Study on heterogeneity characteristics of oil and gas reservoirs

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Abstract. In order to meet the needs of fine adjustment of oilfield development in ultra-high water cut period, the heterogeneity characteristics of reservoirs after well pattern infilling are studied, and the reservoir heterogeneity is evaluated qualitatively and quantitatively. The target block is dissected by the method of cyclic correlation, and the type of sedimentary environment and the number of sedimentary units of the target reservoir are determined. At the same time, through the permeability characteristics of each sedimentary unit, the heterogeneity characteristics of sand body in three aspects, i.e. interlayer, plane and intralayer, are analyzed, which provides an important basis for fine water control and tapping potential of target reservoirs in this block.

1. Introduction

With the increase of well pattern density, the understanding of sand body will become more and more clear. However, it is impossible to increase the net density infinitely in oilfield production. How to accurately describe reservoirs by using existing well pattern conditions is key problem. Taking block A as an example, this paper focuses on the study of interlayer, plane and intra-layer heterogeneity of group B of target reservoir, and determines the heterogeneity characteristics of sedimentary units under target reservoir.

Block A reservoir group B is mainly composed of flood plain facies, distributary plain facies and delta inner front facies. In order to facilitate the study, group B is divided into 12 sedimentary units according to sand body development type and geometric characteristics by cycle correlation method.

2. Interlayer heterogeneity

Intra-layer heterogeneity describes the vertical changes of reservoir properties (lithology, physical properties, etc.) within the scale of a single sand bed, and reflects the vertical changes of the sand body. It is a key geological factor that directly controls and affects the vertical sweep volume of injectant in the interior of the sand body. The characterization parameters of intra-layer heterogeneity are as follows:

- Particle size rhythm: refers to the vertical variation sequence of the particle size of debris in the sand body. There are three kinds of prosody: positive prosody, anti-prosody and compound prosody.

- Location of the highest permeability section: The highest permeability section in the sand body is located at the bottom, top and middle of the sand body. It is generally consistent with the rhythm of granularity.
The inhomogeneous characteristics of permeability in sand bodies are usually characterized by permeability variation coefficient, gradation and heterogeneity coefficient (progressive coefficient). The following are specific:

Permeability gradient: reflects the difference between the maximum and minimum permeability, the greater the value, the stronger the reservoir heterogeneity; the closer the numerical value is to 1, the more homogeneous the reservoir. For example in the equation:

\[ J_k = \frac{K_{\text{max}}}{K_{\text{min}}} \]

Permeability heterogeneity coefficient (Progressive coefficient): A parameter reflecting the variation of permeability, i.e. the difference degree of absolute permeability value, the greater the numerical value, the stronger the reservoir heterogeneity, the closer the numerical value is to 1, and the more homogeneous the reservoir is. For example in the equation:

\[ T_k = \frac{K_{\text{max}}}{\bar{K}} \]

In the above formula:
- \( \bar{K} \) …… Average permeability of each layer
- \( J_k \) …… Permeability gradient coefficient
- \( K_{\text{max}} \) …… Maximum permeability in layer
- \( K_{\text{min}} \) …… Minimum permeability in formation
- \( T_k \) …… Permeability progression coefficient

The results show that the average permeability of the target reservoir is 0.439 \( \mu \text{m}^2 \); the permeability gradient is 5.1; and the heterogeneity coefficient of the interlayer permeability is 3.085. Generally, when the value is greater than 2, the degree of heterogeneity is strong. Generally speaking, the heterogeneity difference between layers is strong.

| Sedimentary unit | Average permeability (\( \mu \text{m}^2 \)) | Maximum permeability (\( \mu \text{m}^2 \)) | Permeability progression coefficient | Permeability ratio |
|------------------|---------------------------------------------|---------------------------------------------|-------------------------------------|-------------------|
| B1               | 0.434                                      | 1.534                                      | 3.535                              | 4.7               |
| B2               | 0.354                                      | 1.465                                      | 4.138                              | 7.6               |
| B3               | 0.508                                      | 1.379                                      | 2.715                              | 8.2               |
| B4               | 0.617                                      | 1.227                                      | 1.989                              | 4.9               |
| B5               | 0.462                                      | 1.124                                      | 2.433                              | 5.1               |
| B6               | 0.462                                      | 1.567                                      | 3.392                              | 6.3               |
| B7               | 0.420                                      | 1.053                                      | 2.507                              | 3.4               |
| B8               | 0.374                                      | 1.120                                      | 2.995                              | 3.8               |
| B9               | 0.448                                      | 1.354                                      | 3.022                              | 3.1               |
| B10              | 0.470                                      | 1.264                                      | 2.689                              | 3.6               |
| B11              | 0.469                                      | 1.206                                      | 2.571                              | 4.9               |
| B12              | 0.478                                      | 1.236                                      | 2.586                              | 5.2               |
| B group          | 0.439                                      | 1.294                                      | 3.058                              | 5.1               |
3. Plane heterogeneity

Planar heterogeneity refers to the plane difference of a single reservoir, including the type, geometry, connectivity of sand body and the distribution difference of permeability of sand body in the plane. The plane heterogeneity of sand body is the main reason for the uneven advance of injectant front, which has great influence on well pattern deployment, the plane sweep efficiency of injected water and the plane distribution of remaining oil. Generally, the heterogeneity characteristics in the plane of sand body are reflected from two aspects: the type of sand body, the geometric shape and connectivity, and the plane heterogeneity characteristics of sand body permeability.

Based on the analysis of sand body type, single sand body geometry and plane permeability difference of B reservoir in this block, the characteristics of plane heterogeneity of each unit are studied. According to the study of sedimentary characteristics of each unit, although the sedimentary models of different units are different, the plane heterogeneity of fluvial facies sand bodies is more serious as long as there are different types of sand bodies. In the same injection-production well group, the main channel-origin sand body seriously interferes with the non-channel-origin sand body. In the same sand body, the plane is also affected by permeability, resulting in the high permeability part interfering with the low permeability part. The basic reason is still the influence of rock particle size and permeability. In addition, from the geometrical shape of sand body, the ratio of sand body in strip channel.

Table 2. Statistical table of plane heterogeneity characterization parameters

| Sand body type       | Maximum permeability (μm²) | Minimum permeability (μm²) | Average permeability (μm²) | Permeability ratio |
|----------------------|-----------------------------|-----------------------------|-----------------------------|-------------------|
| Channel sand         | 1.567                       | 0.280                       | 0.658                       | 5.596             |
| Crevasse channel     | 1.223                       | 0.140                       | 0.352                       | 8.736             |
| Sheet sand           | 0.939                       | 0.038                       | 0.189                       | 24.71             |
| External thin sand   | 0.007                       | 0.001                       | 0.003                       | 7.000             |

4. Intraformational inhomogeneity

Intra-layer heterogeneity describes the vertical changes of reservoir properties (lithology, physical properties, structure, rhythm, etc.) within the scale of a single sand bed, and reflects the vertical changes of the sand body. It is a key geological factor that directly controls and affects the vertical sweep volume of injectant in the interior of the sand body. The characterization parameters of intra-layer heterogeneity are as follows:

- Particle size rhythm: refers to the vertical variation sequence of the particle size of debris in the sand body. There are three kinds of prosody: positive prosody, antiprosody and compound prosody.

- Location of the highest permeability section: The highest permeability section in the sand body is located at the bottom, top and middle of the sand body. It is generally consistent with the rhythm of granularity.

The inhomogeneous characteristics of permeability in sand bodies are usually characterized by permeability variation coefficient, gradation and heterogeneity coefficient (protrusion coefficient). The following are specific:

Permeability coefficient of variation: The smaller the sample deviates from the overall average value, the more uniform the distribution of the sample value is, on the contrary, the stronger the heterogeneity is. Generally, when Kv is less than 0.5, the degree of heterogeneity is weak; when Kv is between 0.5 and 0.7, the degree of heterogeneity is medium; when Kv is greater than 0.7, the degree of heterogeneity is strong. For example in the equation:

\[ K_v = \frac{\delta}{\bar{K}} \]

\[ \delta = \sqrt{\frac{\sum (K_i - \bar{K})^2}{n}} \]
In the above formula:

$K_v$ Coefficient of variation of permeability

$K_i$ Permeability of each layer, $i = 1, 2, 3, \ldots, N$

$\bar{K}$ Average permeability of each layer

$n$ Layer number

The sand body of group B reservoir has the characteristics of bedding structure mainly consisting of lower trough, small trough crisscross and middle-upper wavy. The size and rhythm thickness of bedding become smaller upward, and it is a typical positive gradient sequence. The grain size distribution in the sand body has obvious rhythm, and the grain size difference in each rhythm section is obvious. The sand body is in positive rhythm on the whole, and the distribution of grain size and permeability is good. Correspondence. The thickness and density of interlayer increase upward, and the direction of fluid seepage is consistent with that of interlayer.

Table 3. Statistical table of parameters of intraformational heterogeneity

| Sedimentary unit | Average permeability ($\mu$ m$^2$) | Coefficient of variation of permeability | Permeability progression coefficient | Permeability ratio | Average porosity (%) |
|------------------|-----------------------------------|----------------------------------------|-------------------------------------|-------------------|---------------------|
| B1               | 0.434                             | 0.584                                  | 3.535                               | 4.7               | 27.631              |
| B2               | 0.354                             | 0.702                                  | 4.138                               | 7.6               | 28.561              |
| B3               | 0.508                             | 0.751                                  | 2.715                               | 8.2               | 29.075              |
| B4               | 0.617                             | 0.603                                  | 1.989                               | 4.9               | 29.256              |
| B5               | 0.462                             | 0.649                                  | 2.433                               | 5.1               | 28.871              |
| B6               | 0.462                             | 0.651                                  | 3.392                               | 6.3               | 29.059              |
| B7               | 0.420                             | 0.594                                  | 2.507                               | 3.4               | 28.584              |
| B8               | 0.374                             | 0.655                                  | 2.995                               | 3.8               | 28.720              |
| B9               | 0.448                             | 0.586                                  | 3.022                               | 3.1               | 28.856              |
| B10              | 0.470                             | 0.701                                  | 2.689                               | 3.6               | 29.000              |
| B11              | 0.469                             | 0.672                                  | 2.571                               | 4.9               | 28.953              |
| B12              | 0.478                             | 0.712                                  | 2.586                               | 5.2               | 29.091              |

From table 3, can be seen that there is little difference in the porosity of each unit, B1 has the smallest porosity, reflecting the small carrying capacity of water flow during san body deposition; the average permeability increases with the gradual increase of sand body size; the sand body in B1 is the most inhomogeneous in terms of coefficient of variation; B2 is the largest and B4 is the smallest in terms of penetration coefficient. The results of the calculation of the heterogeneity coefficient in the overall analysis layer show that B4 has better homogeneity, B3 have stronger heterogeneity.

5. Conclusion

- The interlayer heterogeneity of B reservoir in the block A is weak, which is mainly affected by sand body type and permeability in plane. The horizontal heterogeneity is the most serious in channel sand body.

- Reservoir heterogeneity research must be based on fine anatomy and genetic analysis.
Fine and accurate dissection of sand bodies and heterogeneous characteristics of reservoirs are of great guiding significance for fine water control and tapping potential of water flooding and optimization and adjustment of tertiary oil recovery.

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