Study on the law of drillability of stratum in ShunBei #1 block

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Abstract. ShunBei 1 block is located in the northwest of Shuntuoguole low uplift in the north of Tarim Basin, with a block area of 4453km². The reservoirs are mainly distributed in the Middle Ordovician carbonate rocks, and the burial depth is generally more than 7500m. A large number of strike-slip fault zones are developed in ShunBei #1 block, which results in low drilling rate, difficult drilling and poor formation drillability. In this paper, through rock drillability experiment and acoustic test experiment, the experimental analysis of the core of the study block is carried out, and the fitting relation formula of drillability level value is determined by comparing a variety of fitting methods. Based on the calculation model of drillability class value, this paper calculates the drillability class value of Well X in No. V fault zone of ShunBei #1 block, and establishes the drillability profile of Well X. Through the analysis of the drillability profile and drilling conditions, it is believed that with the increase of formation depth, the drillability class value of formation increases, and the drillability of formation becomes worse. Because the fluctuation of the strata drillability class value in the fault zone is small, but the strata drillability class value is large. The drillability class value of the fractured zone strata changes dramatically, showing obvious sawtooth shape, but in general, the value of drillability class value is consistent with that of conventional strata. The strata drillability level of sliding crushing zone increases obviously, but its fluctuation is small. In addition, the drillability of the strata under different fault types is compared. It is concluded that the drillability class value of the strata controlled by the compression fault zone and the strata controlled by the translation and pull-apart fault zone fluctuates very little, but the drillability class value of the strata controlled by the compression fault zone is larger, and the formation drilling difficulty is greater, and the drillability is worse.

1. Geological survey of ShunBei #1 block

ShunBei #1 block is located in the northwest of Shuntuoguole low uplift in the north of Tarim Basin, between Shaya uplift, Shuntuoguole low uplift and Awathi depression, with an area of 4453km². The reservoirs are mainly distributed in the Middle Ordovician carbonate rocks, and the buried depth is generally more than 7500m. The reservoirs are distributed along the strike slip faults on the plane.

A large number of strike-slip faults are developed in the first area of Shunbei, among which the No. 5 strike-slip fault zone is the largest active strike-slip fault zone in the Shuntuogule low uplift, which runs through the Shaya uplift, Shuntuogule low uplift and Katake uplift from the north to the south, controlling the zoning characteristics of the strike-slip fault zone [1-6].
The plane extension length of No. V strike-slip fault zone along the north is nearly 200km. The fault zone is characterized by NE-SW strike-slip fault system to the east and NNW-SSE strike-slip fault system to the west. The reservoir depth is large and the stratigraphic lithology is complex. At the same time, due to the influence of the compression structure, the broken strata are many, the stratigraphic drillability is poor, and the drilling is difficult [7].

2. Calculation of formation drillability level value
Rock drillability refers to the ability of formation rock to resist drilling and fracturing. The measurement and calculation methods of rock drillability mainly include micro-bit test method, acoustic logging method, rock fracture fractal method and so on. The drillability of rock is usually expressed by the value of rock drillability level, which ranges from 1 to 10. The higher the value, the worse the drillability of rock, and the more difficult it is to drill. The drillability grade value of rock has a high correlation with the elastic parameters and strength parameters of rock, including the compressive strength, hardness, Poisson's ratio, elastic modulus and plastic coefficient of rock [8].

In engineering practice, the commonly used method is the sonic logging method, that is, the sonic logging data is fitted with laboratory experimental data to establish the drillability level value model of formation rock, so as to calculate and evaluate the drillability of formation in the whole well section.

2.1. Rock drillability test
The laboratory determination of rock drillability class values requires the help of a rock drillability tester. The specific method is to use the drilling parameters of 31.75mm diameter bit, 889.66N bit pressure and 55r/min speed on the micro-bit drilling experimental frame, drill three holes on the rock sample, the depth of the hole is 2.4mm, and the average drilling time of the three holes is the drilling time \( t_d \) of the rock sample. The logarithm with base 2 is used as the drillability class value \( K_d \) of the rock sample [9]. The rock drillability test was carried out on the rocks from the study block, and the drillability grade value of the rocks was obtained.

2.2. Sound wave time difference test
The rock samples from the study block were cut into a standard core pillar sample with a diameter of 25mm and a length of 50mm. The acoustic time difference test was performed using the Rock Mechanics Triaxial Stress Testing System (GCTS).

2.3. Rock drillability grade value fitting model
The acoustic time difference was fitted with the drillability grade value of the corresponding roller cone bit and PDC bit in various ways. The correlation of these fitting methods was compared, and the fitting method with the largest correlation was determined to get the most suitable fitting model of rock drillability grade value. The figure 1 and figure 2 below shows the drillability level value models of roller cone bit and PDC bit in different fitting ways.
By comparing the different fitting methods, it can be found that the power fitting method has the best correlation between the two drilling conditions. For the study block, the calculation model of drillability class value of roller cone bit is $K_d = 154.96 \times AC^{0.767}$, and that of PDC bit is $K_d = 76.962 \times AC^{0.532}$.

3. Analysis of drillability law of ShunBei #1 block

3.1. Law of formation drillability of different strata
Taking a well X in No. V fault zone of ShunBei #1 block as an example, the law of formation drillability is analyzed. Well X is an exploratory well in the south of No. V fault zone in ShunBei #1 block. The drilling depth was 7890m and the whole well section was drilled with PDC bit. The average mechanical penetration rate of formation overall drilling is 4.76m/h, the mechanical penetration rate is low, the drilling is difficult, the formation drillability is poor. The formation drillability profile of Well X was established using the drillability class value model of PDC bit, as shown in the figure below.
Figure 3. Well X formation drillability section

Combined with drilling conditions and strata drillability profile, the strata of ShunBei #1 block can be found as follows:

1. With the increase of formation depth, the drillability level of the formation increases, and the drillability of the formation becomes worse. The minimum value of drillability class is about 5.6, the maximum value is about 10, the average value of drillability class is about 7.8, the formation drillability class value is large, combined with the drilling conditions, the drilling machine rate is low, the formation drillability is poor.

2. The Neogene and Triassic strata are mainly interbedded with sand and mudstone, and the drillability class value ranges from 5.5-8. The drillability class value gradually increases with the increase of depth, and the drillability changes sharply in the interbedded sand and mudstone, showing a zigzag change.

3. The upper strata of the Permian are igneous rock strata, and the hardness of the igneous rock strata is high, so the drillability level of the strata increases significantly, reaching 8.5-9.5. The drillability of the strata is very poor, and it is difficult to drill the strata. The lower part of the Permian is composed of tuffaceous elastic rocks. The strength and hardness of the formation are reduced, and the drillability level of the formation is reduced, ranging from 7 to 8.5.

4. The Carboniferous is a mudstone stratum, but the hardness of the stratum is different greatly, and the drillability grade value changes significantly. The Devonian - Ordovician Sangtamu Formation is mainly composed of sand and mudstone, and its drillability level is between 8 and 9, so the drillability is poor. Due to the Carboniferous - Silurian strata close to the fracture zone, the fractures are relatively developed, the homogeneity is poor, and the drillability of the strata fluctuates greatly.

5. The Ordovician Yijianfang Formation and Yingshan Formation are oil and gas reservoirs, which are drilled into broken zones. The lithology is dominated by micritic limestone. However, the fracture
results in poor structural integrity of the stratum, and the micritic limestone has high hardness and strength, and the stratum has high drillability level value, so it is difficult to drill.

3.2. Strata drillability law of different fault zone internal structure
The fault zone is a three-dimensional geological body with complex internal structure. According to the degree of deformation inside the fault zone, the fault zone can be generally divided into two internal structural units: induced fracture zone and sliding crushing zone. When the fracture is formed, the stress action leads to the rock fracture. With the strengthening of the fracture activity, the two plates of the fracture surface slide relative to each other, and the broken rock particles fill the space caused by the dislocation of the two plates to form a sliding fracture zone. At the same time, the surrounding rock of the fault zone is accompanied by a large number of fractures due to stress concentration, which forms the induced fracture zone [10-11].

Taking Well Y of No. V fault zone in ShunBei #1 block as an example, the influence of internal structure of fault zone on formation drillability law is analyzed. According to geological analysis, the strata above the Ordovician Yijianfang Formation in Well Y are close to the induced fracture zone, and the strata above the Ordovician Yijianfang Formation and Yingshan Formation are close to the sliding crushing zone. The drillability profile is shown in the figure below.

The induced fracture zone develops, and the stratigraphic homogeneity is poor. The drillability class value of the strata changes dramatically, showing obvious zigzag, but the value of the drillability class value is consistent with that of the conventional strata in general. The rock particles in the sliding crushing zone are fine and compact, and the drillability level is obviously increased, but the fluctuation is small and the stratigraphic homogeneity is relatively good.
3.3. Strata drillability law of different fault zone types

Taking the No. V fault zone in Shunbei #1 block as an example, the types of fault zones include compression fault zone and shift pull-apart fault zone. The main strata controlled by fault zone are reservoirs, namely Yijianfang Formation and Yingshan Formation of Ordovician. Different types of fault zones have different effects on the drillability of strata.

Well X and well Y are the two Wells to the south and north of the No. V fault zone, respectively, which correspond to the compression fault zone and the shift-pull-apart fault zone. Both Wells were drilled with PDC bits, and the formation drillability profiles are shown below. As can be seen from the figure, the formation drillability class values of the reservoir in Well X controlled by the compression fault zone and the reservoir in Well Y controlled by the translation-pull-apart fault zone fluctuate very little. However, the formation drillability class values of the reservoir in Well X are large, and the formation drilling is difficult and the drillability is poor.

4. Conclusions

- Due to the fractured zone, the strata in ShunBei #1 block have poor drillability and are difficult to drill. The drillability class value model of formation rock can be established by fitting acoustic logging data with laboratory experimental data, and the correlation of power fitting method is the best.
- For the study block, the calculation model of drillability class value of roller cone bit is \[ K_d = 154.96 \times A C^{0.767} \], and that of PDC bit is \[ K_d = 76.962 \times A C^{0.532} \].
- With the increase of formation depth, the drillability level of formation increases, and the drillability of formation becomes worse. The fluctuation of drillability level is small due to the large degree of fracture and loose strata in fault zone. However, the fracture results in poor
structural integrity of the stratum, and the micritic limestone has high hardness and strength, and the stratum has high drillability level value, so it is difficult to drill.

- The drillability class value of induced fracture zone strata changes dramatically, showing obvious sawtooth shape, but in general, the value of drillability class value is consistent with that of conventional strata. The strata drillability level of sliding crushing zone increases obviously, but its fluctuation is small.
- Both the strata controlled by the compression fault zone and the strata controlled by the translation-pull-apart fault zone have a small fluctuation in the drillability class value, but the strata controlled by the compression fault zone have a large drillability class value, and the formation drilling difficulty is greater, and the drillability is poor.

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