Lithofacies Types and Quantitative Identification Methods of Reservoirs

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Abstract. Taking Xing A Block of Songliao Basin as an example, based on the core data of closed core wells, the sedimentary characteristics and genetic mechanism of its lithofacies are analyzed. It is considered that there are four types of core lithofacies developed in the study area, which are medium fine sandstone facies, siltstone facies, muddy silt facies and mudstone facies. Based on the crossplot recognition technology, the logging quantitative division standard of lithofacies is determined, and the quantitative interpretation chart of lithofacies is established. According to the laboratory analysis and test data, the reservoir quality characteristics of various lithofacies are summarized. The medium fine sandstone facies and siltstone facies are the main reservoirs in the study area with good physical and oil-bearing properties and high oil displacement efficiency; the physical and oil-bearing properties of argillaceous siltstone are poor and the oil displacement efficiency is low; in siltstone and argillaceous siltstone, the degree of water flooding is low and the remaining oil is relatively rich.

Keywords: Lithofacies, Quantitative Identification Technology, Reservoir Quality, Remaining Oil Enrichment

1. Introduction
Lithofacies refer to the rock mass formed in a certain tectonic environment and sedimentary background, with specific sedimentary characteristics and basically the same rock properties. It is a further subdivision and quantification of sedimentary microfacies. To define the sedimentary, distribution and physical characteristics of rock facies is conducive to the division and distribution of sedimentary facies, as well as the in-depth study of reservoir distribution and quality characteristics [1-2].

On the basis of core observation of closed coring wells, this paper makes a detailed description and summary of the lithofacies characteristics of the reservoir in Xing A Block of Songliao Basin by using the logging data, establishes the logging quantitative identification model of lithofacies types, in order to promote the prediction of the distribution of "sweet spots" of the reservoir in this area, and provides a reference for the study of the lithofacies of the reservoir in other areas. The model defines the distribution of remaining oil potential in different lithofacies, establishes a geological simulation
system, and forms the concept of remaining oil potential in the late stage of ultra-high water cut. Through the study of lithofacies type, physical property characteristics and distribution in this area, the heterogeneity of the delta front reservoir in this area is revealed, which lays a foundation for the formulation and adjustment of the subsequent development project.

2. Geological Background
Xing A Block is located in the north of Daqing paleoanticline. The terrain is relatively flat, with an altitude of 135.0m-149.3m. The landform is a low plain with undulation.

The structure of Xing A Block is relatively gentle, with two wings basically symmetrical. The west wing has a structural dip of 4-5 degrees, the east wing has a structural dip of 2-3 degrees, and the structural high point is near well X1, with an altitude of -780.6m, which dips slowly to the south. All the faults in this area are normal, most of them are NW strike, a few of them are NE strike.

The reservoir in Xing A Block was deposited in the late period of the reverse cycle of Qingshankou Formation and the early period of the compound cycle of Yaojia formation. The oil-bearing intervals are Sartu, Putaohua and Gaotaizi oil layers of oil-bearing assemblage in the middle of Songliao basin. The buried depth of the oil layers is 800m-1200m, and the oil reservoir type is a block oil-gas reservoir controlled by structure.

The lithology is composed of feldspar quartz sandstone, with fine sand as the main structure, argillaceous as the main cement, kaolinite as the main mineral component, intergranular pore as the main reservoir pore, micropore as the second, with porosity ranging from 22% to 31%, with an average of 26.7%, and air permeability of about 600 μm².

The sedimentary reservoir is a large-scale leaf delta deposit belonging to the sedimentary system in the north of the basin, which has the characteristics of multi-stage cycle, uneven lithofacies and frequent interaction of sandstone and mudstone. Among them, the delta distributary plain facies is dominant in PⅠ1-3 layer, and the delta front facies is dominant in other oil layers.

According to the characteristics of complex lithology and strong internal heterogeneity in this area, based on the identification and division of lithofacies, considering core, logging and other data, the reservoir characteristics of various lithofacies are summarized, and the oil displacement efficiency of different lithofacies is studied, so as to predict the location of remaining oil enrichment.

3. Types and Characteristics of Lithofacies
On the basis of systematic observation of nearly 1000m cores from sealed core wells in the study area, the sedimentary characteristics of various types of lithology and the genetic mechanism of different lithology are comprehensively considered, and the lithofacies is divided into four types: medium fine sandstone facies, siltstone facies, muddy siltstone facies and mudstone facies.

3.1 Medium Fine Sandstone Facies
Medium fine sandstone facies is widely developed in the study area, with large thickness, including medium sandstone and fine sandstone. Its supporting structure is particle support (Figure. 1a), which is well sorted, rounded to sub round shape, mostly in massive structure, with not obvious parallel bedding visible. The transport mechanism is traction flow under strong hydrodynamic conditions, which is gray to dark gray. The middle fine sandstone facies is mainly the deposition of the lower part of channel facies.

3.2 Siltstone Facies
The siltstone facies in the study area has large distribution area, large thickness, good separation and rounding of rock particles, good stratification and parallel bedding (Figure. 1b). The transport mechanism is traction flow under the condition of weak hydrodynamic force. The siltstone facies is mainly the deposition of the upper part of channel facies and sheet sand deposition.

3.3 Muddy Siltstone Facies
Muddy siltstone facies is widely distributed in the study area, with thin thickness. It is vertically interbedded with mudstone. The lithology is mainly siltstone, with a small part of mud. Cross bedding and oblique bedding are developed (Figure. 1c). Muddy siltstone facies is mainly composed of top and edge sediments of river channel and inter channel sediments.

3.4 Mudstone Deposits
Mudstone facies is thick in the study area, and mudstone is generally dense and pure, gray black in color (Figure. 1d). Mudstone has high organic matter content. Conchoids and mesophyll fossils can be seen, which are generally foliated, reflecting the characteristics of deep lake facies deposition.

![Medium fine sandstone facies](image1.png) ![Siltstone facies](image2.png) ![Silt bearing facies](image3.png) ![Mudstone deposits](image4.png)

**Figure 1.** Core photos of lithofacies in Xing A Block

4. Quantitative Division of Lithofacies
Because different logging series reflect different aspects of the geophysical properties of the formation, and the depth range of detection is also different, the contribution of logging series to the response of rock facies is also different [3-4].

The well logging data in the study area are relatively comprehensive. The comprehensive analysis shows that the following six kinds of well logging curves are good for distinguishing four types of rock facies in this area. The deep shallow lateral resistivity curve is characterized by small well hole diversion and obvious curve changes for different rock layers with different resistivity; the sonic time difference curve can distinguish different lithology; the minimum and maximum values of 2.5m resistivity logging can determine the top bottom interface of reservoir; the natural gamma curve value increases with the increase of shale content; the natural potential curve at mudstone is straight, and at sandstone the abnormal amplitude of SP curve is the largest, and the larger the mud content of sandstone is, the smaller the abnormal amplitude of SP curve is; for sandstone stratum, there is amplitude difference of microelectrode curve, and the purer the sandstone is, the better the physical property is, the larger the amplitude difference is.
Different lithofacies have different logging response characteristics. The electrical performance characteristics of lithofacies can be analyzed according to the combination of various logging information. The logging curves of shale sedimentary deep shallow lateral resistivity, microelectrode and natural potential are all located at the baseline, with high-resolution acoustic time difference as high value; the natural gamma value of siltstone bearing facies is relatively high compared with that of siltstone free, and the resistivity value of 2.5m is relatively low; the natural potential amplitude difference of siltstone facies is the largest, and the amplitude difference of microelectrode curve is relatively large; for medium and fine sands, the amplitude difference of lithofacies natural potential is large, and so does the micromotor curve.

Quantitative division process of lithofacies:

(1) Using the normalization formula to normalize the above six logging curves can eliminate the errors caused by different logging time. Where: X1 represents the value of normalized well logging curve; X represents the value of original well logging curve; xmax represents the maximum value of processing well section logging, and xmin represents the minimum value of processing well section logging.

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X_1 = \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}}
\]

(2) In this paper, we use the crossplot identification technology to identify the lithofacies step by step[5-10]. The technical route is concluded in 3 steps: ① deep shallow lateral resistivity logging (RLLS/ RLLD) and high-resolution acoustic time difference logging (HAC) distinguish the sandstone type deposition and mudstone type deposition well; ② for sandstone type deposition, the intersection of natural gamma logging (GR) and 2.5m resistivity logging (Rt2.5m) can be further divided It can be divided into no argillaceous sandstone and muddy siltstone facies; ③ for non argillaceous sandstone, medium and fine sandstone facies and siltstone facies can be distinguished by the intersection of microelectrode logging and spontaneous potential logging; Finally, the interpretation model of rock facies can be established by the intersection of six logging curves.

According to the statistics of logging response of various lithofacies, a log interpretation chart (Figure.2, Figure.3, Figure.4) is formed, and the quantitative division standard of various lithofacies (Table 1) is summarized, so as to identify four types of lithofacies in a single well. The comparison of rock facies identified by core and well logging (Figure. 5) shows that the recognition accuracy can reach 81%.
Figure 4. Log interpretation chart for siltstone and medium fine sandstone

Table 1. Quantitative division standard of lithofacies in Xing A Block

| Well logging curve intersection chart | Lithofacies                     | Logging curve                        | Normalized value range |
|--------------------------------------|---------------------------------|--------------------------------------|------------------------|
| Deep shallow lateral resistivity     | Mudstone deposit                | Deep shallow lateral resistivity      | 0—0.052                |
| —High resolution acoustic time difference | Sandstone deposit               | High resolution acoustic time difference | 0.54—1                |
|                                      |                                 | Deep shallow lateral resistivity      | 0.052—0.8              |
|                                      |                                 | High resolution acoustic time difference | 0.15—0.54             |
| Natural gamma ray—2.5m resistivity   | Muddy silt facies               | Natural gamma ray                     | 0.36—1                |
|                                      | No argillaceous sandstone       | 2.5m resistivity                      | 0—0.18                |
|                                      |                                 | Natural gamma ray                     | 0—0.36                |
|                                      |                                 | 2.5m resistivity                      | 0.12—0.35             |
| Spontaneous potential—microelectrode | Silty facies                    | Spontaneous potential                 | 0.2—0.5               |
|                                      | Medium fine sandstone facies    | microelectrode                        | 0—0.65                |
|                                      |                                 | Spontaneous potential                 | 0—0.2                 |
|                                      |                                 | microelectrode                        | 0.1—1                 |
5. Reservoir Quality of Lithofacies

Based on the classification of lithofacies, combined with core data and laboratory analysis data, the physical properties and oil-bearing properties of different lithofacies subtypes in the study area are summarized. The lithology of the study area (with porosity analysis data) mainly includes medium and fine sandstones, siltstone facies and muddy siltstone facies. According to the latest five core wells’ (X3, X4, X5, X6, X7) experimental analysis data, the frequency histogram of physical properties and oil saturation are obtained respectively from Fig.6, Fig.7. It can be seen that the physical properties and oil-bearing properties of medium fine sandstone are the best, followed by siltstone, and argillaceous siltstone is relatively poor.

Figure 5. Core identification and verification of logging lithofacies of Well X2

Figure 6. Porosity percentage of rocks

The reservoir quality characteristics of different lithofacies subtypes are summarized according to the physical properties, oil-bearing properties and pore micro characteristics of different lithofacies (Table 2).

1) Medium fine sandstone facies

The pores of the reservoir are generally intergranular pores, with high porosity and permeability, good oil-bearing property and high oil displacement efficiency. It is one of the main reservoirs in the study area.

2) Siltstone facies

The pores of the reservoir are generally intergranular pores, with high porosity and permeability. The oil-bearing property is oil-bearing and oil leaching, with high oil displacement efficiency, which is one of the main reservoirs in the study area.

Figure 7. Percentage of oil saturation of rocks
(3) Silt bearing facies
The pores of the reservoir are generally intergranular pores, with relatively low porosity and permeability, general oil-bearing property and low oil displacement efficiency, which are secondary reservoirs in the study area.

(4) Mudstone deposits
The pores are mainly intragranular dissolved pores and micropores. However, due to the narrow throat, low permeability and oil-free, they are non-reservoir.

Table 2. Statistics of physical parameters of different types of lithofacies in Xing A Block

| Lithofacies          | Porosity (%) | Permeability (mD) | Pore type                  | Oil-bearing grade | Average oil displacement efficiency (%) |
|----------------------|--------------|-------------------|-----------------------------|-------------------|------------------------------------------|
|                      | Min | Max | Avg | Min | Max | Avg |                     |                                |                           |
| Medium fine sandstone facies | 13.8 | 32.3 | 27.5 | 75  | 895 | 650 | Intergranular pore | Oil-bearing | 64                      |
| Siltstone facies       | 11.8 | 29.2 | 22.5 | 65  | 870 | 610 | Intergranular pore | Oil-bearing or oil immersion | 42                      |
| Muddy siltstone facies | 10.1 | 24.5 | 16.6 | 30  | 560 | 370 | Intergranular pore | Oil immersion or oil spot     | 33                      |
| Mudstone facies        | /    | /    | /    | /   | /   | /   | Intragranular dissolution pore | No display | /                      |

According to the geological seepage difference and actual development situation of different types of rock facies, it is found that the distribution form of remaining oil in different types of rock facies is different. Medium and fine sandstones have good physical properties, fast water injection speed, easy to form water channeling, relatively less remaining oil, which is generally distributed in the upper part of the reservoir; siltstone facies and muddy siltstone facies have poor physical properties, low oil displacement efficiency, low degree of water flooding, and relatively rich remaining oil.

6. Application
By using the comprehensive quantitative identification technology of rock facies in Xing A Block, the quantitative interpretation of rock facies for non coring wells is carried out, the interpretation results are applied for development adjustment, and the hole patching scheme is implemented. At present, good results are achieved. It is estimated that 7900 tons of oil will be increased in total and the net economic income will be more than 7.5 million RMB.

Table 3. Application of lithofacies interpretation results to some wells in Xing A Block

| Well name | Date    | Layer name | Lithofacies type                      | Initial daily oil increase (t) |
|-----------|---------|------------|---------------------------------------|-------------------------------|
| X8        | 20160827| S2,S3,P1   | Siltstone Medium fine sandstone        | 6.27                          |
| X9        | 20160815| S2,S3,P1   | Siltstone Muddy siltstone              | 2.71                          |
| X10       | 20160812| S2,S3,P1,P2| Siltstone                              | 4.6                           |
|   | Medium fine sandstone          |
|---|--------------------------------|
| X11 | 20160618 S2,S3 P1,P2,G1    |
|     | Siltstone, medium fine sandstone, muddy sandstone | 4.89 |
| X12 | 20160822 S2,S3 P1,P2,G1    |
|     | Siltstone Medium fine sandstone | 5.62 |

**Conclusion**

1. The core lithofacies of Songliao basin can be divided into four types: medium fine sandstone facies, siltstone facies, muddy siltstone facies and mudstone facies.

2. By using crossplot identification technology, the comprehensive quantitative identification technology of rock facies in Xing A Block is realized, and the quantitative interpretation chart of rock facies is established.

3. The properties of various sub rock facies reservoirs are different. The medium fine sandstone and siltstone are the main reservoirs in the study area, and the muddy siltstone is the secondary reservoir.

4. The medium and fine sandstones have good physical properties, fast water injection speed, easy to form water channeling, relatively less remaining oil, which is generally distributed in the upper part of the reservoir; siltstone facies and muddy siltstone facies have poor relative physical properties, low oil displacement efficiency, low degree of water flooding, and relatively rich remaining oil.

5. Through the quantitative interpretation of lithofacies for non coring wells, the interpretation results are applied for development and adjustment, and the hole patching scheme is implemented, which has achieved good results.

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