Analysis of Sequence Architecture for Prediction of Hydrocarbon Reservoirs in Early Cretaceous Deposits in the Wuerxun Sag in Northeastern China*

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Abstract

Wuerxun Sag is one of the main oil and gas exploration and development zones in the Hailar Basin. Comprehensive research on the sequence architecture and depositional filling during the Early Cretaceous shows that filling sequences are controlled by tectonic evolution and have distinct phases. Under the tectonism of the episodic fault depression activities and the different activities of synsedimentary fracture, the sequence configuration can be divided into three types: steep-slope type, step-fault type and deep sub-sag type. Tectonism controls the sediment distribution process and sand accumulation. It plays an important role in the sequence architecture and distribution of the sedimentary systems of Wuerxun Sag. Results show that different tectonic units have characteristic sequence styles and depositional systems. Different sequence patterns also determine different kinds of reservoirs in different tectonic units. The fault-controlled steep-slope area mainly develops fault nosing structure reservoirs and fault lithologic reservoirs; step-fault belts in gentle slope areas develop fault-block reservoirs and fault-lithologic reservoirs; in deep sub-sag areas, sand lens reservoirs develop. In addition, the margins of deep sub-sag areas probably develop fault-lithologic reservoirs.

Introduction

The theory of sequence stratigraphy originated in the study of passive continental margin basins; such study analyses the distribution of the configuration of depositional systems controlled by eustacy. However, tectonism plays a more important role in the filling patterns in tectonically active basins (Ravnas and Steel, 1998; Strecker, et al, 1999; Lin, et al, 2001; Pavelic, 2001).

The Wuerxun Sag is located in the central portion of the Hailar Basin (Figure 1). Wuerxun Sag has an area of approximately 2,240km^2 (Jiang, et al., 2008), and is a distinctly asymmetric half-graben. The strata of the Lower Cretaceous are divided into five formations that are described by Wan (2006). The Tongbomiao and Nantun formations consist of conglomerate, sandstone, siltstone and mudstone deposited under alluvial and lacustrine systems; the Damoguaihe Formation consists of typical fluvial-delta and lacustrine deposits (Wan, 2006; Liu, et al. 2006).

Method

This paper is based on previous studies, comprehensive use of seismic data, wireline logs and cores to analyze the characteristics of basin evolution and its effect on the stratigraphic pattern to establish the variations in sequence architecture associated with the different structural units.

Analysis of the Sequence Architecture

The structural evolutionary processes of Hailar Basin are characterized by episodic subsidence. The differences among fault activities and synsedimentary fault combination styles and paleostructure frames determine the sequence architecture and sedimentary distribution style in every rift phase. The stratigraphic sequence frame of the Lower Cretaceous of the Wuerxun Sag can be divided into two second-order sequence sets, five second-order sequences, and eight third-order sequences (Figure 2). The tectonic evolution of Wuerxun Sag can be divided into the rifting period (150.8-131.0 Ma), the fault-depressed transition period (131.0-125.0 Ma), and the sag period (125.0-88.5 Ma). The rifting period can be subdivided into Rifting Period I, Rifting Period II, and Rifting Period III.

According to the interpretation of seismic profiles of the study area and the identification and classification of tectonic units, and considering the direction and path of provenance, three kinds of tectonic stratigraphic frameworks were identified: 1. fault-controlled steep-slope belts, 2. gentle-slope step-fault belts, and 3. deep sub-sag belts. It can accordingly be divided into three types of sequence architecture.

The sequence architecture that developed in the Wuxi steep-fault belt is Type 1, fault-controlled steep-slope. This type of sequence architecture shows different characteristics in different tectonic evolutionary stages (Figure 3). During Rifting Period II in Wuerxun Sag, the fault acted strongly, alluvial fans and fan delta systems were deposited close to faults, and deep or half-deep lacustrine deposits developed locally in the deep sag portion. During Rifting Period III, the tectonic subsidence rate reached its peak. The sedimentary characteristics showed that this period is typical of strong rift subsidence. The lacustrine deposits became larger and deeper within the strong extension. Facies mainly consisted of fan deltas, braided deltas and sublacustrine fans. In the lowstand systems tract (LST) period, the fan delta system was mainly deposited in the steep-slope belt in a shallow lacustrine environment. Due to the front slumping of the fan delta and the turbidity currents, the sublacustrine fan developed locally in the deep lacustrine area. During the subsequent transgressive systems tract (TST) period, the area of the lake significantly enlarged, and the water correspondingly deepened. Condensed sequences that were composed of widespread high-organic deep lacustrine mudstone beds were formed in this period, and became high-quality hydrocarbon source rock in the Wuerxun Sag.

The sequence architecture that developed in the Wudong gentle-slope belt is Type 2. The distributions of sedimentary facies were controlled by multi-level step faults in the different filling evolutionary stages. The step-fault belt consisted of multiple-order concordant faults towards the sag centre, which constituted a multistage transportation path for detrital materials. Sequence patterns were also varied in the different evolutionary stages. With the effect of the synsedimentary fault, along the side of the downthrown block, coarse clastic sediments aggraded vertically. With the deepening water, the facies style changed from fan delta to braided delta or river delta. In general, the boundary of lowstand system tract (LST) was controlled by the gentle-slope step-fault belt. During the LST period, the lacustrine basin was limited. The supply of source material was abundant, and the sand grains could be transported further toward the lake center. The sedimentary region of the fan body was larger. Due to the factors of gravity slumping, some sublacustrine fans developed partly in deeper water areas. During the TST period, the region of the basin expanded in an unprecedented fashion. The turbidity sand bodies developed in the deep lacustrine and half-deep lacustrine settings. During the HST period, the region of the basin reached its maximum. The sand bodies did not extend much further, so the turbidite fans usually were small-scale in the deep lacustrine environments (Figure 4).

The sequence architecture that developed in Wunan sub-sag is Type 3. There was little fault activity, and there was a depocenter of the basin. The main facies were deep lacustrine or half-deep lacustrine deposits, sublacustrine fans and the fronts of fan deltas and braided deltas.

Reservoir Predictions

Different tectonic units were formed with different sequence architectures and different sedimentary patterns, thus determining different types of reservoirs. Fault-nosing structure reservoirs and fault-lithologic reservoirs were mostly adjacent to the fault-controlled steep-slope belt. In the gentle slope step-fault belt, there were stratigraphic overlap unconformity reservoirs, fault-lithologic reservoirs and fault-block reservoirs. In the deep sub-sag belt, self-generating and self-preserving lens reservoirs were common (Figure 5).

Conclusions

(1) Basin filling corresponds to tectonic evolution, which shows the characteristics of obvious episodes. The diverse deposit patterns developed in different tectonic evolutionary stages.
(2) Wuerxun Sag has three kinds of typical tectonic units: fault controlled steep-slope belts, gentle slope step-fault belts, and deep sub-sag belts. Sequence configuration styles were identified based on different tectonic units. Different tectonic units are characteristic of corresponding sequence architecture configurations.
(3) Different kinds of reservoirs developed in the different tectonic units. Fault-nosing structure reservoirs and fault-lithologic reservoirs were generally adjacent to the fault-controlled steep-slope belt; in the gentle slope step-fault belt, there were stratigraphic overlap unconformity reservoirs, fault-lithologic reservoirs, and fault-block reservoirs; in the deep sub-sag belt, self-generating and self-preserving lens reservoirs were common.

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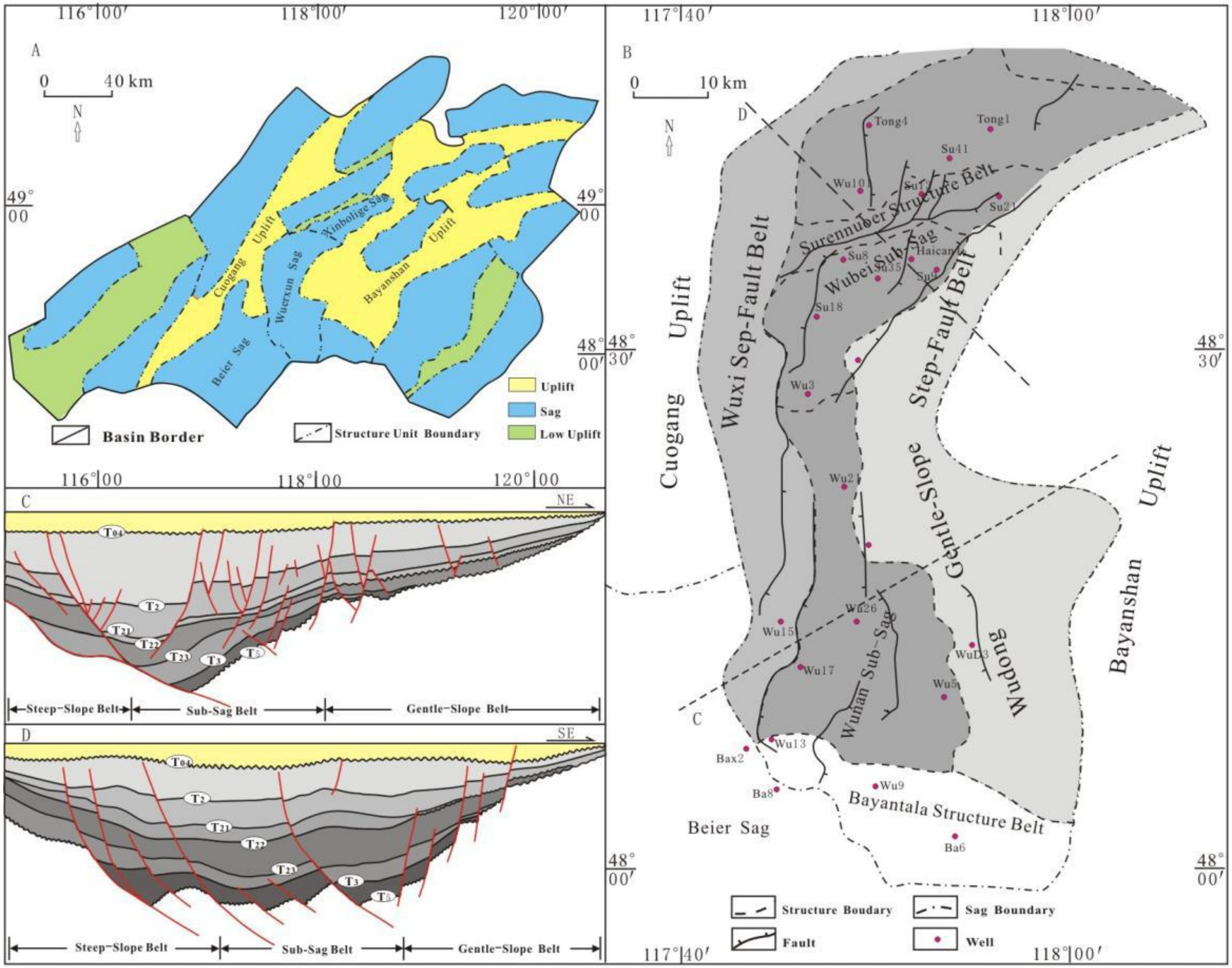

Figure 1. Tectonic lattice frame diagram of Hailar Basin and tectonic lattice frame diagram of Wuerxun Sag.

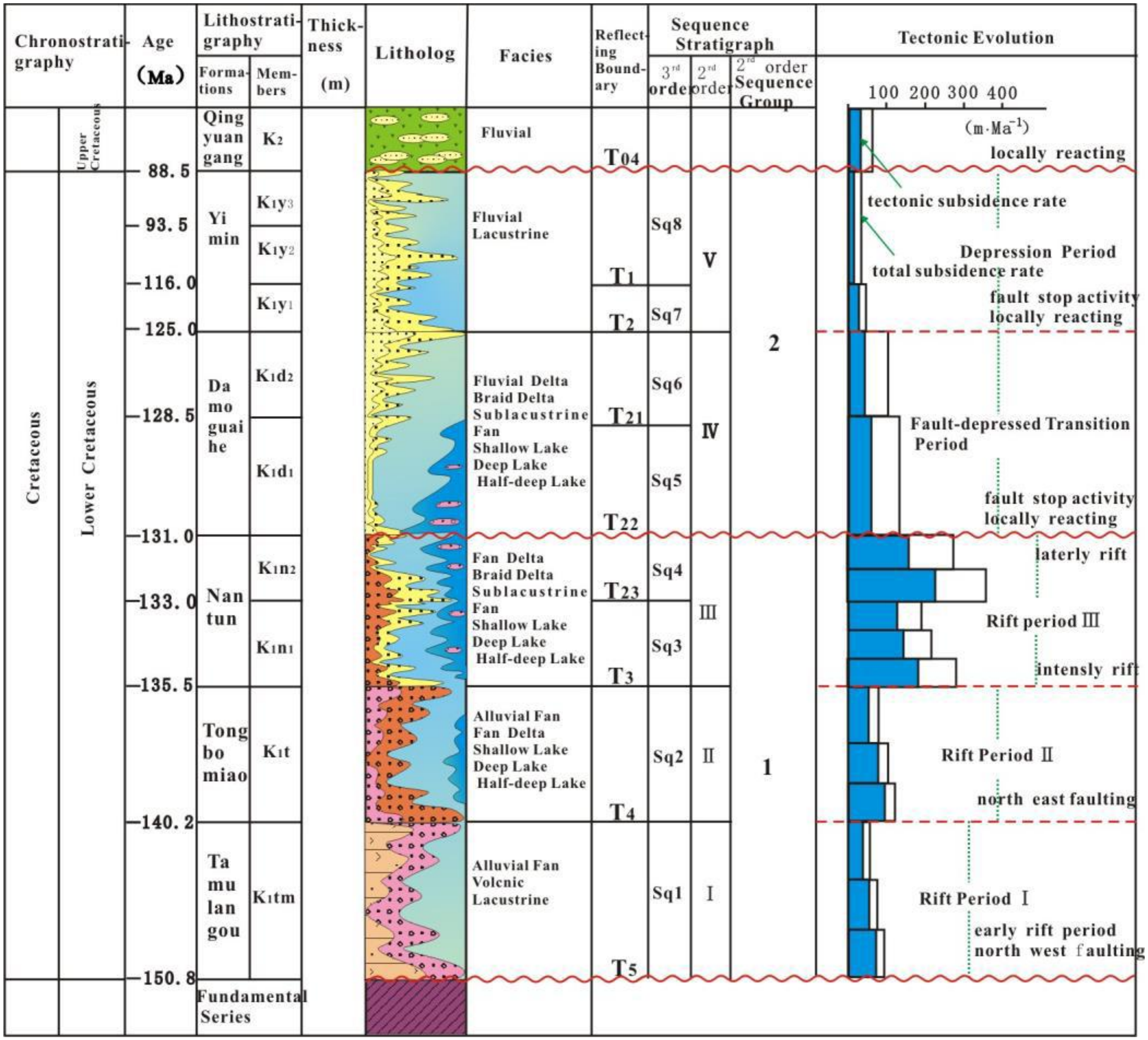

Figure 2. The tectonic evolution of Wuerxun Depression and depositional filling sequences.

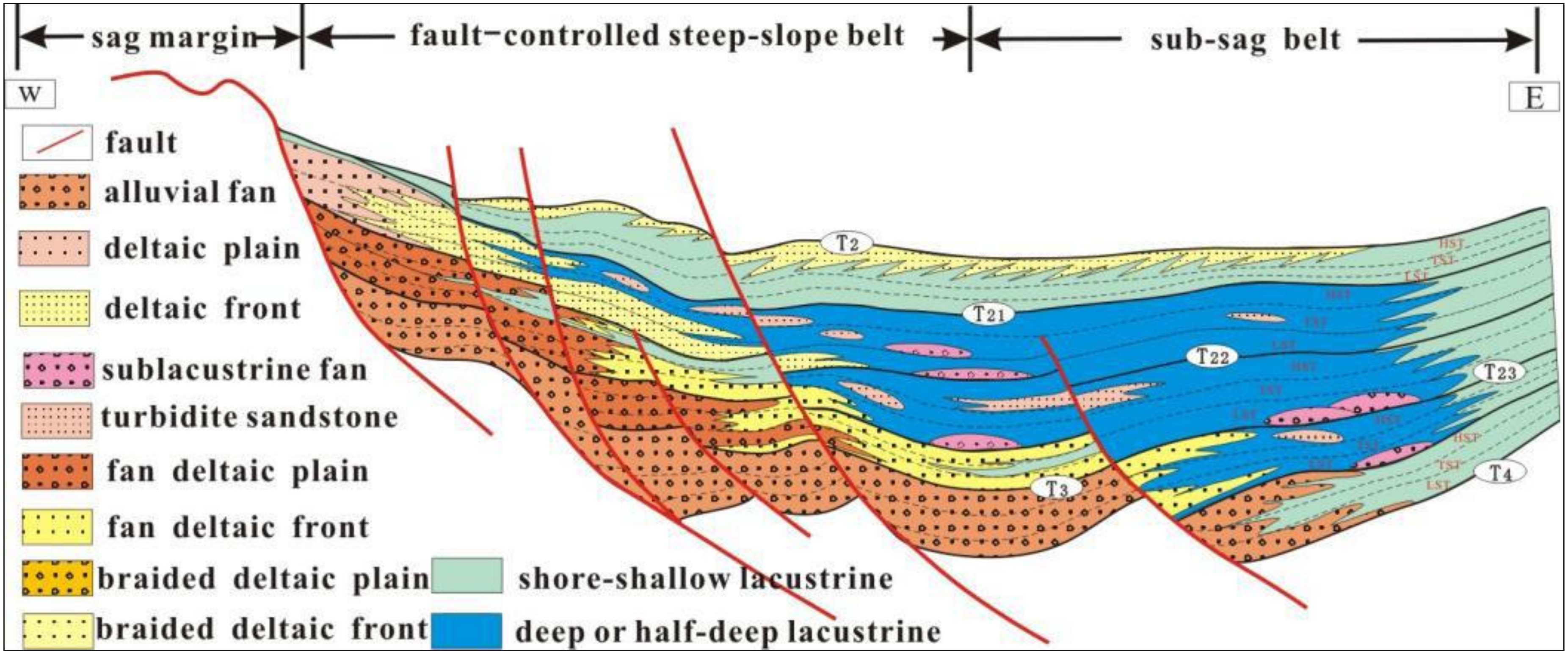

Figure 3. Sequence architecture in the fault-controlled steep-slope belt of Wuerxun Sag.

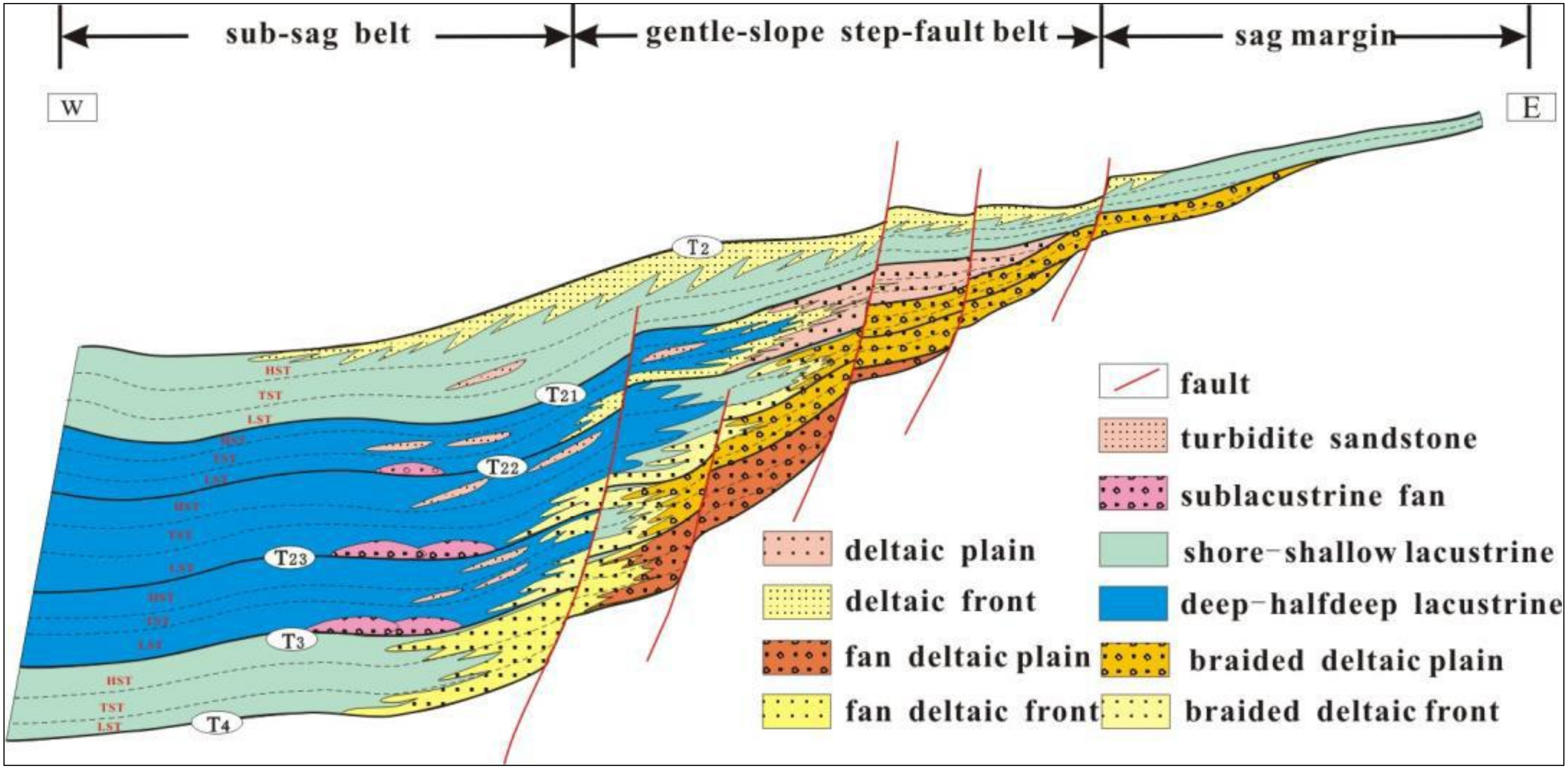

Figure 4. Sequence architecture in the gentle slope of Wuerxun Sag.

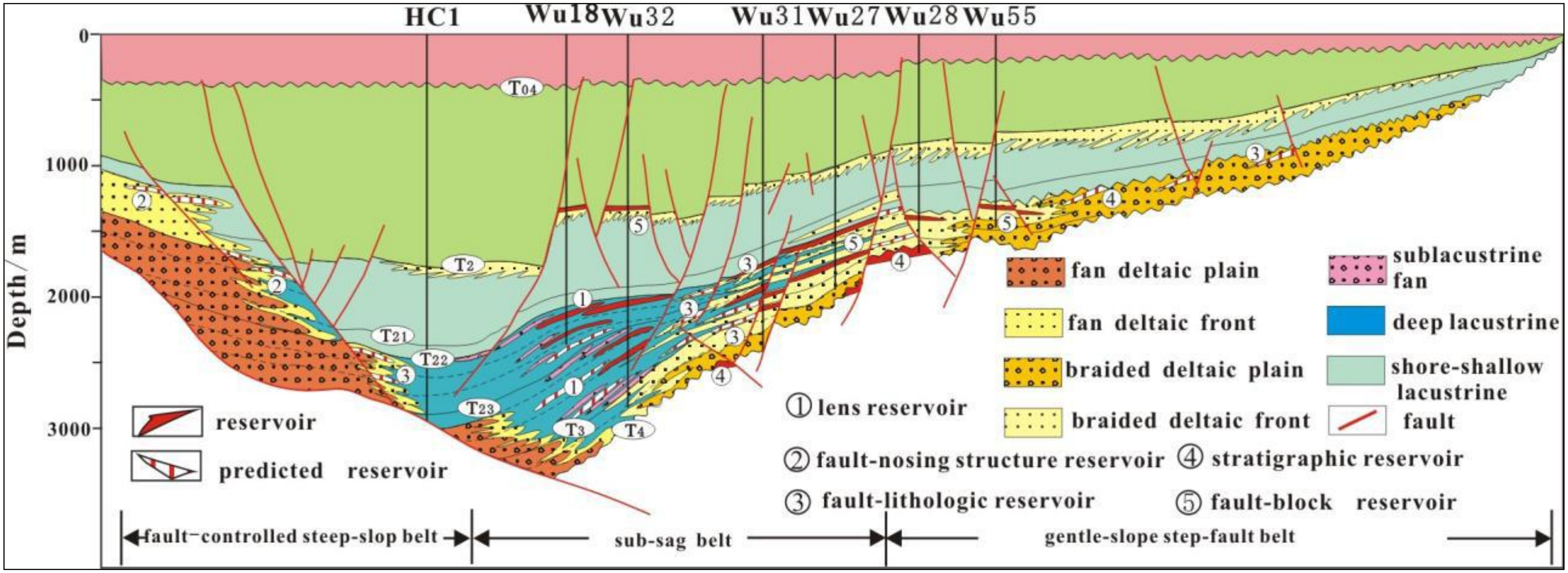

Figure 5. Pattern of oil-gas accumulation in Wuerxun Sag.