Technology And Application On Reservoir Architecture Characterization Based On Sandbodies Spatial Orientation

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Abstract

As the high percent of effective sandbody thickness, the braided river reservoir become to an important exploitation area. The Shihezi group lower 8th section of Sulige gas field is a typical sandy braided river reservoir. Strong reservoir heterogeneity is one of the main restriction factor of gas field development, such as Su X adding area. Referring to the analysis results of modern sedimentary and ancient outcrop configuration, a new reservoir architecture characterize method is presented in this study. The new methods realize river channel sandbody spatial orientation by "changes on bottom of sandbody and microfacies overlay regular pattern", and realize channel bar sandbody spatial orientation by "logging cycle, silt layer position, and microfacies overlay characteristic". The reservoir structure analysis on river channel and channel bar were also carried out, and the effective sandbody control effects by reservoir configuration unit were analyzed. The characterization results show:

1) The two main plane combinations in the single channel sandbody of Shihezi group 8th section in research are: banded channel which width is 1000~2000m and sheet scale channel which width is 1500~4000m.
2) The main reservoir configuration units include the channel bar, braided river channel and flood plain. And the channel bar is the main reservoir element.
3) The scales of sandbodies are different due to different genetic type. The thickness of channel bar is 3~5m, the width is 250~300m, the length is 500~900m. The width of braided river channel is less than 200m. The deposition pattern presents "alternate channel and bar, wide bar and narrow channel" on flat.
4) 5 levels configuration units control the macro distribution of effective sandbodies, four levels configuration unit is the main control factor, 3 levels configuration unit has little effect on the distribution of effective sandbodies.

The proposed method has been successfully used on well location optimization in Sulige gas field. It has reference value for the same type of reservoir configuration.

Introduction

Since the reservoir configuration analysis method was first proposed by Miall in 1985 (Miall 1985), the theory was constantly developed and enriched by sedimentary geologists, and quickly became an important means of accurate reservoir characteristics (especially in the late period of oil and gas reservoirs development). Reservoir architecture refers to the form, scale, direction and their space stack relationships of different reservoir architecture unit and interlayer (Wu 2010; Wu et al. 2008, Wu et al. 2012, Lin et al. 2013). The essence is to study the process of sedimentary environment and the

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relationship of sedimentary products, to systematically reveal the characteristics of sedimentary structure and spatial distribution of three-dimensional space, and to characterize its internal macro heterogeneity (Best et al. 2003; Lynds and Hajek 2006; Lunt et al. 2013).

Reservoir configuration analysis begins with observations of paleo outcrops and modern sediments (Miall 1996; Robinson and Mccabe 1997; Liao et al. 1998; Ma et al. 2003). However, the underground reservoir configuration is relatively backward. Nearly for a decade, with the development of ground penetrating radar, loose surface sedimentation and large tank experiments, it was gradually realized that the dimensional fine dissection of the near-surface sedimentary body (Lunt et al. 2013; Robinson et al. 1997; Liao et al. 1998; Ma et al. 2003; Lunt et al. 2004) summed up a lot of prototype models (Best et al. 2003; Lunt et al. 2004; Peakall et al. 2007; Skellya et al. 2003; Ghazi et al. 2009; Corbeanu et al. 2001) and empirical formula (Leeder 1973; Liu and Jiao 1996; Ma and Yang 2000; Ma et al. 2008), and established relevant reservoir quantitative geological knowledge. The progress of near-surface sedimentary body configuration greatly contributes to the development of underground reservoir configuration analysis. Especially in the dense well pattern area, guided by the reservoir prototype model, reference reservoir quantitative geological knowledge base.

The analysis methods of underground reservoir structure were improved, and related research results emerged one after another (Wu et al. 2008, Wu et al. 2012, Lin et al. 2013; Ma et al. 2008; Zhou et al. 2008; Bai et al. 2009; Liu et al. 2011; Li et al. 2011; Zhang et al. 2013). Reservoir structure is covered by sedimentary systems, such as meandering river, delta, alluvial fan (Lin et al. 2013; Jiao et al. 2009; Yi et al. 2010; Wen et al. 2011; Xin 2008).

Although a lot of experimental research work were carried out and some research results were obtained (Best et al. 2003; Lynds and Hajek 2006; Lunt et al. 2013; Liao et al. 1998; Ma et al. 2003; Lunt et al. 2004; Peakall et al. 2007; Skellya et al. 2003; Sun et al. 2014; Bai 2010) with the limitation of well pattern, the braided river underground reservoir structure always focus on single well identification of channel bar sand body. It sometimes cannot accurately predict the distribution of channel bar sandbodies on the plane, which reduces the reliability of braided river reservoir configuration. Take the Shihezi group lower 8th section of Sulige gas field as an example, through the multilevel sandbodies spatial orientation, this paper discusses the method of underground braided river reservoir architecture characterization, to deepen the theory of braided river reservoir configuration and guide the well deployment of the adjacent area.

Geological Features

The Ordos Basin is a large multi-cycle craton basin. Based on the Archean-Early Proterozoic formation, experienced five sedimentary evolution periods as Aulacogen developed on Middle-late Proterozoic, Shallow sea platform developed on Early Paleozoic, offshore plain developed on Late Paleozoic, inland lake basin developed on Mesozoic, and circumjacent fault depression developed on Cenozoic (He et al. 2003). In the period of whole Late Paleozoic, the Ordos Basin developed Epicontinental Sea, Seaside lake basin and Shallow Sea Platform (Wang et al. 2007). The sedimentary system went through the evolution of Tidal Flat (Lagoon) to Barrier Island developed on Benxi to Taiyuan Period, Lake to Delta developed on Shanxi to Shiqianfeng Period (He et al. 2003; Wen et al. 2007). Sediments have interactive deposit by carbonate rocks, coal seam and terrigenous clastic to terrigenous clastic deposits.

According to the present structural configuration of the basin, combined with the nature of basinal basement, the evolution history of the basin, tectonic development and the structural features, the Ordos basin is divided into six first-order tectonic units with the Yi-shan slope as the main body. Sulige gas field is located in Inner Mongolia Autonomous Region. The structure belongs to Yi-shan slope of the Ordos basin, and exploration area is approximately 3.2×10^4 km^2. It is a large lithologic trap gas reservoir which developed in upper paleozoic coal measures hydrocarbon source beds. The research area is located in the north of the Sulige gas field, bottom-up developed Carboniferous Benxi Formation and Taiyuan Formation, Permian Shanxi Formation, Shihezi Formation and Shiqianfeng Formation during upper Paleozoic. The total sedimentary rock thickness is about 700m. The Shihezi Formation was divided into eight sections from Shihezi 1st section to Shihezi 8th section (He et al. 2003; Yang et al. 2008). The Shihezi 8th section was further divided into two sub-groups as upper Shihezi 8th section and lower Shihezi 8th section. Large and thick braided channel sandbodies of lower Shihezi 8th section is the main gas layer

(He et al. 2003; Wen et al. 2007). The average thickness of sandbodies is 30~40m. The sandbodies are overlaid and spliced by multi-stage channels, and then classified into four groups.

The target area has been under development since 2008, working area is 13.0 km^2. **Figure 1** shows a map of the study area. There are 50 gas wells in the area, and average well spacing is 350~500m. The well spacing in the area is the largest in Sulige Gas Field at present. There are sufficient dynamic information and data so it is suitable to carry out reservoir structure research in this area.

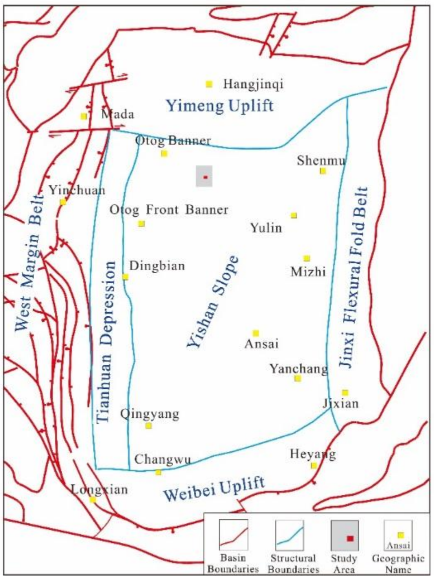

Figure 1—Location of the research area.

Lithologic Features. The study area of lower Shihezi 8th section is a braided river sedimentary system in the background of seasonal arid climate (Chen et al 2008; Li and Yang 2009), and is the main producing formation. During the depositional period, the tectonic activity was stable and the material supply was sufficient (Wang et al 2007), the water was extensive, and the riverstream changed frequently. Macroscopic depositional characteristics show “sand pack mud”. Lithology mainly composes of medium sandstone to gritstone (Li and Yang 2009). In addition, mineral composition is mainly composed of quartz and cuttings. Quartz content is generally between 45~85%, cuttings content is between 2.0~42.6%, feldspar contents is quite small (Wen et al. 2007).

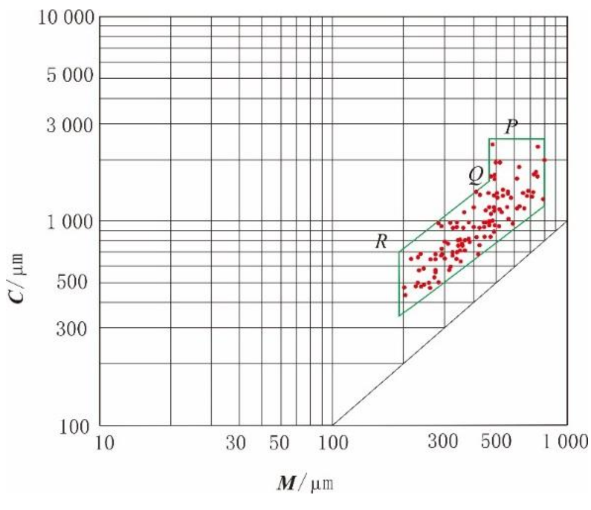

Figure 2—C-M figure of lower Shihezi 8th sandbodies in study area.

Particle Size Characteristics. Observation of core slice microscope and particle size analysis present that, the lithology of lower Shihezi 8th section mainly consists of medium sandstone to gritstone, followed by fine sand, mud, gravel, and silt. Moreover, near-provenance sedimentary characteristics are obvious

(Wen et al. 2007). Main particle size of sandbodies is 0.4～1.0 mm. Most of particle size is coarse. The probability curve of particle size is mainly two-stage style, the size classification is bad, mainly is composed of saltation population, followed by rolling population (Yin et al. 2006). In the C-M figure (**Figure 2**), Q-R stage is well developed and P-Q stage is not developed. This indicates that although the hydrodynamic conditions in the study area are strong, deposition rate is fast, the sediments classification and transformation was bad.

Sedimentary Structure. Sedimentary structure of Shihezi 8th section is various (Wen et al 2007), developed through cross bedding, tabular cross bedding, and parallel bedding (**Figure 3**). The bottom of sandbodies always present scour surface and partial boulder clay, which reflects strong hydrodynamic conditions. The top of sandbodies constantly present horizontal bedding and ripple cross lamination.

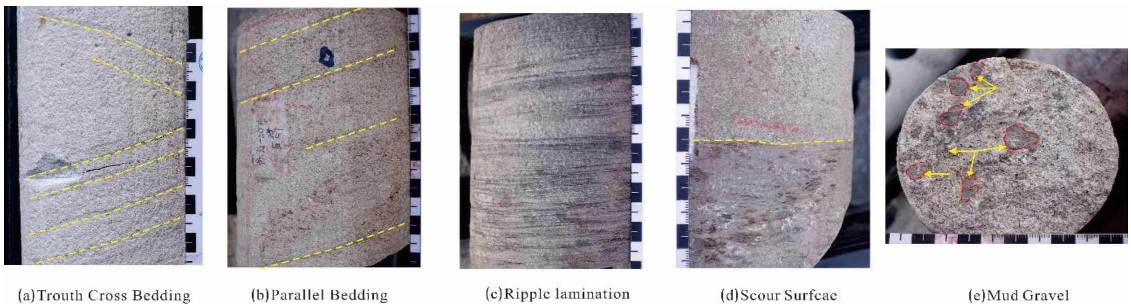

Figure 3—Typical braided river sedimentary structure.

Multi-level Sandbody Configuration

Braided River Sand Body Configuration Level Division. The study is based on Miall's and Wu et al.'s configuration classification scheme (Miall 1985; Wu et al. 2013). The 0th grade is inner laminated interface, 1st grade is laminated interface, 2nd grade interleaving layer interface, 3rd grade is large reapplication or accretion interface by large bottom interface, 4th grade is equivalent to the top and bottom of the large bottom interface, and the 5th grade is top and bottom of the single channel sandbodies. The 0th grade to 5th grade interfaces belong to the classification of lithological configurations (Wu 2010), and the 6th grade interface is single, which represents the beginning or the end of a flood plant. This paper emphasizes the representation of the 4th grade and 5th grade interfaces (single sandbody, single channel) configurationally units distribution.

Characteristics of Configuration Units. Coring well analysis shows that the study area is mainly developed four kinds of configuration units, including channel bar, braided stream, flood plain, and interchannel.

Channel Bar. The channel bar is a main elements of braided river sediments (Yin et al. 2007), formed by sandbodies vertical superposition in several flood events. Lithology mainly is composed of medium sandstone to gritstone. Well logging curve presents "box" type. Both trough cross bedding and tabular cross bedding were developed.

Braided Stream. Braided stream is perennial channel of braided river. Its lithology mainly is composed of medium to fine sandstone. Well logging curve presents a "bell-shape" type, miniature trough cross bedding was developed. The plane forms are interwoven and narrow bands, the profile is top flat and bottom convex. The filling types of braided stream are sand filling, half-sand filling, and mud filling (Sun et al. 2014; Xing 2014).

Flood Plain. Flood plain is distributed at the top of channel. The rocks present gray, sandy brown, brown and black. Lithology mainly consists of mud to silty mudstone, mainly develops horizontal bedding. The thickness changes from several centimeters to tens of centimeters and partial absence. The well logging curve shows high GR value.

Interchannel. The interchannel always develops at the both side of river. The lithology characteristic is mud packed thin sandstone. The stone color, sedimentary structure and logging characteristics are similar as flood plain, and the thickness almost equals to channel sedimentary.

Interface Recognition of Single Well Configuration. Interface recognition of single well configuration is the key of reservoir depositional periods division (Lin et al. 2013). The lower Shihezi 8th section formations are several periods of overlayed composite sandbodies which were crosscut by flush seriously. As a result, it is difficult to identify the configuration interface. Fine core observation shows that there is a thin residual muddy compartment, and obvious flush contact relationship with a new period of channel over it, which can be marked as one of the 5th level interface identification. Mica clastic vertical occurrence is very common, the hydrodynamic conditions was weakened on the last time of single depositional stage. Mica clastic that is hard to deposit in flood period would appear as large numbers, in accordance with the phenomenon. The 5th level configuration interface would be identified and to be recognized as the 4th level interface by the constraint of 5th level.

Single Channel Sandbody Levels Configuration Anatomy

Single Channel Sandbodies Spatial Orientation. Various methods of channel boundary recognition, such as interchannel deposition method, top sand elevation method (Wu 2010; Lin et al. 2013; Chen et al. 2004), were used in single channel recognition. Besides, this study proposed a new method, called "changes on bottom of sandbody and microfacies overlay regular pattern", to confirm single channel boundary, and to characterize spatial orientation. The basic principles are as follows (**Figure 4**).

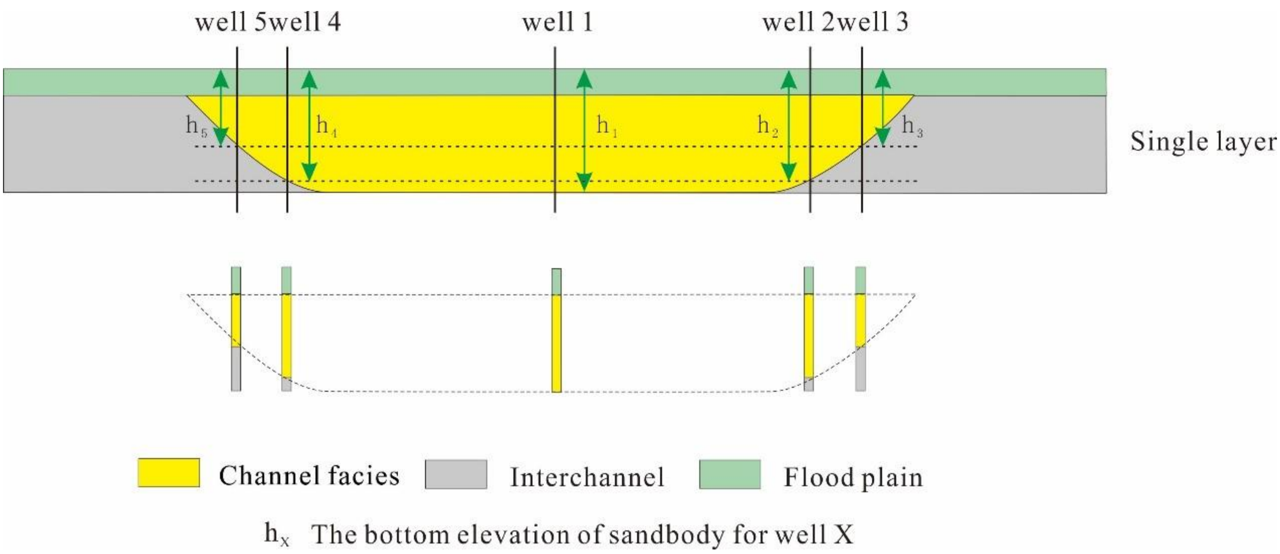

Figure 4—Identify single river schematic.

Single Channel Sandbodies Configuration Characteristics. Based on precise positioning of space, single channel sandbody can be accurately characterized. The results show that the single channel sandbody of lower Shihezi formation 8th section reservoir in SuX encryption area has two main plane combinations: banded single channel and sheet scale single channel (**Figure 5**).

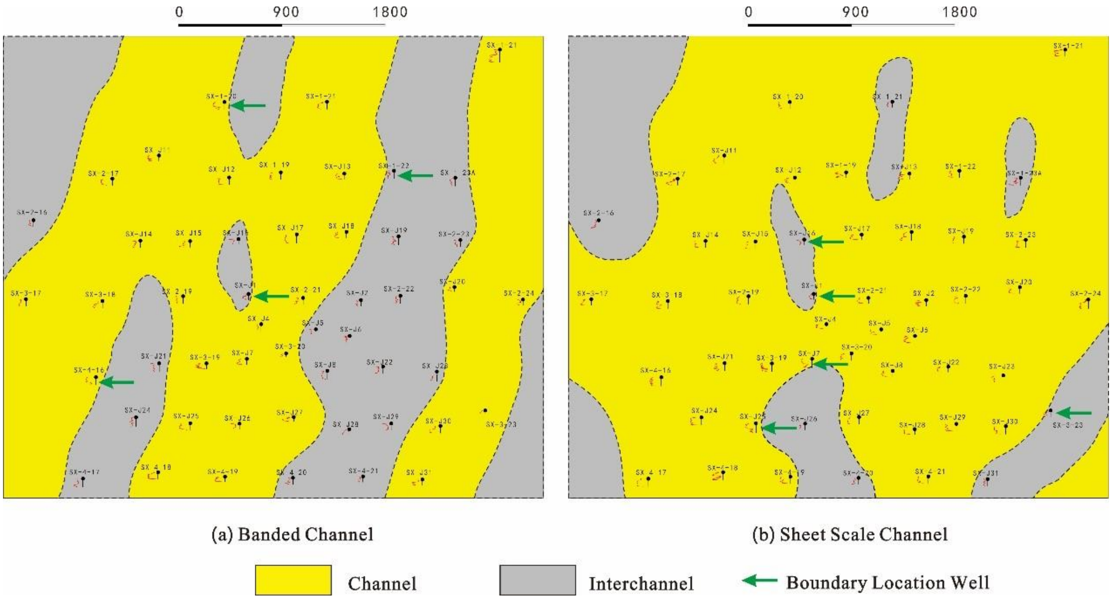

Figure 5─Plane configuration unit of single channel sandbody.

Banded Single Channel. Banded single channel mainly develops in formation 2-1 and 2-2 of lower Shihezi 8th section. The single channels are narrow stripes that are isolated and distributed between the river mudstone. This combination is the result of lower horizontal plane, less supply deposition, a single channel lateral migration capacity. The width of banded single channel is 1000~2000m.

Sheet Scale Single Channel. Sheet scale single channel mainly developed in formation 2-3, 2-2, 1-3, 1-2 of lower Shihezi 8th section. The single river is in a sheet distribution, and the mudstone between the rivers is not developed. This combination results from higher horizontal plane, enough supply deposition, frequent single channel migration or several single channel intertwining and cutting. The width of sheet scale single channel is 1500~4000m.

Anatomical Profile of Single Sandbody

Spatial Orientation Symbol of Channel Bar Sandbodies. Internal channel bar develops mud interlayer (silt layer), vertical positive rhythm is not obvious, SP and GR logging curves are “box” type. Braided waterways are mostly bell-shaped, showing obvious positive rhythm, and interlayers are not developed.

Logging Curve Morphology. The sedimentation of the channel bar is mainly based on the vertical accretion and downstream accretion. Hydrodynamic of upstream face is strong, and weak in negative side water, resulting in the sediment particle size of single accretion layer turning from coarse to fine. Because of downstream accretion, accretion layer is developed later and keep moving to downstream. Therefore, the particle of upstream face changes a little, the logging curve mainly presents a box style. There is a tendency to thicken up at the retral part, the logging curve mainly presents infundibular. It is possible to estimate the approximate location of channel bar in a single well (**Figure 6**).

Silt Layer Development Location. Modern channel bar of braided river shows that, hydrodynamic of upstream face is strong, sediment particle size is coarse. The silt layer is always developed at the negative side of river and the side with weak hydrodynamic (Figure 6). This provides direct evidence to identify the location of channel bar. If a well is drilled to a silt layer, the approximate position can be forecasted (**Figure 7**).

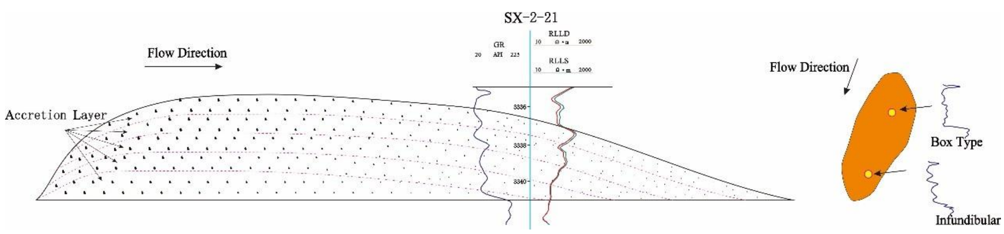

Figure 6─Logging curve morphology.

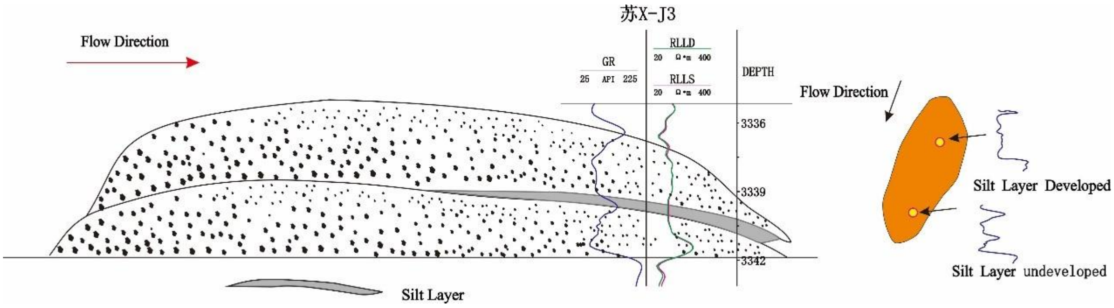

Figure 7─Silt layer development location.

Microfacies Overlay Characteristics. The sedimentation of the channel bar is mainly based on the vertical accretion and downstream accretion. Frequent lateral migration of the braided river causes different accretion layer in the lateral of channel bar. Individual wells show that the channel sandbodies is overlaid with channel bar sandbodies. This is a key mark to identify the edge of channel bar (**Figure 8**).

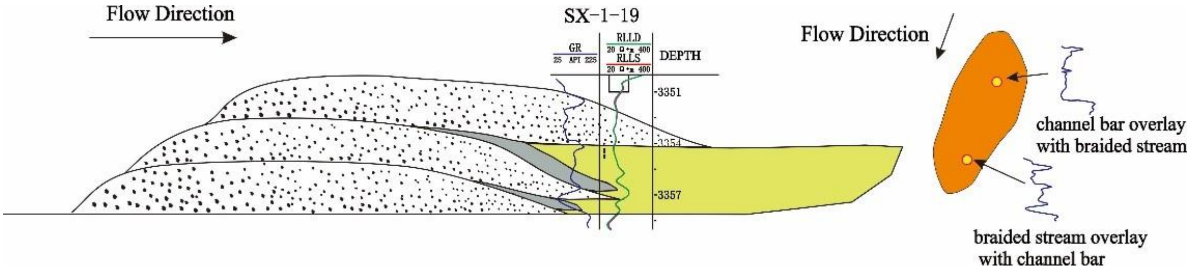

Figure 8─Microfacies overlay characteristics.

Single Sandbody Configuration Characteristics. Single sandbody characteristics show that the thickness of channel bar ranges from 3 to 5 m, the width is 250~300 m, the length is 500~900 m. The width of braided river channel is usually less than 200 m. The deposition pattern presents "alternate channel and bar, wide bar and narrow channel" on flat (**Figure 9**).

Control Effect of Reservoir Architecture on Effective Sandbodies. Five grade interfaces control the effective sandbodies distribution from the macro point of view. Considering the drilling situation, nearly all the effective sandbodies are distributed in the channel, partial channel downcutting, or lateral migration connected effective sandbodies that developed in different periods. The 4th grade interface controls the distribution of channel bar and braided river in single channel. The different filling types of braided distributary channel decide the plane heterogeneity of single channel. Therefore, the distribution of effective sandbodies is affected.

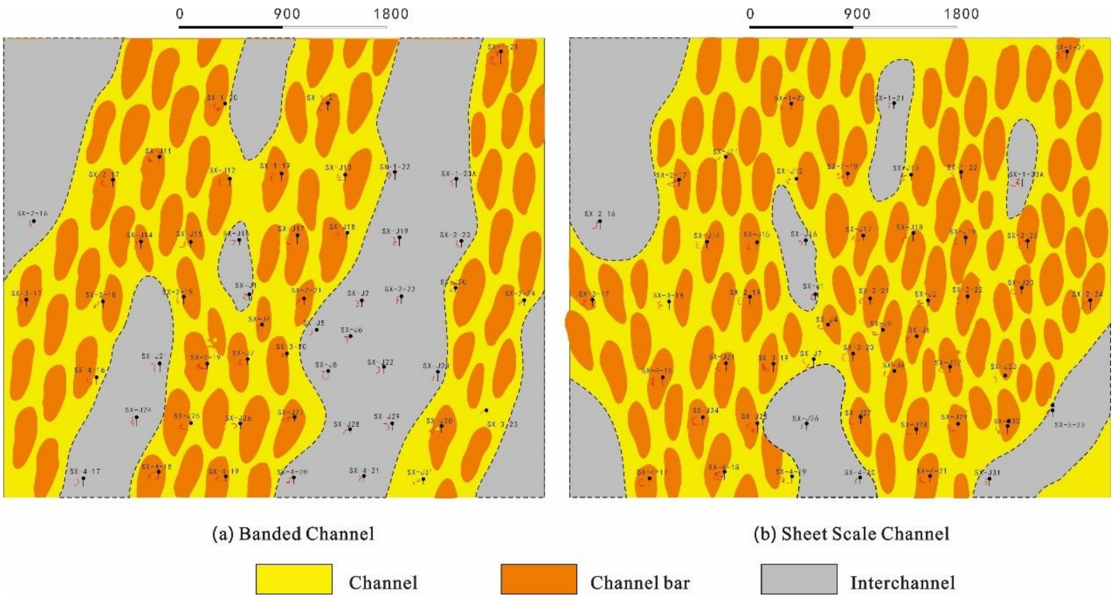

Figure 9—Silt layer development location.

The 4th grade configuration profile shows that most effective sandbodies are distributed in the inter channel bar. And only a few sandbodies are distributed in the channel, which are identified as poor gas reservoirs. The discontinuous siltlayer developed in the 3rd grade of inter channel bar can become an impermeable layer that prevents the fluid from flowing vertically to gas reservoir. The degree of influence relates to thickness and area. If thick and large sandbodies are distributed stably, the effective sandbodies are always in the bottom of channel bar (**Figure 10**).

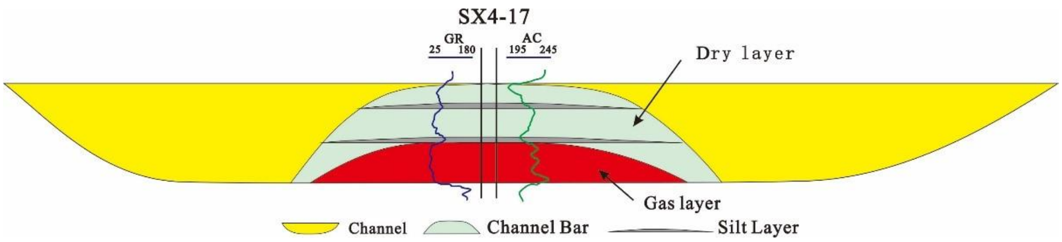

Figure 10—Control Effect of 3rd grade interface.

Conclusions

The new methods were presented to characterize river channel sandbody spatial orientation by "changes on bottom of sandbody and microfacies overlay regular pattern", and channel bar sandbody spatial orientation by "logging cycle, silt layer position, and microfacies overlay characteristic". The reservoir structure analysis on river channel and channel bar was carried out.

There are two main plane combinations in the single channel sandbody of Shihezi group 8th lower section in SuX adding area. The banded single channel, as a narrow band surrounded with interchannel mudstone, is 1000~2000m wide. The sheet scale single channel is distributed as a sheet, interchannel mudstone is less developed, and the width of the channel is 1500~4000 m.

The thickness of channel bar is usually 3~5m, the width is 250~300 m, the length is 500~900 m. The deposition pattern presents "alternate channel and bar, wide bar and narrow channel" on flat.

5th grade configuration unit controls macro distribution of effective sandbodies, 4th grade configuration unit is the main control factor, 3rd grade configuration unit has little effect on the distribution of effective sandbodies. The method has been successfully applied to optimize well location in Sulige gas field, and has reference value to the same type of reservoir configuration.

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Conflicts of Interest

The author(s) declare that they have no conflicting interests.

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