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The impact of a Neogene basalt intrusion on the optical properties and internal structure of the dispersed organic matter in Carboniferous strata (SW-part USCB)

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ABSTRACT

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The S-7 borehole log from the Sumina area (USCB Poland) revealed the presence of three basaltic veins originating from a basalt dyke. Coal interlayers in the rocks surrounding the basaltic veins have been coked to form natural coke. Photometric measurements revealed that the optical properties of the studied natural coke samples are characteristic of semi-graphite (R_{max} > 9%). The natural coke matrix of all of the analyzed samples has a biaxial negative optical character. Vitrinite in the examined natural coke samples is characterized by a lower optical anisotropy than that of the natural matrix and it has a biaxial positive optical character. Vitrinite in almost all samples taken at locations more distant from the intrusion has a biaxial positive optical character. A reversal of the changes of the true maximum vitrinite reflectance and bireflectance with changing distance from the second basaltic vein has been observed. The temperature regime that acted upon the dispersed organic matter located in the immediate vicinity of the intrusion, estimated on the basis of the selected experimental data, is suggested to be higher than 750 °C.

Key words: Optical properties; Natural coke; Neogenic intrusion; Carbonisation.

INTRODUCTION

With increasing rank (degree of coalification) of coal, its chemical, processing, and physical properties resulting from the degree of internal structural order of the coal matter change with some regularity.

Three factors that affect the coalification process are distinguished: rise of temperature, pressure, and geologic time. As opposed to other coal macerals, changes in vitrinite reflectance during the coalification process proceed in a uniform manner, and for this reason among others the optical properties of vitrinite have been adopted in petrography as a maturity parameter (Ergun and McCartney 1960; Stach *et al.* 1982; Van Krevelen 1993; Taylor *et al.* 1998). Reflectance measurements in incident polarized white light can show, that vitrinite in coals is optically anisotropic (Vries *et al.* 1968; Hevia and Virgos 1977; Davis 1978; Hower and Davis 1981a, b; Grieve 1991; Komorek 1996; Littke *et al.* 2012).

Changes in vitrinite reflectance with changing orientation of the polished section are described by means of a triaxial ellipsoid (indicatrix), the axis of which, in any direction, is proportional to reflectance. The three main principal reflectance axes of the indicatrix correspond to the maximum (R_{max}), intermediate (R_{int}), and minimum (R_{min}) reflectance values (Hevia and Virgos 1977). The values thereof are associated with the presence of a directional stress field during the coalification process of the peat-precursors and or during structural deformation (Vries *et al.* 1968; Cook *et al.* 1972; Hower and Davis 1981a, b; Levine and Davis 1984; Houseknecht and Weesner 1997; Bruns and Littke 2015). On the basis of the shape of the indicatrix (optical character of vitrinite) and the orientation of its main axes, conclusions can be drawn related to the tectonic influence of the coal-bearing basin and coalification process (Stone and Cook 1979; Hower and Davis 1981a, b; Levine and Davis 1984; Kilby 1986, 1988; Levine and Davis 1989a, 1989b; Levine and Davis 1990; Grieve 1991; Kilby 1991; Langerberg and Kalkreuth 1991, 1991a; Middleton 1991; Reinhardt 1991;Tsai 1991; Houseknecht and Weesner 1997; Littke *et al.* 2012; Bruns and Littke 2015). The relationships between the axes define the reflectance character of vitrinite:

– isotropic $R_{max} = R_{int} = R_{min}$,
– uniaxial negative $R_{max} = R_{int} > R_{min}$,
– uniaxial positive $R_{max} > R_{int} = R_{min}$,
– biaxial negative $R_{max} > R_{int} >> R_{min}$,
– biaxial positive $R_{max} >> R_{int} > R_{min}$ (Stone and Cook 1979).

Vitrinite of uniaxial negative optical character is characteristic of tectonically undeformed coal deposits. The biaxial negative or positive optical character of vitrinite emerges, when in the process of coalification the coal is subjected, in addition to overburden pressure and rise of temperature, to a tectonic stress field at a non-perpendicular direction in relation to the bedding (Ting 1981; Levine and Davis 1984; Kilby 1986, 1988, Levine and Davis 1989a, b, 1990; Littke *et al.* 2012; Bruns and Littke 2015).

There is therefore a relationship established between the optical properties of coal (vitrinite) and the tectonic stress field of the deposit (Stone and Cook 1979). Results of the researches on the effects of tectonic processes on the optical characteristics of vitrinite in the bituminous coal and anthracites of the Upper Silesian Coal Basin (USCB) were]presented, among others, in the works of Komorek, Morga and Pozzi (Komorek *et al.* 1995; Komorek 1996; Komorek and Pozzi 1996; Pozzi 1996; Morga 2000).

The temperature prevailing in the rock mass is reflected in the degree of coalification of the coaly matter or in the thermal maturity of the organic matter, and is usually expressed by the value of the vitrinite reflectance. It is accepted that the degree of coalification in USCB which occurred subsequent to the deposition of the Carboniferous sediments displays both synorogenic and postorogenic characters, while further coalification was not generated by burial- or tectonic related regional metamorphism, being described as a locally occurring phenomenon. It is usually associated with an additional source of heat resulting from intrusive bodies (Gabzdyl and Probierz 1987; Probierz 1989; Klika and Kraussova 1993). The type of coal alteration depends on the temperature of the igneous intrusion, the duration of the magmatic heating, the distance from the igneous rock, and the original coal rank prior to thermal alteration. The influence of thermal metamorphism on coal is diverse. The width of the contact zone is usually limited from a few centimeters up to several meters (Sarana and Kar 2011). The optical changes of the coal induced by the thermal metamorphism depend on the initial rank of the coal at the time of intrusion (Kwiecińska and Petersen 2004; Hartkopf-Fröder *et al.* 2015).

A common effect of thermal metamorphism of coal is its transformation in the intrusion area up to a meta-anthracite and/or natural coke. The role of pressure and temperature in the transformation processes is widely discussed in the literature (Kwiecińska *et al.* 1992, 1995; Yule *et al.* 2000; Gurba and Weber 2001; Stewart *et al.* 2005; Amijaya and Littke 2006; Cooper *et al.* 2007; Mastalerz *et al.* 2009; Borrego and Martin 2010; Morga 2010; Wang *et al.* 2010; Littke *et al.* 2012; Suarez-Ruiz *et al.* 2012; Valentim *et al.* 2013; Rahman and Rimmer 2014). It is generally believed that pressure counteracts temperature rise, and thus prevents an increase in coalification, which is illustrated by a non-linear increase in the degree of coalification of organic matter with increasing depth. The regional field of burial metamorphism is affected by anomalies associated with thermal metamorphism caused by numerous intrusions found in the USCB (Chodyniecka and Sankiewicz 1978; Gabzdyl and Probierz 1987; Probierz 1989; Probierz and Lewandowska 2004; Matuszewska *et al.* 2015).

Scientific research on coal aimed at determining the rate of change of the optical properties of coal with increasing temperature has shown that after short heating periods at 350–400 °C, the reflectance and bireflectance of vitrinite has increased (Goodarzi and Murchison 1972; Murchison 1991; Jimenez *et al.* 1999).

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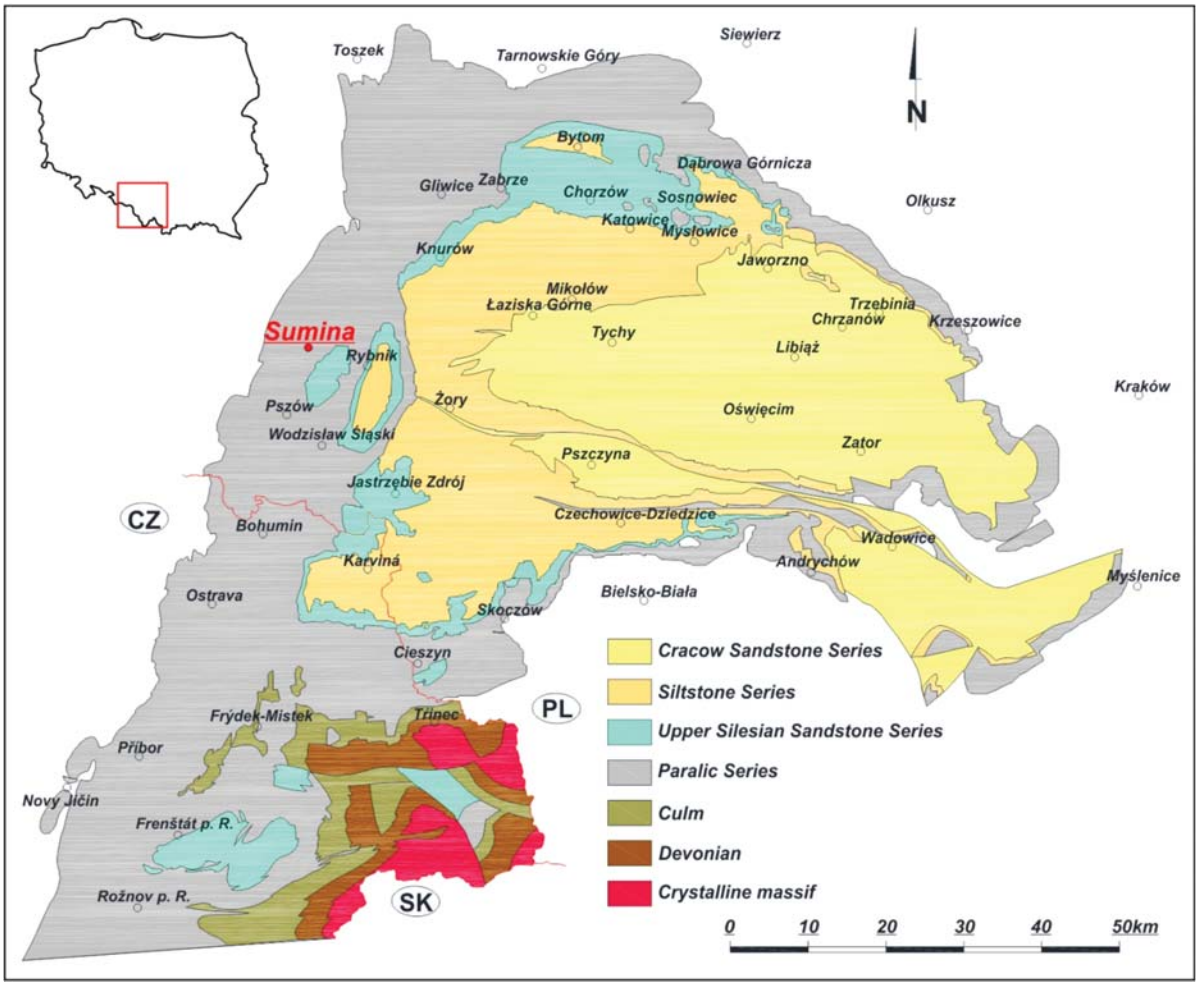


Text-fig. 1. Location of the study area on the background of the geological structure of the Upper Silesian Coal Basin (Poland) (according to Kotas 1994, modified)

Changes in the optical properties of coals studied under laboratory conditions are associated with thermal changes that occur in both the internal structure of vitrinite and the products of its transformation (mesophases and matrix). The nature and intensity of these changes depend on the original degree of coalification and the coking capacity of the precursor material. It has been found that the highest optical anisotropy of vitrinite and matrix is observed in coke formed at a temperature of 1200 °C, after heat treatment of concentrates from typically graphitable substances (coking coal) (Komorek *et al.* 2000; Komorek and Morga 2001; Morga and Komorek 2002; Komorek and Morga 2003; Morga and Komorek 2004).

The mesophase and matrix show a stronger optical anisotropy than the vitrinite. In coke obtained from coking coal the reflectance and bireflectance of the matrix attain values that are typical of graphite (Taylor *et al.* 1998; Komorek and Morga 2001, 2003; Morga and Komorek 2004; Komorek and Morga 2007).

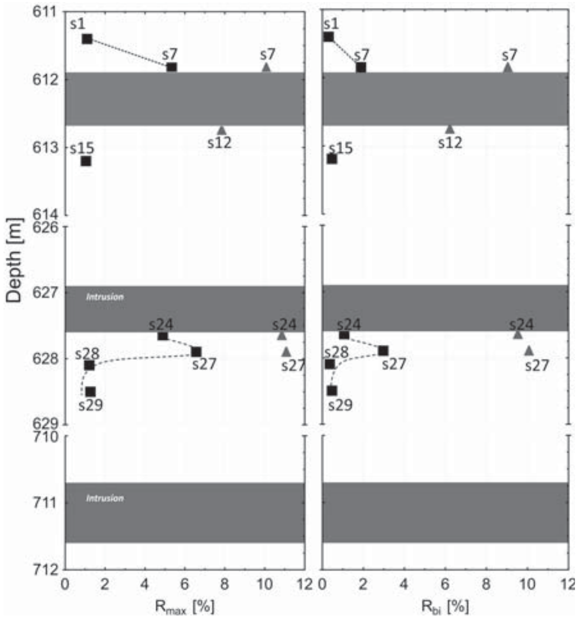
During heating at 1200 °C vitrinite retains its optical character determined in the raw concentrate, despite the changes occurring at lower temperatures, particularly in the plasticization phase (Komorek *et al.* 2000, 2001; Komorek and Morga 2001; Morga and Komorek 2002; Komorek and Morga 2003; Komorek and Morga 2007; Morga and Komorek 2004).

Research aimed at determining the effect of temperature on the optical properties of vitrinite indicates that the changes in the internal structure of vitrinite that take place with increasing heating temperature can be divided into two phases. The first phase occurs in the temperature range of 400 °C to 600 °C, when rapid changes are observed in the optical parameters that characterize the internal structure of the heated vitrinite. Mesophase appears in vitrinite from coking coal at 500 °C or 600 °C. At higher temperature mesophase is transformed into matrix. These changes are associated with the process of degassing and plasticization. The second phase of changes is observed in the temperature range between 800 °C and 1200 °C. Within this range there is a further increase in mean reflectance R_r and bireflectance R_{bi} of vitrinite. The content as well as the value of mean reflectance R_r and bireflectance R_{bi} of the matrix also increase. This means that with an increasing heating temperature the degree of internal structure arrangement of the products of vitrinite carbonization also increases (Komorek and Morga 2001, 2003, 2007; Komorek 2013).

Under geological conditions, magmatic events provide an additional stimulus, leading to thermal transformations of coal. Numerous occurrences of volcanic rocks are present in the southern part of the USCB. Tuff and breccias of basic volcanic rocks as well as basalts have been found in the same part of the USCB (Kuhl 1954; Gabzdyl 1964; Chodyniecka and Sankiewicz 1972, 1978). Veins of basalt originating from a basalt dyke have been encountered during drilling in the Sumina area (well S-7). This well is situated on the northwest slope of the Jejkowice basin (Text-fig. 1).

The results of investigations of the basalt and sedimentary rocks identified in well S-7 were presented in the paper by L. Chodyniecki and J. Sankiewicz (1978). The S-7 well, which was drilled from the surface, penetrates Quaternary formations (claystones and sandstones), Neogene formations (sandy claystones with marl and gypsum interlayers), and Carboniferous formations represented by Gruszów (marginal) layers (Upper Mississippian). The Gruszów layers contain mostly claystones with minor interbedding of mudstones and sandstones. Basalt veins were found in three sections of the sediment core occurring within Carboniferous formations at depths of 611.95–612.8, 626.9–627.70, and 710.70–711.60 m. Their thicknesses were as follows: 0.85, 0.80 and 0.90 m, respectively (Text-fig. 2).

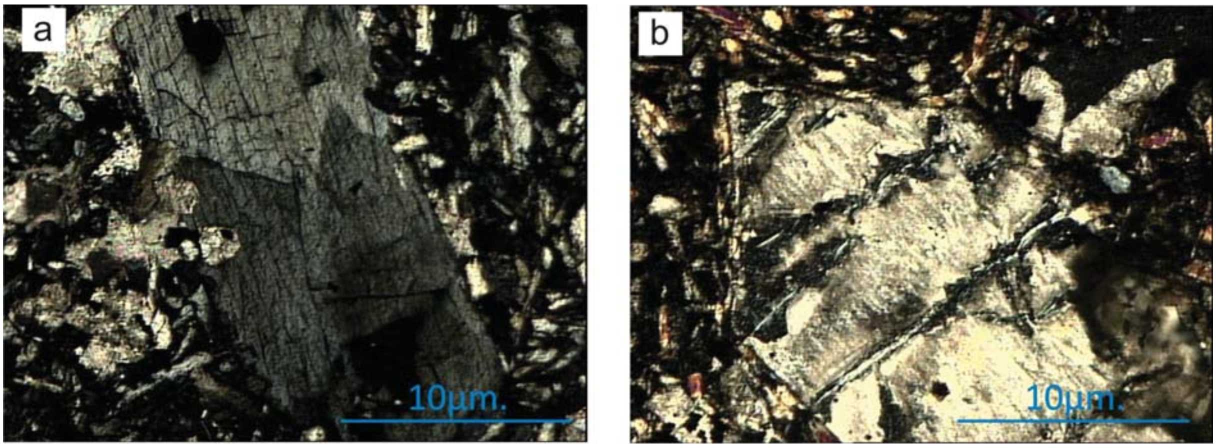
The basalt from the Sumina region belongs to the Central European Volcanic Province (CEVP). It has a holocrystalline porphyric texture and disordered structure. The petrographic composition of the basalts from the individual sections is similar. Phenocrysts include idiomorphic pyroxene (augite, Text-fig. 3a), and olivine pseudomorphs (Text-fig. 3b). Products of pyroxene transformations in the form of chlorites and iron oxides are observed sporadically



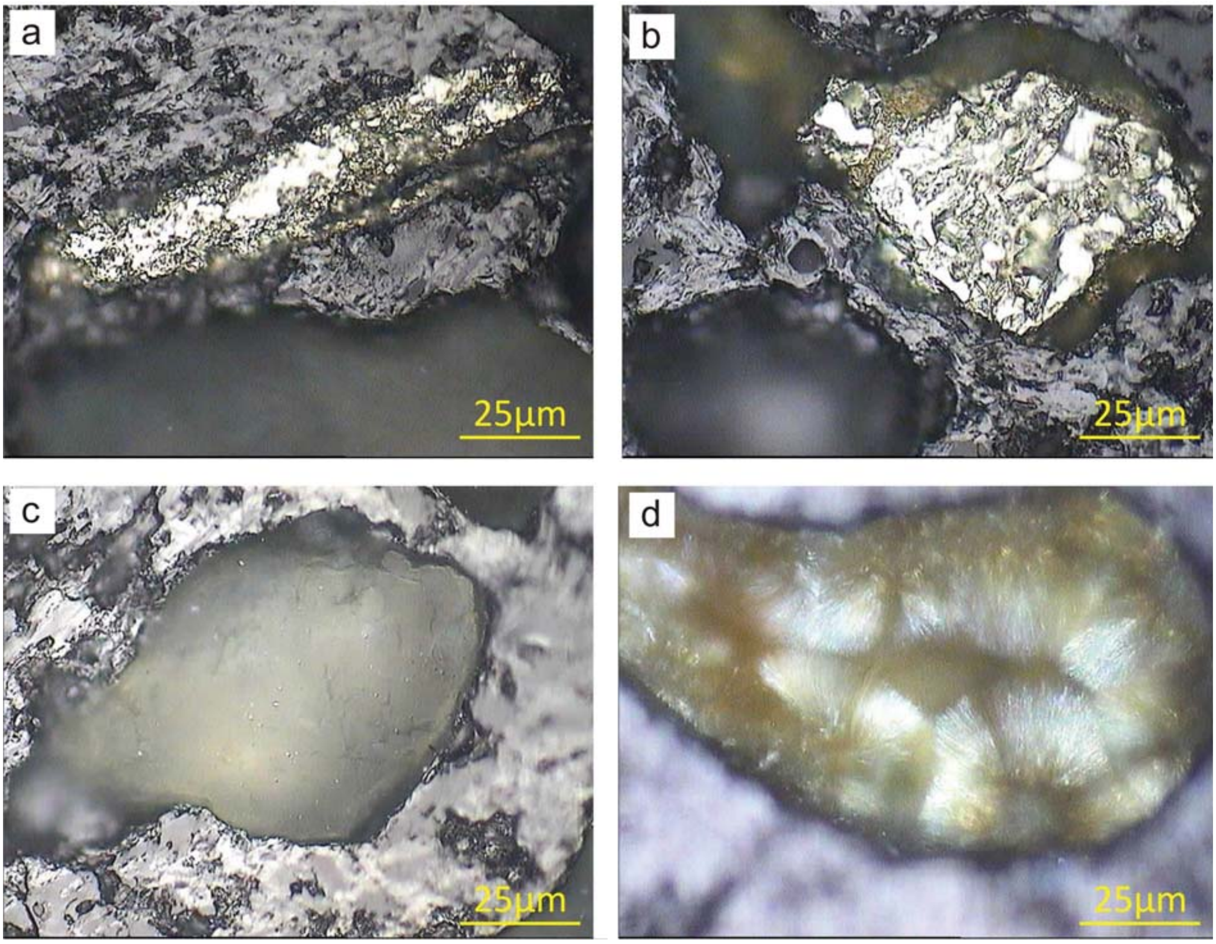
Text-fig. 2. Variation of the optical properties of coke matrix (▲) and vitrinite (■) in the profile of Sumina borehole S7

on the edges of pyroxene grains. Olivine phenocrysts are also highly transformed. Carbonates (calcite, rarely dolomite) and serpentines (chrysotile, rarely antigorite) are the major secondary minerals that fill olivine. The groundmass is composed of fine-grained augite, magnetite, nepheline, zeolites (analcime), and carbonates. Magnetite and nepheline form fine crystals evenly distributed in the groundmass. Zeolites usually fill vesicles and form a mixture of several minerals.

L. Chodyniecka and J. Sankiewicz observed an interface between basalt and sandstone at a depth of 626.90 m. The S-7 well log also revealed the presence of claystones. Basalt/claystone interfaces were found at the following depths: 611.95, 612.80, 627.9, 710.70 and 711.60 m. A brownish-yellow glassy coat has formed on the claystone/basalt endocontact. Coal interlayers in the claystones have been transformed to form natural coke. The presence of some constituents (e.g. natural coke) as well as structural and thermal transformations observed in the claystones (brownish-yellow rock coat) display a clear evidence of thermal metamorphism. This is the effect of the contact metamorphism of basalt on claystone. The presence of numerous vesicles filled with sulphides (Text-fig. 4a, b), carbonates (Text-fig. 4c), and zeolites (Text-fig. 4d) may also be an indication of postmagmatic hydrothermal activity on the solidified



Text-fig. 3. Microphotographs of basalt samples: a – phenocryst including idiomorphic pyroxene (augite); b – calcite-silica pseudomorphs after olivine; (magnification 100×)



Text-fig. 4. Vesicles filled with sulphides (a,b), carbonates (c), and zeolites (d); (magnification 500×)

magma and surrounding rocks (Gabzdyl and Probierz 1987; Probierz 1989; Klika and Kraussova 1993).

This paper is a continuation of a previous study (Chodyniecka and Sankiewicz 1978) and concerns the optical properties of dispersed organic matter in claystones and sandstones occurring in the vicinity of basaltic intrusions (basaltic dykes). Samples from well S-7 containing dispersed organic matter occurring in the vicinity of basalt intrusions are unique in the USCB.

SAMPLING AND METHODS

Studies on the optical properties were carried out on dispersed organic matter examined in samples of claystones and sandstones collected near the basaltic intrusions. The cut samples were used to prepare polished grain mounts for an examination in reflected white light. The samples were prepared and the examination performed in according with PN-ISO 7404-2: 2005. These studies included reflectance measurements (according to PN-ISO 7404-5: 2002) of randomly oriented vitrinite grains and the products of thermal transformations of organic matter (i.e.: matrix of natural coke).

In incident polarized white light every anisotropic constituent shows, when performing a rotation of the microscopic stage through 360°, an apparent maximum R'_{max} and minimum R'_{min} reflectance. Random values of reflectance R'_{max} and R'_{min} were registered for each measurement point. About 100 reflectance measurements were made for each analyzed constituent (vitrinite, and matrix of natural coke) in the individual samples. Based on these results, using Kilby's method and a computer program (Kilby 1986, 1988, 1991), the principle axes of the reflectance indicating surface, RIS: a true maximum R_{max}, intermediate R_{int} and minimum R_{min} reflectance values were calculated. The value of optical anisotropy was expressed by means of bireflectance R_{bi} and by parameters introduced by W.E. Kilby (Kilby 1986, 1988, 1991): R_{am} (am – anisotropy magnitude) and R_{st} (st – style of reflectance indicating surface).

In isotropic bodies $R_{am}= 0$, whereas when $R_{am} > 0$ the value of that factor describes the deviation from the isotropic state. The higher the value the higher is the anisotropy, and at $R_{am} = 0.1$ anisotropy is described as very high (Kilby 1988, 1991).

The optical character of the studied constituents is defined by means of R_{st} (st – style). R_{st} may take on values between -30 and +30. When $R_{st} = -30$, the optical character is described as uniaxial negative, whereas when $R_{st} = +30$, the optical character is uniaxial positive. The values between -30 and +30 allow us to classify coal constituents as biaxial bodies, and the minus and plus signs indicate a negative or positive optical character (Kilby 1988, 1991).

Microscopic examinations were carried out using a Zeiss optical light microscope equipped with a microphotometer. An immersion oil was used with a refractive index $n_o = 1.5176$ at 23 °C and light wavelength $\lambda = 546$ nm.

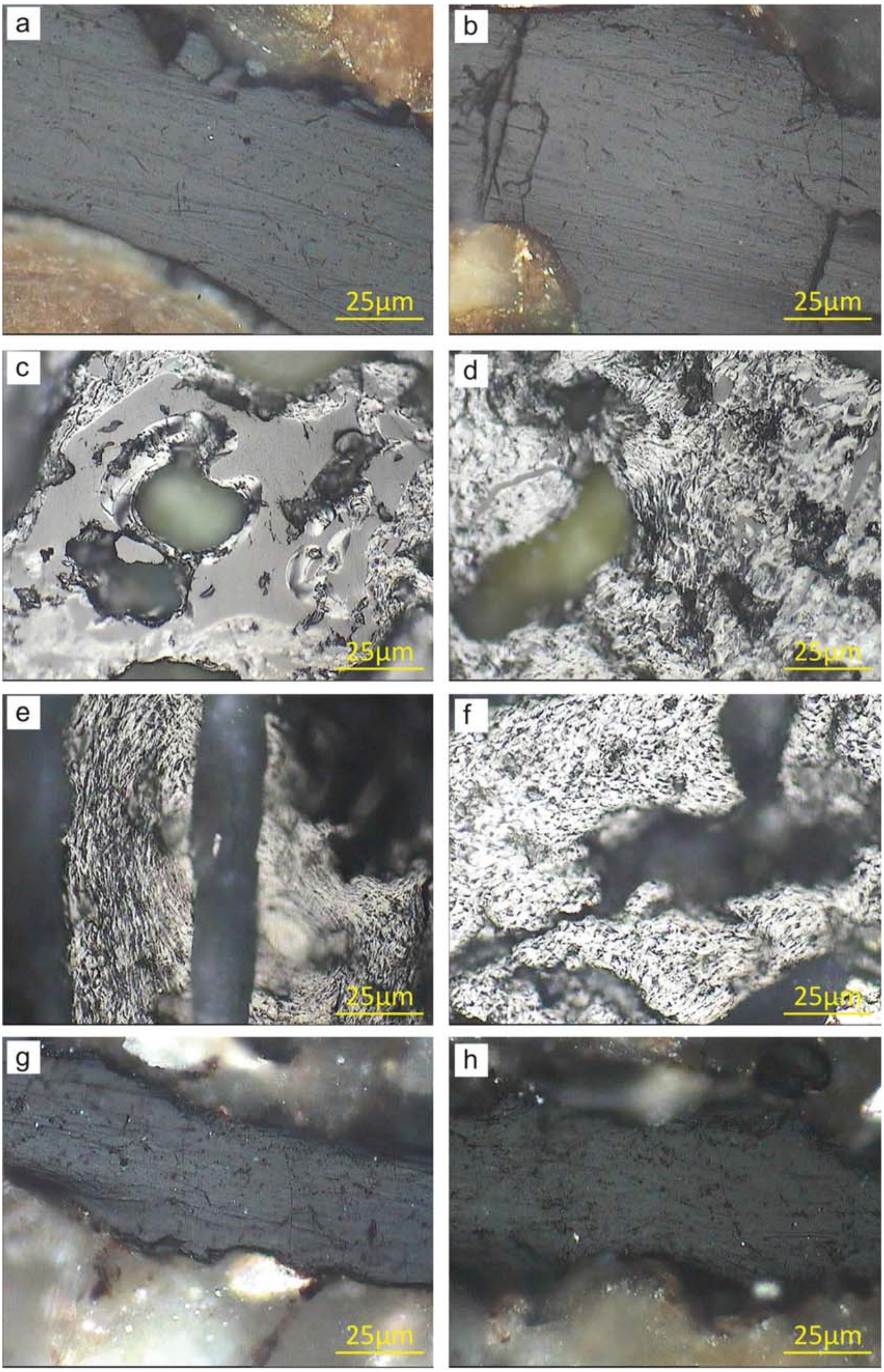
RESULTS AND DISCUSSIONS

At a distance of 25 cm from the upper margin of the uppermost basalt vein and the lower margin of the second vein the presence of porous natural coke was observed (Text-fig. 2). The natural coke is a product of the thermal transformation of organic matter dispersed within the examined sedimentary rocks that surround the basaltic intrusion. The matrix of the natural coke displays mainly a fine- and coarse-grained mosaic texture accompanied by a minor content of vitrinite grains (samples s7, s24, s27). One exception is sample s12 collected from the lower margin of the second vein and lacking vitrinite particles. In addition also some fusinite, semifusinite, and funginite macerals were observed in the natural coke matrix. The coke matrix showed optical anisotropy. Microscopic observations revealed the presence of areas optically uniformly oriented – anisotropic domains (Table 1).

Kilby's diagrams for the natural coke matrix in the examined samples are very clear. The true maximum reflectance values R_{max} calculated from Kilby's diagrams varies from 7.88% to 11.13%, whereas that of intermediate reflectance R_{int} – from 5.00% to 6.97%, and that of minimum reflectance R_{min} – from 1.01% to 1.63% (Table 2).

The bireflectance R_{bi} of the matrix varies from 6.25% to 10.12%. R_{am} varies between 0.22 and 0.27, which means that the internal structure of the coke matrix is highly ordered. The values of R_{st} fall within the interval of -2.58 to -7.99, meaning that the coke matrix in all the analyzed samples has a biaxial negative optical character (Table 2). The optical properties of the studied natural coke matrix are characteristic of semigraphite ($R_{max} > 9\%$) (Taylor *et al.* 1998; Kwiecińska and Petersen 2004).

Text-fig. 5. Microphotographs of vitrinite and natural coke matrix from examined samples: sample S1 – vitrinite isolated particle and lamina (a, b); sample S7 – natural coke grains that constitute vitrinite residues (c), natural coke matrix – visible anisotropic domains (d); sample S12 – natural coke matrix – visible elongated anisotropic domains (e, f); sample S15 – vitrinite laminas (g, h), (magnification 500×) →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Sample	Distance from basalt intrusion [m]	Rock	Forms of organic matter
s1	0.65–0.70	fine-grained sand-stone	Vitrinite – laminas, clasts, in addition to vitrinite (Text-fig. 5a, b), scarce grains of fusinite and semifusinite
s7	0.00–0.05	thermally altered claystone	Natural coke – laminas, lenses, clasts; matrix of mosaic texture, visible anisotropic domains (Text-fig. 5d), grains that constitute vitrinite residues (Text-fig. 5c), scarce clasts of fusinite and semifusinite
s12	0.00–0.05	claystone in direct contact with basalt	Natural coke – clasts and lenses; coke matrix of mosaic texture with visible elongated anisotropic domains, no vitrinite residues (Text-fig. 5e, f)
s15	0.45–0.75	claystone	Vitrinite – laminas and sharp-edged clasts (Text-fig. 5g h), visible clasts of fusinite and semifusinite
s24	0.00–0.05	thermally altered claystone	Natural coke – laminas, porous coke matrix of mosaic texture with visible anisotropic domains; visible grains that constitute vitrinite residues (Text-fig. 6a, b) and clasts of fusinite and semifusinite
s27	0.25–0.45	claystone	Natural coke – laminas, lenses, clasts; matrix with elongated anisotropic domains visible on pore walls, grains that constitute vitrinite residues (Text-fig. 6c, d) and scarce clasts of fusinite, semifusinite and funginite
s28	0.45–0.85	claystone	Vitrinite – laminas, clasts (Text-fig. 6e, f)
s29	0.85–1.15	claystone	Vitrinite – fine clasts and lenses (Text-fig. 6g, h)

Table 1.Characteristics of the examined samples from the Sumina S7 borehole

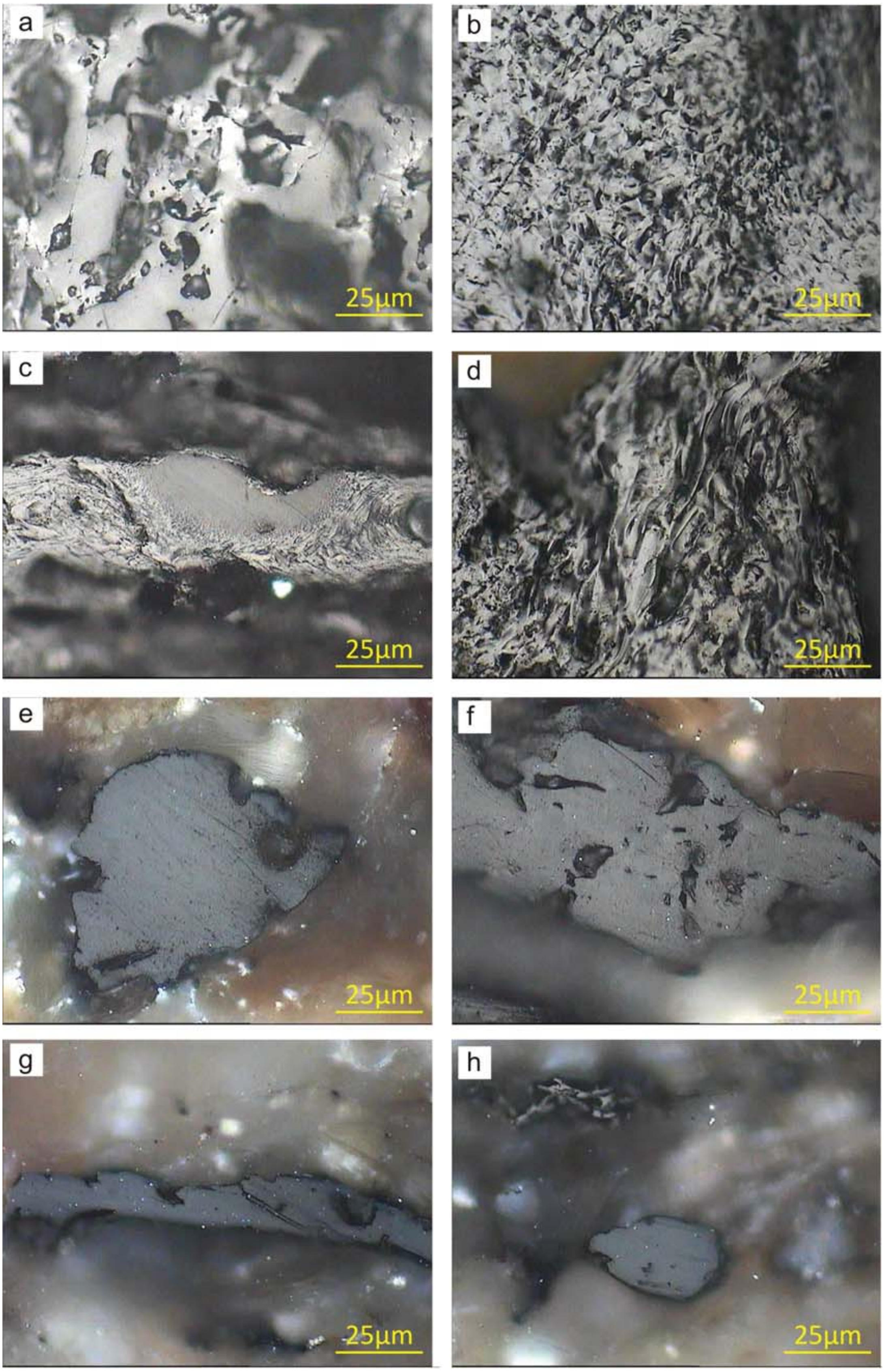
Sample	R'_{max} [%]	s_{max} [%]	R'_{min} [%]	s_{min} [%]	R_{max} [%]	R_{int} [%]	R_{min} [%]	R_{bi} [%]	R_{am}	R_{st}
Vitrinite										
s1	0.97	0.06	0.87	0.05	1.09	0.89	0.75	0.34	0.06	5.89
s7	4.56	0.39	4.21	0.36	5.33	4.28	3.44	1.89	0.07	3.73
s15	0.86	0.11	0.77	0.11	1.07	0.82	0.59	0.48	0.10	1.42
s24	4.54	0.22	4.14	0.24	4.93	4.37	3.82	1.11	0.04	0.39
s27	5.24	0.68	4.51	0.47	6.24	4.68	3.80	2.44	0.08	9.20
s28	1.05	0.08	0.96	0.07	1.22	0.98	0.82	0.40	0.07	6.65
s29	1.10	0.09	1.04	0.13	1.26	1.05	0.78	0.48	0.08	-4.08
Matrix										
s7	8.70	0.85	3.59	1.38	10.12	6.70	1.08	9.04	0.25	-7.99
s12	6.03	0.80	3.37	0.87	7.88	5.00	1.63	6.25	0.22	-2.58
s24	8.86	1.02	4.05	1.54	10.88	6.97	1.31	9.57	0.25	-6.02
s27	8.72	1.23	4.05	1.70	11.13	6.83	1.01	10.12	0.27	-4.95

Table 2. Optical properties of vitrinite and natural coke matrix: R'_{max} – mean apparent maximum reflectance, s_{max} – standard deviation of mean apparent maximum reflectance value, R'_{min} – mean apparent minimum reflectance value, s_{min} – standard deviation of mean apparent minimum reflectance value, R_{max} – true maximum reflectance, R_{int} – true intermediate reflectance, R_{min} – true minimum reflectance, R_{bi} – bireflectance R_{am} – anisotropy magnitude, R_{st} –reflectance indicating surface – style)

In the vicinity of the analyzed area it has been found that the vitrinite from coal seams (not subjected to thermal alteration) has a reflectance of from 0.67% to 1.08% (Adamczyk and Komorek 1999). Thermally altered vitrinite, which is present in the natural coke matrix in minor amounts, has the form of small particles with rounded edges. The true maximum reflectance value of R_{max} calculated from Kilby's diagrams varies from 4.93% to 6.24%, whereas that of intermediate reflectance R_{int} – from 4.28% to 4.68%, and that of minimum reflectance R_{min} – from 3.44% to 3.82% (Table 2).

The bireflectance R_{bi} of thermally altered vitrinite varies from 1.11% to 2.44%. R_{am} assumes values

Text-fig. 6. Microphotographs of vitrinite and natural coke matrix from examined samples: sample S24 – natural coke grains that constitute vitrinite residues (a), natural coke matrix – visible anisotropic domains (b); sample S27 – natural coke grains that constitute vitrinite residues (c), natural coke matrix – visible anisotropic domains (d); sample S28 – vitrinite clast and lamina (e, f); sample S29 – vitrinite lamina and isolated particle (g, h), (magnification 500×) →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in the range of 0.04 to 0.08. The results show that thermally affected vitrinite grains in coke samples are characterized by lower values of true reflectance and by lower optical anisotropy than that of the natural coke matrix. The values of R_{st} fall within the interval of 0.39 to 9.20, meaning that the examined vitrinite in all analyzed samples has a biaxial positive optical character (Table 2).

Thermally altered dispersed organic matter was also observed in samples taken at a distance greater than 45 cm from the respective basalt veins (samples s1, s15, s28, s29) and it is characterised by a lower thermal degree of alteration. Organic matter in these samples was represented mainly by vitrinite occurring in the form of laminas, lenses, and as single grains. Apart from vitrinite, scarce macerals of semifusinite and fusinite were encountered (Table 1).

It should be noted that Kilby's diagrams of the thermally altered vitrinite in these samples are less ordered and more challenging to interpret than those of the severely thermally altered vitrinite in a natural coke matrix discussed above. This may be due to disordering of the vitrinite structure caused by an increased temperature (Komorek and Morga 2001, 2003; Morga and Komorek 2004; Komorek and Morga 2007; Komorek 2013). Therefore, the values of reflectance, bireflectance, and R_{am} and R_{st} calculated for vitrinite in these samples should be treated as approximate. The true maximum reflectance R_{max} of vitrinite varies from 1.07% to 1.26%, whereas the true intermediate reflectance R_{int} – from 0.82% to 1.05%, and the true minimum reflectance R_{min} – from 0.59% to 0.82%. Bireflectance R_{bi} attains values from 0.34% to 0.48%. R_{am} varies between 0.06 to 0.10. The values of R_{st} in nearly all of the analysed samples are positive, meaning that vitrinite displays a biaxial positive optical character (Table 2). Only vitrinite in sample s29 has a biaxial negative optical character (R_{st} = -4.08). Note that most of the vitrinites in coals from USCB are characterized by negative, biaxial or uniaxial optical characters (Komorek 1996; Pozzi 1996; Morga 2000; Adamczyk *et al.* 2014). Differentiation in the optical character of the analyzed samples of these thermally altered vitrinites influenced by a lower degree of thermal alteration may be evidence of changes in their internal structure caused by heat sourced from the respective basaltic intrusions. A confirmation of the effect of temperature on the microstructure of vitrinite in samples taken at a larger distance from the basalt veins may be represented by the pores observed in some vitrinite grains, these pores being probably formed by degassing (s28, s29). The differing optical character of these vitrinites may also result from the fact that the dispersed organic matter observed in the sedimentary rocks and occurring in the form of clasts may be resedimented.

The analysis of the variation of the true vitrinite maximum reflectance value with changing distance from the basaltic intrusion indicates in general that higher values are observed in samples located closer to the basaltic veins. Noteworthy are samples s24, s27, s28 and s29 taken at the lower margin of the second vein (at depths of more than 627m). Here we observe a reversal of reflectance changes with distance from the intrusion similar to that previously described in the literature (Murchison 2006). This can be explained by changes in the arrangement of the internal structure of vitrinite resulting from the influence of heat (Khorasani *et al.* 1990; Murchison 2006). The bireflectance R_{bi} shows a similar reversal of the trend in changes depending on the distance from the second basalt vein (Text-fig. 2).

The calculated values of true maximum reflectance of vitrinite and matrix of natural coke were used to estimate the maximum temperature that acted on the organic matter dispersed in the rocks surrounding the intrusion.

The values of the true maximum vitrinite reflectance were compared with the data obtained for vitrinite subjected to thermal treatment in the laboratory experiments within the range of 400 °C to 1200 °C. The true maximum reflectance values of the natural coke matrix were compared with the data for cokes obtained in the laboratory from coals of different ranks (Morga and Komorek 2004; Komorek 2013). The arithmetic mean and standard deviation of the true maximum reflectance of vitrinite and matrix were calculated for every temperature of heat treatment (400, 500, 600, 800, 1000 and 1200 °C). The relationship was then determined between temperature and the mean value of the true maximum vitrinite and matrix reflectance R_{max} = f(T). In the case of vitrinite that relationship was linear $R_{max} = 0.0099T - 2.7147$ ($r = 0.99$, $p < 0.05$) (Text-fig. 7). In the case of the matrix the relationship R_{max} = f(T) was described with a second-degree polynomial $R_{max} = -1.7748 \cdot 10^{-5}T^2 + 0.0430T - 14.5013$, $p < 0.05$ (Text-fig. 8). These functions were used to obtain general estimates the paleotemperature that acted on the rocks surrounding the basaltic intrusion. The obtained temperature data are only approximations used to correlate the determined reflectance data with the temperatures derived from laboratory conditions (Text-figs 7, 8). These functions were used to determine the paleotemperature that acted on the rocks surrounding the intrusion.

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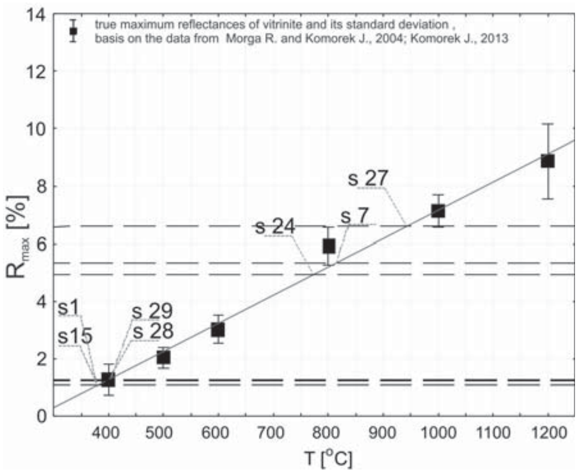
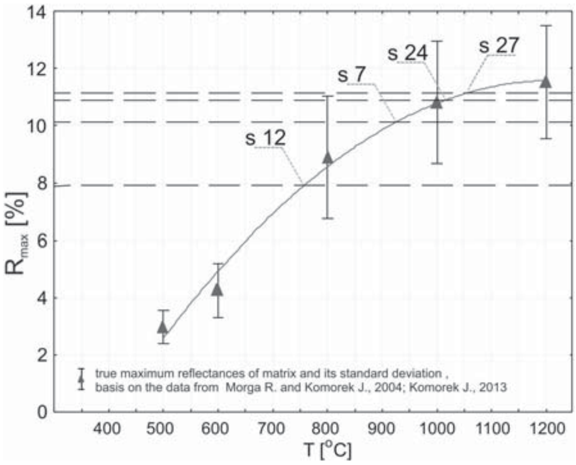


Text-fig. 7. Comparison of maximum vitrinite reflectance with the data obtained for cokes produced in laboratory conditions (Morga and Komorek 2004; Komorek 2013)



Text-fig. 8. Comparision of maximum coke matrix reflectance with the data obtained for cokes produced in laboratory conditions (Morga and Komorek 2004; Komorek 2013)

It can be suggested that in the immediate vicinity of the basalt veins (samples: s7, s12, s24, s27) the estimated temperature was higher than 750 °C (Text-fig. 7, 8). Samples taken from locations more distant from the intrusion (samples: s1, s15, s28 and s29) were found to be very likely subjected to temperatures of around 400 °C. It should be noted that no matrix was found in the samples situated more distant from the intrusion, which may indicate that the temperature acting on these samples was possibly lower than 500 °C. Under laboratory conditions, matrix appears only at temperatures exceeding 500 °C (Komorek and Morga 2001, 2003; Morga and Komorek 2004; Komorek and Morga 2007; Komorek 2013).

CONCLUSIONS

In the Sumina region three Neogene basaltic veins were encountered in the S-7 well, intruding into Carboniferous formations at the depths from 611.95 m to 711.60 m. At a distance of 0.25 m from two of the veins the presence of porous natural coke was observed. This coke consists mainly of fine- and coarse-grained matrix of mosaic texture and is associated with a small content of vitrinite grains as well as fusinite, semifusinite, and funginite macerals.

Dispersed organic matter, represented mainly by vitrinite in the form of laminas, lenses, and isolated particles, was also found in samples taken at a distance greater than 0.45 m from the basalt veins.

The optical properties of the studied natural coke samples are characteristic of semi-graphite (R_{max} > 9%). The examined matrix of the natural coke for all of the analysed samples has a biaxial negative optical character. Vitrinite in the natural coke samples is characterized by lower optical anisotropy than that of the matrix and it has a biaxial positive optical character.

Vitrinite in almost all samples taken at locations more distant from the intrusion has a biaxial positive optical character, with the exception of vitrinite in sample s29, having biaxial negative optical character.

A reversal of the changes of true maximum vitrinite reflectance and bireflectance with changing distance from the second basalt vein, previously described in the literature, has been observed. This is suggested to be related to changes in the arrangement of the internal structure of vitrinite, resulting from the action of heat.

The temperature that had acted on the organic matter in the immediate vicinity of the intrusion, estimated on the basis of experimental data, was higher than 750 °C, while the samples taken from locations more distant from the intrusion (samples: s1, s15, s28 and s29) were found to have been subjected to temperatures of around 400 °C.

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