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Coal and dispersed organic matter in the Miocene sediments of the Upper Silesian Coal Basin (Poland) – new data

Introduction

The Upper Silesian Coal Basin (USCB) is located in southern Poland and in the region of Ostrava-Karviná in the Czech Republic. It is the major coal basin in Poland. It covers an area of about 7,400 km^2 (about 5,800 km^2 within Polish territory) (Jureczka and Kotas 1995).

In the Neogene, the area of the USCB was part of the Polish Carpathian Foredeep (PCF) basin unfilled mainly with Miocene molasse sediments. The Carpathian Foredeep developed during the Early and Middle Miocene as a peripheral flexural foreland basin in front of the advancing Carpathian front (Oszczypko 2006; Oszczypko et al. 2006).

The PCF is about 300 km long and up to 100 km wide and forms part of the large flexural foreland basin that extends along the front of the Carpathians. To the west, the Carpathian Foredeep of Poland and Czechia links up with the Alpine Molasse Basin and to the south-east, it grades into the Ukrainian foreland basin Carpathian Foredeep and is asymmetric

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and predominantly filled with synorogenic Miocene clastic sediments that are up to 3 km thick (Oszczypko 2006; Oszczypko and Oszczypko-Clowes 2012). In the northern and eastern part of the USCB, the Carboniferous overburden also consists of Triassic carbonate rocks (Jureczka and Kotas 1995).

The basement of the Miocene sediments is made up mainly of Carboniferous coal-bearing series in the region of the Upper Silesian Coal Basin. This basement is strongly morphological and differentiated with erosional paleovalleys, canyons, and ridges (Jura 2001).

The lithostratigraphic division of the Miocene from the Carpathian Foredeep, as well as from the other Paratethyan basins in Europe, is complicated with many formal, informal, and regional units (Aleksandrowicz 1997; Aleksandrowicz et al. 1982; Peryt 1997; Buła and Jura 1983a; Rasser and Harzhauser 2008; Piller et al. 2007). The Miocene stratigraphy of the Carpathian Foredeep is mostly based on foraminifera assemblages (e.d. Peryt 1997; Gonera 2001, 2018; Bukowski et al. 2010, 2013, 2018). Petrographic analyses, as well as the results of radio-isotopic dating (40Ar/39Ar) of tuffite, has also provided new insights into the age and correlation of Miocene of the PCF (Bukowski et al. 2010, 2013, 2018).

Many studies have also been carried out on the sedimentology, structural evolution, and paleoecology of the Miocene sediments within the USCB (Aleksandrowicz 1976; Buła and Jura 1983a, b; Peryt 1997; Jura 2001; Gonera 2001, 2018; Oszczypko 2006, Oszczypko et al. 2006; Oszczypko and Oszczypko-Clowes 2012; Peryt 2013). Miocene lithology is also very important in terms of methane concentrations in the Carboniferous coal-bearing series and its emissions into mining excavations and the atmosphere in the Upper Silesian Coal Basin (USCB) (Kędzior and Dreger 2019; Sechman et al. 2020). It has been stated that the highest possibility of methane migration from abandoned coal mines to the surface is in the part of the coal basin where the Miocene overburden covers the allochthonous high-methane zone in the Carboniferous seams (Grzybek and Kędzior 2005). There is also intensive research into the possibility for safe CO_2 geological storage in the Miocene of the Upper Silesia Coal Basin. The Dębowiec Formation, due to its favorable geological and hydrogeological parameters, seems to have the most potential for CO_2 storage (Solik-Heliasz 2011; Koteras 2020).

In this paper, we provide new data on the Miocene development within the USCB. We focus mainly on the analysis of coals, coals clasts, and dispersed organic matter in terms of their origin, degree of coalification, and depositional environment.

1. Geological framework

The Miocene succession in the Upper Silesian Coal Basin lies unconformable on the older substrate (mainly Carboniferous or Triassic). It is composed of highly variable sediments, representing different sedimentary paleoenvironments. Three main phases of geological history can be distinguished: the opening phase (brackish/freshwater environment), the fully developed phase (normal salinity marine), and the closing phase (brackish/freshwater environment) (Gonera 2001). Within the Miocene of the USCB, the following major lithostratigraphic units can be distinguished: the Kłodnica Formation, the Dębowiec Formation, Skawina Formations, the Wieliczka Formation, and the Gliwice Formation (Figure 1).

The Kłodnica Formation is the lowermost part of the Miocene sediments, representing Karpatian. It consists of diversified complex deposits formed in terrestrial, freshwater, and brackish environments, sometimes with an occasional marine influence. The Kłodnica Formation comprises sandy clays with snails (Cepaea), dark gray clays with fragments of flora and brown-coal intercalations, gray marly clays with a scarce fauna of mollusks (Ostrea, Cerithium, Neritina) and foraminifers (Ammonia), as well as clays and sands with fresh-water gastropods (Planorbis) (Aleksandrowicz 1976). The basement of the Kłodnica Formation is locally built of regolith, which is developed as breccias and mottled conglomerates up to around tens meters thick (Buła and Jura 1983b). In the central part of the Kłodnica Formation, there is intercalation of white diatomite, 5 to 40 centimeters thick, which is interpreted as a result of marine ingression that flooded the central part of the Upper Silesia Basin during the Karpatian (Aleksandrowicz 1969). Brown-coal intercalations commonly occur in the Kłodnica Formation profile of the USCB. Brown coal usually forms thin seams and lenses, interbedded with clastic rocks. Brown-coal intercalations are about 1 m thick; however, coal seams may be locally as thick as 8 m. The Kłodnica Formation occurs in the form of patches infilling mainly isolated depressions, and it reaches is up to 100–150 m thick in the central part of the Upper Silesian Basin (Aleksandrowicz 1976; Kasinski and Piwocki 1994; Jureczka and Kotas 1995; Aleksandrowicz 1997; Haisig et al. 2000, 2003; Jura 2001).

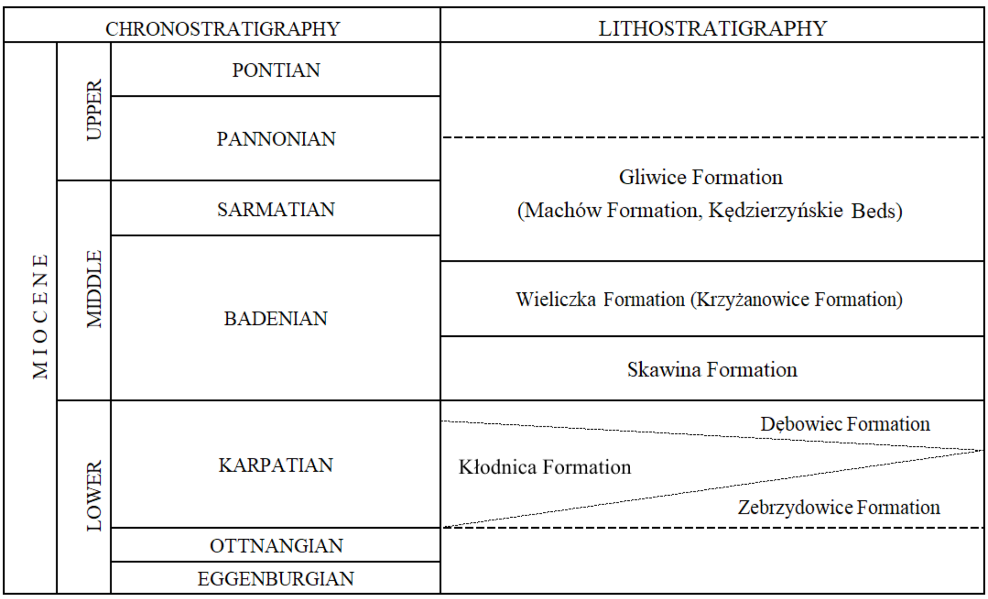

Fig. 1. Lithostratigraphic division of the Miocene in the Upper Silesian Coal Basin
(simplified from Aleksandrowicz 1982, 1997; Piwocki et al. 1996)

Rys. 1. Podział litostratygraficzny miocenu w Górnośląskim Zagłębiu Węglowym

In the southern part of the basin, deep erosional troughs are also filled with sediments of the Dębowiec Formation (Jureczka and Kotas 1995). The Dębowiec Formation is a transgressive coarse-grained Miocene sediment, which occurs mainly between Cieszyn, Jastrzębie and Bielsko (Buła and Jura 1983a, b; Oszczypko and Oszczypko-Clowes 2012). This unit is composed mainly of coarse-grained sandstones. The thickness of the unit may reach up to 260 m (Majer-Durman 2014). A characteristic feature of the Dębowiec Formation is the lack of silt layers and fining upward gradation and the presence of flysch-derived clasts as well as Upper Carboniferous clasts (Oszczypko 2001; Oszczypko and Oszczypko-Clowes 2012; Chylarecka and Filipiak 2004). Carboniferous clasts occur in the layer of basal breccia and conglomerate as exotic and coal-bearing carboniferous rock blocks, coal clasts or in a dispersed form in fine to coarse-grained sandstones. A study of the composition of a heavy fraction of the Dębowiec Formation deposits has shown assemblages of heavy minerals, which indicates the provenance of these deposits from the underlying Upper Carboniferous rocks and from the Carpathian flysch (Heliasz and Manowska 1991). A study of the Dębowiecki conglomerate's clastic material also showed that they are of Carboniferous origin (Majer-Durman 2014). The palynological study of coal pebbles from the Dębowiec Form in the Cieszyn region (Chybie IG1 borehole) indicated the presence of miospore species representing Namurian B, C, and Westphalian A. The Dębowiec conglomerates grade upwards into the marine clayey-sandy sediments of the Skawina Formation, but they were also observed within this formation (Jachowicz and Jura 1987; Chylarecka and Filipiak 2004; Oszczypko and Oszczypko-Clowes 2012). The Dębowiec Formation is of the Late Karpatian/Early Badenian age (Jura 2001; Chylarecka and Filipiak 2004; Bukowski et al. 2018). The latest Early Miocene times were characterized by the development of SW-NE, and NW-SE trending grabens. Subsidence was accompanied by the Early Badenian transgression which flooded both the foredeep and the marginal part of the Carpathians (Oszczypko 1998; Oszczypko et al. 2006).

The Skawina Formation is associated with marly clays with sand or silty gravel admixtures and intercalations of shelly limestones or marls. An abundant marine fauna of mollusks, benthic and planktonic foraminifera, ostracods, echinoid spines, and bryozoans is found in this formation (Aleksandrowicz et al. 1982; Aleksandrowicz 1997; Gonera 2001, 2018; Gonera and Bukowski 2012). Palaeoecological analysis suggests that the Skawina Formation consists of deposits of the full development of marine transgression, its regression and transgression again. Additionally, there was a climate change accompanying these stages (Gonera 2001, 2018). The thickness of this formation is highly variable within the USCB, and generally increases toward the south where it reaches about 1.110 m (Jureczka and Kotas 1995).

The Wieliczka Formation corresponding to the Krzyżanowice Formation developed as claystones with evaporatic rocks (gypsum and rocky salts). It developed mainly in the western part of the USCB and reaches a thickness of about 150 m (Jureczka and Kotas 1995). The genesis of the Badenian evaporite series is connected with the so-called Badenian Salinity Crisis (BSC), which was probably triggered by a rather sudden drop of sea level due to global cooling (Oszczypko 2006; Bukowski et al. 2013).

The Gliwice Formation (the Kędzierzyn Formation) is represented by gray-green clays with sandy intercalations, frequent clayey siderite, and variegated clays in the uppermost part of the profile. Thin lignite lenses, up to 1 m thick, coaly middlings and plant remains occur in this unit. Sediments of the Kędzierzyn Formation were deposited in the northern and central part of the Upper Silesian part of the Carpathian Foredeep (Kasiński and Piwocki 1994). The thickness of the Kędzierzyn Formation reaches 300 m, and it decreases to 10-20 m in the marginal parts, where sandy intercalations occur more frequently (Kasiński and Piwocki 1994; Jureczka and Kotas 1995). The Gliwice Formation consists of sediments representing different paleoenvironments, from the normal marine environment to the stage of progressive reduced salinity and regression. These deposits are internally heterogeneous both in their paleoecology and paleoenvironmental aspects (Gonera 2001).

The Miocene deposits within USCB are overlaying with Quaternary deposits composed of sands and gravels, intercalated by tillites and clays (Jureczka and Kotas 1995).

2. Materials and methods

The material studied comes from core samples from the WSx borehole located in Kryry (near Żory) within the Upper Silesian Coal Basin (Figure 2).

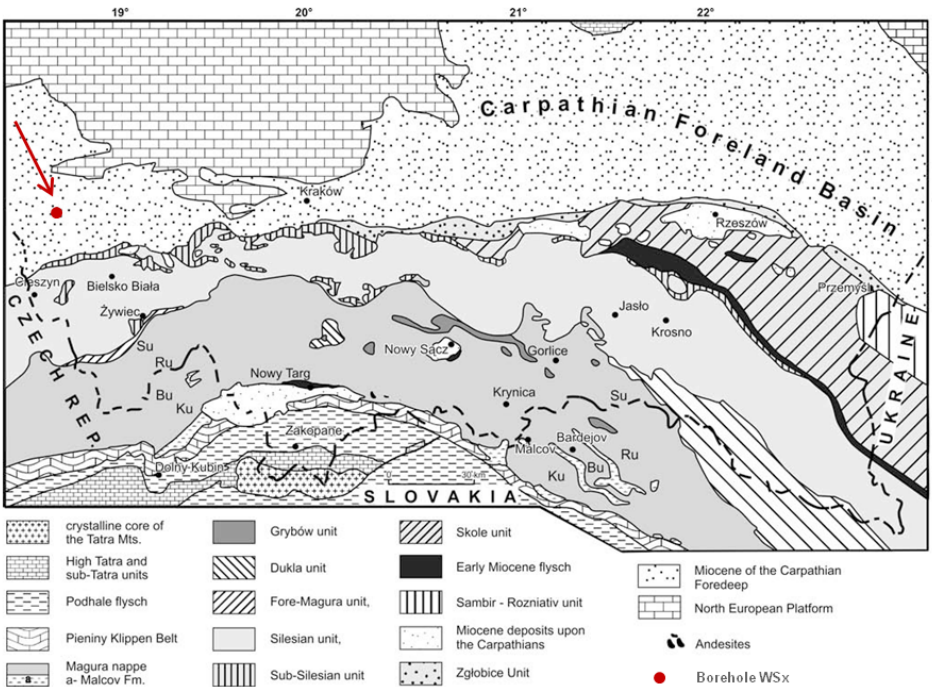

Fig. 2. Geological sketch of the Polish part of the Carpathian and the Carpathian Foredeep (Rasser et al. 2008)

Rys. 2. Szkic geologiczny polskiej części Karpat i Zapadliska Przedkarpackiego

Four brown coal samples (samples number 1–4), two dark gray claystone samples (sample numbers 5 and 6) and two breccia samples (sample numbers 7 and 8) containing coal clasts or dispersed organic matter were selected for the research. The location of the samples within the borehole profile is shown in Figure 3. The studies included random reflectance measurements of the organic matter. Petrographic analysis of organic matter were performed on polished cut samples at the Department of Applied Geology of the Silesian University of Technology according to the ISO 7404-2:2009 and ISO 7404-5:2009 standards.

The random reflectance R_r^o of huminite/vitrinite was determined using monochromatic light with a wavelength of 546 nm, immersion oil (n = 1.518), and Zeiss MPM-400 reflectometers.

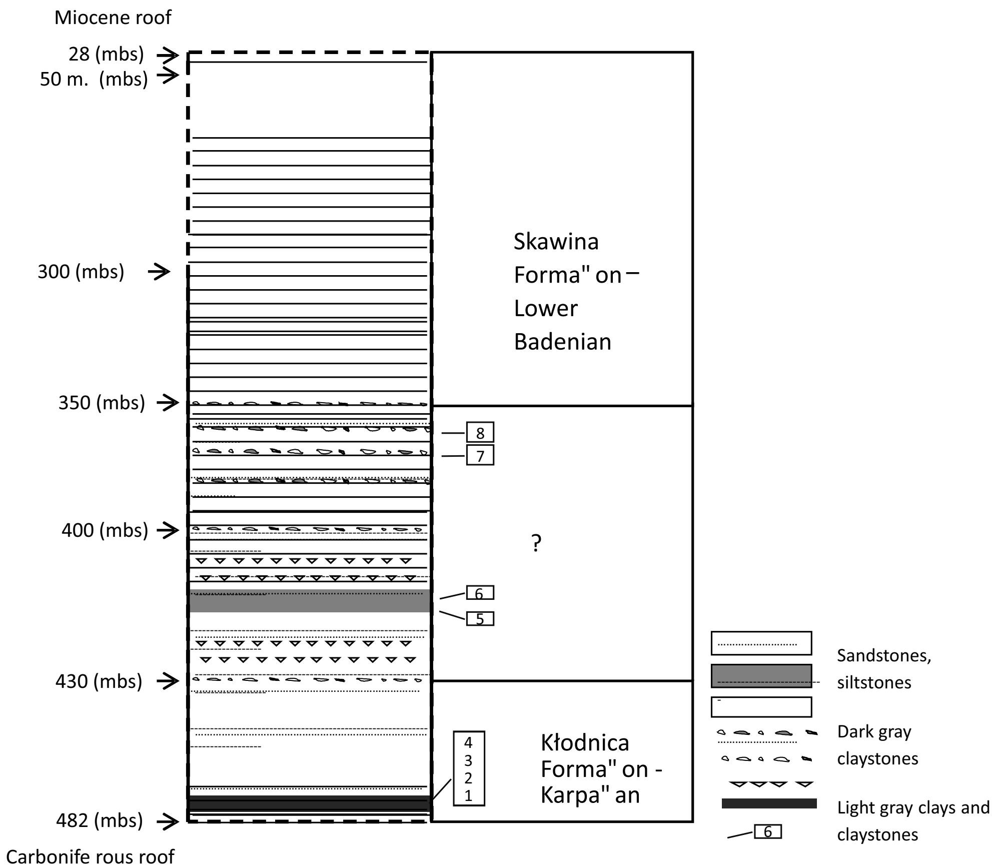

Fig. 3. Simplified profile of the Miocene from the WSx borehole

Rys. 3. Uproszczony profil miocenu otworu wiertniczego WSx

3. Results and discussion

3.1. The Miocene succession in the analyzed borehole

The Miocene succession of the WSx borehole is characterized by high thickness (454 m) and highly variable lithology (Figure 3).

The lowermost part of the profile, at a depth of 482 to 430 m, consists of light gray clays and claystones, sandy clays as well as marly clays with marine and brackish fauna remains. On the bottom of this unit, an 8-m-thick brown-coal layer has been identified. Based on lithological and paleontological data, this part of the Miocene succession was classified as the Kłodnica Formation, representing Karpatian.

The middle part of the Miocene succession (depth of 430 to 350) is lithologically highly variable. It begins with a conglomerate overlaid with gray to dark gray clays and claystones with intercalations of gypsum and carbonate rocks. Gypsum inserts are up to 5 cm thick. Locally, there is cyclic sedimentation of alternating layers of gypsum, carbonate rocks, and clay. Within the claystones package, the presence of black claystones with a large amount of organic matter was found. Above, a package of brown or rusty-red clastic sedimentary rock was found. Within this package, the presence of breccias of conglomerates containing coal clasts, gray Carboniferous sandstone fragments and dispersed organic matter was identified. The stratigraphic position of the unit described above at this stage of research is unclear. The paleontological research, which is in progress, will enable an unambiguous determination of the stratigraphic position of this unit.

The highest part of the Miocene succession (depth of 350 to 28 m), representing the Skawina Formation is made up of light gray marly and sandy clays. An abundant marine fauna of mollusks, foraminifera, and echinoid spines with a variable level of preservation was found in this unit. The Miocene succession is overlaying with Quaternary deposits with a thickness of 28 m composed mainly of sands and gravels.

3.2. Brown-coal layer

At a depth of 474.5–466.6, the presence of a brown coal layer was identified. According to Polish nomenclature, two types of brown coal can be distinguished – "soft brown coal" and "hard brown coal", the latter being of higher rank. Hard brown coal is divided into dull and bright types. This division is based on an increasing degree of coalification (coal rank). According to the globally recognized nomenclature for coal technology, brown coal is categorized as a low rank energetic raw mineral with the release of low-rank C ortho-lignite (soft brown coal), low-rank B meta-lignite (dull brown coal), and low-rank A sub-bituminous coal (bright brown coal) (Wagner 2013). Hard dull brown coal has a fibrous structure in which tree roots and stems as well as other plant matter are still recognizable. Hard bright brown coal is characterized by greater brightness and luster and by the absence of woody texture. Some sub-bituminous coal is macroscopically indistinguishable from bituminous coal. The boundary between dull brown coal (meta-lignite) and bright brown coal (sub-bituminous coal), is considered at random reflectance (R_r^o) of 0.40% (Bielowicz 2012; Wagner 2013). Based on the textural properties (Figures 4 and 5) and the degree of coalification, brown coal found in the analyzed borehole was classified as hard brown coal changing from dull brown coal (meta-lignite) to bright brown coal (sub-bituminous coal). The presence of two varieties of hard brown coal in the studied material was confirmed by petrographic studies. The analysis of the random reflectance of huminite/vitrinite of the bright brown coal samples (Samples 1 and 2) showed the values of R_r^o = 0.45% and R_r^o = 0.47%, while of the dull brown coal (Samples 3 and 4), R_r^o = 0.37% and R_r^o = 0.38% (Table 1). The distribution of the reflectance values R^0 for the bright and dull types is presented in the reflectograms (Figures 6 and 7). The petro-

Fig. 4 . Bright brown coal, borehole WSx, sample 2 – depth 470 m

Rys. 4. Błyszczący węgiel brunatny, otwór wiertniczy WSx, próbka 2, głębokość 470 m

Fig. 5. Dull brown coal, borehole WSx, sample 3 – depth 468 m

Rys. 5. Matowy węgiel brunatny, otwór wiertniczy WSx, próbka 3, głębokość 468 m

Table 1. Random, min and max reflectance huminite/vitrinite of coal, coal clasts, and dispersed organic matter of the Miocene deposits from WSx borehole

Tabela 1. Średnia, minimalna i maksymalna refleksyjność huminitu/witrynitu węgla, klastów węglowych i rozproszonej substancji organicznej utworów miocenu z otworu WSx.

Number of sample/Depth mbs	Type of organic matter	R_r^o (%)	max R^o (%)	min R^o (%)	Standard deviation
8/362	coal crumbs and dispersed organic matter	0.76	1.05	0.35	0.18
7/370	coal crumbs and dispersed organic matter	0.80	1.10	0.29	0.20
6/423	coal crumbs and dispersed organic matter	0.42	0.65	0.22	0.09
5/425	coal crumbs and dispersed organic matter	0.39	0.58	0.21	0.09
4/465	brown-coal layer	0.38	0.52	0.23	0.06
3/468	brown-coal layer	0.37	0.55	0.24	0.07
2/470	brown-coal layer	0.47	0.64	0.34	0.07
1/472	brown-coal layer	0.45	0.62	0.31	0.07

graphic and textural features of the brown coal indicate authigenic sources of organic matter.

Brown-coal intercalations commonly occur within the Kłodnica Formation in the lower part of the Miocene profile of the USCB. Brown coal usually occurs in the form of thin seams, benches, and lenses, interbedded with clastic rocks. Brown-coal intercala-

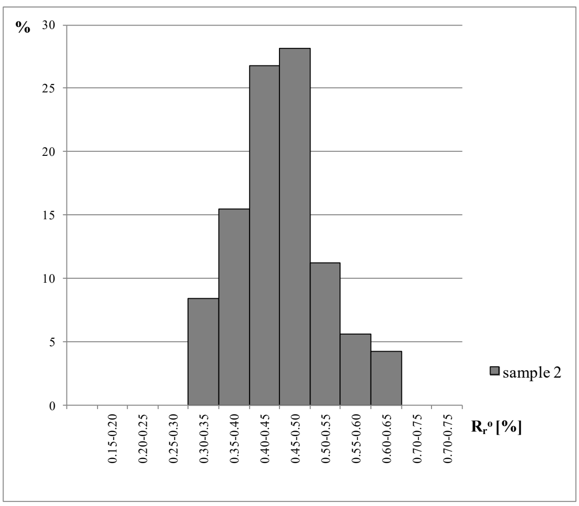

Fig. 6. Huminite/vitrinite reflectogram for the bright brown coal sample (sample 2, depth 470 m)

Rys. 6. Reflektogram huminitu/witrynitu dla próbki błyszczącego węgla brunatnego (próbka 2, głębokość 470 m)

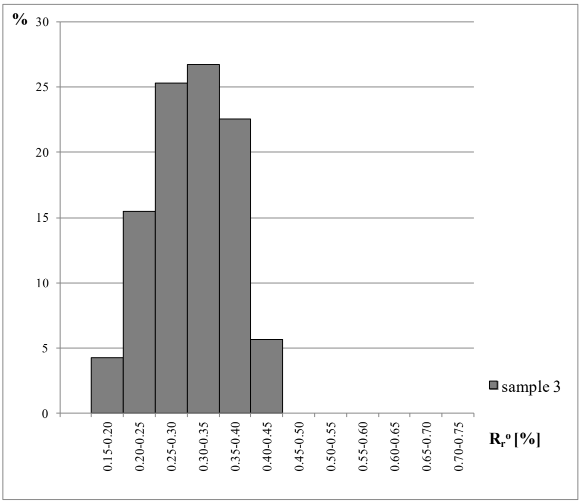

Fig. 7. Huminite/vitrinite reflectogram for the dull brown coal sample (sample 3, depth 468 m)

Rys. 7. Reflektogram huminitu/witrynitu dla próbki matowego węgla brunatnego (próbka 3, głębokość 468 m)

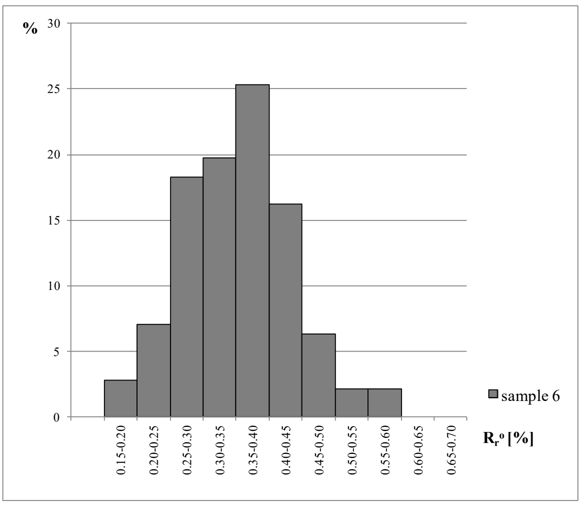

Fig. 8. Huminite/vitrinite reflectogram for organic matter from black claystones (sample 6, depth 423 m)

Rys. 8. Reflektogram huminitu/witrynitu materii organicznej z czarnych iłowców (próbka 6, głębokość 423 m)

tions are mostly about 1 m thick but locally, the coal layer may be as thick as 8 m (Aleksandrowicz 1976; Kasiński and Piwocki 1994; Aleksandrowicz 1997; Haisig et al. 2000, 2003; Jura 2001). The thickness of the brown coal in the analyzed borehole is about 8 m, and it should be mentioned that no brown-coal inserts were observed in the adjacent boreholes.

3.3. Organic matter within claystones

Dark gray to black claystones locally pass into siltstones with coal fragments and dispersed organic matter are present in the analyzed profile at a depth of 427 to 422 m. The analysis of the random huminite/vitrinite reflectance of the organic matter present in black claystones (Samples 5 and 6) showed a low degree of coalification of the organic matter. The R^o values for Sample 5 range from 0.21 to 0.58%, with a random R_r^o value of 0.39%, and for Sample 6 from 0.22 to 0.65%, with a random R_r^o value from 0.42%. Based on the degree of coalification, organic matter found in claystones can be interpreted as redeposited fragments of Miocene brown coal. Dark gray claystones occur within the complex containing evaporates, which may suggest offshore sedimentation conditions and allochthonous provenances of organic matter.

3.4. Organic matter within the complex of sedimentary rocks

Breccias and conglomerates containing coal clasts up to 5 cm in size and dispersed organic matter lie within the complex of clastic sedimentary rocks, at a depth of 360 to 370 m. The presence of gray Carboniferous sandstone fragments was also found there. A characteristic feature of this complex is a brown or rusty red color indicating changes related to the weathering processes

The analysis of the random huminite/vitrinite reflectance of the organic matter present in breccia (Samples 7 and 8) showed the presence of two types of organic matter with different degrees of coalification. The reflectograms for Samples 7 and 8 are bimodal. The value of huminite/vitrinite reflectance for coal crumbs most often showed R^o values from 0.75 to 1.10%. The dispersed organic matter is characterized by a much lower degree of coalification with the most frequently observed R^o values from 0.29 to 0.60% (Figure 9). Random huminite/vitrinite reflectance of organic matter R_r^o is 0.80% for Sample 7 and 0.76% for Sample 8, with a high value of standard deviation (Table 1).

The analysis of the degree of coalification allowed identification of the allochthonous origin of the organic matter. The coal fragments observed in the breccia samples are mainly Carboniferous origin, while the Miocene brown-coal grains (mostly redeposited) dominate within the dispersed organic matter. The stratigraphic position of this unit at this stage of research is uncertain. It is overlain by a thick series of light gray marly claystones with infrequent intercalations of fine-grained sandstones, representing the Skawina Formation.

The presence of the Carboniferous clasts in the Miocene breccia and conglomerates is known from the Dębowiec Formation (Dębowiec beds) (Jachowicz and Jura 1987; Heliasz and Manowska 1991; Chylarecka and Filipiak 2004; Oszczypko and Oszczypko-Clowes 2012; Majer-Durman 2014). The complex of clastic sedimentary rocks in the profile of the analyzed borehole has some features of the Dębowiec Formation. The location of

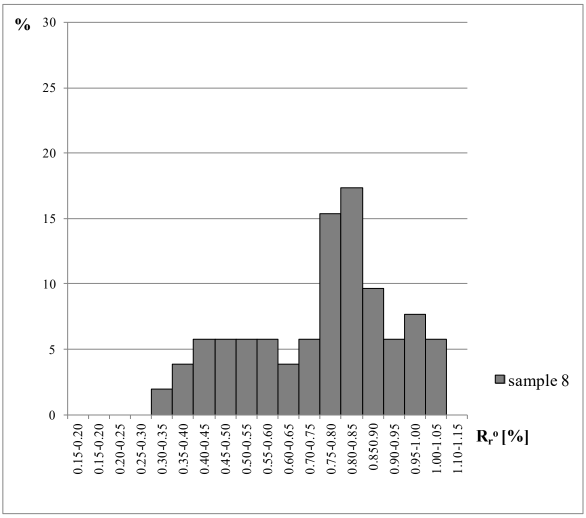

Fig. 9. Huminite/vitrinite reflectogram for organic matter from clastic rocks (sample 8, depth 362 m)

Rys. 9. Reflektogram huminitu/witrynitu materii organicznej ze skał klastycznych (próbka 8, głębokość 362 m)

this complex on the base of the formation, as well as the presence of Carboniferous rocks, may suggest the Dębowiec Formation. However, the red color of this complex and the lack of fining upward gradation, typical for the Dębowiec formation, rather disqualify such identification of this unit. Therefore, this complex cannot be considered as the Dębowiec Formation but rather as its age equivalent.

Conclusion

The Miocene succession in the Upper Silesian Coal Basin is composed of highly variable sediments, representing different sedimentary paleoenvironments. In the study area, the Miocene sediments are characterized by their high thickness and highly variable lithology. The lowermost part of the Miocene succession consists of clays, claystones, sandy clays, and marly clays, which was classified as the Kłodnica Formation, representing Karpatian. The middle part of the profile, with an uncertain stratigraphic position, is made up of clays and claystones with intercalations of gypsum and carbonate rocks as well as a package of brown or rusty-red clastic sedimentary rock. The Miocene profile ends with the monotonous clay-sandy series representing the Skawina Formation.

In the Miocene sediments of the studied area, the presence of organic matter in the form of a coal layer, coal crumbs, and dispersed organic matter was found. A brown layer with a thickness of about 8 m was identified within the Kłodnica Formation. Based on the textural properties and degree of coalification, brown coal was classified as dull brown coal and bright brown coal. Coal clasts and dispersed organic matter were also found within a package of brown or rusty-red clastic sedimentary at the top of the middle of the profile. On the basis of petrographic analysis, two types of allochthonous organic matter with different degrees of coalification were found. The coal clasts are mainly of Carboniferous origin, while the Miocene brown coal grains dominate within the dispersed organic matter. Coal fragments and dispersed organic matter were found within the black claystones located in the middle of the profile. Based on the degree of coalification, organic matter found in claystones can be interpreted as redeposited fragments of Miocene brown coal.

The study of the organic matter of the Miocene sediments in the USCB showed different organic matter provenances (autochthonous and allochthonous) and different ages (Carboniferous and Miocene).

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COAL AND DISPERSED ORGANIC MATTER IN THE MIOCENE SEDIMENTS OF THE UPPER SILESIAN COAL BASIN (POLAND) – NEW DATA

Keywords

organic matter, Miocene, Carpathian Foredeep

Abstract

The paper presents new data on the Miocene development within the Upper Silesian Coal Basin. The Miocene succession of the study area is characterized by high thickness and highly variable lithology. In the Miocene sediments of the studied area, the presence of organic matter in the form of a coal layer, coal crumbs, and dispersed organic matter has been found. The research focused mainly on the analysis of organic matter in terms of its origin, degree of coalification, and depositional environment. The degree of coalification of organic matter was determined by the huminite/vitrinite reflectance.

The hard brown coal layer with a thickness of about eight meters was identified within the Kłodnica Formation. Based on the textural properties and degree of coalification, brown coal was classified as dull brown coal and bright brown coal. Organic matter in the form of coal crumbs and dispersed organic matter were found within a package clastic sedimentary. On the basis of petrographic analysis, two types of allochthonous organic matter with different degrees of coalification were identified. The coal clasts are mainly of Carboniferous origin, while the Miocene redeposited brown coal grains dominate within the dispersed organic matter. Coal fragments and dispersed organic matter derived from the Miocene brown coal were also found within the black claystones. The study of organic matter of the Miocene sediments in the Upper Silesian Coal Basin showed both its autochthonous and allochthonous origins.

WĘGIEL I ROZPROSZONA SUBSTANCJA ORGANICZNA W OSADACH MIOCENU GÓRNOŚLĄSKIEGO ZAGŁĘBIA WĘGLOWEGO (POLSKA) – NOWE DANE

Słowa kluczowe

materia organiczna, miocen, Zapadlisko Przekarpackie

Streszczenie

W pracy przedstawiono nowe dane dotyczące rozwoju miocenu w obrębie Górnośląskiego Zagłębia Węglowego. Sukcesję mioceńską na obszarze badań charakteryzuje duża miąższość i bardzo zmienna litologia. W osadach miocenu badanego obszaru stwierdzono obecność materii organicznej w postaci warstwy węgla, okruchów oraz rozproszonej materii organicznej. Badania koncentrowały się głównie na analizie materii organicznej pod kątem jej pochodzenia, stopnia uwęglenia oraz środowiska depozycji. Stopień uwęglenia materii organicznej oznaczono na podstawie refleksyjności huminitu/witrynitu. W obrębie Formacji Kłodnickiej zidentyfikowano warstwę twardego węgla brunatnego o miąższości około ośmiu metrów. Na podstawie właściwości teksturalnych i stopnia uwęglenia węgiel brunatny zaklasyfikowano jako węgiel brunatny twardy matowy i węgiel brunatny twardy błyszczący. Substancja organiczna w postaci okruchów węgla i rozproszonej substancji organicznej zidentyfikowana została w obrębie pakietu klastycznych skał okruchowych. Na podstawie analizy petrograficznej zidentyfikowano dwa rodzaje allochtonicznej materii organicznej o różnym stopniu uwęglenia. Okruchy węgla są głównie pochodzenia karbońskiego, natomiast w rozproszonej materii organicznej dominują redeponowane ziarna mioceńskiego węgla brunatnego. Okruchy węgla i rozproszoną materię organiczną pochodzącą z mioceńskiego węgla brunatnego stwierdzono również w czarnych iłowcach. Badania materii organicznej osadów mioceńskich w Górnośląskim Zagłębiu Węglowym wykazały zarówno jej autochtoniczne, jak i allochtoniczne pochodzenie.