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THE MINERAL CHARACTER AND GEOMECHANICAL PROPERTIES OF THE TRANSITIONAL ROCKS FROM THE MESOZOIC-NEOGENE CONTACT ZONE IN THE BEŁCHATÓW LIGNITE DEPOSIT

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ABSTRACT

Purpose Beginning more than 30 years ago, opencast lignite mining in the "Bełchatów" area is an important source of accompanying minerals. Lignite mining in the "Bełchatów" mine yields, on average, more than 35 million tonnes per annum and requires removing more than 110 million cubic meters of overburden. Therefore the mine outside of the main mineral exploitation of lignite, leads to a large-scale economy of accompanying minerals. Part of the minerals are present in the overburden and are exposed on the slopes of the opencast mine; these minerals are selectively exploited in the event of the absence of recipients stored on anthropogenic deposits. The object of this mineralogical-geochemical study is a group of transitional rocks such as opoka-rocks, gaize and marls exposed when contact occurs between Neogene sediments and Mesozoic basement rocks in the "Bełchatów" lignite deposit. In the case of these rocks, during preliminary geological research carried out on the mine, doubt often appear as to their explicit petrographic character and hence their practical use. Advanced mineralogical methods allow mistakes in their identification to be avoided and a geomechanical study indicates possible direction of their practical use.

Methods The heterogeneous petrographic character of the examined rocks required the use of a broad research spectrum. The following microscopes were used in the framework of the mineralogical research: Polarizing Olimpus BX51 and electron (SEM) FEI Quanta 200FEG equipped with an X-ray spectrometer (EDX Genesis) and backscattered electron detector (BSE). In addition, observations were carried out using a cathodoluminescence apparatus, the Cambridge Image Technolgy Ltd CCL 8200 mk3 model, and a polarizing microscope, type Nikon Optiphot 2. Determination of the phase composition (qualitative and quantitative) was made using X-ray diffraction and utilizing the powder method of Debye-Sherrer. An X-ray diffractometer, a Philips PW 3020 X'PERT, was also used in the study. Analyses by Fourier transmission infrared spectroscopy were performed using the production apparatus BIO-RAD, model FTS 165, equipped with a package of programs for the digital processing of results. The chemical composition was determined by atomic absorption spectroscopy (AAS) using a spectrophotometer Philips PU 9100Xi Camera SX-100 and atomic emission spectroscopy with inductively coupled plasma (ICP AES) using spectrometer 40 PLASMA. The geomechanical properties were determined in accordance with the following standards: open and total porosity (PN-EN 1936:2001) compressive strength in air – dried state (PN-EN 1926:2001), bulk density and density (PN-EN 1936:2001), relative humidity (PN-EN 1925:2001); absorbability of stone material (PN-EN 13755:2002) and abrasion on the face of Boehme (PN-84/B-04111).

Results Mineralogical-petrographic studies of the transitional rocks showed that the dominant component was SiO_2 which was presented in the form of opal type A and CT, chalcedony, quartz and microquartz. In addition, it was found that the rocks studied had been covered by secondary mineralization processes. The observations carried out showed that these rocks underwent primary silicification and decalcination processes, which contributed to the diverse petrographic nature of the rocks studied and secondarily experienced a change in their physico-mechanical properties. The silification process was the result of diagenetic processes taking place within the Neogene argillaceous rocks occurring when a sub-coal series is situated in the immediate vicinity of the bedrock. There was a release of extruded silica-rich water from the clays during the mechanical compaction process. Some amounts of silica may also be derived from plagioclase dissolution and the transformation of terrigenous material, mainly grains of potassium feldspar. The precipitation of silica from porous solutions occurred most when coinciding with the presence of carbonic acid formed by the decomposition of organic substances of vegetable origin.

Practical implications The studies carried out have a significant practical implication, as the transitional sediments from the "Bełchatów" lignite deposit can be used in the production of building materials.

Originality/ value Against the background of a number of published papers on the rocks accompanying lignite seams there is a lack of the mineralogical-petrographic studies of the transitional sediments in the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit taking into account the aspect of raw materials. This paper has been produced to fill the void in this area.

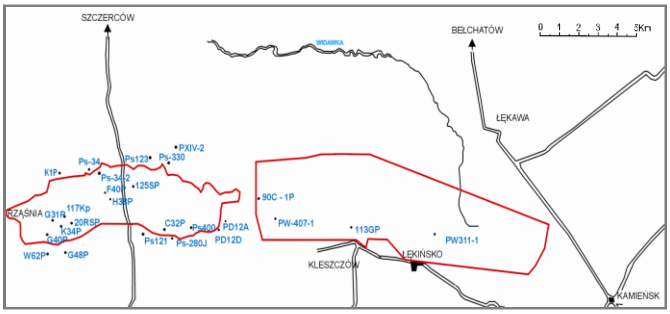
Keywords
transitional rocks, mineral, Bełchatów lignite deposit, geomechanical properties

1. INTRODUCTION

A precise knowledge of the mineral composition of rocks helped us to assess the causes of the formation of specific physical-mechanical properties and also allowed us to predict their behavior under varying geological-engineering conditions. Geomechanical features were often conditioned by the type of silica binding material, the type of bioclastic content, or the breaking up of the ingredients that form rocks. The transitional rocks studied belonged to the group of rocks with a heterogeneous mineral composition which led a large degree of uncertainty in their identification. Their correct petrographic classification required the use of detailed mineralogical and chemical studies. In addition, these rocks were often used as building material or were the basis of many buildings. There was a great deal of importance when it came to knowledge of their mineral composition and mineralization processes as this often led to changes in the primary and secondary characteristics of the rocks which had an affect on the geomechanical parameters.

2. THE RESEARCH MATERIAL

The contact zone in the "Bełchatów" lignite deposit was composed of Mesozoic bedrocks and Neogene bottom deposits of the sub-coal complex. The research carried out made it possible to distinguish between Mesozoic deposits: limestones, opoka-rocks, gaizes, flints, diatomites, marls and medium grain rocks. The weathered sediments of the sub-coal complex were represented by breccias (polymictic and monomiktic), decalcified opoka-rocks and kaolin clays (Ratajczak, Kosk, & Pabis, 2002; Gilarska & Stachura, 2005). To a group of the transitional rocks which have been the subject of research were: opoka-rocks, gaizes and marls (Manecki & Muszyński, 2008). The basis for sampling material making for the research was collected during the profiling of boreholes, both hydrological and reservoir. Drilling wells were placed within "Bełchatów" and "Szczerców" mining fields. The sampling material was additionally supplemented by information and a sample taken from the southern slope of the exploited exavation, collected during the profiling of boreholes, both reservoir and hydrogeological, made in the "Bełchatów" and "Szczerców" mining fields. A total of 26 boreholes were tested (Fig. 1) and 42 samples were collected including 29 samples coming from cores and 13 from the outcrop.



Explanation: — – boundaries of the deposit, G48P – borehole

Fig. 1. Draft of the layout of sampling in drilling wells in the "Bełchatów" lignite deposit

3. RESULTS OF THE RESEARCH

3.1. The mineral character of the siliceous transitional sediments

The group of the siliceous transitional rocks from the Mesozoic-Tretiary contact zone in the "Bełchatów" lignite deposit was represented by opoka-rocks and decalcified geiza. Outcrops of these kinds of sediments were revealead on the Sub--Cenozoic surface, among others, on the edge of the rift valley. They were interbedded with marls and limestones. The opoka--rocks from the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit were rocks with a mikrocrystalline-organogenic or micritic-detritial structure. The texture is compact, unoriented and only locally parallel. A background of the opoka-rocks was mainly formed by carbonate substance, developed as micrite and opal. Besides bioclastic content, a presence of quartz grains with varying degrees of roundness in the rocky background among detritial material was revealed. Relics of hydromuscovite and nodules of glauconite were occasionally encountered. The aggregation of small crystals of pyrite with idiomorfic outline and the presence of individual grains of heavy minerals, mainly zircon was also noted. Some of these types of rocks showed the characteristics of opoka-rocks which were influenced by secondary mineralization processes. Silification and decalcination among the most common processes should be distinguised. The effects of the silification have been indicated quite clearly in the microscope image. The silica replacing carbonates in the siliceous opoka-rocks was represented by chalcedony and opal type CT. This mineral tended to replace carbonates in the bioclasts (Fig. 2), (Gilarska & Stachura, 2005; Pękala, 2012).

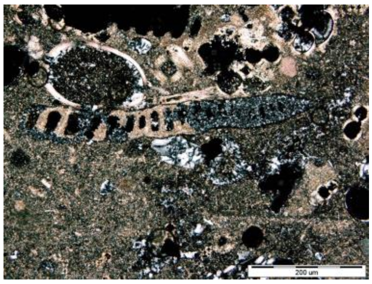


Fig. 2. Replacing carbonate bioclasts by chalcedony. Polarizing microscope, XP

The observations carried out led to the conclusion that, among the studied rocks, some of them were under the influence of decalcification processes. This consists of the dissolving and then leading of calcium carbonate. Rocks consisting of silica, which are highly porous and have a very low apparent density relative to the surrounding rocks were created, these rocks are called decalcified opoka-rocks. The carbonate minerals were an accesoric component. They could be found in the pore spaces between the chalcedony aggregates. They reached a size of about 0.01 mm. Their presence was confirmed by infrared spectroscopic studies. This proved the existence of a band of 1443 cm^{-1} (Fig. 3).

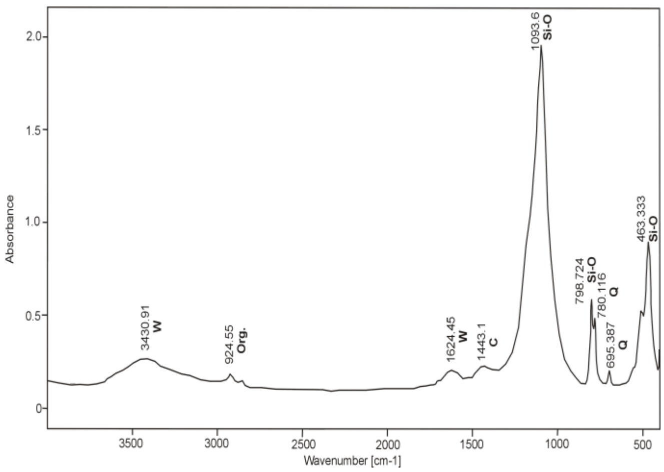


Fig. 3. The infrared spectroscopic spectrum of decalcified opoka-rocks from the weathered complex in the "Bełchatów" lignite deposit. Explanation: W – H 2 O, Org. – the organic substance, C – carbonates, Q – quartz and Si-O – silica

The decalcified gaizes with, regards to their appearance, resembled sandstones and mudstones. They accompanied mostly opoka-rocks. They were sometimes situated directly on the Mesozoic carbonate bedrocks. Their color was gray-white, sometimes with a greenish tint. The texture of these rocks was unoriented, slightly porous with an organo-detrital structure. A rocky cement was represented by a semi-crystalline or cryptocrystalline sillica, as well as claylike substance. It was sometimes slightly pigmented by brownish organic matter. A Detrital material was distributed in a disorderly manner. It was represented by siliceous organic skeletal elements, mostly needle sponges and shells of radiolarians or diatoms. The sillica that built them consisted of predominantly the chalcedony form and rarely opal (Fig. 4). Chalcedony also created a secondary fill in the pores of the rocks. In such instances chalcedony fibers were arranged in a concentric – radial creating a distinctive form of a "rozette" (Fig. 5). Plates of hydromuscovite and muscovite, biotite and partly chloritized biotite as well as quartz grains were situated within the detrital material. The grains of quartz were typically sharp-edged or at most slightly rounded. The presence of plate claylike minerals was also confirmed by observations carried out using a scanning electron microscope (Pękala, 2012).

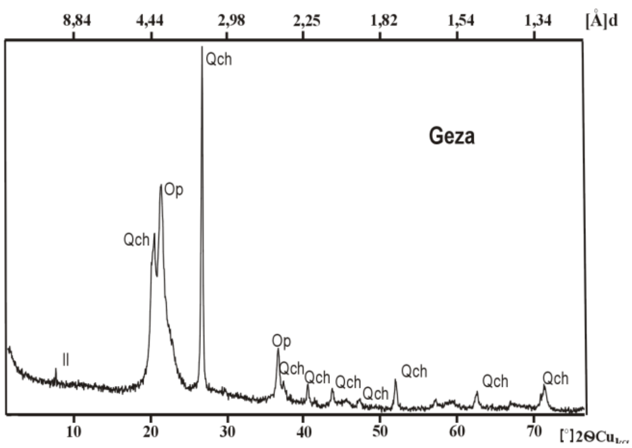


Fig. 4. The X-ray-pattern of the decalcified gaize from the Mesozoic--Neogene contact zone in the "Bełchatów" lignite deposit. Explanation: Qch – chalcedony, Op – Opal CT, Il – illite

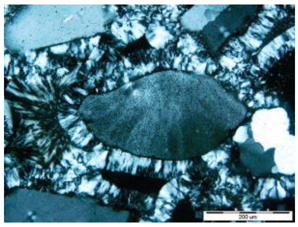


Fig. 5. Quartz surrounded by fibrous chalcedony creating distinctive rims in the decalcified gaize. Polarizing microscope, XP

3.2. The mineral character of the carbonate transitional deposits

The group of the transitional rocks with carbonate character in the Neogene sediment-Mesozoic bedrock contact zone was represented by Upper Cretaceous marls. These rocks had an organogenic structure. Their texture was compact, sometimes directional and the background had a carbonate-clayelike character. The calcite that built it had a microcrystalline character. These rocks were composed of numerous bioclasts and grains of terrigenous material. Shells of molluscs and echinoderms fragments could be distinguished among the carbonate organic debris. Well-preserved organic remains composed of silica could also be found. There were mainly needle sponges, radiolarians and spines of sea urchins. Cathodoluminescence studies have shown differences in the color of calcite. The rocky background was composed of calcite with luminescence which was red in color. The calcite building bioclats showed a yellow luminescence. Calcite with red and yellow luminescence was formed as a result of the secondary mineralization processes. Calcite with red luminescence was influenced by the diagenetic solutions that were rich in Fe^{2+}. Calcite with yellow luminescence crystallized in conditions experiencing a shortage of Fe^{2+} and with substantial support of Mn^{2+}. This kind of terrigenous material was represented by psamitic quartz grains with varying degrees of roundness. In addition, it consisted of spherical aggregates of glauconite, single plates of biotite and muscovite. Phase identification by X-ray diffraction showed that the silica present in the samples tested occured in the form of opal CT and quartz. The impact of calcite, clayey minerals and muscovite on the diffraction patterns was also recorded (Pękala, 2012).

3.3. The chemical properties

The chemical composition of the transitional rocks from the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit is shown in table 1. The results of the chemical analyzes is presented as maximum, minimum and average values for the different types of rocks.

Table 1. The chemical composition of the transitional rock groups from the Mesozoic--Neogene contact zone in the "Bełchatów" lignite deposit [% wt.]

Chemical composition	Types of rocks and results								
	Marls			Opoka-rocks			Gaizes		
	Min.	Max.	Avg.	Min	Max	Avg.	Min	Max	Avg.
CaO	27.34	43.87	32.64	16.00	30.50	25.14	0.50	19.82	5.85
SiO_2	11.45	26.95	21.14	40.20	66.90	49.23	63.20	93.59	85.25
TiO_2	0.03	0.73	0.16	-	0.22	0.06	0.025	0.27	0.09
Al_2O_3	1.78	7.52	4.50	0.72	4.50	3.10	1.05	1.16	1.11
Fe_2O_3	0.81	9.42	2.77	0.59	1.68	0.90	0.30	0.60	0.37
MgO	0.08	2.76	0.96	0.13	1.99	0.40	0.11	0.86	0.40
MnO	0.02	0.32	0.09	0.004	0.02	0.01	0.002	0.02	0.01
Na_2O	0.03	0.50	0.25	0.05	0.12	0.07	0.09	1.00	0.50
K_2O	0.02	0.75	0.20	-	0.70	0.43	0.08	0.81	0.34
P_2O_5	0.02	0.16	0.50	0.003	0.09	0.03	0.002	0.07	0.03

3.4. The geomechanical properties

The physical and mechanical parameters of the transitional rocks from the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit were varied. The fact that the silicified opoka-rocks showed significantly lower values of total porosity is noteworthy. The maximum value for this parameter in these rocks was 24.3 (% vol.). Within the opoka-rocks that were affected by decalcination processes this parameter did not exceed 44.5 (% vol). The compressive strength of the silicified opoka-rocks in an air-dried state was considerably higher (52.0 MPa) when compared to the decalcified opoka-rocks (31.9 MPa). In addition, silicified opoka-rocks had a higher apparent density – 1.9 g/cm^3. The apparent density in the decalcified opoka-rocks was in the range of 1.32–1.41 g/cm^3 which allowed them to be classified as so-called light opoka-rocks (Pękala & Hycnar, 2013). The tested gaizes also showed high compressive strength values (Rc) in the range of 55 MPa. Comparing the results of the geomechanical properties of Cretaceous opoka-rocks and gaizes (Maastrichtian) from the "Bełchatów" mining field with the results of other authors investigating the Cretaceous transitional sediments, we may have noticed that these rocks are characterized by a high mechanical strength. Compressive strength in the air-dried state of the Cretaceous opoka-rocks and gaizes from the Lublin Upland (Pinińska, 2008) was in the range of 10 to 40 MPa. In addition, these rocks had a higher apparent density – 1.9 g/cm^3 and lower water absorption – 11%. Meanwhile, the density and water absorption provided by Pinińska (2008) for rocks of Cretaceous age was, respectively, 1.4–1.6 g/cm^3, n > 35%. In the case of marls the rocks in air-dried state were durable and their strength values were situated in a range of 3–30 MPa. The content of the clay greatly affected the geotechnical characteristics and could be seen as moisture. Claylike marls tended to lead to water absorbtion and swelling. In the case of higher carbonate content, marls behaved like limestones or dolomites. When the mineral composition had a higher silica content these rocks had increased strength and water resistance.

In the framework of the presentation, chemical composition dependent on the geomechanical parameters, an example of correlation between the content of SiO_2 and CaO in the transitional rocks in relation to compressive strength in air-dried state was made. Figure 6 shows a clear relationship between the analyzed parameters. Strength parameters grow with the increase of the silica and corbonate content decrease.

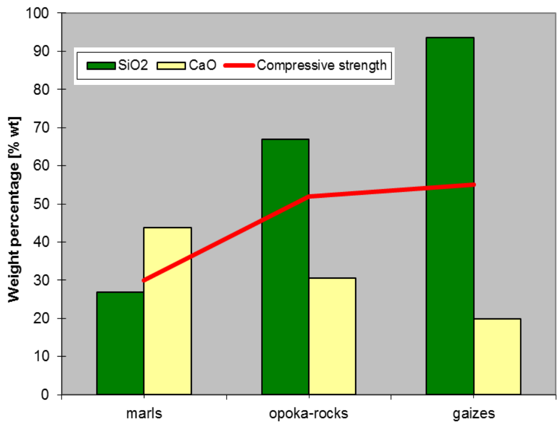


Fig. 6. Correlation of SiO_2 and CaO content to the compressive strength in the air – dried state for the transitional rocks from the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit

SUMMARY

1. The mineralogical study of the transitional rocks from the Mesozoic-Neogene contact zone in the "Bełchatów" lignite deposit showed that some of these rocks were influenced by secondary mineralization processes. The occurrence of marls, opoka-rocks and gaizes that underwent the silicification processes was confirmed. The effects of this process caused an increase in the hardness and firmness of the rocks. This was evidenced by the high compressive strength parameter, in the air-dried state, measured in the range of 52 MPa for silicified opoka-rocks and 55 MPa for gaize.
2. It should also be noted that the studied rocks, as a result of mineralization processes, were not homogeneous rocks. Rocks that were influenced by decalcination processes; this also affected their physical characteristics-resulting in lower mechanical strength parameter (Fig. 6).
3. The siliceous enrichment process in the rocks followed by replacement of carbonate organic debris, filling voids and pores of rock was observed. The silica replacing carbonate and forming rocky binding material typically took the form of opal (type A or CT) or chalcedony which occasionally appeared in the form of microcrystalline quartz.
4. As could be seen from recent geomechanical research the common use of opoka-rocks and gaizes as structural material is fully justified. This affected not only their availability, lightness and ease of mining but also the beneficial qualities of strength, ability to harden and the relatively low susceptibility to anthropogenic corossive activity.

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References

Gilarska, A., & Stachura, E. (2005). Charakterystyka mineralogiczno-petrograficzna skał krzemionkowych ze strefy kontaktu trzeciorzęd-mezozoik w złożu węgla brunatnego „Bełchatów" [Mineralogical and petrographic characteristic of the siliceous rocks of the Tertiary-Mesozoic contact zone in the Bełchatów lignite deposit]. *Zeszyty Naukowe Politechniki Śląskiej, Seria Górnictwo*, (269), 97–107.

Pinińska, J. (2008). Właściwości geomechaniczne opok [Geomechanical properties of opoka-rocks]. *Górnictwo i Geoinżynieria*, *32*(1), 293–301.

Manecki, A., & Muszyński, A. (Eds.). (2008). *Przewodnik do petrografii* [Guidebook to petrography]. Kraków: Akademia Górniczo-Hutnicza.

Pękala, A. (2012). Charakterystyka mineralogiczno-geochemiczna skał przejściowych ze strefy kontaktu mezozozik – neogen w złożu węgla brunatnego „Bełchatów" [Mineralogical-geochemical study of the transitional rocks from the Mesozoic-Neogen contact zone in the "Bełchatów" lignite deposit]. *Górnictwo i Geologia*, *7*(2), 187–205.

Pękala, A., & Hycnar, E. (2013). Opoki ze złoża węgla brunatnego „Bełchatów" – charakterystyka petrograficzna i możliwości wykorzystania [Upper Cretaceous opoka-rocks from the Bełchatów lignite deposit – their petrographic character and possibilities of using]. In T. Ratajczak, G. Rzepa, & T. Bajda [Eds.], *Sorbenty mineralne. Surowce, Energetyka, Ochrona Środowiska, Nowoczesne Technologie* (pp. 337–345). Kraków: Akademia Górniczo-Hutnicza.

PN-EN 1936:2010 *Metody badań kamienia naturalnego. Oznaczanie gęstości objętościowej oraz całkowitej i otwartej porowatości* [Polish Standard. Methods of test for natural stone. Determination of bulk density, total and open porosity].

PN-EN 1926:2001 *Metody badań kamienia naturalnego. Oznaczenie wytrzymałości na ściskanie w stanie powietrzno-suchym* [Polish Standard. Methods of test for natural stone. Determination of compressive strength in the air-dried state].

PN-EN 1925:2001 *Metody badań kamienia naturalnego. Oznaczanie współczynnika nasiąkliwości kapilarnej* [Polish Standard. Methods of test for natural stone. Determination of water absorption coefficient of the capillary].

PN-EN 13755:2002 *Metody badań kamienia naturalnego. Oznaczanie nasiąkliwości przy ciśnieniu atmosferycznym* [Polish Standard. Methods of test for natural stone. Determination of water absorption at atmospheric pressure].

PN-84/B-04111. *Materiały kamienne. Oznaczenie ścieralności na tarczy Boehmego* [Polish Standard. Determination of abrasibility on the disk of Boehme].

Ratajczak, T., Kosk, I., & Pabis, J. (2002). *Osady zwietrzelinowe ze strefy kontaktowej trzeciorzęd mezozoik w złożu węgla brunatnego „Bełchatów" – ich litologia, charakter surowcowy i możliwości wykorzystania* [Weathered sediments from the Mesozoic-Tertiary contact zone in the Bełchatów lignite deposit – their lithology, raw material character and possibility of use]. Kraków: Instytut Gospodarki Surowcami Mineralnymi i Energią PAN.