УДК 552. 578.3 "6231"+(282.252)

PALAEOGENE SEQUENCES WITH SEDIMENTARY CHARACTERISTICS CONTROLLING THE LACUSTRINE OIL SHALE OF THE MEIHE BASIN*

Rong Liu[1,2], Zhaojun Liu[1,2], Xiaofeng Hu[3], Pingchang Sun[1], Yueyuie Bai[1], Chao Zhang[1]

[1]*College of Earth Sciences, Jilin University, 130061 Changchun, China,*
e-mail: jpuliurong@163.com / liurong@jlu.edu.cn

[2]*Key Laboratory of Oil Shale and Coexistent Energy Minerals of Jilin Province, 130061 Changchun, China*

[3]*Key Laboratory of Marine Geology and Environment,Institute of Oceanology,Chinese Academy of Sciences, 266071 Qindao,China*

Поступила в редакцию 2 февраля 2015 г.

As a case study, the Meihe Basin, a typical Cenozoic faulted basin, was divided into and identified as five three-order sequences by utilizing core, well logging, and seismic data, as well as palaeontological and geochemical data. Field measurements of sections, core observations, and a comprehensive analysis revealed that the basin is mainly composed of deposits of alluvial fan, fan delta, lacustrine facies, and gravity flows, and oil shale is mainly developed in semi-deep and deep lacustrine environments. The comprehensive study of the sediment-sequence stratigraphy indicates that Sequence I was formed in the initial rifting stage of the basin, dominated by coarse clastic sediments of alluvial fan and fan delta. Sequence II was formed in the rifting expansion stage of the basin, with more developed sediments of fan delta and lacustrine. Sequence III was formed in the largest expansion stage of the basin, dominated by mudstone of deep lacustrine facies and gravity flow deposits. Sequence IV was formed in the shrinking stage of the basin, dominated by sediments of delta and lacustrine fan. Oil shale aise mainly developed in the transgressive system tract (TST) and highstand system tract (HST) of Sequence III (Mudstone Member of lacustrine facies). The lake flooding effect of TST can reduce the decomposition amount of organic matter, increase in organic matter production, and reduce the amount of dilution, thus forming oil shale with a thin consistency but high quality. In the period of the HST, the larger accommodation space and excellent organic matter preservation conditions are conducive to developing stable oil shale with a greater consistency. During the high water level period, however, due to the oxygen brought in by turbidites, the decomposition of organic matter is often increased, resulting in the formation of low-quality oil shale.

Keywords: **Meihe Basin, oil shale, sequence, sedimentary.**

INTRODUCTION

Located in the Dunmi fault zone, the northern extended branch of the Tanlu Fault Belt, the Meihe Basin is China's famous Paleogene faulted basin containing coal and oil shale [21]. Here, predecessors have conducted extensive exploration and research work on coal-bearing strata, but limited research on oil shale strata of the basin [24, 26, 7, and 8]. With its rise and development, sequence stratigraphy has become an important theory and method for prospecting and prediction of sedimentary energy minerals. In the research of oil shale, more and more scholars have begun applying the theory of sequence stratigraphy in the research on origin and distribution rules of oil shale, and they have achieved certain results. In general, they have found that oil shale is formed in deep lacustrine environments, and that higher lake levels and larger accommodation spaces are beneficial to the sedimentation of oil shale [19, 12, 11, and 27]. The Meihe Basin is Located in Northeast China where the development of Cenozoic and stratigraphic sedimentary sequences are relatively complete. This paper examines the sequence and sediments of oil-bearing shale strata and discusses oil shale distribution and its formation mechanisms, thus providing some theoretical guidance for future exploitation and prediction of oil shale resources.

GEOLOGICAL SETTING

The Meihe Basin is a Cenozoic fault basin located in the Dunmi fault zone, one of the northern extended branches of the Tanlu Fault Belt (Fig. 1). The structural evolution covers pre-basement structuring,

* статья публикуется в авторской версии.

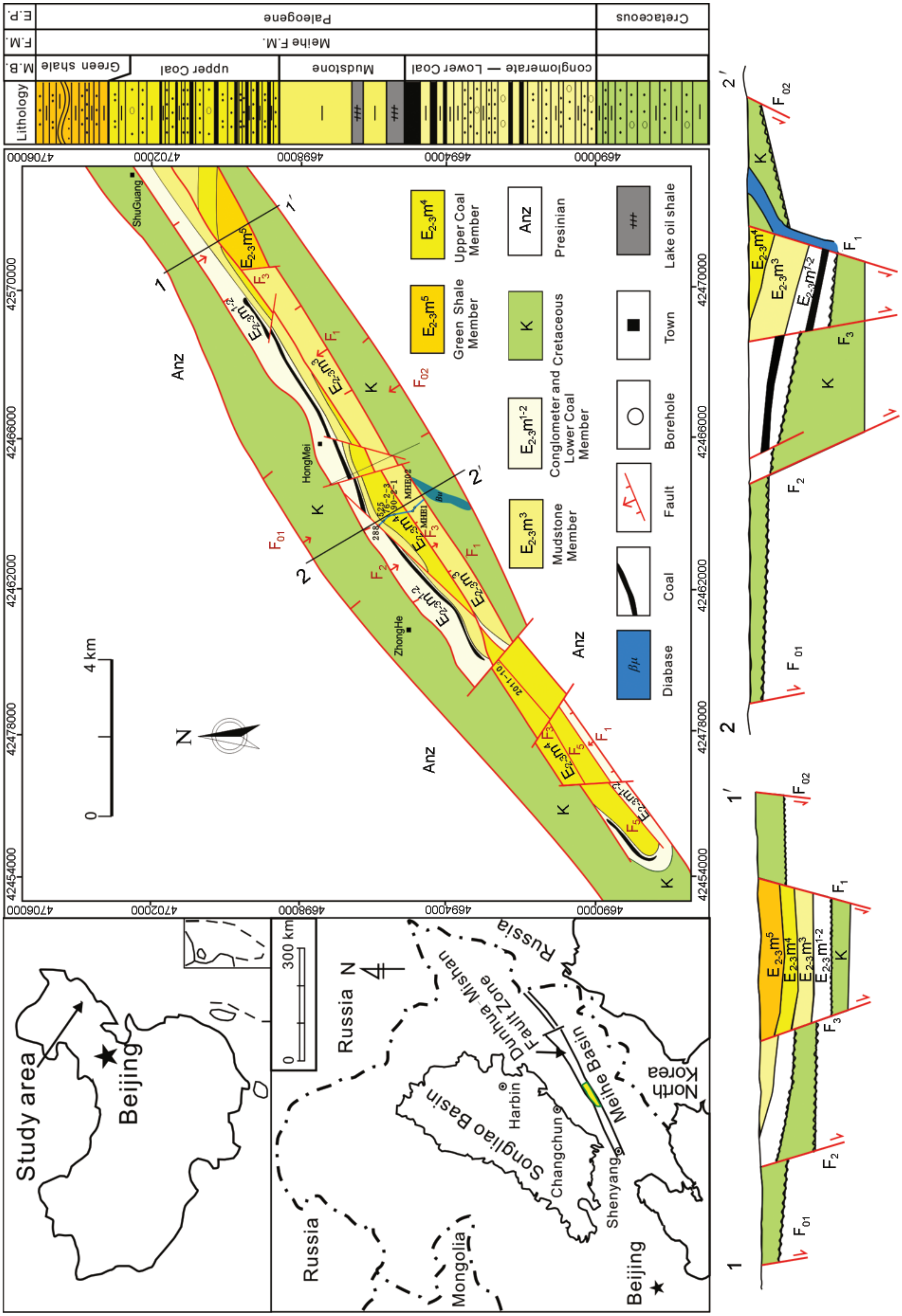


Fig. 1. The geological structure of the Meihe Basin and location in northeastern China.

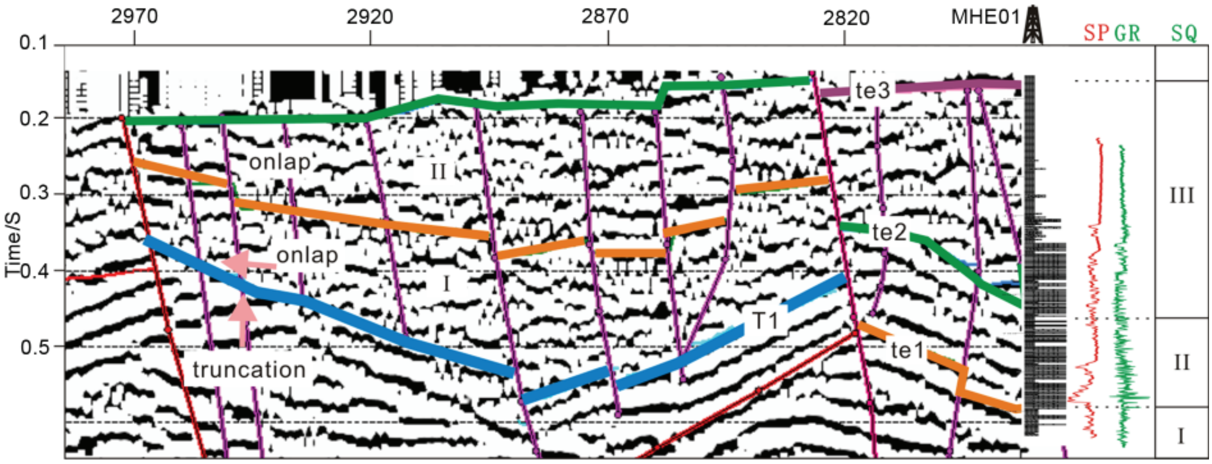


Fig. 2. Seismic profile and sequence stratigraphic framework of line 678 in Meihe Basin.

synsedimentary structuring, and late structural deformation. The pre-basement structuring of the basin appeared in the late Mesozoic, and the tensional structuring of the late Yanshan movement formed the Meihe Basin, dominating Cretaceous sedimentary. The synsedimentary structuring of the basin occurred in the early Paleogene, and the opposite inclined tensional faults F_1 and F_2 at the basin edge formed a long and narrow rift, dominating sediment thickness and distribution characteristics of energy mineral resources of the Meihe Formation. After synsedimentary structuring, the basin filling was complexe, and late structural deformation began to develop. In addition, the extensional fault F_3 cut the basin, accompanied by pyroxenite invasion and basalt eruption [24] . The basement of the basin belongs to the Anshan group's metamorphic rocks of the Pre-Sinian system as well as the solid purple and purple-red (mixed with grayish green) coarse clastic rocks of the Cretaceous system. Moreover, the basin is filled with Paleogene coal-bearing strata and oil shale strata of the Meihe Formation, overlaid by the Neogene system [26, 7, and 8].

The targeted strata of this study are in the Meihe Formation of the Cenozoic Paleogene system, and the previous data and study show that the Meihe Formation was developed in Eocene-Oligocenea strata, with Paleocene stratum missing. This formation can be divided into five members, namely, (from bottom to top) the bottom Conglometer ($E_{2-3}m^1$), the Low Coal Member ($E_{2-3}m^2$), the Mudstone Member ($E_{2-3}m^3$), the Upper Coal Member ($E_{2-3}m^4$), and the Green Shale Member ($E_{2-3}m^5$). The Meihe Formation has an average thickness of 1.160 m and unconformable contact with underlying strata, representing a complete sedimentary structural evolution of the basin. The oil shale is mainly developed in the Mudstone Member ($E_{2-3}m^3$), and the oil shale is generally grayish-brown and grayish-black, with the development of horizontal bedding and massive bedding (Fig. 2).

MATERIALS AND METHODS

By using more than 200 exploration wells for coal exploration in the Meihe Basin, observing the cores from 15 key wells, and conducting an indoor comprehensive analysis, we established the framework for the stratigraphic and corresponding sequence of the basin. Among all the wells, comprehensive and systematic studies were focused on three core wells that can comprehensively reflect the strata of the Meihe Formation (Fig. 2), namely, Meihe Well 1, which revealed the Conglometer; Meihe Well 10, which revealed the Low Coal Member and Mudstone Member; and Meihe Well 3, which revealed the top part of the Mudstone Member, upper coal-bearing section, and green rock section. Based on the comprehensive analysis of these three total coring wells, the stratigraphic sequence evolution of the Meihe Formation in this area was reconstructed. This was then taken as tangible data for a systematic study on the sediment-sequence evolution of the Meihe Formation.

OIL SHALE CHARACTERISTICS

The oil shale in the Meihe Basin developed in the Mudstone Member, appearing mainly in dark brown and brown, with a relatively low density. In the dark brown oil shale, plant stem fossils were found, while in the brown oil shale, fossils of lacustrine biologies, such as conchostracans and ostracods, were frequently found. By comparison, the oil yeild in the dark brown oil shale is higher than that in the brown oil shale. Usually, the horizontal bedding is well developed in oil shale of better quality, whereas the massive bedding is developed in the oil shale of poorer quality (Fig. 3 j–m).

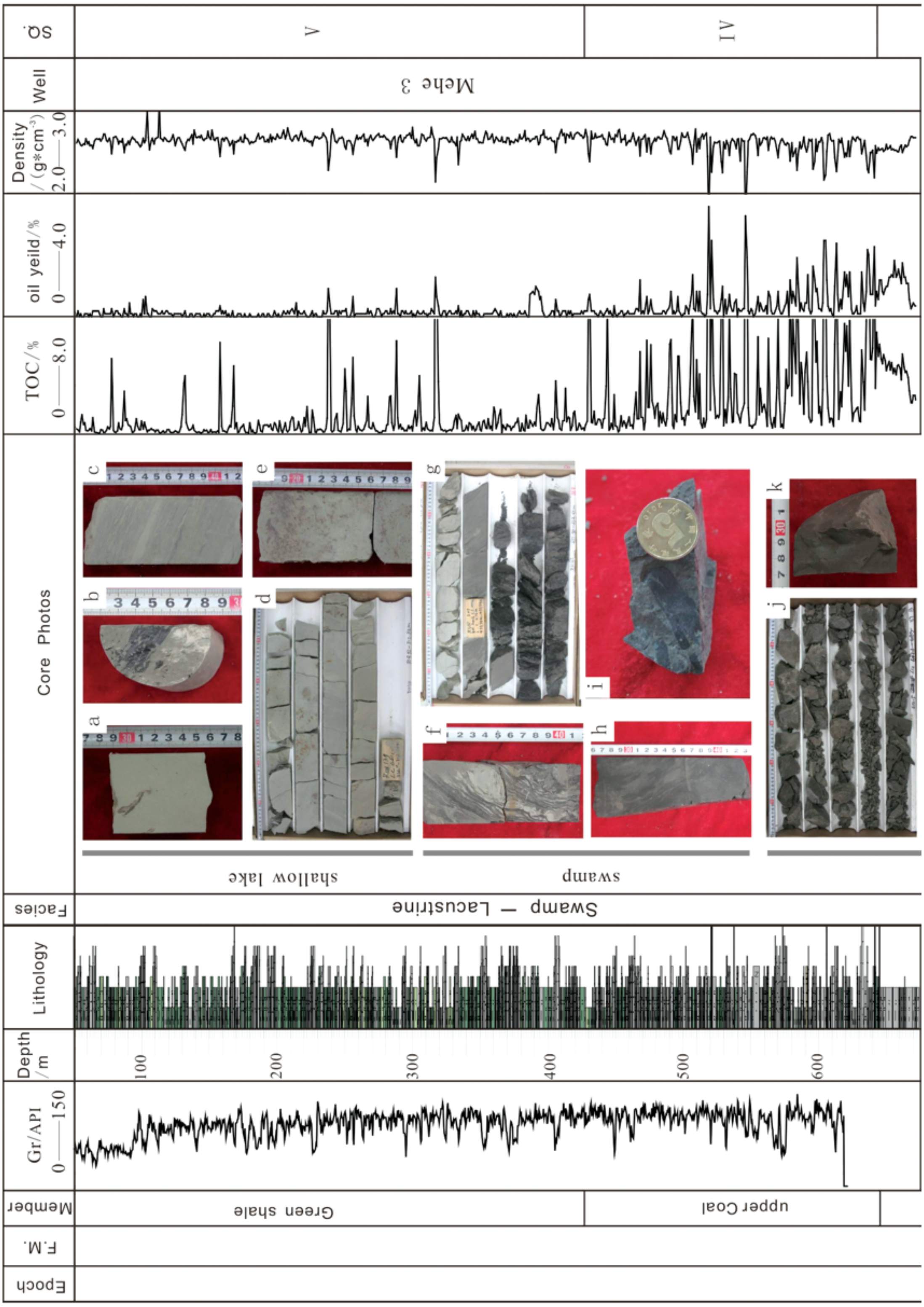
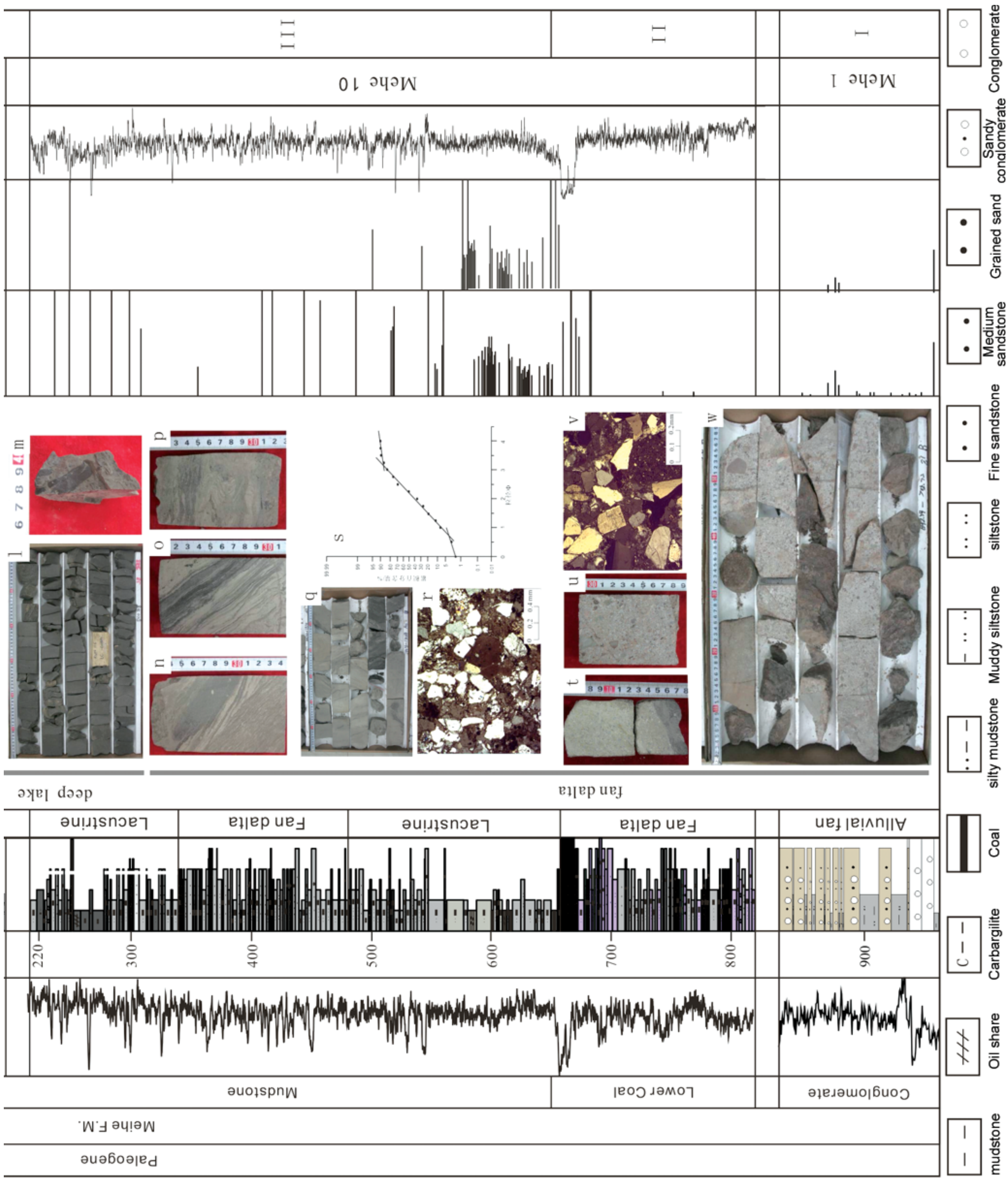


Fig. 3. Sedimentary and sequence stratigraphic features in Meihe Basin.


Paleogene
Meihe F.M.
Mudstone
Lower Coal
Conglomerate
220
300
400
500
600
700
800
900
Lacustrine
Fan dalta
Lacustrine
Fan dalta
Alluvial fan
deep lake
fan dalta
Mehe 10
Mehe I
III
II
I
mudstone
Oil share
Carbargilite
Coal
silty mudstone
Muddy siltstone
siltstone
Fine sandstone
Medium sandstone
Grained sand
Sandy condlomerate
Conglomerate

SEQUENCES OF THE MEIHE FORMATION

In the process of the sequence division, this paper adopted the sequence classification method proposed by Van Wagoner [22]. At the same time, we used the scheme of continental sequence division proposed by Liu Zhaojun et al. [13, 14] for the division of the three-order sequence system tract. In addition, the three-order sequence was divided into four system tracts, namely, the lowstand system tract (LST), the transgressive system tract (TST), the highstand system tract (HST), and the regressive system tract (RST). Beneath the LST is the sequence boundary, while above there is the first main flooded surface; beneath the TST is the first main flooded surface, while above there is the maximum flooded surface; beneath the HST is the maximum flooded surface, while above there is the lacustrine regressive downlap surface; and beneath the RST is the lacustrine regressive downlap surface, while above there is the sequence boundary. In the superposition mode, generally, the LST is a small accretion or small progradational parasequence set; the TST is a retrogradational parasequence set; the HST is an aggradational parasequence set; and the RST is a large progradational parasequence set.

This paper conducted the sequence stratigraphic recognition and division mainly by such approaches as core observation, seismic interpretation, well logging data, and geochemical testing analysis. In addition, the authors divided the Meihe Formation into one megasequence, one supersequence, and five three-order sequences, while determining the sequence development characteristics of the Meihe Formation in the Meihe Basin.

Sequence stratigraphy recognition marks

The megasequence and supersequence are recognized mainly with the help of core observation, seismic interpretation, and well logging data. Here, the megasequence boundary refers to the regional angular unconformity boundary between the Paleocene-Eocene and Lower Cretaceous (T1). Moreover, the truncation is found beneath the T1 boundary in the northwest side of the basin, and the super-phenomenon is found above the same (Fig. 2).

The three-order sequence, system tract and parasequence are usually recognized and classified with the help of core data, well logging data [28], seismic data [11, 22], paleontology data [11], geochemistry data [2, 3, 6, 15, 17, 25], and inorganic element geochemistry data [1, 18]. The te1, te2, and te3 boundaries on the seismic profile are boundaries of the Sequences I, II, and III, respectively. The truncation or onlap appeared in seismic data. On the well logging curve of the MHE01 well and MH10 well, an obvious threshold appeared above and beneath the curve boundaries of the natural gamma and spontaneous potential (Figs. 2 and 3). Sedimentary facies changes and sedimentary cycle boundaries often appeared on the boundary of the three-order sequence. The sedimentary facies boundary between Sequence I and II of the Meihe Formation is the interface between Sequence I and II (Fig. 3). In addition, at the top of Sequence I, the coarser middle-fan channel sedimentary has developed amidst alluvial fans, while at the bottom of Sequence I, a fine subaqueous distributary channel and inter-channel sedimentary have developed as of the fan-delta plain. The sedimentary cycle in the core data can also indicate the sequence boundary. Inside Sequence I, from bottom to top, purplish-red glutenites, grayish-green sandstones and siltstones, light gray siltstones and mudstones, and grayish-black mudstones have developed, respectively. Meanwhile, at the bottom of Sequence II, purplish-red glutenites, sandstones, and mudstones have developed. In such sedimentary cycles are sequence boundaries (e.g. the boundary between the purplish-red glutenites at the bottom of Sequence II and the grayish-black mudstones at the top of Sequence I). A pollen analysis also showed differences in biological assemblage (Fig. 4). Moreover, on the sequence boundary, mutations often happened to the elemental abundance (e.g. in the bottom boundary of Sequence III, obvious mutations appeared in such elements as Be, V, Cr, and Co that reflect properties of ancient lacustrine waters). The analysis of sporopollen assemblage of the MH10 well also suggested differences among biological assemblages in boundaries of the three-order sequences. For example, the sporopollen fossils in the strata of Sequence II (Low Coal Member) are dominated by the assemblage of ***Ulmipollenites- Abietineaepollenites- Pinuspollenites-Quercoidites***, while those in the strata of Sequence III (Mudstone Member) are dominated by the assemblage of ***Ulmipollenites-Ulmoideipites-Quercoidites-Abietineaepollenites***, with clear boundaries between two three-order sequences.

The boundaries of system tracts (parasequence sets) are recognized mainly by the differences in rock particle size, mudstone color, sand-strata ratio, parasequence thickness, well logging curve amplitude, and organic geochemical characteristics [14]. Taking Sequence IV for example (Fig. 5), first, the LST uses the sequence boundary as its bottom boundary and uses the first flooded surface represented by dark mudstones, which are rich in organic matter, as its top boundary. The lithology has little overall change and is dominated by grey siltstones and sandstones with relatively coarse granularity. The spontaneous potential curve exhibits a finger combination of middle-high value, with little overall amplitude changes. This takes the superposition mode of the aggradational parasequence set. Second,

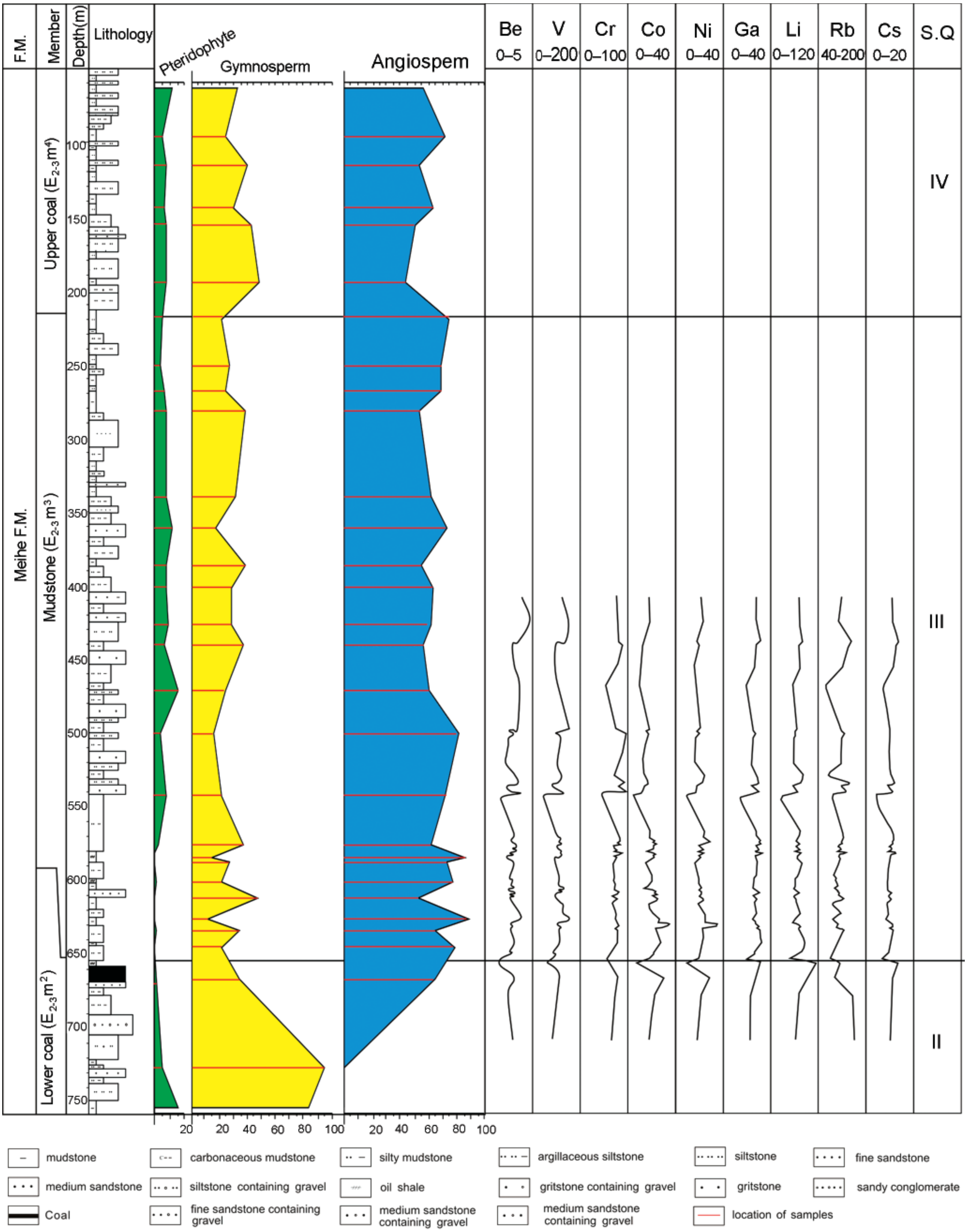


Fig. 4. Pollen and element geochemical response of sequence stratigraphy in Meihe Basin.

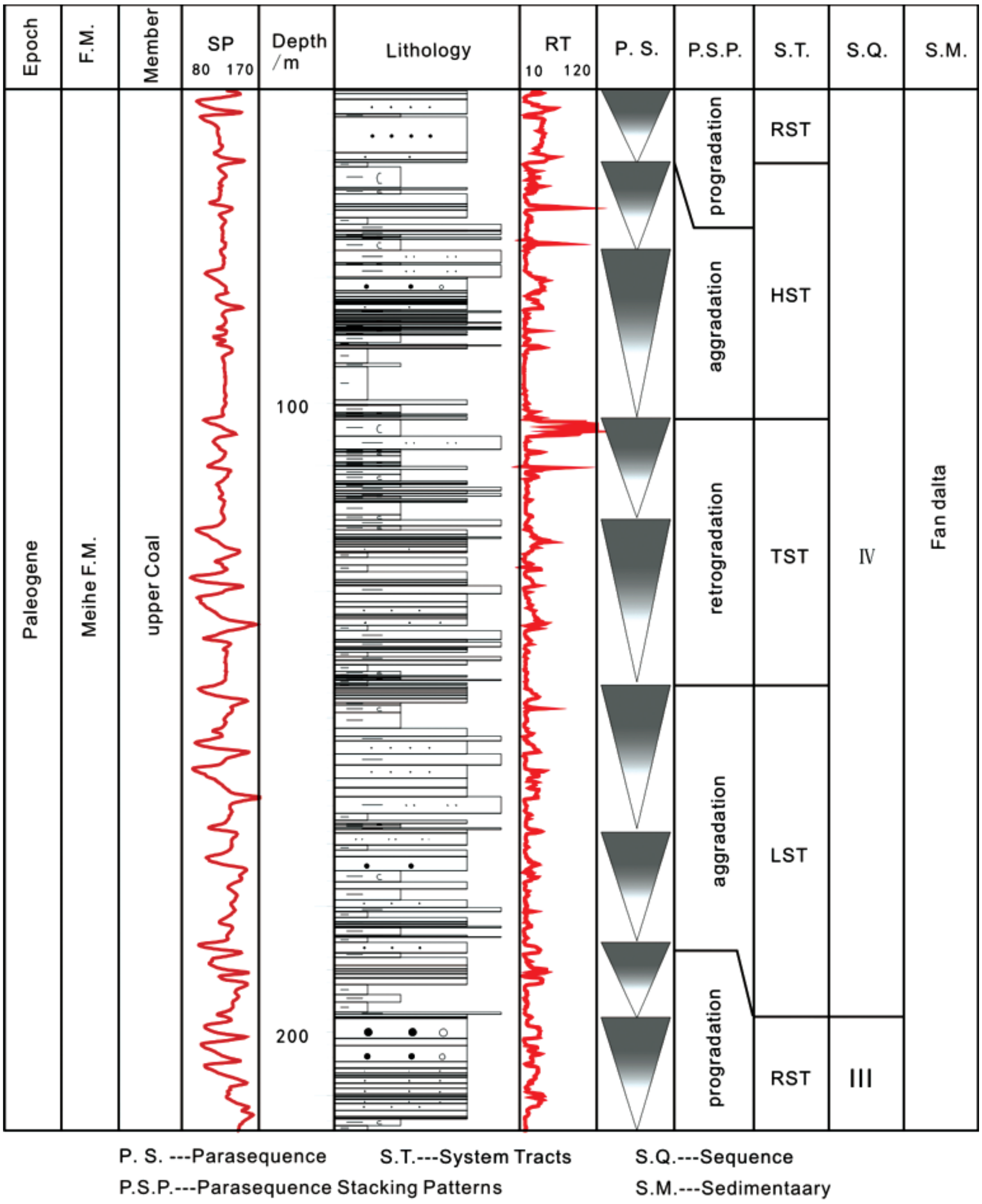


Fig. 5. System tract of sequence IV in Meihe Basin.

the TST uses the first flooded surface as its bottom boundary and uses the maximum flooded surface represented by dark mudstones with stable thickness and rich organic matter as its top boundary. The lithology is dominated by siltstones and mudstones, with the percentage of sandstone decreasing and granularity tapering. The natural potential curve exhibits a finger interaction combination of middle-low amplitude, with the overall amplitude reduced upwards. This takes the superposition mode of retrogradational parasequence set. Third, the HST uses the maximum flooded surface as its bottom boundary and uses the lacustrine regressive downlap surface as its top boundary. The lithology is dominated by mudstones, usually with developed oil shale strata. The natural potential curve exhibits a low-rising dentate, with a small overall amplitude variation. This takes the superposition mode of the aggradational parasequence set. Fourth, the RST uses the lacustrine regressive downlap surface as its bottom boundary and uses the sequence boundary as its top boundary. The lithology is dominated by sandstones and siltstones, with the granularity coarsening upwards. The natural potential curve exhibits a finger combination of middle-high amplitude, with the overall amplitude enlarging upward. This takes the superposition mode of the parasequence set.

Treating the flooded surface or the corresponding interface as its boundary, the parasequence has a set of sequences of relatively conformable rock or rock groups with a genetic relationship. In addition, it is the sedimentary combination of water change, manifesting as one order lower than the parasequence set [14]. Mostly, it has recorded the process where the water body suddenly deepens and gradually shallows. Due to its smaller thickness (usually from a few meters to 20 m), the parasequence cannot be recognized through conventional seismic data. Therefore, it is studied mainly through core data, outcrop data, and well logging data. This parasequence exhibits the lithology mutation surface of granularity suddenly thinning in terms of sediment granularity, and Sequence I and Sequence III have developed such typical parasequences. In Meihe Well 1, Sequence I mutated from varicolored sandy conglomerates to sedimentary grey silty mudstones or black mudstones (Fig. 6 a). Meanwhile, in the Meihe 2011-10 well, Sequence III mutated from grey white conglomeratic coarse sandstones to sedimentary black-grey mudstones or black-grey carbonaceous mudstones (Fig. 6 b). These boundaries all showed the characteristics of sudden transgression, representing the initiation of a new parasequence.

The parasequence can have a boundary that exhibits sudden deepening of the color of the fine-grained sediments, and some of these parasequences are found having developed in Sequence II of this area. For example, in Meihe Well 2, the dark gray silty mudstone directly overlies the grey siltstone (Fig. 6 c); and in Meihe Well 3, the black grey argillaceous siltstone directly overlies the dark gray mudstone and siltstone (Fig. 6 d). These boundaries are the results of a water body suddenly deepening and an improvement of the reduction degree of muddy sedimentary environments.

In addition, the bottom boundary of the oil shale can also be a parasequence boundary, such as the bottom boundary of the grayish-brown oil shale in Meihe Well 2 (Fig. 6-e) as well as the bottom boundary of dark grey oil shale and brownish-gray oil shale in the Meihe 2011-10 Well (Fig. 6 f). This is because the water suddenly deepened, thus accelerating biological death and organic matter accumulation.

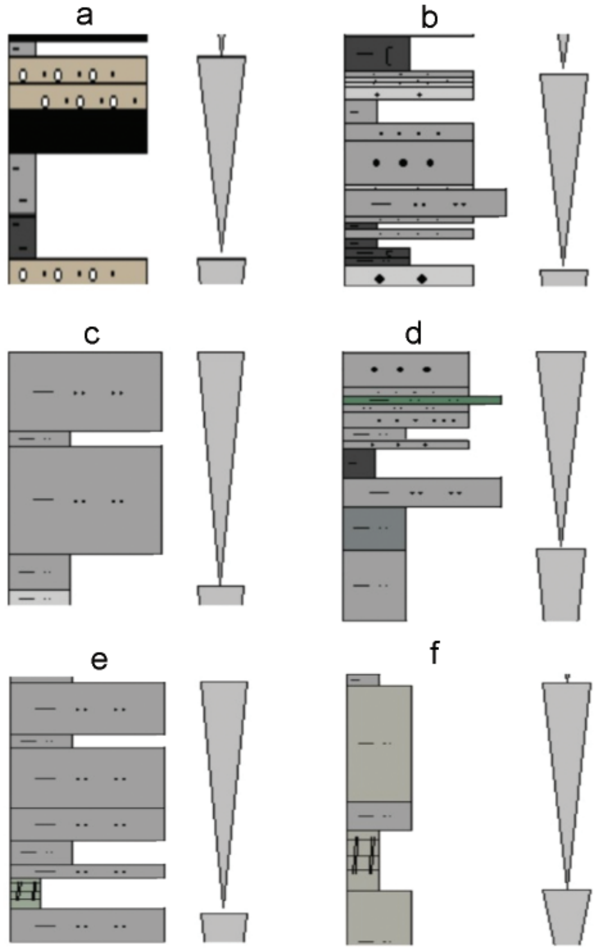


Fig. 6. Parasequences and recognition marks.

Mutation of fining-upward sequence: a – Sequence I of MHE1(Depth from710.0–738.0 m), b – Sequence III in Well 10 (Depth from 115.5–147.6 m); Mutation of the core colour: c – Sequence III of MHE02 (Depth from 233.8–254.2 m), d – Sequence II of MHE3 (Depth from 462.8–483.6 m); Oil shale layer bottom as the Parasequence boundary: e – Sequence II of MHE02 (Depth from 160.6–188.2 m), f – Sequence II of MHE10 (Depth from 562.7–594.5 m).

Sedimentary and sequence-stratigraphic characteristics of the meihe formation

Based on the observation of the total coring wells in the Meihe Basin, and combined with seismic data, well logging data, and geochemical testing data, we determined the developmental features for the sequences of the Meihe Formation in Meihe Basin and divided the Meihe Formation into five three-order sequences.

Here, Sequence I, which is roughly equivalent to the bottom conglomerate section, is a complete three-order sequence composed of the LST, TST, HST, and RST. The basin is in the initial stage of sedimentation. In addition, due to intensive tectonic movement, near provenance, and small scale, it in general comprises a set of coarse clastic sediments, mainly with developed sediments of alluvial fan, fan delta, and shallow lacustrine. As a whole, this reflects the sequence stratigraphic framework dominated by alluvial and fan-delta sediments of the basin in the initial rifting stage (Figs. 3 and 7).

Sequence II, roughly equivalent to the Low Coal Member, is composed of the LST, TST, and HST, with the RST missing. Since a supersequence boundary exists between Sequence II and Sequence III, there is an obvious

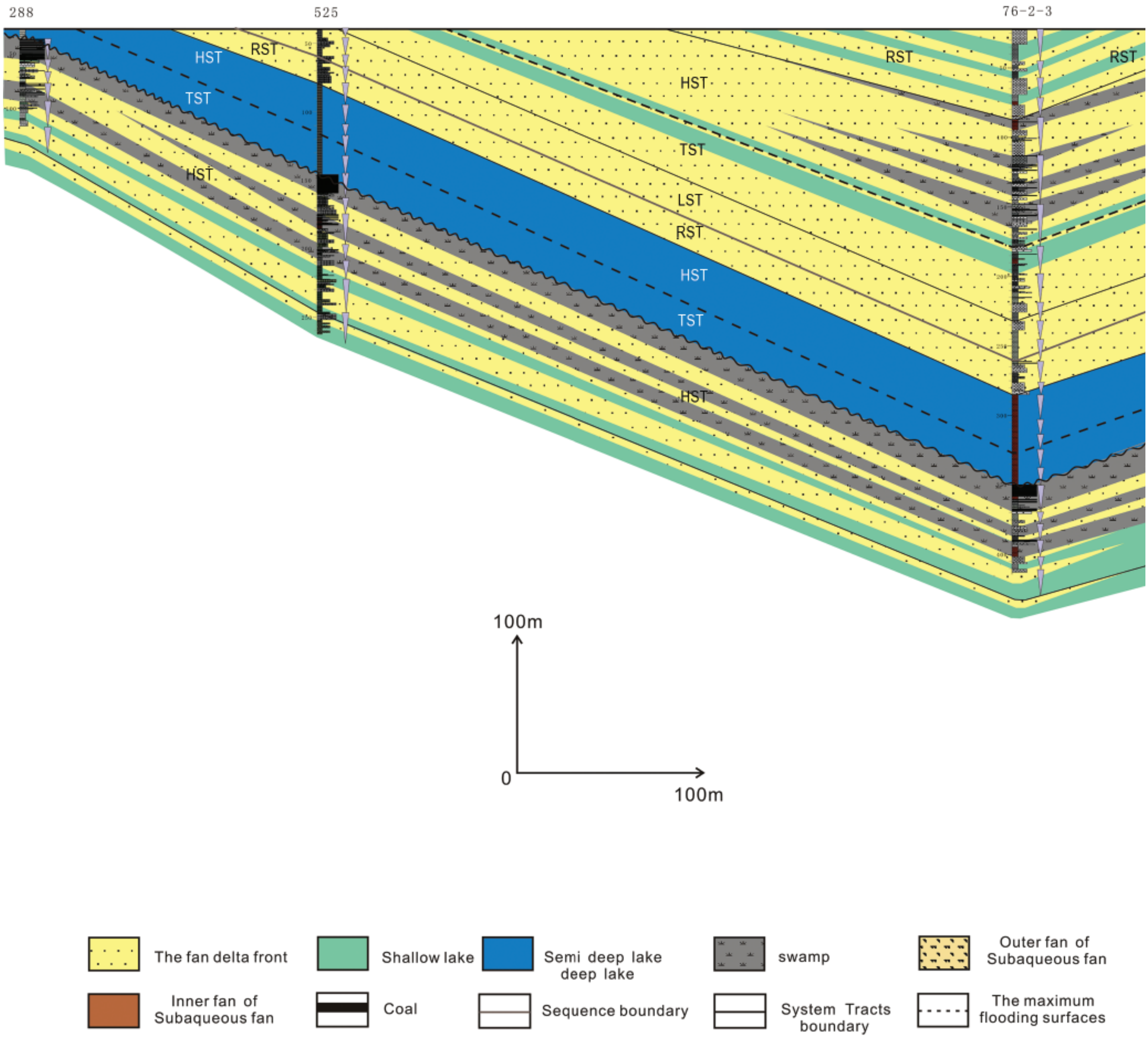
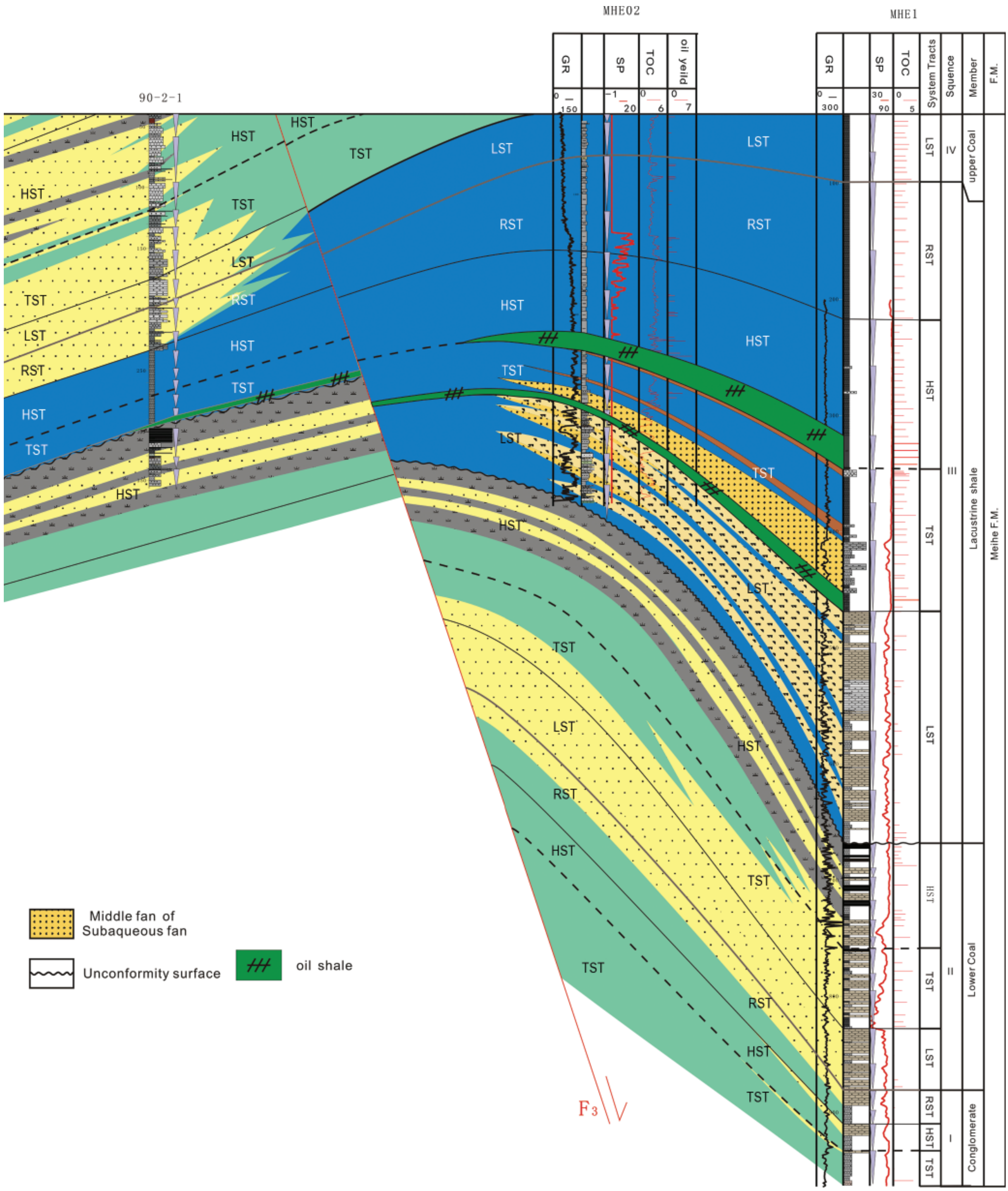


Fig. 7. Sequence stratigraphic framework correlation in Meihe Basin.


MHE02
MHE1
90-2-1
GR
SP
TOC
oil yeild
System Tracts
Squence
Member
F.M.
LST
RST
HST
TST
IV
III
II
I
upper Coal
Lacustrine shale
Lower Coal
Conglomerate
Meihe F.M.
F3
Middle fan of Subaqueous fan
Unconformity surface
oil shale

unconformity boundary between the two. The sedimentary environment mainly comprises alluvial fan, fan-delta, and lacustrine sediments. The LST has mainly developed a fan-delta sand body with coarser granularity. The TST is composed of fan-delta subaqueous distributary channels and inter-channels, with a thin coal seam developing in the upper part. The HST is mainly composed of limnetic sediments and fan-delta channel sediments in the early period, and is mainly composed of limnetic sediments and shallow lacustrine sediments in the late period. This sequence reflects the sequence stratigraphic framework dominated by sediments of fan delta, swamp, and shallow lacustrine for the basin in the rifting expansion stage (Fig. 7).

Sequence III, which is roughly equivalent to the Mudstone Member with local unconformable contact against the Low Coal Member, is a complete three-order sequence composed of a LST, TST, HST, and RST. In this sequence, both the tectonic sedimentation rate and growth rate of the accommodation space is at the maximum. The basin is in an undercompensated state, with the water depth continuously deepening until reaching the maximum expansion stage. The gentle slope side in the northwest of the basin lacks a LST, while the steep slope side in the southeast has a complete system of tracts. The sediment thickness shows obvious characteristics of being thin in the northwest and thick in the southeast. Sequence III has mainly developed sediments of fan delta, lacustrine, and subaqueous fan. The stable subaqueous fan sediment mainly developed in the LST and TST at the steep slope side of the basin. Meanwhile, the paroxysmal subaqueous fan sediment mainly developed in the front end of the fan delta of the TST. Sequence III reflects the sequence stratigraphic framework dominated by deep lacustrine sediment of the basin in the largest expansion stage (Figs. 7 and 8).

Sequence IV, which is equivalent to the upper coal-bearing section, is a complete sequence composed of the LST, TST, HST, and RST. It has mainly developed sediments of fan delta and lacustrine. Although the sediment thickness of the sequence is significantly larger, it shows characteristics of being thin in the northwest and thick in the southeast. Sequence IV overall reflects the sequence stratigraphic framework dominated by sediments of fan delta and lacustrine for the basin in the contraction stage (Fig. 7).

The Green shale Member corresponding to Sequence V has only developed locally, mainly with sediments of shore and shallow lacustrine, which has lower research value.

SEQUENCE AND SEDIMENTARY CONTROLLING ON OIL SHALE

The formation of sequence stratigraphic units of the continental fault basin is subject to structural factors, climatic factors, sediment supply, and lake level fluctuations [4, 5, 9, 10, 16, 20]. Through such combined effects of the above factors, different distribution rules of various sedimentary minerals in the framework of the evolving space-time have resulted.

Lacustrine oil shale has mainly developed in the TST and HST of Sequence III (Mudstone Member). In the TST, the subaqueous fan and semi-deep to deep lacustrine facies sediment dominate, and with the reduced scale of subaqueous fan, the sediment is mainly composed of deepwater dark mudstones, oil shale, and distal turbidites (Fig. 9). During this period, the basin accommodation space was much larger than the growth rate of the sediment, with retrograding sediments developed therein. Thus, during the flooding period, the effect of the terrigenous clastic on the lake was limited only to the edge of the basin without extending further in the direction of the basin, with a smaller amount of dilution. At the same time, the flooding effect usually occurred in the expansion stage of lacustrine basin development, and with mid-deep water and strong photosynthesis, the lake had higher productivity. During flooding, the water suddenly deepened, which promoted sudden changes in the lake water medium, leading to an acceleration of biological death and organismic accumulation. Due to the rapid accumulation, the previously deposited organic matters were rapidly buried without being oxidized. Therefore, the flooding effect could reduce the decomposition rate of organic matter, increase organic matter production, and reduce the dilution amount of oil shale, thus achieving very good organic matter enrichment conditions that often resulted in the formation of high quality oil shale. In the TST period of Sequence III of the Meihe Basin, the highest oil yeild of the oil shale was found as high as 11.40 %, but its thickness was very thin, only 0.3 m. In the HST period, the basin accommodation space was equal to the growth rate of the sediments, and the lake level and shoreline would not change much with time. In addition, the water body was relatively stable, usually developing semi-deep and deep lacustrine sediments, with larger accommodation space and good conditions for preservation of organic matter. In this period, due to the slow sedimentation rate and the little external dilution effect, organic matters in deep lacustrine sediment could be well preserved. Therefore, the enrichment organic matter was relatively high, making it easy for the stable oil shale of great thickness to develop. However, its oil yeild appeared relatively low compared with the TST, generally belonging to the low-grade oil shale. Meanwhile, the thickness is relatively stable and large. The Meihe Basin would be subjected to the serious effect of turbidity current in the HST period, and the oxygen brought in by the turbidity current would increase the decomposition rate of organic matter. Therefore, only

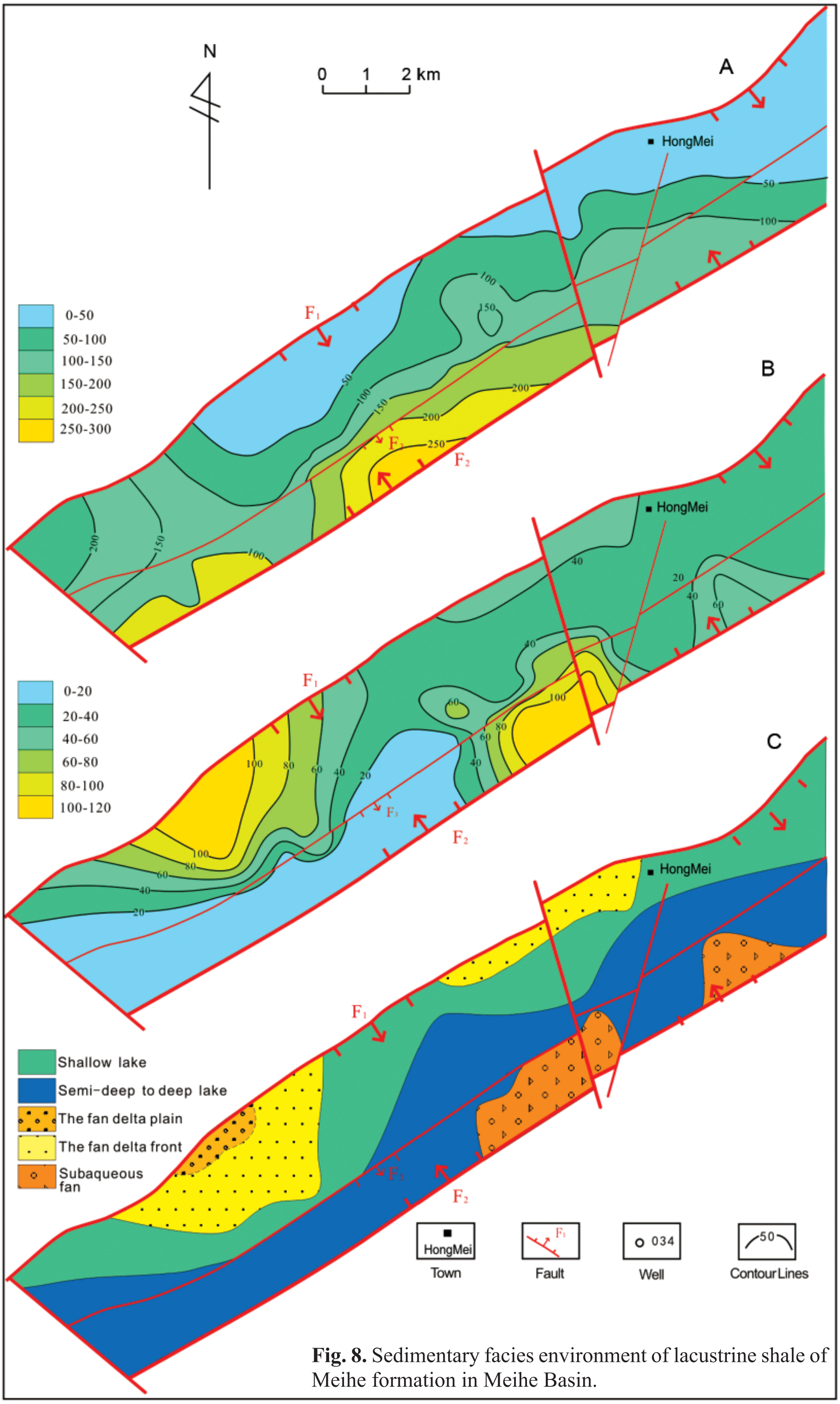


Fig. 8. Sedimentary facies environment of lacustrine shale of Meihe formation in Meihe Basin.

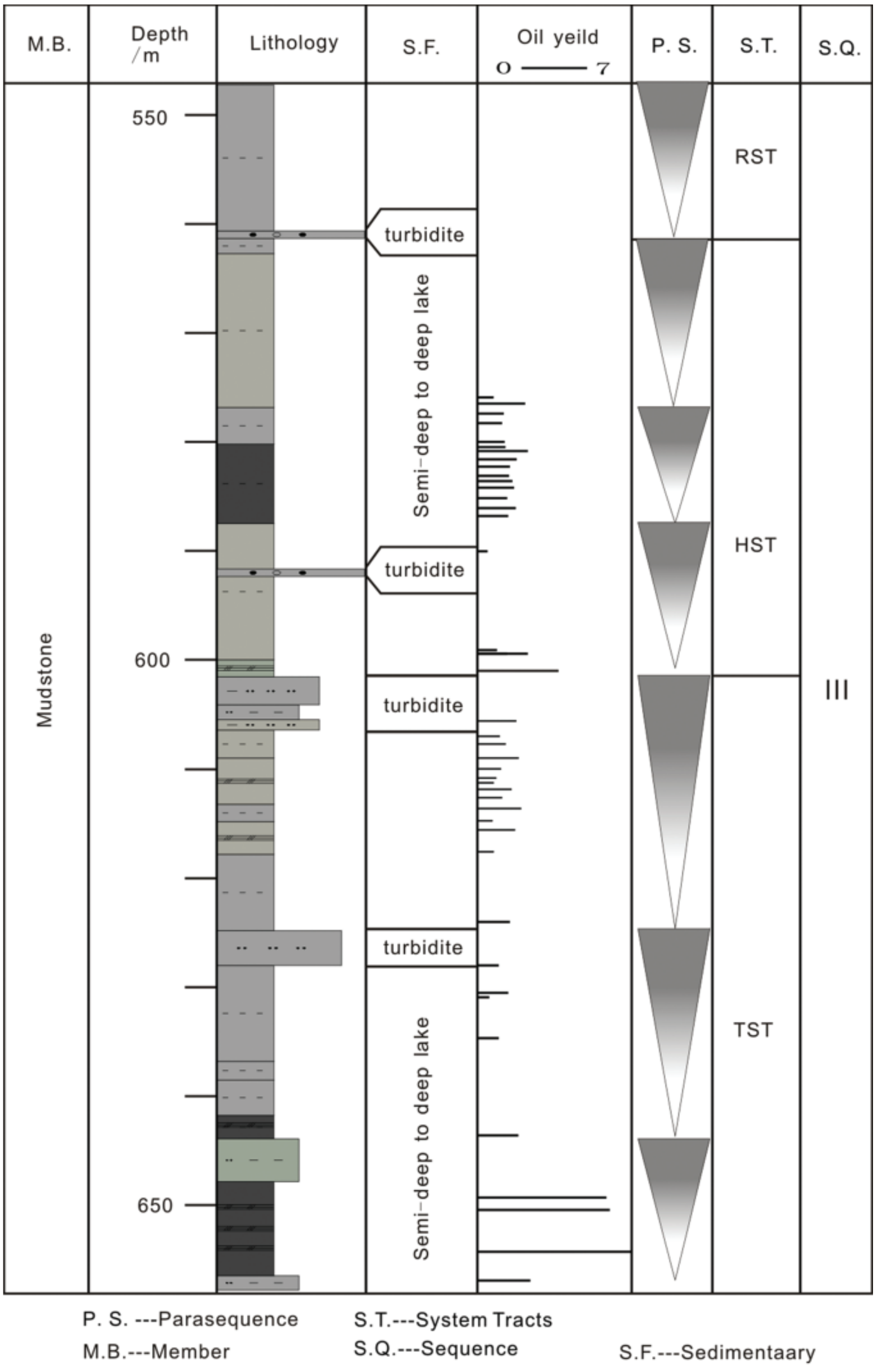


Fig. 9. Oil shale distribution of Sequence III in Meihe Basin.

the oil yeild of the horizons (MH1 and MH02) located in the center position of the basin could reach the industrial grade of oil shale (i.e. 3.5 %), and the test result showed that the oil yeild of the shale from other positions was below this industrial grade of 3.5 %.

CONCLUSION

(1) The Meihe Formation in the Meihe Basin has been recognized as five three-order sequences: Sequence I was formed in the initial rifting stage of the basin, dominated by coarse clastic sediments of alluvial fan and fan delta; Sequence II was formed in the rifting expansion stage of the basin, with much developed sediments of fan delta and lacustrine; Sequence III was formed in the maximum expansion stage of the basin, dominated by deep lacustrine mudstones and gravity flow sediments; and Sequence IV was formed in the shrinking stage of the basin, dominated by fan delta and lacustrine sediments.

(2) The Meihe Basin has been recognized as having sediments of alluvial fan, fan delta, limnetic facies, lacustrine facies, and subaqueous gravity flow, as well as oil shale mainly developed in semi-deep and deep lake environments of lacustrine facies.

(3) Oil shale mainly developed in the TST and HST of Sequence III (Mudstone Member). The flooding effect of the TST could reduce the decomposition rate of organic matter, increase organic matter production and reduce the dilution amount of oil shale. Thus, this could achieve very good enrichment conditions for organic matter, which could result in the formation of high quality oil shale. During the period of the HST, the large accommodation space and good conditions for organic matter preservation were conductive to the development of stable oil shale with greater thickness. However, in this period, the oxygen brought in by turbidites would often increase the decomposition of organic matter, thus forming oil shale of poor quality.

ACKNOWLEDGEMENT

We would like to thank Dr. Song Wei (Manager of Meihe Coal Mines) and Mr. Li Dexiang (also in Meihe Coal Mines) for field work support. Cores MH2 and MH3 were generously provided by the Royal Dutch Shell plc to Jilin University.

This study was supported by the National Natural Science Foundation of China (41302097), National Potential Oil-Gas Resources (Oil Shale Exploration and Utilization), Cooperation and Innovation Construction Project for Production and Research (OSP/OSR-01), the special research project of public service sectors of the Ministry of Land (1A12ZL20121105104), Cutting-edge Science Interdisciplinary Innovation Project of Jilin University (200903035), Seed Funding Project of Jilin University, and Funding Project of Jilin province technology & development plan (Youth Research Fund) (20090167).

REFERENCES

1. Bohacs K M, Carroll A R, Neal J E, et al. Lake-basin type,source potential, and hydrocarbon character: An integrated sequence-stratigraphic geochemical framework[J]. AAPG Studies in Geology, 2000, 46: 3–34.
2. Bohacs K M. Source quality variations tied to sequence development in the Monterey and associated formations, south western California[J]. AAPG Studies in Geology, 1993, 37:177–204.
3. Creaney S, Passey Q R. Recurring patterns of total organic carbon and source rock quality within a sequence straitigraphic framework[J]. AAPG Bulletin, 1993, 77(3): 386–401.
4. Eschard R,Lemouzy P, Bacchiuna,et al. Combining sequence stratigraphy, geostatistical simulations and production data for modeling a fluvial reservoir in the chauchoy field (Triassic ,France)[J].AAPG Bulletin,1998,82(4):545–568.
5. Guo Jianhua, Gong Shaobo, Wu Dongsheng, Sedimentary Sequence of the T–R Cycle and A Studied Example in the Continental Fault Lacustrine Basin[J], Acta Sedimentologica Sinica,1998,16(1):8–13. [In Chinese, summary in English].
6. Hao Fang, Chen Jianyu, Organic Facies Compositions of Sequences and Systems Tracts and Its Studying Significances[J], Geological Science and Technology Information, 1995, 14(3): 79-83 [in Chinese, summary in English].
7. Hu Shanting, Jing Huilin, Wu Keping, Wang Liwei. The Depositional Systems and D epositional System Tracts in Meihe Basin[J].Coal Geology & Exploration, 1996, 24(3):4–5. [in Chinese, summary in English].
8. Hu Shanting, Kang Xidong, Wu Keping, et al. Sedimentary coal accumulating environment of Meihe Basin[J]. Coal Geology of China, 1996, 8(2): 13–15. [in Chinese, summary in English].
9. Ji Faliang, Continental Fault Basin of Sequence Stratigraphy [M].Beijing: Petroleum industry press,1996. 1~74. [In Chinese]
10. Keith W Shanely, Peter J McCabe. Perspective on the sequence stratigraphy of continental strata[J].AAPG Bulletin,1994,78(4): 544–568.
11. Liu Rong. Research on Oil shale Characteristics and Metallogenic Mechanism of Cenozoic Fault Basins in Eastern Northeast Region, Doctoral Dissertation,2007, 1–40.[in Chinese]
12. Liu Zhaojun, Liu Rong. Oil shale resource state and evaluating system[J]. Earth Science Frontiers , 2005 , 12(3):315–323 [in Chinese, summary in English]
13. Liu Zhaojun，Cheng Rihui，Yi Haiyong． Continental Basin Seismic Sequence Stratigraphy of the Kailu Basin，China ［C］// International Symposium on Deep and Regional Geophysics and Geology． Changchun: Jilin University，1994: 46–47．
14. Liu Zhaojun，Dong Qingshui，Wang Simin，et al. Introduction and Application of Continental Sequence Stratigraphy ［M］. Beijing: Petroleum Industry Press，2002． [In Chinese].
15. Mann U, Stein R. Organic facies variations, source rock potential and sea level changes in Cretaceous Black Shales of the Quebrada Ocal, Upper Magdalena Valley, Colombia [J]. AAPG Bulletin, 1997, 81(4): 556–576.
16. Moyo T, Steel R J. The Middle Jurassic Oserberg Delta, Northern Sea: a sedimentological and sequence stratigraphic Interpretation[J].AAPG, Bulletin,1997,81(7):1070–1086.
17. Passey Q R, Creaney S, Kulla J B, et al. A practical model for organic richness from porosity and resistivity logs[J].AAPG Bulletin, 1990, 74(12): 1777–1794.
18. Peters K E, Snedden J W, Sulaeman A, et al. A new geochemica-l sequence stratigraphic model for the Mahakam delta and Makassar slope, Kalimantan, Indonesia[J]. AAPG Bulletin, 2000, 84(1): 3–34.
19. Pingchang Sun, Reinhard F. Sachsenhofer, Zhaojun Liu, Susanne A.I.Strobl, Qingtao Meng, Rong Liu, Zhen Zhen. Organic matter accumulation in the oil shale- and coal-bearing Huadian Basin(Eocene; NE China）,International Journal of Coal Geology, 105（2013：1–15.
20. Strecker Uwe, Stridtmann J R, Smithson. A conceptual tectonostratigraphic model for seismic facies migration in a fluvio-lacustrine extensional basion[J]. AAPG Bulletin, 1999, 83(1):43–61.
21. Sun Xiaomeng, Wang Shuqin, Wang Yingde, et al. The structural feature and evolutionary series in the northern segment of Tancheng-Lujiang fault zone[J]. Acta Petrologica Sinica, 2010,

26(1): 165–176. [in Chinese, summary in English]
22. Thomas,L.Davis:Seismic faeies analysis: pitfalls and applications in cratonic basins, Geophysies: The leading edge of exploration,1987.
23. Van Wagoner. et al. Silicilastic sequnece stratigraphy in well logs.cores.and outcrops：Concepts for high~resolution corrlelation of time and facies[J]. AAPG Mehtods in Exploration Series，1990, No. 7.
24. Wang Feng, Li Huijie and Wang Dequan. Meihe Basin Coal-accumulating Paleostructure Analysis[J]. Coal Geology of China, 2008, 20(7): 13–15. [in Chinese, summary in English]
25. Wignall P B, Maynard J R. The sequence stratigraphy of transgressive black shales[J]. AAPG Studies in Geology,1993, 37: 35–48.
26. Wu Keping, Liu Yingxin, Ji Baoze, et al. Sedimentary coal accumulating environment and prospecting coal prospect of Meihe Basin[J].Jilin Geology, 2008, 27(3):24–29. [in Chinese, summary in English].
27. Zhang Jian, Liu Zhaojun, DU Jiang-feng, Liu Rong, Wang Weitao, Liu Shiyou, Jing Baoze, Sedimentary Characteristics of the Oil Shale in the Paleogene Dalianhe Formation in the Yilan Basin, Heilongjiang Province[J], Journal of Jilin University(Earth Science Edition), 2006, 36(6) :980–985 [in Chinese, summary in English].
28. Zhu Jianwei, Liu Zhaojun, Liu Kui, Dong Qingshui,Guo Wei,Wang Simin, Application of Geophysical Data Processing Technique in Sequence Stratigraphy[J], World Geology, 2001, 20(3): 300–306. [In Chinese, summary in English].

Рекомендована к печати Г.Л. Кирилловой

Жун Лю, Чжаоцзюнь Лю, Сяофэн Ху, Пинчан Сунь, Юэюйэ Бай, Чао Чжан

Палеогеновые секвенсы с осадочными характеристиками, контролирующими озерные горючие сланцы бассейна Мэйхэ

Бассейн Мэйхэ – типичный кайнозойский приразломный бассейн. Разрез подразделен на пять последовательностей третьего порядка по данным керна, каротажа скважин, сейсмического изучения, а также палеонтологических и геохимических исследований. Полевые исследования разрезов, изучение керна и всесторонний анализ выявили, что бассейн сложен в основном отложениями аллювиального конуса выноса, дельтового конуса выноса, озерной фации и гравитационного течения. Горючие сланцы развиты в основном в обстановках глубокого и полуглубокого озера. Всесторонний анализ секвенсстратиграфии осадков свидетельствует, что последовательность I образовалась на начальной стадии рифтообразования бассейна, когда преобладали крупнозернистые кластогенные осадки аллювиального и дельтового конусов выноса. Последовательность II формировалась на стадии расширения бассейна с более распространенными осадками дельтового конуса выноса и озерной фации. Последовательность III образовалась на стадии самого большого расширения бассейна с доминированием аргиллитов глубоководной озерной фации и отложений гравитационных потоков. Последовательность IV образовалась в стадию оседания бассейна. В ней преобладали осадки дельтового конуса выноса и озерные. Горючие сланцы развиты в основном в трансгрессивном фациальном ряду (TS) и системе высокого стояния уровня моря (HST) секвенса III (аргиллитовая пачка озерной фации). Эффект повышения уровня воды в озере в трансгрессивном фациальном ряду может привести к уменьшению количества разложения органического вещества, увеличению образования органического вещества и уменьшению раствора, образуя таким образом горючий сланец слабой консистенции, но высокого качества. В период высокого стояния условия большего пространства аккомодации и отличная сохранность органического вещества являются благоприятными для образования стабильного горючего сланца с лучшей консистенцией. В период высокого уровня стояния воды, однако, благодаря привнесению турбидитами кислорода разложение органического вещества часто повышенное, что приводит к образованию горючих сланцев низкого качества.

Ключевые слова: **бассейн Мэйхэ, горючие сланцы, секвенсы, седиментация.**