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MESOZOIC SEQUENCE STRATIGRAPHIC FRAMEWORK FEATURES AND ITS GENETIC ANALYSIS OF SONGLIAO BASIN, NORTHEAST CHINA

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A hierarchy of sequence stratigraphic subdivisions is suggested for the Late Jurassic – Cretaceous deposits of the Songliao basin based on the results of seismic survey and also holes and outcrops. A megasequence, supersequence set, supersequences, sequences and parasequences are distinguished characterizing stages of the basin development and different-order cyclic recurrence. Regional and global factors are considered that govern the course of the basin evolution.

Key words: **sequence stratigraphy, Mesozoic, Songliao, Northeast China.**

INTRODUCTION

At the very begining, the most important significance of sequence stratigraphy is that it helps us reconstruct the eustatic sea level change and to carry out global stratigraphic correlation. With the development of the theory, it is discovered that sequence stratigraphic framework features are related to not only eustatic sea level change, but also geologic background of a basin, basin type, climate, tectonics and sedimentary influx, that is to say that the sequence stratigraphic framework features of a basin is the comprehensive response to the above factors. It indicates that we can get more important information of the basin evolution through the study of sequence stratigraphic framework features.

The Songliao basin is located in the hinterland of Northeast China, geographically covering the area of E119°40'–E128°24', N42°25'–N49°23'. The basin stretches in the NNE direction, with a length of 750 km, width of 350 km and an area of 260000 km^2 (Fig. 1). The basin is surrounded by the Siberian, North China and Pacific plates. Because of the interaction among the above three plates during Mesozoic time, the complexity of geologic structure, the nature of the basin and the features of the tectonic and sedimentary evolution have been long disputed by geologists. This paper attempts to reveal the genesis and the evolutionary law of the basin through the study of the Mesozoic sequence stratigraphic framework features of the region.

THE CLASSIFICATION OF SEQUENCE STRATIGRAPHY

Virtuall, sequence stratigraphy is the study of the cyclic isochronous stratigtaphic framework and the distribution model of the sedimentary strata within the isochronous stratigraphic framework. The cyclic movement of different rank base–level cycles causes the differences in cyclicity and scale of the sedimentary cycles, that is the grading of sequences. Sequence grading or sequence classification is essential to set up

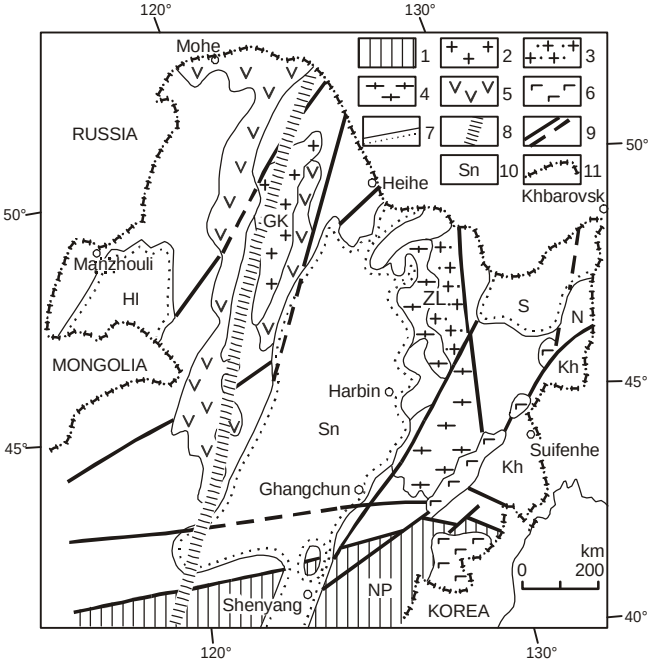


Fig. 1 Tectonic sketch map of Songliao basin and its adjacent region.

1 – Archean – Early Proterozoic basement with Paleozoic cover; 2 – Caledonian granites; 3 – Late Hercynian–Indo–Sinian granites; 4 – Late Indo–Sinian granites; 5 – Mesozoic volcanics; 6 – Cenozoic basalts; 7 – boundaries of Mesozoic–Cenozoic sedimentary basins; 8 – gradient zone (from gravimetric data); 9 – faults, specified and presumed; 10 – lettering for major structural elements; 11 – state border; Sn–Songliao basin; Hl – Hailar basin; S – Sanjiang basin; NP – North China plate; N – Nadanhada terrane; Kh – Khanka terrane; GK – ensemble of terranes of Greater Khingan; ZL – Zhangguangcai–Lesser Khingan zone.

sequence stratigraphic framework and to study sequence stratigraphy, but great divergence of views exists in sequence grading. Van Wagoner [3] organized sequence stratigraphic units into nine grades. They are Megasequence, Supersequence (set), Sequence, Parasequence set, Parasequence, layer set, layer, lamination set and lamination. Vail [7] classified sequence into five grades: Megasequence (>50 Ma), Supersequence (Supersequence set 27–40 Ma, Supersequence 9–10 Ma), Sequence (0.5–5 Ma), Parasequence (0.05–0.5 Ma), Minorsequence (0.01–0.05 Ma). The narrow sense "sequence" is the third order sequence of the system.

In a continental basin, the base-level change caused by tectonic movements, climate change, sediment influx and the events of transgression results in the formation of a series of different order sequences and sequence boundaries (including various unconformities). It is clear that sequence grading is essential for the erection of sequence stratigraphic framework and study of sequence stratigraphy. Through the study of the Upper Jurassic–Cretaceous sequence stratigraphy of the Songliao basin and the analysis of base–level cycles, considering various classification schemes, this paper puts forth a five-grade continental sequence stratigraphic classification plan.

CHARACTERISTICS OF SEQUENCE STRATIGRAPHIC UNITS AND THEIR RELATED BOUNDARIES

The recognition of sequence stratigraphic units is the key to the study of sequence stratigraphy. After a great deal of study of cores, outcrop, well logs and seismic data, we concluded the recognizable signs of different sequence stratigraphic units in the research region.

Megasequence (1st order sequence stratigraphic unit)

The first order tectonic event is the result of the crust pull–apart, thermo–cooling and gravity release, their stratigraphic symbol is uplift and the development of a basin [7]. The Late Jurassic–Cretaceous Songliao basin is a continental rift basin caused mainly by extension [3]. Its lower boundary is an angular unconformity with the Upper Jurassic overlying the Middle Jurassic Baicheng formation or the Permian. Its upper boundary is an unconformity with the Tertiary overlying the Cretaceous. On the seismic profile of the region, the lower boundary is related to the T_5 reflection surface, and the upper boundary is related to T_0^1 reflection surface. There are obvious truncate under the surfaces and onlap above the surfaces. In fact, the two boundaries are regional angular unconformities covering an area over the Songliao basin. They affect the whole Northeast China, even vast areas of Northeast Asia. They are obviously the result of the first order tectonic event, which represents the whole process of the

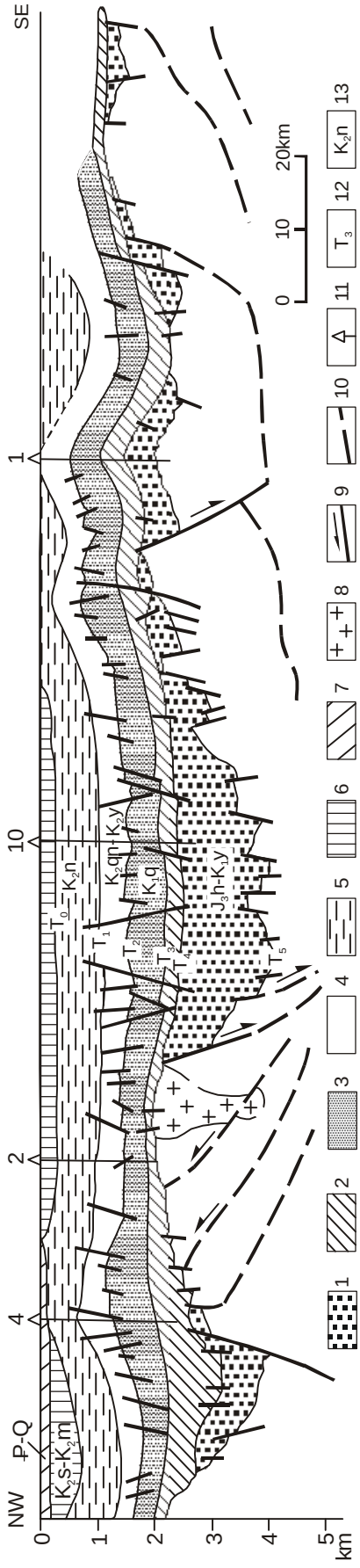


Fig. 2 Geologic–geophysical profile of Songliao basin.

1 – Huoshiling Formation–Yingcheng Formation; 2 – Denglouku Formation; 3 – Quantou Formation; 4 – Qingshankou Formation and Yaojia Formation; 5 – Nenjiang Formation; 6 – Sifangtai Formation and Mingshui Formation; 7 – Tertiary and Quaternary assemblages; 8 – granitoids; 9 – faults; 10 – inferred decollement; 11 – wells and their numbers; 12– reflection surfaces; 13 – indices of formations.

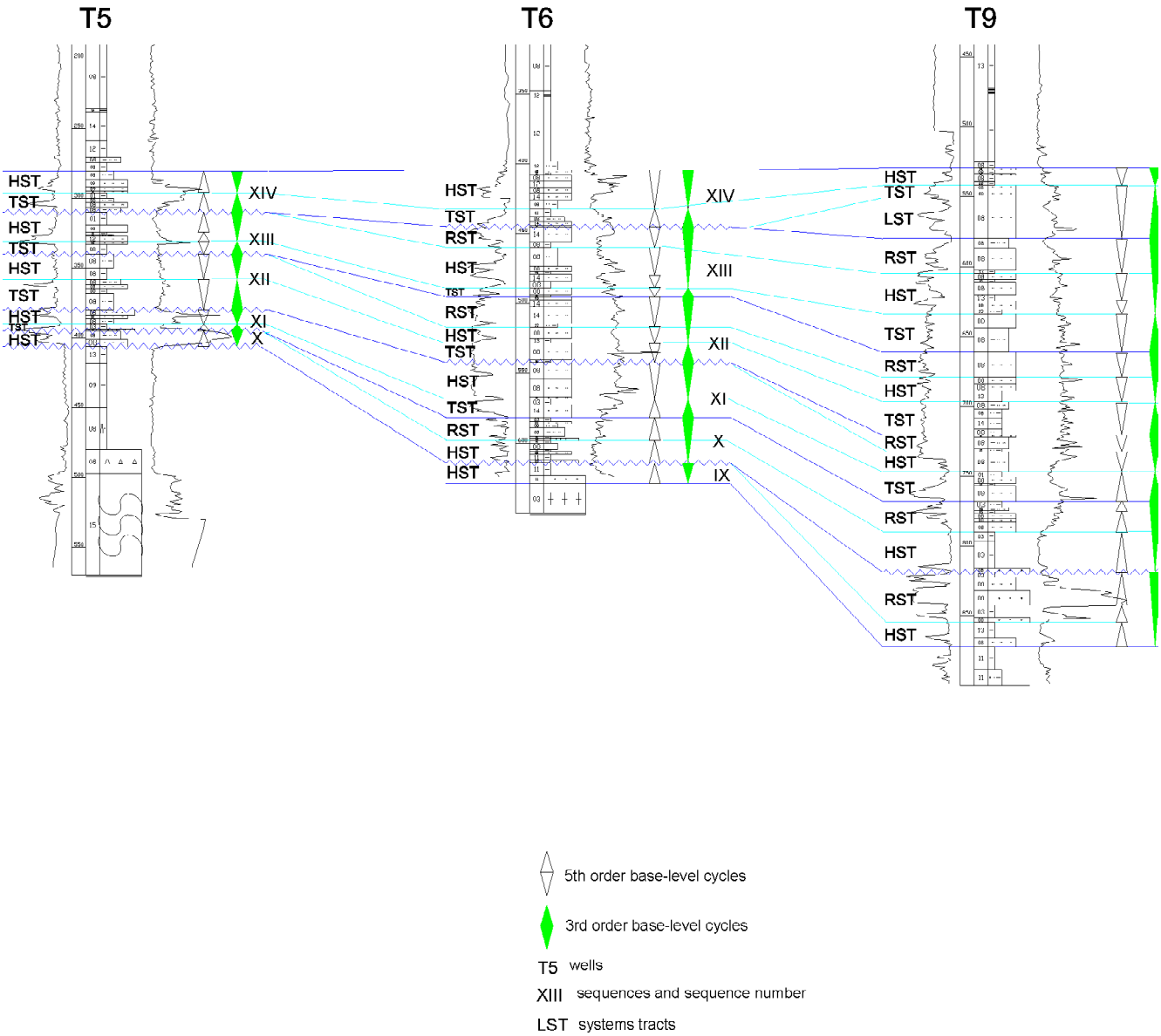
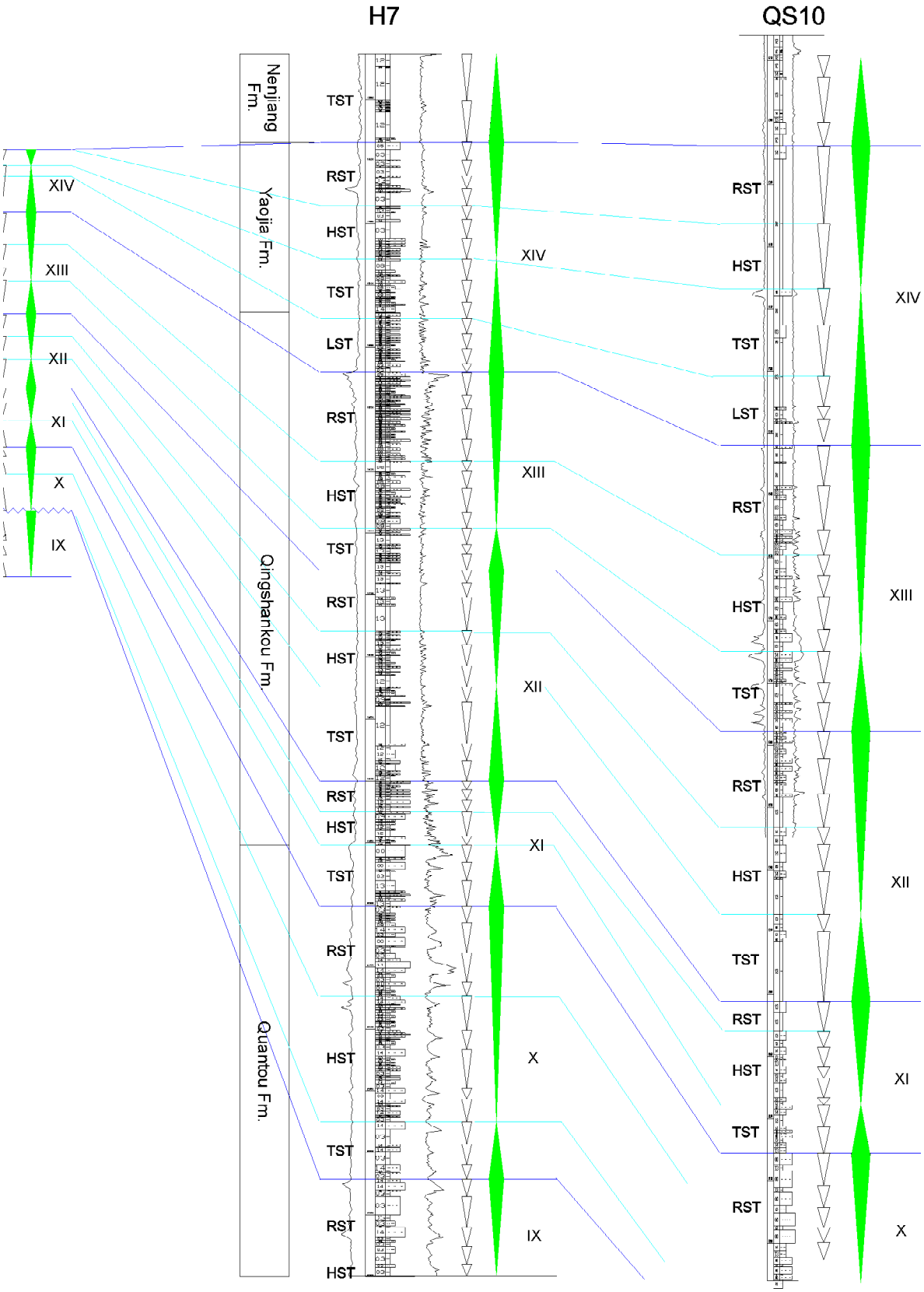


Fig. 3. High resolution sequence stratigraphic framework correlation across well T5 to QS10.


H7
QS10
Nenjiang Fm.
Yaojia Fm.
Qingshankou Fm.
Quantou Fm.
XIV
XIII
XII
XI
X
IX
TST
RST
HST
LST

rift basin from its starting to the end. So, Megasequence, with a duration over 60 Ma, is usually the result of a type of basin genesis (Fig.2).

Supersequence set, Supersequence (2nd order sequence stratigraphic unit)

The supersequence set is the result of different tectonic stress fields of a basin with the same genesis, approximately with the same a structure layer with a duration between 20 to 60 Ma. The supersequence set is usually bounded by basin–scale angular unconformities. There are two such boundaries in the Songliao basin, that is the T_4 and the T_0^3 reflection surface. There is a stratigraphic gap, which was demonstrated as truncate on a seismic profile, over a large area under the boundaries. T_4 is a boundary between the syn–rift Subsidence Supersequence set and the post–rift Thermosubsidence Supersequence set. Beneath the boundary, there are over 30 Huoshiling formation – Yingcheng formation stage fault basins scattered seperatedly, and a overlapped unified sag basin above the boundary. T_0^3 is the boundary separating the post–rift Thermosubsidence Supersequence set and the post–rift Shrinking Supersequence set. There is an evident angular unconformity around the boundary, which was demonstrated as truncate on seismic profiles. Apparently, the distributional range of the post–rift Shrinking Supersequence set is withered and shifted westward.

The supersequence is the result of different tectonic evolutionary stage in the same tectonic stress field or a different tectonic phase of the same stress field with a duration of 10–20 Ma. The syn–rift subsidence supersequence set can be divided into the Primary Fault, Lower Fault and Upper Fault Supersequence. All of them developed in the stage of the fault basin. Their boundaries are a parallel unconformity within the basin or a local angular unconformity. T_4^1 and T_4^2 are supersequence boundaries. In the sagging stage, the supersequence boundaries are a conformity and a parallel unconformity, e. g. there are stratigraphic gaps that mark the local parallel unconformity at the top of Qingshankou formation under the Yaojia formation and the top of the Denglouku formation under the Quantou formation, corresponding to the T_1^1 and T_3 reflection surfaces.

Sequence (3rd order sequence stratigraphic unit)

The sequence is the basic unit in the sequence stratigraphic classification system. The sequence is a set of stratigraphic units bounded by an unconformity and a related conformity (local unconformity) with a duration of 2–6 Ma. A depositional break, erosion and symbols of exposure to the air can be found on the local unconformity surfaces (Fig.3). On seismic profiles, local truncate can be seen under the sequence boundary and onlap above the sequence boundary. The sequence boundary is always identified as a steep value or a sudden change in well logs. Two kinds of the third order sequences of the region can be recognized. Type I sequence consists of the lowerstand systems tract (LST), transgressive systems tract (TST), highstand systems tract (HST), and regressive systems tract (RST). Compared with type I sequence, type II sequence lacks LST, that is a base–level rising occurs immediately right after RST of the last sequence without a forced base–level fall. Sequence XI, XII, XIII and XV are all type II sequences (Fig.3, 4).

Parasequence set (4th order sequence stratigraphic unit)

The parasequence set consists of a set of parasequences with a genetic relationship and a certain stacking pattern, and, usually, is bounded by main flooding surfaces and their related surfaces [8]. According to the stacking pattern, three types of parasequence sets can be recognized: progradational, aggradational and retrogradational. Each parasequence set corresponds to certain stage of a third order base–level cycle. The systems tract (approximately corresponds to parasequence set) is the assemblage of sedimentary systems, which deposit at the same time. According to the four–part dividing method (a sequence consists of four systems tracts) [4], usually, LST is small-scale aggradational or small scale progradational parasequence set, TST is retrogradational parasequence set, HST is an aggradational parasequence set, RST is large-scale progradational set. These features can be easily recognized from well logs. On some seismic profiles with a higher resolution, the primary onlap surface as the boundary between LST and TST, the maximum onlap surface as the boundary of TST and HST, and certain downlap surface as the boundary of HST and RST can be identified.

SEQUENCE STRATIGRAPHIC FRAMEWORK CONTROLLING FACTORS AND THE BASIN EVOLUTION

Sequence stratigraphic framework and its controlling factors

On the basis of sequence stratigraphic classification and base–level cycle grading, through the synthetical study and analysis of cores, outcrop, well logs and seismic data of the region, two wider regional angular unconformity surfaces (T_5 and T_0^1), two basin–scalet angular unconformity surfaces (T_4 and T_0^3) and sixteen local unconformity surfaces are recognized. According to these surfaces, combined with the regional tectonic background, basin evolutionary course, climate change cycles and base–level change cycles, the Upper Jurassic–Cretaceous of the Songliao basin can be classified into 1

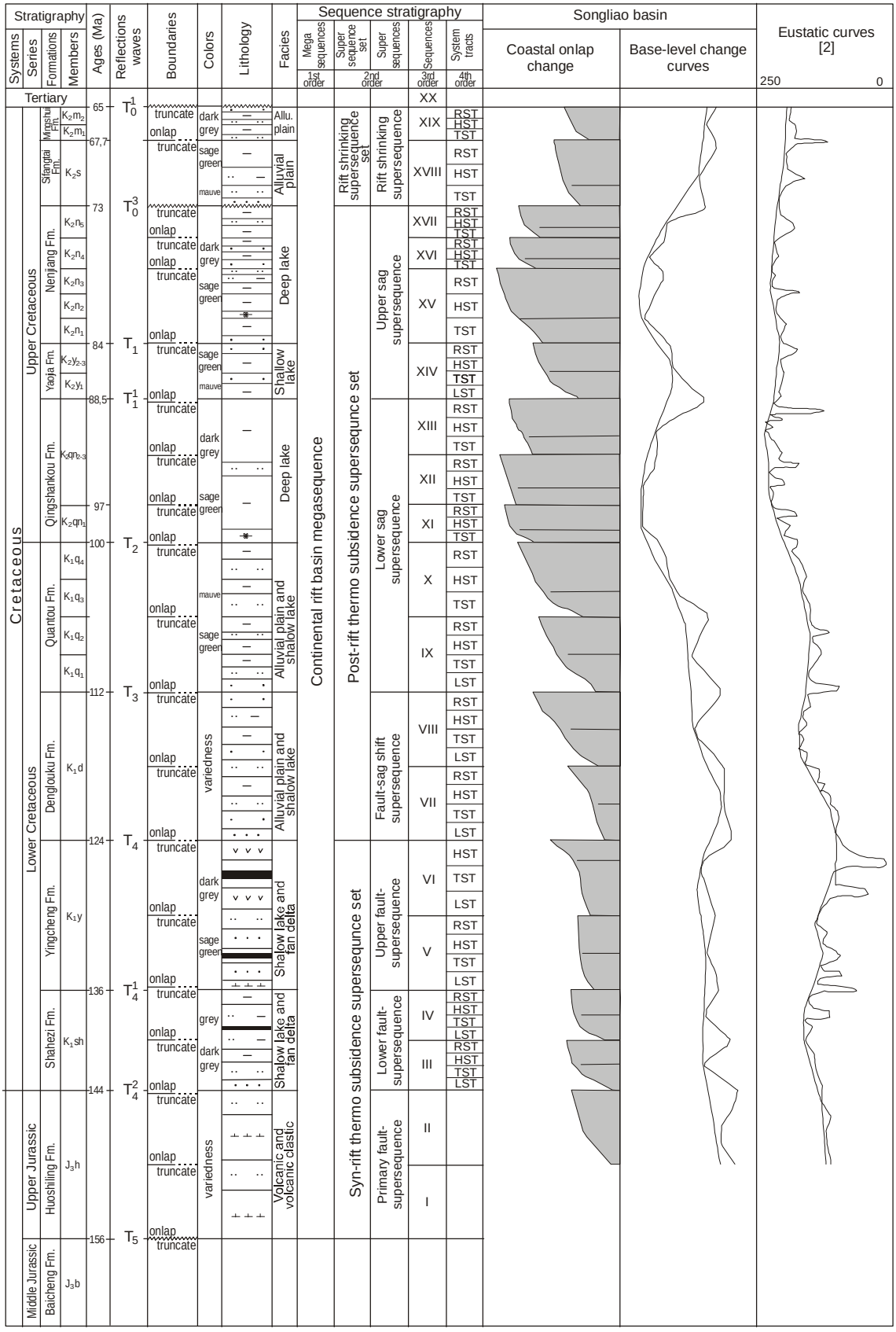


Fig. 4. Sequence stratigraphy and base–level change chart of Songliao basin.

megasequence, 3 supersequence sets, 6 supersequences, 19 sequences, and 58 systems tracts (Fig.4). All of these stratigraphic units form the Mesozoic sequence stratigraphic framework of the Songliao basin.

Cross [1] considered that the base-level change is subject to the comprehensive factors of eustasy, tectonic subsidence, sediment load compensation, sediment influx and sedimentary topography. Sequence stratigraphy is the result of cyclic change of base–level and its related accommodation space. As for the Songliao basin, the features of its sequence stratigraphic framework are synthetical response to tectonic movements, climate change, sediment influx rate change ,and transgression events. Tectonic factors play a leading role in the development of lower frequence sequences (1st and 2nd order sequence), climate change is of great importance to second order sequences of the sagging stage, and even a bit of change of all the above four factors will affect the formation of high frequence sequences (3rd and 4th order sequence).

Basin evolution

The Songliao rift basin developed on a basis of Early Mesozoic over–collision between the Siberian plate and the North China plate. The over–collision thickened the crust of the research area and developed a series of EW intermountain basins and thrusts during the Middle Jurassic [5], while the whole evolutionary process of the Mesozoic rift basin is the result of interaction between the Pacific tectonic domain and the Eurasia continent. This interaction determined the sequence framework features of the Mesozoic Songliao basin, and developed an integrated Continental Rift Megasequence.

During 180–135 Ma, the Faralon plate moved in the NE direction compared with the Eurasia continent with a velocity of 5.3–10.7 cm/y. Maruyama and Seno [6] regarded this period as a transcurrent movement stage. At the time, the relationship between the Faralon plate and the Eurasia continental margin might be a transform fault. Under the above influence, especially the isostasy of the thickened crust of the basement of Songliao basin, crust extension, which resulted in the development of over 30 separated fault basins, was triggered. This period belongs to the Syn–rift Subsidence Supersequence set. The episodic process of the tectonic stress field formed the Primary Fault Supersequence and the Lower Fault Sepersequence. During 135–127 Ma, the Izanagi plate subducted obliquely towards the Eurasia plate with a high speed of 30 cm/y. This caused NE or NNE faults of the Yingcheng formation in the region, and formed the Upper Fault Supersequence characterized by strike–slip pull–apart fault basins. Through the careful sequence stratigraphic research into some fault basins of the Songliao basin, it has been discovered that there is no prominent evidence which indicates that climate plays a remarkable role in the development of a fault sequence. Because the activity of contemperaneous fault is the dominant factor which affects the formation of a fault basin, it is reasonable to regard the episodic contemperaneous movement of basin–control faults and the change of the tectonic subsidence rate as the main factors which determined the development of the third order sequence.

Around 127 Ma, the Izanagi plate and the Kula plate obliquely subducted, slowed down (21.1 cm/y), meanwhile, the extension of the Songliao basin weakened, and post–rift thermosubsidence occurred. During 124–73 Ma, thermosubsidence formed the Post–rift Thermo-subsidence Supersequence set. The tectonic subsidence curve and sporopollen analysis indicate that, with the value of thermo subsidence and climate changing, The Fault–sag Shift, Lower Sag and Upper Sag super-sequences developed. Stratigraphic gaps exist between every two adjacent supersequences. In the sagging stage, tectonic subsidence, climate change and sediment influx rate change controled the development of the third order sequence. It is worth mentioning that many evidences of transgression event have been found in the Early Qingshankou formation stage (95 Ma±) and Early Nenjiang formation stage (80 Ma±) [3]. The two periods happen to be the two maximum flooding periods in Haq's [2] eustatic curves. It is evident that transgression affected the development of the sequence in the region, and formed the sequence characterized by type II sequence.

During 74–53 Ma, the Pacific plate subducted right towards the Eurasia continent with a speed of 10.6 cm/y. The eastern margin of the Eurasia continent uplifted, which might be related to the sedimentary area shrinking and the sedimentary center shifting westwards of the Songliao basin. This period developed the Post–rift Shrinking Supersequence (set). Finally, the evolutionary history of the Mesozoic Songliao rift basin ceased.

REFERENCES

1. Cross T. A. High–resolution stratigraphic correlation from the perspective of base–level cycles and sediment accommodation // Proceedings of Northwestern European Sequence Stratigraphy Congress. 1994. P. 105–123.
2. Haq B. U., Hardenbol J. and Vail P. R. Mesozoic and Cenozoic Chronostratigraphy and Cycles of Sea–level Change. In: Wilgus C. K., Hastings B. S, Kendall C. G. St. C., Posamentier H. W., Ross C. A. and Van Wagoner J. C. (eds.), Sea–level changes: An integrated approach. Soc. Econ. Paleontol. Mineral., Spec. Publ., 1988. V. 42. P. 71–108.
3. Liu Zhaojun, Wang Dongpo, et al. Sedimentary Characteristics of the Cretaceous in the Songliao Basin. Acta Geologica Sinica, 1993 V. 6(2). P. 167–180.
4. Liu Zhaojun, Guo Wei, Dong Qingshui, et al. Lacustrine Basin Sequence Stratigraphic Term System and Model.

1997, 27 (Supplementary II). P. 54–60 (in Chinese).
5. Liu Zhaojun, Kirillova G. L., Zhang Xingzhou and Wang Simin. Meso–Cenozoic Tectono–Stratigraphic Complexes in the Manzhouli–Suifenhe Transect Zone and the Adjacent Territory as a Reflection of Geodynamic Evolution of the Region // Geology of Pacific Ocean. 1999. V. 14. P. 857–870.
6. Maruyama S., Seno T. Orogeny and Relative Plate Motions: Example of the Japanese Islands // Tectonophysics. 1986. V. 127. P. 305–329.
7. Vail P. R., Audemard F., Bowman S. A., Eisner P. N. and Perez-Cruz C. The stratigraphic signatures of tectonics, eustasy and sedimentation – an overview. In: Einsele G., Ricken W. and Seilacher A. (eds.), Cycles and events in stratigraphy. Springer-Verlag, 1991. 617–659.
8. Van Wagoner J. C., Mitchum R. M., Jr., Campion K. M. and Rahmanian, V. D. Siliciclastic Sequence Stratigraphy in Well Logs, Cores and Outcrop: Concepts for High Resolution Correlation of Time and Facies. AAPG Methods in Exploration Series , Tulsa, 1990. V. 7. P. 1–55.

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Лю Чжаоцзюнь, Ван Сыминь

Особенности мезозойских секвенсстратиграфических подразделений и генетический анализ бассейна Сунляо, северо-восточный Китай

Предложена иерархия секвенсстратиграфических подразделений для позднеюрско-меловых отложений бассейна Сунляо, основанная на данных сейсморазведки, а также скважин и обнажений. Выделены мегасеквенс, серии суперсеквенсов, суперсеквенсы, секвенсы, парасеквенсы, характеризующие стадии развития бассейна и цикличность разных порядков. Рассмотрены региональные и глобальные факторы, контролирующие ход эволюции бассейна.