Analysis of Remaining Oil Distribution and Influencing Factors in B Development Zone

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Abstract Faults are well developed in development area B of Songliao Basin, the development effect is poor. The main reason is that the distribution law of remaining oil and its controlling factors in this area are not well understood. In view of this problem, this paper carries out research and analysis on the basis of relevant data. It is considered that the remaining oil is mainly distributed vertically in the sand-rich layer and horizontally in the intersection of faults, the end of faults, the footwall of reverse faults and the sand-rich area far from faults. Further analysis shows that faults are the key controlling factors of remaining oil distribution in this area. They are shown in two aspects: one is fault sand control, i.e. soft-link and hard-link fault transition zones control the channel of sand body into lake, and then control the enrichment area of sand body. A few sand-rich areas far from faults actually occur on faults. When faults upper plate generating tilt, clastic material is formed by long-distance transportation, which is also the result of fault influence; secondly, the oil control by sealing faults, that is, a large set of mudstones above S reservoir group are dragged into faults in the process of fault dislocation, resulting in good lateral sealing, which is conducive to oil enrichment. This study has a good reference value for tapping the potential of remaining oil in this area.

1. Introduction
Faults are well developed in development area B of Songliao Basin, the relationship between injection and production of oil and water wells is not perfect, and the development effect is poor. Later, 102 new wells were deployed after researching the faults. After the oil wells were put into production, the distribution of high and low production wells is scattered, and the water content and oil production are quite different. The main reason is the lack of clear understanding of the distribution law of remaining oil and its controlling factors in this area, which leads to insufficient basis for deploying new wells. To solve this problem, this paper carries out relevant research work.

2. Geological background
The development area B is located at the western end of the anticline structure in the north of S oilfield in Songliao Basin. It is a wide and gentle anticline structure complicated by faults (figure 1). The dip angle of the study area is 2° ~3°, and the average height of the ground is about 150m. There are 29 large and small faults in this area, all of which belong to normal faults. The strike is NNW and the fault sealing is good. The maximum extension length of faults is 2.6 km, the minimum extension length is only 0.2 km, the maximum fault distance is 81.5 m, the minimum fault distance is 0.8 m, and the average dip angle of faults is 60° ~70°.
Previous fine geological studies show that 32 sand formations have developed in the background of delta plain and delta front subfacies. Most of the single sand bodies are less than 3m in thickness. They can be divided into three sets of S, P and G reservoirs and eight reservoirs, namely S1, S2, S3, P1, P2, G1 and G2.

3. Distribution characteristics of remaining oil

Remaining oil mainly refers to the underground crude oil which can not be produced after a certain production method has been exploited. Therefore, the remaining oil is distributed in the area where the original oil and gas are relatively enriched. To study the distribution of the remaining oil, it is necessary to clarify the distribution law of the original oil and gas enrichment area.

3.1. Vertical distribution characteristics of oil reservoirs

In order to study the vertical distribution characteristics of oil reservoirs, four near east-west well profiles perpendicular to the strike of faults were evenly selected. The profiles covered all the faults developed in the study area. At the same time, the logging, oil testing and drilling data of 40 development wells in the combined well profile were collected and sorted out to draw reservoir profiles. All reservoir profiles show that S2, S3 and P1 are oil layers with high oil saturation and large thickness. G1 and G2 are oil-water layers with low oil saturation and small thickness. Generally, the oil-bearing property of the reservoir decreases and the reservoir becomes thinner as the depth increases (figure 2).

![Figure 1. Three-dimensional topographic map of the research area.](image)

3.2. Distribution characteristics of remaining oil

In order to determine the planar distribution characteristics of remaining oil in the study area, oil saturation data of 428 development wells put into operation after 2004 in each sandstone group were collected and sorted out, and oil saturation contour maps of each reservoir were drawn. The maps show that the remaining oil in the study area is mainly concentrated in fault-related areas, i.e. fault intersection, fault end and reverse fault footwall. The remaining oil enrichment far from the fault is mainly controlled by sedimentary sand bodies (figure 3). Among them, 77.5% of the remaining oil is related to faults, especially at the end of faults. Accounting for 55% (figure 4).

![Figure 2. Near west-east reservoir profile map.](image)
Figure 3. Current and initial contour map of the typical area in S2 oil reservoir.

A and B are the contour maps of the present and original oil saturation of the 1\textsuperscript{st}-3\textsuperscript{rd} sand formation of S2 oil reservoir, respectively. The remaining oil in the figure A is mainly distributed in the descending plate of reverse fracture. C and D are the contour maps of the present and original oil saturation of the 4\textsuperscript{th}-6\textsuperscript{th} sand formation of S2 oil reservoir, respectively. The remaining oil in the figure C\textsubscript{1} is distributed at the intersection of faults. The remaining oil in the figure C\textsubscript{5} is distributed at the end of the fault.

Figure 4. The statistics on remaining oil distribution location.

4. Controlling factors of remaining oil

4.1. Fault controlled sand body distribution

The results show that the average thickness of sand bodies in S2, S3 and P1 is more than 15 meters, and the average sand ratio is more than 38%, which is higher than other reservoirs (figure 5). By comparing this phenomenon with the characteristics of the main reservoirs with larger thickness of S2, S3 and P1, it can be concluded that in vertical direction, the original oil and residual oil are mainly concentrated in the sands with larger thickness and higher sand ratio, in other words, the sandy layer is beneficial to oil enrichment. On the other hand, from the plane view, in figure 3C\textsubscript{1} and 2 in figure 3D\textsubscript{3} and 4 correspond roughly to 1 and 2 in figure 6 respectively, which also corroborates to some extent the above viewpoint of sand-rich oil control.
Vertically, the number of sand bodies is related to source supply, structure, climate and other factors, which is the main reason for the difference of sand body content in S, P and G reservoirs. However, in the same reservoir, the uneven distribution of sand bodies is mainly controlled by syngenetic faults. The syngenetic faults in this area have the characteristics of sectional growth. During the process of sectional growth, a fault transition zone is formed, in which the intersection and end of faults are soft connection transition zones and the reverse faults are hard link transition zones (figure 7). The two transition zones control the channel of sand body into lake, and the front of the channel position is sand body enriched area.

Figure 5. The statistics on average sand thickness and average sand ratio of every oil layer.

Figure 6. Sand ratio contour map from the 4th-6th sand sets in S2 oil layer.

Of course, the aforementioned statistics also mentioned that 22.5% of the remaining oil is located...
in the sand-rich areas, which are far away from the fault location, seemingly unrelated to the fault, but in fact it is not. When the upper wall of a fault is tilted and the tilt direction is close to the fault plane tendency, the debris material from the footwall of the fault will not accumulate at the upper wall edge near the fault plane immediately after crossing the fault plane, but will be deposited after a relatively long distance transportation along the upper wall stratum tendency. Therefore, free sand rich zones are also controlled by faults.

4.2. Control of remaining oil distribution by the sealing property of faults

Although 1 and 2 in figure 3C and 3 and 4 in figure 3D correspond roughly to 1 and 2 in figure 6 respectively, the corresponding relationship is not strict. In areas with high sand ratio, there is not always accumulation of primary oil and residual oil. Whether oil can be enriched or not, another more important factor is the sealing property of faults.

Statistics show that the thickness of single sand body is generally less than 3 m, the fault spacing is generally about 12 m, and the fault spacing is larger than the thickness of single sand body. It is difficult to achieve ideal results by lateral sealing based on the lithological differences between the two sides of the fault. However, field outcrop shows that there are large sets of mudstone caprock in the strata above S reservoir group, and the mudstone is dragged forward by faulting. A good lateral seal is formed in the fault zone.

Based on the results of three-dimensional seismic interpretation in the study area, 13 key faults are carefully sorted out, and loaded into TrapTest software system for mathematical geological modeling. SGR (Yielding, 1997) algorithm is used to calculate the sealing of faults. The calculation results show that with the increase of SGR value, the lateral sealing ability of faults increases, and the SGR value of 20% is the critical value of lateral sealing of faults. The SGR distribution of a fault plane formed by this method shows that the SGR values of S2, S3 and P1 are higher and their sealing ability is better (figure 8), which is the key to their better oil-bearing.

![Figure 8. Some fault plane SGR distribution map.](image-url)

5. Conclusion

This study shows that the remaining oil is mainly distributed vertically in S2, S3 and P1 reservoirs, and horizontally in the intersection of faults, the end of faults, the footwall of reverse faults and the sand-rich areas far from faults. Further analysis shows that the fault is the main factor to control the distribution of residual oil.

1) Fault sand control. Segmented growth syngenetic faults often form two kinds of transition zones: soft connection and hard link. Soft connection includes fault intersection and fault end. Hard link includes reverse fault descending plate. The two transition zones control the channel of sand body into lake, that is, the distribution range of sand-rich area. When the upper wall of a fault is tilted and the tilt direction is consistent with the fault plane tendency, the debris from the lower wall crossing the fault plane will be transported along the upper wall tilt direction for a long distance before depositing, seemingly unrelated to the fault.

2) The oil control by sealing faults. The strata above S reservoir group is thicker mudstone strata, which is dragged into the fault zone under the action of faults and forms good lateral sealing conditions. The distribution of SGR value on the fault plane also shows this.

In a word, faults play a key role in the distribution of remaining oil in this area, and this
understanding has important reference significance for tapping potential and increasing production.

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