small volumes of pressure pre-tests used to determine that the pressure recovery will return to the same formation pressure, only after the cake breaks up with the formation. When the two pressure pre-tests return to the same value, it means that the cake breaks. When the formation mobility is low, Type 2 has better applicability; and when the formation is not easy to sand, the pressure drop at one time is larger than that at the same pressure, so the instability of Type 2 is more suitable for sand-prone formation testing.

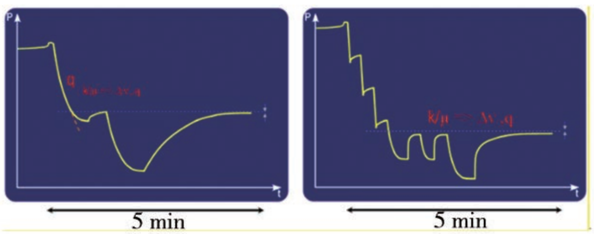


Figure 4
The Schematic Diagram of Time Optimization Test Mode

3. WORKING PROCESS OF FORMATION PRESSURE TESTING WHILE DRILLING

3.1 Positioning

The StethoScope tool Positioning depends on logging curve, such as GR, resistivity, neutron density and so on, then the probe will be aligned to the targetformation[12].

3.2 Contact

The tool detector is surrounded by a rubber sealing gasket, and the other side of the sealing gasket is a seat sealing piston. Under the impetus of the hydraulic system, the seat sealing piston and the sealing gasket are respectively close to the side of the wellbore, the detector at the center of the gasket is only in communication with the target formation fluid, which is not only isolated from the well bore mud, but also separated from other formations, which is ready for the test.

3.3 Testing

While the instrument is pushing against the sealing gasket, a pressure drop around the probe sucks through the wall mud cake and the formation fluid enters the instrument.At the same time, the pressure gauge records all the pressure changes in the pipeline throughout the process. Pressure change refers to the static pressure of the mud column at beginning, the pressure drop after pushing, the pressure recovery after closing, and finally the static formation pressure.

3.4 Out of Touch

After completion of the pre-test of a measuring point, the seat sealing piston and the sealing gasket automatically reclaim. The instrument will clean the pre-test chamber by the hydraulic system and restore to the original state before reclaiming. The instrument can then be relocated to the next test point.

4. THE APPLICATION OF FORMATION PRESSURE TESTING WHILE DRILLING

The main application of formation pressure testing while drilling in development wells are that determining the energy depletion profile of oil reservoirs to prevent the pollution caused by mud invasion; determining the local formation overpressure caused by water injection to prevent production well flooded quickly; determining the reservoir pressure weather reduced to the saturation pressure to prevent the oil viscosity rapidly rising caused by large amount of gas out; adjusting the well pattern after drilling; determining the closure of the fault to provide the basis for the decision of production and water injection; determining the fluid connectivity between two or more sand bodies; and real-time monitoring formation pressure and fluidity changes in the horizontal well. At present, the main application of offshore oil and gas fields in China is to determine the energy depletion profile of oil reservoirs to provide strong data support for stabilizing production and controlling water, and also reduce the risk of well blowout and the lost of circulation.

5. APPLICATION FOR FORMATION PRESSURE TESTING WHILE DRILLING OF B OILFIELD

5.1 Fault Sealing Analysis

D sand in A14 well block drilling 4 wells has been developed for 2 years, and the reservoir pressure has declined about 3.0 Mpa. According to the production data, the dynamic reserves calculated by the material balance formula is 11.9 million barrels, which is larger than the proved in the fault block (Figure 5). The fault throw of F1 becomes smaller from southeast to northwest, overlapping to the fault F2, and the D sand thickness is about 14.0 m, the fault throw of F1 in northwest end is less than 10.0 mD sand body on both sides is partially butted, and the possibility of reservoir connectivity is great. Therefore, A17 well is deployed in the south side of the fault to evaluate potential reserves, and designed formation pressure testing while drilling. If A17 well drilled oil or oil-water interface, while the formation pressure drop, indicating that the fault is not sealed, and A17 well will produce early, water inject late. If original formation pressure is shown, indicating that the fault is sealed, and A17 well was production well, A17 well block would be drilled more wells according to the production conditions of A17 well.

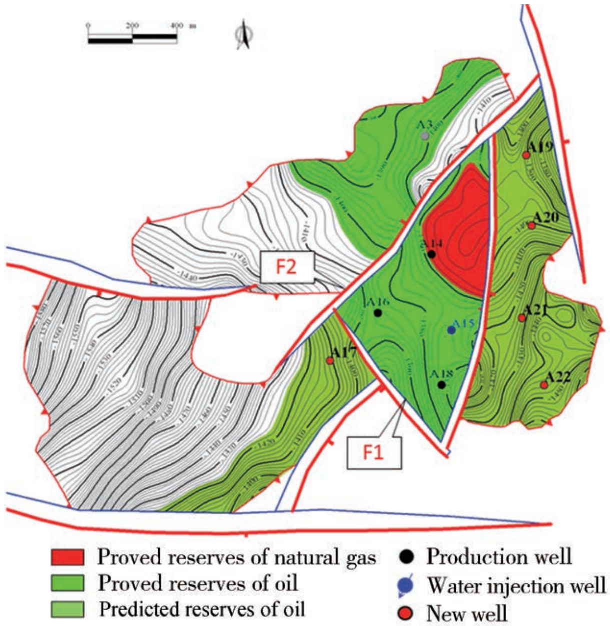


Figure 5
Well Pattern Design of D Sand Body Before Drilling

After the implementation of A17 well, oil layer is 6.0 m, and oil-water layer is 4.5 m, and 1.3 million barrels is evaluated and upgraded to proven reserves. In order to better understand the vertical distribution of formation pressure and avoid the influence of pressure testing errors, the upper and lower layers of the D sand body has measured the pressure data (result shown in Table 1, Figure 6).

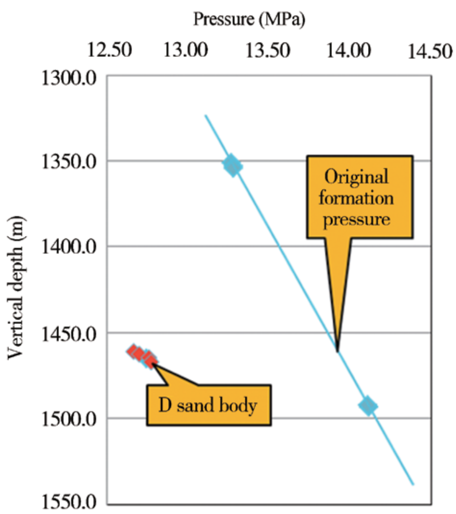


Figure 6
Pressure Distribution of A17 Well

Table 1
Pressure Data of A17 Well

Number	MD / m	TVD / m	Pressure / MPa
1	1,968.1	1,351.1	13.268
2	1,971.0	1,352.8	13.277
3	1,973.4	1,354.2	13.279
4	2,168.0	1,461.0	12.662
5	2,171.0	1,462.5	12.696
6	2,175.0	1,464.5	12.756
7	2,177.0	1,465.5	12.743
8	2,180.0	1,467.0	12.770
9	2,232.0	1,492.0	14.110
10	2,233.5	1,493.3	14.116

According to the results, the pressure of D sand body of TVD: 1,461.0-1,467.0 m is about 12.7 MPa, the pressure of the upper water layer of TVD: 1,351.1-1,354.2 m is about 13.3 MPa, which is the original formation pressure. thepressure of the lower water layer of TVD: 1,492.6-1,493.3 m is about 14.1 MPa, which is the original formation pressure. According to the regression formula of the water layers pressure, the original formation pressure of D sand body should be 13.9 MPa, Comparing the measured results, pressure dropped by about 1.2 MPa, which indicates that the fault is not sealed. D sand bodies on both sides of fault are connected. Therefore, according to pre-drilling design, the well A17 produce early, water inject late (Figure 7).

D sand body reserves upgrade to 6.9 million barrels after drilling A17 well. If the western fault of A14 well is not sealed and the reservoirs are connected with A3 well, the proven reserves are 1.3 million cubic, which is still less than the dynamic reserves. This shows that the eastern fault of A14 well may not be sealed, and the potential is large in Eastern block of A14 well. Therefore, 4 wells A19, A20, A21, A22 (Figure 6) are deployed in Eastern block of A14 well to evaluate potential reserves, and A20 well which will be drilled first is designed formation pressure testing while drilling.

If A20 well is drilled into the oil reservoir, while the formation pressure drop, indicating that the fault is not sealed, on both sides of the sand body for the same fluid system, the proven reserves were 4.4 million barrels in Eastern block, only support two wells to develop, A21 and A22 wells will be canceled. If there is no pressure drop in the formation, indicating the fault is sealed, then continue to drill A21 and A22 wells to evaluate the potential reserves.

After the implementation of A20 well, oil layer thickness is 12.0 m, and the pressure data is shown in Table 2, Figure 8.

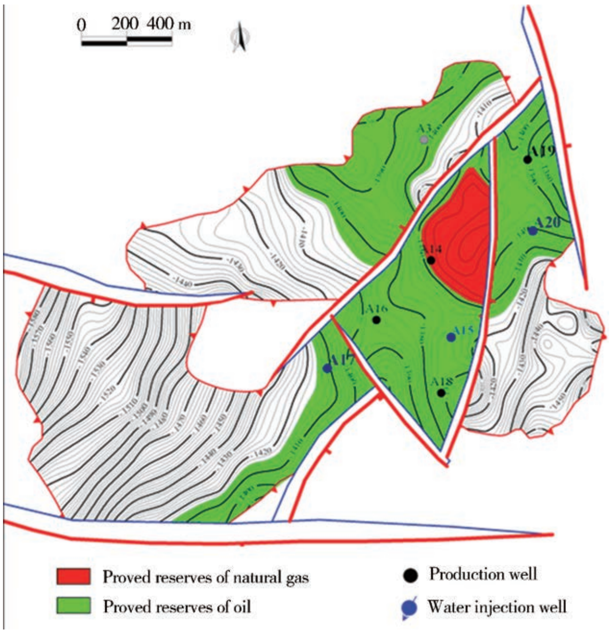


Figure 7
Well Pattern of D Sand Body After Drilling

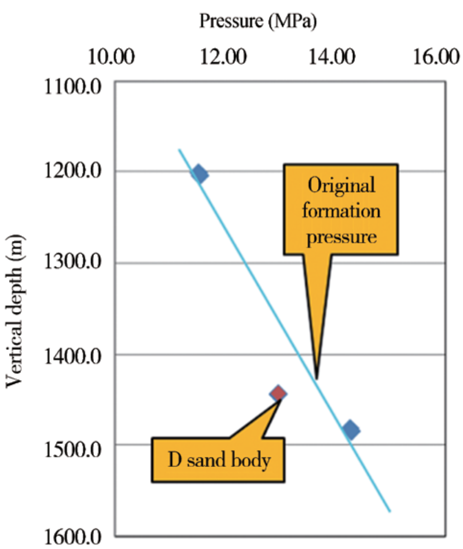


Figure 8
Pressure Distribution of A20 Well

According to the results of the pressure testing, the pressure of D sand of TVD: 1,443.0-1,444.4 m is about 13.0 MPa, the pressure of the upper water layer of TVD: 1,201.5-1,204.7 m is about 11.5 MPa, which is the original formation pressure. The pressure of the lower water layer of TVD: 1,482.0-1,484.0 m is about 14.3 MPa, which is the original formation pressure. According to the regression formula of the water layer pressure, the original formation pressure of D sand should be 13.9 MPa. Comparing the measured results, pressure dropped by about 0.9 MPa, which indicates that the fault is not sealed, the sand bodies on both sides of fault are connected, and the oil water interface is consistent. The proved reserves are 4.4 million barrels, according to pre-drilling design, cancellation of the two wells in the low position, A20 well will produce early and water inject late (Figure 7).

Table 2
Pressure Data of A20 Well

Number	MD / m	TVD / m	Pressure / MPa
1	1,250.0	1,201.5	11.5
2	1,253.5	1,204.7	11.6
3	1,507.5	1,443.0	13.0
4	1,508.5	1,443.9	13.0
5	1,509.5	1,444.4	13.0
6	1,549.0	1,482.0	14.3
7	1,551.1	1,484.0	14.3

5.2 Connectivity Analysis of Reservoir

Shallow gas reservoir exist in A4 well area of B oilfield which affecting seismic data quality. The reservoir prediction reliability is poor, the distribution and internalconnectivity of the reservoir are not understood, which brings great difficulties to the deployment of well pattern.

There are 5 wells in A4 well area. But only A12 and A4 well produce in B sand body. B sand body has been developed for nearly 5 years, reservoir pressure dropped by 5.0 MPa, and is in urgent need of water injection (Figure 9a). Based on the dynamic data of A12 and A4 well, the B sand body is estimated to be 5.7 million barrels meters using material balance method and numerical simulation method. The present proved reserves are only 2.9 million barrels. The B sand body is fluvial facies sediments, the source is from the north, and the channel distribution from north to south. So the reservoir exists in the south. Therefore, the south of the A4 well deployment of a production well A10, which could evaluate probable reserves and improve the well pattern. In order to determine the reservoir connectivity timely, A10 well designs formation testing while drilling. If the pressure is lower than the original pressure, the reservoir between A4 well and A10 Well is connect, A4 well will be adjusted into water injection well. If the pressure is the original pressure, the reservoir between A4 well and A10 well is not connect, the lower productivity A12 well will be adjusted into water injection.

The thickness of B sand body in A10 well is 8.0 m. The pressure results are shown in Table 3 and Figure 10.

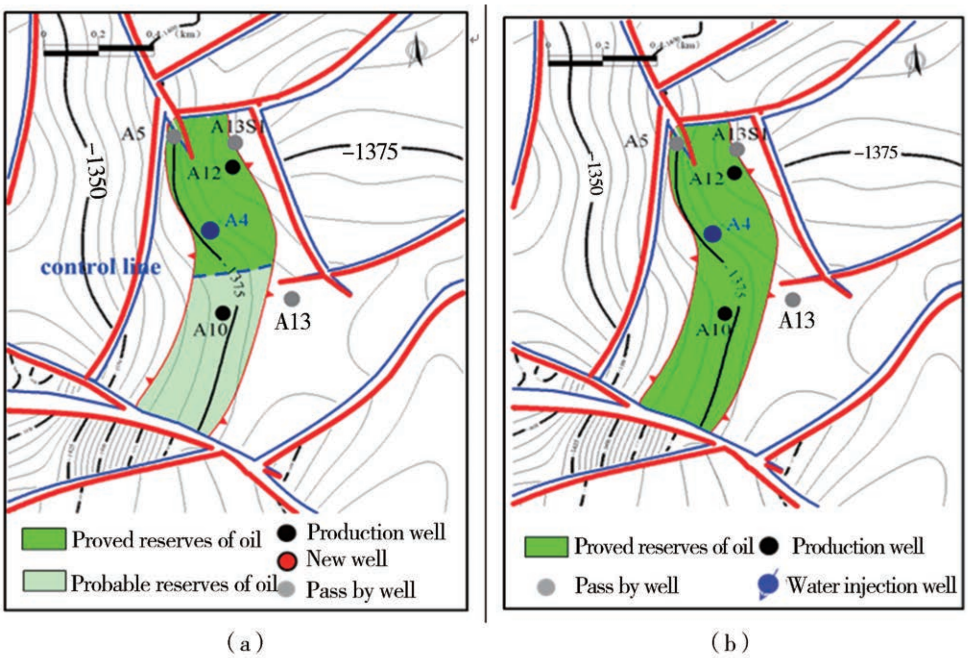


Figure 9
Well Pattern of B Sand Body (a: Before Drilling; b: After Drilling)

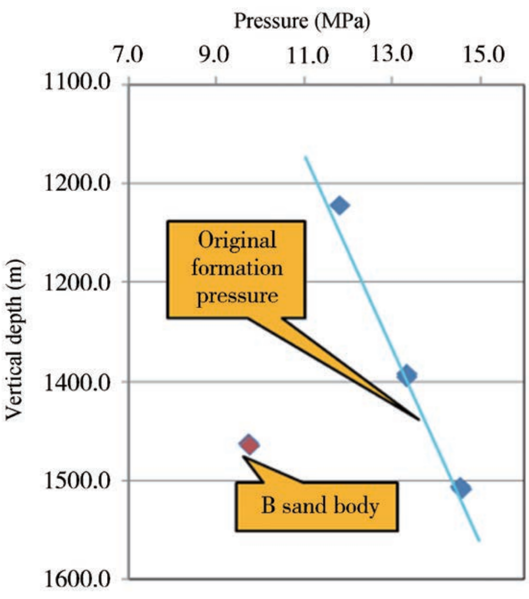


Figure 10
Pressure Distribution of A10 Well

According to the results of the pressure testing, the pressure of B sand body of TVD: 1,462.6-1,465.2 m is about 9.7 MPa, the pressure of the upper water layer of TVD: 1,223.1 m is 11.8 MPa, which is the original formation pressure. The pressure of the other upper water layer of TVD: 1,392.8-1,395.7 m is about 13.3 MPa, which is the original formation pressure. The pressure of the lower water layer of TVD: 1,506.6-1,509.1 m is about 14.6 MPa, which is the original formation pressure. According to the regression formula of the water layer pressure, the original formation pressure of B sand should be 14.2 MPa. Comparing the measured results, pressure dropped by about 4.5 MPa, which indicates that the reservoir between A4 well and A10 Well is connect. According to the design of the pre drilling program, A4 well was adjusted into water injection well for A12 and A10 (Figure 9b).

Table 3
Pressure Data of A10 Well

Number	MD /m	TVD / m	Pressure / MPa
1	1,603.9	1,223.1	11.8
1	2,001.0	1,392.8	13.3
2	2,006.9	1,395.7	13.3
3	2,140.2	1,462.6	9.7
4	2,141.0	1,463.0	9.7
5	2,145.5	1,465.2	9.8
6	2,228.0	1,506.2	14.6
7	2,233.0	1,509.1	14.6

CONCLUSION

(a) The working principle, main measurement results and operation process of formation pressure test while drilling are described in this paper.

(b) This paper introduces the application of formation pressure test while drilling in B oilfield which plays a great role in judging the fault sealing and reservoir connectivity, and optimizing the injection production well network.

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