Oil Shale, 2016, Vol. 33, No. 3, pp. 203–215 ISSN 0208-189X
doi: 10.3176/oil.2016.3.01

ACCUMULATION STAGES AND EVOLUTION CHARACTERISTICS OF OIL SHALE AND COAL IN THE DUNHUA-MISHAN FAULT ZONE, NORTHEAST CHINA

PINGCHANG SUN[(a)*], ZHAOJUN LIU[(a)], YUEYUE BAI[(a)], YINBO XU[(b)], RONG LIU[(a)], QINGTAO MENG[(a)], FEI HU[(a)]

[(a)] Key-Laboratory for Oil Shale and Coexisting Minerals Mineralization, Exploration and Exploitation, College of Earth Sciences, Jilin University, Changchun 130061, China
[(b)] Oil & Gas Survey, CGS, Beijing, 100029, China

Abstract. *Several coal- and oil shale-bearing basins are distributed in the Dunhua-Mishan Fault Zone in Northeast China, while there are certain differences in sedimentary association and occurrence characteristics between the deposited rocks. Based on the results of previous research on stratigraphic correlation, the depositional age of sediments in the Fushun Basin is the Paleogene-Eocene, in the Huadian Basin it is the Eocene-Oligocene, and in the Meihe Basin, the Eocene-Early Oligocene. In the Fushun Basin, huge thick coal seams were formed in the Guchengzi Formation, thick low-quality oil shale layers were distributed in the lower part of the Jijuntun Formation and thick high-quality oil shale layers were developed in the Upper Jijuntun Formation. In the Meihe Formation of the Meihe Basin, coal seams were deposited in both the Lower Coal-bearing Member and the Upper Coal-bearing Member, while oil shale layers were formed in the Middle Mudstone Member. In the Huadian Basin, thin high-quality oil shale layers were deposited in the Oil Shale Member and thin coal seams were accumulated in the Carbonaceous Shale Member. Thick coal seams were mainly deposited in the swamp with abundant land plant supply during the initial tectonic subsidence stage of the Dunhua-Mishan Fault Zone in the warm and humid paleoclimate. Relatively high-quality oil shale layers were all formed in the deep lake during the maximum tectonic subsidence evolution stages of these three basins, and the organic matter sourced from algae. Oil shale in the Fushun and Meihe basins was deposited in the warm and humid paloeoclimate, while in the Huadian Basin the climate varied from wet to dry. Investigation showed the Dunhua-Mishan Fault Zone to have gone through two coal-forming stages and one oil shale-forming stage. Coal seams in the Fushun Basin and the lower part of the Meihe Basin accumulated in the Ypresian stage, while those in the Huadian Basin and the*

* Corresponding author: e-mail *sunpingchang711@126.com*

upper part of the Meihe Basin were deposited in the Bartonian-Priabonian stage. In contrast, oil shale layers in these three basins were all mineralized in the Lutetian stage.

Keywords: *Dunhua-Mishan Fault Zone, coal-bearing basin, oil shale-bearing basin, metallogenic stage, Paleogene.*

1. Introduction

The Dunhua-Mishan Fault Zone is the northern segment of the Tancheng-Lujiang Fault Zone in Northeast China, which formed a series of graben basins that deposited energy minerals oil shale and coal [1]. There exist distinct differences in sedimentary association, depositional stages and occurrence characteristics between the coal-bearing and oil shale-bearing layers in these graben basins. Cui and Liu [2] studied the metallogenic regularities of energy minerals in the Dunhua-Mishan Fault Zone and suggested that oil shale- and coal-bearing layers were deposited almost simultaneously with no definite beginning and end of the deposition time. This study has selected three typical basins – the Fushun Basin, the Meihe Basin and the Huadian Basin – to analyze their accumulation stages and the evolutionary characteristics of oil shale and coal on the basis of previous research results.

2. Geological setting

2.1. Tectonic characteristics

The Dunhua-Mishan Fault Zone stretches south of the city of Shenyang, passing through Fushun, Meihe, Huadian and Dunhua cities to the northeast of Mishan and Hutou cities, and finally extending into Russia across the Wusuli River (Fig. 1), with the general trend of 50° NE and the total length of 900 km. Similarly to the Tancheng-Lujiang Fault Zone, the Dunhua-Mishan Fault Zone is a strike-slip fault zone. Based on the deformation features of the northern segment of the Tancheng-Lujiang Fault Zone during various geologic stages in the Mesozoic to Cenozoic, the tectonic evolution can be subdivided into the following stages: 1) the left-lateral strike-slip ductile shear stage (the last stage of J_2, Middle Jurassic), 2) the left-lateral tenso-shear stage (the earlier-mid period of K_1, Lower Cretaceous), 3) the right-lateral compression shear stage (the later period to the last stage of K_2, Upper Cretaceous), 4) the right-lateral strike-slip fault depression stage (E, Paleogene) and 5) the structural inversion stage (the end of E_3, Oligocene) [3]. The Paleogene sedimentary evolution of Fushun, Meihe and Huadian basins was mainly controlled by the right-lateral strike-slip fault depression and structural inversion stages.

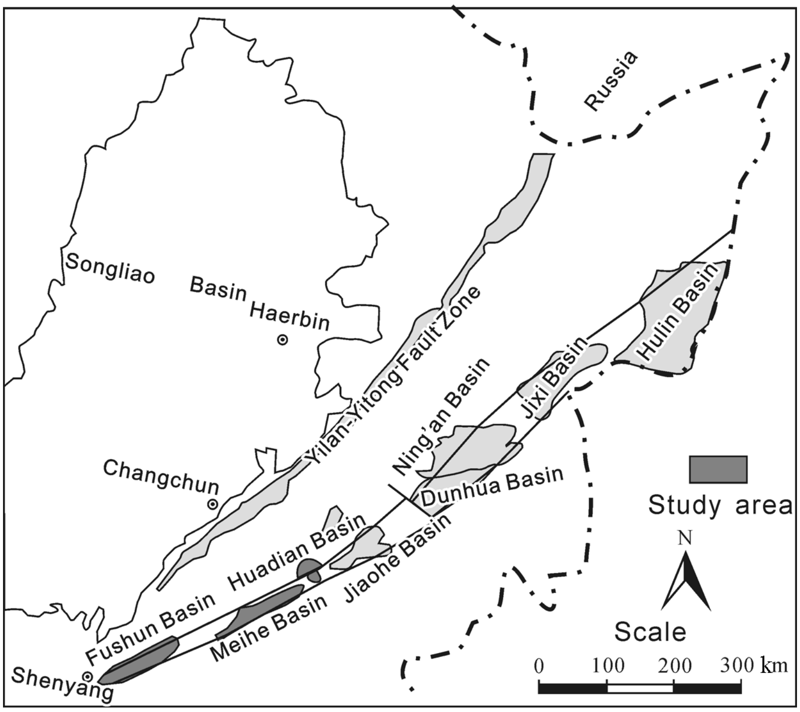

Fig. 1. The distribution of coal- and oil shale-bearing basins in the Dunhua-Misha Fault Zone (according to [1]).

2.2. Lithostratigraphy

The Paleogene strata in the Fushun Basin from bottom to top can be further divided into the Laohutai, Lizigou, Guchengzi, Jijuntun and Xiloutian formations [4]. Whereas the Paleogene Meihe Formation in the Meihe Basin consists of the Conglomerate Member, the Lower Coal-bearing Member, the Mudstone Member, the Upper Coal-bearing Member and the Green Mudstone Member [5], the Paleogene Huadian Formation in the Huadian Basin is subdivided from bottom to top into three members: the Pyrite Member, the Oil Shale Member and the Carbonaceous Shale Member [6].

3. Age of oil shale formations

The stratigraphic correlation between the main sedimentary strata of basins in the Dunhua-Mishan Fault Zone has been carried out (Fig. 2). As a whole, the sediments in this zone were mainly formed in the Paleogene whereas the exact depositional age of each basin needs to be further studied. Sediments in the Fushun Basin were formed earliest and its basalt age indicated the evolution time of 66 Ma, while the pollen record showed its sedimentation

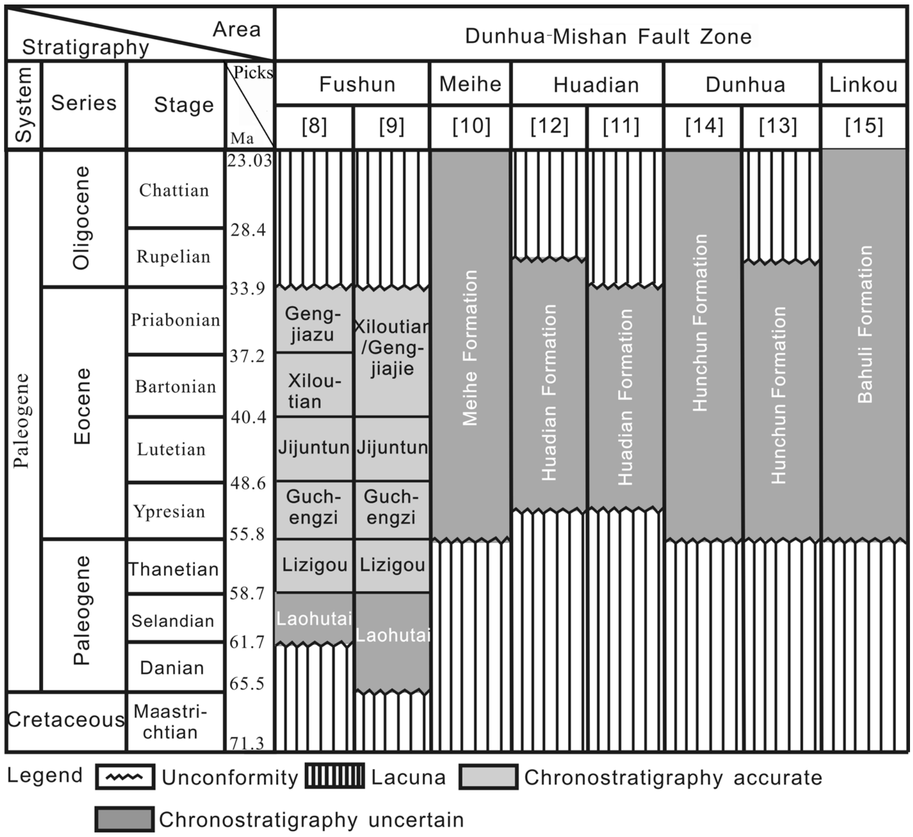

Fig. 2. Stratigraphic correlation in the basins in the Dunhua-Mishan Fault Zone.

age to be the Selandian and the end age the Priabonian [7–9]. As a result, the depositional age of the Fushun Basin is considered to be the Paleogene to Eocene. The stratum combination and pollen records of sediments in the Meihe Basin indicated its deposition during the Eocene to Oligocene sedimentary stage [10]. As to the Huadian Basin, there exist two viewpoints. Zhang et al. [11] have pointed out that sediments in the Huadian Basin were deposited in the Eocene, while Meng [12] has found out that sediments in the Huadian Basin were accumulated in the Eocene to Early Oligocene, based on pollen records. Sediments in the Duhua and Linkou basins have the same depositional age, the Eocene-Oligocene [13–15], and the basalt age of samples from the Upper Hunchun Formation in the Dunhua Basin indicated the age of about 30 Ma [13], which points to the terminal stage of the Middle Rupelian.

4. Occurrence of oil shale and coal

4.1. Fushun Basin

Coal seams in the Fushun Basin were mainly formed in the Paleogene Laohutai, Lizigou and Guchengzi formations (Fig. 3). Sediments in the Laohutai Formation consist predominantly of basalt, tuff, carbonaceous shale and coal seams, and coal seams are usually arranged in a honeycomb style with a limited distribution. Sediments in the Lizigou Formation are chiefly composed of tuffaceous shale, sandstone, tuff and thin coal seams of one or two layers with a limited distribution. Thick coal seams are mainly distributed in the Guchengzi Formation, their total thickness may reach 195 m. The TOC content of coal seams ranges from 54 to 83 wt%, the ash content is very low (Table 1) and the HI value is 222–413 mg HC/g TOC. The mineral part of coal is dominated by kaolinite (K), andreattite (I/S), illite (I) and quartz (Q) (Table 2). Oil shale is mainly deposited in the Jijuntun

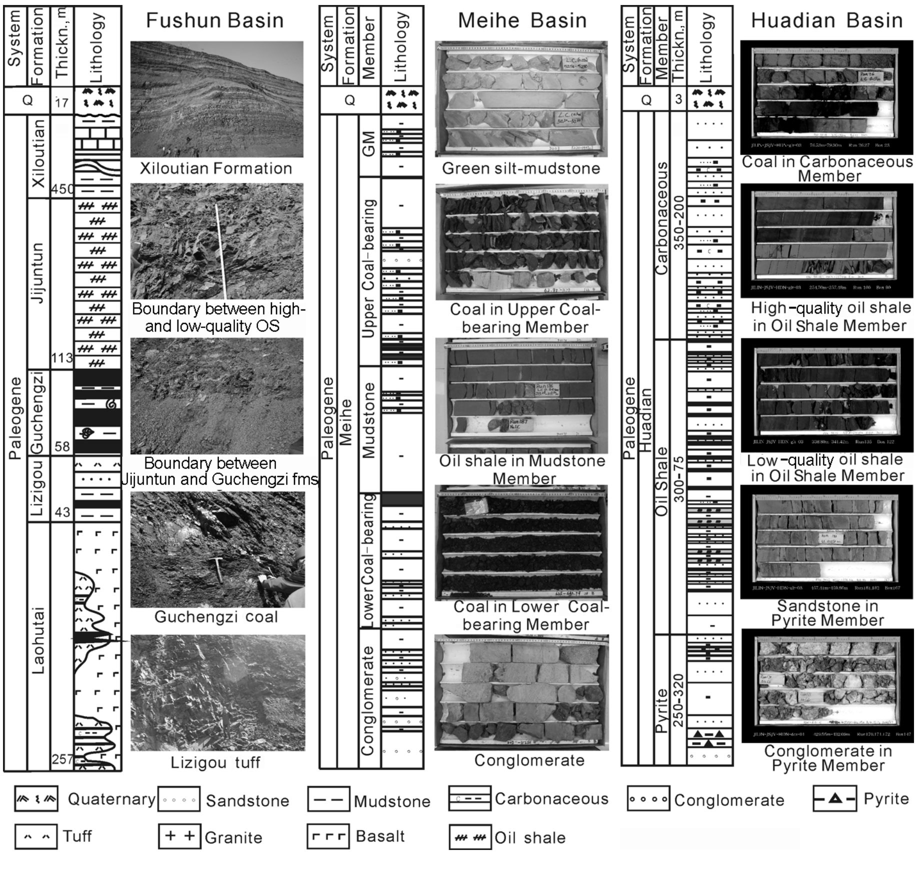

Fig. 3. The basin filling characteristics of Fushun, Meihe and Huadian basins. (Abbreviations used: Q – Quaternary, OS – oil shale, fms. – formations, GM – Green Mudstone, Thickn. – Thickness.)

Table 1. Geochemical characteristics of oil shale and coal in Fushun, Meihe and Huadian basins

Basin		Fushun	Meihe	Huadian
Coal	Occurrence layer	Guchengzi Fm.	Meihe Fm. (Lower Coal-bearing Mb. and Upper Coal-bearing Mb.)	Huadian Fm. (Carbonaceous Mb.)
	Thickness, m	39–195	5–64	1.8–2.9
	TOC, wt%	54–83	50–79.4	42.5–68.3
	S_2, mg HC/g TOC	150.7–265.2	134.2–246.9	84.3–189.4
	HI, mg HC/g TOC	222–413	246–353	161–251
	T_{max}, °C	416–426	425–431	425–431
	Ash content, wt%	2.4–31.7	3.6–40	28.6–36.8
Oil shale	Occurrence layer	Jijuntun Fm.	Meihe Fm. (Mudstone Mb.)	Huadian Fm. (Oil Shale Mb.)
	Thickness, m	60.0–162.2	10–20	2.5–22.3
	TOC, wt%	6.2–23.6	6.6–25.3	6.5–31.7
	Oil yield, wt%	3.5–14.7	3.5–11.4	3.5–25.0
	S_2, mg HC/g TOC	22.8–147.8	25.34–118.2	28.5–235.7
	HI, mg HC/g TOC	378–699	271–566	299–744
	T_{max}, °C	429–445	421–438	425–441
	Ash content, wt%	89.3–66.1	88.7–69.1	85.2–53.0

Abbreviations used: Fm. – Formation, Mb. – Member.

Table 2. Mineral composition of oil shale and coal in Fushun, Meihe and Huadian basins, %

Basin		K	S	I/S	I	Q	Fs	PI	Sid	Py	Cc	DoI
Fushun	Coal	11–22	–	8–14	5–7	19–43	5–7	1–3	4–7	1–2	–	–
	Oil shale	4–20	–	11–21	3–10	30–65	4–6	1–5	3–9	1–2	6–16	1–14
Meihe	Coal	7–14	–	7–14	17–30	3–7	3–6	3–6	1–4	1–3	–	–
	Oil shale	18–35	–	10–17	21–30	25–35	2–7	2–9	2–5	1–2	1–3	1–5
Huadian	Coal	7–14	20–49	–	7–14	10–40	2–5	2–6	–	2–3	8–16	–
	Oil shale	10–37	23–36	–	8–17	26–56	2–4	2–6	–	1–7	3–27	–

Symbols used: K – kaolinite, S – smectite, I/S – andreattite, I – illite, Q – quartz, Fs – potassium feldspar, PI – plagioclase, Sid – siderite, Py – pyrite, Cc – calcite, DoI – dolomite.

Formation. The low-quality light brown oil shale is usually distributed in the lower part of the formation with a total thickness of 28 m and oil yield 3.5–6.0 wt%, whereas the high-quality oil shale is primarily accumulated in the formation's upper part with a total thickness of 88 m and oil yield higher than 6.0 wt% [1]. The maximum TOC content of oil shale may reach 23.6 wt% and oil yield 14.7 wt%. Oil shale has the HI value of 378–699 mg HC/g TOC, which is much higher than that of coal seams. In contrast to coal seams, the relatively low TOC content of oil shale has caused its relatively high ash content, 66.1–89.3 wt% (Table 1). Quartz predominates in oil shale, followed by clay minerals kaolinite, andreattite and illite. Calcite (Cc) and dolomite (DoI) are also present in oil shale (Table 2). The overlying formation is the Xiloutian (Genjiajie) Formation, whose sediments are mainly gray calcareous shale interlayered with light gray marlstone.

4.2. Meihe Basin

The Paleogene Meihe Formation is the main sedimentary stratum of the Meihe Basin (Fig. 3). The bottom Conglomerate Member consists predominantly of a series of thick beds of conglomerate, sandy conglomerate and greywacke. Coal seams mostly occur in the Lower Coal-bearing Member and the Upper Coal-bearing Member, being in the former present as thick coal seams (max 79.4 m) interlain with coarse sandstones, and in the latter as thin coal seams interlain with fine sandstones [16]. The TOC content of coal seams is between 50 and 79.4 wt%, the ash content ranges from 3.6 to 40 wt%. The HI value of Meihe coal seams is similar to that of Fushun coal. At the same time, Meihe coal contains much more illite. Oil shale is mainly deposited in the Mudstone Member, its oil yield is 3.5–11.4 wt% and the total thickness 10–20 m, which is much less than that in the Fushun Basin [17]. The HI value of oil shale in the Meihe Basin is a little lower than Fushun oil shale's. Compared to the Fushun Basin, clay minerals in Meihe oil shale and coal are present in lower quantities, however, the quartz content of oil shale is much higher (Table 2). The Green Mudstone Member is overlain by the Upper Coal-bearing Member and the main sediments are green siltstone and fine sandstone.

4.3. Huadian Basin

The Huadian Basin is filled by the non-marine Huadian Formation (Fig. 3). Sediments of the Pyrite Member are mainly varicolored conglomerate, sandstone, purplish-red mudstone and thin carbonaceous shale. Oil shale of high quality (usually 8–12 wt%) is deposited in the Oil Shale Member and the oil yield can reach max 25 wt%. The thickness of a single layer is only 0.7–3.8 m and the total thickness 2.5–22.3 m (Table 1). The distinguished differences in TOC and S_2 content between different oil shale layers in the basin have led to the HI value of very wide range. A lot of sandy stripes are contained in the oil shale-bearing layer [18]. The Carbonaceous Shale Member is the layer that deposited the main coal seams with other sediments such as fine siltstone and grayish-green mudstone. Coal seams are mostly thin with a thickness less than 1 m in only 3–5 layers. Coal seams in the Huadian Basin are less abundant in organic matter and richer in ash than those in the Huadian and Fushun basins (Table 1). In contrast to the Fushun Basin, coal seams and oil shale in the Huadian Basin are rich in clay minerals smectite (S) and illite and lack andreattite (Table 2).

Finally, the T_{max} values in the investigated three basins indicate that oil shale and coal seams are thermally immature to marginally mature (Table 1).

5. Environments and evolution characteristics of oil shale and coal accumulation

Combining stratigraphic correlation and rock association, we conclude that there existed two coal-forming stages and one oil shale-forming stage in the Dunhua-Mishan Fault Zone (Fig. 4).

Based on the sporopollen combination, primary clay mineral type and inorganic geochemical data, coal seams in the Guchengzi Formation of the Fushun Basin were deposited in the warm and humid paleoclimate [4, 7].

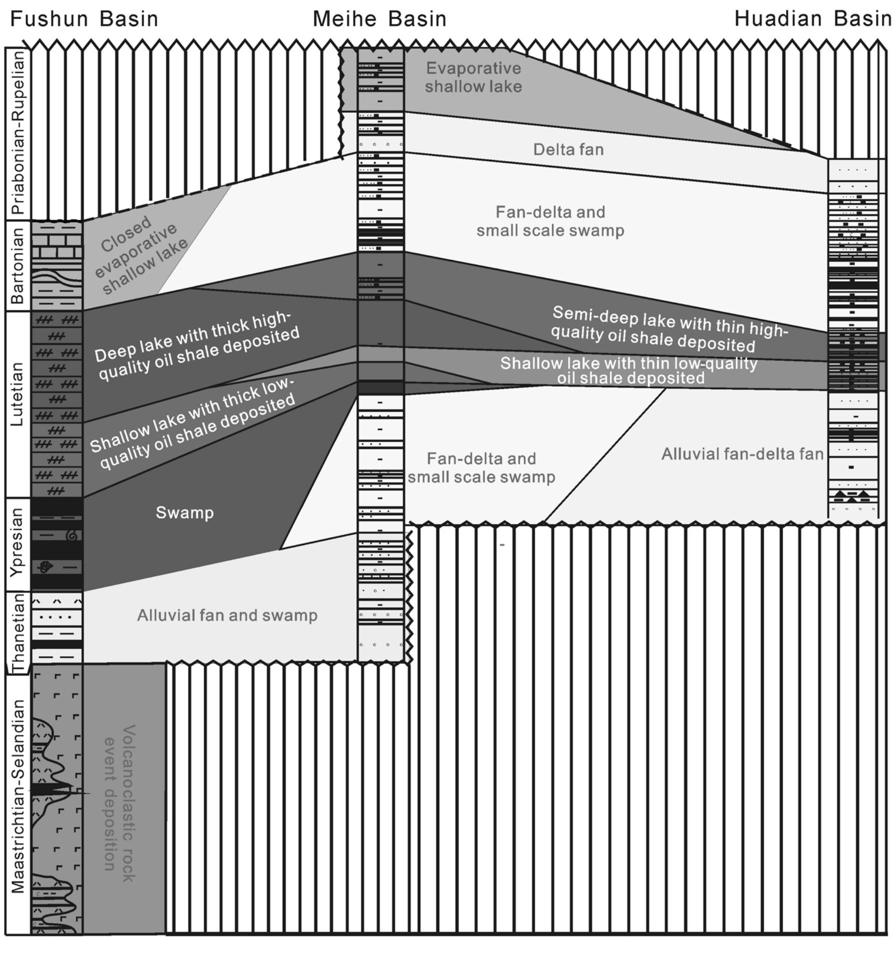

Fig. 4. The characteristics of energy minerals distributed in the Dunhua-Mishan Fault Zone (according to [2], modified).

According to Meng [12] and Bai et al. [5], who used the palynological data and the relevant approach in the Huadian Basin and the geochemical ratio in the Meihe Basin, the Upper Pyrite Member in the Huadian Basin and the Lower Coal-bearing Member in the Meihe Basin were both developed in the same paleoclimate as the Guchengzi Formation in the Fushun Basin. Meanwhile, the Guchengzi Formation in the Fushun Basin, the Lower Coal-bearing Member in the Meihe Basin and the Pyrite Member in the Huadian Basin were all deposited in the initial tectonic subsidence evolution stage of the Paleocene Dunhua-Mishan Fault Zone. Previous studies show that the age of the Guchengzi Formation is the Ypresian [19], so this time could be considered the first stage of coal formation. The eruption of basalts has caused the Fushun Basin to undergo rapid tectonic subsidence. When the tectonic activity ceased, there formed a stable swamp. As terrigenous detrital supply was poor, thick stable coal seams were formed in the Guchengzi Formation. The low-ash coal seams were mainly formed in the freshwater paleoenvironment in the low-lying mire and the high-ash coal seams were primarily formed in the fluvio-lacustrine environment, the source of organic matter in coal seams being mostly conifers with little alginite supply [20]. Meanwhile, the Meihe Basin began to subside and deposited the sediments of the Meihe Formation. In the Early Ypresian, the sediments were predominantly alluvial fan and fan-delta sediments and thin discontinuous coal seams at small scales developed locally. In the Late Ypresian, stable freshwater swamps were formed [17] and deposited stable great-thickness coal seams. However, as in the Huadian Basin there was no deposition of sediments in the Early Ypresian, then no coal seams were formed in the basin at that time either. On the whole, coal seams were mainly deposited in the southwestern segment of the Dunhua-Mishan Fault Zone in the Ypresian, the tectonic subsidence with the simultaneous formation of the stable swamp being the key factors for coal formation.

In all the three basins, oil shale deposited in deep water during the maximum tectonic subsidence evolution stage, and its layers covered the lower coal-bearing layers. So it can be concluded that oil shale layers in these three basins in the Dunhua-Mishan Fault Zone were all deposited at the same time, in the Lutetian. As seen from the evolution of Fushun, Meihe and Huadian basins, oil shale was mainly accumulated in the period when the lake level was the highest, the tectonic setting the most stable and the terrigenous supply the least. During the early depositional stage of the Jijuntun Formation, the lake was mainly filled with semi-deep lake sediments and the source of organic matter was abundant algae combined with conifer debris, forming low-quality oil shale. On the other hand, in the late stage of the Jijuntun Formation, the lake became deeper and the terrigenous supply decreased, thus thick high-quality oil shale deposited in the environment favourable for preservation [21]. The depositional environment in the early stage of the Mudstone Member in the Meihe Basin was similar to that in the early stage of the Oil Shale Member in the Huadian Basin, in both of which fan-delta and shallow lake sediments predominate [5, 22]. The thin low-quality oil shale was formed in a shallow lake, the organic matter source being higher land plants mixed with aquatic materials [22]. During the late stage of the Mudstone Member in the Meihe Basin and the late stage of the Oil Shale Member in the Huadian Formation, the sediments were mostly formed in a semi-deep lake, and the source of organic matter was mainly aquatic materials, both of which having contributed to the formation of thin high-quality oil shale [18, 23]. However, oil shale in all the three basins was formed in fresh water conditions, based on the biomarker compounds analysis [4, 5], while the paleoclimate in each basin was different. In the Fushun and Meihe basins it was warm and humid [4, 5], varying from wet to dry in the Huadian Basin [12]. Though, the different paleoclimate conditions for oil shale formation need to be further studied. This is because oil shale in the Dunhua-Mishan Fault Zone was formed in the same series but in different ages.

The other stage of coal formation is the Barionian-Priabonian. Quan et al. [19] pointed out that during the Middle to Late Eocene, the Dunhua-Mishan Fault Zone experienced one cooling event and coal seams only formed in the Meihe and Huadian basins. As regards the Fushun Basin, the tectonic subsidence was almost finished in the Bartonian-Priabonian and the fillings were formed in an evaporitic environment with little terrigenous supply, thus no coal seams were deposited during this stage [21]. However, the tectonic subsidence was still continuing in the Meihe Basin and the terrigenous supply was intense, developing thus abundant fan-delta sediments. Coal seams were found to have formed in the swamp and fan-delta plain [16]. The Huadian Basin had a similar tectonic and depositional environment to that of the Meihe Basin, while coal seams were distributed in a relatively limited scale and are thin [6, 18]. In general, although the paleoclimate in this stage was stable compared with that in the first stage, the development of coal seams was limited because of the abundant terrigenous supply and unstable depositional environment.

During the Oligocene, the evolution of the Fushun Basin came to an end while in the Huadian and Meihe basins it ceased in the Middle Rupelian and Chattian, respectively. In the Oligocene, the climate was cold with a lastingly low temperature and the depositional environment was poor for the formation of oil shale and coal, indicating the end of oil shale and coal accumulation.

6. Conclusions

In the Dunhua-Mishan Fault Zone, sediments in the Fushun Basin were formed in the Paleogene-Eocene, in the Meihe Basin they accumulated in the Eocene-Oligocene and in the Huadian Basin, in the Eocene-Lower Oligocene.

In the Fushun Basin, thick medium-quality oil shale was deposited overlying huge thick coal seams. In the Meihe Basin, oil shale of medium thickness was buried in the basin's middle part, while thick coal seams were deposited below oil shale and thin coal was developed above it. In the Huadian Basin, thin high-quality oil shale was deposited below thin coal seams.

Thick coal seams in the Fushun and Meihe basins were deposited in the swamp with abundant land plant supply during the initial tectonic subsidence evolution stage and in the warm and humid paleoclimate. The relatively high-quality oil shale was formed in the deep lake during the maximum tectonic subsidence evolution stage of these three basins, and the main source of organic matter was abundant algae. Oil shale in the Fushun and Meihe basins was accumulated in the warm and humid paleoclimate, while the climate in the Huadian Basin varied from wet to dry.

There were two coal-forming stages and one oil shale-forming stage in the Dunhua-Mishan Fault Zone. Coal seams in the Fushun Basin and the lower part of the Meihe Basin were formed in the Ypresian, and those in the upper part of the Meihe and Huadian basins were deposited in the Bartonian-Priabonian. Oil shale in these three basins accumulated in the Lutetian.

Acknowledgements

This research project was financially supported by the Specialized Research Fund for the National Natural Science Fund (41402088), the China Postdoctoral Science Foundation Grant (2014M550174 and 2015T80303) and the Science and Technology Development Plan of Jilin Province (20150520070JH).

REFERENCES

1. Liu, Z. J., Yang, H. L., Dong, Q. S., Zhu, J. W., Guo, W., Ye, S. Q., Liu, R., Meng, Q. T., Zhang, H. L., Gan, S. C. *Oil Shale in China*. Petroleum Industry Press, Beijing, 2009, 343 pp (in Chinese with English abstract).
2. Cui, X. S., Liu, F. The metallogenic regularities of energy minerals in the Dunhua-Mishan fault zone. *Jilin Geology*, 2012, 31, 81–84 (in Chinese with English abstract).
3. Sun, X. M., Wang, S. Q., Wang, Y. D., Du, J. Y., Xu, W. Q. The structural feature and evolutionary series in the northern segment of Tancheng-Lujiang fault zone. *Acta Petrologica Sinica*, 2010, **26**(1), 165–176 (in Chinese with English abstract).
4. Meng, Q. T., Liu, Z. J., Bruch, A. A., Liu, R., Hu, F.. Palaeoclimatic evolution during Eocene and its influence on oil shale mineralisation, Fushun basin, China. *J. Asian Earth Sci.*, 2012, **45**, 95–105.
5. Bai, Y. Y., Liu, Z. J., Sun, P. C., Liu, R., Hu, X. F., Zhao, H. Q., Xu, Y. B. Rare earth and major element geochemistry of Eocene fine-grained sediments in oil

shale- and coal-bearing layers of the Meihe Basin, Northeast China. *J Asian Earth Sci*., 2015, **97**, 89–101.
6. Sun, P. C., Liu, Z. J., Meng, Q. T., Liu, R., Jia, J. L., Hu, X. F. Effect of the basin-fill features on oil shale formation in Paleogene, Huadian Basin. *Journal of China Coal Society*, 2011, **36**(7), 1110–1116 (in Chinese with English abstract).
7. Qu, S. Characteristic and its geological significance of the palynological assemblage of the Lower Tertiary Genjiajie Group in Fushun Basin. *Journal of Changchun University of Earth Sciences*, 1993, **23**, 411–415 (in Chinese with English abstract).
8. Hong, Y. C., Yang, Z. Q., Wang, S. T., Sun, X. J., Du, N. Q., Sun, M. R., Li, Y. G. *A Research on the Strata and Palaeontology of the Fushun Coal Field in Liaoning Province*. Science Press, Beijing, 1980 (in Chinese).
9. Chen, B. L., Qu, S. Q., Fang, D. Q., Dou, H., Che, Q. P. Reinvestigation of the Eogene System in Fushun Basin. *Journal of Daqing Petroleum Institute*, 1995, 19, 19–22.
10. Hu, S. T., Kang, X. D., Wu, K. P., Wang, Y. F. Sedimentary coal accumulating environment of Meihe Basin. *Coal Geology of China*, 1996, **8**(2), 13–15 (in Chinese with English abstract).
11. Zhang, P. L., Lu, B. C., Li, C. T., Sun, J. R., Liu, A. Discovery of the Huadian Fauna of the early Tertiary and its geological significance. *Jilin Geology*, 1986, **12**(4), 1–14 (in Chinese with English abstract).
12. Meng, Q. T.. *Research on Petrologic and Geochemical Characteristics of Eocene Oil Shale and Its Enrichment regularity, Huadian Basin*. Jilin University, 2010, 136 pp (in Chinese with English abstract).
13. Wang, D. F. The Paleocene basalts in the Fushun District and their tectonic significance in development of Tancheng–Lujiang Fault Belt. *Acta Petrol. Mineral*., 1986, **5**(3), 212–219 (in Chinese with English abstract).
14. Wang, H. F., Zhang, T. S., Dai, C. R., Luo, M., Hu, W. W., Xie, X. A. Stratigraphic division and correlation of the Upper Jurassic-Pliocene in the Dunhua basin. *Geology in China*, 2008, **35**(1), 40–53 (in Chinese with English abstract).
15. Jin, L. Y. Characteristics of Wulin-faulted stratum and oil shale deposit in Liushuhezi basin, Linkou County. *Coal Technology*, 2009, **28**(9), 143–144 (in Chinese with English abstract).
16. Bai, Y. Y., Liu, Z. J., Sun, P. C., Liu, R., Hu, X. F., Zhao, H. Q., Xu, Y. B. Organic matter accumulation patterns of coal bearing layers in the lower part of Meihe Formation in Paleogene, Meihe Basin. *Journal of Coal Science & Engineering (China)*, 2014, **39**(S2), 458–464 (in Chinese with English abstract).
17. Li, B. Y., Yao, S. Q., Sun, P. C., Xu, Y. B., Liu, R., Bai, Y. Y. Characteristics and origin of oil shale in Meihe Basin. *Global Geology*, 2014, **33**(2), 457–464 (in Chinese with English abstract).
18. Sun, P. C., Sachsenhofer, R. F., Liu, Z. J., Strobl, S. A. I., Meng, Q. T., Liu, R., Zhen, Z. Organic matter accumulation in the oil shale- and coal-bearing Huadian Basin (Eocene; NE China). *Int. J. Coal Geol*., 2013, **105**, 1–15.
19. Quan, C., Liu, Y. S. C., Utescher, T. Paleogene temperature gradient, seasonal variation and climate evolution of northeast China. *Palaeogeogr. Palaeocl*., 2012, **313–314**, 150–161.
20. Strob, S. A. I., Sachsenhofer, R. F., Bechtel, A., Meng, Q. T. Paleoenvironment of the Eocene coal seam in the Fushun Basin (NE China): Implications from

petrography and organic geochemistry. *Int. J. Coal Geol*., 2014, **134–135**, 24–37.

21. Liu, R., Liu, Z. J., Meng, Q. T., Sun, P. C., Zhou, R. J., Liu, D. Q., Yang, D. Paleolake evolution of Eocene in Fushun basin. *Acta Sedimentologica Sinica*, 2010, **28**(4), 688–695 (in Chinese with English abstract).
22. Strobl, S. A. I., Sachsenhofer, R. F., Bechtel, A., Gratzer, R., Gross, D., Bokhari, S. N. H., Liu, R., Liu, Z. J., Meng, Q. T., Sun, P. C. Depositional environment of oil shale within the Eocene Jijuntun Formation in the Fushun Basin (NE China). *Mar. Petrol. Geol*., 2014, **56**, 166–183.
23. Xu, Y. B., Liu, R., Liu, Z. J., Sun, P. C., Wang, J. P., Yao, S. Q., Hu, X. F., Zhao, H. Q. Deposition evolution and enrichment pattern of organic matter of the Meihe Formation in the Paleogene, Meihe Basin. *Journal of China Coal Society*, 2013, **38**(11), 2007–2016 (in Chinese with English abstract).

Presented by A. Soesoo
Received June 2, 2015