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Study and Application of Fine Dissection Methods for Inter-river Sands in Large Shallow River-controlled Delta Plains

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Abstract: Applying the data of coring wells and logging curves of dense well network, identifying the sedimentary sands of different river systems and contemporaneous periods with the methods of standard layer approximation control and comparison of reference layer combinations, establishing a set of logging phase models of inter-river sands, and using the models as a guideline for micro-phase identification, we have studied the distribution and combination characteristics of the micro-phase sands of the inter-river sand bodies, as well as the type of connectivity with the sand bodies of the river and the relationship, and clarified the distribution characteristics and residual oil distribution of the sand bodies of the inter-river sands. The characteristics of different types of sand body movement and residual oil distribution were clarified, effective dredging methods were proposed, and measures such as oil testing and fracturing were taken, which played an important role in guiding the adjustment and dredging of oil fields in the late stage of high water content.

Keywords: River-controlled delta; Logging phase mode; Connectivity type; Mobilisation status; Effect analysis

Introduction

The river-controlled deltaic plain inter-river sand body is a set of vertical accretionary deposits formed by multiple river breaks or floods during flooding periods, which are usually thinly laminated-thinly interbedded and stacked on both sides of the river channel [1-3]. In Xingnan Oilfield, such sand bodies are developed in the PI1-3 layers of the delta front phase and the diverging plain phase. Statistical Xingnan Development Zone PI1-3 layer, the inter-river sand has a certain thickness ratio, and the mobilisation is poor, with a large residual potential. However, from the current research status of inter-river sand, no in-depth study has been carried out in China, and there is a lack of comprehensive understanding of the planar distribution scale of the inter-river sand body, microphase type and the connectivity status between wells, etc. Therefore, in order to satisfy the needs of the oilfield development to adjust and explore the potential, and to better guide the development of the oilfield.

1. Fine anatomy method of inter-river sand body

PI inter-river sand has the characteristics of thin thickness of single layer, many layers, and big change of layer position, which is not easy to be distinguished on the logging curve. In view of this particularity of inter-river sands, research is carried out in terms of unit subdivision and comparison, establishment of inter-river sand micro-phase model, plane micro-phase identification and morphology combination, and ultimately the fine anatomy of single sand body of inter-river sands is realised.

1.1 Subdivision and comparison of river sand units

1.1.1 Adopt the "planar well network" comparison method to control the comparison of the whole area.

In the study area, we make a longitudinal and transverse closed skeleton profile across the whole area, and use it to control the comparison of the whole area; under the control of the boundaries of each unit of the closed skeleton profile, we carry out the comparison of the wells; from big to small graded control, graded comparison, graded closure. This increases the reliability and uniformity of the comparison.

1.1.2 Single-well comparison using the "standard layer approximation control, reference layer series - tectonic mode" comparison method

(1) Comparison using standard layer

Firstly, find the first standard layer which is very stable and obvious in the study area for comparison, after comparing the upper and lower standard layers and accurately controlling the stratum in between, then find the second standard layer or a better marker layer in between, and compare the top standard layer and the bottom standard layer to the middle layer, so as to realise the high-precision and accurate comparison.

(2) Comparison with reference layer when no standard layer is available

In the absence of a standard layer, a thin rock layer that can be clearly distinguished from the upper and lower neighbouring strata, easy to identify and compare on the plane, and can be continuously traced within a small area can be used as a reference layer for comparison.

(3) Comparison using tectonic patterns

Tectonic influence is fully considered, such as faults causing missing, duplicated, thickness increase or decrease of stratigraphy or comparison markers, etc. Tectonic model of the comparison area established by a small number of typical wells can be used to guide the comparison.

By adopting the above two methods, not only avoiding the "boundary error expansion", but also improving the work efficiency; at the same time, overcoming the thin thickness of the sand body between the river and the problem of frequent changes in the layers, preventing the string of layers, and improving the accuracy of the comparison.

1.2 Establishment of the logging phase model of the river sand

Because of the thin development of the sand body, the curve morphology characteristics are not obvious, and its microphase characteristics have been described in a general way [4-7], in order to understand the internal architecture of the river sand and fully understand the river sand body, we based on the coring well data from the lithology, laminations, curvilinear elements, and other aspects of the sand microphase of the river sand in a detailed study, and the establishment of the five logging phase mode.

Natural dyke microphase: It is a sand dyke formed parallel to the riverbed by the accumulation of fine silt-grade material carried by the river water along both banks of the riverbed due to the high water level of the river during the flooding period [8]. It is dominated by transitional lithology and thinly interbedded siltstone, about 2-4m thick. Small microfine interbedded laminations, unidirectional oblique laminations, and horizontal undulating laminations are developed. The curve is characterised by medium width, (toothed) box shape, medium-thick layer, and top-bottom mutation.

Decision watercourse: It is a small fixed watercourse deposit gradually formed by the main diversion channel breaking the natural dyke during the period of mega-flood [9], with fine grain size, mainly fine sandstone and siltstone; the thickness of the sand body is very thin, mostly less than 2.5m; the vertical grain-size sequence with the bottom mutation, the top mutation, or the faster gradual change, and the slightly positive cyclic feature. The curves are characterised by medium-high amplitude, flat bell-shaped, fine-layered, bottom-mutated, top-mutated or gradual features.

Breakout fan: a sedimentary body that accumulates at the breakout and is distributed in the shape of a fan as a result of the river overtopping the natural embankment during the flood period [10]. It usually shows obvious small positive rhythms, and the bottom with scouring surface or mutation surface, but compared with the sand body of the waterway at the break, its layer is thin, generally less than 0.5m; fine grained and high mud content, with siltstone and muddy or calcareous siltstone, transitional lithology is dominant. Curve characteristics are dominated by medium amplitude, extremely flat bell-shaped, very thin layer, bottom mutation, top mutation or gradual change characteristics.

Overbank sand: It is a large area of thinly bedded mat sand formed by general overbanking of the river during flooding, or a local thinly bedded lamellar sand body formed by local overbanking [11]. In general, the grain is fine, the mud content is high, the rotational nature is not obvious, the scouring surface is not developed, sometimes see the bottom scouring surface or the top and bottom gradient; with less developed small and medium-sized interbedded laminations, unidirectional oblique laminations, block laminations and so on. The curve is characterised by medium amplitude, single finger-like, very thin layer, top and bottom mutation or gradual change.

Intercurrent mud: the mud between the above-water intercurrent is a thicker layer of single purple, mottled, grey-green dominated, blocky laminations; the mud between the underwater intercurrent is dominated by dark grey, grey, grey-green, with extremely developed and clear laminations, with horizontal laminations. Colour and stratification are important markers for distinguishing underwater and onshore depositional environments. The curve is the lowest amplitude, linear feature.

1.3 Microphase identification and planar morphology combination of river sand

River sand micro-phase identification and planar morphology combination is complementary, inseparable. How to outline the plane morphology truly, we mainly carry out from two aspects:

One is to use the logging curve for single well microphase identification. Natural dike, breakwater waterway, roots of breakwater fan and other micro-phase features are obvious and easy to identify, can be based on the logging phase mode directly on a single well to determine the phase. While the overflow bank sand, the end of the fan micro-phase type characteristics are similar, according to the single well characteristics to determine the maximum possible types, but also carefully recorded its rhythmic characteristics, curve morphology features, and so on. Secondly, the combination of each microphase genesis pattern of the river is referred to while determining the phases. The combination is determined according to the information indicated on the single well and with reference to its relative positional relationship with the river.

2. Understanding after fine anatomical study of river sand

2.1 Understanding of inter-river sand plane distribution characteristics

The inter-river thin-layered sand of the PI group has obvious river control, and its overall macro-distribution and development are affected by river control factors such as river location, type, scale, embankment development, and river hydrodynamic conditions. After the fine description of the inter-river thin-layered sand, we have recognised its planar distribution characteristics, which can be classified into three categories according to the morphology and scale of the inter-river thin-layered sand.

(1) Large mat-shaped distribution of inter-river sand

This type of sand body is developed in the delta in the leading edge of the far shore depositional environment, the inter-river sand is well developed, due to the distance from the lake shore and the water body is deeper, the underwater diversion channel embankment limitation is poor, so that both sides of the river flow smoothly, thus forming a more development of the underwater mat-like thin layer of sand. This kind of sand body micro-phase type is single, mainly diffuse sand between underwater diversion, into mat or sheet distribution, the drilling rate is 85.8%, other micro-phase type is not developed, sporadic distribution of sharp extinction area, the drilling rate is 14.2%.

This kind of large-area mat-like distribution of diffuse sand, in the direction perpendicular to the river channel, from the underwater diversion channel to the underwater diversion between the main body of the diffuse sand → diffuse sand inner edge → diffuse sand outer edge → underwater diversion between the mudstone, with a strong regularity. The lithology, physical properties and oil content gradually deteriorate from the edge of the river channel to the direction away from the river channel.

(2) Inter-river sands locally distributed in patches or narrow bands at the edge of the river channel

This type of sand body is mainly distributed in the delta within the front edge of the underwater nearshore depositional environment, due to the shallow water near the bank, the river bank is higher, thus controlling the scale of the diffuse flow, the formation of local pieces or narrow band distribution of the inter-river thin layer of sand, inter-river thin layer of sand drilling encounter rate of 22.7%. The microphase type is mainly dominated by submerged diversion diffuse sand, and there are a small number of submerged breakwater channels, submerged breakwater fans, submerged natural dyke microphase, with a large distribution of sharp extinction area, and the drilling encounter rate is 48.6 per cent.

(3) Inter-river sands distributed in the form of ring and band between river channels or strips along the river channel.

This type of sand body is mainly distributed in the delta diversion plain environment, mostly located in the inter-channel ring band distribution, or along the direction of the river strip distribution, inter-river thin sand drilling encounter rate of 20.6%. The microphase type is dominated by overflow bank sand, natural dyke and breakout fan, but the scale is small, which is caused by the development of land down-cutting river channel, dyke and its mud anti-shock property to limit the breakout and control the overflow bank. The tip extinction zone is distributed in strips or sporadically, and the drilling encounter rate is 12.4 per cent.

2.2 Understanding of the change characteristics of the river sand before and after fine dissection

(1) The distribution scale of the inter-river sand becomes smaller after fine dissection, and the morphology is closer to the subsurface reality

In the previous description, we describe the inter-river sand body of the same sedimentary unit in a general way, and the distribution range of the inter-river thin-layered sand is poorly described, and the scale of the description is too large; through the study of the fine anatomy of the inter-river sand body, we can accurately recognise the geometric morphology and the distribution range of the inter-river sand body of different periods, and the scale of the distribution of the inter-river thin-layered sand body after dissection has become smaller, and the boundaries of the sand body are more real and clearer, and are closer to the actual situation of the underground. The actual situation.

(2) After the fine dissection of the inter-river sand, the contact location with the river sand changes

After fine dissection of the inter-river thin-layered sand, it makes us realise that the contact position between the inter-river thin-layered sand and the river channel sand in different periods is different, and should be analysed specifically, not generalised. Three inter-river thin-layered sands are developed longitudinally from bottom to top of unit PI33b in well 4-B313, which are in contact with the boundary of the river channel of PI33b1 before fine dissection. After fine dissection, the thin sand at the bottom of the channel separated from the channel and formed a new thin sand unit with the inter-river thin sand formed in the early part of well 4-B313, whereas the thin sands formed in the middle and late part of well 4-B313 were in contact with the channel boundary of PI33b2 and the channel boundary of PI33b1, respectively. The dissection makes us clearer about the changes in the location of the contact between the interstitial sands and the river channel boundary in different periods.

3. River sand fine anatomy results to guide oilfield development

3.1 Connected relationship between river sand and river sand body

In the study area, the statistical analysis of the rhythmicity of the river sand located at the edge of the river channel shows that 90% of the river sand curves have positive rhythmic characteristics. Therefore, we mainly focus on the relationship between river sand bodies with positive rhythmic characteristics and inter-river sand connectivity. According to the formation period of the inter-river sand, we classify the connectivity between the inter-river thin layer sand and the river sand into the following types.

When the inter-river sand is in contact with the bottom and middle of the river body sand, the connectivity is good. When the thin-layered sand is in contact with the top of the river sand body, the connectivity is poor because the river sand is mostly orthorhombic and the physical properties of the sand body at the top deteriorate. When the river sand is in contact with the natural dike or the breakout fan micro-phase, the general connectivity is poor, because the physical properties of the natural dike microphase are poor and most of the layers are high; while the breakout fan sand body has a small contact area with the river, so these two microphase sands are poorly connected to the river sand. Isolated inter-river sand, wave modification of the formation of underwater diversion between the thin layer of sand body, such as due to the surrounding tip extinction, and the river sand is not connected. At the same time, when the inter-channel sand is in contact with the upper part of the abandoned channel, it is not connected due to the top mud shading.

3.2 Utilisation status of inter-river sand

We made full use of the water washing data of coring wells, water flooding layer interpretation data and water injection well suction profile data to analyse the mobilisation status of the inter-river thin layer sand.

(1) Using the water washing data of coring wells, the thickness of sand washing between the river is low, and the water washing is mainly within the layer.

The analysis of the data of three coring wells, including Xingnan Development Zone 2-Check 375 well, shows that the overall water washing thickness of the sand between the river is low, with the proportion of the water washing thickness being 15.6%, and the proportion of the unwashed thickness being 83.5%, which is poor in terms of mobilisation. From the analysis of the washing condition of the surface and inner layer of the coring wells, the movement of the surface layer is relatively good, with the proportion of the washed thickness of 58.3% and the proportion of the unwashed thickness of 41.7%. This fully illustrates that although the thickness of the thin sand development between the river is small, there is still non-homogeneity within the layer.

(2) Using three encrypted wells water flood layer interpretation data analysis, the inter-river sands are dominated by unflooded and low water flooding, and the degree of water flooding is low.

Through the three encrypted wells in the study area of the inter-river sand surface layer water flooding interpretation data for statistics, the effective layer of the thickness of the un-flooded 46.0%, the proportion of the thickness of the low flooded 27.4%, low un-flooded accounted for the total thickness of the effective layer of the inter-river sand of 73.4%, with a large proportion, and the proportion of the medium flooded, high flooded thickness of only 26.6%, which can be seen that the inter-river sand water flooding is lower, with a certain degree of residual potential.

(3) Using the water injection well suction profile data, we analysed the mobilisation status of different microphases and types of inter-river sands.

The degree of utilisation of different microphase types of inter-river sands varies, with overbank deposits being the best utilised, followed by the breakwater watercourses, and the breakwater fans and natural dykes being the worst utilised in the microphase. The mobilisation of different types of inter-channel sands varied, with good mobilisation of inter-channel sands in large mats and poor mobilisation of inter-channel sands in inter-channel loops. Among the inter-river thin layer sands distributed in large mats, the thin layer sands at the edge of the river channel were well utilised, and the thin layer sands far away from the river channel were poorly utilised.

The analysis of the utilisation status of inter-river sands shows that the overall utilisation status of inter-river sands is poor, with the proportion of layers and thicknesses well utilised being 32.1% and 33.8% respectively, and the proportion of layers and thicknesses poorly utilised and unutilised being 67.9% and 66.2% respectively, so there is a large remaining potential, which is the main object of adjusting and tapping in the future. We can excavate the remaining potential of inter-river sands through fracturing modification or hole patching. Meanwhile, for the remaining oil of the river sands distributed at the edge and top of the river, measures can be taken for the inter-river sands connected with the river, so as to excavate the remaining potential at the edge of the river and improve the mobilisation of the river sands.

3.3 Analysis of the effect of inter-river sand measures

(1) Oil test of local unused area and off-surface reservoirs at the river edge

Oil test was conducted on Xingnan encrypted test wells 2-B3422 and 3-B3411, and the effects are shown in the table (Table 1).

Table 1 Table of oil testing effect of three encrypted test wells

Well No.	Stratum	Outer surface thickness(m)	Sandstone thickness(m)	Effective thickness(m)	Way	Oil test results	
						Daily production of oil(t/d)	Daily water production(m^3/d)
2-B3422	PI1	1.2	0.3	0.3	Oil test	1.3	0
2-B3422	PI2	1.6			Oil test	0.109	0
2-B3422	PI3	2.8	0.3	0.3	Fracturing	4.7	4.0
3-B3411	PI1	0.6	0.6	0.6	Perforation	10.0	0

2-B3422 well test oil 3 layers, PI1 layer and PI2 layer. Among them, PI1 layer develops off-surface thickness of 1.2m, effective thickness of 0.3m, from the logging curve, the microelectrode curve has amplitude difference, permeability of 133mD, water flooding is interpreted as unflooded, from the microphase diagram analysis, is located in the river side of the local overflow bank deposition, the surrounding wells have not been shot holes, it is an unused area, after the oil test, the daily production of 1.3t of oil, no water, the PI2 layer is an independent off-surface layer, the development of the thickness of 1.6m, curve shape is a jagged box, has a certain formation thickness, after the oil test, the daily production of 0.3t of oil, no water. 1.6m, the curve form is jagged box shape, with certain stratum thickness, after oil test, the daily oil production is 0.109t. After fracturing of PI3 layer, the daily oil production is 4.7t, the effect is better.

(2) The top of the river channel deterioration part contact inter-river sand oil test

Well 3-B3411 develops effective thickness of 0.6m, oil saturation is 65%, the logging curve is finger-like with amplitude difference, and water flooding is interpreted as unflooded. From the microphase diagram analysis, 3-B3411 well is located in the edge of the river channel, in contact with the top of the river channel sand variance parts, there is a water well 3-B345 wells around, but the oil wells have not shot holes, so the analysis of the well area for the residual oil area, the daily oil production of the test oil 10t. Through the analysis of the effect of the above layers of measures, to achieve the following two points of understanding:

The inter-river sands or watercourses in contact with the top deteriorated part of the river sands are usually the residual oil-rich area, and it is recommended to make up the hole for dredging. For the inter-river sands that develop a certain off-surface thickness, if they are poorly utilised or not utilised, fracturing measures can be used.

4. Conclusion

(1) In view of the characteristics of the inter-river sands, the “planar well network comparison method” and the “standard layer approximation control, reference layer series - tectonic mode” comparison method are adopted to achieve the fine dissection to the single-phase sand body. Based on the data from the coring wells and the logging curves of the dense well network, five logging phase models, namely, natural dyke, breakwater waterway, breakwater fan, overflow sand (diffuse sand), and interflow mud, have been established.

(2) With the change of depositional environment, the scale of inter-river sand development gradually becomes smaller and the microphase type of development also changes from a single underwater diffuse sand to multi-phase from the far shore depositional environment of the inner front edge of the delta → the near shore depositional environment of the inner front edge of the delta → the depositional environment of the delta diversion plains.

(3) The formation period of the inter-river sand is different, and its degree of connectivity with the river is also different. Generally speaking, the inter-river sand in contact with the bottom and middle of the river sand is well connected, and the inter-river sand in contact with the top of the river sand is poorly connected.

(4) Among the different microphase types of inter-channel sands, the overbank sedimentary inter-channel sands are highly mobilised, and the three microphase types of the breakwater channel, natural dyke and breakwater fan are poorly mobilised. Among the better-developed overbank sedimentary sands, the inter-river sands distributed in large mats were well utilised, and the inter-river sands distributed in a ring belt between the channels were poorly utilised. Overall, the inter-river sand is poorly mobilised and has a large remaining potential.

(5) It is suggested that when selecting wells for measures, the oil content, permeability and lithology of the logging curves should be analysed comprehensively, and at the same time, combined with the characteristics of planar distribution, the wells with good oil layer conditions and planes in the remaining oil zone should be selected for measures to be reformed.

References

[1] Liu Guotao, Zhao Wei, Long Tao, He Yuhang et al. Research on the division method and modeling technology of internal structural units in river sand bodies [M], 2006

[2] Chen Fengxi, Liu Haifeng, etc. The application of variation function in predicting the scale of braided river sedimentary sandstone reservoirs [J] Journal of Chongqing University of Science and Technology (Natural Sciences Edition), 2008, 10 (1): 9-11

[3] Zhang Juan. Research and application of thin reservoir prediction technology based on multiple linear regression analysis in Shengli exploration area [J] Chinese Journal of Engineering Geophysics, 2013, 10 (1): 91-94

[4] LI Zhandong, ZHANG Lishuang, LI Yang, et al. Channel sand characterization based on the fusion of multiple iterative attributes—a case study of Z area of Fuyu oil layer in Daqing oil field[J]. Progress in Geophysics, 2017, 32(3): 1161-1168.

[5] Ricker, N. The form and nature of seismic waves and the structure of seismograms.Geophysis, 1940, 5(4):348~366.

[6] Ricker, N. Wavelet contraction, wavelet expansion and the control of seismic resolution, Geophysics, 1953, 18(4):769~792.

[7] Cui Shuqing, Liu Xuejun. Research on Reservoir Heterogeneity of Es32+3 Sub segment in Shahejie Formation of Gaoshangbao Oilfield [J] Journal of Xi'an Shiyou University (Natural Science Edition), 2005, 20 (2): 22-24

[8] Wu Tao, Yang Yong, Wang Defa. Research on modeling methods for braided river reservoirs [J] Acta Semanticologica Sinica, 1999, 17 (2): 258-261

[9] Guan Shihua, Gao Shengwei. The initial adjustment method and effect of injection in braided river sedimentary reservoirs [J] Journal of Xi’an Shiyou University (Natural Science Edition), 2003, 18 (2): 36-39

[10] Wu Tao, Wang Jianguo, Wang Defa. A Study on Sedimentology of Braided River Sand Body Reservoirs - Taking the Outcrop Sand Body in Zhangjiakou Area as an Example [J] Acta Semanticologica Sinica, 1998, 16 (1): 27-33

[11] Zhu Xiaomin, Zhao Dongna, Zeng Hongliu, etc. Sedimentary characteristics and seismic sedimentological response of the shallow water delta of the Qingshankou Formation in the Qijia area of the Songliao Basin [J] Acta Semanticologica Sinica, 2013, 31 (5): 889-897