The Methods for Connectivity Judgment on Reservoir Layers

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Abstract. Determining reservoir layer connectivity is the base for an oil field development. The work should be done in the first time. It affects the effects of the following works. However, for some oil field with complex reservoir layers, the study hasn't fully been done, that causes the oil production rate decreases rapidly and bad oil field development. On the other hand, the simpler the oil field is, the earlier the development should be, thus increasing oil production becomes more and more difficult today, lots of detail works should be done for a complex oil field, the study of reservoir layer connectivity is very important in it.

1.   Introduction

The method for reservoir layer connectivity study is almost limited in layer correlation, which is the method using well log curve to determine if two layers connected or not, but, it is not definite for some layers only using one method, and may cause mistake for other works, such as exploration for oil field, oil-water-gas distribution characteristics, plan for oil field development, selection for perforation zone, plan for water injection, and so on, there are some of such examples and experience. Especially for some oil field with very complex reservoir layers, the layer connectivity has not been recognized clearly, and thus oil production rate decreases, production well has no responsibility to injection wells, oil production did not increase for perforation on new layers. In order to develop oil field better, a reliable geologic base is needed, reservoir layer connectivity study is a fundamental work in it. A comprehensive study concept is introduced in the paper, which is not only thinking about layer correlation, but also is for sedimentary environment, seismic data, oil field development data, fault characteristics, etc. Nine methods are presented with some actual data here. This paper also discusses the relationship between the methods, and points out how to use the methods to study reservoir layer connectivity for a special oil field. Using the methods better will raise the level of the field development and increase total oil production.

2. Sedimentary environment analysis

This is for an overall grasp on the sedimentary pattern of an oil field, and it can guide the fine judgment of reservoir layer connectivity. It is inappropriate to contrast one layer with another only using the shape of well logging curve on the first time.

Sedimentary environment refers to the peculiar physical, chemical and biological conditions, including natural geographic conditions, climate, biological development, sedimentary medium physical and chemical properties and geochemical conditions. These conditions change according to the place and time, which leads to the change of the sediment on the plane and vertical, and then make

the reservoir layer distribution regularly. Grasping its change rule for layer classification and correlation is of great significance.

The influence of factors of the sedimentary environment is different on the plane, and on the vertical layers. On the plane, the tectonic condition is the main control factor when compare it with other factors such as climate, biology, natural water body. The control action on the deposition changes with the area on land or water, as in delta sedimentary system of sea and land interchange, from high area to low area, from land to sea, the sedimentary face distributes regularly, in the order: on delta plain, delta front and front delta. In reservoir layer comparison, therefore, putting the compared well in a point of such a system is basic to determine the characteristics of the reservoir layer, and then to have a fine comparison according to the morphological characteristics of the logging curve. For vertical layers, tectonic block going up and down, which is caused by tectonic movement, changes with time, it causes water intake or retreat, it reacts on the sediment rhythm. We needed to place a layer on a vertical point of the rhythm.

For a particular layer, knowing its sedimentary conditions help to do the connectivity research accurately.

3. Seismic data
Using conventional 3D seismic data can help us to do research of reservoir layer connectivity.

3.1. Using seismic data to determine faults
Firstly the fault itself needs to be determined, secondly, using fault properties determine its closure, and then determine its effect on the reservoir connectivity (for detail see the paragraph below). Here paying special attention to distinguish the difference between the small faults and sedimentary pinch out is needed.

3.2. To study layer pinch out point using seismic phase axis
If the layer thickness is greater than the vertical seismic resolution, the layer interface can be calibrated on the seismic section. When the interface reflection with discontinuous phase axis, the reservoir layer is not connected, and vice versa. For example, there is a Jurassic reservoir, the thickness of single layer is about 30m, and it is thicker than the seismic resolution, the seismic reflection is clutter, intermittent, overlap crisscross, it represent poor connectivity (figure 1, the part below the green line).
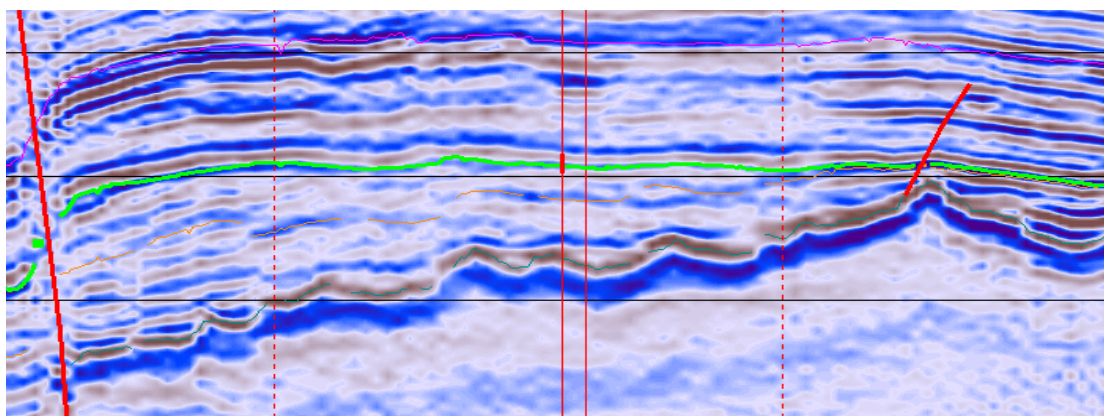

Figure 1. The continuous and discontinuous phase axis of seismic data.

If the layer thickness is less than the seismic vertical resolution, the situation is complicated. For the discontinuous reflection interface in phase axis of a seismic cross section, the layer is discontinuous. For the continuous interface reflection, the reservoir layer may be continuous or discontinuous. There is an example of a cretaceous reservoir for the continuous layer, the thickness of single layer is only 3-5m, less than the seismic resolution, the seismic reflection axis is smooth and

successive (figure 1, The part near and above the green line), the layer connectivity is good, and the actual well logging data shows the judgment, the layer thickness varies little, contrast logo is clear on the logging curve shape. For the discontinuous example, Mr. Yuming Cao points out that "the solution of a continuous phase axis of seismic section is greatly increased after the singularity analysis; some continuous phase axis presents discontinuous layers".

For thin layers, it is needed to improve the resolution of seismic data. Generally speaking, the resolution can be improved by increasing signal-to-noise ratio, pressing low frequency wave and increasing high frequency and singularity analysis.

3.3. Seismic data can be used to restore the ancient structure
The ancient structure is used to guide the study of sedimentary face and then the layer correlation.

3.4. Seismic data for the layer correlation
It is an effective method to study the connectivity of layers combining seismic data with logging data, and they can do calibration each other.

4. Fault analysis
The following eight methods are used to judge the open or closure of a fault, and then to study layer connectivity.

4.1. Rock configuration analysis
It is a better manner to judge reservoir lateral sealing ability of a fault by the contact of the rocks of both sides of the fault.

4.2. Fault mechanics method
Checking the size of the positive pressure putting on fault surface is used to judge fault surface sealing ability.

4.3. The reservoir properties of two fault plate
If two sets belong to the same oil - gas - water system, the fault is open, and vice versa (figure 2).
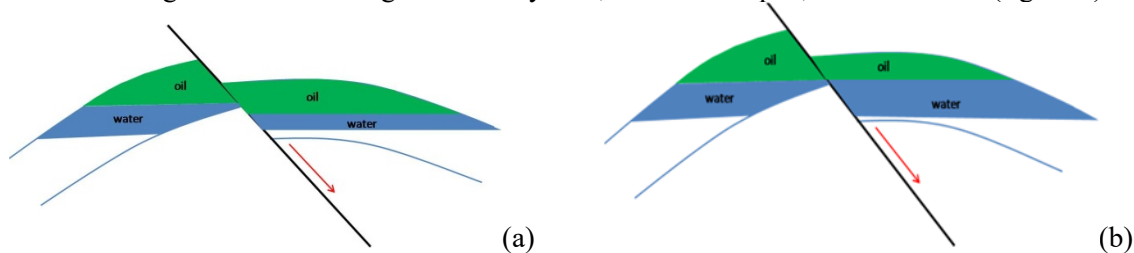

Figure 2. The different oil-water-gas system ((a) for two systems, (b) for one system).

4.4. Fluid inclusion research method
Put forward different depth samples of the fluid inclusions along the fault zone, determinate the homogenization temperature, and the time of the fracture fluid activity can be determined according to the fluid property, and then the fault opening and closing time may be obtained.

4.5. Acoustic time difference method
If the acoustic time of fault zone is same as that of the surrounding rock mass, the fault is closure, and vice versa.

4.6. Fault mudstone smear coefficient and seismic velocity spectrum recognition

It is based on reservoir shale content to do judgment, high shale content indicates better sealing ability of the fault.

4.7. Transverse fault sealing coefficient method
Using factors such as tectonic block, rock type and reservoir cap evaluates the ability of the sealing characteristics of fault plane.

4.8. Mathematic comprehensive evaluation method
It is a weighted method to judge the fault sealing ability by giving evaluation factors different weight.

5. The method using well logging curve comparison
Logging curve comparison method can more accurately describe reservoir connectivity than other methods.

Sedimentary face is the main factor for determining the layer logging curve shape, late digenetic changes modify the layer deposited lightly.

The connecting layer has almost the same logging curve shape, the curve shape of the different forms reflect different layers, which is the principle of judging layer connectivity. Well logging curve shape is a reflection of the layer characteristics; and layer characteristics is mainly decided by sedimentary environment, the research attracted the attention of many experts and scholars, a lots of forefathers research works have been done, forming a new discipline, namely log face. Mr. Zheng Ma generally studied log face, he summarized the logging curve shapes to 6 large phases, 21 secondary faces and 7 combined faces, which can be used to guide the study of the relationship between the logging curve shape and the sedimentary face. Face in single and multi-facies combination (rhythm) has different characteristics. Using well logging curve data, according to the principle of "cycle control, hierarchical contrast", the layers with the same (similar) curve shape and the same sedimentary face belong to the same single layer, as a connecting layer.

It is inappropriate to study the connectivity of a layer only considering the comparison of this layer, the similarity of layers above and below the single layer is also needed to be studied, which means not only to compare the single layer. If the layer is connected, the ideal conditions are as follows: 1.comparison mark clear and stable, 2.the segment length consists of several layers are equal or nearly equal, 3.rhythm like, 4.number of layers is equal, 5.depth trend of all layers is consistent, 6.curve shape of every layer is similar. There is no ideal condition in actual data, the nature is ever-changing, and change is eternal. The reasons causing the changes of a layer are the variation in thickness of sand body, fault, unconformity surface, layer bifurcating or merging, shale content change, and so on.

Logging face study is one of the methods of the research for sedimentary face, we also can use geography, outcrop observation and core observation, the cutting description, thin section identification, grain size analysis, palaeontology, heavy minerals, electron microscopy method, to do a comprehensive research of sedimentary face and establish the rock-logging curve shape-sedimentary phase relation in the region, guiding the contrast of layer.

The author advises to pay more attention to the traditional, conventional research methods for the sedimentary face, such as core study, it is more important with intuitive, fine, sensibility, and is the first hand information.

Log data for face research is rich, but the coring data is relatively small, pay attention to combine logging data and core data for study.

The analysis above is based on geology; the following analysis is mainly concerned with oil field development.

6. Pressure system
If the pressure characteristics are same in the reservoir, the layer is connected, and the oil-gas-water formed in it belongs to one system, and vice versa. It is needed to pay attention to the pressure test time for pressure recovery fully, so stable formation pressure can be obtained.

7. Oil-water-gas system

For different oil-water-gas system, the layers containing them are not continuous.

For the same oil-water-gas system, there are two kinds of circumstance：The first one is relatively simple, the sedimentary layers are connected; the second one is some complex, the layers may be not connected originally and be connected late. For example, there is a Jurassic reservoir, the original thick layers pinch out frequently, but due to the fault, fracture, unconformable surface, different layers form a unified oil-water interface. The layers are connected by later geologic reforms (figure 3).
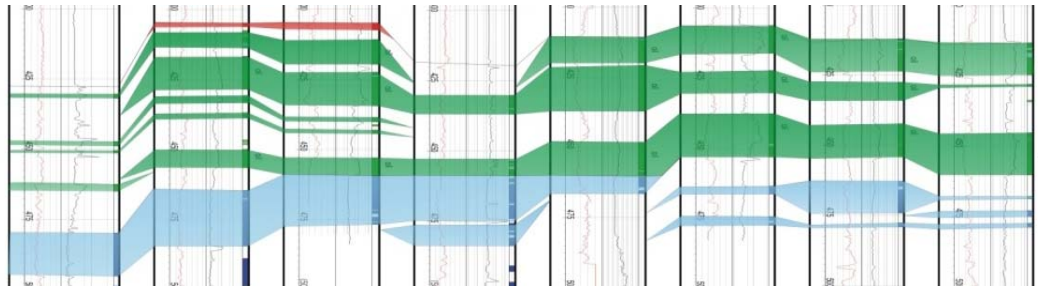

Figure 3. Not connected layers with unified oil-water interface.

8. Tracer test

Firstly, tracer is injected into the injection well, secondly, the oil-water samples are taken from the production well, thirdly, the samples are tested, finally, the connectivity is judged according to the test results. If the tracer is found in the sample, the layers are connected, and vice versa. If the well spacing, layer thickness, and injection condition is almost the same, the grade of connectivity may be judged according to the tracer flowing velocity. High velocity corresponds with good connectivity. The velocity is affected by clay content and its type, wet ability. The tracer is selected according to the chemical and biological stability, sensitivity, adsorption of layer, soluble, solubility in the reservoir fluid and pollution to the environment. The tracers used commonly are chemical, radioactive isotopes and trace substances.

9. Water Flooding Response

This method is available for water flooding development oilfield, the properties of production well response to injection well can be used to judge the connectivity between wells, good responsibility indicates better connectivity, and vice versa. Generally speaking, if the production well is effective to injection well, it mainly presents "four indexes increase and one index drop", "four indexes increase" refers to the increase of produced fluid, oil production, water cut, pressure, "one index drop" is the gas-oil ratio decrease. The amount of indexes increase or drop of wells differs largely. A research shows that the connectivity of layers is the main reason for the difference. There is an example of water flooding development block, the better the responsibility of production well responses to injection well is, the better the connectivity of the wells are. The responsibility indexes are response well number, action period, water flooding velocity, validity period and fluid increase, total oil increase. The study shows that the good indexes are concerned with good layer connectivity-type I (figure 4).
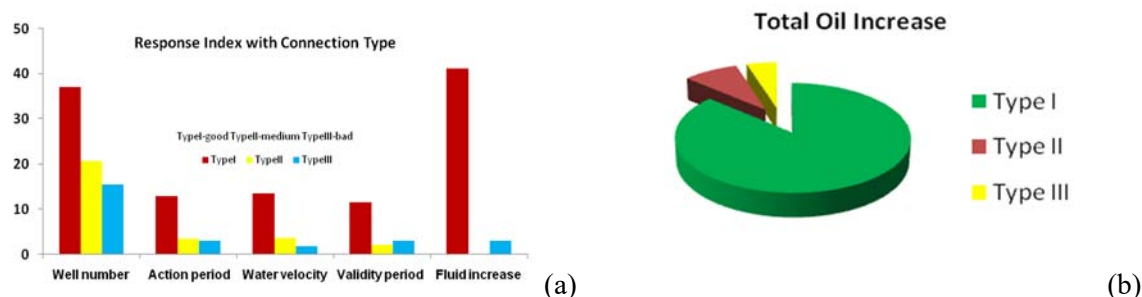
Figure 4. The responsibility of production well to injection well with connectivity type.

10. Geochemical indicators

If the reservoir layers are connected, they belong to the same closed system, and oil-gas-water has similar geochemical indicators, such as Na^+, Mg^{++}, Nitrogen compounds, the total salinity, water type, etc.

The use of the method

As presented above, there are nine judgment methods, every method has its characteristics and limitations and the applications of various methods unavoidably are restricted by the actual data obtained from oil field.

For the perspective of the method sequence, method 1-4 are used before the production of oil and water Wells, it is the study in the first time; Methods 5-9 are used after putting wells into production, it can judge the results of method 1-4, and is the subsequent methods.

In actual application, the author advises that the sedimentary environment and seismic data analysis method are used to grasp the reservoir layer distribution in larger range (on the plane and vertical). Well logging curve shape contrast is the fundamental, exact, main method, the pressure system, oil-gas-water system and others are the auxiliary judgment methods.

11. Conclusion

The study of reservoir connectivity is a comprehensive, fundamental work, which requires lots of research work, especially for a complex oilfield, which is the key of the oil field geological research. The work should be done according to actual condition of your specific oil field. It is a wise consideration to invest in early research than trying to fix up the problems on latter days.

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