[PS]High-Frequency Stratigraphic Sequence Characteristics in Gentle Slope Zones in Large Depression Basins – Case Study of Qingshankou Formation in Northern Songliao Basin, China*

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Abstract

Large continental depression basins where broad and gentle paleogeomorphic slope was widely developed are important types of the petroliferous basins in China. Over fifty years of exploration, huge reserves of gas and oil was discovered in them, especially in Songliao Basin, Erdos Basin, Dzungars Basin and so on. Fluctuation of lake-level was frequent and impacted large areas to form multicycle and multirank source-reservoir-cap assemblages. In theses basins, large lake delta sediments dominated and extensive sands distributed favorably to form overlapped and continuous hydrocarbon accumulation zones.

Songliao Basin, as a famous prolific producer of hydrocarbon, is a giant dually-structured basin of rift-depression with an area of 26×10^4 km^2. The basin went through a rifting stage from Late Jurassic to early Early Cretaceous, then a post-rift thermal subsidence stage from mid-late Early Cretaceous to mid-Late Cretaceous. Its important producing reservoirs are in the depression sediment, including the Quantou, Qingshankou, Yaojia and Nenjiang formations. Paleogeomorphology of the basin was a broad gentle slope, except in the west where steep slope existed. Giant delta systems were developed in the north and in the south of the basin. Therefore, it is important to study high-frequency stratigraphic sequence characteristics and its control factors in the gentle slope zones in large depression basins to forecast favorable sedimentary reservoir facies and guide exploration.

High-Frequency Stratigraphic Sequence Scheme of Qingshankou Formation

To understand sandbody and hydrocarbon accumulation, a great deal of stratigraphic sequence study has been done by others, while little work has been done to understand high-frequency sequences in the gentle slope in the depression stage. Qingshankou Formation is not only one of two source strata, but also an important hydrocarbon target of depression sediment in Songliao Basin. It is a main producer in

Longhupao Oil Field in northern Daqing Placanticline and the southern basin. This article discusses high-frequency stratigraphic sequence in the gentle slope belts in depression basins, with the Qingshankou Formation as an example. Comprehensive data, including core observation, logging response, seismic reflection and paleo-biology were used to identify the sequence boundaries, flood surfaces, subfacies and microfacies to establish logging curve frame correlations, their corresponding seismic reflection sections, and the sedimentary microfacies sections. Based on this work, high-frequency sequence dividing criteria, scheme of the Qingshankou Formation, and the sedimentary facies were developed. The full section of strata in the northern Songliao Basin was divided and correlated to make the plane maps.

Qingshankou Formation, which is part of TST and HST, mainly HST of the second-order sequence in Songliao Basin, is composed of fluvial, deltaic, and lacustrine sedimentary systems from edge to center of the basin. Its thickness ranges from about 300 to 500 meters, with a maximum of 640 m. It is made up of three third-order sequences, respectively corresponding to the first, the second and the third member of the Qingshankou Formation. These three members all consist of TST and HST (no LST was developed). The first section was further divided into two forth-order sequences, the second into three and the third also into three (Figure 1). All of the forth order sequences were comprised only of TST and HST, with no LST. The time span of the forth order sequences was about 0.5-1.5 Ma with a thickness range of 20-85 m (Figure 1).

Because of the wet, hot climate and transgression on a large scale during Qingshankou deposition, the lake-level was high enough that lacustrine facies were developed extensively throughout. Paleogeomorphology was relatively gentle without obvious broken belts, indicating the tectonic processes were stable in the large depression basin. The sequences, including the forth order sequences, in a large depression basin are obviously controlled by the frequent accommodation space according to fluctuations of the lake-level. When the lake-level ascended, TST were developed and made up of retrogradation cycles and/or progradation. When the lake-level descended, HST were developed and composed mainly of progradational cycles. Since shoal delta systems and lacustrine sediment constituted the main part of the formation, LST sedimentary-bodies, such as wedge-shaped sedimentary bodies and sub-lacustrine fans, etc., hardly existed.

Sedimentary Characteristics of Qingshankou Formation and the Control Factors

Provenances supply of the shoal deltas came from meandering rivers of combined load or suspension load which ran perennially over long distances and the channels were constrained. Area of the deltas was very large, as much as 2.5×10^4 km^2, which was composed of the plains and the fronts with large areas (Figure 2). The delta front top-surfaces were gentle slope and the progradational structure was gradual. Distributary channels and sheet sandstones were flourishing, but estuary dams were few as the dams developed early were easily rebuilt or destroyed. Pre-delta sediment usually belonged to normal shallow lacustrine facies. Based on these characteristics of the Qingshankou Formation, the type of deltas should be shoal deltas.

The maximum gradient in the northern basin was less than 0.5° according to the thickness of Qingshankou Formation and the planar distance during deposition. The gradient is so small sediment extended far into broad lake regions to form shoal deltas.
Paleontology suggests a wet, hot climate, and provenances supply was relatively sufficient with high concentrations of suspension load. The lake water was brackish or saline, so it was easy to develop hyperpycnal river flows into the lakes. The hyperpycnal flows behaved as distributary channels under water of tractive current that flowed very far. The flows took sediment forward into the lake and unloaded a little into the estuaries and continued unloading forward. Therefore, the deltas with gentle top were thin and extended over a large area. Under the control of the paleoenvirronment and the paleoclimate, the rivers carried a high concentration of suspension load of fine siltstone and mudstone quite far into the lake which resulted in shoal deltas.

As the climate was wet and hot, global sea-level rose and the rivers had such large kinetic energy with enough run-off that distributary channels under water were easily formed by transporting sediment by their inertia force. That avoided full unloading into estuaries, forming shoal deltas beyond.

Conclusions

The high-frequency sequences, including the forth-order sequences, in gentle-slope zones in a large depression basin were obviously controlled by changes of the accommodation space resulting in frequent fluctuations of lake-level. When the lake-level ascended, TST were developed that were made up of mainly retrogradational cycles with a few progradational cycles. When the lake-level descended, HST were developed that were composed of progradation cycles. Shoal delta systems were a main part of the sediment, and LST hardly existed. The shoal deltas were widely developed because of the small paleogeomorphic gradient, the large density contrast of river water to lake water, large suspension load of the rivers, the large runoff and so on. Exploration of lithologic reservoirs should be focused on distributary channels, and sheet sands of the shoal deltas in gentle slope zones in large depression basins, and have been verified by hydrocarbon shows in drilled wells.

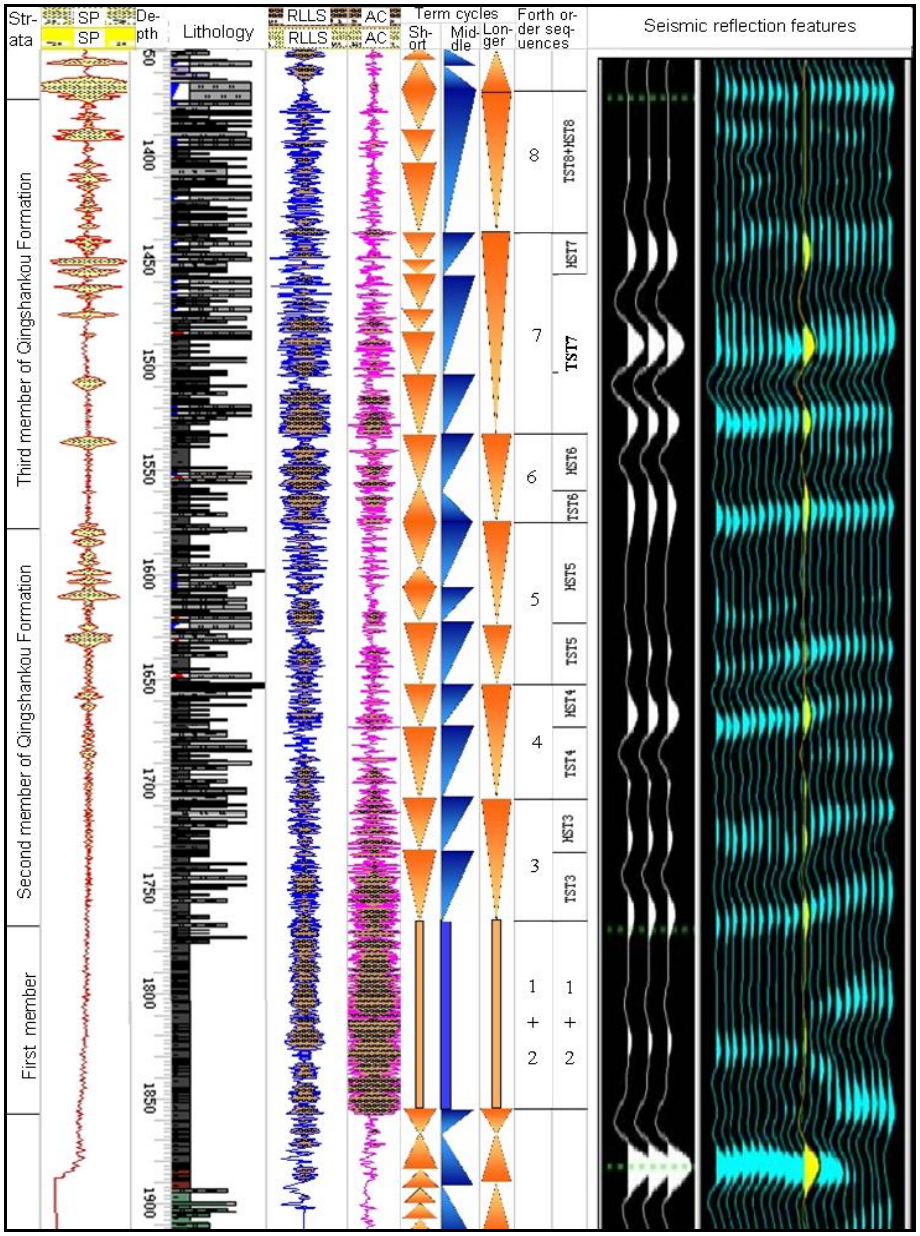
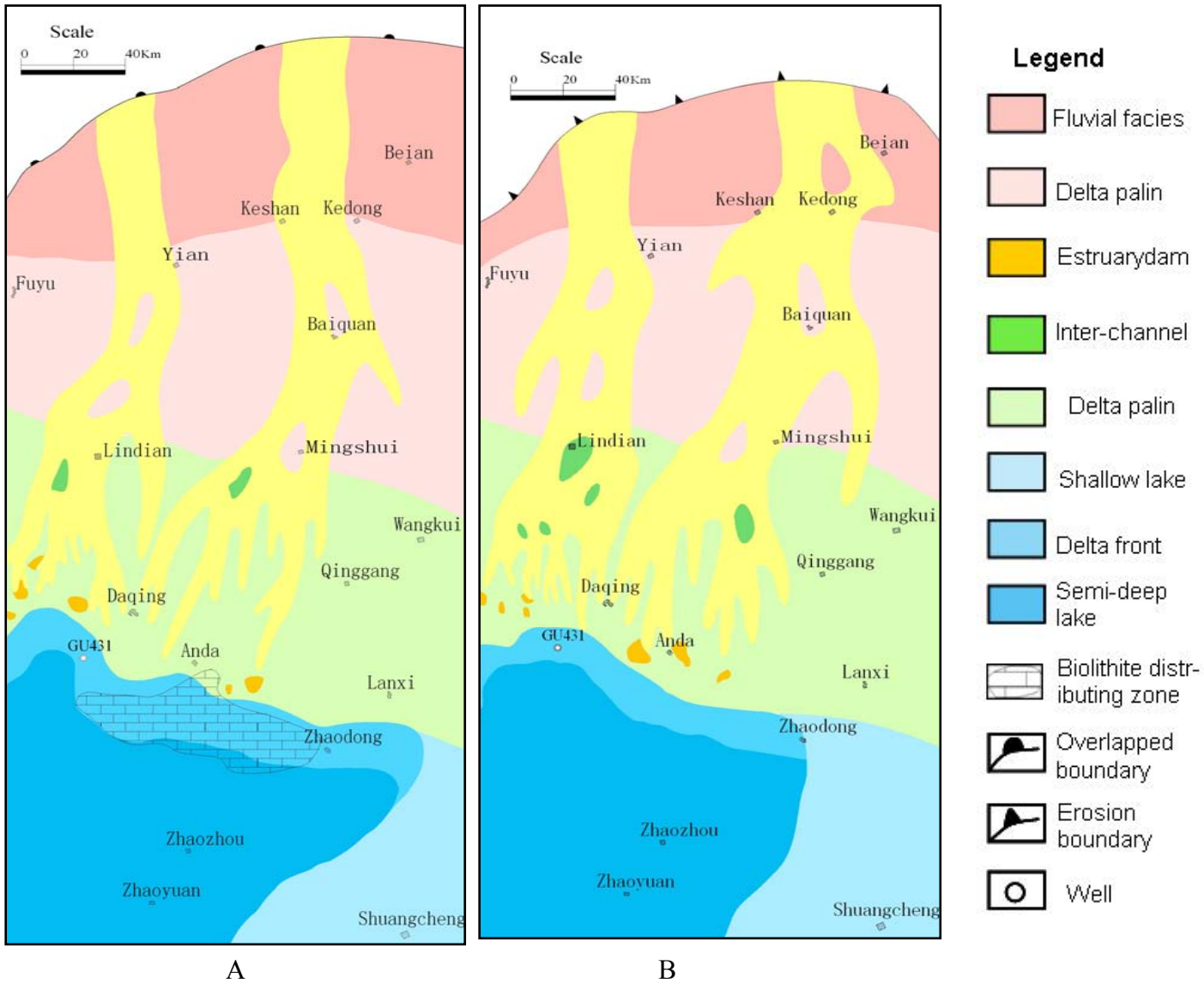


Figure 1. High-frequency stratigraphic sequence histogram of the Qingshankou Formation in northern Songliao Basin.



A B

Figure 2. Facies maps of (A) TST4, and (B) HST4.