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THE MINERALOGY OF THE PELITIC FRACTION OF THE LOWER CARBONIFEROUS DOMBAROVSK ANTHRACITE DEPOSITS, SOUTH URALS, RUSSIA

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(4 figures, 1 table)

ABSTRACT. The sedimentary complexes of the Dombarovsk deposits (Ural eastern slope) underwent important transformation. The diagenetic rock alteration and the organic matter metamorphism observed in the Lower Carboniferous rocks are assumably due to frequent high tectonic stresses of various directions. Coals were transformed into anthracites of high degree of metamorphism, with a graphite-like structure in most altered parts. Intensive P-T stresses also transformed the minerals. The host rock minerals became structurally altered as to yield the $2M_1$ micas typical of high-temperature.

Keywords: diagenetic rock alteration, organic matter metamorphism.

1. Introduction

Our investigations are devoted to the study of the extent of transformation of the Lower Carboniferous sedimentary complexes located in the Ural eastern slope. These are similar in age and composition, but differ in tectonic setting, dislocation and extent of metamorphic transformation. Lower Carboniferous coal-bearing sedimentary complexes are widespread over the entire eastern slope of the Urals. The Man'in coal occurrence is located to the north. The eastern part of the Sverdlovsk region in the middle Urals host several coal deposits in the Egorshin-Kamensk district (near Yekaterinburg). Poltavo-Bredinsk district and Dombarovsk deposits are located in the south of eastern slope of the Urals (Fig.1). The Lower Carboniferous coal-bearing formations vary in thickness averaging 500-700 m. Sometimes coal-bearing sequence reaches a thickness of 900-1000 m. Sedimentary complexes consist of coaly argillites, siltstones, sandstones, shales and coal seams of paralic origin with thickness varying from 0.5 m to 1.2 m.

Coal rank increases from north to south, according to vitrinite reflectance values (R_o). High volatile matter bituminous coals were recovered in the Man'in coal occurrence (R_o=0.75-1.0%). There are low volatile matter bituminous coals and anthracites in the Egorshin-Kamensk coal district (R_o=2.2-3.5%) and anthracites of higer rank in the Dombarovsk deposits (R_o=4.7-5.3%).

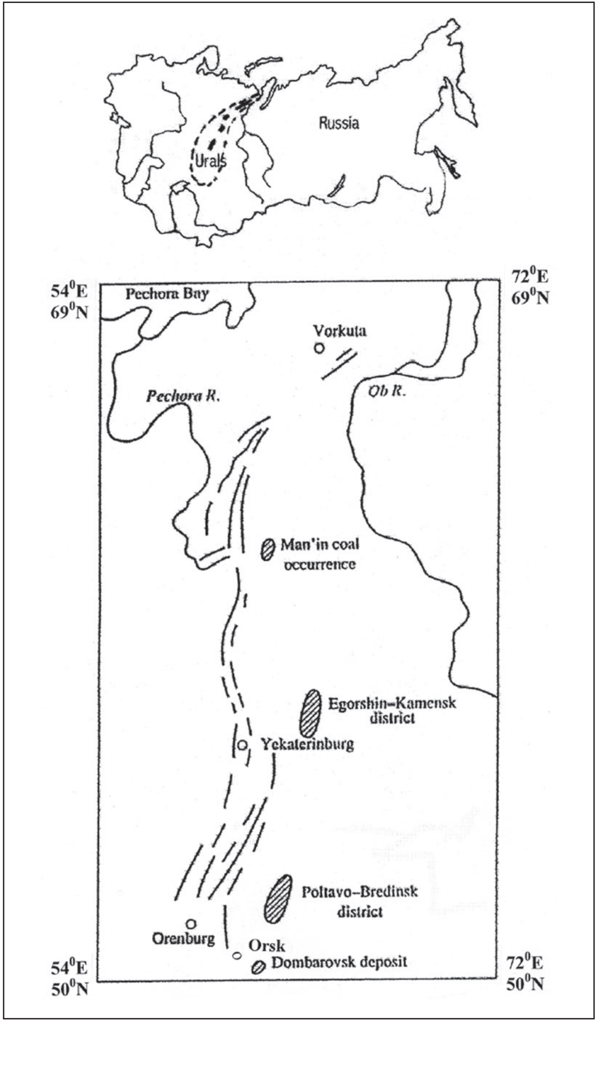

Figure 1. Geographical location and schematic distribution of the Lower Carboniferous coal-bearing sediments on the Ural eastern slope.

The key study concerns the Dombarovsk Lower Carboniferous series as the extreme southern manifestation in the Ural eastern slope. They share the genetic character and age with earlier studied the Man'in coal occurrence (Northern Urals) and Egorshin and Altynai deposits in the Egorshin-Kamensk district (Middle Urals), (Stukalova *et al.*, 2001).

The 2001 fieldwork carried out in the Orenburg region (South Urals) enabled to collect abundant data. As shaft mining and drilling have been abandoned in the Dombarovsk deposits, the Lower Carboniferous rock samples of different lithological varieties were collected in two Dombarovsk quarries, which exposed the highly dislocated, folded and pinched coal-bearing sediments. Abundant occurence of ore mineralization permited to attribute the local Lower Carboniferous rock outcrops to both anthracitic and haematitic conditions.

2. Geological setting

The Dombarovsk deposits were described in detail by L.D. Basharkevich, O.V.Zhukov and A.N.Sukhorukov (Basharkevitch, 1967; Coal base…, 2000). These authors mainly focused on the coal quality. The raw rocks and the pelitic rock fraction composition as well as the extent of transformation were studied in less detail.

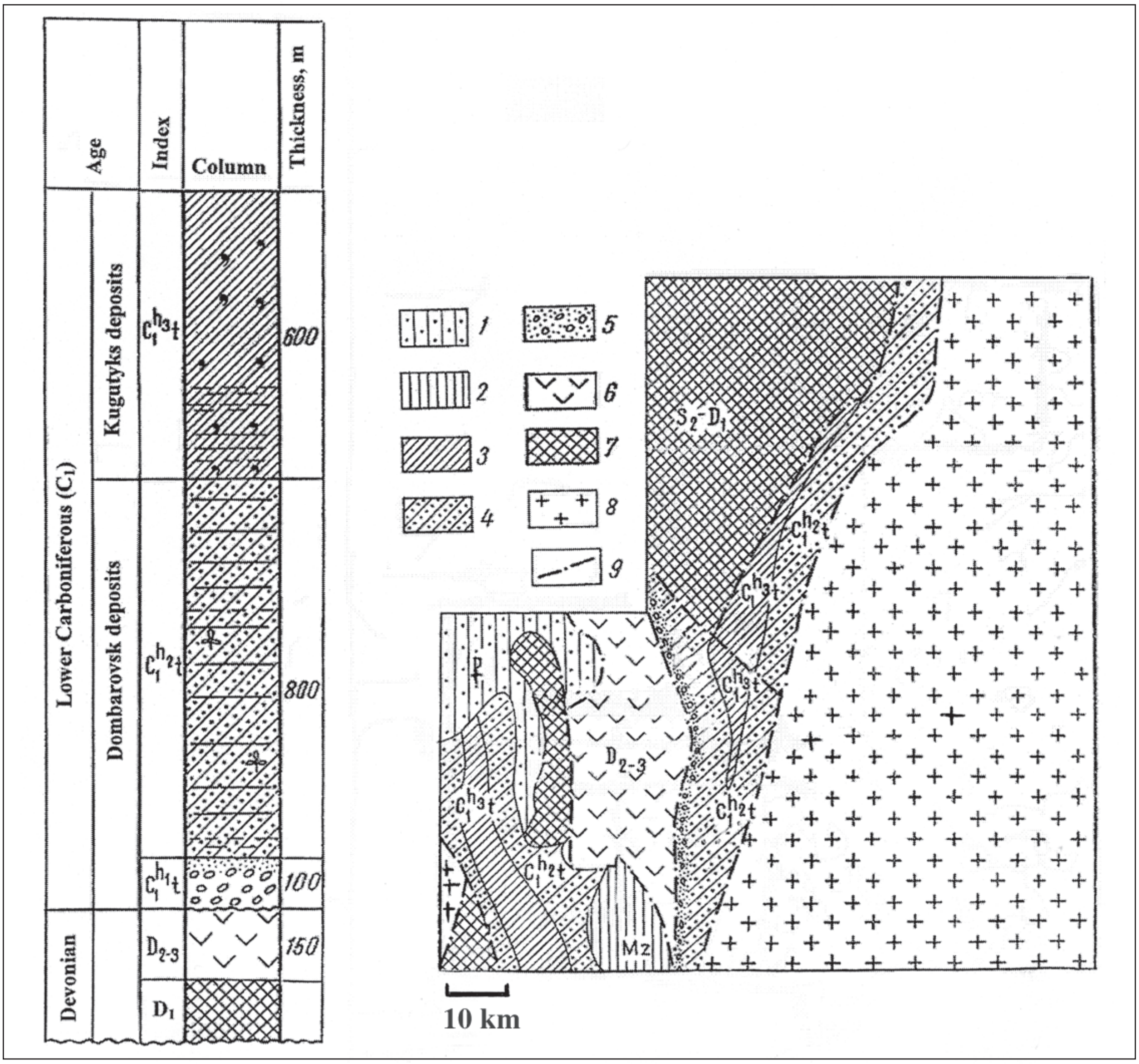

Figure 2. Schematic geological map of the Dombarovsk deposits (arrow represents 10 km): 1 - Paleogene eluvial loams, 2- Mesozoic (Mz) sands, 3 - Lower Carboniferous Kugutyks terrigenous deposits (C1h3t), 4 - Lower Carboniferous Dombarovsk coal-bearing deposits (C1h2t), 5- Lower Carboniferous conglomerate series (C1h1t), 6 - Middle-Upper Devonian (D2-3) tuffs of basaltic and andesitic porphyrites, 7 - Silurian and Devonian (S2-D1) intrusive and volcanic basic and andesitic rocks, 8 - Precambrian granites and gneisses, 9 - faults.

This paper focuses on the analysis of the pelitic fraction, which composition permits to assess the extent of post-sedimentary rock alteration.

The Dombarovsk deposits are located in the Orenburg district, 100 km East of the town of Orsk (Fig.1). They are confined to the Dombarovsk fault graben, located in the joint zone of the Magnitogorsk depression and the East-Urals rise (Coal base…, 2000). The structure is filled with Paleozoic sediments (Fig.2). On the West there are Silurian and Devonian (S_2-D_1) intrusive and volcanic basic and andesitic rocks and Middle-Upper Devonian (D_{2-3}) tuffs of basaltic and andesitic porphyrites. To the East of structure there are Precambrian granites and gneisses. The Lower Carboniferous (C_1) sequence comprise conglomerate series ($C_1^{h1}t$), Dombarovsk coal-bearing deposits ($C_1^{h2}t$) and Kugutyks terrigenous deposits ($C_1^{h3}t$). Mesozoic (Mz) sands without coals and Paleogene eluvial loams with thickness 1.0-10.0 m also spread. The strongly dislocated Lower Carboniferous Tournaisian (C_1) coal-bearing sequence reaches a thickness of more than 900-1000 m (Fig.2). The productive Dombarovsk deposits comprise highly metamorphosed sandstones, siltstones, claystones, shales, and coaly rocks affected by different cleavage types, with coal interlayers and coal seams of paralic origin with thickness varying from 0.5 m to 1.2 m (Basharkevitch, 1967). The coal potential decreases northward and southward of the central sector where both investigated quarries are located.

Anthracite with various textures is often folded and smashed into pieces, with a carbon content (C^{daf}) of 91,0-94,6% (Coal base…, 2000). The vitrinite reflectance (R_o) is high (4,7 - 5,3%), (Alekseev *et al.*, 1997).

3. Petrographic studies

In rock and coal polished sections the coal shows a strong anisotropy in polarized reflected light and a heterogeneous structure, typical of anthracites of high rank. The peak reflectance value (R_o) is equal to or above 5,3-5,5%.
The coal polished sections studied in reflected light at high magnification, show fragments of vegetable tissue, sometimes with a distinct cellular structure. These fragments are composed of different microcomponents, including vitrinite (telinite and collinite) and inertinite (Fig.3, photo 1, 2). Strong anisotropy and distinct heterogeneous structure as observed under crossed nicols exhibit uncommon remains of cellular cavities (Fig.3, photo 3,4). Coarse and fine haematite inclusions are present (Fig.3, photo 3). Curved, elongated vitrinite lenticles occur in coaly siltstones (Fig.3, photo 5, 6). Their heterogeneous, inner structure is distinctly recognized under crossed nicols in several highly altered areas. Vitrinite (anthracite) lenses show numerous fissures, developed either as voids or as mineral infilling. Highly elongated anthracite lenticles with plication (assumably due to tectonic stress) demonstrate the rock alteration when in a consolidated state (Fig.3, photo 5,6).

4. Composition of the pelitic rock fraction

Results of X-ray analyses of the pelitic fraction of coaly claystones and siltstones sampled from coal-bearing Lower Carboniferous Dombarovsk series are here provided.

Oriented aggregates of the pelitic fraction (1-2μm) were extracted for X-ray examination from clay suspension in water and settled on a glass plate. The X-ray DRON-2.0 difractometer (CuK_a – radiation) has been used for analyses.

The X-ray analyses show dioctahedral mica as the dominant mineral in all samples, associated with pyrophyllite and chlorite (Fig.4). Some samples contain kaolinite and a mixed-layer mineral, with minor amounts of quartz and feldspar. Na-mica was assumed to be present.

N° sample	lithology	mineral composition	X-ray mica characteristics					
			$d_{(001)}$ (Å)	c sin β (Å)	Hb	$I_{(001)}/I_{(002)}$	$I_{(001)}/I_{(001)}/I_{(003)}$	Polytypism of the micas
1	coaly claystone	K-mica, rectorite, chlorite, kaolinite, quartz, feldspars	9,90	19,99	110	2,6	50-19-31	$2M_1$+1M
2	coaly claystone	K-mica, Na-mica, haematite, quartz	9,94	19,99	120	2,6	55-16-29	$2M_1$>1M
3	coaly siltstone	K-mica, pyrophyllite, chlorite, quartz, feldspars	9,96	19,95	105	2,5	49-19-35	$2M_1$
4	coaly siltstone	K-mica, pyrophyllite, chlorite	9,94	19,98	110	2,6	46-18-36	$2M_1$
5	siltstone	K-mica, Na-mica, rectorite, kaolinite	9,89	19,98	120	3,1		?

Table 1. Results of X-ray analyses of the pelitic rock fractions of the Dombarovsk deposits.

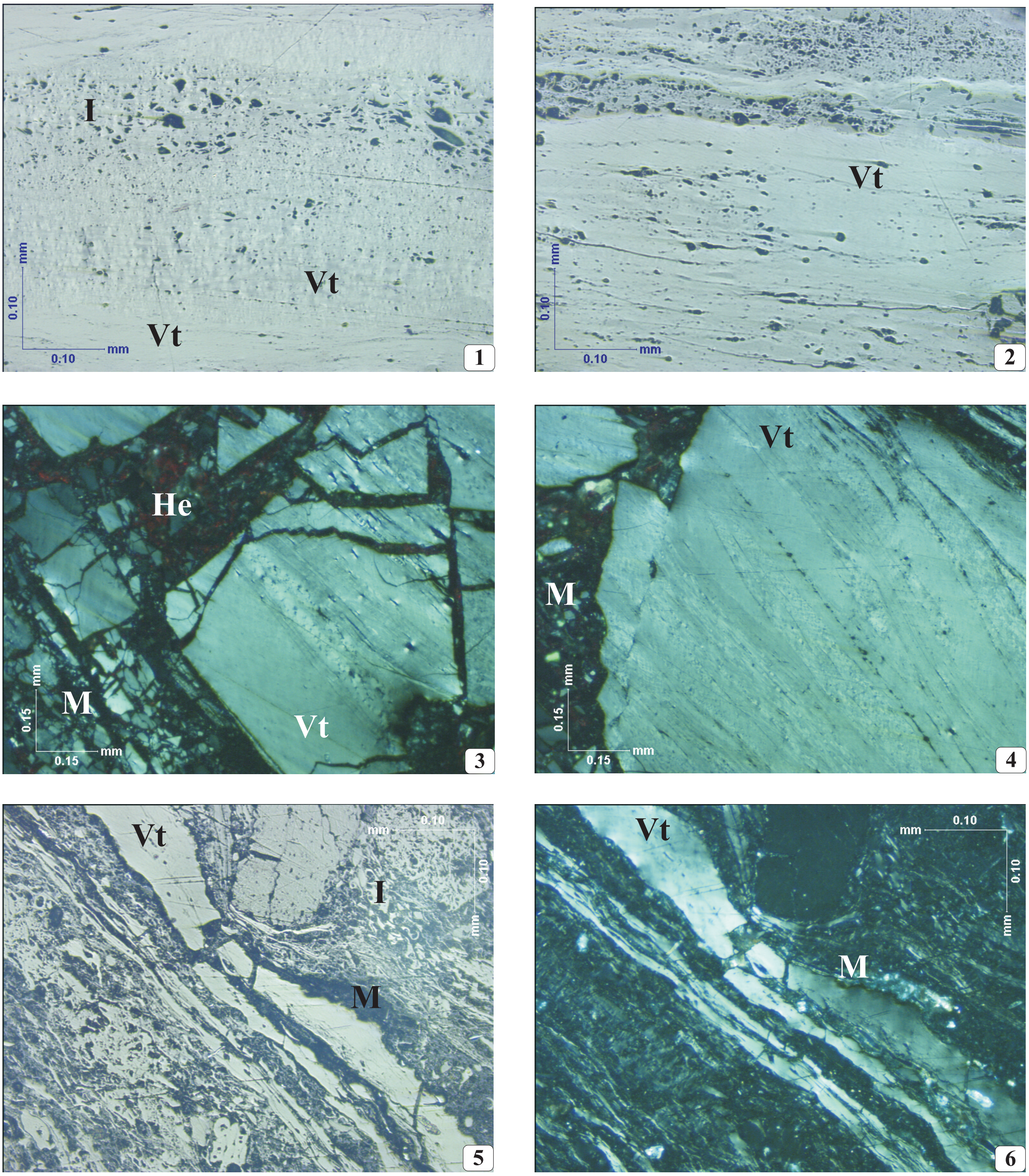

Figure 3. Photomicrographs of polished sections of the Lower Carboniferous anthracites and coal-bearing rocks from the Dombarovsk deposits (South Urals). Polarized reflected light, 300^x.
1, 2 - Anthracite polished sections: fragments of vegetable tissue, sometimes with a distinct cellular structure. Organic components: vitrinite (telinite and collinite) -Vt, and inertinite - I. 3, 4 - Anthracites showing a strong anisotropy under crossed nicols, and a heterogenous structure typical for anthracites of high rank. Anthracite fragments with numerous fissures, filled with haematite (He) and clay minerals (M).
5, 6 - Curved, elongated vitrinite lenticles in a coaly siltstone. The heterogenous structure is recognized under crossed nicols, in highly altered areas. Vitrinite (Vt) lenses are affected by numerous fissures, with clay mineral infilling (M).

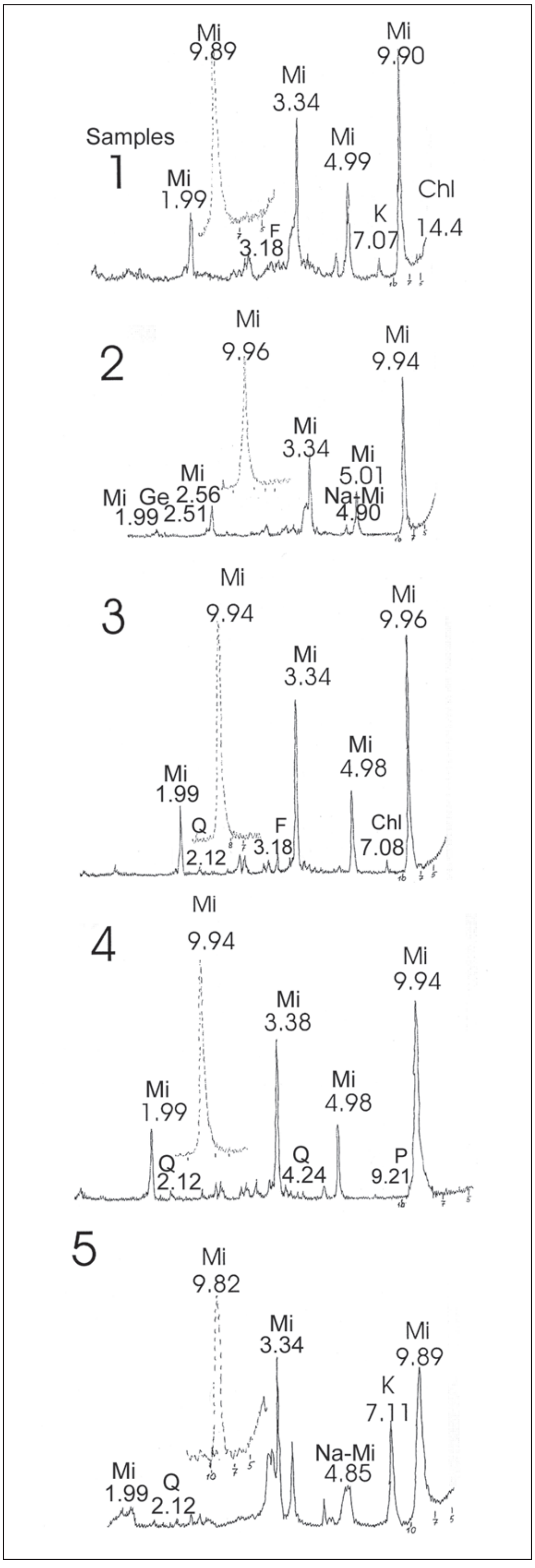

Figure 4. XRD patterns of the pelitic rock fractions of the Dombarovsk deposits.

The phase composition for several samples and X-ray characteristics of the micas were tabulated and showed the following parameters: the first basal $d_{(001)}$ reflection; the $c \sin\beta$ (Å) parameter; the crystallinity index of Weber (Hb); the intensity ratio of the two first reflections $I_{(001)}/I_{(002)}$; the intensity ratio of the three reflections $I_{(001)}/I_{(002)}/I_{(003)}$; the mica structural modification (see Table).

The pelitic fraction chiefly contained a mica belonging to the $2M_1$ polytype with typical reflexions at 4.99; 4.98; 3.38; 3.34; 1.99 Å. The light-colored dioctahedral potassium micas (K-micas) occurred in most samples without hydrated states. The first reflection $d_{(001)}$ was as 9.89-9.96 Å (Fig.4).

The $c \sin\beta$ (Å) parameter corresponds to the thickness of the mica's structural packets: its value is controlled by the packet's composition and by the ionic radius of the cations filling the interlayer space. It is calculated from the fifth basal reflection as $d_{(005)}$ x 10 estimated for two-layer modification (Micas, 1984). In our case, this value was 19.95 - 19.99 (Å). The packet's thickness varies insignificantly, indicating that the micas composition differred slightly from that of a muscovite, with potassium interlayer filling.

The first order basal reflections may merge, while the fifth-order ones differred for K- and Na-mica, and may thus be used to detect the occurrence of Na-mica in the pelitic fraction. The 1M-mica and Na-mica varieties also occurred in the studied samples.

K-mica showed a rather high range of crystallinities. The crystallinity index after K.Weber (Weber, 1972) determined from the formula: $Hb=Hb_{(001)}/Hb_{(001)Q}x100$ was from 105 to 120. Such values are typical of high-temperature, well structured non-hydrated micas. Micas mostly belonged to the $2M_1$ polymorphs.

The pelitic fraction also contained chlorite (with $d_{(001)}$ varying from 13.8 to 14.0 Å and its $d_{(003)}$ from 4.72 to 4.69 Å), and pyrophyllite (9.21; 4.60 and 3.06 Å). A few samples contained kaolinite. Feldspars (Na-Ca plagioclase and orthoclase) and quartz occurred in minor amounts. Haematite was identified by its typical reflexions at 3.68; 2.698; 2.515; 2.209; 1.841 and 1,693Å.

Several samples contained rectorite (a regular mixed-layer pyrophyllite-smectite) characterized by its sequence of reflections at 21.8; 10.52; 5.34; 4.98 and 4.76 Å in its natural (air dried) state. After solvation with ethylene-glycol these reflections shifted to 25.6; 13.0; 9.72; 6.6 and 5.24Å. After heating at 550°C, the reflections shifted to 21.9; 9.78; 6.45 and 4.86 Å. Several samples of the oriented aggregates of the pelitic fraction below 1μm contained a pure rectorite, sometimes mixed with $2M_1$ mica and pyrophyllite.

5. Discussion and conclusion

The Dombarovsk deposits were formed in complex geological conditions, as recurrently emphasized in many publications (*i.e.* Basharkevitch, 1967; Alekseev *et al.*, 1997).

The diagenetic rock alteration and the organic matter metamorphism observed in Lower Carboniferous rocks are assumed to be due to repeated tectonic stresses developed along different trends. Due to the high degree of metamorphism the coal has been transformed into anthracite with a graphite-like composition in most altered occurrences. The primary host rock minerals became structurally altered into $2M_1$ micas typical for high-temperature conditions. The structural properties of the Dombarovsk deposits anthracite - its fractionation nature, goffering and strong anisotropic properties indicated that the coal deposits endured stresses. Besides, these rocks have also been affected by hydrothermal solutions, including ore mineralization. Thanks to fractures, these hydrothermal fluids penetrated into the organic matter of the coal seams. The organic matter was than cemented and transformed into hydrocarbon-ore aggregates.

Intensive P-T conditions have affected both the mineral matter and the composition of the pelitic fraction. These conditions triggered the clay mineral transformation, in particular, the appearance of $2M_1$ polytype at temperatures of 200-250°C.

All X-ray characteristics of the micas indicate that the pelitic fraction of the Dombarovsk sediments actually mainly contains a $2M_1$ mica, altough 1M and Na-mica also occur. The association of $2M_1$ and 1M micas and of rectorite in the pelitic fraction suggested a stepping evolution affecting the Dombarovsk deposits. The transformation temperature reached sometimes 160°C (the occurrence of the rectorite) and than over 220°C (transformation into $2M_1$ mica polymorph).

Clay mineral alteration at high temperatures is well illustrated: for instance, any increase in temperature changes a parent or inherited smectite into a more or less regular illite-smectite mixed layer, while illite remains stable to temperatures higher than 220°C (Micas, 1984; White and Hedenquist, 1995). The 1M mica politype is known to be a non-stable phase, while the $2M_1$ mica is the only thermodynamically stable polymorph. Occurrence of $2M_1$ mica has been established in the present study, and indicates a deep metamorphism which has affected the studied sedimentary complexes.

The pelitic rock fractions from the Egorshin and Alynai coalfields in the Egorshin-Kamensk district (near Yekaterinburg, Middle Urals) are composed of kaolinite, illite-smectite mixed-layers, pyrophyllite, chlorite and quartz, but without any $2M_1$ mica (Stukalova *et al.,* 2001).

The mineralogy of the pelitic fractions allows to conclude that post-sedimentary transformations of the Dombarovsk deposits (South Urals) were more intense than in the Middle Urals Egorshin and Altynai coalfields.

The transformation of humic organic matter in Lower Carboniferous coal deposits of the Urals eastern slope is controlled by: 1) the extent of diagenetic alteration of organic matter, resulting from the sedimentary basin subsidence and 2) subsequent geologic processes, imposed on the already-formed coals (stresses related to the formation of collision belts in Urals).

Provided other conditions are alike, a direct relationship exists between the regional tectonic stress and coal rank in particular coal fields. Besides, clay diagenesis in the pelitic fraction in the host rock changes from mixed-layer smectite-mica varieties to micas of $2M_1$ polytype modification, stable at high pressure and temperature values.

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