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## **Integrated Reservoir Characterization of Thin Bed Reservoir in Desert Area\***

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### **Abstract**

Located in the center of Taklimakan Desert, the seismic data in Tarim Oilfield are of low SNR and low resolution. As an oil field with more than two decades' production, Tarim Oilfield faces problems of complex structural pattern, reservoir heterogeneity, declining production and rising water cut as well. Aiming at these problems, an integrated reservoir characterization workflow is formed during this study. This method integrates the techniques of surface seismic, VSP, well logging and reservoir dynamic analysis to solve reservoir development issues and reduce the uncertainty in the prediction of remaining oil in the reservoir. Among the techniques, the resolution enhancement procedure with VSP-driven processing and relative preserved processing is the basis for the subsequent steps. This measure can best remove the influences of earth absorption and near surface impact to get a high-resolution image while relatively preserving reservoir amplitude, frequency, phase and wave form. Based on the high-resolution seismic data and well logging data, with correct geological concept and proper interpretation technique, several minor faults are detected and both the structural and sedimentary isochronous stratigraphic frameworks are established. Under this isochronous stratigraphic framework, the reservoir static model is established with the calibration of well logging and seismic data. Finally, under this reservoir static model, the reservoir production data analysis is carried out to detect thin inter-bed reservoirs, to predict the distribution of residual oil and to optimize the development plan. The integrated reservoir characterization workflow proposed in this paper has been successfully applied to Tarim Oilfield. Four stages of fault activities are recognized and several minor faults which affecting the oil-water relation are found during the study. In addition, the drilling results show that the relative error between wells and structural map is controlled within 1.29% using the integrated methods mentioned above. Finally, with the analysis of reservoir production data and seismic inversion results, the spatial distribution of residual oil is predicted and several favorable areas are pointed out. This paper provides an effective way of seismic data processing, structure interpretation and reservoir characterization for oilfields in desert area with thin inter-bed reservoirs and long production history.

## Introduction

Old oilfields in China have successively entered into the middle to late stage of oil production (Lin et al, 2011). Affected by complex structural pattern, strong reservoir heterogeneity, declining production and rising water cut, large amounts of remaining oils are still resorted in the subsurface and they have laid an important material foundation for a long-term stable yield in old oilfields. For the old oil fields in desert areas, although detailed reservoir description is an effective way to solve reservoir development issues and reduce the uncertainty in the prediction of remaining oil in the reservoir, the characterization of thin-bedded reservoirs with strong heterogeneity are not that easy to carry out. It calls for the integration of surface seismic, VSP, seismic interpretation, well logging and reservoir dynamic analysis.

Located in the center of Taklamakan desert ([Figure 1](#)), the seismic data of Tarim oilfield are of low SNR, and are largely affected by the condition of near surface. In addition, as an old oil field with more than two decades' production, it also faced with the problems of complex structural pattern, reservoir heterogeneity, declining production and rising water cut as well. Therefore, this paper takes an old oil field in Tarim oilfield as an example to explore an integrated reservoir characterization workflow for other old oil fields in similar situation.

## Case study

### 1) Resolution enhanced processing

In this research, the purpose of the seismic processing is to remove spatial variations of reflected energy, frequency, phase and wavelets caused by near surface, and source variation. In addition, we were trying to compensate the subsurface absorption as much as possible, and then obtain spatially relative variations of a reservoir with a high-resolution image. During the study, the VSP-driven seismic processing workflow proposed by Ling Yun, etc. are choose, it including three key steps: ZVSP parameter extraction, VTI and HTI parameter extraction using WVSP and 3DVSP data and VSP-driven surface seismic processing. After these three steps, the influences of earth absorption and near surface impact to get a high-resolution image while relatively preserving reservoir amplitude, frequency, phase and wave form.

By comparing the seismic section of conventional processing ([Figure 2a](#)) and VSP-driven surface seismic processing ([Figure 2b](#)); it is easy to see that the data processed by VSP-driven surface seismic processing has a relatively high seismic apparent dominant frequency. What's more, in the section after VSP-driven surface seismic processing, the reflection events within the target interval are more continuous and the SNR and quality of image in the deep formation are improved dramatically. Since the full-azimuth seismic acquisition was used this time, the locations of the faults are clearer and more minor faults can be detected. For the study is aiming at the thin bed reservoirs, the VSP-driven surface seismic processing pays more attention to the relative preservation of reservoir information, and to widen the seismic wave band as much as possible in this principle, and a wider wave band is more benefit to the research of reservoirs.

## **2) Minor faults detecting**

The research area has experienced multiphase tectonic evolution, different kinds of faults under different geologic stress in different time. In previous research, most of the faults are interpreted as reverse faults, while this time, a set of normal faults are recognized ([Figure 3](#)). In addition, this set of normal faults is considered to be closely related to the accumulation and distribution of oil in CI oil group.

Affected by the condition of near surface in desert area, the dominant frequency of seismic reflection is relatively low, therefore, rising the dominant frequency and using the right seismic attribute are effective ways to get a better fault interpretation result. [Figure 4](#) shows the display results of faults location by different seismic attributes, it is clear that the location of faults in fault shape attribute is much clearer than that in coherence attribute. Therefore, this study uses the VSP-driven surface seismic processing to interpret faults vertically, and using the fault shape attribute to determine the horizontal distribution of faults. By this means, much more minor faults are detected this time than the year 2012 ([Figure 5](#)).

To summarize, the faults developed in the research area have the following characteristics. Firstly, during the late stage of Caledonian movement, normal faults with NW trending were well developed in Tazhong area. These normal faults cut through the lower Paleozoic sediments, and the fault movement lasted to late Hercynian period. Secondly, the NE trending strike-slip faults developed in the early Hercynian period might be the main oil source faults. What's more, the middle to late Hercynian period are the main developing stages of reverse faults in Tazhong area, of which the No. 4 reverse fault controlled the tectonic features of the whole area. Finally, the wide spread volcanoes in Permian formation indicate the tensional tectonic environment in this period. The normal faults generated by Caledonian movement were developed successively, and showed the characteristics of strike-slip faults. The minor normal faults developed in CI oil group during this period play a very important role in the migration and accumulation of reservoirs in CI oil group.

## **3) Geostatistical inversion and sandbody distribution**

Geostatistical inversion integrates high-resolution well data with low resolution 3-D seismic, and provides a model with high vertical detail near and away from well control. This generates reservoir models with geologically plausible shapes, and provides a clear quantification of uncertainty to assess risk. Geostatistical inversion integrates data from many sources and creates models that have better resolution than the original seismic, match known geological patterns, and can be used for risk assessment and reduction. Compared with seismic attributes, using geostatistical inversion can avoid the non-uniqueness of lithology.

Limited by the thin bed reservoir and low seismic dominant frequency seismic data, this study uses geostatistical inversion to predict the distribution of sandbody, which avoids the non-uniqueness of impedance inversion. The inversion results not only match with the verification wells but also meet the needs of expanding the distribution of sandbody. On the section of geostatistical inversion, the thin inter-bed reservoir can be detected, and the sandbodies, which are thought to be connected before, can be separated now ([Figure 6](#)).

Taking layer A as an example, based on the probable lithologic distribution from geostatistical inversion ([Figure 7a](#)), and combined with the research of sedimentary facies, we assume that the places with the probability over 0.5 are covered with sand. With this assumption, the sandbody distribution in layer A can be predicted, and the sandbody pinch-out boundary can be drawn ([Figure 7b](#)).

#### **4) Residual oil distribution**

Since not all the sandbodies are filled with hydrocarbons, it is necessary to distinguish reservoir sands with the ordinary ones, and then predict the distribution of residual oil. First, we need to decide which kind of reservoir we are studying. From the north-south reservoir profile ([Figure 8](#)), we can see that the two wells on the north are on a relatively lower position; the oil layers are much thicker. The analysis of the production performance of these two wells presents a feature of high production and low watercut, the fault between them are not sealed. While the adjacent well on the same profile are on a higher position but the reservoirs are filled with water, therefore, we believe that the sands developed in those three wells are not belonged to the same set of sandbody. Therefore, we assume that the reservoir on the north of the studying area is lithologic reservoir. Similarly, from the east-west reservoir profile ([Figure 9](#)), we can see that the oil layers are controlled both by the structure and by lithology, the reservoir on this profile is structural-lithologic reservoir. Therefore, two types of reservoirs are developed in the research areas, which are lithologic reservoir and structural-lithologic reservoir.

With the understanding of reservoir types, based on the sandbody distribution and sand top structural map, two sets of reservoir sands were delineated (as is shown in [Figure 10](#)), and the residual oil distribution has been predicted. Trough the predicted distribution of residual oil, the predicted reserve has been increased by 40%; this gives the old oil field new development potential.

### **Conclusions**

After the whole workflow of integrated reservoir characterization, the following conclusions can be drawn:

1. The joint processing of VSP-driven and relative preserved processing can best remove the influences of earth absorption and near surface impact to get a high-resolution image while relatively preserving reservoir amplitude, frequency, phase and wave form. In addition, the results of the joint processing can meet the need of interpretation in desert area.
2. Based on the high-resolution seismic data and well logging data, more minor faults can be detected and both the structural and sedimentary isochronous stratigraphic frameworks can be established.
3. Using geostatistical inversion to predict the distribution of sandbody can meet the need to detect the thin inter-bed reservoirs and expand the distribution of sandbody.
4. Combining with the reservoir classification and the production of developing wells, we can predict the distribution of residual oil and optimize the development plan.

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Figure 1. Location of the studying area.



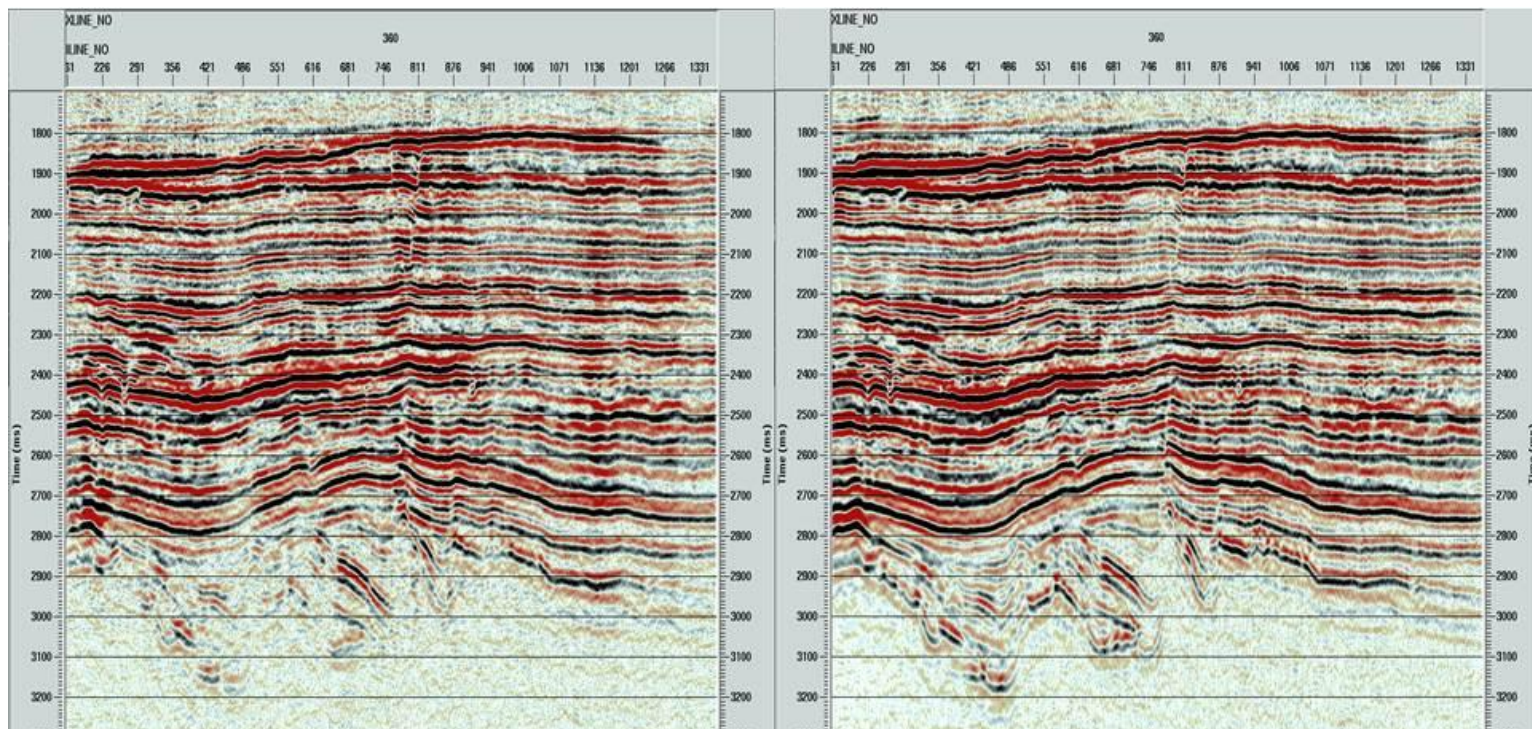


Figure 2. Seismic section comparison of two methods of processing (crossline) a)conventional processing; b) VSP-driven surface seismic processing.

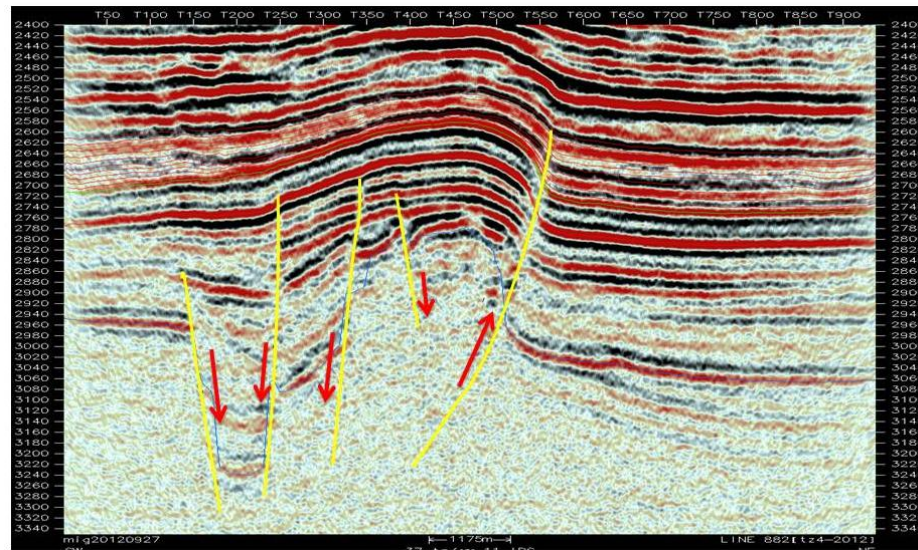


Figure 3. Faults interpretation on seismic section.

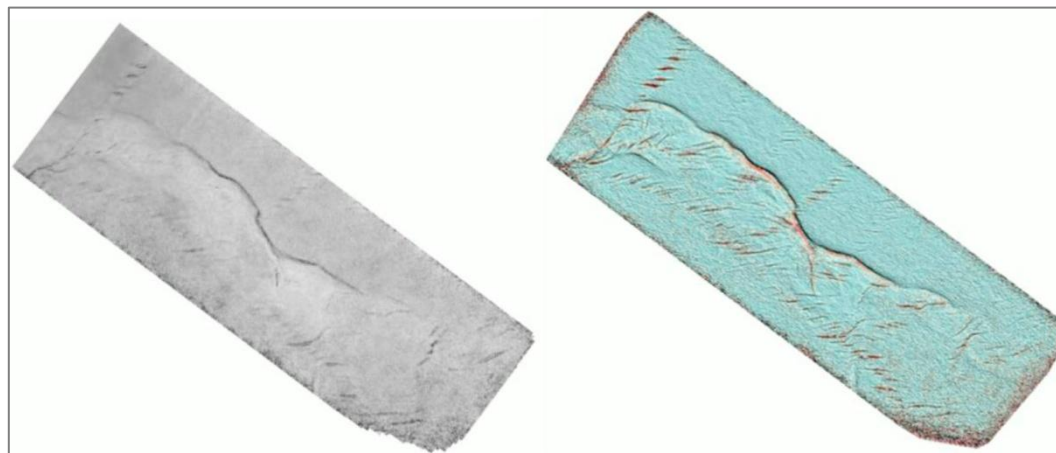


Figure 4. Faults' location on different seismic attributes a) faults display in coherence attribute slice; b) faults display in fault shape attribute slice.





Figure 5. Comparison of fault distribution a) fault interpreted in 2012; b) fault interpreted in 2012.

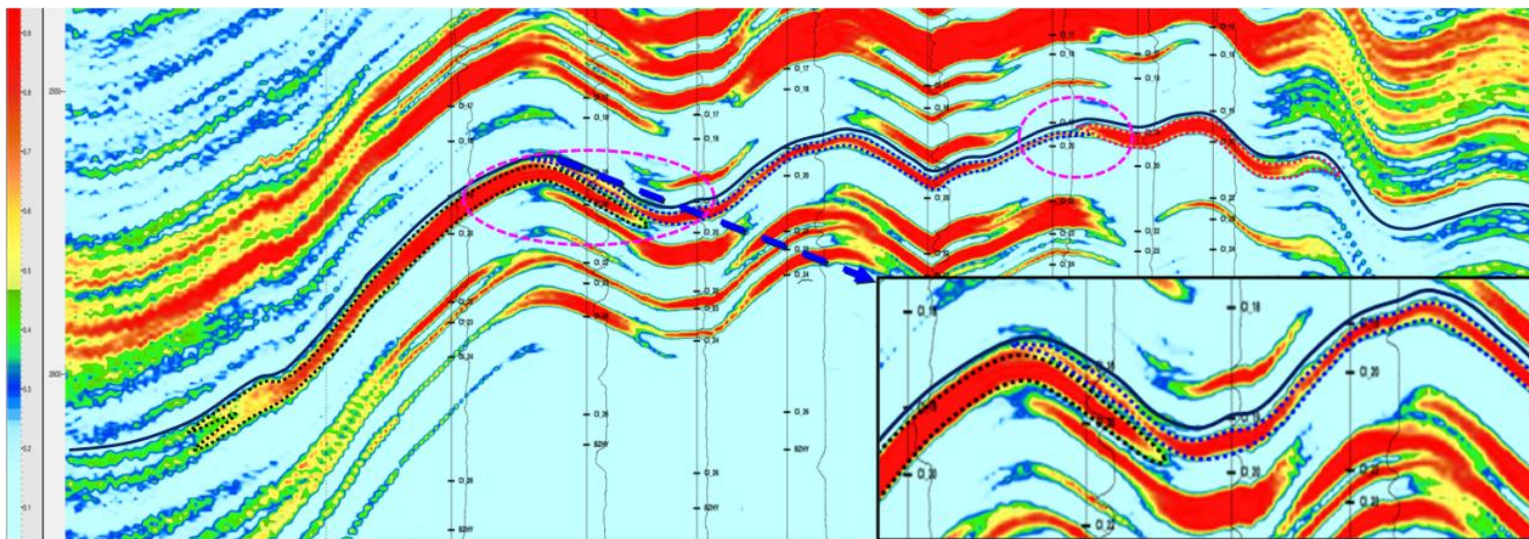
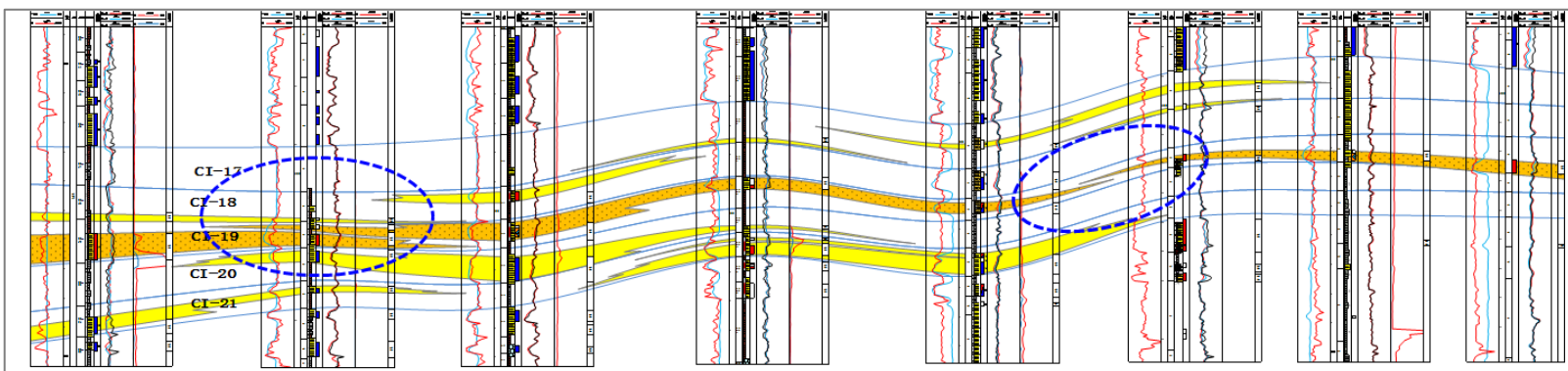


Figure 6. Different shapes and distribution of sandbodies by different means; a) distribution of sandbody on the geostatistical inversion section;



b) the well logging interpretation of sandbodies.

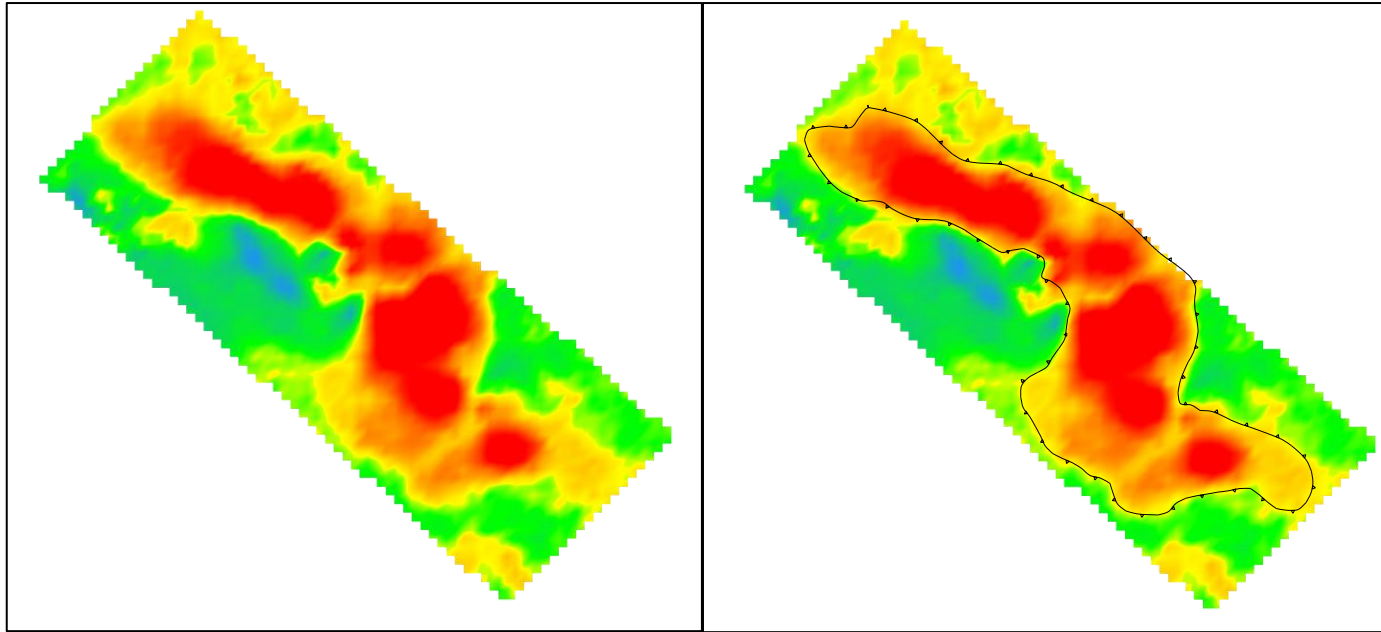


Figure 7. a) Lithology probability of sandbody; b) Sandbody pinch-out boundary.

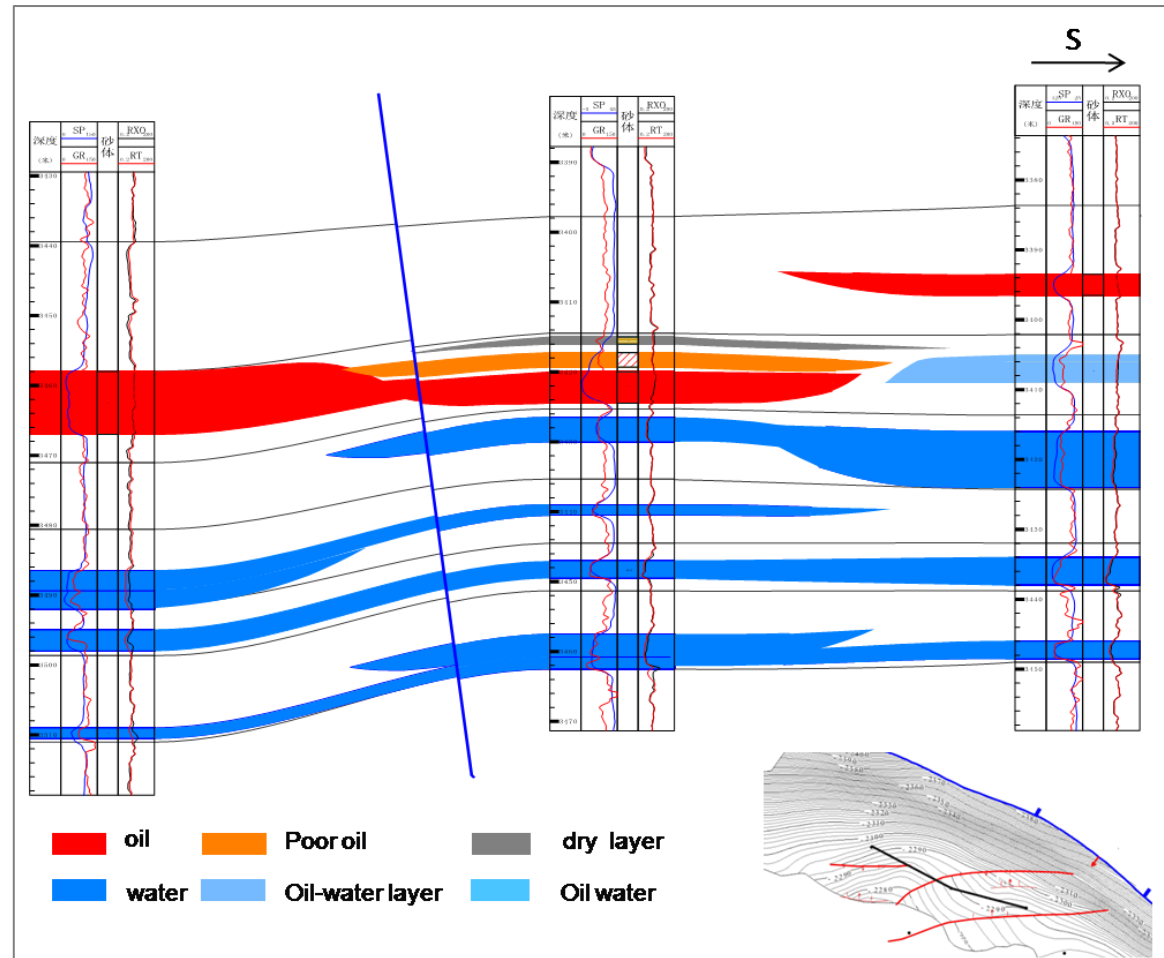


Figure 8. Reservoir profile of layer A (north to south).



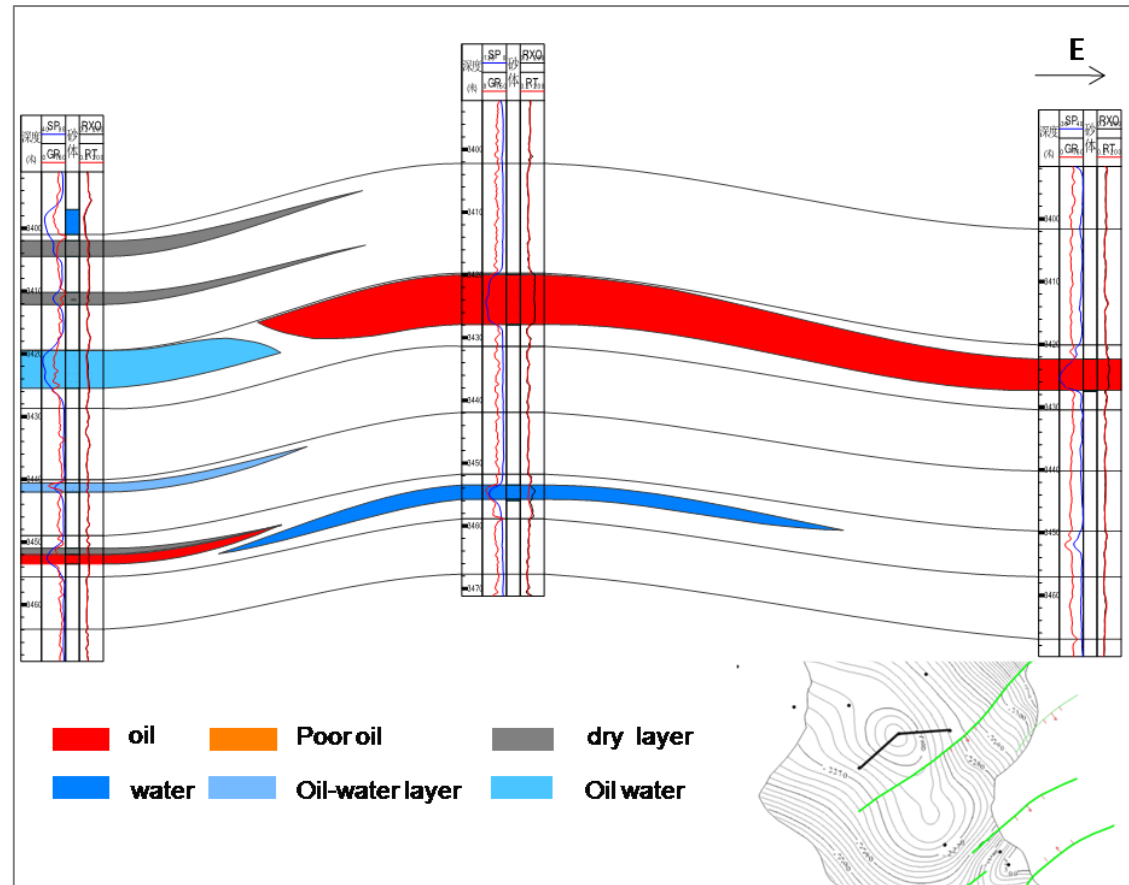


Figure 9. Reservoir profile of layer A (west to east).

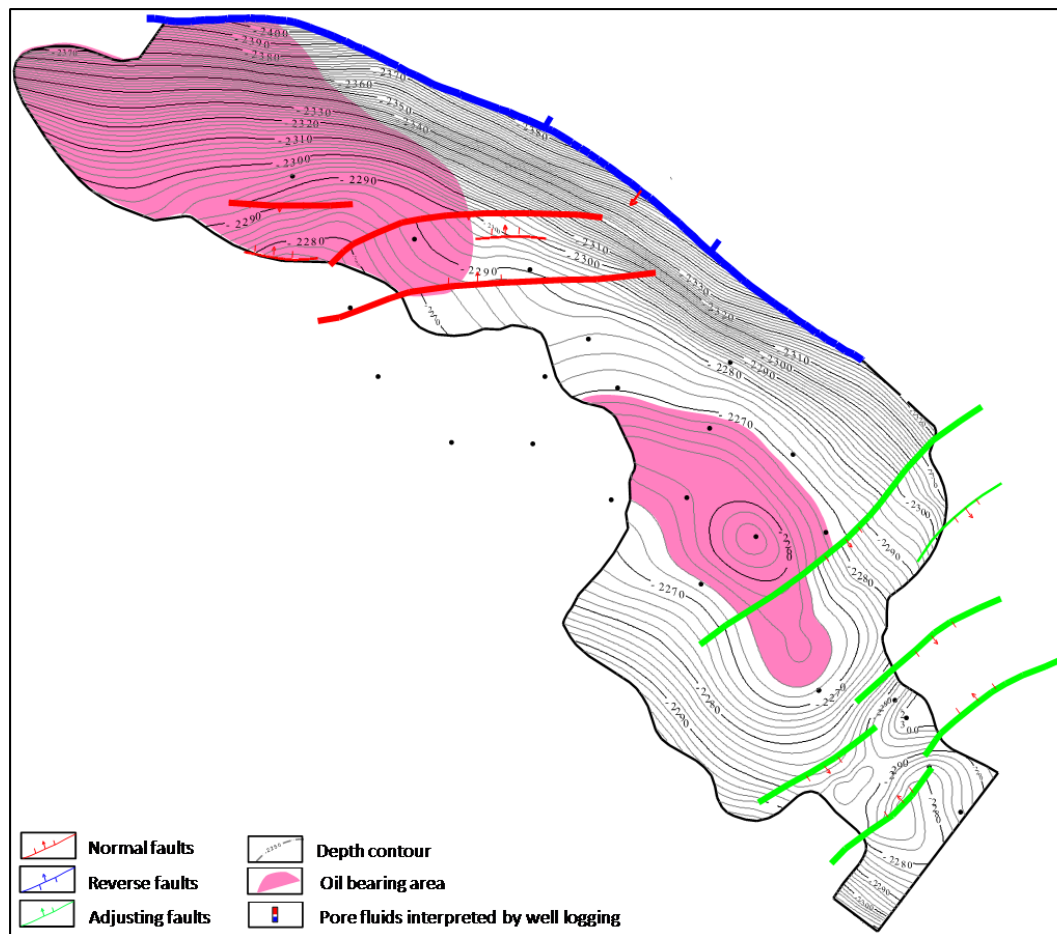


Figure 10. Predicted residual oil distribution of layer A.