



PETROGRAPHICAL STUDY OF ANTHRACITES FROM EUROPEAN COAL BASINS

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Abstract. The anthracites from several coal basins occurring in France, Germany, Ireland, Poland, Romania, Russia, Ukraine and United Kingdom were studied in reflected plane-polarised light (Olympus microscope). Three maceral groups (vitrinite, inertinite, liptinite) and associated mineral matter were distinguished. All the anthracites are dominantly composed of vitrinite (75–95%), inertinite is minor (2.5–19%), and liptinite is very rare (up to 1.5%, with one exception — 4.4%). In vitrinite group, the following macerals: collotelinite, telinite, collodetrinite, vitrodetrinite, and pseudovitrinite were recognised. In inertinite group, the most abundant are fusinite and semifusinite. Liptinite in general is dominated by sporinite. In some anthracites, liptinite was not accounted at all, perhaps, in such highly metamorphosed anthracites, sporinite underwent a rapid change in chemical and physical composition, and became optically indistinguishable from vitrinite. In a few samples, sporinite can be recognised from its vitrinite matrix by a distinct optical morphology.

Optical microscopical studies of all anthracites revealed significant heterogeneity of the samples, clearly visible under crossed nicols with the use of higher magnifications. This heterogeneity reflects the differences in coal facies, in primary maceral composition, inherited from peat or sub-bituminous stages but also in strain or pressure being distributed inhomogeneously during formation of anthracite. In all cases, heterogeneous microtexture (fine, coarse, granular, mosaic, and fibrous) was observed. Porous and lamellar particles coexist very often together. Coke-like structure, with numerous devolatilization vacuoles, was also recognised. Pyrolytic carbon occurring as veins, sub-parallel to bedding, can be easily noticed in some samples. Pyrolytic carbon types are presumed to originate from volatiles evolved during condensation reactions.

Reflectance values (R_{\max}) of anthracites vary from 2.3% up to 8.9%. These samples which exhibit R_{\max} higher than 6% were considered as meta-anthracites. It seems, that the latter are made of conglomerates of graphite-like complexes having preferential planar orientation and structurally less organised compounds with typical turbostratic arrangement of the aromatic units.

Key words: anthracites, heterogeneity, microtexture, reflectance.

INTRODUCTION

Anthracites are high rank coals belonging to sedimentary solid fossil fuels. They are, since many years, objects of interdisciplinary studies. They represent final stage of coalification range. Precise and versatile identification of anthracites, which are proved to be heterogeneous natural substance (Duber *et al.*, 1997, 2000), requires close co-operation between chemists, physicists, geologists, and petrologists. It is commonly known that these specialists have quite different view concerning

microtexture, microstructure, and they use different methods of their examination.

We would like to present the optical methods based on reflected light microscopy (Olympus, Japan and Axioskop Opton, Germany microscopes, with monochromatic linearly polarised light of $\lambda = 546$ nm with oil immersion and MPM 200 microphotometer).

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RESULTS

Microscopic observations of all the anthracites samples allowed us to divide them into two groups. The results of petrographic composition and reflectance measurements are listed in Table 1. The first group of samples comprises real anthracites (nos. 1–5), and the second contains samples (nos. 6–11) which are meta-anthracites, according to the ICCP classification (Kwiecińska, 1980; Taylor *et al.* 1998). The anthracites of the first group were previously examined by Kwiecińska (1967), Chruściel *et al.* (1985), Wilk and Pawlak (1985), Gabzdyl and Probiez (1987), Kwiecińska and Pawlak (1988), Probiez (1989), Komorek *et al.* (1995), Komorek (1996), Pozzi (1996), Kwiecińska and Nowak (1997), Duber *et al.* (2000). All of them are Carboniferous in age. Samples 2 and 3 come from the area of volcanic activity in which thermal metamorphism of coal was observed. The all anthracites from the first group, are dominantly composed of vitrinite; inertinite is minor, and liptinite is very rare. In vitrinite group, the following macerals: telinite, collotelinite, collodetrinite, vitrodetrinite, and pseudovitrinite (Plate I, Phots. 1–4) were recognised, according to the new ICCP system of the vitrinite maceral group subdivision (Wolf, 1998). Vitrinite varies from 78% up to 88.7%. In particular samples all varieties of vitrinite macerals are discernible. They have slightly different reflectivity and more or less distinct microstructure, especially collotelinite occurring in laminae and collodetrinite in disseminated particles (Plate I, Phot. 2). They exhibit either isotropy or weak anisotropy. In two samples (2, 3), in some laminae of collotelinite, we can see traces of devolatilisation of coal substance indicating an influence of thermal metamorphism on organic matter.

In inertinite group, all macerals (fusinite, semifusinite, micrinite, macrinite, sclerotinite, and inertodetrinite) are represented. They reach the amount up to 18.6%. The most abundant are: inertodetrinite, semifusinite and fusinite exhibiting different types of preserved tissue, including “bogen structure” as well. Aggregates of micrinite, macrinite, and single sclerotia are subordinate. In this group of anthracites, reflectivity of

inertinite remains higher than that of the associated vitrinite (Plate I, Phots. 3, 4).

Liptinite group of macerals is represented in a negligible percentage, with one exception in case of sample from Victoria mine where it attains the value of 4.4%. Liptinite is dominated by sporinite. It exists sometimes in remnants, and together with cutinite can be recognised from the vitrinite matrix by a distinct optical fabric.

Among inorganic compounds prevail framboids of pyrite and clay substance building intergrowths with coaly matter classified as carbargillite. High content of mineral matter (7%) in the sample 2 can be explained by the influence of hydrothermal liquids in a relatively short distance from the coal seam.

The second group comprises the samples derived from Ireland (Misz, 1997), France (Robert, 1988), Romania (Nedelcu, 1995), Ukraine, and Russia. In this group of samples (6–11), content of vitrinite varies from 80.5 to 92.1%, inertinite from 5.7 to 18.3%, and liptinite from 0 to 0.8%. The same macerals, except for telinite, were noticed. Vitrinite is laminated and highly metamorphosed. Vitrinite layers are composed of closely spaced alternating light and dark laminae. Variable intensity of anisotropy reveals significant heterogeneity of vitrinite. The reflectivity of collotelinite is higher in many cases than reflectivity of inertinite. According to Taylor *et al.* (1998), these samples should be classified as meta-anthracites.

On the basis of chemical data, the inertinite macerals lose some of their oxygen and hydrogen during the coalification process, becoming enriched in carbon. These samples have the value of vitrinite reflectance (R_{\max}) above 6%, with the exception of sample 6 which has $R_{\max} = 5.52\%$. For all of these specimens bireflectance is above 1; it means that they show very strong anisotropy. Bireflectance in our case varies from 1.44 to 3.54 (see Table 1). Anisotropy is confirmed by optical studies of all samples from the second group of anthracites. We can observe, under the crossed nicols, variable range of its intensity, from normal to extremely high anisotropic matrix. (Plate I, Phot. 5).

Table 1

Petrographic composition and reflectance data of anthracites

No	Country	Region or basin	Vitrinite [%]	Inertinite [%]	Liptinite [%]	Mineral matter	R_{\max} [%]	R_{\min} [%]	Bireflectance	Optical anisotropy of vitrinite
1	Poland	Victoria mine, L. Silesia	85.2	9.6	4.4	0.8	2.38	1.95	0.43	lack or very lack
2	Poland	Wałbrzych mine, L. Silesia	88.2	4.8	0	7.0	2.30	1.95	0.35	lack or very lack
3	Poland	Moszczenica mine, U. Silesia	88.7	11.2	0	0.1	3.34	2.89	0.45	weak
4	Wales UK	Pays de Galle	84.7	12.0	0.8	2.5	2.81	2.27	0.54	weak
5	Germany	Preusag mine, Ruhr basin	78.0	18.6	1.4	2.0	3.33	2.44	0.89	strong
6	Ireland	Leinster coal field	89.0	7.2	0.7	3.1	5.52	4.08	1.44	weak
7	France	La Mure Alps	83.8	15.4	0	0.8	6.15	3.98	2.17	very strong
8	Romania	Schela formation	92.1	5.7	0	2.2	6.26	3.55	2.71	very strong
9	Ukraine	Swierdlowisk	88.8	7.8	0.8	2.6	6.60	3.97	2.63	very strong
10	Ukraine	Donbass	82.5	11.1	0	6.4	6.19	3.69	2.50	very strong
11	Russia	Listwian Kuzbass	80.5	18.3	0	1.2	8.87	5.33	3.54	extremely strong

We can also notice several types of microtexture: fine, coarse, granular (Plate I, Phot. 6; Plate II, Phot. 1), mosaic, ribbon (Plate II, Phot. 1), and fibrous (Plate II, Phot. 5), and coke-like structure with numerous devolatilization vacuoles (Plate II, Phot. 2) which are interspersed with collotelinite layers. These porous and lamellar particles coexist together. They presumably represent turbostratic (randomly oriented network) and graphitic (preferred orientation) domains. In meta-anthracite stage, the proportion of the graphite-like particles increases (*op. cit.*). In two samples (10, 11) pyrolytic carbon (Plate II, Phot. 3) is also visible. Pyrolytic carbon types are thought to originate from volatiles evolved during condensation reactions.

In particular samples, the differences are in the content of inertinite which varies from 5.7 to 18.3%, but amount of it is hard to evaluate precisely. Sometimes, the macerals from this group, especially fusinite (Plate II, Phot. 4), are very low reflecting. Fusinite in general is isotropic but pyrofusinite has some kind of anisotropy. This feature is typical for meta-anthracite stage. Liptinite was either not accounted at all or in a very small percentage (maximum 0.8%), recognised as a meta-sporinite. Perhaps in such highly metamorphosed coals spores underwent a rapid change in chemical and physical composition and became optically indistinguishable, therefore difficult to determine. This is a very common feature described by many authors (Stach *et al.*, 1982; Taylor *et al.*, 1998). In a few cases, we noticed in meta-sporinite higher reflectance and higher anisotropy than in the accompanying vitrinite.

Mineral matter contents are low, except for the sample from Donbass basin (6.4%). It consists of clays, carbonates (Plate II, Phot. 5) and pyrite (Plate II, Phot. 6).

Considering petrographic composition and reflectance data of anthracites studied here, we can suppose that the division of samples on anthracites and meta-anthracites is done properly. Heterogeneous microtexture of anthracites can also be specified quantitatively by their optical properties expressed in numerical values. Thus, the measurements of reflectance values of anthracites (R'_{\max} , R'_{\min}) and their interpretation based on Kilby's method (1988, 1991) made possible estimation of textural unhomogeneity of anthracites. From the TEM studies (Rouzaud, Oberlin, 1990; Blanche *et al.*, 1995) we know that anthracites are constituted of polyaromatic Basic Structural Units (BSU) which have preferential orientation. This mutual orientation of BSU is understood as texture. The kind of texture can be determined by the size and dimensions of the Reflectance Indicating Surface (RIS). Reflectance which strictly corresponds to texture is described as a three-dimensional ellipsoid, called the Reflectance Indicating Surface (RIS). According to Kilby's method (1988, 1991), based on three principal axes: R_{\max} , R_{\min} , and R_{INT} reflectance values, characteristic RIS parameters R_{st} , R_{ev} , and R_{am} can be determined (Duber *et al.*, 1999).

For the present paper, we have measured the R'_{\max} and R'_{\min} reflectance values for all anthracites on non-oriented vitrinite grains in polarised light, in minimum of 350 points per sample. It has been found that the areas of R'_{\max} and R'_{\min} coupled points

Table 2

Weighted means of RIS parameters values (R_{st} , R_{ev} , R_{am}), number of textural classes (N) and heterogeneity coefficient (H_t) of the anthracites studied

No	N	H_t	R_{st}	R_{ev}	R_{am}
1	33	0.080	-14.95	2.12	0.086
2	5	0.158	-21.29	2.04	0.080
3	6	1.064	-14.09	3.04	0.060
4	6	0.242	-20.66	2.43	0.082
5	6	0.524	-19.40	2.75	0.114
6	4	0.130	-18.20	4.57	0.121
7	4	0.035	-24.09	4.52	0.167
8	3	0.045	-16.34	4.23	0.219
9	4	0.067	-23.62	4.59	0.192
10	3	0.005	-24.16	4.32	0.191
11	5	0.407	-21.46	6.12	0.195

overlap significantly. It is assumed then that sets of coupled R'_{\max} and R'_{\min} data can be divided into several classes in which R'_{\max} and R'_{\min} zones do not overlap. As a result of this division, three to six classes of couples of R'_{\max} and R'_{\min} values for individual anthracite have been identified. It is concluded that the classes obtained in such a way correspond to particles of anthracite of different optical character and, thus, of diversified microtextures.

The reflectance indicating surfaces have been drawn and characteristic RIS parameters (R_{st} , R_{ev} , and R_{am}) calculated for each class of all examined anthracites (Tab. 2). The shape and dimensions of the RIS are different for various classes of individual anthracite. In our opinion, it is the result of microtextural heterogeneity of anthracites. This conclusion corresponds with TEM studies (Blanche *et al.*, 1995). To avoid the details which are described in paper of Duber *et al.* (2000), we can only emphasise that parameter R_{ev} is rather connected with chemical structure (hydrogen contents, atomic ratio H/C), and R_{st} , R_{am} reflect mutual orientation of BSU, it means the texture. We can draw the conclusion that the texture of anthracites is understood as a mutual orientation of the BSU.

The application of Kilby's method to bituminous coals is fully (perfectly) motivated but in case of anthracites (high rank coals) with heterogenic texture of vitrinite (main component of anthracite) this method should be modified. Therefore, this modification was the aim and main subject of previous paper (Duber *et al.*, 2000). Modified Kilby's method allows to determine the heterogeneity of anthracites through forming the textural classes and introducing the coefficients of relative variability (H). In Table 2 we included the coefficient of total heterogeneity (H_t) and number of textural classes accounted for particular anthracites.

CONCLUSIONS

1. Petrographical investigations (maceral composition and reflectance data) allowed to divide the samples into two groups: anthracites and meta-anthracites.

2. The analysis of results of reflectance values by means of modified Kilby's method confirmed this division in all aspects.

3. The anthracites characterise more heterogeneity of texture than meta-anthracites. In the case of anthracites, it is the

greater number of textural classes and the higher value of the total heterogeneity parameter H_t .

4. The meta-anthracites are less heterogeneous; they have lower number of textural classes and low parameter H_t .

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P L A T E S

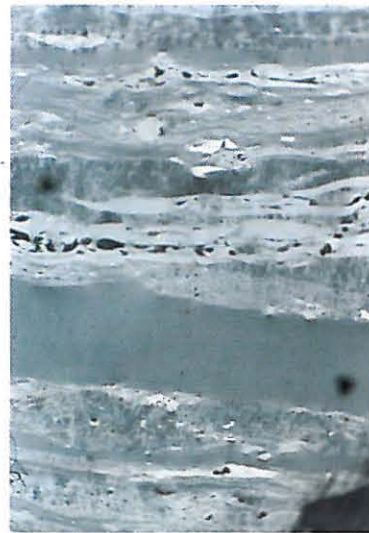
All photographs are made in linearly polarised reflected light microscopy in oil immersion.
Magnification is 400x.

PLATE I

- Phot. 1. Pseudovitrinite in the anthracite from the Wałbrzych mine.
- Phot. 2. Microstructure of anthracite from Victoria mine. Lamination of collotelinite and collodetrinite. Fragments of fusinite are also visible.
- Phot. 3. Fusinite and collotelinite in the anthracite from Preusag mine.
- Phot. 4. The same image under crossed nicols.
- Phot. 5. Microtexture of the meta-anthracite from Romania. Strong anisotropy is visible under crossed nicols.
- Phot. 6. Microtexture of the meta-anthracite from Romania. Crossed nicols.



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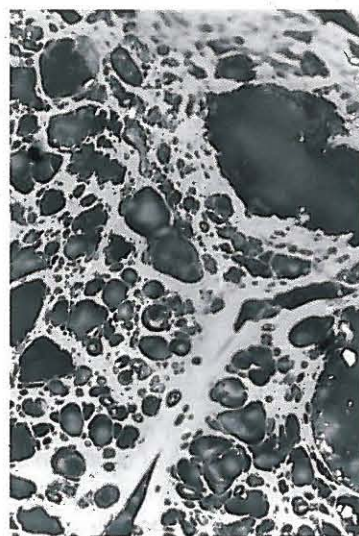
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PLATE II

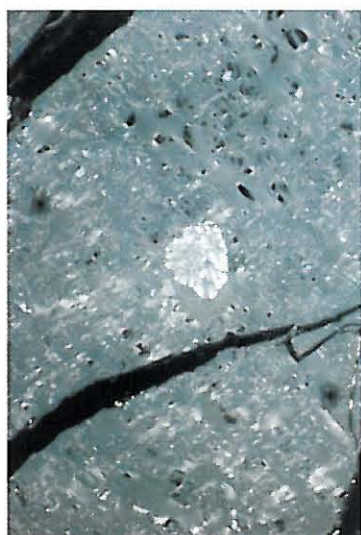
- Phot. 1. Granular and ribbon microtexture of the meta-anthracite from Russia. Crossed nicols.
- Phot. 2. Coke-like structure with numerous devolatilization vacuoles. The meta-anthracite from Ukraine.
- Phot. 3. Pyrolytic carbon in the meta-anthracite from Ukraine.
- Phot. 4. Low reflecting fusinite in the meta-anthracite from Russia.
- Phot. 5. Intergrowth vitrinite with carbonates. The meta-anthracite from Ukraine shows fibrous texture under crossed nicols.
- Phot. 6. Framboids of pyrite occurring in the meta-anthracite from Ireland.



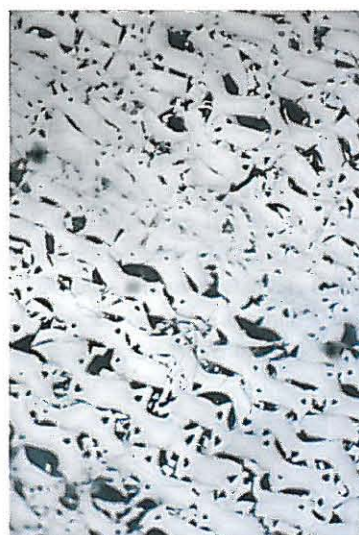
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