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Petrographic Characterization of Sapropelite Coal

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Abstract

The petrographic composition of sapropelite coal from different deposits of Russia was investigated. It was revealed that the studied samples contain more than 75 % of macerals of the liptinite group, 8 to 24 % macerals of the vitrinite group, and minor amount of the group of inertinites (mainly fusinite), not more than 1–2 %. To determine the genetic maturity of the studied sapropelite coal, the reflectivity of vitrinite was determined. It was established that the vitrinite reflection index in the samples varies within a relatively narrow range from 0.27 % (the sample from the Charchik deposit) to 0.41 % (the sample from the Taimylyr deposit).

Keywords: sapropelite coal, petrographic analysis, macerals, liptinite, alginite, vitrinite

INTRODUCTION

Sapropelites (the term originates from the Greek word saprys, which means rotten, and pelys, which means silt or mud) are fossil coals formed as a result of metamorphism of the residues of lower plants and protozoa organisms under the conditions of lacustrine or lagoon facies, unlike humolites (or humus coal), which are the products of decomposition of the residues of higher plants under the conditions of bog facies. According to the composition, decay degree and the metamorphism of initial material, sapropelites and humite-sapropelines are distinguished [1, 2]. Sapropelites are characterized by a higher yield of volatile substances (55–70 %, sometimes up to 90 %) than humolites, high hydrogen content (7–12 %), and increased heat of combustion. They have grey colour, dull lustre, shell-like fracture and homogeneous structure without banding. As a rule, sapropelites occur as rather thin layers, only in some deposits they form entire strata or bands. The most widespread sapropelites are bogheads and semi-bogheads. Sapropelites in scattered forms are the major organic matter of oil-source rocks.

Sapropelite coal most frequently forms rather thin layers, they do not always spread over deposit area for long distances, which hinders their mining. As a consequence, sapropelites are still practically not in use. However, due to its chemical composition, sapropelite coal may serve as a raw material for processing for the purpose of obtaining solid and liquid hydrocarbon products [3–8]. To give a correct evaluation of the properties of sapropelites and to determine the most reasonable areas of their use, it is first of all necessary to study their substantial and petrographic composition.

In the present work, we describe the results of the studies of petrographic composition of sapropelite coal from different deposits of Russia.

EXPERIMENTAL

Six samples of sapropelite coal from the Coal Bank formed at the Institute of Coal Chemistry and Chemical Materials Science of RFC CCC SB RAS were used as the objects of investigation. The samples were encoded as Charchik (1) and Taymylyr (6) bogheads from the Lena basin; sapropelite from the Moscow coal basin sampled from the Seredeyskaya mine (2); sapropelite from the Sobolevo deposit of the Kansk-Achinsk basin (3); sapropelite of the Budagovo deposit of the Irkutsk basin (4); sapromyxite from the Barzas deposit in the Kuzbass (5).

The Charchik and Taymylyr deposits are situated in the Olenek district of the Lena basin (the Republic of Sakha, Yakutia. Lenses and lens-like interlayers of dull hard bogheads with shell-like fractures occur in the beds of black coal. The thickness of boghead lenses reaches 2.5 m at the Charchik deposit and 0.6 m at the Taymylyr deposit [3, 9, 10].

The Moscow coal basin is one of the oldest ones within the European part of Russia. The basin contains numerous isolated deposits of brown coal. According to petrographic characteristics, humolites and sapropelites are distinguished in coal from the Moscow basin. Sapropelite coal occurs in interlayers 0.3 to 1.0 m thick. A sample of sapropelite was taken from the Seredeyskaya mine (the Sukhinichi district, the Kaluga Region), which is situated at the western wing of the Moscow brown coal basin [3, 11].

The Sobolevo deposit is situated in the eastern part of the Itat-Bogotol coal-bearing region (Kans-Achinsk basin). The most exposed bed Moshchniy emerges over the whole area of the deposit. Coal from this deposit is brown humus, sometimes mixed sapropelite-humite. Sapropelite units occur separately in a number of strata in the mass of brown coal. The thickness of these units varies within a broad range – from 0.65 to 8.30 m [3].

The Budagovo deposit is in the north-western part of the Irkutsk coal basin. All known coal fields in this basin are within the Cheremkhovo suite, which confines also the major deposits of saptopelites and humite-sapropelites. The Budagovo deposit is represented by high-quality sapropelites; they are black with a brownish hue, and their structure is homogeneous [3, 9].

In addition to black coal resources of different marks, the Kuznetsk coal basin contains also sapropelite coal occurring in the Barzas coal-bearing region and are confined to the basement of Medium Devonian sediments. The coals of the deposit for the Osnovnoy layer in the Barzas suite; its thickness varies from 0.8 to 4.8 m. The deposit is characterized by non-complicated tectonics, and the beds are only slightly deformed. Plate-like coal forms the major part of the bed and is fractured in large plates; they are usually easily split into thinner plates [3, 12].

The preparation of coal samples for analysis included crushing to a particle size less than 1.6 mm and extraction with a mixture of alcohol and benzene (1 : 1) according to the Grefe method for 6 h, and then the samples were dried at a temperature of 105 °C in the drying box to the constant mass.

To carry out petrographic analysis correctly, the high-ash samples from the Barzas, Sobolevo and Budagovo deposits were concentrated in a mixture of CCl4 and benzene according to GOST 1186–2014, Supplement A. The fraction with a density less than 1.5 g/cm^3 was used for analytical studies. The ash content in the samples from the Sobolevo and Budagovo deposits exceeded 20 %, so these samples were additionally subjected to sequential demineralization with concentrated hydrochloric and hydrofluoric acids.

The petrographic analysis was carried out using an automatic complex for the evaluation of mark composition of coal, SIAMS-620 system (Russia) in oil immersion. A portion of air-dry sample ground according to GOST R 55663–2013 was mixed with the binder (shellac), and one side of it was processed with a grinding-and-polishing machine to obtain smooth surface.

Coal petrographic terminology was used in the microscopic studies: liptinite, vintrinite and intertinite [13–17]. Microcomponents were counted manually over 100 points with a 300 times magnification in the reflected light; the quantitative relations were determined by point counting. The results of petrographic studies are shown for so-called pure coal, without taking into account mineral substances. To determine the maturity of the studied sapropelites, we used vitrinite reflectance. The low content of this maceral in the samples hindered interpretation of the histograms of vitrinite reflection, and the error in each of the average values was 0.1 %.

Technical analysis was carried out using standard methods. The total sulphur content was calculated according to the Eshka method according to GOST 8606–2015 (ISO 334:2013). The elemental composition of the organic mass of sapropelite coal samples was determined with the help of element analyzer Thermo Flash 2000 (Thermo Fisher Scientific, Great Britain), determination results were recalculated for the dry ash-free state (daf).

RESULTS AND DISCUSSION

The characteristics of the studied samples of sapropelite coal are presented in Table 1. Coal samples are characterized by increased values of the yield of volatile substances: from 56.4 to 83.8 %. The majority of samples contain low sulphur concentrations: sulphur content in their organic mass is less than 2 %. A sample from the Seredeyskaya mine (sulphur content 3.2 %) may be related to sulphur-containing coal. The ash content of samples prepared for petrographic analysis was less than 11 % (see Table 1).

Characterization of the petrographic composition of sapropelite coal samples is shown in Table 2. Three groups of macerals were detected in the samples: liptinite, vitrinite, and inertinite.

Among these three groups of macerals, the dominating species is liptinite (more than 75 %). The content of macerals of the vitrinite group is 8–24 %, while the content of the inertinite group macerals is minimal: not more than 1–2 % as a total. The revealed inertinite components are mainly represented by fusinite, which occurs in sole fragments with cellular structure (Fig. 1, *a*), and in combination with macrinite. Macrinite is a maceral occurring in the form of unstructured bodies of diverse shapes and sizes (see Fig. 1, *b*). The colour of macrinite in reflected light changes from light-grey to yellowish-white.

In the samples of the studied sapropelites, liptinite is represented mainly by the macerals of the alginate group. Alginite group unites microcomponents formed from the most stable algae rich in lipids (fats, wax, resins) and therefore these macerals contain the maximal amount of hydrogen. Depending on the degree of conservation of the anatomic structure, they are divided into structural ones (thallomoalginite), with more or less pronounced cellular or crumbly structure, and unstructured species (colloalginite) – a product of the deep decomposition of the former [2, 13, 18–20].

Thallomoalginite is dark-grey in the reflected light; it may have a different degree of the conservation of initial structure of plant residues – from colonies with the outline characteristic of a

TABLE 1

Characterization of the studied samples of sapropelite coal

Sample code	Technical analysis, %				Elemental composition, % per daf			Atomic ratio	
	W^a	A^d	V^{daf}	S_t^d	C	H	(N + S + O)	H/C	O/C
1	1.7	3.4	83.8	0.7	74.3	10.1	15.6	1.63	0.16
2	5.3	3.9	76.5	3.2	74.9	9.6	15.5	1.54	0.15
3	1.5	1.5	73.9	0.8	77.8	9.9	12.3	1.53	0.12
4	5.1	4.1	72.5	0.7	77.2	9.7	13.1	1.51	0.13
5	1.0	11.6	64.2	1.1	83.2	8.8	8.0	1.27	0.07
6	6.7	6.4	56.4	0.5	88.7	8.8	2.5	1.19	0.02

Note. 1. W^a is analytical humidity, A^d is ash content, V^{daf} is the yield of volatile substances, S_t^d is total sulphur content, daf is the dry ash-free state of the sample. 2. Here and in Table 2, in Fig. 1 the samples are from: 1 – the Charchik deposit, 2 – Seredeyskaya mine, 3 – the Sobolevo deposit, 4 – the Budagovo deposit, 5 – the Barzas deposit, 6 – the Taymylyr deposit.

TABLE 2

Petrographic composition of the samples of sapropelite coal

Sample code	Microcomponent composition, %				$R_{o,r}$, %
	Liptinite (alginite)		Vitrinite	Inertinite	
	TA	CA			
1	50	25	23	2	0.27
2	83	8	8	1	0.33
3	6	70	24	–	0.29
4	5	87	8	–	0.37
5	6	85	8	1	0.35
6	44	43	13	–	0.42

Note. 1. TA is thallomoalginite, CA is colloalginite, $R_{o,r}$ is vitrinite reflectance. 2. For designations, see Table 1.

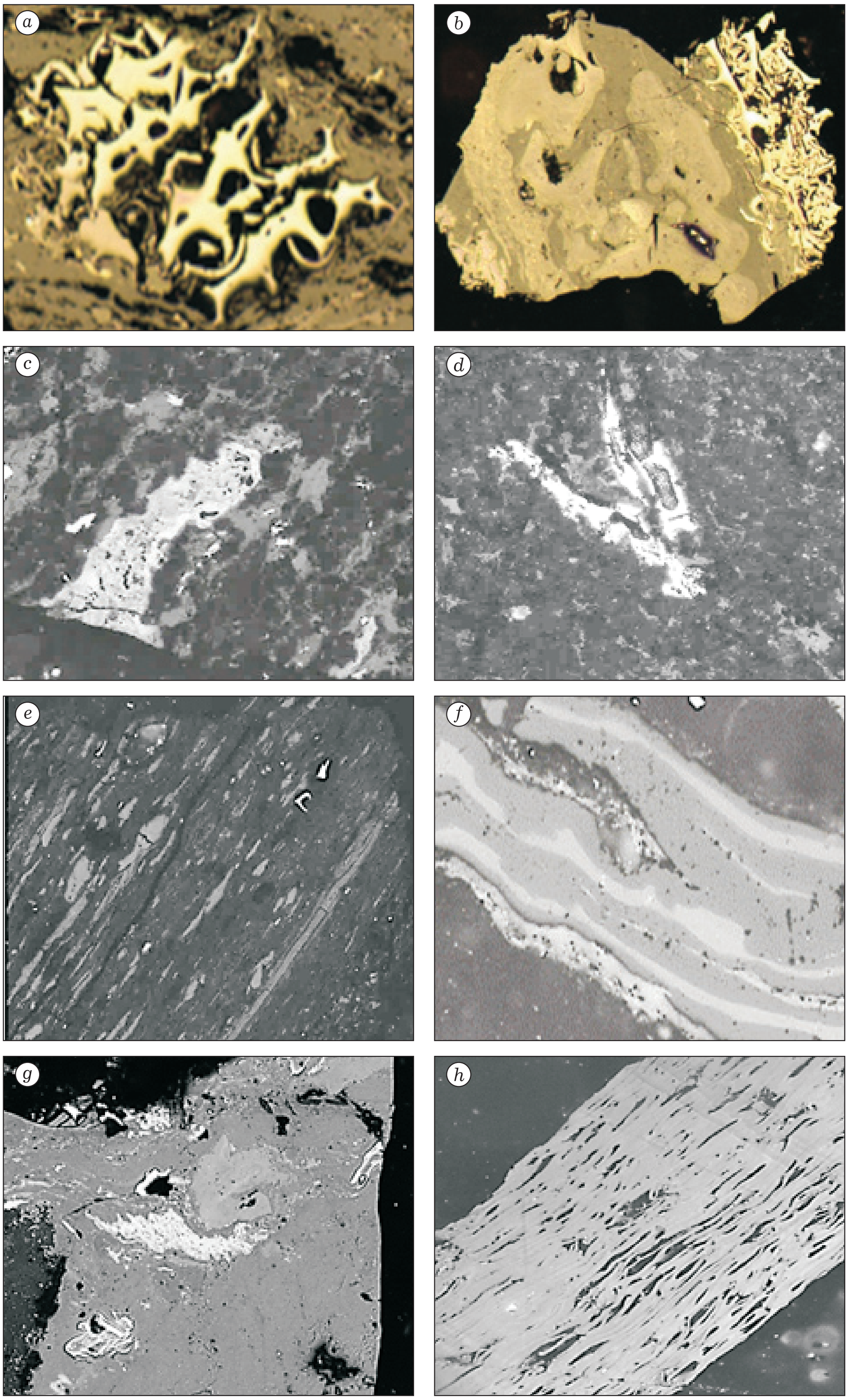

Fig. 1. Microphotographs of the surface of thin polished sections (reflected light, oil immersion, magnification 300) of the studied sapropelite coal samples with different petrographic macerals: *a* – sample 2 (fusinite with cellular structure conserved to different extents); *b* – sample 3 (fusinite, macrinite); *c* – sample 2 (thallomoalginite with vitrinite); *d* – sample 1 (a fragment of oxidized vitrinite in thallomoalginite); *e* – sample 4 (colloalginite oriented along layering); *f* – sample 5 (accumulation of lipoid components with fine fragments of vitrinite); *g* – sample 1 (collinite with the lenses of telinite, inertinite and liptinite); *h* – sample 6 (collinite interlayering with liptinite). For sample designation, see Table 1.

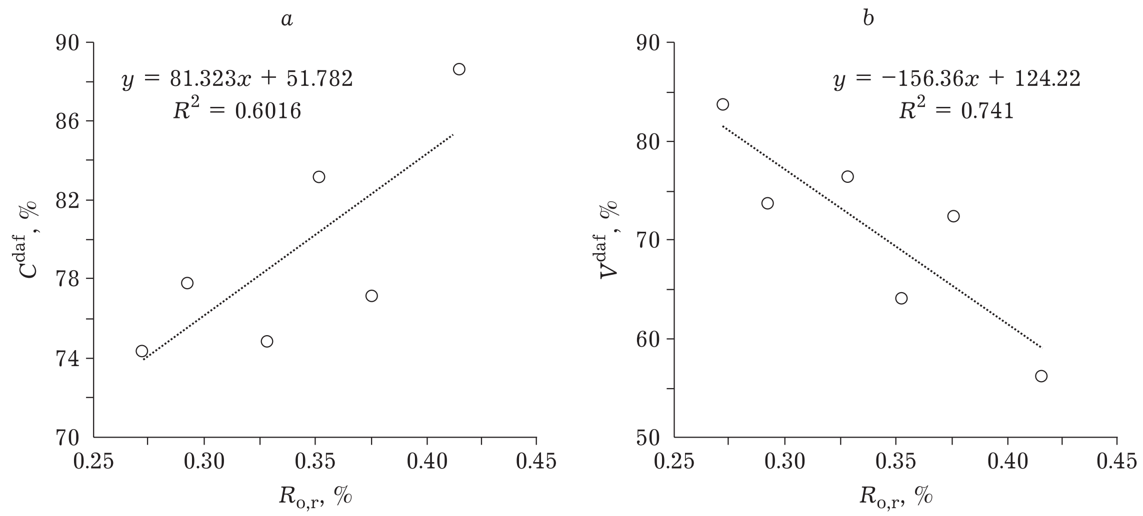

Fig. 2. Correlation of vitrinite reflectance ($R_{o,r}$) of sapropelite coal samples with carbon content (*a*) in their organic mass and with the yield of volatile substances (*b*).

definite algae genus and clearly distinguished contours shaped as oval and spindle-shaped bodies devoid of internal structure [2, 13]. Usually, these are corpuscles with non-uniform crumbly structures (see Fig. 1, *c*, *d*).

Colloalginite is an unstructured sapropele basic mass cementing the formed elements and mineral admixtures; it is formed through gelatinization of lower algae. Its colour is dark-grey in the reflected light, similarly to thallomoalginite [2, 13] (see Fig. 1, *e*).

The largest number of microcomponent of the alginate group was revealed in sample 2 from the Seredeyskaya mine (91 %), and in the samples from the Budagovo (92 %) and Barzas (91 %) deposits (see Table 2). The largest amount of thallomoalginite (TA) was detected in sapropelite from the Seredeyskaya mine. Colloalginite (CA) dominates in coal samples from the Budagovo, Sobolevo and Barzas deposits. The samples from the Barzas deposit contain also small amounts of liptinite microcomponents represented by dark-grey culiculas and spores (see Fig. 1, *f*).

The group of vitrinite macerals is mainly represented by collinite in the form of unstructured mass cementing all other macerals (see Fig. 1, *g*, *h*). The largest amount of vitrinite was detected in the samples from the Charchik (23 %) and Sobolevo (24 %) deposits. Vitrinite reflectance ($R_{o,r}$) in the samples varies within relatively narrow range from 0.27 % (sample 1, the Charchik deposit) to 0.41 % (sample 6, the Taymylyr deposit) (see Table 2).

It is known that an increase in the degree of maturity of sapropelites and kerogenic shale is connected with an increase in carbon content in their organic mass [20–22]. Vitrinite reflectance established for the studied samples was compared with carbon content C^{daf} and the yield of volatile substances V^{daf} (Fig. 2). The graphic analysis revealed a correlation (R^2 = 0.6–0.7) between these parameters.

CONCLUSION

The petrographic composition of six samples of sapropelite coal from different deposits of Russia was carried out. The studied samples are low-sulphur and are characterized by the increased yield of volatile substances (56.4–83.8 %) and increased H/C atomic ratio (1.19–1.63).

The visual analysis of the polished thin sections allowed us to determine the maceral composition of the studied coal samples. It was established that the content of liptinite group macerals in the samples exceeds 75 %, the content of vitrinite group macerals varies from 8 to 24 %, and inertinite group is present in minor amounts – not more than 1–2 %.

Vitrinite reflectance was used to determine the genetic maturity of the studied sapropelites. It was established that vitrinite reflectance ($R_{o,r}$) in the samples varies within a relatively narrow range from 0.27 % (sample 1, the Charchik deposit) to 0.41 % (sample 6, the Taymylyr deposit). An increase in vitrinite reflectance in sapropelite samples is connected with the change in chemical composition and the technological properties of their organic mass. It is demonstrated that an increase in $R_{o,r}$ is accompanied by an increase in carbon content, a decrease in the yield of volatile substances and H/C atomic ratio.

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REFERENCES

1 Stach E., Mackowsky M. T., Teichmueller M., Taylor G. H., Chandra D., Teichmueller R., Coal Petrology, Berlin: Gebruder Borntraeger, 1982. 532 p.
2 Zhemchuzhnikov Yu. A., Ginzburg A. I., Foundations of Coal Petrology [in Russian], Moscow: Izd-vo AN SSSR, 1960. 185 p.
3 Bodoev N. N., Sapropelite Coal [in Russian], Novosibirsk: Nauka, Sib. Otd-e, 1991. 120 p.
4 Semenova Z. V., Smirnov N. I., Bochkarnikova E. A., Ptashkin O. E., Hydrogenation of sapropelite of various Siberian deposits [in Russian], *Khimiya Tv. Topliva*, 1997, No. 3, P. 70–75.
5 Patrakov Yu. F., Fedyaeva O. N., Fedorova N. I., Gorbunova L. V., Effect of ultrafine grinding of coal in H-donor solvent on its ability to thermal dissolution [in Russian], *Khimiya Tv. Topliva*, 2006, No. 3, P. 24–32.
6 Patrakov Yu. F., Fedorova N. I., Pavlisha E. S., Thermal dissolution of mechanically activated Barzas sapromyxite coal in benzene under supercritical conditions [in Russian], *Khimiya Tv. Topliva*, 2011, No. 4, P. 32–37.
7 Zykov I. Yu., Dudnikova Yu. N., Kozlov A. P., Fedorova N. I., Ismagilov Z. R., Adsorption characteristics of carbon sorbents from naturally oxidized Barzas coal, *Chemistry for Sustainable Development,* 2017, Vol. 25, No. 6, P. 564–568.
8 Korol I. S., Savelyev V. V., Golovko A. K., Composition of soluble organic matter of the boghead shale (the Taymylyr deposit) [in Russian], *Vestn. Tom. Gos. Un-ta. Khimiya*, 2017, No. 9, P. 6–14.
9 Kuznetsov D. T., Oil Shales of the World [in Russian], Moscow: Nedra, 1975. 368 p.
10 Patrakov Yu. F., Fedorova N. I., Characteristics of oil shale and boghead from the Olenek district of the Lena basin [in Russian], *Khimiya Tv. Topliva*, 2009, No. 3, P. 3–8.
11 Vorobyev B. M., Coal in the World [in Russian], Vol. III. Moscow: Gornaya Kniga, 2013. 752 p.
12 Ulanov N. N., Composition, properties and possible routes for non-fuel use of coal from the Barzas deposit [in Russian], *Khimiya Tv. Topliva*, 1992, No. 5, P. 17–25.
13 Fomin A. N., Coal Petrographic Studies in Petroleum Geology [in Russian], Novosibirsk: IGiG SO AN SSSR, 1987. 166 p.
14 Fomin A. N., On the nature of barzassite (Summary), *Oil Shale*, 1990, Vol. 7, No. 1, P. 36–41.
15 Stukalova I. E., Sykorova I., Makh K., Petrographic types of brown coal [in Russain], *Izv. Vuzov. Geologiya i Razvedka*, 2012, No. 1, P. 27–33.
16 Səkorová I., Pickel W., Christanis K., Wolf M., Taylor G. H., Flores D., Classification of huminite – ICCP System 1994, *Int. J. Coal Geol.,* 2005, Vol. 62, P. 85–106.
17 Pešek J., Sýkorová I., A review of the timing of coalification in the light of coal seam erosion, clastic dykes and coal clasts, *Int. J. Coal Geol.,* 2006, No. 66, P. 13–34.
18 Mingareev R. Sh., Tuchkov I. I., Management of the Deposits of Bitumen and Oil Shale [in Russian], Moscow: Nedra, 1980. 572 p.
19 Stolbova N. F., Isaeva E. R., Coal Petrology [in Russian], Tomsk: Izd-vo TPU, 2013. 77 p.
20 Bogorodskaya L. I., Kontorovich A. E., Larichev A. I., Kerogene: Methods of Investigation, Geochemical Interpretation [in Russian], Novosibirsk: Publishing House of SB RAS, Geo branch, 2005. 254 p.
21 Bhowmick T., Nayak B., Varma A. K., Chemical and mineralogical composition of Kathara coal, East Bokaro coalfield, India, *Fuel*, 2017, Vol. 208, P. 91–100.
22 Hackley P. C., Cardott B. J., Application of organic petrography in North American shale petroleum systems: A review, *Int. J. Coal Geol.,* 2016, No. 163, P. 8–51.