ISSN 2616-5872 Vol.5, Issue 3: 1-6, DOI: 10.25236/AJEE.2023.050301

# Application of trend surface analysis to reservoir distribution in Wayaopu Oilfield

**Ma Huiyan**

*School of Earth Sciences and Engineering, Xi'an Shiyou University, Xi'an, China*
*hhhhyve@hotmail.com*

***Abstract:*** *In order to determine the distribution of oil reservoirs, the trend value and residual value of the top structure and layer thickness of Chang-6 in Wayaopu Oilfield were analyzed by using the method of trend surface analysis, and the relationship between oil well distribution, production, structural location and residual value was comprehensively analyzed by combining the existing geological data. This study uses the method of mathematical modeling to deepen the study of reservoir distribution law through existing data. The results show that the existing oil wells have obvious combination characteristics on the structural residual trend and thickness residual trend. Most oil wells in the structural positive residual area and the thickness negative residual area have high productivity, and the structure has become the main factor to control the oil well productivity. Through the significance test, it is proved that the mathematical model conforms to the actual geological conditions and has guiding significance for the distribution of oil reservoirs in the study area.*

***Keywords:*** *Trend surface analysis; Wayaopu Oilfield; Reservoir distribution law; Trend surface; Residual analysis*

## 1. Introduction

In the process of exploration and development in Qujiagou oil field of Wayaopu Oilfield, the complex oil-water relationship in this area has gradually been exposed. The statistical results of oil test and production test show that the daily oil production per meter of the Chang-6 oil layer group in Qujiagou block is generally low [1], and the heterogeneity of the reservoir is strong [1-2], resulting in the increasingly complex distribution of oil and gas in the vertical and horizontal distribution. The predecessors have carried out basic geological research on this block, but have not further analyzed and predicted the favorable areas for exploration and development in this area. Therefore, it is necessary to use appropriate methods to predict the favorable areas.

In order to determine the distribution of oil reservoirs, the geological model that conforms to the actual geological conditions can be established by analyzing the layer thickness and top elevation of Qujiagou Chang-6, and the scientific method of trend surface analysis can be used to discover the distribution law of oil reservoirs. On the other hand, because the overall terrain of the study area is flat and monoclinic, it is difficult to identify low-amplitude structural traps, and it is impossible to determine the possible accumulation area of oil and gas, and the law of reservoir distribution needs to be studied. Therefore, the method of trend surface analysis can be considered to identify the possible distribution of oil reservoirs to provide direction for development. The mathematical geological method of trend surface analysis has been widely used in the exploration and development of oil reservoirs. The effectiveness of this method has been proved by the successful practice of many scholars [3-4]. The application of this method in Qujiagou area of Wayaopu Oilfield, combined with the existing oil production data, also proved the feasibility of this method.

## 2. Geological Background

Wayaopu Oilfield is located in the middle of the northern Shaanxi slope of the Ordos Basin. This area is located in the northern Shaanxi slope structural zone, and the stratum is flat (Fig. 1). The thickness of each sub-layer of Chang-6 formation has little change. From the perspective of basin structural characteristics, the basin falls in the west and rises in the east, rises in the east and falls in the west. The overall trend is relatively gentle, showing a gentle monocline dipping westward, with an average slope of 1.0 m/km and an inclination of less than 1 ° [5].

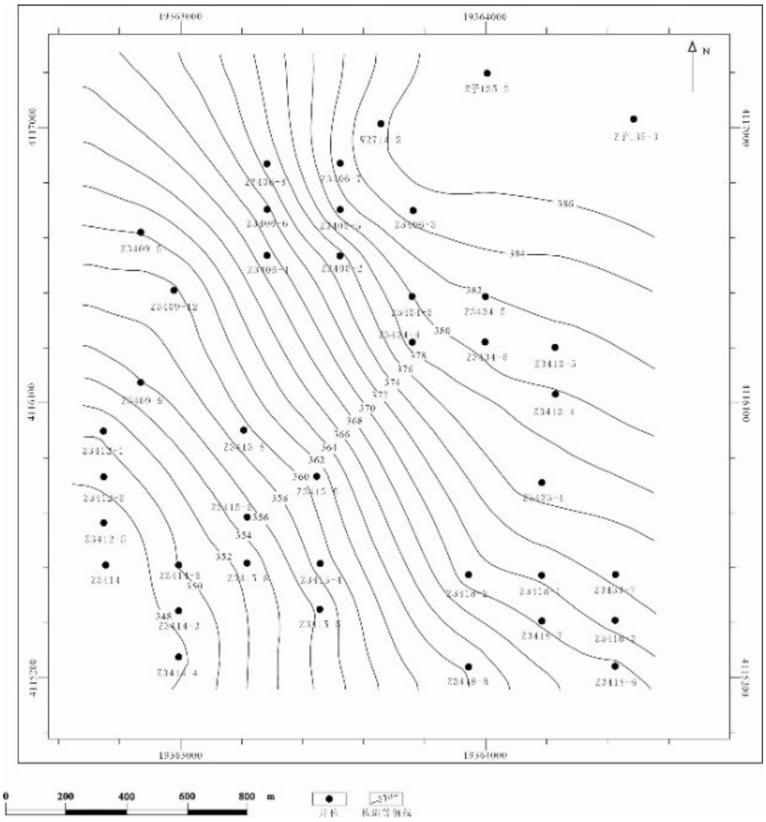

*Figure 1: Structural Drawing of Qujiagou Chang-6 Top Surface*

The stratum thickness in this area is stable, and the lithology is mainly gray and gray-white thick layer-block fine sandstone, medium-fine sandstone, siltstone and gray and dark gray silty mudstone, mudstone interbedding with different thickness. The thickness of single sand body varies from 2 to 20 m. It is divided into four oil reservoir subgroups. The sedimentary environment of Chang-6 in this area is delta. Since the lake basin began to shrink, the delta front gradually changed from Chang-6-4 to Chang-6-1 to delta plain [5].

Due to the uneven thickness of the sand body in this block, the distribution of oil and gas has not been determined. In order to further determine the possible enrichment areas of oil and gas in this area, the trend chart and residual chart of the thickness of the Chang-6 horizon and the Chang-6 top structure of 44 production wells in this block are made by using the method of trend surface analysis, so as to study and analyze the reservoir types in this area.

## 3. Basic principle of trend surface analysis

### *3.1 Basic Mathematical Principles*

Trend surface analysis is a statistical analysis method. Its basic mathematical principle is to use known variables to fit a mathematical surface, that is, "trend surface", to make the surface infinitely close to the actual surface [6]. In the process of trend surface analysis, three important values are involved, namely trend value, residual value and fitting degree. The trend value reflects the regional changes in a large range, such as the regional tectonic background; The residual value reflects the characteristics of local changes, and the residual value can be used to find local abnormal zones, providing a good reference value for studying the oil and gas distribution in the region [7]

Assume that the geological variable z has been observed for n times, and n groups of observation values $(x_i, y_i, z_i)(i = 1, 2.3, \cdots, n)$ are obtained, and the polynomial surface equation can be obtained from n groups of observation values. Namely

$$\hat{z} = b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 + \cdots \quad (1)$$

ISSN 2616-5872 Vol.5, Issue 3: 1-6, DOI: 10.25236/AJEE.2023.050301

Where, $\hat{z}$ is the trend value of geological variable $z$, x, y is the geographical coordinate of geological variable z, and $b_0, b_1, b_2, \cdots, b_m$ is the polynomial surface equation coefficient that can be obtained from n groups of observation values.

To minimize the $\sum_{i=1}^{n}\left(z_i - \hat{z}_i\right)^2$ of the sum of squares of the total deviation, the coefficient $b_0, b_1, b_2, \cdots, b_m$ of the polynomial surface equation can be obtained through the extreme value principle, and the polynomial trend surface equation can be obtained.

### *3.2 Fit of trend surface*

The fitting degree of the trend surface refers to the overall approximation degree between the trend value on the observation point and the measured value. Remember

$$Q = \sum_{i=1}^{n}\left(z_i - \overline{z}\right)^2, Q_2 = \sum_{i=1}^{n}\left(\hat{z}_i - \overline{z}\right)^2 \qquad (2)$$

Where, is the observed value and trend value of the geological variable at the second observation point; Is the average of the observed values of geological variables.

Define

$$C = \frac{Q_2\left(b_0, b_1, \cdots\right)}{Q} \times 100\% \qquad (3)$$

is the fitting degree of the trend surface.

Generally speaking, the higher the frequency of the trend surface used, the higher its fitting degree, indicating the higher the coincidence between the trend value and the observed value, but it should also be analyzed according to the specific situation.

According to the above principles, the fitting degree of the thickness primary trend surface in this analysis is about 11.17%, the fitting degree of the secondary trend surface is about 12.5%, and the fitting degree of the tertiary trend surface is 80.66%. The fitting degree of the first trend surface of the structure has reached 95.8%, and the fitting degree is good. At the same time, it also shows that the Chang6 horizon in the study area is a gentle slope.

### *3.3 Residual analysis*

The residual analysis refers to the analysis of the residual map made by the residual value data, so as to find the abnormal zone in the map and further explain the geological significance of the abnormal zone. The residual value at point is the difference between the observed value and the trend value, namely

$$\Delta z_i = z_i - \hat{z}_i \qquad (4)$$

The residual map made by the residual analysis can be used to find out the abnormal zones of the block, which are often related to specific geological conditions, such as oil generation conditions [7]. Therefore, the residual map can reflect the change characteristics of the reservoir top and bottom of the micro structural trend surface of the reservoir and the relative height of the reservoir interface in local small areas. By analyzing the local height of the reservoir, we can study its impact on the production performance and remaining oil distribution of the oilfield [3].

### *3.4 Significance test*

To check whether the trend surface established before is meaningful, you can check:

$$F = \frac{Q_2\left(b_0, b_1, \cdots\right) / \left(L-1\right)}{\left[Q - Q_2\left(b_0, b_1, \cdots\right)\right] / \left(n-L\right)} \qquad (5)$$

ISSN 2616-5872 Vol.5, Issue 3: 1-6, DOI: 10.25236/AJEE.2023.050301

Obey $F\left(L-1, n-L\right)$ distribution. Where, L is the number of coefficients of polynomial trend surface equation, and n is the number of observation points.

Through the above significance test, at the significance level α When it is 0.05, $F > F_{\alpha}$, it is considered that the change of trend surface response variables is significant, and the established trend surface is reliable.

In order to ensure that the mathematical model can match the actual situation well, it is necessary to meet certain constraints to ensure the accuracy of the established model and the conclusions. Therefore, the following points should be paid attention to in the process of combining the model with practice:

1) The number of observation points should be much more than the number of terms of the polynomial trend surface equation. The maximum number of terms of the cubic trend surface equation is 10. The number of 44 production wells studied has met the requirements.

2) Because the horizontal and vertical coordinates of the observation points in this analysis are of large magnitude, it is easy to cause large differences in the magnitude of each parameter in the calculation process. Therefore, the horizontal and vertical coordinates should be appropriately adjusted to maintain the same magnitude to prevent overflow.

3) Generally, the trend surface map made may have boundary effect, so some results of the boundary effect area cannot be used for geological interpretation, at most as a reference.

## 4. Trend surface analysis results

### *4.1 Trend surface characteristics*

The third polynomial trend surface analysis and the first polynomial trend surface analysis are made for the thickness and top elevation of the stratum of Chang6 in this area, so as to make the third polynomial trend surface map of thickness and construct the first polynomial trend surface map, and analyze them.

It can be seen from Figure 2(1) that the thickness trend values in the northeast and southwest regions of the study area are high, while the thickness trend values in the southeast region are low, and the central region of the study area is in the middle. On the other hand, it can be inferred that the provenance of the study area comes from the northeast and southwest directions through the thickness cubic trend surface map, which provides a reference for the study of provenance direction of the study area.

From Figure 2, we can see the basic characteristics of the terrain change in the study area. The tectonic setting of the study area is a west-dipping monocline, the trend value from west to east is constantly increasing, the terrain is flat, and the tectonic change is single. Then through the positive and negative residual areas of the structural residual map, we can analyze the type and possible distribution of oil reservoirs in this area, better identify the local high and low points of the structure in this area, and study the significance behind it, so as to provide direction for the exploration and development of this area.

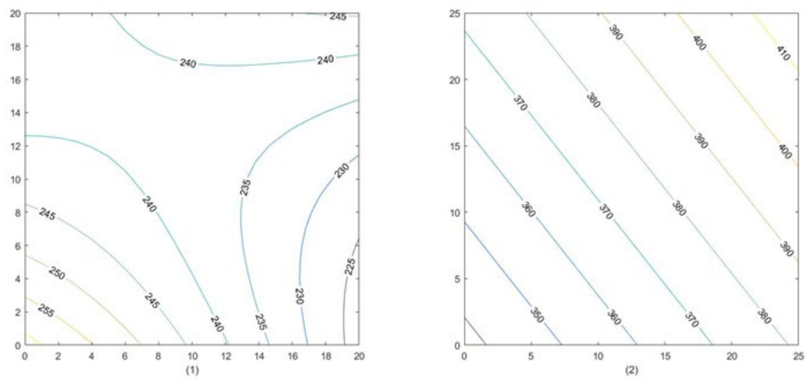


*Figure 2: Thickness tertiary trend surface (1) and tectonic primary trend surface (2)*

ISSN 2616-5872 Vol.5, Issue 3: 1-6, DOI: 10.25236/AJEE.2023.050301

### *4.2 Structural trend surface and reservoir distribution*

Through calculation, it is obtained that the equation of constructing the first trend surface is:

$$\hat{z} = 377.09 + 1.77x + 1.39y \tag{6}$$

The fitting degree of the trend surface is $C = \frac{Q_2}{Q} = 95.8\%$ , and the significance test is $F = \frac{7745.3/(3-1)}{338.12/(44-3)} \approx 469.41$ , $F > F_{0.05}(2,41) = 3.226$ , indicating that it is at the significance level $\alpha = 0.05$ Next, the trend surface fitting is significant, and the construction of a trend surface is reliable.

Through the analysis of the structural trend residual contour map, we can find that the positive residual area of the block is to the east of the area, and is in a zonal distribution. The boundary between the negative residual area and the positive residual area is well distinguished. Oil and gas have been found in 44 production wells in this block, but the output varies. Through the analysis of production and structural residual map, it is found that the production of a large part of oil production wells in the positive residual area of the structure is higher than the average production, and these wells are located at the high point of the positive residual area. It shows that the distribution of oil reservoirs in this area is likely to be affected by structural factors, and the main oil reservoir type is structural oil reservoir. Through the structural trend residual contour map, the underground reservoir microstructure can also be determined, highlighting its local high and low points. The positive residual area of the structure can not only find the rules of reservoir distribution, but also serve as a favorable position for the distribution of residual oil in the later stage of oilfield development, providing reference value for the development of residual oil. [4]

Further analysis shows that there are individual wells with high production in the low value area of negative residual area, indicating that structure is not the only factor affecting the distribution of oil reservoirs. The residual map of thickness trend surface can be used to further study the factors affecting the distribution of oil reservoirs in this block, and the lithology can be used as a guess.

### *4.3 Thickness trend surface and reservoir distribution*

Through calculation, it is obtained that the equation of constructing the first trend surface is:

$$\begin{aligned}\hat{z} &= 261.66 - 1.53x - 2.47y - 0.02x^2 + 0.12xy + 0.06y^2 \\ &-9.6\times10^7 x^3 - 3.1\times10^5 x^2 y + 4.4\times10^5 xy^2 - 3\times10^5 y^3\end{aligned} \tag{7}$$

The fitting degree of the trend surface is $C = \frac{Q_2}{Q} = 80.66\%$ , and the significance test is $F = \frac{6475.66/(15-1)}{1552.82/(44-15)} \approx 8.6384$ , $F > F_{0.05}(14,29) = 2.050$ , indicating that it is at the significance level $\alpha = 0.05$ Next, the trend surface fitting is significant, and the construction of a trend surface is reliable.

The analysis of thickness trend surface can help to understand the lateral change of formation lithology and study the relationship between oil and gas enrichment. It is generally believed that the area with positive residual trend of thickness is the area with larger sandstone thickness and more layers on the overall sedimentary background, such as the main channel and its main migration area [8].

By analyzing the residual contour map of the thickness trend surface, we can observe that the positive residual area of thickness is blocky, distributed in the west of the central part of the study area, and the negative residual area is located in the southeast of the central part. The wells with high production are located in the positive residual area, indicating that the lithology of the area affects the distribution of oil reservoirs. However, only a small number of wells exist in the area with positive residual thickness, indicating that lithology has a low impact on reservoir distribution. Combined with production analysis, it is found that structural factors have a high degree of influence on reservoir distribution.

The above analysis shows that the reservoir types of the Chang-6 layer can be divided into three types:

ISSN 2616-5872 Vol.5, Issue 3: 1-6, DOI: 10.25236/AJEE.2023.050301

(1) The reservoir mainly affected by the structure is mainly characterized by the positive structural residual trend. This type of reservoir has a high output (part of the thick black coil), which can be used as the preferred key area for exploration and development, and has important guiding significance for the optimization of favorable areas; (2) The oil reservoir mainly affected by lithology is mainly characterized by a positive thickness surplus trend, and the highest point of the thickness surplus area may also have oil wells with high productivity. It can be used as a secondary option for exploration and development; (3) The oil reservoir affected by both structure and lithology is mainly characterized by both positive structural residual area and positive thickness residual area.

## 5. Conclusions

Through the statistics and analysis of the production and the number of wells in the remaining area, we can find the relationship between the production and the structure, and between the thickness of the positive and negative remaining areas and the production, so as to put forward suggestions for drilling arrangement that can be considered:

(1) The drilling shall be arranged in the positive residual area of the structure. Combining structural residual map with production, it is found that the production of positive structural residual area is relatively high, which indicates that the oil reservoir in this block is greatly affected by structural factors, and priority should be given to the development of positive structural residual area.

(2) It is better to arrange near the high point of the positive residual area of the structure. The positive residual area of the structure has certain advantages. It is further found that the area with residual value greater than 3.5 m has higher production and is an ideal development area.

(3) It is better to drill in the remaining area with negative thickness trend. Although the structural residual area is an ideal area, some areas are affected by lithology, and the distribution of oil reservoirs will change accordingly, which is of reference significance.

To sum up, it is hoped that the largest area is the area with positive structural residual trend and negative thickness residual trend, and further development of this block can be given priority.

## References

*[1] Li Yan. (2013). Study on reservoir characteristics and oil layer distribution law of Chang-6 oil layer formation in Qujiagou block, eastern Ordos basin. Unpublished master's thesis, Northwest University, Shaanxi, China.*

*[2] Zhang Xinbo (2015). Geological Study of Yanchang Formation in Qujiagou Oil Region of Wayaopu Oilfield. Unpublished master's thesis, Xi'an Shiyou University, Shaanxi, China.*

*[3] Li Xinfeng. (1999). Application of trend surface residual analysis in the study of reservoir microstructure. Daqing Petroleum Geology and Development, (06):12-14+53.*

*[4] Wang Fengqi. (2016). Application of two-dimensional trend surface analysis in micro-amplitude structure identification. Resource development and market, 32(08):907-910+1026.*

*[5] Yang Hua. (2012). Triassic sedimentary geology and reservoir distribution in Ordos basin. Beijing: Science Press.*

*[6] Chen Liguan. (1981). Preliminary application of mathematical geological method in oil exploration of monoclinic zone in northern Jiuxi basin. Oil and gas geology, (04):351-358.*

*[7] Wang Yachun. (2015). Mathematical geology of oil and gas, Beijing: Petroleum Industry Press.*

*[8] Liu Xiuzhen. (1996). Discussion on the control factors and types of natural gas reservoirs in YG gas field by trend surface analysis. Petroleum geophysical prospecting, (4):87-96.*