

# Study on the Reservoir Interlayer in The Southern Part of Tianci Bay in the Ordos Basin

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**Abstract:** The study of reservoir interlayers is an indispensable content to reveal reservoir heterogeneity. The main formation of Chang 4+5 in Tianciwan South Oilfield of Jingbian Oil Production Plant has entered the development stage of high water cut, and the distribution of remaining oil is complex. In order to meet the needs of oilfield development and production, it is necessary to study the development status of interlayer in this formation. At present, the study of interlayers mainly relies on manual analysis of logging curves. Due to the variety of logging curves and the huge amount of data, the research process is time-consuming and low efficiency. This paper takes the Chang4+5 reservoir group of Tianci bay South Oil field of Jingbian Oil Production plant as the main research object, aiming at the existing problems of heavy workload and low accuracy, an automatic separation identification method is proposed. This method is based on logging data, and through digital filtering and gradient discrimination, it realizes rapid and accurate identification of interlayers.

**Keywords:** Heterogeneity; logging curve; automatic identification; gradient discrimination.

## 1. Introduction

The existence of compartments divides the reservoir into several disconnected or semi-connected flow units, thus controlling the movement of the fluid inside the reservoir. The genetic type and spatial distribution of reservoir interlayers are the main factors controlling the distribution of remaining oil. Therefore, the main purpose of this paper is to understand the geological conditions of the Chang-4 +5 oil formation in the south of Tianci Bay and improve oil recovery efficiency. Under this premise, it is particularly important to analyze and study the causes and distribution characteristics of regional interlayers by various methods [1].

On the technical route of the research, this paper firstly determined the sedimentary facies type of the Chang-4 +5 oil layer in the south of Tianci Bay by analyzing the core laboratory data and combining with the well logging curve. Then, under different genetic conditions, the electrical and physical properties of the rock layer with different lithology were analyzed to determine the types of interlayers and the characteristics of the well logging curve of the study horizon. Through filtering method, outliers are removed from the log curves of the study interval, and the trend values of various log curves are determined. Combined with gradient discrimination method, radar distribution maps of log parameters of different types of interlayers are drawn, so as to find out the amplitude ranges of different types of interlayers in various log curves, so as to realize the automatic division of interlayers in the whole study interval.

## 2. Geological Background of The Study Area

The study area is situated in the middle of the northern Shaanxi within the Ordos Basin. The regional structure is a gentle west-dipping monocline with a dip angle of less than 1° (7-10m km gradient). The internal structure is simple and

there is featuring a low-amplitude nasal uplift formed by localized differential compaction. Sedimentary facies are controlled by the distribution and reservoir performance of oil and gas reservoirs, and serves as the foundation for studying the relationship between the distribution of interlayers and geological environment. Through the comprehensive analysis of the well logging curve in the study area, combined with the previous research results, it is shown that the delta facies deposits are developed in the long 4+5 of the study area, and the main microfacies such as distributary channel, interdistributary bay, break fan and natural levee are identified. Distributary channel is the main reservoir sand body in the study area, and it is the main factor affecting the characteristics and distribution of interlayer.

## 3. The Division of The Compartment

### 3.1. Type of interlayers layer and log characteristics

The barrier is a non-permeable rock layer that prevents or blocks fluid movement. It has large area, large thickness and good stability, and can prevent oil and gas from flowing freely due to pressure difference. It is an important geological basis in reservoir development.

Interlayer is a non-seepage layer existing in the oil-bearing strata. It has a small thickness and poor continuity. It cannot effectively prevent or control the movement of the fluid, but it has an impact on the fluid seepage velocity and seepage effect. It is also an important factor in the formation of heterogeneity in the reservoir. It is customary to refer to the low-permeability or non-permeability layers distributed in the oil-bearing system as interlayers.

Due to the differences of sedimentation, diagenesis and other geological processes, different types of interlayers are formed accordingly. According to the core observation results in the southern Tianci Bay and the lithology and electrical characteristics of the intercalations, the delta plain facies in

the study area can be divided into three types: muddy intercalations, calcareous intercalations and physical intercalations.

### 3.1.1. Muddy intercalations

It includes mudstone, silty mudstone, argillaceous siltstone and sand-bearing mudstone. Argillaceous interlayers are generally formed by thin suspended sediment due to weakened hydrodynamic forces. The distribution and scale of these compartments are closely related to the sedimentary microfacies. The grain size of sediments in different microfacies changes gradually, the distributary channel is the largest, the interdistributary bay is the smallest, and other

microfacies sediments are between the two. The sedimentary microfacies of diverging ridge bays and natural levees with a high content of fine sediment are the developing areas of mud interlayers [1].

The shale interlayer is mainly reflected in the mudstone characteristics in the logging curve, which is manifested as the spontaneous potential near the baseline, the microelectrode amplitude decreases obviously, and the amplitude difference is almost zero or very small. The deep side resistivity is low, decreasing to more than 50% of the adjacent layer. Sound wave time difference is high; The diameter curve is clearly enlarged (Fig. 1).

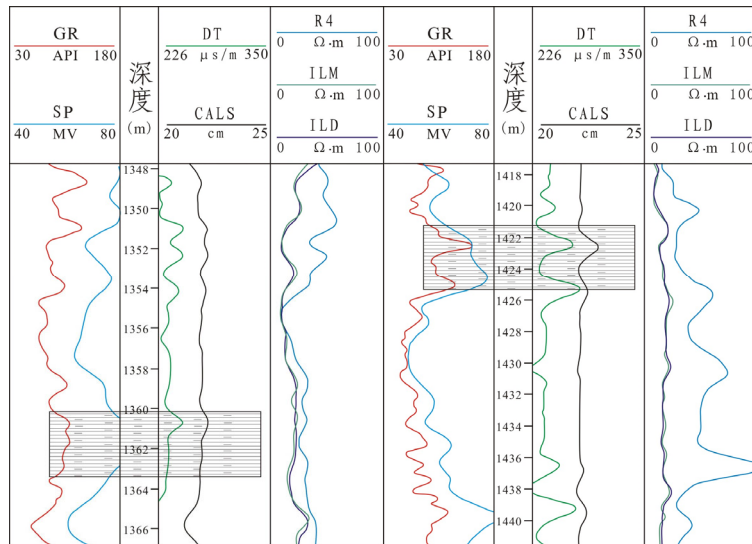


Figure 1. Log response characteristics of the southern Tianci Bay muddy interlayer

### 3.1.2. Physical intercalations

Due to changes in lithology, diagenesis, etc., the reservoir physical property deteriorates, has a certain porosity and permeability, but does not reach the lower limit of effective thickness physical property, which has an impact on fluid flow. This type of interlayer is usually a low permeability band in the high permeability sandstone reservoir, mainly composed of poor physical properties of fine sandstone, siltstone and argillaceous fine sandstone, and the local area is often in wave or horizontal rhythm or graded contact with the sandstone

reservoir. The formation reasons include smaller particle size, poorer sorting, increased cement content and enhanced cementation.

The log features are: The resistivity curve mainly shows low resistivity, the SP curve shows a decrease in negative anomaly amplitude, the density log curve shows low density, the density value is generally about 2.0g /cm<sup>3</sup>, the acoustic wave time difference is the median, the well diameter curve generally shows expanding diameter, and the microelectrode curve is between the mudstone and the calc interlayer, with a certain amplitude difference (Fig. 2).

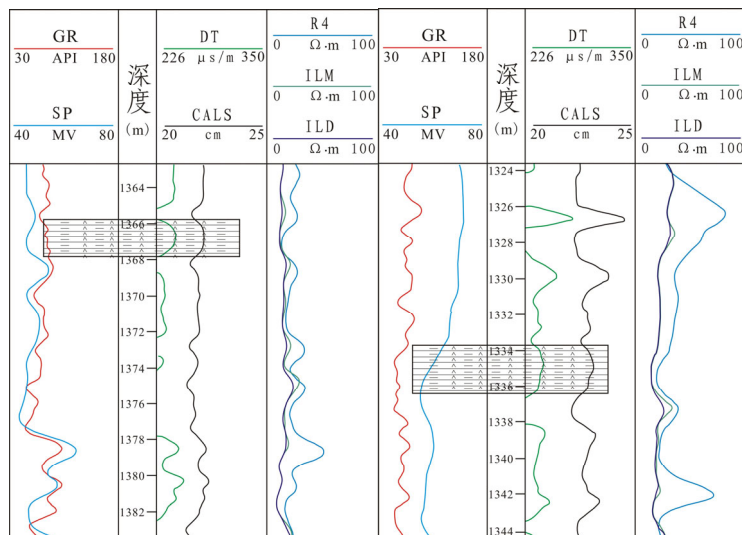


Figure 2. Log response characteristics of physical barrier in southern Tianci Bay

### 3.1.3. Calcareous intercalations

Calcareous interlayers are often found in sandstone reservoirs with good physical properties, and the density is generally greater than 2.2g/cm<sup>3</sup>. Generally, the content of calcareous cement is high in the top and bottom of sandstone layer, and its formation mechanism is related to the diagenetic transformation of clay minerals. At the same time, the well diameter curve is more regular, and generally there is a high

content of calcium cement in the top and bottom of the sandstone layer. The mechanism of this phenomenon is related to the diagenetic transformation of clay minerals.

The characteristics of the logging curve are as follows: the deep lateral resistivity is higher than or close to the reservoir resistivity, the microelectrode curve is sharp and the amplitude difference is small, the acoustic time difference is significantly low, and the well diameter curve is not expanded (Fig. 3).

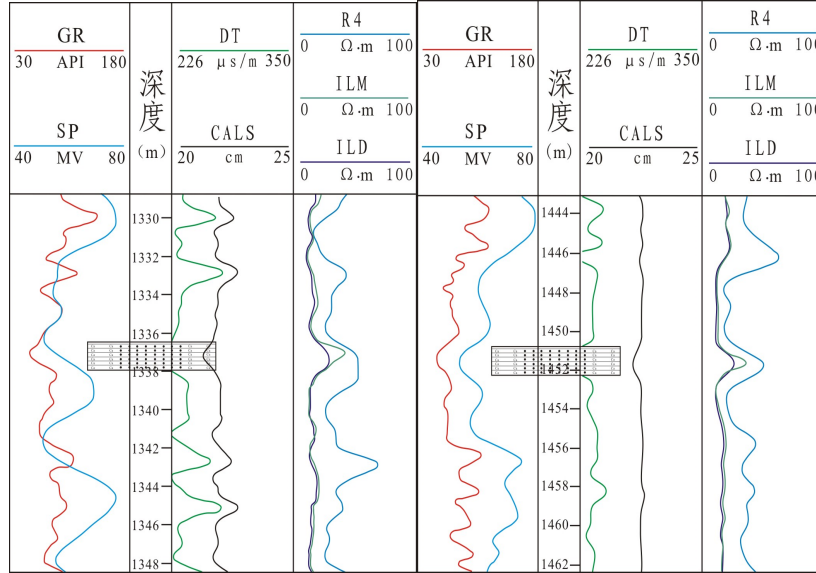


Figure 3. Log response characteristics of calcareous intercalation in southern Tianci Bay

### 3.2. Automatic identification and division of interlayer

Through petroelectric analysis, it is found that the parameters such as natural gamma ray, acoustic wave time difference and well diameter curve show high sensitivity to the response of the interlayer. Therefore, as long as the abrupt position of the log curve on the study interval can be automatically identified, the purpose of automatically dividing the interlayers can be realized.

The trend value of logging curve refers to the stable change value of all kinds of logging curves in the reservoir segment, which can be used as a significant sign to identify the intercalation. When there is no intercalation development in the reservoir and only subtle particle size and physical properties change, the trend value shows a smooth curve. If it is observed that the logging curve value deviates sharply from the trend value, it can be judged that there is an interlayer [2].

In the case of the development of interlayers, some of the electrical data of the reservoir segment have a large deviation. In order to obtain the trend value of logging curve accurately, it is necessary to reconstruct the electrical measurement curve by eliminating outliers, so as to better understand the reservoir characteristics and changes.

This paper adopts a sliding digital filtering method. In this method, the logging curve is cleverly regarded as the fitting result of the optimal value of the parabola, so that the sliding mean of the curve can be calculated accurately. This step not only simplifies complex geological data, but also reinforces its inherent regularity. By using the sliding mean instead of the original log value, we can better grasp the trend characteristics of the formation and filter out the outliers in

the curve [3].

The smoothing and filtering formula is as follows:

$$Y_i = \frac{1}{35} [17y_i + 12(y_{i-1} + y_{i+1}) - 3(y_{i-2} + y_{i+2})] \quad (1)$$

In the formula:

$y_i$ —the sampled value of point  $i$  on the curve before smoothing;

$Y_i$ —the sampling value of point  $i$  on the smoothed curve;

$y_{i-1}, y_{i+1}, y_{i-2}, y_{i+2}$ —Sampling values at points  $i-1, i+1, i-2, i+2$  on the curve before smoothing.

In addition, after long-term immersion in mud, the mudstone on the well wall expands after absorbing water, which is easy to cause collapse and diameter expansion, resulting in the increase of acoustic lag value (AC) and the decrease of resistivity value measured by logging instruments, so the curve should be corrected. The calculation formula is as follows:

First, the upper limit  $T_{max}$  of the acoustic time difference (AC) of the destination interval is calculated:

$$T_{max} = V_{sh} \times \Delta t_{sh} + (1 - V_{sh}) \times \Delta t_p \quad (2)$$

In the formula:

$\Delta t_p$ —the maximum sonic lag value of pure formation, us/m;

$\Delta t_{sh}$ —maximum sonic time difference value of shale at non-collapse site, us/m;

And then compare them one by one

$T_{max}$  &lt; If AC is used,  $AC = T_{max}$  takes precedence.

$T_{max}$  &gt; For AC,  $T_{max}$  prevails.

### 3.3. Identification of interlayer type

Although the above can be automatically divided into compartments, but can not identify the specific type of compartments. Therefore, a method is proposed to identify the type of interlayer by using natural gamma gradient, acoustic wave time difference gradient and borehole diameter gradient. The natural gamma gradient is to reveal the existence and distribution of the interlayer by calculating the gradient of the natural gamma measurement. The gradient of acoustic time difference is used to calculate the gradient of acoustic logging data to detect the thickness and velocity change of the interlayer. On the other hand, the gradient of borehole diameter is calculated to infer the type of interlayer [4].

Natural gamma gradient method: Natural gamma gradient is the amount of gamma ray deviation from the reservoir gamma trend value per unit distance. Calculated as follows:

$$dG_R = \Delta G_R / \Delta h \quad (3)$$

$$\Delta G_R = |G_{Rq} - G_{Rmax}| \quad (4)$$

In the formula:

dGR—natural gamma gradient, API/m;

ΔGR—Maximum variation in natural gamma, API;

GRq—reservoir gamma trend value, API;

GRmax—the peak or valley value at which the reservoir gamma ray increases or decreases due to intercalation, API;

Δh—maximum variation of parameter corresponds to thickness, m.

Sonic time difference gradient method: The sonic time difference gradient refers to how much the sonic time difference deviates from the trend value of the reservoir sonic time difference within a unit distance. The formula is as follows:

$$dT_c = \Delta T_c / \Delta h \quad (5)$$

$$\Delta T_c = |T_{cq} - T_{cmax}| \quad (6)$$

In the formula:

dTc—acoustic time difference gradient, s/m<sup>2</sup>;

ΔTc—maximum change in sonic time difference, s/m;

Tcq—trend value of reservoir acoustic wave time difference, s/m;

Tcmax—the peak or valley value, s/m, at which the interval between layers causes an increase or decrease in the difference between sound waves in the reservoir.

Borehole gradient method: The borehole gradient refers to the unit distance

The amount of deviation from the trend value of the reservoir diameter from the inner diameter can be calculated by the following formula:

$$dD_b = \Delta D_b / \Delta h \quad (7)$$

$$\Delta D_b = |D_{bq} - D_{bmax}| \quad (8)$$

In the formula:

dDb—gradient of diameter change;

ΔDb—maximum change in well diameter, cm;

Dbq—trend value of reservoir diameter, cm;

Dbmax—The peak or valley value at which the reservoir diameter increases or decreases due to intercalation, cm.

$$X = (X^* - X^*_{min}) / (X^*_{max} - X^*_{min}) \quad (9)$$

In the formula: X is the normalized data, X∈[0,1], X\* is the original data, X\*min and X\*max are the minimum and maximum values of a log curve respectively [4].

According to formula (3) - (8), the parameters of natural gamma gradient, acoustic wave time difference gradient and borehole diameter gradient of the different types of interlayers divided in the core were calculated. After the recognition parameters of various interlayers were normalized according to formula (9), radar maps of different types of interlayers were drawn (Fig. 4) [5].

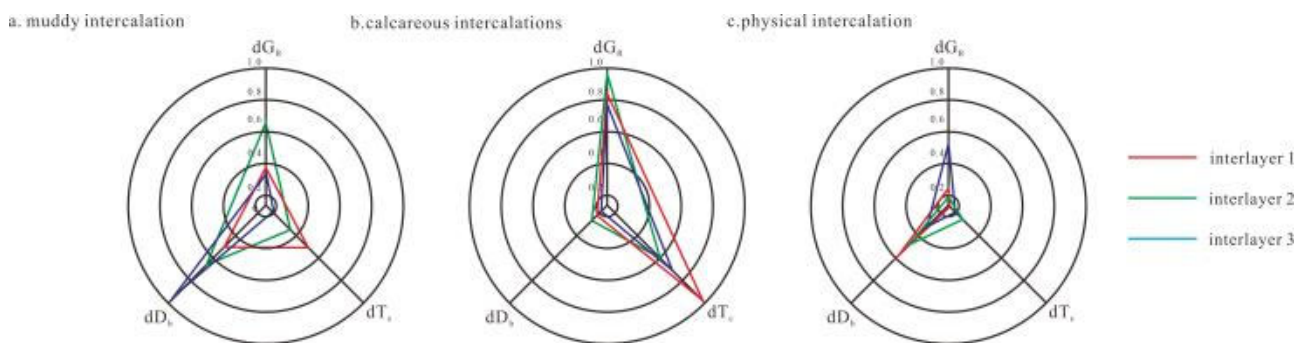


Figure 4. Radar distribution of different logging parameters.

It can be seen from Fig.4 that the shale interlayer has the characteristics of high well diameter gradient, medium natural gamma gradient and medium sonic time difference gradient. The calcareous interlayer has the characteristics of high natural gamma gradient, high acoustic time difference gradient and low diameter gradient. The physical interlayer has the characteristics of medium gamma-ray gradient, medium diameter gradient and low acoustic wave time

difference gradient.

### 3.4. Application effect

By using the trend value of logging curve and the gradient discrimination method, a core well in the southern research interval of Tianci Bay is compared, and the results are shown in TABLE I. For the core well, 10 interlayers are identified, and the recognition degree is more than 80%. Through core

identification, it is found that when the small layer is thin and the surrounding core has certain changes, it is likely to be

mistaken for the interlayer, but the overall identification effect is good[6].

**Table 1.** Core Identification Check Interlayer

depth of stratum (m)	interlayer	lithology
1.1	muddy intercalation	gray silty mudstone
1.3	physical intercalation	grey argillaceous siltstone
0.3	Non-intercalation	brown gray oil siltstone
0.9	muddy intercalation	grey argillaceous siltstone
0.8	physical intercalation	grayish-brown siltstone
1.7	muddy intercalation	gray silty mudstone
0.5	Non-intercalation	brown gray oil siltstone
0.6	physical intercalation	grey siltstone
1.5	muddy intercalation	gray silty mudstone
0.7	physical intercalation	grey siltstone

## 4. Interlayer Distribution

With the increasing precision of reservoir research, the naming of interlayers and interlayers is actually relative. The interlayer of the sandstone group can be called the interlayer of the oil group, the interlayer of the small layer can be called the interlayer of the sandstone group, and the interlayer of the single sand layer is the interlayer of the small layer. These compartments exist vertically at the sedimentary interfaces of different levels. The interlayer of the sandstone group was deposited between two adjacent phases, corresponding to the multi-phase gravity flow overlapping interface, the time is relatively long, the formed interlayer distribution is stable, the extension range is wide, and the area is large. The small interlayer corresponds to two adjacent single-phase gravity flow interfaces, the deposition time is relatively short, the formed interlayer distribution stability is poor, the extension range and thickness are small. The interlayer in the small layer corresponds to two adjacent single gravity flow interfaces, the deposition time is shorter, the thickness is small, and it is difficult to preserve under the erosion of gravity flow, and it is scattered.

Based on the division of intermezzanine, a comparative profile of intermezzanine connecting Wells was drawn. According to the drawn profile, it can be seen that a set of continuous and uninterrupted muddy layers developed in the west of the study area, but the thickness was not very stable. The thickness became thinner as the area moved to the southwest, and the physical intermezzanine was relatively developed.

## 5. Conclusion

Based on the above research, the following conclusions are drawn:

1.By studying the regional geological background of the study area and analyzing the logging data of the core well in detail, it is clear that the deltaic facies deposits are mainly developed in the deltaic plain in the Chang 4+5 formations in the study area. This sedimentary environment is characterized by its complex microfacies structure, which mainly includes distributary channels, interdistributary bays, break fans and natural levees.

2.Through the observation and description of the core in the study area, and the analysis of physical and electrical properties, it is concluded that there are mainly muddy compartments, physical compartments and calcareous compartments in the south of Tianci Bay.

3.In this paper, a set of automatic partition of compartments is proposed. Through the reconstruction of the reservoir log curve, the fitting of the trend value and the analysis of the degree of deviation from the trend value of the log data, several compartments are automatically divided. By calculating the natural gamma gradient, acoustic wave time difference gradient and well diameter gradient of the interlayer, and drawing the radar map after normalization processing, the properties of the interlayer can be sensitively identified.

4.The logging response characteristics of the interlayer in the southern Tianci Bay oil layer are obvious and easy to identify. The interlayer thickness is relatively large, the distribution is stable and the continuity is good. The thickness of interlayer in the small layer is between 0.2m and 1.8m, which is obviously affected by the distribution of sediment and sand body, showing sporadic and banded distribution. The interlayer of the sand group is less, the thickness is small, and relatively stable, the change is not large, and the extension is short, which has a control effect on the remaining oil.

## References

- [1] Sun Niyuan. Research on reservoir interlayers in the delta front of Dongying Formation, Suizhong 36-1 Oilfield [D]. China university of petroleum (Beijing), 2021. DOI: 10.27643 /, dc nki. Gsybu. 2021.000318,pp.43-48
- [2] YU QiuJun. Standardized processing method of multi-well logging data: A case study of M Oilfield [J]. Petroleum Geology and Engineering, 2019,34(06):118-122.
- [3] Xue L W. Design and implementation of logging data interpretation system based on React framework [D]. Xian university of electronic science and technology, 2022. DOI: 10.27389 /, dc nki. Gxadu. 2022.002326, pp.38-40.
- [4] DU Jiann.Research on logging evaluation technology of flooded layer based on curve reconstruction method [D]. China university of petroleum (Beijing), 2019. DOI: 10.27643 /, dc nki. Gsybu. 2019.001291,pp.31-51.
- [5] Chen Yan, Jiao Shixiang, Cheng Chao et al. Semi-supervised interlayer identification method based on autoencoder [J]. Special Oil and Gas Reservoirs,2021,28(01):86-91.
- [6] Yasser,Aya,Leila, et al. Reservoir heterogeneity analysis and flow unit characteristics of the Upper Cretaceous Bahariya Formation in Salam Field, north Western Desert, Egypt[J]. Arabian Journal of Geosciences, 21,14(16).
- [7] Li Ning, Xu Binsen, Wu Hongliang et al. Application status and prospect of artificial intelligence in well logging formation evaluation [J]. Acta Petrolei Sinica, 2021,42(04):508-522.

- [8] Mitten A, Mullins J, Pringle J, et al. Depositional conditioning of three dimensional training images: Improving the reproduction and representation of architectural elements in sand-dominated fluvial reservoir models[J]. *Marine and Petroleum Geology*, 2020, 113.
- [9] Hosseinyar G, Moussavi-Harami R, Fard A I, et al. Facies analyses and depositional setting of the Lower Cretaceous Shurijeh–Shatlyk formations in the Kopet Dag–Amdarya Basin (Iran and Turkmenistan)[J]. *Geological Journal*, 2019, 54(3).
- [10] Wu Xueting. Study on distribution characteristics and genesis of Jurassic calcareous interlayer in Shinan area [D]. Xi'an petroleum university, 2020. DOI: 10.27400 /, dc nki. Gxasc. 2020.000565.