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Analysis of sedimentary characteristics of section 71 in Donggou area, Ordos Basin

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Abstract

The Ordos Basin's Donggou area is rich in oil and gas resources and is a key exploration and development region for the Yanchang Oilfield. A detailed characterization of its gravity flow sedimentary system is of great significance for oil and gas exploration. This paper focuses on the Chang 7 oil layer group, analyzing the geological and sedimentary structural characteristics of the block. It combines core samples, well logging data, 3D seismic data, and previous research findings to study the gravity flow sedimentary types and distribution characteristics of the Chang 71 section in the study area. The results show that the study area has developed turbidite subtypes, which can be further divided into turbidite channels, inter-channels, and channel overflow microtypes. Two main types of gravity flow sediments have been identified: turbidite deposits and sandy clastic flow deposits. The plan view of the sedimentary microtypes shows that the main water channel extends from northeast to southwest in a strip-like pattern, with poor continuity perpendicular to the source direction. Submerged composite turbidite channels and inter-channels are alternately distributed with muddy deposits. The research findings provide a theoretical basis for further in-depth studies

Keywords

Gravity flow deposition; Donggou area of Ordos Basin; Chang 7 group of Yanchang; turbid fan.

1. Introduction

Deep-water gravity flow deposition is one of the hot topics in current academic research. Gravity flow deposits often form sandstones with high porosity and permeability, making them ideal sites for oil and gas reservoirs; in recent years, significant breakthroughs have been made in oil and gas resource exploration and development in deep-water lake basins[1-4]. The Ordos Basin, located in northwest China, is one of the largest oil and gas-bearing basins in the country, where gravity flow deposits are widely developed[5]. Many scholars in China have conducted research on this region, constructing various models of gravity flow deposition and identifying key controlling factors[6-8]. However, different scholars have varying views: Zhang Yian believes that the basin has extensively developed mixed gravity flows[9]; Liu Fen studied the sedimentary characteristics of the southwestern part of the basin, discussing the basin's sedimentary model and concluding that the slope-to-deep lake area is a region where gravity flows develop[10]. Yang Renchao, Li Wenhou, Zou Cailai, Li Xiangbo, and others explored the mechanisms of lacustrine gravity flow formation and identified hetero-gravity flow sand bodies[11-14]; Lu Qiqi divided the gravity flow deposits of the southwestern part of the basin into five microfacies types and established a gravity flow channel-leaf complex sedimentary model[15].

The Donggou area is located in the southern part of the basin and has been identified as a key exploration and development target, with its rich oil and gas resources confirmed. However, current research on the gravity flow sedimentary system in this region still faces limitations, such as imprecise identification of sedimentary microfacies and unclear delineation of sand bodies, leading to significant uncertainty in reservoir prediction. This paper focuses on the Chang 7_1 sub-section of the Donggou area in the Ordos Basin. By integrating previous studies and analyzing core data from the work area, as well as comparing logging data, we have clarified the sedimentary microfacies and sand body distribution, providing guidance for further research.

2. Regional geological characteristics

The Ordos Basin is a stable intra-cratonic basin, generally sloping gently eastward and steepening westward. It comprises six major structural units: the Yimeng Uplift, the Weibei Uplift, the western margin thrust zone, the Tianhuan Sag, the northern Shaanxi slope, and the western Shanxi fold belt [16-18]. The block area is 371,040 km^2, with a rich sedimentary system primarily consisting of alluvial fans and fan deltas, rivers (including braided and meandering streams), lake deltas, lakes, and aeolian deposits (as shown in Figure 1). The surrounding ancient uplifts provide ample material sources for the basin; the Upper Triassic Yanchang Formation is subdivided into 10 oil-bearing units from top to bottom, numbered [19-21]. The Donggou area is located in the southern part of the northern Shaanxi slope within the primary structural unit of the Ordos Basin, covering an area of 146.6km2. This study focuses on the Upper Triassic Yanchang Formation at the 71st member level, dividing it into two sub-members, 71-1 and 71-2, based on thin mudstones within the sub-oil-bearing units and considering sedimentary cycles.

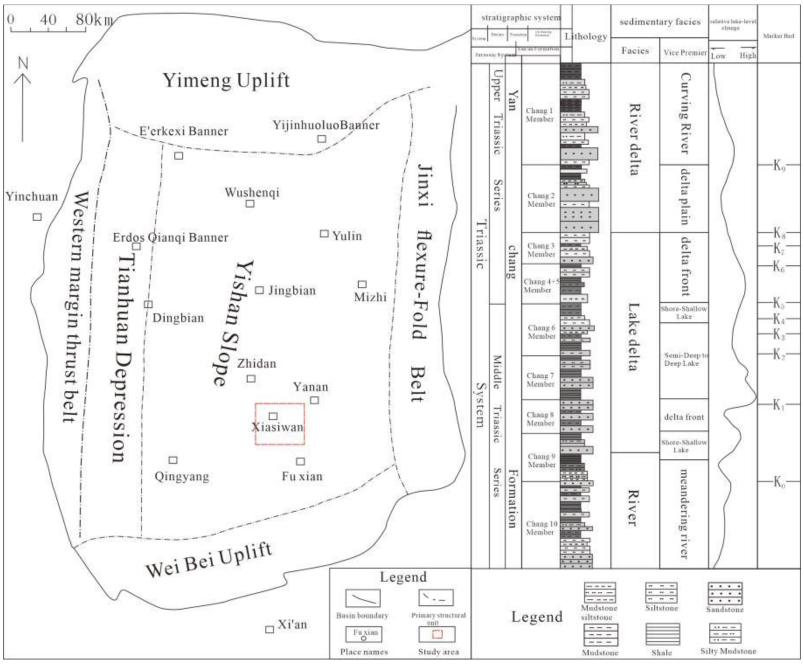


Figure 1 Location map of the study area and composite bar chart of the extended group

3. Depositional phase recognition marker

3.1. Rock type and color characteristics

The lithofacies is a comprehensive reflection of the color, clastic components, and grain size of rocks, directly reflecting the sedimentary environment of the rock [22]. By analyzing the macroscopic chromaticity, micro-characteristics of clasts, and mineral composition from the scanning electron microscope of the core samples from the Chang71 section in the Donggou block, it is found that the main lithologies of the core wells in the study area are gray fine sandstone and dark gray mudstone, revealing clear patterns of sedimentary environment evolution [21]. The fine sandstone is predominantly light gray and gray, with oil-bearing sections showing a brownish tone, mainly developed in the Chang7_1 and Chang7_2 sub-sections, reflecting active oxidation conditions under high-energy waterway environments; siltstone and silty claystone mostly exhibit transitional colors ranging from gray to dark gray. Mudstone and silty claystone generally display reduction color characteristics, ranging from dark gray to black or gray-black.

3.2. Rock structure characteristics

Based on the grain size analysis data from 133 samples collected in 12 wells within the study area, the probability cumulative curve of the Chang 7 reservoir sandstone is mainly two-phase, consisting of a jumping aggregate (with a high slope, φ values concentrated between 2 to 4, accounting for 65% to 80%) and a suspended aggregate (φ values> 4, accounting for 20% to 35%). The rolling aggregate is underdeveloped (Figure 2-1). The grain size distribution shows that the jumping aggregate predominates: with a high slope (60 to 75) and fine sand dominance (φ = 2 to 4, corresponding to median grain size of 62.5 to 250 μm), indicating a strong traction flow transport mechanism and faster deposition rates; the suspended aggregate is secondary: with a low slope (<30) and silt-clay components (φ> 4), suggesting low-energy suspension and settling at the distal end.

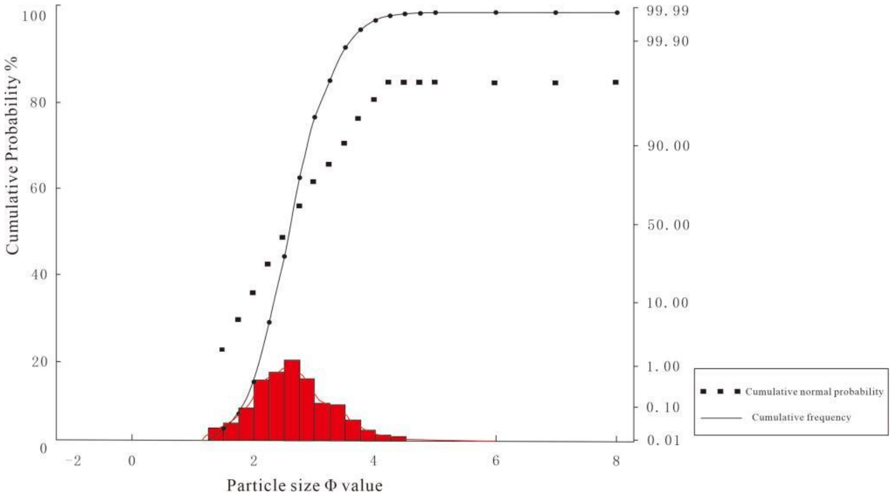


Figure 2-1 C14-2 well length 72-1 reservoir grain size probability cumulative curve (modified by Liu Xiuchan 2023 [23])

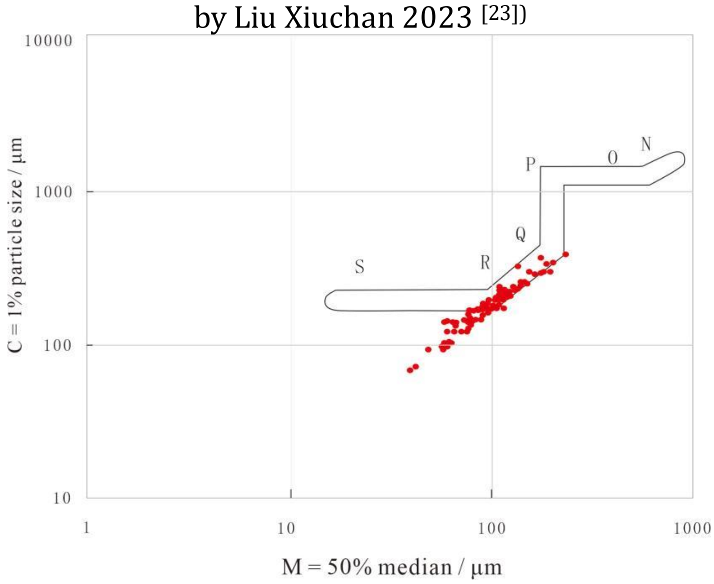
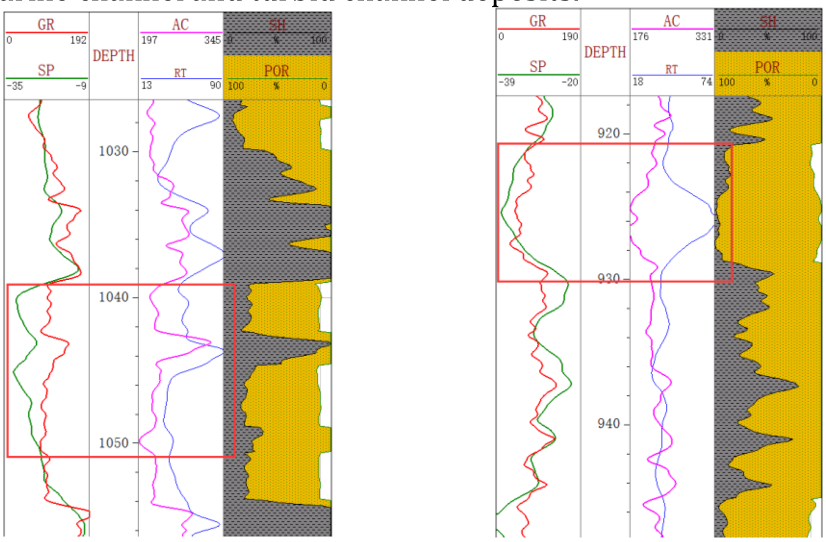


Figure 2-2 C-M diagram of reservoir (modified from Liu Xiuchan 2023 [23])

The sample point cluster is parallel to the C=M baseline, the mean value of C is 182.6 μm, the mean value of M is 107.0 μm, and C/M = 1.7;According to the turbidite model of progressive suspension and rapid accumulation, combined with regional background, it is determined as a slow slope collapse type turbidite (the contrast steep slope type C/M>2.5, C value is often>500 μm).

3.3. Logging phase marks

Well logging curves are the physical responses to changes in various rock properties along the depth of the wellbore, reflecting important genetic indicators such as lithology, grain size, sorting, clay content, and vertical sequence [24]. The main types of well logging facies in the Chang 7 oil layer group in the study area include: natural gamma showing box-shaped, bell-shaped, toothed, and funnel-shaped facies, with smooth and micro-toothed types being more common. The well logging response in the 1038-1052m section of the Chang 7 oil layer group at well C27-1 is characterized by typical box-shaped features (Figure 2-4a), with the curve morphology mainly being smooth or slightly toothed, the bottom contact relationship being abrupt, and the top showing a gradual transition, overall displaying a positive turn sequence. This feature indicates that this section was formed under a sedimentary environment with sufficient source supply and stable hydrodynamic conditions. Well C218-1 shows bell-shaped characteristics at the 921m-931m section of the Chang 7 oil layer group (Figure 2-4b), which can be described as low-amplitude bell-shaped or toothed bell-shaped, with the amplitude being greatest at the bottom and gradually decreasing upwards, or a combination of small-amplitude sawtooth shapes. This reflects a gradual decrease in water flow energy and a continuous reduction in source supply. Vertically, it shows a positive grain sequence structure, with fine sandstone at the bottom and siltstone or mudstone deposits at the top, representing delta front submarine channel and turbid channel deposits.



a.Box type (C27-1 well) b. Bell-shaped (well C218-1)

Figure 2-4 Common well logging phase curve characteristics of section 7 in Donggou Block

3.4. Single well phase analysis

Well C66-2 has 71 sections with a thickness of 38.95m. The upper part is mainly composed of gray-black mudstone, interspersed with siltstone, and the sandstone deposits are characterized by cross-bedding, parallel bedding, and horizontal bedding. The natural gamma curve values are relatively high, indicating a sub-mesofan facies in turbidite channels. Section 72 has a thickness of 34m, with dark-colored mudstone occurring in continuous patches from 984m to 1004m, and the natural gamma curve shows a jagged column shape; Section 73 has a thickness of 28.9m, representing semi-deep to deep lake deposits, with sedimentary microfacies being deep lake mud facies, and the natural potential curve showing a moderate amplitude bell shape.

Overall, the lower part is dominated by turbidite channel microfacies, while the middle and upper parts are characterized by turbidite channel interbedded sedimentary microfacies; the Bao Ma sequence combination is well-developed, including ABC, BC, and BCD sequences.

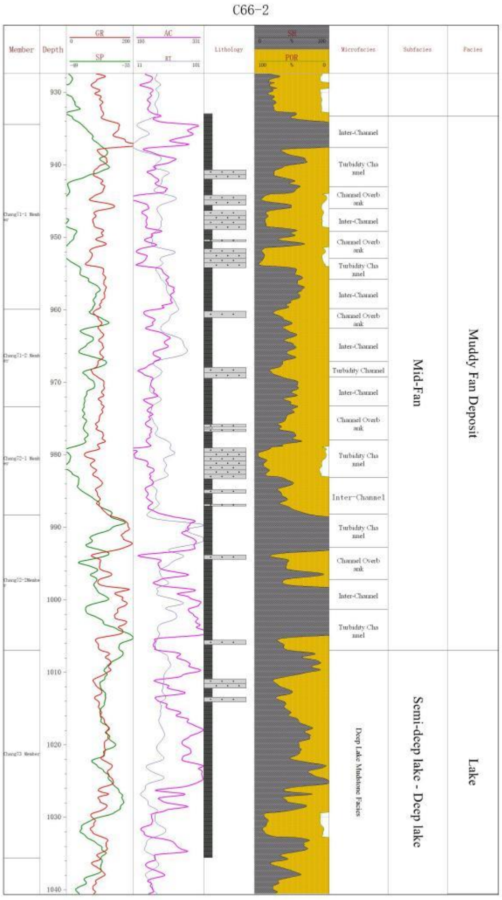


Figure 2-5 Comprehensive bar chart of sedimentary facies in study area C66-2

4. Sediment types and characteristics

4.1. Turbid water channel microphase

The rock mainly consists of fine sandstone and siltstone, with thin layers of mudstone and silty mudstone interbedded. Visible bedding includes horizontal, parallel, cross-bedded, wavy, and small cross-stratification. In some sections, an incomplete Bao Ma sequence segment BC is displayed. The sandstones have poor sorting, with a relatively gentle bimodal grain size probability curve; well logging curves show natural potential curves that are toothed or slightly toothed box-shaped, bell-shaped, etc., mostly with moderate amplitude. Vertically, multiple episodes of turbidite channel sand bodies are visible, showing a positive correlation trend from bottom to top, gradually becoming finer.

4.2. Microphase of waterway overflow

In the microfacies system of waterway overflow, the CDE segment composite turbidite deposits typically exhibit lateral discontinuous distribution characteristics. The single-layer thickness ranges from 5 to 20 cm, composed of light gray and grayish-white siltstone, with the base in direct contact with deep cementite and the upper part in contact with fine sandstone layers. Grain sequence stratification, parallel stratification, and wavy stratification can be observed. From a vertical sequence perspective, this sedimentary unit exhibits complete Baima sequence structural characteristics, with widespread development of trough molds and slot molds at the interface, and common mud-gravel enrichment layers on the scouring surface; the main sedimentary layer in the middle: a medium-thick layer of gravelly sandstone, with various types of sedimentary structures developing within the layer, including: a) normal grain sequence stratification; b) parallel stratification; c) horizontal wavy stratification; d) ripple stratification; accompanied by sliding and collapse deformation structures; the upper fine-grained transition layer: lithology gradually changes to alternating layers of muddy siltstone and silty shale, reflecting the process of gradually weakening hydraulic forces.

4.3. Microphase between turbid water channels

This microfacies developed in the low-lying sedimentary areas on the side margins or between adjacent channels of turbid waterways. Its vertical sequence is characterized by incomplete preservation due to intense erosion and modification by later turbid waterways, with generally thin residual deposits. The lithofacies assemblage features rhythmic interbeds composed of thin-layered siltstone, clayey siltstone, and silty claystone and mudstone. The sandstone component exhibits significant spatial differentiation: along the direction of ancient water flow, the thickness of individual layers decreases from 20 cm to less than 5 cm, with grain size transitioning from fine sandstone to extremely fine sandstone, and the intensity of depositional structures gradually diminishes. Natural potential curves show medium-low amplitude finger-like or box-shaped patterns, reflecting the characteristics of thin-layered sand-mud interbeds; this microfacies feature indicates that it formed during intervals of turbidity current activity, with deposition strongly influenced by the migration and modification of adjacent channels, making it an important marker for identifying the spatial configuration of paleochannel systems.

5. Types and distribution characteristics of gravity flow

5.1. Gravity flow deposition type

The main sedimentation in the study area is turbid flow deposition and sandy debris flow deposition.

(1) Turbidite deposition, where high-density turbidites driven by gravity unload in deep water environments to form sedimentary units. The formation is controlled by the triggering mechanism of gravitational flow events. The main lithology of this sequence consists of medium to thick laminated fine-grained sandstone, with thin-layered clay-siltstone layers developing within it. Well-developed horizontal stratification and wavy sand ripple characteristics can be observed in the siltstone sections. Corresponding well logging curves exhibit typical high-amplitude zigzag box structures and ovoid morphological features.

(2) Sand debris flow deposition, consisting of blocky fine sandstone, and locally fine sandstone and mudstone, siltstone. Blocky stratification, sliding collapse deformation structure and grain sequence stratification appear in the fine sandstone. The corresponding well logging curve gamma logging curve presents a typical box-shaped morphology.

5.2. Section feature analysis

As shown in Figure 3-1, the section passes through wells P105, C216-1, C29-2, C48-1, C101-3, C310-1, C311-3, and C314-3. Overall, the Chang 71 and Chang 72 formations are primarily composed of fine sandstone, with varying sizes but mostly forming irregular lens bodies that are thicker in the middle and thinner on both sides. The sandstone deposits are continuous and widely distributed. In the Chang 71-1 sand group area, the sandstone is underdeveloped, with poor thickness and connectivity of the stratigraphic sand bodies, mostly developing as thin lens-like structures. The Chang 71-2 formation is mainly characterized by turbidite fan deposition, with well-developed sandstone and good physical properties, making it rich in oil. It can be divided into two microfacies: turbidite channels and between turbidite channels, indicating good connectivity between sand bodies, suggesting a sufficient supply of source material from the northeast direction.

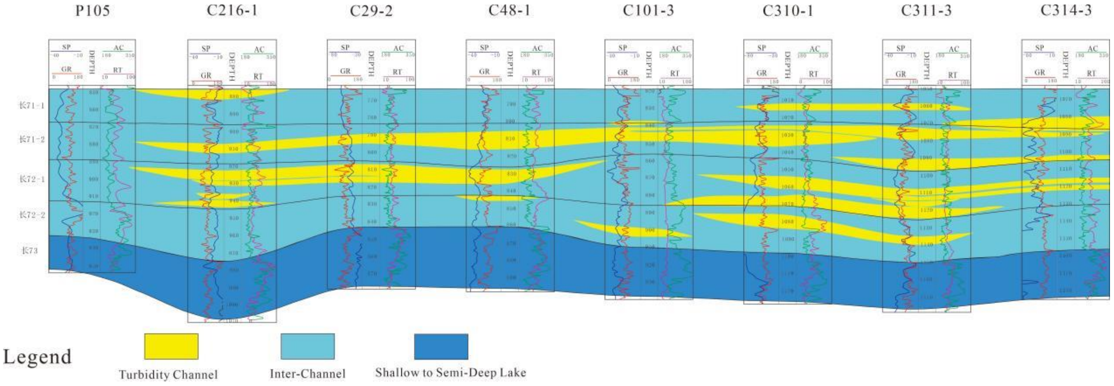


Figure 4-1 P105-P314--section of well 3

5.3. Distribution characteristics of sand body

The planar distribution characteristics of sand bodies at various stratigraphic levels in the study area are strictly controlled by the direction of material sources and the spatial distribution patterns of sedimentary facies. Based on single-well facies and cross-section analysis, combined with sand-to-soil ratio data, a 71-meter-long sedimentary facies plan view was drawn. The 71-meter section belongs to the middle-lateral turbidite fan. It mainly consists of 3 to 5 underwater composite turbidite channels, with the main channel extending from northeast to southwest in a strip-like pattern. The continuity along the material source direction is poor, and the interaction between the underwater composite turbidite channels and turbidite channels is characterized by alternating mud deposits.

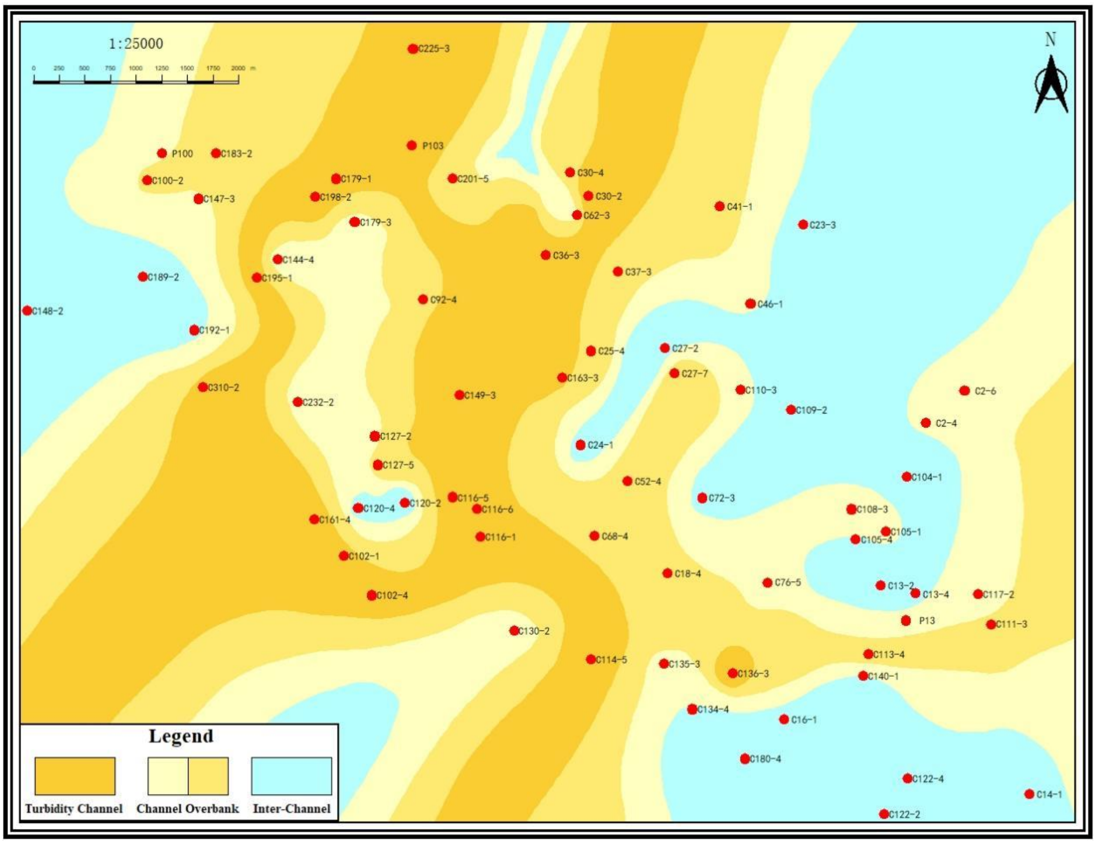


Figure 4-2 Plan view of sedimentary facies in the study area

6. Conclusion

The Chang 71 section is primarily composed of gray fine sandstone and dark gray mudstone, with parallel and horizontal stratification; the main well logging facies types in the Chang 7 oil layer group include: natural gamma showing box-shaped, bell-shaped, tooth-shaped, and funnel-shaped, with smooth and micro-toothed types being more common; the Chang 71 section has developed turbid water channels, and between these channels, there are overfilling deposits; gravity flow deposition types mainly consist of turbid flow deposition and sandy clastic flow deposition.

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