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GEOCHEMISTRY OF RARE EARTH AND OTHER TRACE ELEMENTS IN CHINESE OIL SHALE

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Abstract. *In this paper, the characteristics of some trace elements and rare earth elements (REEs) in oil shales were examined by inductively coupled plasma mass spectrometry (ICP-MS). It was noted that the content of most trace elements under study ranged from 1 to 50 µg/g. Trace elements with a content < 1 µg/g and > 50 µg/g were also determined. Elements whose abundance in the Earth's crust is high have a high content in oil shale as well. Rare earth elements in oil shale are closely connected with terrigenous clastic rocks, whose supplies of land-derived matters have been relatively stable. Additionally, it was indicated that the fractional degree of high rare earth elements (HREEs) and light rare earth elements (LREEs) in oil shale was remarkable, and the diagenetic environment of oil shale samples was similar.*

Keywords*: trace elements, oil shale, coal, rare earth elements (REEs), crustal abundance.*

1. Introduction

Oil shale (OS), from which shale oil may be generated, is a fine-grained sedimentary rock containing aquatic organisms derived organic matter called kerogen (about 5–50%). Oil shale is classified as sapropelic coal with rich minerals, and is considered as a solid fossil fuel with a low heat value. In many countries, oil shale is a major source of energy. Its estimated reserves in China are approximately 2×10^{12} tons, which is equivalent to 80 billion tons shale oil. This amount is just next to the United States', Brazil's and Estonia's, ranking fourth in the world [1]. At present, China's discovered reserves of OS are about 32×10^{12} tons and are chiefly distributed over 55 deposits located in the provinces of Jilin, Guangdong and Liaoning. Hence,

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the exploitation and utilization of oil shale has been an important part of Chinese national energy development strategies [2].

Coal and oil shale as fossil fuels contain various trace elements besides major elements. Most trace elements are present in all coals at exceedingly low levels, less than 1 mg/g, some even less than 1 μg/g. The emission of potentially toxic trace elements during the utilization of coal and oil shale may cause environmental pollution. The researchers throughout the world have systematically studied the distribution of trace elements in coal [3–6]. Despite the relatively late start, also in China the corresponding investigations have been carried out [7–10].

Rare earth elements (REEs) are trace elements which carry important information about the origin, source, evolution and original environment of rock. Compared with trace elements in coal, REEs in coal have been studied more extensively and more resultfully by Chinese scientists Wang et al. [11], Dai et al. [12] and Liu et al [13].

At the same time, there are but few investigations on the enrichment and distribution characteristics of trace elements and REEs in Chinese oil shale. Fu et al. [14, 15] and Zhao [16] studied the content of trace elements and REEs in oil shale from northern Tibet, China. Fu et al. [15] and Bai et al. [17] also investigated the modes of occurrence of trace elements and REEs in oil shale respectively from Huadian and Wangqing, by the sequential chemical extraction procedure. The study on trace elements in oil shale may contribute to reflecting the original environment of oil shale, to promoting the rational utilization of usable elements and to decreasing environmental pollution with hazardous elements during a comprehensive utilization of oil shale.

In this work, the contents of trace elements and REEs in oil shale samples from several mineral areas of China were determined by inductively coupled plasma mass spectrometry (ICP-MS).The distribution and enrichment of trace elements were also analyzed. The results of the study will serve as a foundation for a further exploration and utilization of oil shale.

2. Materials and methods

For the study, 22 oil shale samples were chosen, including one sample from Beitaizi (JH-10) and Wangqing (JW), four from Gonglangtou (JH-6–JH-9) and Meihekou (JM-1–JM-4), and five from Dachengzi (JH-1–JH-5) in Jilin province; one sample from Dongning (HDN), Liushuhe (HLH) and Dayingzi (LK), and two from Jinbaotun (JL-1, JL-2) in Heilongjiang province; and two from Xinjiang (X-1, X-2) in Xinjiang province.

The content of trace elements in oil shale was measured by ICP-MS at the Testing Center of Jilin University. ICP-MS as a highly sensitive technique is capable of determining a wide range of metals and also nonmetals at concentrations below one part in 10^{12} (trillion). Used in trace elemental analysis, it has several advantages over atomic absorption techniques, such as high speed, precision and sensitivity. However, determination of lower concentrations is more prone to be disrupted by trace contaminants in the lab ware and reagents used.

3. Results and discussion

3.1. Trace elements content in oil shale

Table 1 presents data on the content of trace elements in oil shale determined in this work. From the table it can be seen that the content of most trace elements ranges from 1 to 50 µg/g, but some elements are present at a concentration of less than 1 µg/g or more than 50 µg/g. At the same time, individual samples differ in trace element content, which displays a relatively high enrichment degree, in particular, in sample LK.

The range and average values of the concentration of trace elements in Chinese oil shale samples are shown in Table 2. For comparison, the average concentration of trace elements in Estonian oil shale [4] and Chinese coal [18], as well as Clarke value in oil shale [19], and crustal abundance [20] are given.

A comparison of the average contents and content ranges of trace elements in oil shale (OS) with those in Chinese coal (C) is illustrated in Figures 1 and 2, respectively. As shown in Figure 1, the average content of Ba, Cr, Cs, Cu, Ga, Ni, Ta, Tl, V and Zn in oil shale is two times higher than those in Chinese coal. However, the average content of As, B, Cd, Mo, Sb, Se and Hg in oil shale is significantly lower, while that of other elements is mostly the same. As can be seen from Figure 2, compared with the content range of trace elements in Chinese coal, the content of Be, B, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Ba, Ta, W, Tl, Th and U in oil shale samples is close to the upper limit. The Cs content is a little higher than the upper limit in Chinese coal. The content of Ge, Sr, Sn and Sb is within the content range, and that of Se, Mo, Cd, Hg and P is close to the lower limit in coal.

Aunela-Tapola et al. [3] reported the content of several trace elements in Estonian and US Green River oil shales, and found that Mn, Cu, Zn, As, V and Cr were present in Green River oil shale at higher concentrations. Meanwhile, the content of Cu, Ni, Co, V, Cr and Mn in Chinese oil shale is

Table 1. Content of trace elements in oil shale

Content, *w* µ g/g	Trace elements
≥ 100	Ba, Mn, Sr, Ti
≥ 50–100	V, Cr, Zn
≥ 1–50	Cu, Li, Ni, Ga, Y, B, Pb, Co, Th, Cs, Be, Ge, As, Sn, Ta, Re, Tl, U, W
≥ 0.1–1	Mo, Pd, Ag, Sb
< 0.1	Hg, Te, Cd

Table 2. Content of trace elements in different oil shale samples and Chinese coal, *w* μ g/g

Element	Chinese oil shale		Estonian oil shale average value [4]	Clarke [19]	Chinese coal [18]		Crustal abundance [20]	
	Range	Average value			Range	Average value	Range	Average value
Be	1.5–4.8	2.5	94	3	0.1–6	2	1.3–2	1.73
B	2–253	47	55	10	10–250	63	10–13	11.3
Ti	907–7382	3200	–	4600	16–4201	528	5400–9590	6250
V	19–475	92	22	130	2–100	21	110–180	143
Cr	20–130	60	15.5	90	2–50	12	71–200	127
Mn	57–4811	1060	306	850	4–109	77	774–1549	1090
Co	3.1–24.4	14	2.7	19	1–20	7	23–26	24.7
Ni	5–139	38	13.2	68	2–65	14	75–89	81.3
Cu	9–270	41	6.7	45	1–50	13	45–63	56
Zn	11–290	94	76	95	2–106	35	65–94	76.3
Ga	9.4–28	20	–	19	1–20	9	15–18	16.7
Ge	0.6–3.3	1.9	–	1.6	0.5–10	4	1.4–2.0	1.6
As	0.6–10	2	18.8	13	0.4–10	5	1.9–2.2	2.6
Se	0.05–0.3	0.1	–	0.6	0.1–11	2	0.075–0.10	0.0883
Sr	46–810	280	168	300	27–3000	136	215–480	382
Y	10–64	27		26	0.5–22	8	19–40	27.7
Mo	0.6–11.3	1.9	4.9	2.6	1–15	4	1.0–2.0	1.43
Cd	0.01–0.4	0.1	0.3	0.8	0.01–3	0.2	0.15–0.20	0.177
Sn	0.6–3.2	2	-	6	0.4–5	2	1.7–4.0	2.9
Sb	0.1–5	0.9	0.4	1.4	0.1–10	2	0.2–0.7	0.507
Cs	1.8–16.5	10	–	5	0.1–3	1	1.0–1.4	1.23
Ba	109–719	440	59	580	13–400	82	390–600	463
Ta	0.45–15.7	2.3	–	80	0.06–4	0.7	1.2–2.0	1.6
W	0.6–48.4	4.3	–	71.8	0.1–9	2	0.4–1.1	1.13
Hg	0.00–0.12	0.02	–	0.4	0.01–1	0.15	0.057–0.17	0.103
Tl	0.38–4.1	1.3	0.43	1.4	0.1–1	0.4	0.48–1.0	0.727
Pb	6–38	16	27.3	20	10–47	13	12–16	14
Th	2.6–22	11	–	12	0.5–15	6	5.8–10	7.6
U	1.1–11.5	4	2.18	3.7	0.5–10	3	1.7–2.5	2.07

quite high. Accordingly, Mn, Zn, V, Cu and Cr in Chinese Huadian oil shale, Estonian oil shale and US Green River oil shale show a high enrichment degree unlike those in Chinese coal. Furthermore, the released amount of trace elements from Estonian oil shale is greater than from Chinese coal. In addition, the fact that trace elements are constantly detected in the moss within a radius of 1–30 km around the oil shale fired power plant suggests that their release in the process of oil shale combustion may eventually exert a negative influence on the surrounding environment.

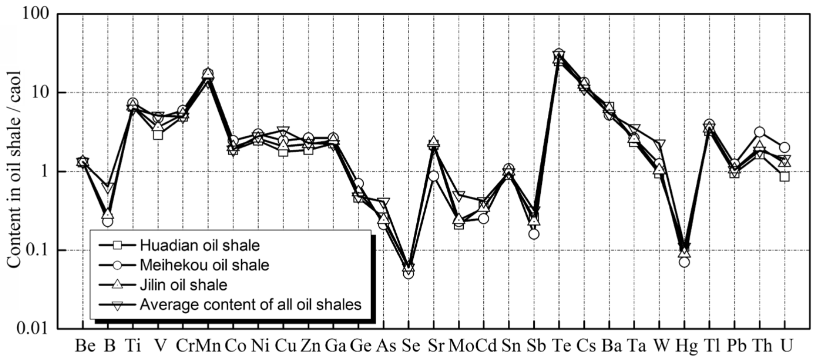

Fig. 1. Ratio of the average content of individual oil shale elements to the average concentration of individual coal elements.

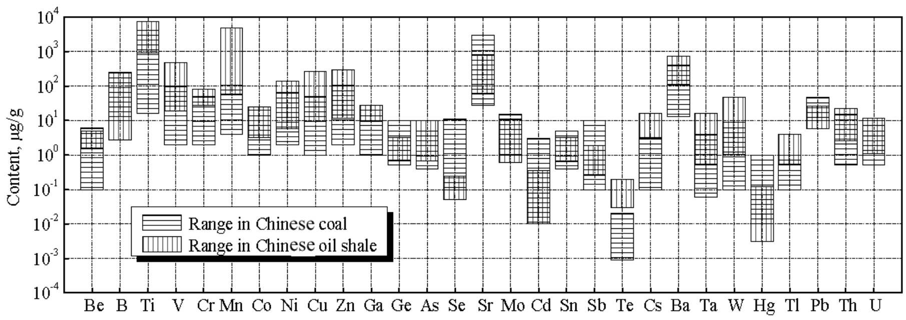

Fig. 2. Content range of elements in oil shale and coal.

3.2. Enrichment degree of trace elements in oil shale

The variation of the content of trace elements in the Earth's crust and in all oil shale samples is illustrated in Figure 3. It is clearly seen that the corresponding curves for all oil shale samples and crustal abundance are similar. Hence, the distribution of trace elements in oil shale is primarily influenced by the geochemical cycling of elements, and elements with a higher

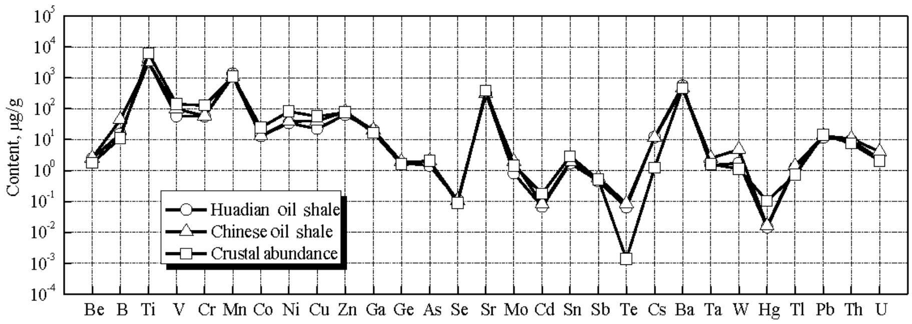

Fig. 3. Content of elements in oil shale and their crustal abundance.

abundance in the Earth's crust, such as Ti, Ba, Sr, Mn, etc., have an elevated content in oil shale as well.

The enrichment factor (EF) is a measure of the enrichment degree of trace elements in sediment. It enables analyzing the environmental impacts of heavy metals, both nature- and human-derived. It is necessary that some elements should be considered as reference (or standard) elements. EF equals the content ratio of elements to reference elements in oil shale samples divided by such a ratio in the Earth's crust as shown in Equation (1):

$$\mathrm{EF} = \left[\frac{(C_\mathrm{i} / C_\mathrm{n})_\mathrm{OS}}{(C_\mathrm{i} / C_\mathrm{n})_\mathrm{BG}} \right], \quad (1)$$

where C_i is the concentration of element i, C_n is the concentration of a reference element, and OS and BG denote oil shale and background, respectively.

Generally, a standard element, such as Al, Ti, Sc, Zr, etc., should have stable geochemical properties. In this paper, Ti is considered as a standard element, and its crustal abundance as a background value. Usually, EF < 1 signifies "poverty", 10 > EF > 1 "normal", and EF > 10 "enrichment". According to such a rule, Cs in oil shale samples is of high "enrichment", Hg belongs to "poor", and other elements are "normal".

3.3. Rare earth elements in oil shale

The measured contents of rare earth elements in oil shale samples are presented in Table 3. A comparison shows the REEs content ranges in oil shale to be the same as those in Chinese coal. REEs ranged from La–Eu as light rare earth elements (LREEs) to Gd–Lu as heavy rare earth elements (HREEs). The average content of LREEs in oil shale samples is twice higher than that in Chinese coal, and the HREEs abundance is 1–1.5 times higher. Compared with Chinese coal, in oil shale the enrichment degree of LREEs is higher than that of HREEs. The average content of REEs in Chinese oil shale is nearly equal to that in North American shale composite (NASC). The HREEs content in samples JM-1–JM-4 is high and that of LREEs low. However, the REEs content in JH-7 is abnormally low. This is due to that JH-7 originated from the bottom of the eleventh floor of Huadian mine area. As established by XRD, its organic content is high, and REEs in Huadian oil shale mainly exist in the inorganic mineral part [21]. This is why the REEs concentration in sample JH-7 is relatively low.

The geochemical parameters of REEs can reflect their characteristics, representing the degree of enrichment and source. LREE/HREE is the ratio of LREE to HREE contents, and $\mathrm{La_N/Yb_N}$ is the ratio of chondrite-normalized elements. $\delta\mathrm{Eu_N}$ and $\delta\mathrm{Ce_N}$ are anomalies of Eu and Ce by

Table 3. Content of rare earth elements (REEs) in different oil shale samples and coal, *w* µg/g

Sample \ REE	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
JH-1	24.46	41.90	5.59	19.67	3.33	0.72	3.22	0.51	2.60	0.51	1.51	0.25	1.42	0.28
JH-2	29.95	51.77	6.86	24.42	4.17	0.90	4.00	0.63	3.19	0.63	1.86	0.31	1.74	0.36
JH-3	23.92	40.77	5.55	19.57	3.40	0.76	3.27	0.50	2.58	0.51	1.53	0.25	1.44	0.28
JH-4	34.67	59.84	7.75	26.35	4.54	0.96	4.14	0.66	3.34	0.65	1.92	0.32	1.83	0.41
JH-5	38.53	67.68	8.52	28.35	4.77	0.96	4.15	0.64	3.37	0.64	1.92	0.33	1.89	0.43
JH-6	26.17	44.45	6.01	22.29	3.81	0.86	4.24	0.67	3.46	0.69	2.08	0.34	1.89	0.36
JH-7	12.83	21.60	3.02	10.96	1.88	0.42	1.88	0.30	1.64	0.33	1.05	0.17	1.01	0.21
JH-8	57.32	103.2	12.73	43.20	7.26	1.45	6.24	1.00	5.14	0.99	2.89	0.49	2.79	0.63
JH-9	45.62	91.67	11.39	40.19	6.83	1.42	5.90	0.96	5.02	0.95	2.79	0.48	2.65	0.59
JH-10	55.88	102.9	13.64	52.00	9.35	2.12	11.32	1.87	10.16	2.17	6.46	1.08	5.79	1.02
JL-1	35.00	64.66	8.47	29.90	5.27	1.05	5.09	0.83	4.42	0.87	2.67	0.45	2.61	0.55
JL-2	30.93	58.85	7.80	27.83	4.85	1.01	4.63	0.75	4.12	0.81	2.39	0.41	2.31	0.48
JM-1	52.93	93.22	11.46	37.90	6.35	1.26	5.40	0.82	3.73	0.66	1.93	0.31	1.67	0.32
JM-2	74.11	135.0	16.63	57.36	9.74	1.99	8.61	1.34	6.05	1.05	3.00	0.48	2.46	0.49
JM-3	57.32	107.4	13.60	47.87	7.90	1.57	6.72	1.05	4.94	0.92	2.70	0.44	2.41	0.45
JM-4	64.40	117.2	14.27	47.38	7.95	1.56	6.64	1.01	4.67	0.84	2.43	0.40	2.15	0.42
JW	30.86	64.22	6.88	26.61	4.97	1.18	4.61	0.78	3.75	0.76	2.15	0.31	1.96	0.30
HDN	33.27	56.60	7.74	27.86	5.17	0.91	6.24	1.10	6.78	1.53	4.72	0.82	4.58	0.90
HLH	22.31	37.08	5.11	18.16	3.21	0.71	3.57	0.57	3.01	0.62	1.83	0.28	1.43	0.26
LK	41.66	73.35	10.90	41.73	7.66	1.62	8.64	1.49	8.51	1.87	5.70	0.99	5.76	1.09
X-1	19.76	35.31	4.89	18.29	3.35	0.72	3.54	0.58	3.28	0.66	1.99	0.33	1.99	0.43
X-2	25.34	44.56	6.22	22.86	4.21	0.90	4.52	0.75	4.07	0.81	2.42	0.40	2.34	0.51
Max	74.11	135	16.63	57.36	9.74	2.12	11.32	1.87	10.16	2.17	6.46	1.08	5.79	1.09
Min	12.83	21.6	3.02	10.96	1.88	0.42	1.88	0.3	1.64	0.33	1.05	0.17	1.01	0.21
Average	38.06	68.78	8.87	31.40	5.45	1.14	5.30	0.86	4.45	0.89	2.63	0.44	2.46	0.49
Chinese coal	17.79	35.06	3.76	15.03	3.01	0.65	3.37	0.517	3.141	0.731	2.081	0.335	1.975	0.323
Chondrite	0.315	0.813	0.115	0.597	0.192	0.0722	0.259	0.0473	0.325	0.0723	0.213	0.0333	0.208	0.0323
Crustal abundance	39	43	5.7	26	6.7	1.2	6.7	1.1	4.1	1.4	2.7	0.3	2.7	0.8
NASC	31.50	66.50	7.90	27.00	5.90	1.18	5.20	0.79	5.80	1.04	3.40	0.50	2.97	0.44

chondrite-normalized values as shown in Equations (2) and (3), respectively [22]:

$$\delta \mathrm{Eu}_N = \mathrm{Eu}_N / (\mathrm{Sm}_N \times \mathrm{Gd}_N)^{1/2} \quad (2)$$

$$\delta \mathrm{Ce}_N = \mathrm{Ce}_N / (\mathrm{La}_N \times \mathrm{Pr}_N)^{1/2}, \quad (3)$$

where Eu_N, Sm_N, Gd_N, Ce_N, La_N and Pr_N denote the chondrite-normalized values of elements.

The geochemical parameters of REEs in Chinese oil shale are given in Table 4. As seen, the average ΣREE of REEs is 171.20 μg/g, ΣLREE is

Table 4. Geochemical parameters of rare earth elements (REEs) in different oil shale samples and coal

Sample	ΣREE	LREE	HREE	LREE/HREE	La_N/Yb_N	δEu_N	δCe_N	La_S/Yb_S	δEu_S	δCe_S
JH-1	105.97	95.67	10.30	9.29	11.37	0.68	0.84	1.62	1.03	0.85
JH-2	130.79	118.07	12.72	9.28	11.37	0.68	0.85	1.62	1.03	0.86
JH-3	104.33	93.97	10.36	9.07	10.97	0.70	0.83	1.57	1.07	0.84
JH-4	147.38	134.11	13.27	10.11	12.51	0.68	0.85	1.79	1.04	0.87
JH-5	162.18	148.81	13.37	11.13	13.46	0.67	0.87	1.92	1.01	0.89
JH-6	117.32	103.59	13.73	7.54	9.14	0.66	0.83	1.31	1.00	0.84
JH-7	57.30	50.71	6.59	7.69	8.39	0.69	0.81	1.20	1.05	0.82
JH-8	245.33	225.16	20.17	11.16	13.57	0.67	0.89	1.94	1.01	0.91
JH-9	216.46	197.12	19.34	10.19	11.37	0.69	0.94	1.62	1.05	0.95
JH-10	275.76	235.89	39.87	5.92	6.37	0.64	0.87	0.91	0.97	0.88
JL-1	161.84	144.35	17.49	8.25	8.85	0.63	0.88	1.26	0.95	0.89
JL-2	147.17	131.27	15.90	8.26	8.84	0.66	0.89	1.26	1.00	0.90
JM-1	217.96	203.12	14.84	13.69	20.93	0.66	0.89	2.99	1.01	0.90
JM-2	318.31	294.83	23.48	12.56	19.89	0.67	0.90	2.84	1.02	0.91
JM-3	255.29	235.66	19.63	12.01	15.71	0.67	0.90	2.24	1.01	0.91
JM-4	271.32	252.76	18.56	13.62	19.78	0.66	0.91	2.82	1.01	0.92
JW	149.34	134.72	14.62	9.21	10.40	0.76	1.03	1.48	1.16	1.05
HDN	158.22	131.55	26.67	4.93	4.80	0.49	0.83	0.68	0.75	0.84
HLH	98.15	86.58	11.57	7.48	10.30	0.65	0.81	1.47	0.98	0.82
LK	210.97	176.92	34.05	5.20	4.78	0.62	0.81	0.68	0.93	0.82
X-1	95.12	82.32	12.80	6.43	6.56	0.65	0.84	0.94	0.98	0.85
X-2	119.91	104.09	15.82	6.58	7.15	0.64	0.83	1.02	0.97	0.84
Average	171.20	153.70	17.51	8.78	10.22	0.65	0.88	1.46	0.99	0.89
Max	334.90	294.96	39.94	7.39	8.45	0.62	0.90	1.21	0.95	0.91
Min	57.30	50.71	6.59	7.69	8.39	0.69	0.81	1.20	1.05	0.82
Chinese coal	87.77	75.30	12.15	6.20						
Chondrite	3.29	2.10	1.19	1.77	1.00	1.00	1.00	0.14	1.52	1.01
Crustal abundance	141.40	121.60	19.80	6.14	9.54	0.55	0.68	1.36	0.84	0.68
NASC	160.12	139.98	20.14	6.95	7.00	0.66	0.99	1.00	1.00	1.00

REE – rare earth element; LREE – light rare earth element; HREE – high rare earth element.

153.70 μg/g and ΣHREE is 117.51 μg/g. Meanwhile, these values are approximately equal to those in NASC. The average value of LREE/HREE is 8.76 μg/g, and LaN/YbN is 10.22 μg/g, which indicates that the content of LREEs in oil shale is much higher than that of HREEs. The fractional degree of HREEs and LREEs is remarkable, representing a distinct LREE-enriched pattern.

The average ΣREE in Chinese coal is 87.45 μg/g, which is higher than that in oil shale and world coals calculated by Valcovic and in American coal proposed by Finkelman [23]. It is clear that the enrichment degree of REEs in oil shale is much higher than that in coal.

The average ΣREE in Huadian oil shale samples is 156.28 μg/g, ΣLREE 140.31 μg/g, ΣHREE 15.97 μg/g, LREE/HREE 12.6 μg/g, and LaN/YbN is 10.28 μg/g. In addition, the average LREE/HREE in oil shale samples of Meihekou is 12.97 μg/g, while LaN/YbN is 19.5 μg/g. Such values indicate that Meihekou oil shale is highly REEs-enriched. The fractional degree of HREE and LREE is remarkable, and exhibits a distinct LREEs-enriched pattern because of the sedimentary environment and climate change.

3.4. Distribution pattern of REEs

The geochemical characteristics of REEs are reflected by their distribution pattern data. The standardization based on chondrite, which reflects the differentiation degree of the sample and characteristics of the source region in comparison with pristine terrestrial materials, is one of the approaches to the study of the distribution pattern of REEs in shale sediment. The standardization distribution data on oil shale is shown in Figure 4, and relative calculated results are presented in Table 3. From Figure 4 it can be seen that the REEs distribution patterns of samples are similar as their curves all lean to the right. Additionally, the standardization value decreases gradually from La to Lu, and the corresponding curve assumes a V shape. At Eu, the distribution pattern of La–Eu (LREEs) is characterized by a steep

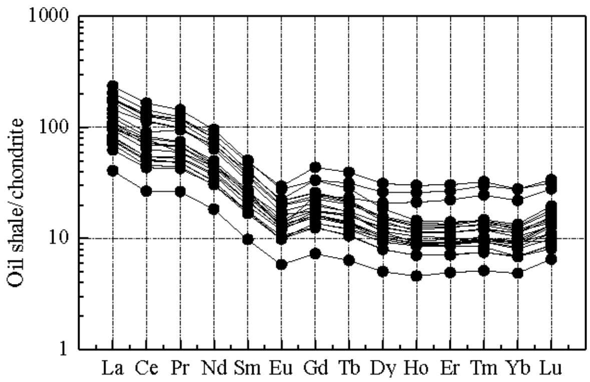

Fig. 4. Distribution pattern of REEs in oil shale.

curve and Gd–Lu (HREEs) by a gentle curve, which implies that the diagenetic environment of oil shale samples is similar. The similarity of REEs distribution shows that their source has been the same during the formation of oil shale, and suggests that REEs in oil shale have a close connection with terrigenous clastic rocks, and the supply of terrestrial material has been stable.

4. Conclusions

The content of trace elements in oil shale ranges from 1 to 50 μg/g, some being present at a concentration < 1 and > 50 μg/g. The elements with a higher abundance in the Earth's crust have an elevated content in oil shale as well. Comparison shows that the content of Be, B, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Ba, Ta, W, Tl, Th, U and Cs in oil shale samples is slightly higher than the upper limit in Chinese coal, while that of Se, Mo, Cd, Hg, Pb is close to the lower limit in coal. The EF of elements in oil shale with Ti as a standard element and the crustal abundance as a background value indicates that oil shale is highly enriched with Cs, non-enriched with HG, while the enrichment degree of other elements is normal.

Compared with Chinese coal, the enrichment degree of light REEs in oil shale is higher than that of heavy ones. An average content of REEs in oil shale is approximately equal to that in NASC. The similarity of REEs distribution indicates that the source of REEs is the same during the formation of oil shale, and suggests that REEs in oil shale have a close connection with terrigenous clastic rock, and the supply of terrestrial material has been stable.

In this paper, the enrichment characteristics of trace elements and REEs in different Chinese oil shale samples have been analysed. The current work will lay the foundation for a further study on the occurrence of trace elements in oil shale, as well as their transformation. The study is also of great significance for the development of green oil shale industry from both the theoretical and practical point of view.

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