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An effect of igneous intrusion on the structure, texture and microtexture of coal from the Sośnica coal mine, Upper Silesian Coal Basin, Poland

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Two coal samples from the Sośnica coal mine, Poland, were analysed in this study. One sample was the natural char collected at the contact of magmatic intrusion, and another sample was the raw coal that was pyrolised in a laboratory furnace. Temperature of pyrolysis was similar to that calculated for the intrusion. The obtained char was analysed to compare its features with those characterizing a natural char sample. Optical microscopy, transmission electron microscopy and Raman spectroscopy studies show that the char from unaltered coal is characterized by the least developed structure, texture and microtexture compared to the natural char. Hence, it can be concluded that geological pressure generated by both the intrusion and the overburden, strongly affects the process of molecular ordering that took place during the heating of coal. The textural, structural or microtextural parameters of coal cannot be used as a geo-thermometer, because they are strongly dependent not only on the temperature but also on other factors.

Key words: coal structure, transmission electron microscopy, Raman spectroscopy, igneous intrusion.

INTRODUCTION

Heat and pressure generated by igneous magma intruding within coal seams can strongly influence its physicochemical and structural properties (Taylor et al., 1998). The degree of rock transformation depends on the temperature of intruded magma, the duration of magmatic-derived heat, and the distance between intruded magma and rock (Kwiecińska and Petersen, 2004; Rimmer et al., 2009; Yao and Liu, 2012). As a result of intrusion impact on coal seam, a natural coke can be formed at the coal-intrusion contact (Kwiecińska and Petersen, 2004). The effects of magmatic intrusion on the coal are observed in many coalfields. The largest deposits of thermally altered coals are found in India, USA and China (Stewart et al., 2005; Singh et al., 2008; Yao et al., 2011). The effect of intrusion on coal always includes an increase in coal molecular ordering degree that is manifested by an increase in mean optical reflectance and anisotropy (Chandra, 1965; Stewart et al., 2005; Singh et al., 2007; Yao et al., 2011). The development of pore and fracture systems and a decrease in volatile content are also usually observed (Cooper et al., 2007; Mastalerz et al., 2009), as well as distinct changes in coal chemistry and mineral matter transformations. The development of volatile release was also reported (Golab et al., 2007; Pang et al., 2007; Walker et al., 2007; Schimmelmann et al., 2009; Jiang et al., 2011; Valentim et al., 2011). Moreover, natural coke is characterized by a well-organized optical texture and structure measured by various techniques. Clear dependences between the temperature of intrusion body and a set of parameters measured via optical microscopy, e.g. maximum and minimum reflectance, bireflectance and Killby's transforms were reported (Komorek et al., 2010). Similar investigations of natural coke ordering were performed with use of Raman spectroscopy and scanning electron microscopy and SEM. All of the results confirm that the heat supported from the magmatic body causes an increase in the degree of molecular arrangement of heated coal (Sarana and Kar, 2011; Singh et al., 2013; Wu et al., 2014). Unfortunately, these results do not answer the question about how other factors influence the structural transformation of coals that were heat-altered in the coal bed. Taking account that tectonic forces may cause textural transformation of vitrinite, which is manifested by increased mean reflectance and change in optical character (Komorek et al., 1998), it may be expected that the force generated by intruding magma on the surrounding coal may cause a similar effect. On the other hand, it is well-known that an increase in coal structure ordering can be resulted by its carbonization. Such a process is accomplished in laboratory or industrial furnaces where a portion of coal is heated in an inert atmosphere. As a result, coke or char is produced and its structure, texture and microtexture are a fingerprint of physicochemical characteristics of parent coal and the final temperature of the process. In general, distinct from the conditions of natural coke formation, coal carbonized in a fur-

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nace is not influenced by strong mechanical forces. Hence, conclusions drawn on the basis of comparison of coke or char structure, performed as a result of heat influence on coal in geological conditions and in the furnace, should partially explain if geological pressure generated by an igneous intrusion affects the natural coke molecular ordering. It has been found that geological pressure affects the natural coke R_0 values (Chandra, 1965), but the results of detailed investigations concerning the impact of pressure generated in a seam on the degree of coal ordering defined at different levels of its organization have not been described. The aim of this work is to evaluate the effect of geological pressure and temperature on the optical texture, microtexture and structure of coal in coal samples from the Sośnica mine.

GEOLOGICAL SETTING

The Upper Silesian Coal Basin (USCB) is one of the major coal basins in Europe, situated in southern Poland and the northern Czech Republic. It covers an area of ca. 7,500 km^2 (Jureczka and Kotas, 1995; Kędzior, 2009). The USCB represents a kind of molasses filling the foreland of the Moravian and Silesian parts of the Variscan folding zone. The basement of Carboniferous coal-bearing rocks consists of Precambrian, Cambrian, Devonian and Carboniferous sequences (Jureczka and Kotas, 1995; Probierz et al., 2012). These rocks belong to four lithostratigraphic series (Figs. 1 and 2):

- Paralic Series (Upper Mississippian-Lower Pennsylvanian; Namurian A) – characterized by the presence of clastic and phytogenic sediments with horizons containing marine- and brakish-water faunas, thin coal seams, and terrestrial-marine sediments;
- Upper Silesian Sandstone Series (Lower Pennsylvanian, Namurian B and C) – characterized by the occurrence of thick coal seams that are rich in intertinite;
- Mudstone Series (Lower and Middle Pennsylvanian; Westphalian A and B) – characterized by the occurrence of thin vitrinite-rich coal seams;
- Kraków Sandstone Series (Middle Pennsylvanian; Westphalian B, C and D) – characterized by the presence of porous and permeable sandstones and vitrinite-rich seams.

The western part of USCB is folded and cut by numerous faults (Probierz et al., 2012), while the eastern part is character-

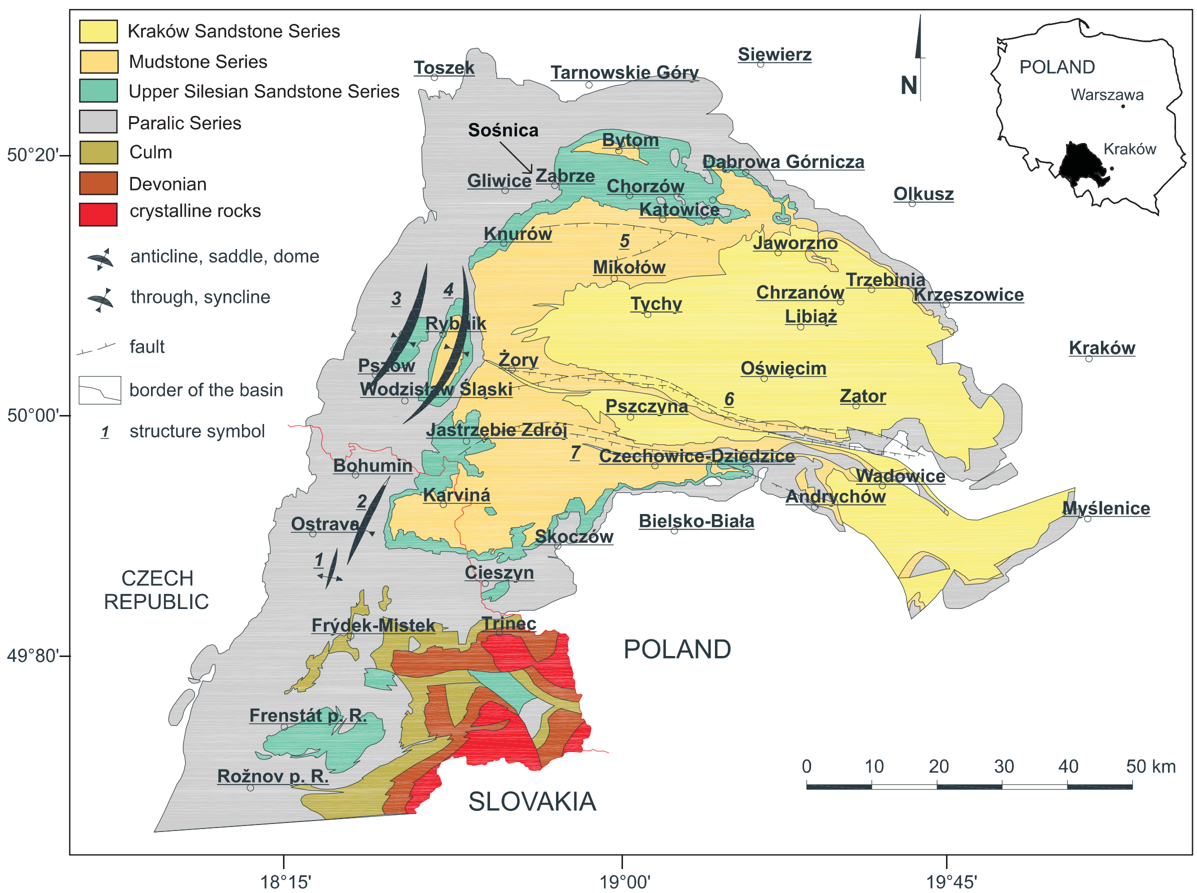

Fig. 1. A geological sketch of the Upper Silesian Coal Basin (modified after Probierz et al., 2012) showing the location of the Sośnica coal mine

1 – Michałkowice saddle, 2 – Orlova fold, 3 – Jejkowice trough, 4 – Chwałowice trough, 5 – Kłodnica fault, 6 – Żory-Piasek-Jawiszowice-Wysoka fault zone, 7 – Gorzyce-Bzie Zameckie-Czechowice-Kęty fault zone

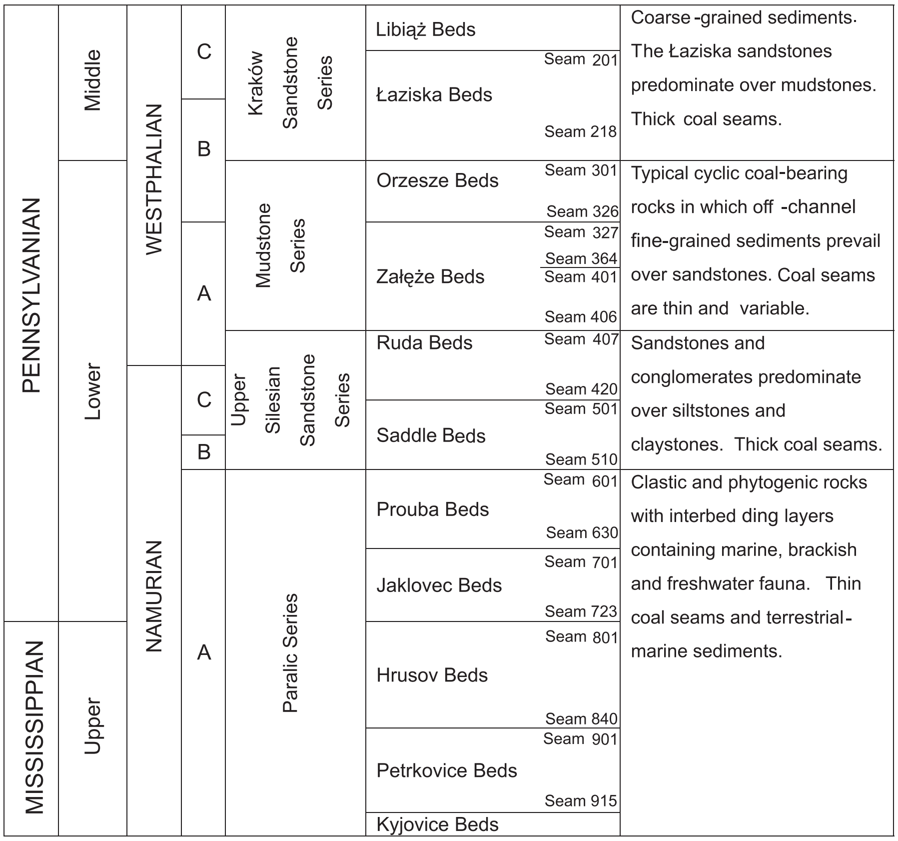

Fig. 2. Simplified lithostratigraphic division of the Carboniferous in the Upper Silesian Coal Basin (modified after Jureczka and Kotas, 1995)

ized by features typical for platform zones (Jureczka and Kotas, 1995). Three zones of structural development can be distinguished within the coal-bearing sequence:

– fold tectonic zone;
– fault-block tectonic zone;
– fold-thrust tectonic zone (Kotas, 1972).

Two troughs (Jejkowice and Chwałowice) and two overthrusts (Michałkowice saddle and Orlova fold) occur within the fold tectonic zone. The fault-block tectonic zone covers most of the USCB area. Horizontal coal beds are interrupted by major fault zones of parallel strike and significant throw towards the south (Kłodnica, Żory–Piasek–Jawiszowice–Wysoka and Gorzyce–Bzie Zameckie–Czechowice–Kęty fault zones). Fold-thrust tectonic elements abutting the basin to the north and north-east include several anticlinal structures.

Numerous igneous intrusions within the Carboniferous rocks were found in the southwestern part of the Upper Silesian Coal Basin (USCB). Their occurrence has been reported in both the Rybnik Coal Area (Kuhl, 1963; Borowski and Piłat, 1968; Chodyniecka and Stankiewicz, 1972, 1978; Gabzdyl, 1964) and in the Gliwice and Knurów region (Kuhl, 1954; Duźniak et al., 1976; Kapuściński, 1990). Intrusive bodies of various ages that occur within the USCB rocks represent different petrographic types such as basalt, diabase, melaphyre and volcanic breccia (Chodyniecka and Hanak, 2000). Strong transformation of these rocks indicates that hydrothermal phenomena were associated with these intrusions. Some of the intrusive bodies were found within the Upper Silesian coal seams. The intrusions were interpreted as dykes and branching sills that were squeezed into the ceiling parts of the seams (Gabzdyl et al., 1992). The intrusive rocks are represented by carbonatized basalts, melaphyres, diabases, andesites and microdiorites which are frequently undistinguishable macroscopically from the clastic fine-grained rocks. The present chemical composition of volcanites is a result of magma contamination. The secondary minerals are as follows: dolomite, calcite, chlorites, zeolites, uralite, biotite, sericite and kaolinite. At the direct contact with the intrusion, coal changed into coke or natural semicoke, mylonite and contact anthracites. The current amount of evidence on volcanic phenomena in the western part of the Upper Silesian Coal Basin shows that they are regional in character.

The Sośnica coal mine (currently the Sośnica-Makoszowy coal mine) is located in the northwestern part of USCB in Gliwice (Fig. 1). The oldest coal-bearing rocks recognized in these region belong to the Petrkovice Beds. These are overlain by the Hrusov and Jakovlec beds. Thin coal seams occurring within these beds are exploited by Sośnica coal mine. The Paralic Series is directly overlain by strongly coal-bearing rocks representing the Upper Silesian Sandstone Series. Coal seams exploited from these beds are thick (<12.5 m) and surrounded by coarse-grained sandstones and conglomerates. These rocks are overlain by the Ruda, Załęże and Orzesze beds. The Kraków Sandstone Series is absent in this part of USCB. The Sośnica region is located between two large tectonic structures: Main Saddle and Orlova Overthrust. Because of that, coal seams in this region are folded and cut by numerous faults. Moreover, some intrusion bodies were found within the coal-bearing rocks in this region.

INTRUSION CHARACTERISTICS

The intrusion body that was detected within the coal seam in the Sośnica coal mine can be defined as a dyke originated from basaltic-doleritic-trachytic magma (Chodyniecka and Hanak, 2000). This vertical dyke, 8 × 12 m in size, branches off into two veins, each 2 m across, 0.6–0.8 m thick sills branching off the dyke are found in the coal seams nos. 503, 501 and 416. The route of the dyke was investigated over a distance of about 300 m from coal seam 507 to coal seam 416. The intrusion exposed in the Sośnica coal mine can be compared with volcanic phenomena found in the Polish part of the Lower Silesian Coal Basin, with respect to its size and influence on coal. The intrusive rock is characterized by a low silica content while the contributions of calcium and magnesium are relatively high. Microscopic examination shows the presence of a number of specific minerals such as: biotite, quartz, calcite, hematite, pyrite, illite, kaolinite, dolomite and zeolites. The mineral composition presented above confirms that the initial igneous rock was strongly metamorphosed. It was found that the contact temperature at the time of the intrusion penetration into the coal seam was in the range of 700–800°C (Matuszewska and Cebulak, 2006). Using Ar-K dating, it was also estimated that the intrusive body was formed during Late Permian and Triassic times (Matuszewska and Cebulak, 2006).

STUDIED OBJECTS

Samples studied in this work were collected from coal seam 416 in the Sośnica coal mine in Gliwice (Fig. 1). Each sample, 2 kg in weight, was collected from the coal seam bottom. Sample 1 was collected at the distance of 1.5 m from the intrusion, and it was not under the influence of magma heat (Fig. 3A). Sample 2 was taken at the contact of intrusion, and it was strongly changed under high temperature provided from the intrusion as well as under overburden pressure. It can be assumed that it was a natural char characterized by thick-walled and porous texture (Fig. 3B). The unaltered sample of coal was pyrolised in a laboratory furnace to a temperature of 800°C, in an argon atmosphere. Obtained char (Fig. 3C), marked as sample 3, was analysed to compare its features with those characterizing a char sample that was formed in natural conditions. Basic characterizations of the studied samples are presented in Table 1.

METHODS

OPTICAL MICROSCOPY

Microscopic characteristics of the texture of sampled rocks were determined with a reflected light optical microscope *Axioskop MPM-200* (Opton-Zeiss, Germany) using monochromatic plane polarized light of λ = 546 nm. Coal grains of ≤3.0 mm diameter were embedded in epoxy resin and polished according to the procedure recommended by the International Committee for Coal and Organic Petrology (1963). The apparent maximum (R_{max}) and minimum (R_{min}) reflectance values were automatically measured on randomly oriented coal grains, in immersion oil, at the magnification 500×. For accurate determination of the reflectance indicating surface (RIS), the modified Killby's method was used. Values of apparent maximum and minimum reflectances were measured and processed according to the Kilby's method (Kilby, 1988) and its modifications (Duber et al., 2000).

TRANSMISSION ELECTRON MICROSCOPY

Samples to be analysed by means of transmission electron microscopy (TEM) were prepared using the following procedure. Firstly, they were ground with ethanol in a mortar. The specimens were then put into an ultrasonic bath to disperse aggregates. The resulting suspension was placed on a copper grid covered with a carbon film. After evaporating the alcohol, the specimens were placed into the microscope column for analysis. The TEM observations were performed using a *Philips EM400T* with magnification 23,000× and acceleration voltage 100 kV. The 002 dark field technique of observation (002DF) was selected for the study. Molecular-oriented domains forming microtexture were observed on the TEM images as white fields marked in Figure 4 by white rectangles. Each white field was registered by two images collected for two orthogonal aperture positions. Over 3,000 objects representing molecular-oriented domains were analysed for each sample. Obtained TEM images were digitally processed and the average area of MOD surfaces, S_{MOD}, were determined according to a technique developed by Smędowski (Smędowski and Krzesińska, 2013).

RAMAN SPECTROSCOPY

The Raman analyses were carried out using a *Jobin Yvon T64000* spectrometer containing an Ar laser of wavelength 514.5 nm. The laser power at the sample surface was controlled at 0.5 mW, and the laser spot diameter reaching the sample – at ca. 1 μm. Thus, the Raman microprobe actually provided averaged information for a large number of randomly distributed microcrystallites. The spectra were recorded in the range of 800–2,000 cm^{-1}, covering first-order bands, e.g. the D-band and G-band (Fig. 5). Each Raman spectrum was decomposed into four curves related to different structures that form carbon materials, and the characteristic structural parameters were calculated (Sadezky et al., 2005).

RESULTS

Different parameters describing the degree of molecular ordering of coal and char were discussed to analyse the influence of geological factors on their structure, microtexture and texture. The values of elemental composition of samples are presented in Table 1. Unaltered coal (sample 1) is characterized by the elemental composition typical for bituminous coals from the Sośnica coal mine. It is characterized by the relatively low carbon content which indicates that this sample can be industrially classified as a steam coal – the carbon content in coking coals mined in Poland is typically >86% (Smędowski and Krzesińska, 2013). Both moisture and ash contents are relatively low. Natural char sample (sample 2) is characterized by high carbon content; however, it is lower than the contribution of this element in sample 3. It means that the effect of devolatilisation and chemical transformation of studied samples was stronger for the con-

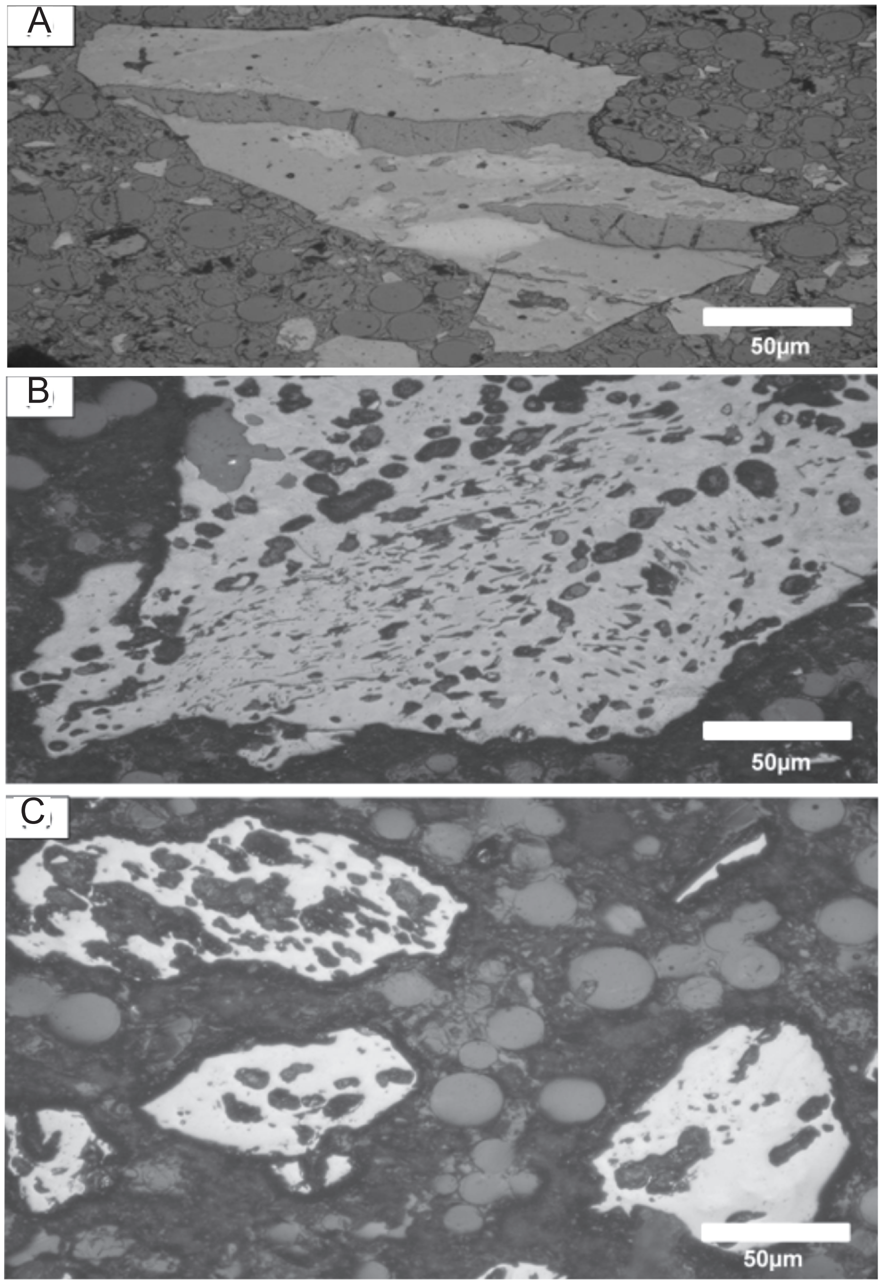

Fig. 3. Microphotographs of: A – sample 1 – unaltered coal, B – sample 2 – natural char, C – sample 3 – char performed in a laboratory

Table 1

Ultimate and proximate analysis

Sample	C^{daf} [%]	H^{daf} [%]	S^{daf} [%]	N^{daf} [%]	O^{daf} [%]	M^{ad} [%]	A^{ad} [%]
1 – unaltered coal	83.50	4.65	0.32	1.39	10.14	2.12	1.50
2 – natural char	93.22	1.04	0.57	0.71	4.46	1.20	5.50
3 – artificially produced char	97.28	0.86	0.34	1.50	0.02	5.67	4.36

C – carbon, H – hydrogen, S – sulphur, N – nitrogen, O – oxygen, M – moisture, A – ash, ^{daf} – dry and ash free basis, ^{ad} – as-determined basis

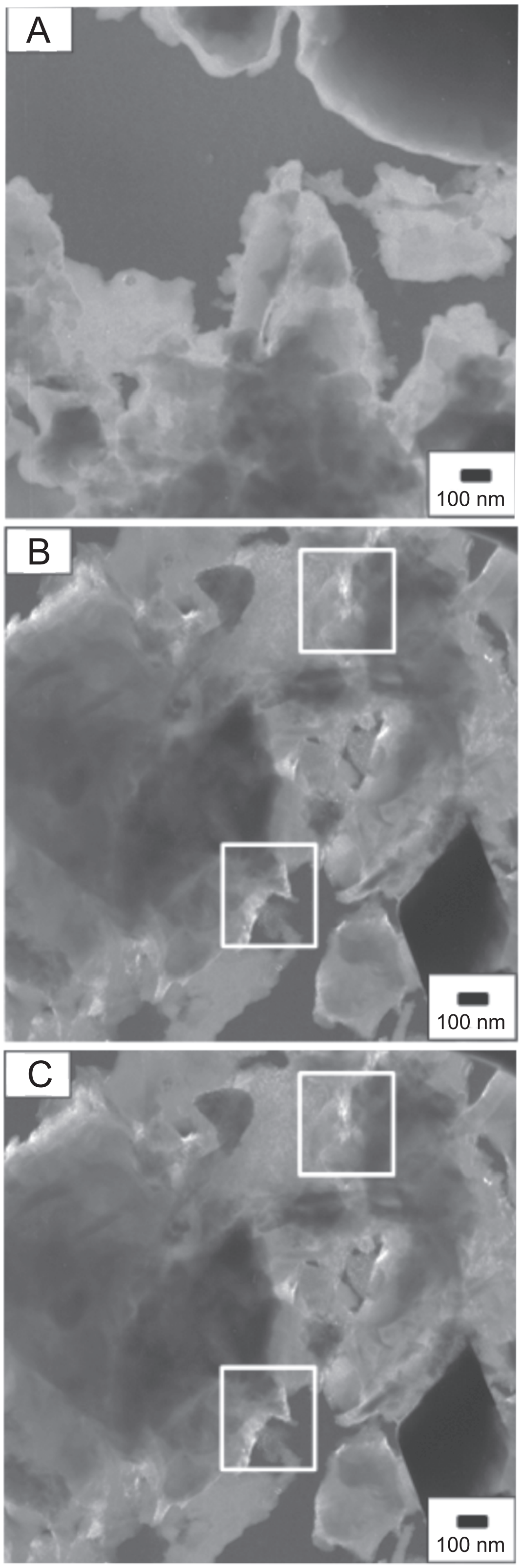

Fig. 4. TEM images of sample microtexture: A – sample 1, B – sample 2, C – sample 3

White objects in rectangles represent molecular-oriented domains (MOD)

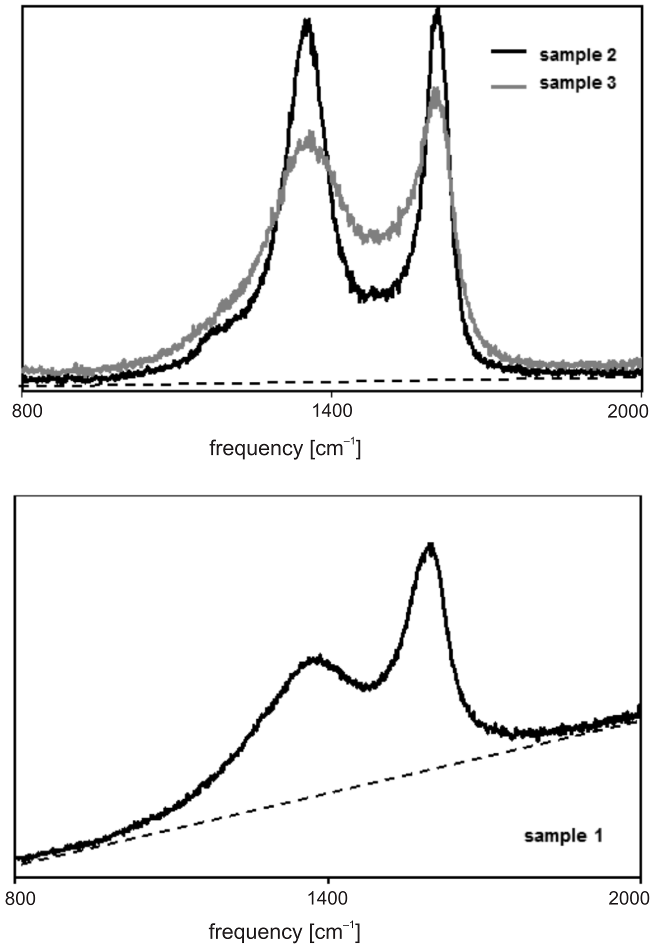

Fig. 5. Raman spectra of the samples

ditions prevailing in the laboratory furnace than for those in the coal bed affected by the intrusion.

Figure 6 shows Kilby's cross-plots drawn for all three samples. For the natural char (Fig. 6A) it can be seen that R_{max} and R_{min} sets of data are almost separable, whereby only two textural classes have been distinguished. It means that this sample is very homogeneous in terms of optical anisotropy so it can be concluded that its optical texture is relatively well-organized. Moreover, values of reflectances vary over a wide range from 1–12% and the maximum difference between R_{max} and R_{min} measured in the same point, bireflectance, is also high, at almost 8%. For the unaltered coal, it can be seen that the Kilby's plot (Fig. 6B) clearly differs from the former one. Sets of R_{max} and R_{min} strongly overlap each other and it is impossible to distinguish a border between these two classes without digital data processing. As a result of these analysis, up to five textural classes have been found within the sample. Maximum bireflectance detected on the Kilby graph is <0.4%, and it indicates that the molecular units forming coal texture are very small and not arranged in larger objects. Optical texture of the char sample that was obtained by the pyrolysis of unaltered coal does not correspond with the chemical changes that took place during the carbonization. Although sample 3 is strongly devolatilized, which is manifested by the very high carbon content, the degree of molecular ordering described by reflectance is not very high. On the other hand, heterogeneity of this sample is quite low and only three textural classes have been determined as a result of Kilby's plot analysis (Fig. 6C). The maximum bireflectance

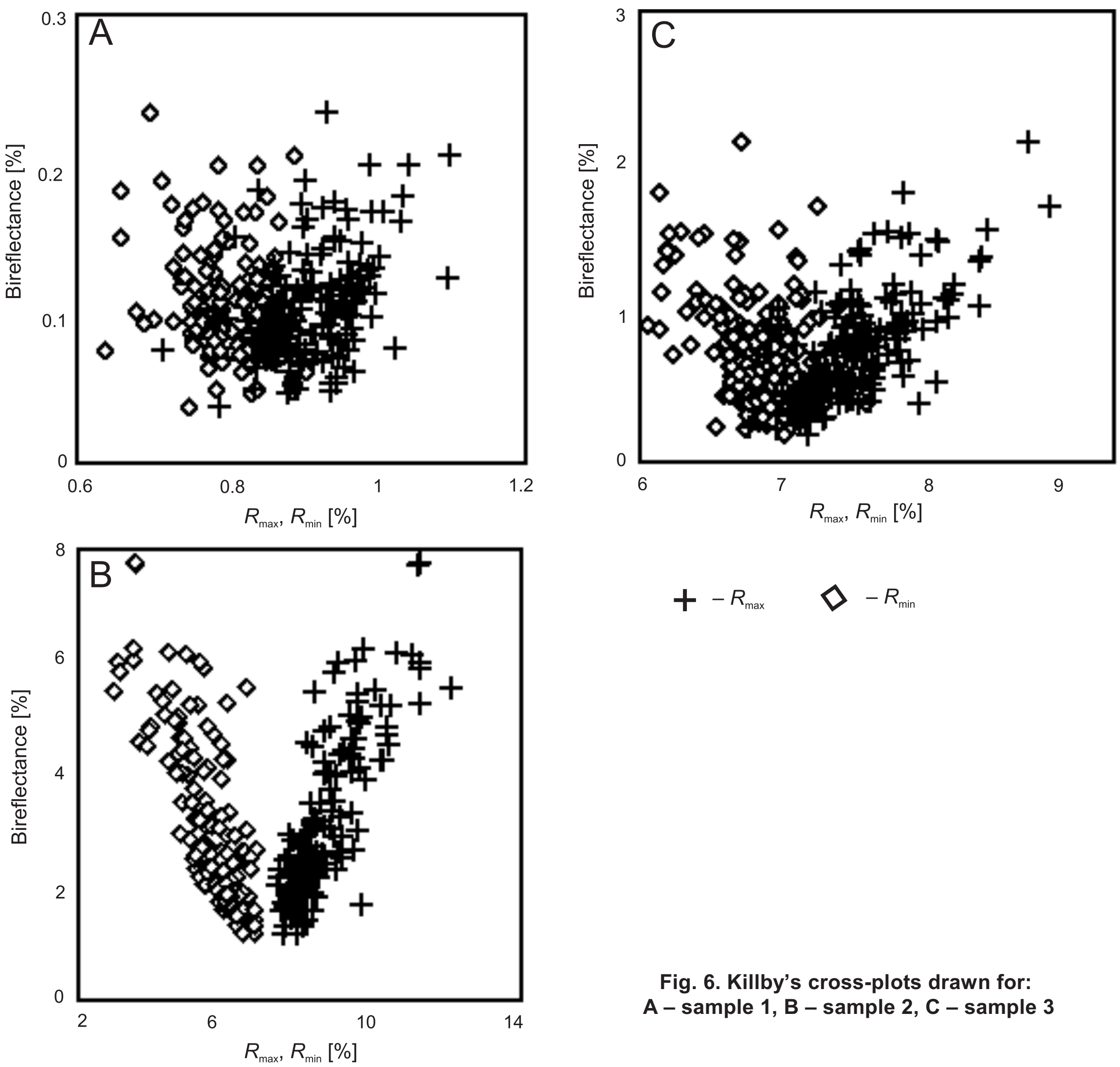

Fig. 6. Killby's cross-plots drawn for:
A – sample 1, B – sample 2, C – sample 3

found on this plot was about 2% and it is almost 6% points less than for the natural char sample.

All data presented on the cross-plots were digitally processed, and weighted mean values of Killby's parameters, e.g. maximum reflectance (R_{MAX}), minimum reflectance (R_{MIN}), bireflectance (R_{bi}), equivalent R_{IS} radius (R_{ev}), and RIS elongation (R_{am}) have been determined (Table 2). Values of R_{MAX}, R_{MIN}, and R_{bi} clearly indicate that optical structure of sample 2 differs from that detected for sample 3. The R_{MAX} is higher while R_{MIN} is lower for the natural char, whereby the bireflectance of this sample is almost 6% points higher than for the char obtained by the carbonization of coal in the furnace. Similar conclusions can be drawn from the values of other Kilby's parameters; e.g. Ram values define RIS elongations and confirm that sample 2 shows the most anisotropic structure. Based on the calculated R_{MAX} and R_{MIN} values, averaged RIS shapes have been drawn for each sample (Fig. 7). The presented curves confirm all conclusions discussed above.

Molecular structure and microtexture of the samples were also analysed by means of Raman spectroscopy (RS) as well as transmission electron microscopy (TEM). These two methods are much more sensitive than optical microscopy so they were used to identify and depict the details of the differences between molecular ordering of coal and char samples. The 002DF TEM images of the char samples are presented in Figure 4B, C, while an image of unaltered coal is shown in Figure 4A. It can be seen that the microtexture is clearly distinguishable in the images of chars. White dots representing basic structural units (BSU) are clustered forming molecular-oriented domains (MOD) whose average areas seem to be similar for both chars. Such clusters are not observed in the images of coal. To describe microtexture in details, values of molecular-oriented domains average area (S_{MOD}) were calculated with use of a method developed by Smędowski (Smędowski and Krzesińska, 2013). These values indicate that the microtexture of natural char is slightly better organized than that observed for char marked as sample 3. The value of S_{MOD} determined for sample 3 is similar to that calculated for coke produced in a Jenkner's retort from coal collected from the Krupiński coal mine, which is characterized by similar features as that studied in this work (Smędowski and Krzesińska, 2013). The average area of MOD calculated for sample 2 is higher by <1.7 nm^2 than that determined for sample 3.

Figure 5 presents Raman spectra of studied samples. It can be seen that the spectrum of unaltered coal is very different from the other two. The basic line of this shift is strongly inclined, which results from the high fluorescence as an effect of unordered aliphatic carbon atoms present in the whole structure. The values of geometrical parameters calculated for a particular Raman band are presented in Table 3. In the whole spec-

Table 2

Values of optical parameters

Sample	R_{MAX}	R_{MIN}	$R_{bi} = R_{MAX} – R_{MIN}$	R_{ev}	R_{am}	Number of textural classes
1	0.92	0.81	0.11	0.85	0.080	5
2	8.65	5.59	3.06	6.33	0.220	2
3	7.57	6.72	0.85	7.21	0.065	3

R_{MAX} – maximal average reflectance, R_{MIN} – minimal average reflectance, R_{bi} – bireflectance, R_{ev} – equivalent RIS radius, R_{am} – RIS elongation

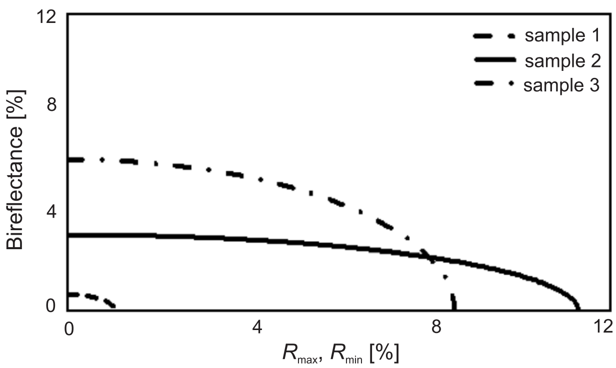

Fig. 7. Reflectance Indicating Surfaces (RIS) of the samples

trum, contribution of two bands representing poorly ordered carbon forms, e.g. D_1 and D_2 bands, which correspond to a high degree of structural disorder, is the highest for the unaltered coal. The same conclusions can be drawn based on the D and G band FWHM values. Both the G-band and D-band for sample 1 are very broad. It indicates that there are a lot of different defects within the packets of carbon layers. Summarizing, this spectrum is characterized by a shape that is typical for raw coals. Comparing the Raman spectra detected for studied chars, it can be seen that they clearly differ from each other. Although both main bands of sample 2 are located in a similar position as adequate curves on the spectrum of sample 3, e.g. G-band position is 1605 cm^{-1} and D-band position is 1350–1355 cm^{-1}, but they are distinctly narrower and have much lower FWHMs.

INTERPRETATION AND DISCUSSION

Analysis of the results shows that the structure, texture and microtexture of coal affected by the intrusive body were better developed than of char produced in laboratory scale. As might be expected, the parameters defining the molecular order of unaltered coal are the worst from among all samples studied. It is important that such a poor anisotropy of sample 3 is not strange considering that the pyrolised coal was characterized by a relatively low rank. Thus, the anisotropy of natural char is relatively high, suggesting that there were other factors that affected coal transformation that took place in the coal bed. Presented results confirm the conclusions drawn by Chandra (1965) who showed that the optical anisotropy of heat that affected coals may also be additionally deteriorated due to geological pressure. Chandra (1965) has shown that, for some American heat-affected coals, the values of $R_{o,\,max}$ and $R_{o,\,min}$ are similar to those calculated for chars produced as a result of carbonization of unaltered coals. Whereas, for some other samples, the differences between optical bireflectances detected for natural and artificially produced chars, are very high. It is an evidence for the occurrence of an additional factor that influences coal texture ordering. Other authors (Cooper et al., 2007; Golab et al., 2007; Singh et al., 2007, 2008; Mastalerz et al., 2009; Rimmer et al., 2009; Schimmelmann et al., 2009; Valentim et al., 2011) also reported that the optical reflectances of natural chars are affected by magmatic intrusions, but they did not study the influence of particular factors, e.g. temperature or pressure, on textural ordering of coals. Schimmelmann et al. (2009) found that the larger the intrusive body, the higher reflectance of char affected by it. It can be assumed that such an increase of reflectance may be partially caused by the increase of pressure generated by larger intrusion.

Taking into account that the Sośnica region is strongly affected by tectonic activity and the studied samples were collected from a depth of about 200 m, it can be assumed that the optical characteristics of natural char are an effect of temperature and pressure exerted by the overburden and intrusion body. This pressure could be high enough to cause the molecular units to be arranged in one plane, forming larger objects. Hence, it can be suspected that the strong reorganization of coal optical texture, due to heating in geological conditions, is caused by the combination of two factors, e.g. temperature and geological pressure.

Table 3

Values of parameters characterizing Raman bands

Sample	G-band			D-band			D_1+D_2 band	Band ratios		
	Centre [cm^{-1}]	Area [%]	FWHM [cm^{-1}]	Centre [cm^{-1}]	Area [%]	FWHM [cm^{-1}]	Area [%]	I_D/I_G	A_D/A_G	S_{MOD} [nm^2]
1	1594	23.25	72.4	1365	56.53	195.9	20.23	0.76	2.43	1.53
2	1605	19.35	50.9	1350	63.92	109.9	16.73	1.15	3.30	6.56
3	1605	14.98	70.7	1355	68.41	185.7	19.96	1.25	4.57	4.87

Based on the TEM results, it can be concluded that the effect of geological conditions on char microtexture is not very strong. The average area of MOD calculated for sample 2 is higher only by <1.7 nm^2 than that determined for sample 3. This is probably caused by initial coal characteristics. It is known that the development of char microtexture is controlled by two factors associated with the caking ability, i.e. coal rank and coal fluidity. The Sośnica coal is a relatively low-rank and low-fluidity coal, and therefore the conditions that occurred during the heating of it do not prefer a BSU ordering.

By comparing the Raman results with the conclusions drawn by other researchers (Sheng, 2007), it can be assumed that the natural char sample studied by us is characterized by a higher degree of structural ordering than the char produced by the carbonization of coal in laboratory scale. Moreover, both band ratios, i.e. I_D/I_G and A_D/A_G, are higher for sample 3 indicating that the contribution of disordered structures represented by the D-band outweigh the content of more ordered objects represented by the G-band of Raman spectra.

Based on the results obtained with use of both Raman and TEM measurements, similar conclusion to that found from optical investigations can be drawn. The degree of ordering detected for the natural char sample is distinctly higher than that detected for char produced in the laboratory. Unfortunately, in literature there is no evidences on the influence of other factors, e.g. pressure, on the dimension of molecular-oriented domains or the Raman spectra shape. However, taking into account that SMOD and structural parameters calculated from Raman spectra correlate with optical anisotropy (Smędowski et al., 2011; Smędowski, 2011; Smędowski and Krzesińska, 2013), it can be concluded that the heat associated with the igneous intrusion and pressure generated by both overburden and intruding magma, have a clear impact on the degree of ordering of carbon layers and on the dimension of molecular-oriented domains.

Summarizing, all the presented results indicate that the sample collected from the Sośnica coal mine seam was altered not only by the temperature of intrusion but also by the other factors. Taking account the geological conditions of the Sośnica region and the conclusions drawn by Chandra (1965), it can be presumed that the geological pressure was an additional factor that affected the structure, microtexture and texture of the studied natural char.

CONCLUSIONS

The structural, microtextural and textural degree of ordering of two char samples was investigated in this study. One of them originated from a coal seam affected by a basaltic intrusion. The second one was produced in the laboratory scale by the carbonization of unaltered coal sampled from a coal seam with a maximum temperature similar to that estimated for the intrusion. The results allow drawing the following main conclusions:

– all results indicate that the unaltered coal sample strongly differs from the studied chars in terms of structure, microtexture and texture;
– an effect of devolatilisation and chemical transformation of coal is stronger in the case of coal processed in the laboratory furnace than in the coal bed affected by the intrusion;
– values of parameters determined for both chars indicate that the sample collected from the coal seam is characterized by a higher degree of ordering than the char produced under laboratory conditions;
– the highest discrepancy was detected for the values of optical parameters, while the lowest was found for the factor determined by means of TEM;
– values of structural, textural and microtextural parameters cannot be used as a "geothermometer", because they are distinctly affected by other factors, e.g. a combination of overburden-related geological pressure, intruding magma, or tectonic activity.

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