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Genesis, identification and distribution of the interlayer in rhythmic layering in continental low permeability reservoirs

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ABSTRACT: Study on the interlayer has developed associated with in-depth exploration and development of oil fields, which is an indispensable part to characterize reservoir heterogeneity. This study relates to a comprehensive research method of interlayer in rhythmic layering in continental low permeability reservoirs. During the process of waterflooding development, distribution characteristics of interlayer in the single well, plane, cross-well, and well group should be analyzed based on identification and genesis of interlayer. And thus the three-dimensional model of interlayer could be constructed in order to reveal its spatial distribution characteristics in continental reservoirs. Practice in continental oil fields has shown that the type and distribution of interlayer play an important role in controlling remaining oil. Mastering the distribution rule of interlayer can better explore the distribution of remaining oil. Through in-depth analysis on the interlayer, better development results could be achieved by taking different measures to trap the potential. Also, utilizations of interlayer results for the analysis of injection connectivity could facilitate petroleum engineers to adjust the injection layers, and thereby increasing the efficiency of oil field development.

KEYWORDS: Interlayer, continental reservoirs, low permeability, distribution, remaining oil.

1 INTRODUCTION

During the waterflooding process of continental oil fields, it is difficult to evaluate reservoir flow distribution and seek favorable distribution of remaining oil zone because of the relatively severe reservoir heterogeneity. Given the influence and constraint of the tectonic evolution, sedimentary patterns and diagenesis, the genesis and distribution of interlayer become complex in rhythmic layering. Interlayer occurrence to a certain extent, affects the direct configuration relationship between the sand and interlayer, and thus affects the fluid movement of reservoir sandstones. Flow barrier and seepage discrepancy caused by interlayer are the major factors of the unswept water injection, which is especially evident in continental reservoirs [1]. Therefore, carrying out study on interlayer is of great significance and practical value.

Interlayer is a kind of relatively non-permeable layer, which is distributed unstably within sandstones and has a barrier effect of the non-permeate rocks in the oil field development process [1,2,3]. In fact, the interlayer within sandstones is also an internal interlayer within flow units, with an area usually less than half of the area of flow unit and often only a few

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centimeters thick. Despite an increase in the heterogeneity of the reservoirs owing to generally small extending and poor stability of interlayer, however, interlayer has played a favorable role in EOR process.

The traditional interlayer analysis and identification methods tend to focus on logging identification or plane distribution of interlayer. It rarely involves interlayer modeling in low permeability reservoirs, which is not conducive to the effective characterization of interlayer during the development of low permeability reservoirs. This study introduces integrated approach combining qualitative and quantitative, which contributes to understand fine characterization of reservoir geology by causes, characteristics, distribution and identification of interlayer in rhythmic layering of continental low permeability reservoirs for the first time. Also, study on interlayer helps to explore for the distribution of remaining oil. And the methodology has been already widely used in Bohai Bay Basin, Songliao Basin, Subei Basin, and Junggar Basin in China.

2 Methods

Abundant logging data, combined with core observation, thin sections, scanning electron microscopy and other analysis assay technology for interlayer identification provided an important basis, and also provided a favorable condition for the genesis analysis of interlayer. Samples were selected for thin sectioning and scanning electron microscopy, which were taken for the habits of diagenetic minerals in selected samples.

By characterization from lateral side to vertical direction, from single well to the plane, from two-dimensional (2-D) to three-dimensional (3-D), it could determine frequency and density of interlayer more easily. Thus, a comprehensive characterization method was formed to improve the accuracy of cross-well identification (Fig. 1), to provide a reliable basis for oil-water movement and remaining oil distribution, and to enrich heterogeneity theory of continental reservoirs.

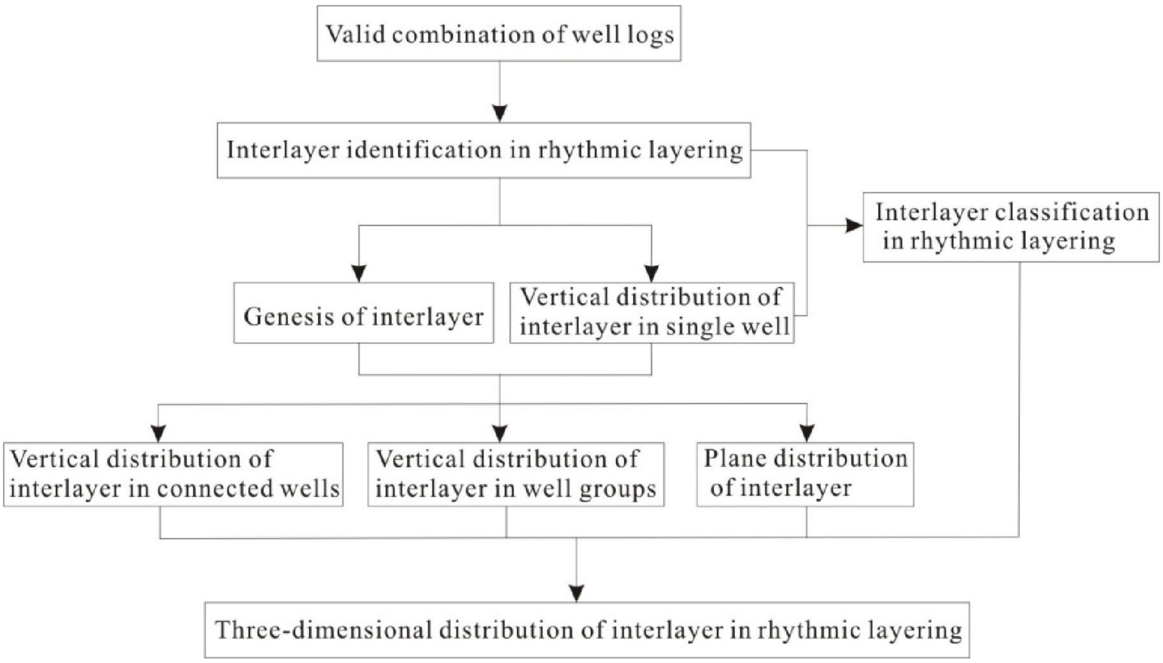

Fig. 1. Flow diagram showing a comprehensive characterization method of interlayer in rhythmic layering

3 Results and Discussions

3.1 Identification and genesis of interlayer

Considering that different types of interlayer corresponding to different logging response characteristics, it is necessary to select effective combination of well logs preferably. In general, the relative abundance of logging data provides a reliable foundation to carry out interlayer recognition in rhythmic layering. Combining core calibration, we can identify and analyze interlayer exactly on the level of single well.

Because of different study areas experiencing different depositional environments, coupled with the complex transformation by late diagenesis, it causes of different types of interlayer [5,6]. In accordance with the general consensus about continental reservoirs, interlayer comprises three types: muddy interlayer, calcium interlayer, and physical interlayer.

Muddy interlayer is formed by depositional environments under hydrodynamic conditions, including mudstone, silty mudstone, muddy siltstone and gravel mudstone. The emergence of muddy interlayer mainly consists of muddy wave layer, side laminated layer, and muddy bands within beddings. The main characteristics of this type of interlayer are small thickness, extremely irregular distribution, and strong reservoir heterogeneity, which increase the difficulty of the recovery from oil and gas reservoirs [4]. Well logs of muddy interlayer show low values of deep lateral resistivity, stable low microelectrode and neutron gamma values, high values of acoustic time, and spontaneous potential closing to the baseline. Conditions of muddy interlayer formation include: (1) semi-deep lake or deep lake depositional environments; (2) high-density turbidity currents converting to low-density ones [1].

The main rock types of calcium interlayer contain fine - coarse gravel sandstones, followed by sandy conglomerates, medium - fine conglomerate and medium - fine sandstone, which show dense lithology, impermeable or poor permeable. Clay matrix contents in interstitial materials are rare, but calcareous cement contents exceed 10% with mainly calcite, ferrous calcite, and small amounts of dolomite and ankerite (Fig. 2). Well logs of calcium interlayer manifest as higher deep lateral resistivity values, spikes of microelectrode curve, and apparent low values of acoustic time. Conditions of calcium interlayer formation include: (1) the evaporation of pore water or CO_2 degassing in meteoric environments; (2) carbonate cementation development from combination of released CO_2 by diagenetic thermal evolution of organic matters and Ca^{2+} or Mg^{2+} within formation water [1]. This type of interlayer is more prone in thin sandstones, contact parts between top or bottom of reservoirs sandstones and mudstones, muddy clumps attachments in internal reservoirs [4].

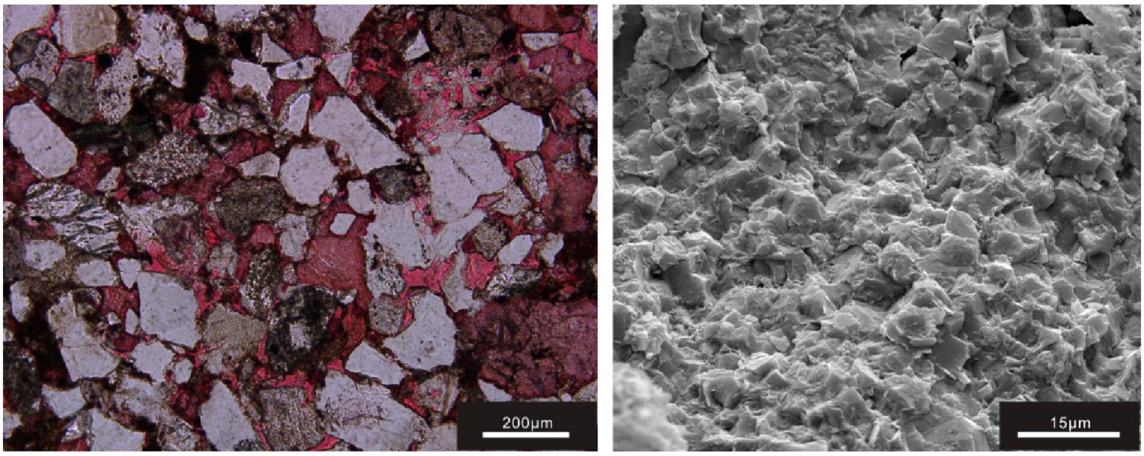

Fig. 2. Thin section and scanning election photomicrographs showing calcareous cement contents of calcium interlayer

Lithology of this type of interlayer mainly denominates in grease mark fine or silt sandstones, with high muddy contents. It has a certain porosity and permeability, but generally it does not reach the lower limit of the effective thickness of properties. Logging curves are characterized by low values of deep lateral resistivity, medium acoustic time and neutron gamma values, and weak anomaly spontaneous potential curves. With scattered distribution and strong randomness, physical interlayer may be derived from clutter stacked or residence deposits.

3.2 COMPREHENSIVE CHARACTERIZATION METHODS OF INTERLAYER IN RHYTHMIC LAYERING

Figuring out the classification and genesis helps to predict the distribution of regional interlayer. So it requires for a comprehensive analysis of interlayer in rhythmic layering of continental low permeability reservoirs, which is more accurate, reliable, and systematic relying on laboratory analysis.

Cross-well forecasting and modeling are the cores of interlayer research. The longitudinal changes of high and low permeability layers inside sandstones constitute permeability rhythm [7,8,10]. Interlayer is distributed in the upper parts of positive rhythm and the lower parts of counter-rhythm.

Based on the identification of interlayer, we could classify interlayer in rhythmic layering and determine the development of interlayer by calculating the thickness, analyzing lateral continuity, plane stability, and cross-well comparability.

To understand the overall distribution of interlayer, it is necessary to analyze the distribution characteristics in rhythmic layering, mainly from vertical position, plane distribution, number, and area. In this case, cross-well sections (Fig. 3a), well group distribution (Fig. 3b), and plane distribution (Fig. 3c) maps about interlayer can be plotted, which is benefit to further analyze the influences of the deposition and diagenesis on interlayer.

Using depositional theory and geostatistical methods [9], 3-D model and 3-D fence model corresponding to the distribution of interlayer are able to establish (Fig. 4). This model is on the basis of 3-D fine structural model and constraints of distributed interlayer of single well. As a result, it reflects 3-D distribution charactistics of interlayer in rhythmic layering, achieving higher accuracy of interlayer distribution analysis. This method provides a more reliable geological model to guide the internal potential adjustments of oil fields.

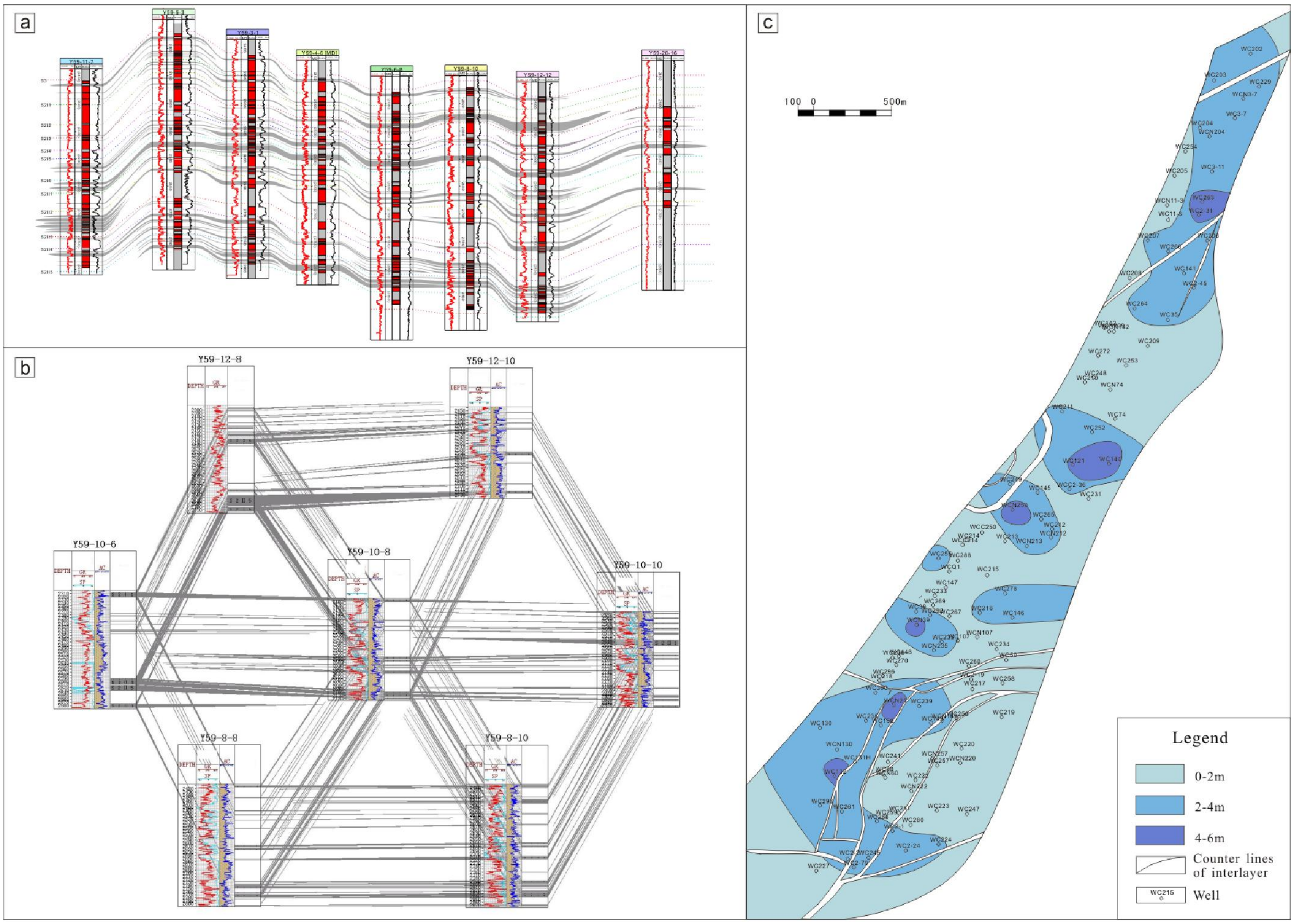

Fig. 3. Map showing the distribution characteristics of interlayer plotted on cross-well sections, well group, and plane

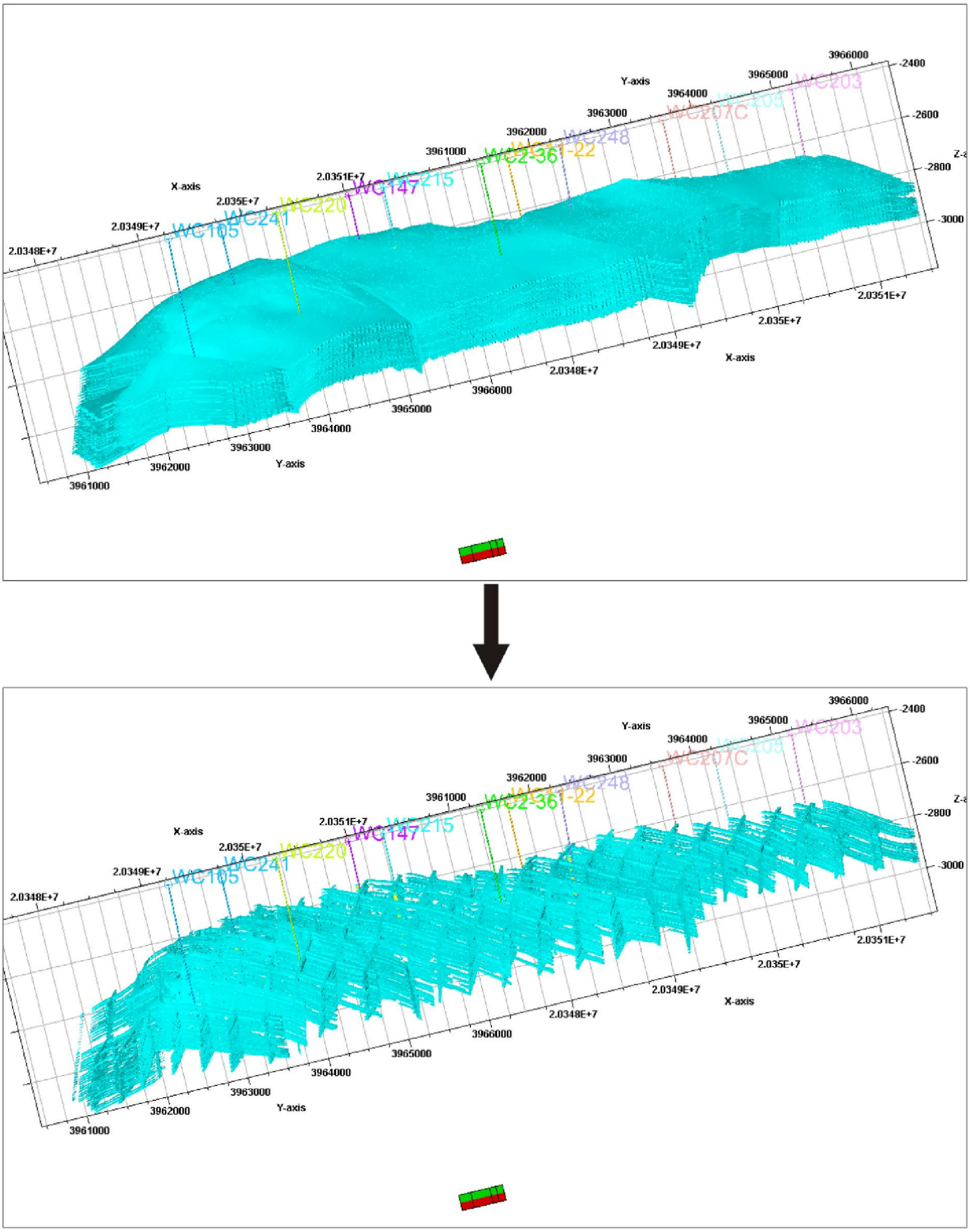

Fig. 4. 3-D model and 3-D fence model maps showing the distribution of interlayer

3.3 IMPACT ON REMAINING OIL OF INTERLAYER IN RHYTHMIC LAYERING

Since the presence of interlayer, the formation of seepage barrier could control the oil-water movement to a certain extent and have a greater impact on remaining oil distribution [11-15]. Remaining oil is usually distributed in the lower permeability part, which is considered as the top of rhythmic layering [16]. The major impact on remaining oil of interlayer is related to interlayer position, perforation location, and the relationships between injection wells and interlayer. The appearance of interlayer, which makes multi-stage distribution of remaining oil within reservoirs, has changed the distribution patterns of remaining oil. The location where the distribution density and frequency of interlayer are greater, with better production potential, has a higher degree of remaining oil within the control of interlayer [17]. If the injection wells have drilled interlayer but only injection above the location of interlayer, the remaining oil will be enriched under the interlayer [18]. Mastering the development of interlayer can better propose targeted measures for remaining oil digging.

4 CONCLUSION

There are extensive muddy interlayer, calcium interlayer, and physical interlayer, which can be identified in continental low permeability reservoirs. Not only do the three types of interlayer have different causes, but also its lithology, distribution characteristics, and logging response characteristics vary with each other. Based on the recognition of interlayer, a complete set of comprehensive characterization methodology of interlayer in rhythmic layering is established, which can further analyze the impact of interlayer on the distribution of remaining oil. Carrying out studies on interlayer in rhythmic layering is particularly important in the late period in the oil fields development. Strengthening the research on the interlayer will be conductive to predict the case of oil and gas production and lay a more solid foundation for the law of oil-water movement.

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