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Distribution of Hyperpycnal Flow Related Sandstone Deposits in a Lacustrine Shale System: Implication for Hydrocarbon Reservoir Exploration in the Chang 7 Oil Member of the Triassic Yanchang Formation, Ordos Basin, China

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Abstract: Gravity flow deposits are important hydrocarbon reservoirs in deep lacustrine deposits. Previous studies have paid much attention to the hydrocarbon reservoirs in those intrabasinal classic turbidite deposits. However, relatively little is known about the distribution of oil reservoirs in those extrabasinal hyperpycnal flow deposits. With the help of cores and wireline logging data, the present study undertakes a description and interpretation of subsurface shale oil reservoirs in the deep lake deposits in Chang 7 member, Yanchang Formation, Ordos Basin. Parallel bedded fine sandstone (Sh), massive bedded fine sandstone (Sm), massive bedded fine sandstone with mud clasts (Smg), deformed bedded siltstone (Fd), wave-lenticular bedded siltstone (Fh) and black shale (M) were found and interpreted in those deep lake deposits. The deposits were interpreted as hyperpycnal flow deposits which developed in channel, levee and deep lacustrine facies. The development of the Chang 7 sand body increased gradually, and the sand body of Chang 7_1 was found to be the main position of sandy hyperpycnites. The fine description of the sand body indicated a channelized sedimentary pattern. The thick sandy hyperpycnites mainly developed in the middle of those channels, and the eastern part of the study area was found to be the main deposition position of the hyperpycnal flow deposits. From the perspective of plane overlap and single well analysis, a thick sand body is the favorable position for the development of an oil reservoir, which has a significant control effect on the reservoir scale and oil production. This research can aid in understanding the facies distribution of hyperpycnal flows and has implications for hydrocarbon reservoir exploration.

Keywords: hyperpycnal flow; gravity flow; Triassic; Yanchang Formation; Ordos Basin

1. Introduction

A lacustrine basin is rich in shale oil resources and has great potential for shale oil exploration and development. Many gravity flow sandstones have been found in semi-deep lacustrine and deep lacustrine deposits [1]. The sandstones are surrounded by dark source rocks formed in deep lacustrine facies, and have good hydrocarbon generation potential. The gravity flow deposit sandstones can form interbedded hydrocarbon reservoirs in a shale system. At present, the study of gravity flow sandstone reservoirs has become the focus of sustainable exploration and development of oil and gas in the Basin, and the sedimentary genesis and distribution of gravity flow reservoirs is an important topic [2–7]. For a long time, the description and interpretation of lacustrine basin gravity flow deposits was mainly based on the classical classification of gravity flow deposits [8–14]. The classification divides gravity flow into sliding, slump, debris flow and turbidity current related to the sedimentary process. The "classic" turbidite models have been widely applied in gravity flow sedimentology research in lacustrine basin sedimentology.

More recently, research in the direct supply of sediment gravity flows by flood events into deep lacustrine basins via hyperpycnal flows has provided new perspectives for the understanding of sandstone distribution in deep lacustrine deposits [7]. Hyperpycnal flow is a type of high density sediment gravity flow originating from an estuary during a flood period, flowing along the bottom of the sedimentary basin in a quasi-steady state [1]. Forel (1885) first discovered the phenomenon of density plumes in Lake Geneva [15]. Bates (1953) introduced a rational classification of deltas, recognizing three categories, termed hypopycnal flow, homopycnal flow and hyperpycnal flow [16]. Since the 1980s, sedimentologists have intensively investigated sediment gravity flows by flood events [17–20]. Mulder (1995) redefined the concept of hyperpycnal flow [3]. Instead of emphasizing the high density property of the flow, Mulder proposed the definition as being the density of flow when higher than a certain critical value, which is referred to as hyperpycnal flow in hydraulics [8]. Mulder (2001) defined hyperpycnite as a fine-grained deposit. It is characterized by the vertical coarsening upward, and then fining upward variation in grain size, reflecting an increasing and then decreasing magnitude in the fluvial-related discharge [21]. The deep-water gravity flow theory has been questioned and debated since its inception. There is still no unified knowledge on the key issue of classifying deep-water gravity flow types [5–7,21–25]. A host of scholars have shown that floods, as a more common mechanism of action, play a more critical role in the generation of deep-water gravity flow [23,24]. Overall, the formation of hyperpycnal flow requires three basic conditions: sufficient density difference between the two fluids, and sufficient depth of water body and sudden flood events. In terms of the input fluid density conditions, the marine (or brackish water) environment is much higher than the terrestrial (or fresh water) environment. Active tectonic, humid climate, steep terrain, and sufficient supply of plant debris material favor the formation of hyperpycnal flow [1]. Those hyperpycnal flow deposits generated by floods in lacustrine basins are quite different from the "classic" turbidite models because of typical sedimentary structures, such as water causing cross-beddings, the sharp contact surfaces between layers or erosion contact surfaces, and coal fragments and leaves [1,25]. This new theoretical breakthrough is being discussed and confirmed by more and more geologists. However, the current research about hyperpycnal flow deposits mainly focuses on the basic theoretical research about the sedimentary model of hyperpycnal flows. The correlation between the hyperpycnal flow related shale oil reservoir distribution is still a question to be further explored, especially in shale oil exploration research.

Ordos Basin is the largest oil and gas production base in China and is rich in unconventional oil and gas resources [9–11]. The Chang 7 member of the Triassic Yanchang Formation is composed of interbedded shale oil reservoirs formed by gravity flow deposits. In 2019, the shale oil exploration of the Yanchang Formation achieved a large breakthrough in Qingcheng Oilfield, southwest of Yishan Slope, Ordos Basin. Recent exploration and development studies have shown that the shale oil resources of the Upper Triassic Yanchang Formation in the Bazhu area, which is in the northwest of Qingchengda Oilfield, have good development potential. The efficient development of shale oil mainly depends on the geological model of the deep lacustrine deposits. Therefore, the Chang 7 member of the Upper Triassic Yanchang Formation in the Bazhu area could be an analog to analyze the distribution of oil reservoirs in shale deposits formed by hyperpycnal flow in lacustrine deposits.

This study focuses on the distribution of hyperpycnal flow related sandstone deposits in a lacustrine shale system using core, wireline log curves, and oil production data. The study aims are listed as follows: (1) to describe and interpret the depositional characteristics of the hyperpycnal flow deposits; (2) to obtain horizontal distribution of hyperpycnal flow related sandstone; and (3) to discuss oil reservoir distribution in hyperpycnal flow related sandstone. Following this, the horizontal distribution of the hyperpycnal flow related sand bodies as well as oil reservoirs is clarified in the Chang 7 Member. This study focuses on discussing distribution characteristics of hyperpycnal flow deposits as oil reservoirs and the implication for hydrocarbon reservoir exploration in shale deposits.

2. Geological Setting

The Bazhu area is located in the southwest of Ordos Basin, with a relatively gentle structure (Figure 1a). Under the influence of tectonic movement, the Ordos Basin formed a large lacustrine basin in the Late Triassic epoch. During the depositional period of the Yanchang Formation, the Ordos Basin had a large area and flat topography, and there were several sedimentary provenances around it, such as Yinshan ancient land in the north, Alashan ancient land in the west, and North Qinling ancient land in the south [12]. The evolution of the lake basin during the sedimentary period of the Triassic Yanchang Formation was a complete cycle of water inflow and outflow under tectonic control, which underwent a complete development process of initial subsidence (the sedimentary period of Chang 10), rapid development (the sedimentary period of Chang 9–Chang 8), strong depression (the sedimentary period of Chang 7), gradual shrinkage (the sedimentary period of Chang 6–Chang 4+5) and extinction (the sedimentary period of Chang 3–Chang 1) [11]. These provenances continued to supply sediments to the basin, forming thick terrigenous clastic deposits. During the sedimentary period of Chang 7, the Ordos Basin formed a large area of semi-deep lacustrine and deep lacustrine deposits, preserving a set of organic-rich dark shale deposits. This set of shale is an important source rock in the basin. Due to the sufficient supply of detrital material around the lake basin, the fluvial–deltaic deposits continuously accumulated, and the lake basin obtained sediments from those depositions. Typical deep-water gravity flow deposition was formed in the semi-deep lake-deep lake depositional environment [14]. These gravity flow deposits have a large area of continuous distribution, forming an important shale oil reservoir with good development potential.

At present, there are several ideas regarding the trigger mechanism of the gravity flow deposition in the Chang 7 member of the Yanchang Formation. It was previously thought that delta front sediment instability triggered gravity flow deposition. In recent years, flood triggered hyperpycnal flow deposits have been found in the Chang 7 member. The lithology of the Chang 7 member mainly includes fine sandstone, siltstone, argillaceous siltstone, silty mudstone, black mudstone, and oil shale. The mudstone interbedded with sandstone is black in color, rich in organic matter, and fossils can be seen [26]. Deep-water sedimentary information, such as flute, groove, and soft sediment deformation, is developed in the sand and shale deposits.

The Chang 7 member is a good target to study the deposits of deep lake gravity flows. Under the guidance of sequence stratigraphy, the Chang 7 stratigraphic framework was established in the study area [27–29]. The Chang 7 member was divided into three base level cycles, which were further finely divided. The thickness of each base level cycle in Chang 7 member was relatively stable. The structural map revealed structure high in the east and low in the west, with a small structure high in the local area.

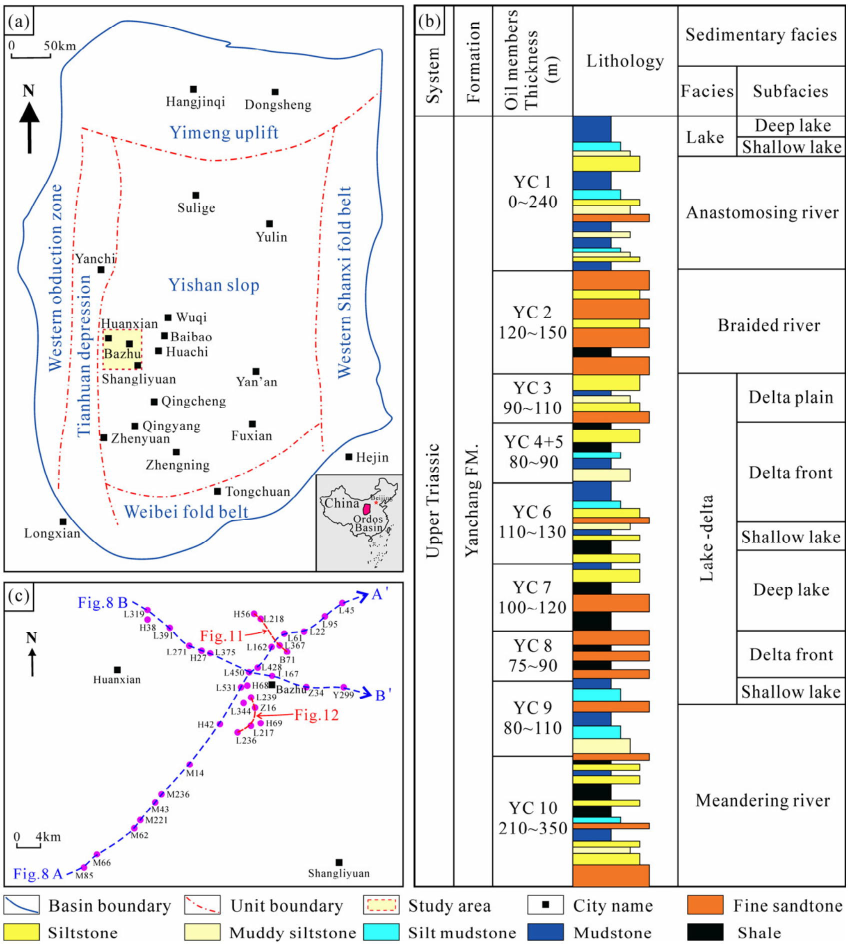

Figure 1. Location of the Bazhu area, with tectonic setting of the Ordos Basin and the stratigraphy division. (**a**) Map showing the division of tectonic units of the Ordos Basin. (**b**) Stratigraphical section of the Yanchang Formation. (**c**) Profiles and typical wells in study area (modified from Liu et al., 2015 [11]).

3. Data and Methods

This study was conducted using core, wireline log curves and oil test production data. Wireline log curves from 500 wells were used for the prediction of the gravity flow sandstone in plan view. The wireline log curves used in this study are from the database of PetroChina Changqing Oilfield Company. Detailed descriptions of the cores in the Chang 7 member were taken for identification and interpretation of sedimentary facies. In this study, cored wells in the study area were comprehensively analyzed for lithofacies, based on factors such as color, sand size, and sedimentary structure that can reflect sedimentary origin and environment. Lithofacies development and vertical sequence of the deposits were summarized. The characteristics of lithofacies from the different depositional sequences were described and interpreted using core descriptions and well-logging curves in the Yanchang Formation. Based on the study of lithofacies types and logging facies analysis of the Chang 7 member, sedimentary facies interpretation was conducted on the wells in the study area. The flood-related origin of the turbidites were revealed through plant debris, vertical grain-size distribution and erosional surfaces in this study.

Wireline log curve data were used to identify sedimentary facies in other wells without cores. The vertical depositional sequences of the Yanchang Formation from the proximal to distal part were summarized through the comparison of typical sedimentary profiles from proximal to distal direction. The distribution of hyperpycnal flow related sandstone in plan view was described through sedimentary facies and a sandstone isopach figure. With the assistance of those processes, the vertical and horizontal distribution of deposits was investigated through sedimentary facies and sandstone isopach figures. On the basis of plane analysis and section analysis, the genesis and evolution of sandstone were discussed. As the hyperpycnal flow related oil reservoirs were developed, the oil production result data were collected. The relationship between shale oil accumulation and hyperpycnal flow related sandstone distribution was analyzed for further discussion.

4. Results

4.1. Deposition Characteristics of the Deep-Water Sandstone

4.1.1. Sedimentary Facies

According to the core observations (Figure 2), the sandstone reservoir of the Chang 7 member in the study area has several lithofacies types, such as parallel stratified fine sandstones (Sh), massive fine sandstone (Sm), massive sandstone with mud clasts (Smg), deformed siltstone (Fd), lenticular stratified heterolithic sandstone (Fh), and black shale (M).

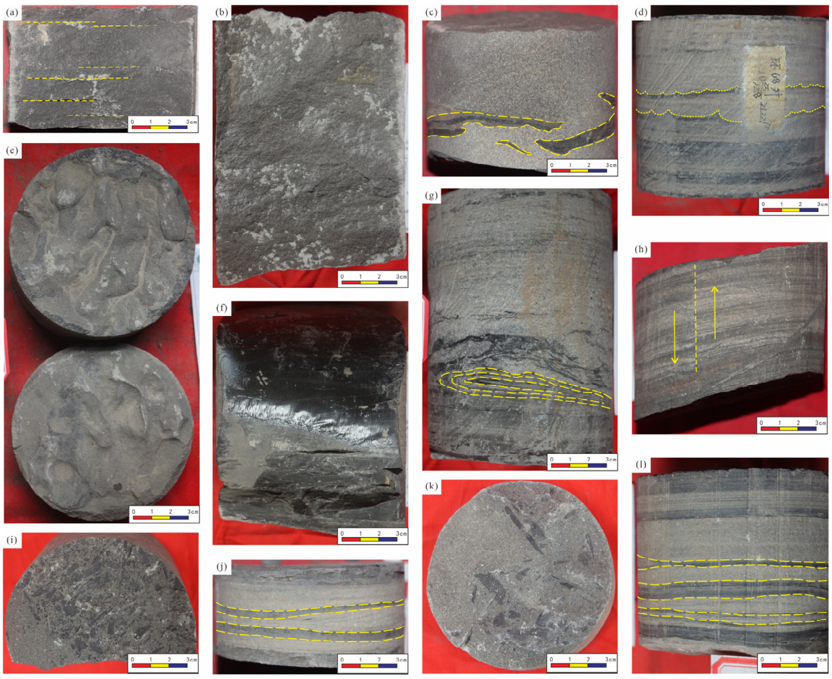

Figure 2. Photographs of cores in the Chang 7 member of the Yanchang Formation. (**a**) Well H38, 2361.25 m, parallel lamination marked by yellow dot lines. (**b**) Well H68, 2112.57 m, massive bedding sandstone. (**c**) Well H27, 2173.75 m, massively-bedding sandstone with mud clasts marked by dot lines. (**d**) Well H68, 2122.76 m, deformed stratified sandstone flame-like structure marked by dot lines. (**e**) Well H27, 2130 m, flute in the base of sandstone bed. (**f**) Well H68, 2116.24 m, slump tectonic surface. (**g**) Well H68, 2011.57 m, convolute bedding marked by dot lines. (**h**) Well H38, 2258.3 m, small scale syn-depositional fault marked by dot lines. (**i**) Well H38, 2361.25 m, fine and abundant plant debris. (**j**) Well H27, 2174 m, heterolithic stratification with ripples in sandstone marked by dot lines. (**k**) Well H69, 2395.9 m, plant debris in sandstone. (**l**) Well H69, 2186.2 m, heterolithic lenticular stratification marked by dot lines. (Location, Figure 1c.)

The lithofacies of parallel stratified sandstone (Sh) (Figure 2a) are typical facies in turbidity deposits. It was formed by vertical accretion caused by a rapid deposition condition. The massive sandstone is homogeneous (Figure 2b) and no lamination was found inside. Black mud gravel can be seen locally in the massive sandstone with mud clasts (Figure 2c). The shape of the mud gravel is different, indicating that deep lake mud sediments were involved and deposited rapidly during turbidity current migration.

The lithofacies of deformed stratified fine siltstones (Fd) often have enveloped convolute bedding and collapsed deformation structures (Figure 2f).

In some local samples, a small-scale fault (Figure 2h) with a size of about 7–10 cm had developed, indicating that stratification was broken, which may have been caused by a paleo-earthquake during the sedimentary period. A flame-like structure and groove mold are visible, which are the key evidence of turbidite deposition. Heterolithic sandstone (Fh) is formed from thin mud laminae interbedded with sand laminae (Figure 2j,l). It indicates mixed sand–mud deposits in the distal part of turbidity flow deposits during the waning period of the turbidity flow. A large number of plant debris were found in the sandstone laminae (Figures 2i,k and 3a,b), which is quite common. Plant debris differ in size and shape and retain the structures of plant leaves, reflecting the long-distance transport process of terrigenous plant leaves by hyperpycnal flow during a flood period. The black shale (M) lithofacies are mainly composed of deep lacustrine shale, and are interbedded with other lithofacies. According to the above analysis, since large-scale slump deposition was not seen in the cores of the study area, the interpretation results of sedimentary lithofacies were closely related to the hyperpycnal flow deposition. lithofacies were closely related to hyperpycnal flow deposition. The sediments that showed a linear arrangement of coarse grains (Figure 4a,b) in the central level of couplets with a coarsening upward part followed by a fining upward part were interpreted as hyperpycnal flow deposition. The vertical grain-size distribution was ascribed to waxing and waning energy levees during flood. Combined with the previous research experience in the Ordos Basin, the study area developed a large amount of flood-related turbidites.

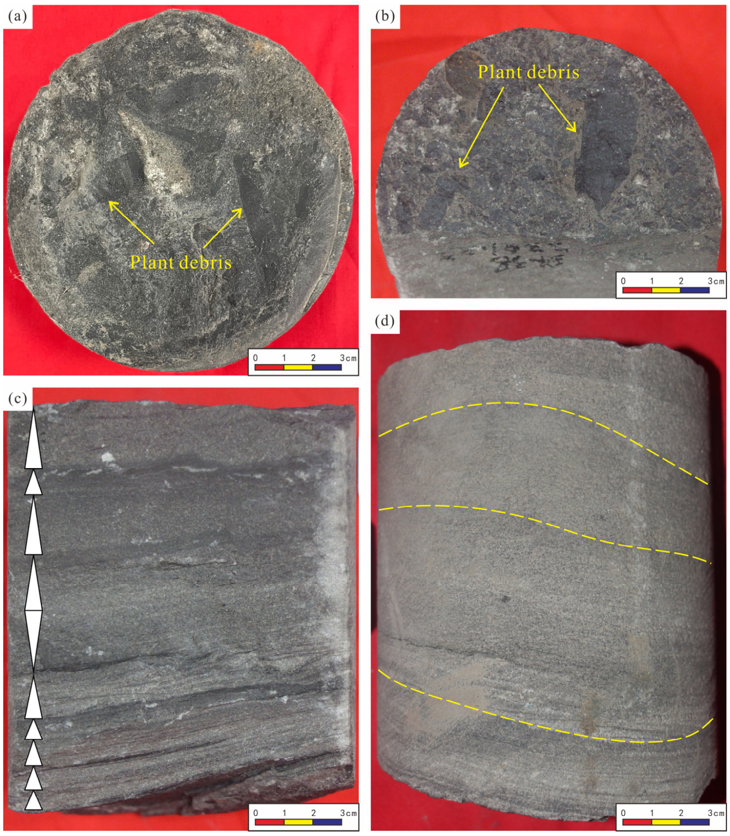

Figure 3. Photographs of cores in the Chang 7 member of the Yanchang Formation. (**a**) Well H68, 2139.63 m, plant debris in sandstone, marked by yellow arrows. (**b**) Well H38, 2361.25 m, fine and abundant plant debris marked by yellow arrows. (**c**) Well H38, 2250.45 m, detail of hyperpycnites showing the frequent vertical variation in grain size marked by white triangle. (**d**) Well H38, 2250.45 m, erosional surface in hyperpycnal flow deposits marked by yellow dotted line. (Location, Figure 1c.)

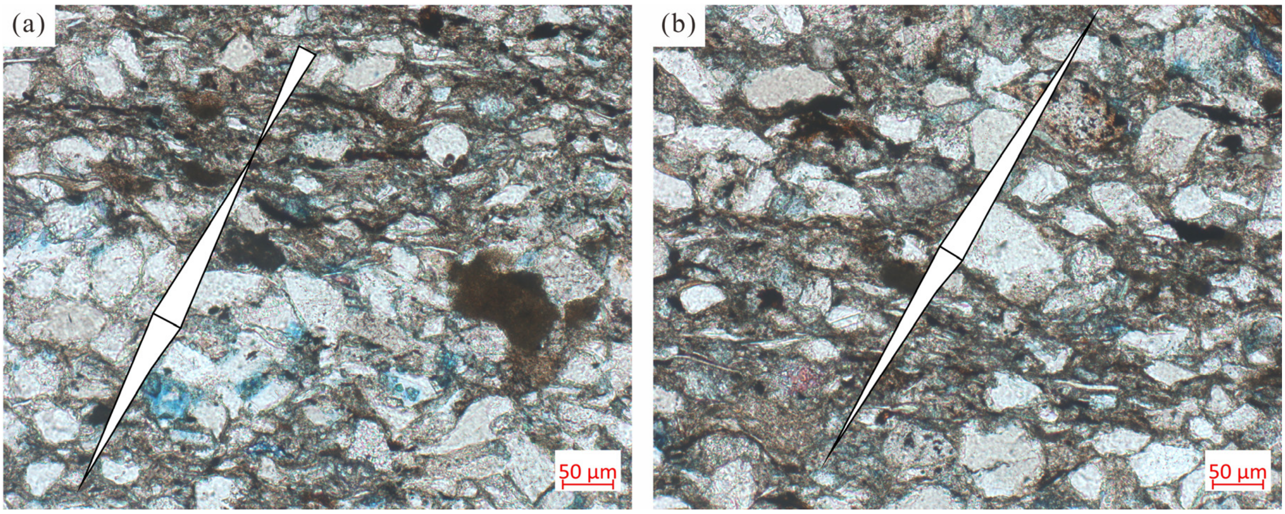

Figure 4. Representative microscope images of hyperpycnite in the Chang 7 member of the Yanchang Formation. (**a**,**b**), Well H38, 2250.45 m, detail of a hyperpycnite showing the vertical coarsing upward and fining upward variation in grain size.

4.1.2. Facies Interpretation from the Cores

Based on the study of lithofacies types and the logging facies analysis of the Chang 7-member, sedimentary facies interpretation was conducted on the wells in the study area (Figure 5). Deep-water sandstone mainly develops in an extrabasinal turbidite fan formed by hyperpycnal flows. Three facies could be further identified in the deposits, including channel, levee, and deep lake shale around the channels.

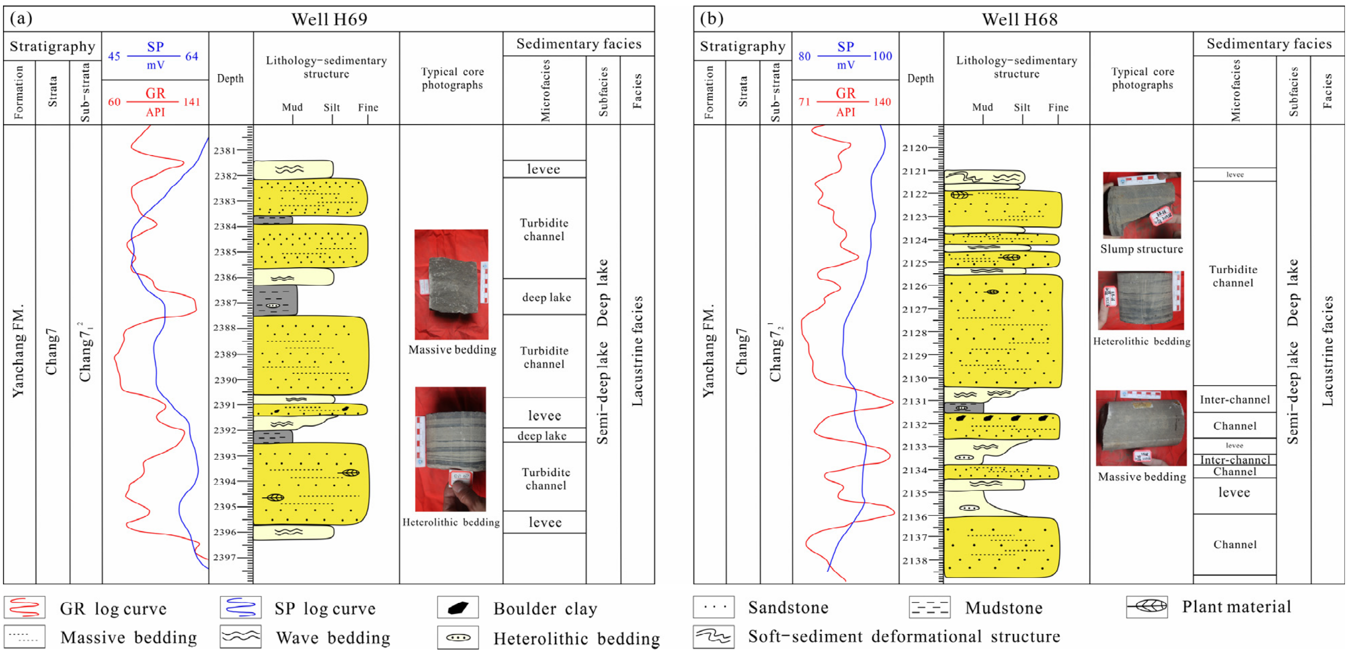

Figure 5. Facies interpretation in typical wells with cores. (**a**) Well H69. (**b**) Well H68. (Location, Figure 1c.)

A turbidite channel is mainly composed of fine-grained sandstone and siltstone with mudstones, mixed with thin layers of gray, dark gray mudstone and silty mudstone. Fossil fragments and plant debris sandstone are occasionally found in fine-grained sandstone and siltstone. The gamma ray curve exhibits as box shaped and bell shaped.

The levee facies are mainly silty mudstone, with interbedded siltstone and argillaceous siltstone. The common sedimentary structures include ripple cross bedding, deformation structure, and heterolithic bedding. Plant debris are found in siltstone and mudstone. Adjacent to the turbidite channel, the natural gamma curve is of medium to low amplitude finger shape and funnel shape.

The deep lake deposits are mainly composed of black mudstone deposits, and the gamma ray curve is generally flat. The facies are deposited near the sandstone deposits, with pure dark mudstone and carbonaceous mudstone widely distributed near the sandstone deposits.

4.2. Distribution of the Hyperpycnal Flow Related Sandstone

According to well interpretation, well cross-section and sandstone contour map (Figures 6–9), the distribution of hyperpycnal flow related turbidity sandstone could be described in the study area. According to data from 542 samples, the thickness of hyperpycnal flow sandstone in the Chang 7_1 sub-member mainly ranges from 5 m to 15 m. The thickness of hyperpycnal flow sandstone in the Chang 7_2 sub-member mainly ranges from 0 m to 10 m. The thickness of hyperpycnal flow sandstone in the Chang 7_3 section mainly ranges from 0 m to 5 m (Figure 6). Average thickness of hyperpycnal flow sandstone in the Chang 7_1–Chang 7_2 sub-member is about 6 m (Figure 7). Moreover, statistical results show that the thickness of hyperpycnal flow sandstone in the Chang $7_1{}^2$ sub-member is distributed between 0.8 m and 19.7 m, with an average of 7 m, which is significantly higher than other sub-members. The average thickness of hyperpycnal flow sandstone in Chang $7_2{}^2$ is the lowest, at 5.13 m. Most sandstones were deposited in the Chang 7_1 and Chang 7_2 base level cycle. The Chang 7_3 base level cycle mainly deposited shale deposits.

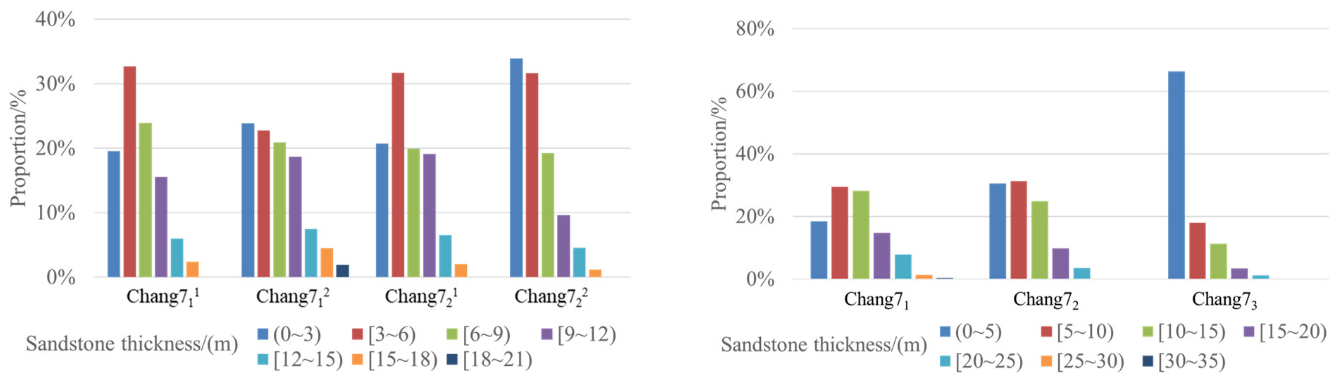

Figure 6. Histogram of sandstone thickness interpreted from wells.

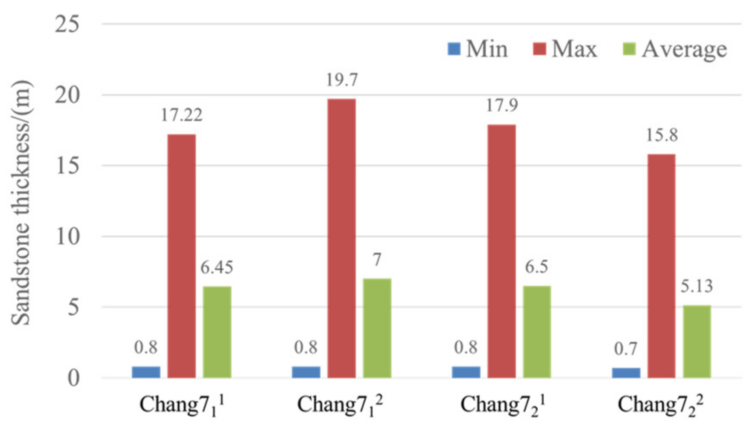

Figure 7. Statistical histogram of maximum and minimum sandstone thickness.

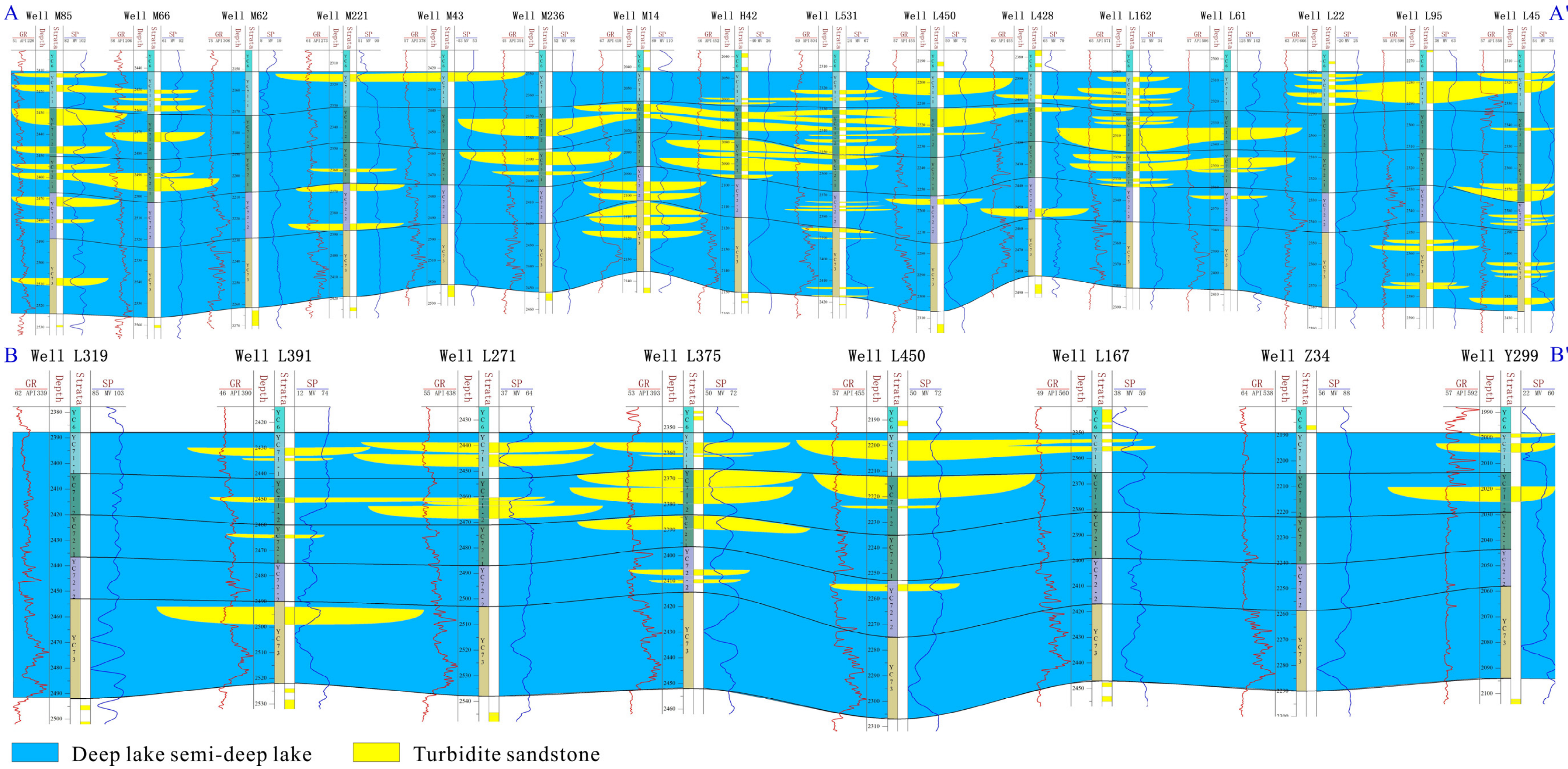

Figure 8. Sedimentary facies interpretation cross-section in the study area. (See well location in Figure 1c.)

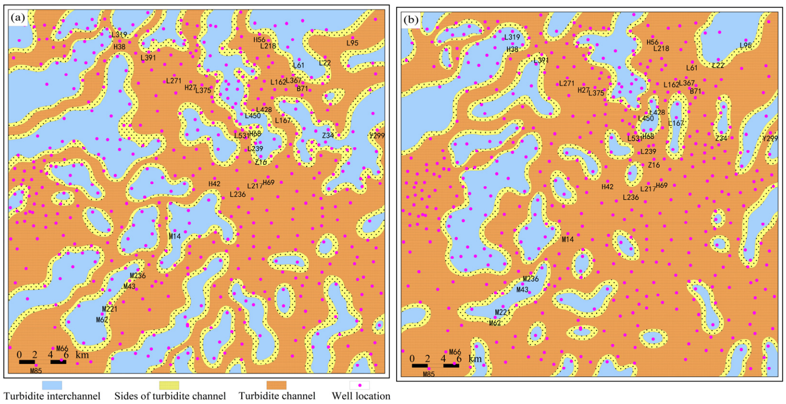

Figure 9. Sedimentary facies distribution of Chang $7_1{}^1$ and Chang $7_1{}^2$ members in the study area. (**a**) Chang $7_1{}^1$ small layer. (**b**) Chang $7_1{}^2$ small layer.

Based on single well facies analysis, a cross-section (Figure 8) with well log curves was performed along the flow direction and one cross-cutting flow direction to analyze the variation of sedimentary facies. The profile along flow direction (A-A′) revealed that turbidite sandstone are mainly distributed surrounding deep lake shale. The sand bodies have lateral continuity across a long distance in the section. The lateral continuity of sand bodies is different in the profile (B-B′) vertical to flow direction. The sand bodies mainly developed in isolation. Both profiles showed that the sand body development scale gradually increased from bottom to top. This was controlled by a depositional process in which the base level fell and sediments from the rivers gradually increased and flowed into the deep lake basin during flood events.

In the study area, Chang 7_3 mainly developed semi-deep lacustrine to deep lacustrine facies. At this time, the base level rose rapidly, and the sediment supply was insufficient. The sandstone was locally deposited at small scale. The ratio between sandstone and stratum thickness is less than 20%.

In the sedimentary period of Chang 7_2, the sediment supply of the basin increased. The hyperpycnal flow related channel deposits developed. The overall distribution of sand bodies in Chang 7_2 is relatively wide, and the sand ratio is larger than twenty percent. The distribution of sandstone was obviously controlled by the distribution of sedimentary facies of the turbidity channel. During the deposition period of Chang 7_1, the sandstone was more widely distributed overall (Figure 9a,b), and the thickness of the sand body is the largest in the Chang 7 member. The central and eastern part of the study area is the dominant channel deposition area of extrabasinal turbidites (Figure 10a,b). This reflects the descending process of base level cycle. The fluvial derived sediments were continuously supplied to the deep lake under transportation of hyperpycnal flows.

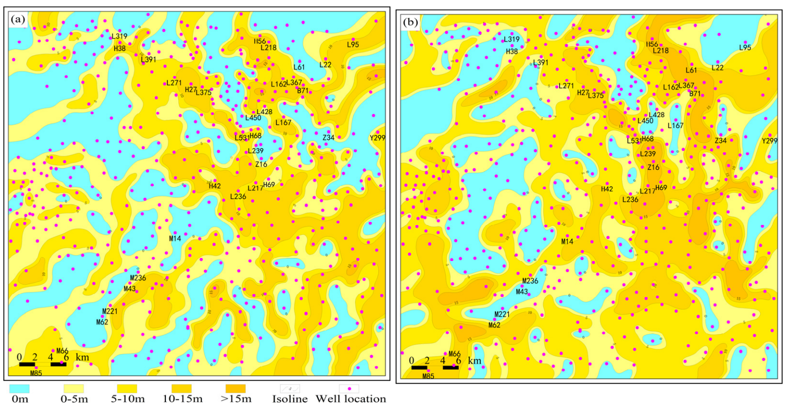

Figure 10. Sandstone thickness of Chang $7_1{}^1$ and Chang $7_1{}^2$ members in the study area. (**a**) Chang $7_1{}^1$ small layer. (**b**) Chang $7_1{}^2$ small layer.

5. Discussion

5.1. Oil Reservoir Distribution in Hyperpycnal Flow Related Sandstone

It can be observed from the oil reservoir cross-section (Figures 11 and 12), that the hyperpycnal flow deposits could form oil reservoirs in the study area. According to the distribution of hyperpycnal flow sand bodies in the study area, the sand bodies of Chang 7 oil formation are hyperpycnal flow related channel sand bodies, which have a wide distribution range, large thickness, are overlapping sand bodies, and have relatively continuous distribution. The scale of the hyperpycnites controls oil reservoir distribution. From the view of plane superposition and single well analysis, a thick sand body is the favorable position for oil formation development. The oil reservoirs were developed in those interbedded sandstone in shale deposits. Controlled by the distribution of sandstone facies and local structural variation, the up-dip pinching of the sandstone could form a trap surrounded by the shale (Figure 11). This could form a good condition for the accumulation of oil generated from the shale deposition in the Chang 7 member of the Yanchang Formation, although the oil reservoirs were mainly formed in channel deposits with good reservoir quality. Due to diagenesis-related reservoir quality, thin bedded tight sandstone with poor porosity was also formed in the sandstones (Figure 12). Those tight layers could not form good oil reservoirs. The thin bedded tight sandstone could have formed during flood events with less sediment supply or at a distal position to the hyperpycnal flow deposits.

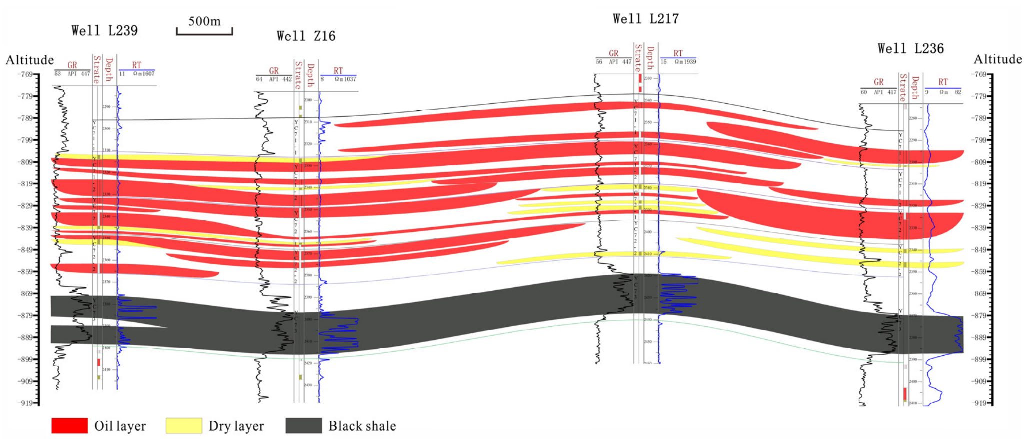

Figure 11. Multi-well reservoir cross-section in the study area (L239-L236 section). (See well location in Figure 1c.)

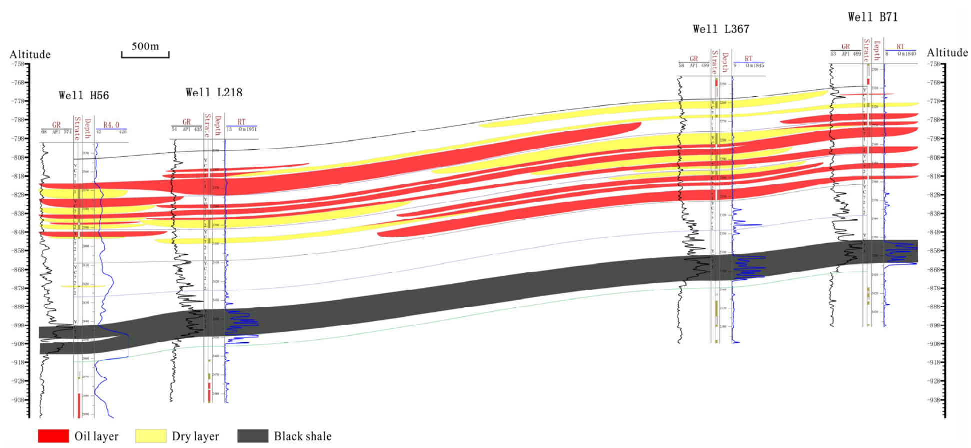

Figure 12. Multi-well reservoir profile in the study area (H56-B71 section). (See well location in Figure 1c.)

5.2. Oil Production of Hyperpycnites Related Reservoirs

As the hyperpycnal flow related reservoirs were developed in the study area, the production result data were collected for further research. The high production wells are mainly located in sand body thickness greater than 10 m. For example, the daily oil production of well L344 is 65 t, and the thickness of hyperpycnal flow sandstone in Chang 7_1^2 is 13 m. Statistical results show that the porosity of the sandstone ranges from 9.2% to 12.1%, the permeability of the sandstone ranges from 0.1 mD to 0.3 mD, and the oil content saturation ranges from 40% to 69%. Meanwhile, sandstone lithofacies are characterized by low value of resistivity, acoustic interval transit time and natural gamma (Figure 13). The daily production per well is positively correlated with the thickness of the hyperpycnal flow related sand body. When the thickness of hyperpycnal flow sandstone is lower than 5 m, the daily oil production per well is less than 5 t. When the thickness of hyperpycnal flow sandstone is 5–10 m, most of the daily oil production per well ranges from 5 t to 10 t. When the thickness of hyperpycnal flow sandstone is more than 10 m, most of the daily oil production per well is greater than 10 t (Figure 14). Therefore, the development scale of the reservoir plays an important role in shale oil enrichment. The difference in the development scale of sand bodies is one of the important reasons leading to the productivity difference. The development effect of an oil-bearing reservoir with a large sand body thickness and continuous development is better than those developed in thin bedded sandstone. The sandstone thickness could be related to good reservoir quality, with better oil production results. The large scale hyperpycnal flow channels in a proximal area could be good oil reservoirs with good development effect. The sandstone in the distal area may have more dry layers with poor reservoir quality and development effect.

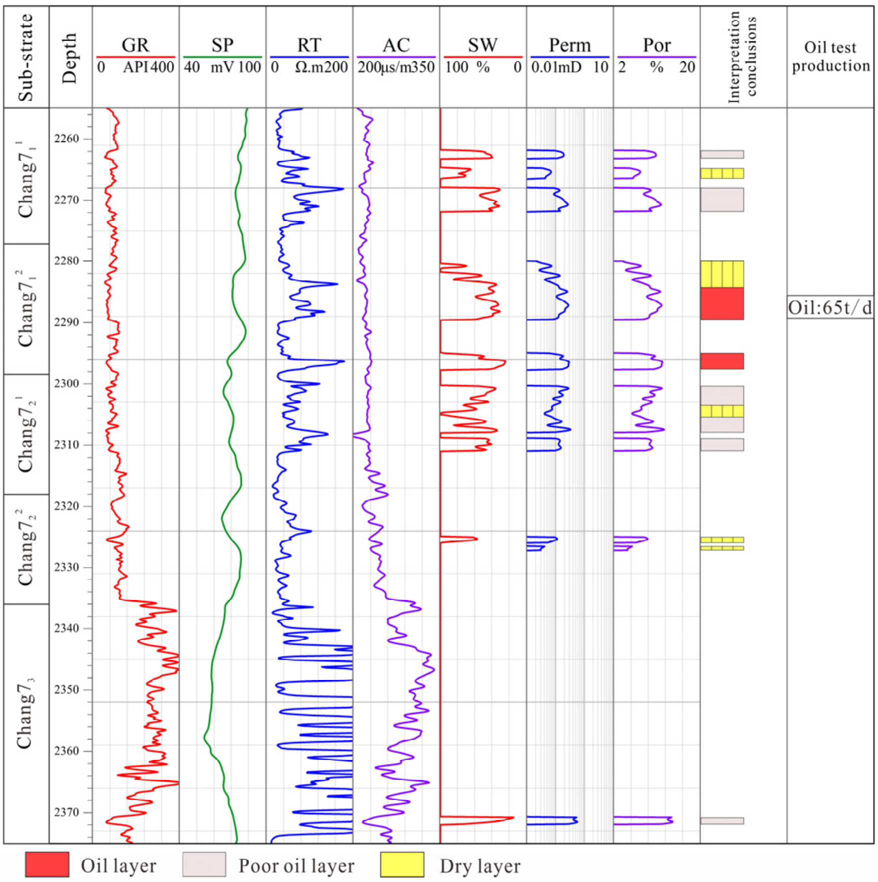

Figure 13. Log response analysis of hyperpycnites and shales in well L344. (See the well location in Figure 1c).

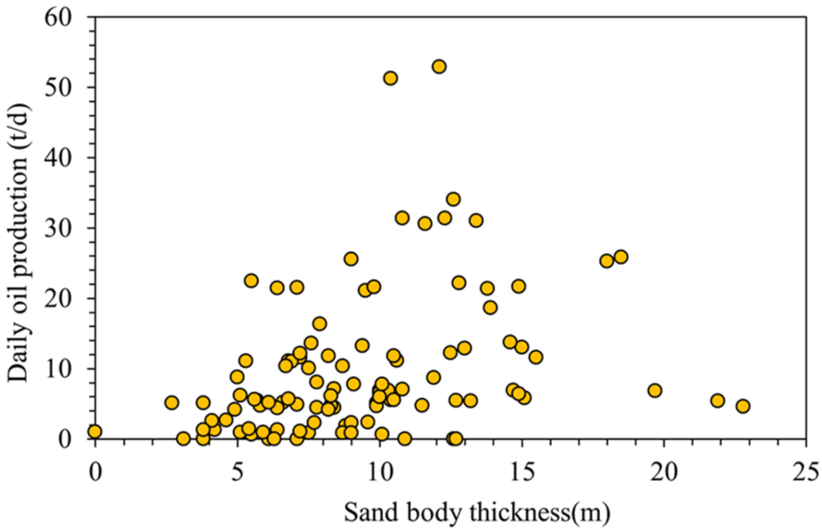

Figure 14. Relationship between sandstone thickness and oil production from wells.

6. Conclusions

1. The hyperpycnal flow deposition was developed in the Chang 7 member of Yanchang Formation in Bazhu area, southwest Ordos Basin. There are several lithofacies types, such as parallel bedded fine sandstone (Sh), massive bedded fine sandstone (Sm), massive bedded fine sandstone with mud clasts (Smg), deformed bedded siltstone (Fd), wave-lenticular bedded siltstone (Fh), and black shale (M). Inside, three facies of hyperpycnal channel, levee and deep lacustrine facies can be identified;
2. The extrabasinal turbidity flows of the Chang 7 member developed in deep and semi-deep lacustrine environment. Influenced by the fluvial supply from southwest of the basin, the sediments were plunged into the lake basin. The hyperpycnal flow deposits in Chang 7_2 and Chang 7_1 were developed in a large area. The complex turbidite channel sand body is the main position of sandstone development in the black shale background environment;
3. The development of the sand body of Chang 7 increased gradually, and the sand body of Chang 7_1 was the main position of sandy hyperpycnites. The fine description of the sand body indicated a channelized sedimentary pattern. The thick sandy hyperpycnites mainly developed in the middle of those channels, and the eastern part of the study area is the main deposition position of the hyperpycnal flow deposits;
4. From the analysis of the actual well data, the distribution range and scale of high-quality reservoirs are controlled by the sedimentary characteristics of those sand bodies generated by the hyperpycnal flow. The sedimentary dynamic and facies belt could be the main reason for the sandstone variation of hyperpycnites. From the perspective of plane overlap and single well analysis, the thick sand body is the favorable position for the development of an oil reservoir, which has a significant control effect on the reservoir scale and oil production.

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