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Method and Description of Sedimentary System Characterization Based on Sequence Stratigraphy

Jianmin Zhang, Hui Cai, Honglin Yue, Pengfei Mu

Bohai Oilfield Research Institute, Tianjin Branch of CNOOC Ltd., Tianjin, China
Email: tanjie3@cnooc.com.cn

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Abstract

A Oilfield is the most representative mid to deep oil field in the Bohai Sea, with the main oil bearing intervals being the upper and middle Shahejie-3 sections of the Paleogene Shahejie Formation. By combining well seismic analysis, the middle section of Shahejie-3 is divided into high-level system tract and forced lake retreat system tract, corresponding to the II oil formation and I oil formation, respectively. Using sequence stratigraphy methods, based on seismic profiles and drilling lithological cycles, the high stand system tract is divided into 5 stages of delta progradation. The first and second stages are high angle S-type progradation with large sedimentary thickness, the third stage is oblique progradation, and the fourth and fifth stages are S-oblique composite progradation; By combining seismic data, we characterized the large-scale (8 small-scale) progradation bodies of 5 periods, clarified the distribution characteristics of reservoir planes, and laid the foundation for the later exploration of oilfield potential.

Keywords

Middle Section of Shasan, Sequence Stratigraphy, Sedimentary System, Characterization

1. Oilfield Overview

The Laizhou Bay Depression in the Bohai Bay Basin is located in the southeastern part of the Bohai Sea, with an area of approximately 1780 km^2. The depression is adjacent to the Kendong Uplift to the west, the Ludong Uplift to the east by the controlling fault, the Weibei Low Uplift to the south, the Laibei Low Uplift to the north, the Huanghekou Depression to the northwest, the Miaoxi De-

pression to the northeast, and the Qingdong Depression to the southwest. It is sandwiched by two branch faults of the Tan Lu strike slip fault, forming a dust-pan shaped fault depression structure with a north fault and a south overtaking fault. It is a Cenozoic depression developed on the Mesozoic basement (Yang et al., 2016; Wang et al., 2018; Xin et al., 2013; Niu, 2012) (**Figure 1**). The western branch of the Tan Lu strike slip fault zone cuts the western slope of the Laizhou Bay depression, and the eastern branch of the Tan Lu strike slip fault zone is the eastern controlling fault of the Laizhou Bay depression. On the profile, the depression is characterized by a steep north to south and gentle south to north, and a deep west to shallow east to west in an east-west direction. The Laizhou Bay depression can be divided into secondary structural units such as the northern steep slope zone, northern depression, central structural zone, southern depression, and southern gentle slope zone (Peng et al., 2009; Qin et al., 2020).

A Oilfield is located in the northern steep slope zone and Beiwa of Laizhou Bay Depression, 35 km north of Bozhong 34-1 Oilfield and about 70 km east of Longkou. The average water depth within the oilfield is 17.3 meters (Yue et al., 2023; Zhang et al., 2018). The regional structure is located on the descending plate of the southern boundary fault (Laibei No. b1 Fault) of the Laibei Low Uplift, adjacent to the Laibei Low Uplift to the north by the Laibei No. n1 Fault, and adjacent to the northern depression of the Laizhou Bay Depression to the south. The overall structural form is a semi anticline structure complicated by the fault (Yue et al., 2019).

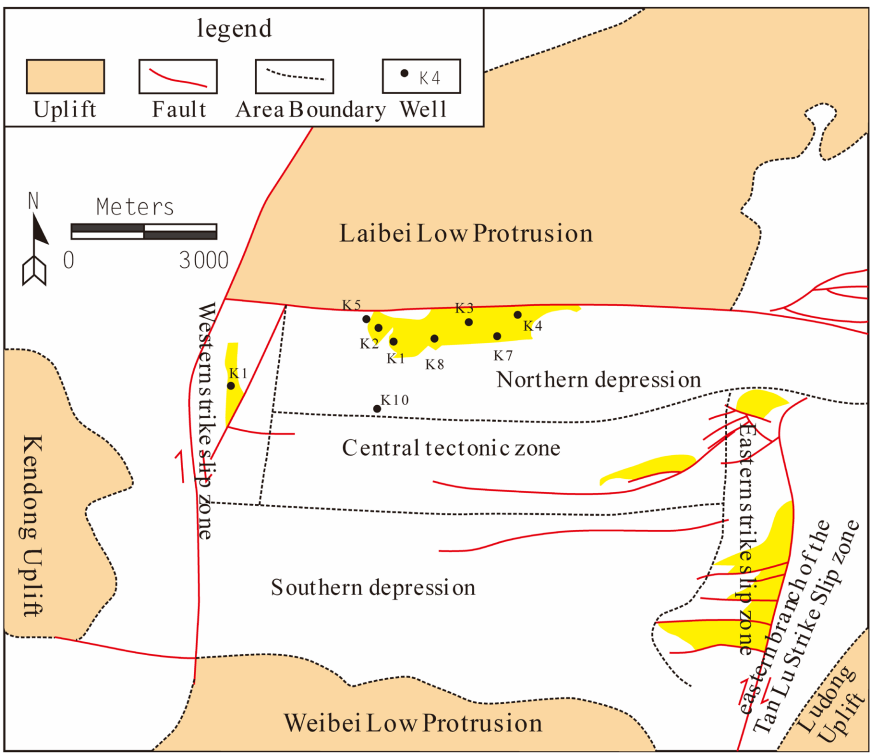

Figure 1. Structural Location of Laizhou Bay Depression in Bohai Bay Basin.

The Laizhou Bay Depression is based on the Mesozoic Era and consists of the Quaternary Plain Formation, the Neogene Minghuazhen Formation, and the Guantao Formation from top to bottom, as well as the Paleogene Dongying Formation and Shahejie Formation. The Shahejie Formation is further subdivided into Shahejie Member 1, Shahejie Member 2, Shahejie Member 3, and Shahejie Member 4. The oil bearing strata are mainly developed in the Shahejie Member 3 of the Paleogene Shahejie Formation, followed by the Minghuazhen Formation (Zhao et al., 2019; Zhu et al., 2018; Zhou & Sun, 2019). As the largest mid to deep oil field in the southern region of the Bohai Sea, efficient development of the oilfield is of great significance. On the one hand, it can enrich the prediction technology of mid to deep reservoirs in the Bohai Sea, and on the other hand, it also provides reference significance for the subsequent development of mid to deep oil fields.

2. Distribution Characteristics of Sequence Stratigraphy

Based on the identification results of seismic sequences, drilling and logging sequences, and system tracts, and on the basis of completing the division of single well sequences and the calibration of seismic synthesis records, a multi well sequence correlation profile combining well seismic data in the study area is established. The seismic profiles and stratigraphic comparison of the connected wells KL10-1-A23, KL10-1-1, KL10-1-8, KL10-1-B6, and KL10-1-4 show that the thickness of the northeast strata in the study area is relatively thin, and there is a trend of thickening towards the west (**Figure 2**), indicating that the west side of the study area is the main sedimentary center. The drilling in the study area basically did not penetrate the SQs3M sequence, and the SQs3M high-level system tract roughly corresponds to the II oil formation in Shasan Middle, while the forced lake retreat system tract corresponds to the I oil formation in Shasan Middle. The sedimentary thickness of the SQs3M high-level system tract in the sequence is large, with a maximum thickness of about 380 meters in the western part of the study area, gradually thinning from west to east (280 - 380 meters), reflecting the advancement process of multiple progradational deltas.

3. Distribution Characteristics of Sedimentary Systems

The thickness distribution characteristics of each oil formation plane under the constraint of sequence framework can reflect the migration law of sedimentary centers in each sedimentary period (Dickinson, 1988; McPHERSON et al., 1987; Li, 2003). This study combines well seismic analysis within the isochronous stratigraphic framework, combined with geological stratification, inversion results, single well sand shale combination relationship, and logging interpretation results, to divide the sand body combinations of different sedimentary periods in the study area into three types. The A-type sand layer is mainly developed within the SQs3U sequence, characterized by a combination of thin interbedded sand and mudstone, with a single sand body thickness of about 2 - 5 meters; The

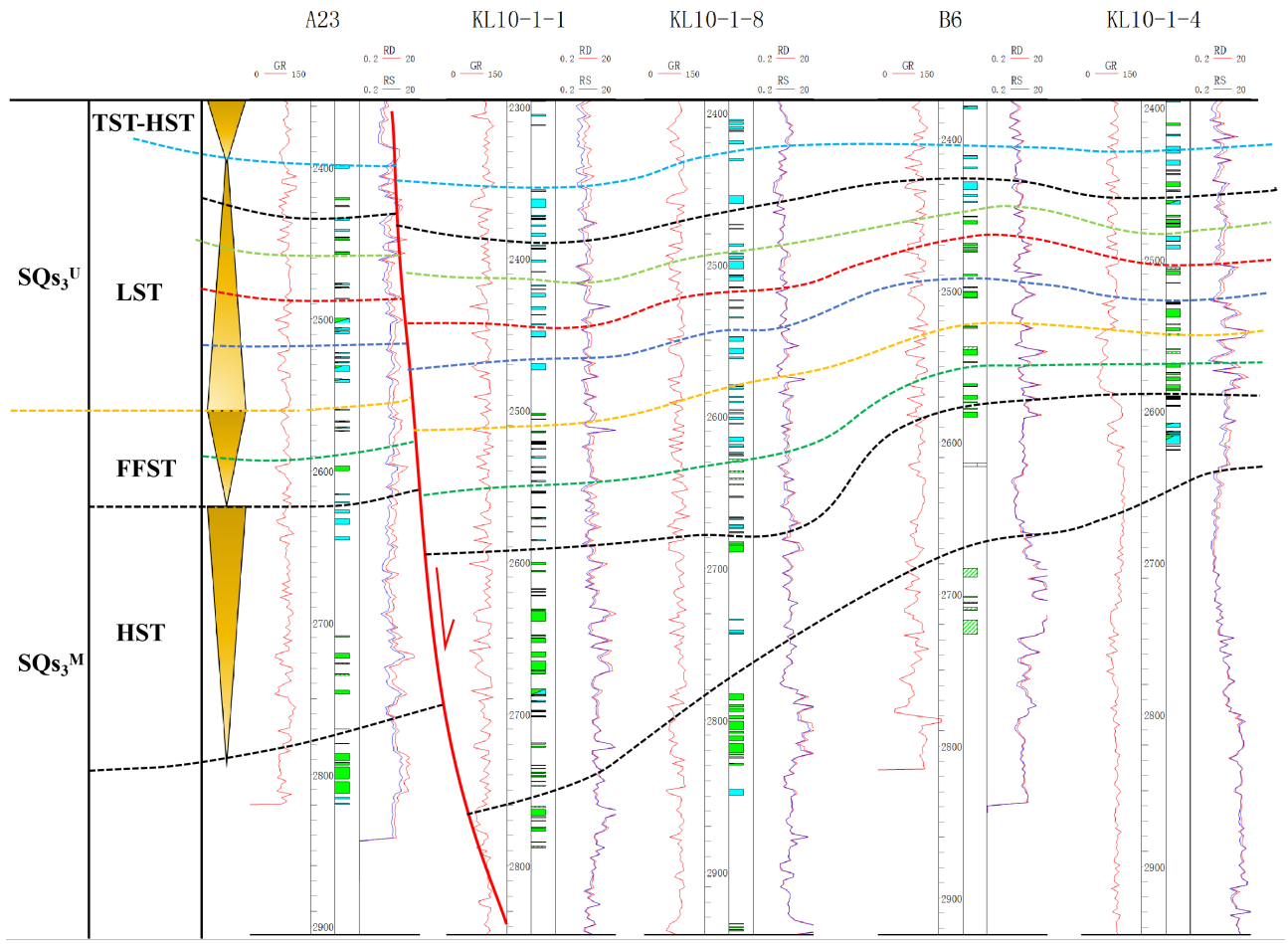

Figure 2. Sequence profile of Shasan member in A oilfield, Laizhou bay depression, connected well in the direction of source.

thickness of Class B single sand body ranges from 4 to 8 meters, mainly developed in the SQs3M high-level system tract of the sequence. Based on the tracking of progradational reflection relationships in seismic profiles and the analysis of the cyclicity of logging lithology, the SQs3M high-level system can be divided into 5 stages of delta progradational bodies; A-B type reservoirs are mainly developed in the forced lacustrine retreat system tract of sequence SQs3M, characterized by interbedded sand and mudstone, with a single sand body thickness of 4 - 6 meters.

Based on seismic profiles and drilling lithological cycles, the thick sand bodies (Class B) of the SQs3M high-level system tract in the Sha 3 Member sequence of A oilfield can be divided into 5 progradational bodies. The east-west seismic profile of the study area (CDP3020) shows that the first and second progradations are high angle S-type progradations with large sedimentary thickness, the third is oblique progradations, and the fourth and fifth are S-oblique composite progradations (**Figure 3**).

The east-west profile of CDP3280 still shows that the thick sand bodies of the SQs3M high-level system tract can be divided into 5 stages of delta progradation. The 3rd stage of progradation can also be finely divided into three sub stages,

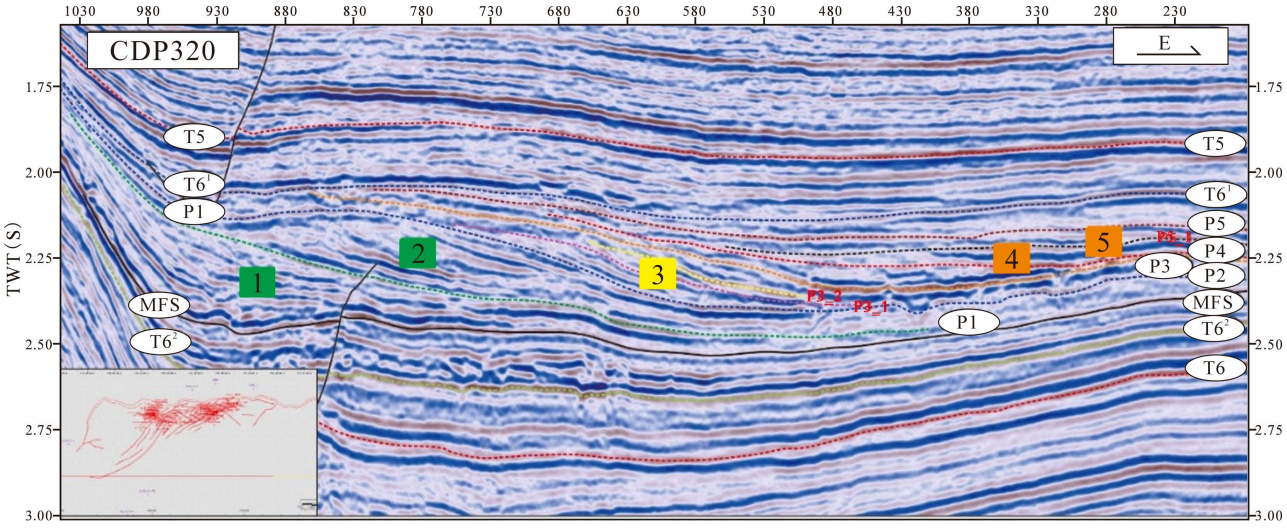

Figure 3. Division of progradation periods in the SQs3M high-level system tract of A oilfield sequence in Laizhou Bay depression (CDP3220).

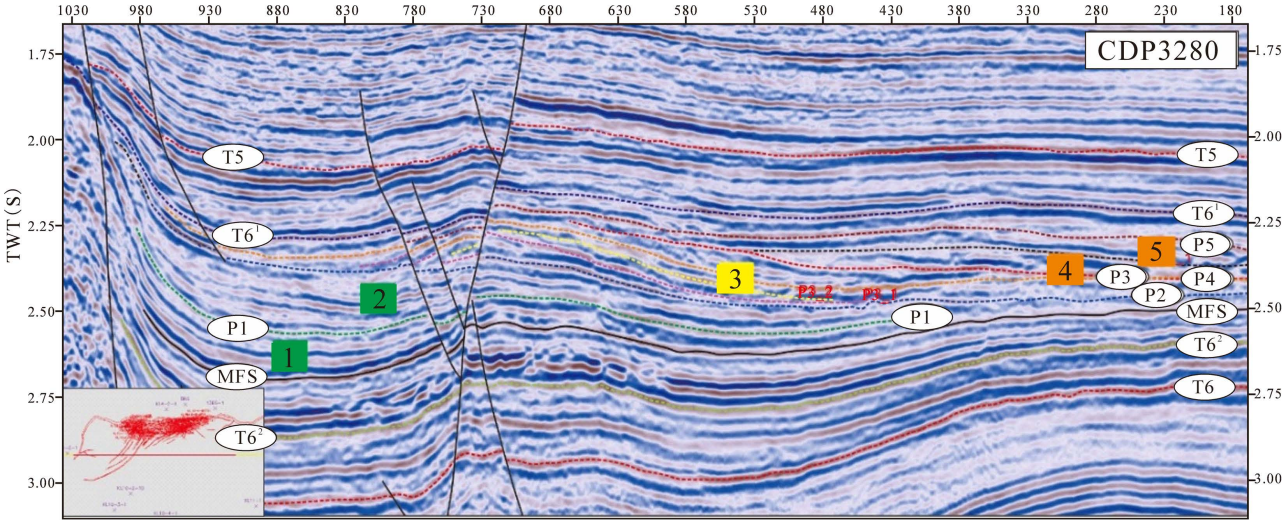

Figure 4. Division of progradation periods in the SQs3M high-level system tract of A oilfield in Laizhou Bay depression (CDP3280).

and the 5th stage of progradation can be finely divided into two sub stages (Figure 4).

The seismic profiles of CDP3460 passing through wells KL10-1-1 and KL10-1-8 in an east-west direction show that the first well area of A oilfield mainly develops the third stage progradational bodies, while the eighth well area mainly consists of the third and fourth stages progradational bodies (Figure 5).

The seismic profile of SW-NE passing through KL10-1-7 well shows that the 7 well area of A oilfield mainly corresponds to the 3rd, 4th, and 5th progradational bodies (Figure 6).

To clarify the distribution characteristics of each stage of delta progradation in the SQs3M high-level system tract on the plane, seismic tracing and interpretation of 5 large-scale (8 small-scale) progradations were completed, and thickness

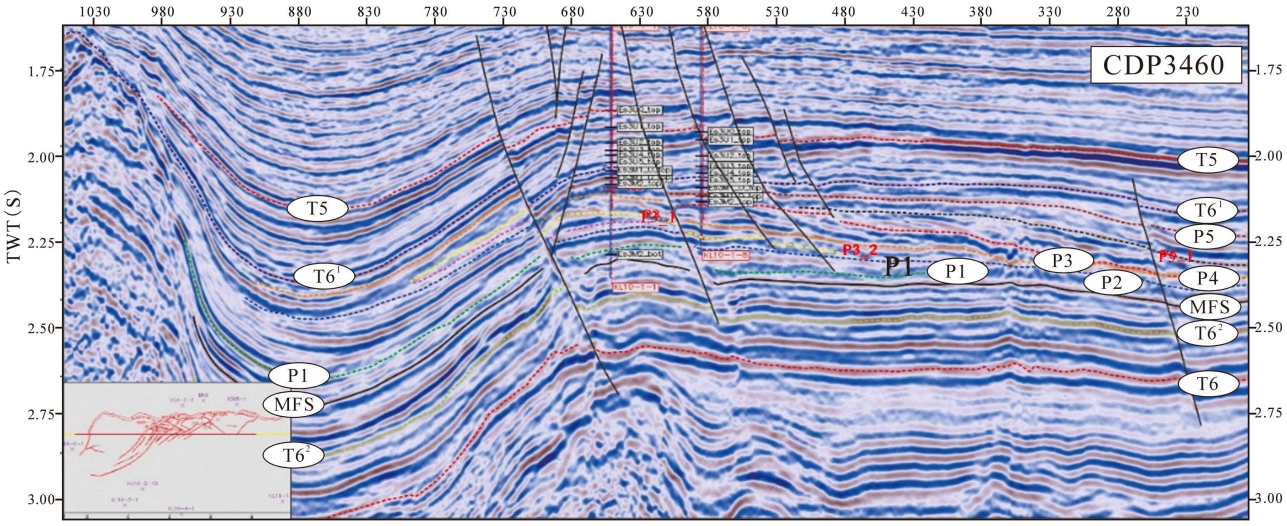

Figure 5. Division of progradation periods in the SQs3M high-level system tract of A oilfield in Laizhou Bay depression (CDP3460).

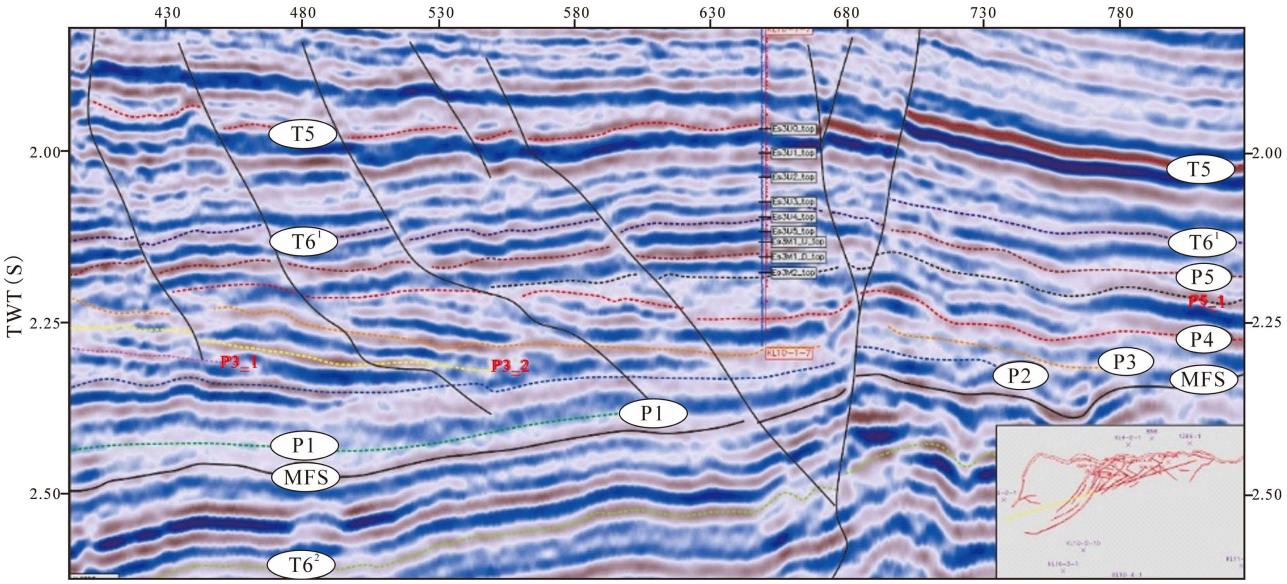

Figure 6. Division of progradation periods in the SQs3M high-level system tract of A oilfield in Laizhou Bay depression (SW-NE direction).

plane maps of each stage of delta progradation in the SQs3M high-level system tract were prepared (**Figure 7**). The center of the sedimentary thickness of the first stage delta leaf in the Shasan section is located on the westernmost side of the study area, and the sedimentary thickness decreases from west to east (**Figure 7(a)**); In the second phase, the sediment thickness center of the delta leaf migrated eastward and has not yet reached the A oilfield well area. The sediment thickness thinned from west to east (**Figure 7(b)**); In the third phase, the sedimentary center of the Delta Duoye continued to migrate eastward, mainly depositing in the 5 well area, 2 well area, 1 well area, 8 well area, and 6 well area; The third period of delta lobes is finely divided into three sub periods. The 3-1

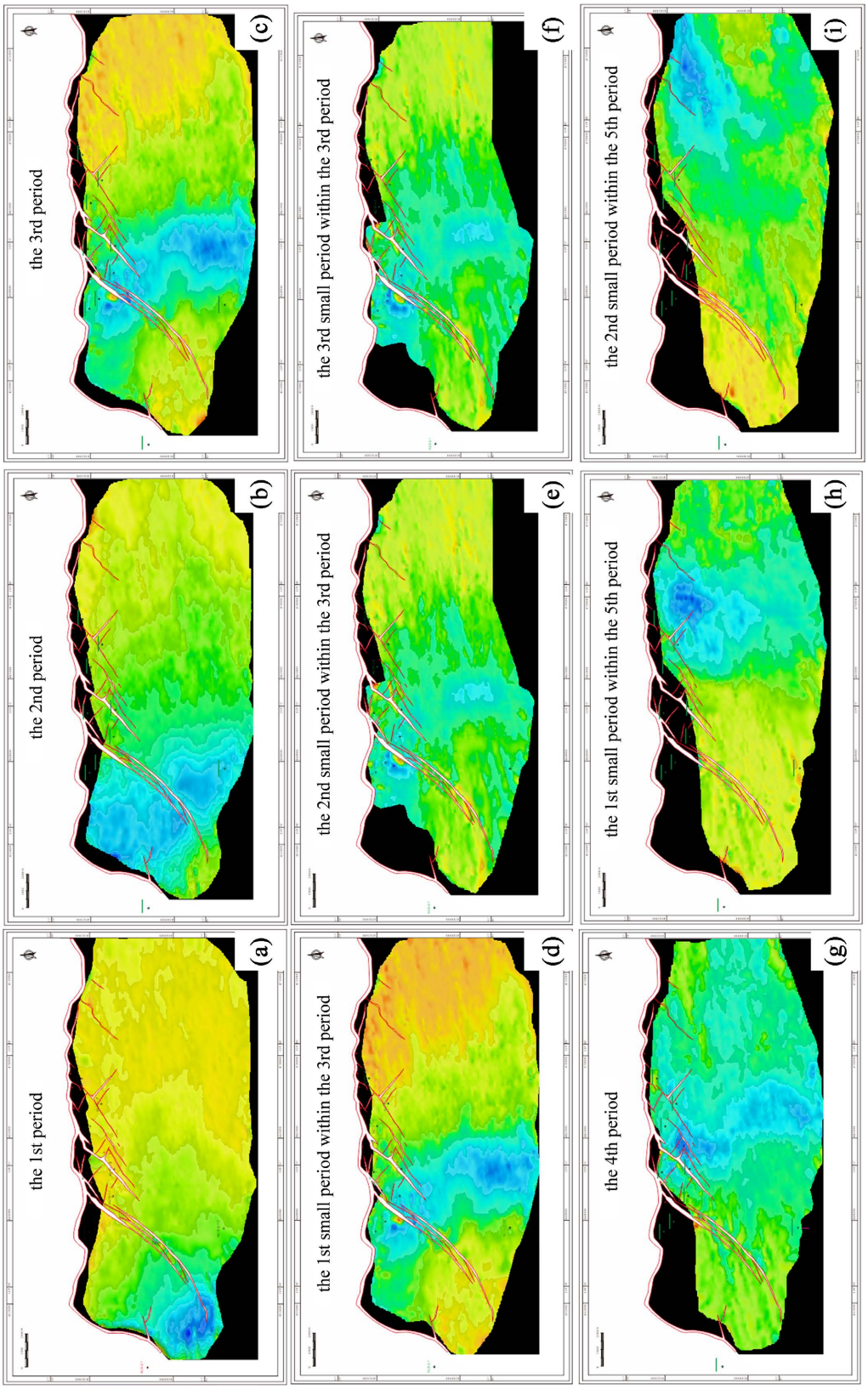

Figure 7. Distribution of stratigraphic thickness of various stages of progradation in the SQs3M high-level system tract of A oilfield in Laizhou Bay depression. (Blue indicates greater thickness, yellow indicates thinner thickness).

sub periods of delta lobes are mainly deposited in the 5 well area, 2 well area, and 1 well area (**Figure 7(c)**). The 3-2 sub periods of delta lobes advance forward, mainly located in the 5 well area, 2 well area, 1 well area, and 8 well area (**Figure 7(d)**). The center of sedimentary thickness in the 3-3 sub periods is mainly in the 2 well area (**Figure 7(e)**); The fourth phase of Delta Duoye continued to push eastward, mainly deposited in the 6 well area, 8 well area, 3 well area, and 7 well area (**Figure 7(f)**); The 5^{th} period of delta lobes continued to advance towards the southeast direction, with a thickness center developed south of the 4^{th} well area. The 5^{th} period can be finely explained as a 2-stage progradation body. The sedimentary range of the 5^{th} to 1^{st} stage of delta lobes was in the 3^{rd}, 7^{th}, and 4^{th} well areas (**Figure 7(g)**). The 5^{th} to 2^{nd} stage of delta lobes continued to advance towards the northeast direction, and the range of the lobes was basically not within the A oil field well area (**Figure 7(h)**, **Figure 7(i)**).

4. Conclusion

1) By combining well and seismic data, the sequence stratigraphy of the middle section of Shahejie-3 is divided into high-level system tract and forced lake retreat system tract, corresponding to the II oil formation and I oil formation of Shahejie-3, respectively. On the basis of system domain division, fine research on reservoir prediction is carried out.

2) Based on seismic profiles and drilling lithological cycles, the sedimentary system of the high stand system tract in the middle section of the Shasan Formation is characterized. The thick sand bodies in the high-level system tract are divided into 5 stages of progradation, with the first and second stages being high angle S-type progradation with large sedimentary thickness. The third stage is oblique progradation, and the fourth and fifth stages are S-oblique composite progradation; Combining seismic data, the characterization of 5 large-scale (8 small-scale) progradation bodies laid the foundation for later oilfield exploration.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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