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INNOVATION IN THE COPPER INDUSTRY

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Social sciences

Introduction

The concepts of innovation, industry, and coppe – as intended by the editors of the monograph translated to readers – determine the theoretical field of the discussed considerations. They appear in various research perspectives, in broadly understood engineering and technical sciences, as well as in social sciences. Therefore, they constitute an open area of interpretation that cannot be reduced to a single interpretation or closed within one specific theoretical field. Innovation and issues related to its individual aspects are currently perceived as one of the fundamental issues determining socio--economic development. Globalization, technological and social changes, the permanent metamorphosis of the sphere of production, trade, services, consumption, and the constantly growing market awareness of buyers have become the sources of the intensification of the observed competitive phenomena. Meeting these new conditions forces organizations to search for new, more effective, and flexible ways of competing and to constantly identify all possibilities of modeling and rationalizing the market position. From the perspective of the Copper Basin, and in particular of the State Treasury company KGHM Polska Miedź SA, the importance of innovation should be perceived in a broader context, not only relating to the functioning of the company itself, but also to the enhancement of the development of Polish economic policy. Therefore, regardless of the definition, competitiveness is one of the most important determinants of modern enterprises, and innovative solutions can – and should – be sought in the product, process, marketing and image, and organizational spheres.

This monograph entitled "Innovation in the Copper Industry" consists of thirteen chapters, which are divided into two parts. The first one includes considerations and research results in the field of technical and engineering sciences. The next part deals with topics originating from the area of social sciences. The authors of the texts are, among others specialists conducting research in the most important academic centers in the country, employe-

es of research institutes, companies, and management staff at KGHM Polska Miedź SA

The part devoted to issues from technical and engineering sciences begins with the work entitled "*Application of the method of laser spectroscopy in the classification of mining materials*", authored by **Anna Wojciechowicz, Łukasz Buczkowski , Jędrzej Kowalewski, Michał Zięba and Mikołaj Podgórski**. The authors of the paper show the possibility of using distance studies by laser-induced plasma spectroscopy (LIBS) for the quantitative and qualitative recognition of useful minerals. The work presents a detailed analysis of the results obtained for samples of halites, potassium salts, lignite, and preliminary results obtained for copper-bearing shales. The obtained results confirm the effectiveness of the application of this modern measuring technique for mining materials testing.

Adam F. Idziak in the chapter entitled "*Selected aspects of the seismicity of the Upper Silesian Coal Basin*" analyzes the time, spatial and energy distributions of strong shocks of the Upper Silesian Coal Basin. The seismicity of this region has many similarities to the seismicity that can be observed in areas where natural earthquakes occur. The author emphasizes that the activity of strong tremors changes in time and space, and the research shows their seriality. The challenges faced by analytical chemistry laboratories related to the use of innovative solutions in industry were discussed in the chapter by **Tadeusz Gorewoda** and **Jacek Anyszkiewicz**, entitled "The challenges of analytical chemistry – keeping up with changes in the copper industry." The authors emphasize that the constantly developing industry forces the continuous introduction of new technologies in order to improve chemical analyzes.

Marcin Przybyła and Wacław Szetelnicki in the chapter entitled "The use of a mobile laboratory to assess the quality of the natural environment and the possibility of its use in measurements in underground mining excavations". Equipping such laboratories with unmanned aerial vehicles, portable analyzers or portable gas chromatographs allows them to be used in underground mining excavations.

Barbara Namysłowska-Wilczyńska described the application of geostatistical studies to the analysis of the variability of the ore deposit parameters in the chapter entitled "Estimation of the Parameters of the Cu Deposit in the „Rudna" Mine Based on the Application of Geostatic Methods with Even Conditioning on the Example of the Mining Side R-1, R-3". The obtained results of the analysis indicate the migration of mineralizing solutions, the

process of formation of the present form of the deposit, and the diversification of copper mineralization was of a multi-phase nature.

In the chapter titled "Numerical hydrogeological model of copper mine deposits of KGHM Polska Miedź S.A." **Jacek P. Gurwin, Marek Wcisło, Stanisław Staśko,** and **Robert Tarka** presented the possibility of using a modern tool, which is numerical hydrological modeling. The model studies included the entire aquifer system, including the river network in the form of main rivers and their tributaries, as well as the Żelazny Most tailings pond. The use of this type of innovative tools is necessary for the management of groundwater resources, carrying out drainage works, and in particular for forecasting and designing drainage of KGHM Polska Miedź S.A. mines.

Artur Wilczyński, Barbara Namysłowska-Wilczyńska, Stanisław Downorowicz, authors of the article "Possibilities of sustainable water resources and energy management in mining of the copper deposits." Acquisition of the abovementioned resources could improve the economic efficiency of the mines.

In the last chapter of the technical and engineering part of the monograph entitled "Experience in the field of practical use of data from mining machinery monitoring", the authors **Mirosław Lewicki** and **Paweł Śliwiński** emphasize the essence of the relationship between the period of effective operation in terms of the availability of mining machines and economic conditions. In the research, they used the TCO total cost method, which enables direct comparison of the operating costs of machines with the effectiveness of their work.

The second part of the monograph consists of studies originating from the area of social sciences. It opens with a chapter by **Paweł Greń** and **Miłosz Czopek**. In their deliberations, the authors attempt to show how KGHM Polska Miedź SA carries out its image-building activities in its closer and more distant surroundings. The subject of consideration will also be the analysis of the results of research related to the diagnosis of areas that have the strongest impact on the positive reception of the copper holding.

In the following chapter, **Jolanta Dmowska** deals with topics related to the innovativeness of Polish enterprises. The author draws attention to their insufficient activity in this sector, which is dictated by, inter alia, financial, infrastructural and personnel limitations and know-how. Thus, the article proposes some solutions that could encourage companies to start operating in the area of innovation.

Miłosz Czopek and **Piotr Spaliński** in their publication draw attention to the essence of effective knowledge management in enterprises. On the basis of quantitative and qualitative research, the authors assess the organizational maturity of KGHM Polska Miedź SA in this area and the level of IT services provided to support the search for information in the company. The analysis of the research results also allowed for the identification of benefits related to the implementation of the KGHM Search application.

In the next chapter, **Robert Kaszuba** mentions the implementation of process innovations in the area of production and logistics of enterprises. The author points out that it is possible only by constantly improving the quality of the services provided, which he describes as "the art of excellence".

The whole monograph ends with a chapter by **Miłosz Czopek** and **Marta Kazusek** devoted to recruitment, onboarding, and training in the Covid-19 pandemic in the enterprises of the Copper Basin.

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Engineering and technical sciences

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Application of the method of laser spectroscopy in the classification of mining materials

Summary

The subject of the article is the analysis of the results obtained during distance studies of laser-induced plasma spectroscopy (LIBS). The research is used to determine the chemical composition of minerals and rocks contained in useful minerals. As part of the work, the results obtained for rock salt, potassium salt, and brown coal samples were analyzed. Measurements were also made for copper-bearing shales, but the interpretation of the results is only in the preliminary stage and will be the subject of future publications. The results obtained for the halite samples showed that the main elements of the tested samples were sodium and chlorine, but there were also small admixtures of such elements as potassium, magnesium, calcium, or bromine. As expected, the basic building block of potassium salts is potassium, the second element of high intensity is chlorine, and in addition, the presence of small amounts

of magnesium and sodium was observed in the chemical composition of the tested samples. The results of tests carried out for brown coal samples showed the presence of the highest intensity spectra for the elements carbon, sulfur, oxygen, and nitrogen. The conducted research shows that the LIBS method is applicable in determining the chemical composition of rocks and minerals from a given distance.

Keywords: laser-induced plasma spectroscopy, LIBS, useful minerals, the chemical composition of useful minerals

ZASTOSOWANIE METODY LASEROWEJ SPEKTROSKOPII W CELU KLASYFIKACJI MATERIAŁÓW GÓRNICZYCH

Streszczenie

Przedmiotem niniejszego artykułu jest analiza wyników, jakie uzyskano podczas badań dystansowych spektroskopii plazmy indukowanej laserem (LIBS). Badania służą do określania składu chemicznego minerałów i skał zawartych w kopalinach użytecznych. W ramach prac przeanalizowano wyniki uzyskane dla próbek soli kamiennej, potasowej oraz węgli brunatnych. Pomiary wykonano również dla łupków miedzionośnych, jednak interpretacja wyników jest dopiero w fazie wstępnej, co będzie przedmiotem następnych publikacji. Uzyskane wyniki dla próbek halitów wykazały, że głównymi pierwiastkami badanych próbek jest sód i chlor, jednak występują w nich również niewielkie domieszki takich pierwiastków, jak potas, magnez, wapń czy brom. Podstawowym budulcem soli potasowych jest zgodnie z oczekiwaniami potas, drugim pierwiastkiem o dużej zarejestrowanej intensywności jest chlor, poza tym w składzie chemicznym badanych próbek zaobserwowano również występowanie niewielkich ilości magnezu i sodu. Wyniki badań przeprowadzonych dla próbek węgli brunatnych wykazały występowanie widm o największej intensywności dla pierwiastków węgla, siarki, tlenu i azotu. Z przeprowadzonych badań wynika, że metoda LIBS znajduje zastosowanie w określaniu składu chemicznego skał i minerałów z założonej odległości.

Słowa kluczowe: spektroskopia plazmy indukowanej laserem, LIBS, kopaliny użyteczne, skład chemiczny kopalin użytecznych

1. Introduction

The proper functioning of the mining industry depends, inter alia, on the selective use of mineral resources, which directly affects the quality of the product obtained and the amount of waste generated in the processing process. Determining the chemical composition of rocks and determining the degree of their mineralization is a key element in the proper process of extracting useful minerals. The chemical composition of rocks can be examined using chemical methods and instrumental analyzes, the former of which require prior preparation of samples for testing, and the latter – the determination of the chemical composition – is time-consuming. Instrumental methods can be analyzed much faster. These methods include, inter alia, spectroscopic, optical, electrochemical, resolving, and radiometric methods[1]. However, it should be remembered that the sensitivity of these methods may be lower, and the determination of the content of ingredients is indirect[2]. Currently, the most frequently used method is X-ray fluorescence analysis (XRF), but it requires prior preparation of samples, e.g. powdering or grinding[3]. A method that is increasingly used to determine the chemical composition of materials is laser-induced plasma spectroscopy (LIBS). Among the numerous advantages, the following options deserve attention: conducting measurements on samples in every aggregate state, performing measurements both in the laboratory and in situ in real time, operating in the so-called "calibration-free" mode, without the need to apply calibration standards[4]. The LIBS technique can be successfully combined with other

1 Saba J., *2008. Wybrane metody instrumentalne stosowane w chemii analitycznej*. Wydawnictwo Uniwersytetu Marii Curie Skłodowskiej

2 Kocjan R., 2000. *Chemia analityczna. Analiza jakościowa. Analiza klasyczna*. PZWL, Warsaw; Minczewski J., Marczenko Z., 1985. *Chemia analityczna III (Analiza instrumentalna)*. Warszawa: PWN

3 Kamiński M., Romanik G., 2007. *Techniki i metody przygotowania próbki – mineralizacja, techniki konwencjonalne i mikrofalowe oraz ekstrakcja do fazy stałej (SPE)*. Instrukcje do ćwiczeń laboratoryjnych Metody Analizy Technicznej/Metody Kontroli i Zapewnienia Jakości.

4 Ciucci A., Corsi M., Palleschi V., Rastelli S., Salvetti A., Tognoni E., 1999. *New procedure for quantitative elemental analysis by laser-induced plasma spectroscopy*. Applied Spectroscopy 53 (8), Sharma SK, Misra AK, Lucey PG, Weins RC, Clegg SM, 2007. *Combined remote LIBS and Raman spectroscopy at 8.6 m of sulfur-containing minerals, and minerals coated with hematite or covered with basaltic dust*. Spectrochimica Acta A 68, Tognoni E., Cristoforetti G., Legnaioli S. and Palleschi V., 2010. *Calibration-free Laser-Induced Breakdown Spectroscopy: state of the art*. Spectrochimica Acta B 65, pp. 1–14.

spectroscopic methods, e.g. VIS-NIR, Raman spectroscopy[5], or optical hyperspectral imaging[6].

The beginnings of the technique related to the excitation of plasma using laser techniques date back to the 1960s, and its development was observed shortly after the invention of the pulse ruby laser. The year 1963 is considered to be the birth of laser-induced plasma spectroscopy, and since then there has been an intensive development of the method. In the field of mining and geology, one of the most important achievements were: in 1989, the use of the method for the detection of metals in soil, in 1992, the first attempts to perform LIBS research in space applications, and in 2000, the introduction of a commercial device for carbon composition analysis[7]. The great interest in the method leads to its increasingly wider application in various fields, including industry. Currently, thanks to the LIBS technique, it is possible to determine the chemical composition of e.g. environmental, metallurgical, metallic, and non-metallic samples[8], plastics, sewage sludge, liquids, aerosols, gases, biological samples, and much more[9]. The method is also used in the study of the stratigraphy of surface layers, the analysis of the chemical composition of metallic coatings and their thickness[10], but also in the analysis of aggregate mineralogy[11], and in the search for minerals and rocks[12].

In Poland, the method of Laser-Induced Plasma Spectroscopy (LIBS) is not popular. In the vast majority of cases, the analysis of the chemical composition of rock and mineral samples is performed using analytical methods,

5 SK Sharma, *Combined…*, *op. cit*.

6 Melessanaki K., Papadakis V., Balas, C., Anglos D., 2001. Laser-induced breakdown spectroscopy and hyper-spectral imaging analysis of pigments on an illuminated manuscript. Spectrochimica Acta Part B 56, pp. 2337–2346.

7 Cremers D., Radziemski L., 2006. *Handbook of Laser-Induced Breakdown Spectroscopy*, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester.

8 Boueri M, 2010. *Laser-induced plasma on polymeric materials and applications for the discrimination and identification of plastics*. Université Claude Bernard – Lyon I.

9 Hahn DW, Omenetto N., 2012. *Laser-Induced Breakdown Spectroscopy (LIBS), Part II: Review of Instrumental and Methodological Approaches to Material Analysis and Applications to Different Fields*. Applied Spectroscopy vol. 66 (4), pp. 347–419.

10 Sarzyński A., Skrzeczanowski W., Napadłek W., 2006a. *Zastosowanie laserowo indukowanej spektroskopii emisyjnej do badania składu chemicznego i grubości powłok metalicznych*. Prace Instytutu Elektrotechniki 228, p. 180–186

11 Varghese B. A, 2017. *Analysis of aggregate mineralogy using LIBS*. Harmon RS, DeLucia FC, McManus CE, McMillan NJ, Jenkins TF, Walsh ME, Miziolek A., 2005. *Laser-induced breakdown spectroscopy (LIBS) – an emerging field-portable sensor technology for real-time, in-situ geochemical and environmental analysis*. Environment Analysis 5, pp. 21–28

12 Sweetapple M., Tassios S., 2015. *Laser-induced breakdown spectroscopy (LIBS) as a tool for in situ mapping and textural interpretation of lithium in pegmatite minerals*. American Mineralogist, 100, pp. 2141–2151

which, unfortunately, is time-consuming and does not provide continuous information. Therefore, the popularization of the LIBS method would significantly increase the speed of information obtained, which would translate into the possibility of making quick, precise decisions about the direction of exploitation.

2. Research methodology

Laser-induced plasma spectroscopy is a method that is widely used in determining the qualitative and quantitative composition of samples in each state of aggregation. It is a non-invasive research method, and the small size craters (average from 0.1 to 10 mm, depth from 0.1 to 10 μm)[13] that are formed during the measurements are of no importance for rocks mined on an industrial scale.

The LIBS technique consists in focusing a high-power laser pulse using a focusing lens on the surface of the test sample and generating plasma by the means of laser radiation on the sample. It is assumed that the intensity of the radiation needed to generate the plasma should exceed at least 0.1 GW/cm^2, The focused beam of a pulsed laser causes a local temperature increase, and then a small amount of the material melts and evaporates, and causes its ionization (ablation). As a result of the evaporation of the material and the surrounding atmosphere, a plasma with a temperature of 103–105K is formed[14]. At such a high temperature, atoms and ions are excited and emit intense linear and continuous radiation (inhibition and recombination), corresponding to the types of elements found in the plasma. After the laser pulse ceases, the plasma begins to cool down. When the plasma is cooled, the electrons of atoms and ions in the excited states go into natural ground states, causing the plasma to emit light with characteristic spectral peaks (linear radiation specific to the emitted elements found in the plasma). This is how the spectroscopic spectrum occurs[15]. The aim is to create a plasma

13 Szarzyński A., Skrzeczanowski W., Napałek W., *Application...*, *op. cit.*

14 Szarzyński A., Skrzeczanowski W., Napałek W., *Application...*, *op. cit.*; Sarzyński, A. Skrzeczanowski, W. Napadłek, W., *Possibility...*, *op. cit.*

15 Skrzeczanowski W., *Research... op. cit.*Skrzeczanowski W., 2008b. *Wybrane aspekty fizyczne i aparaturowe wpływające na dokładność pomiarów wykonywanych metodą LIBS. Materiały VI Konferencji Naukowo-Technicznej PPM'08*, Russo RE, Mao XL, Liu HC, Yoo JH, Mao SS, 1999. *What is LIBS?*: https://appliedspectra.com/technology/libs.html – accessed on 01/21/2020.

that is in thermodynamic equilibrium and whose elemental composition is the same as that of the test sample. The radiation produced by surface ablation is collected and recorded using optical fiber and transmitted to the spectrometer. Performing a detailed analysis of the spectra of linear radiation allows the identification of atoms and ions in the plasma that correspond to the chemical composition of the tested sample[16]. The mechanism of plasma formation is the basic process that must occur to obtain data on the chemical composition of the test sample. A hot plasma cloud is created by the action of a short, intense laser pulse on the test sample. The supplied energy excites, ionizes, and then evaporates the material[17].

Measurements of selected samples were made using the Diamond FLQ fiber laser and the Ocean FX spectrometer. The nominal output wavelength of the laser is 1064 mm, the average power is 110 W, the peak power is 12 kW, the pulse duration is 80–500 ns, and the frequency of their generation (PRR) is 20 to 200kHz. The device emits invisible, infrared pulsed laser radiation corresponding to class 4. An intelliCUBE 10 scanning head was used to guide the laser beam. The beam was deflected using two mirrors on galvanometric drives, and an f-theta lens was used to focus the beam[18]. Ocean FX spectrometer was used to collect the data, the spectral range of which is from 200 to 1100 nm, optical resolution – 2.39 pixels, and the integration time is from 10 μs to 10 s[19]. The constructed prototype of the measuring station (Fig. 1) made it possible to test selected samples of mining materials from a distance of 7 to 15 cm.

The described research was carried out on selected samples of rock salt, potassium salt, and brown coal. Additionally, preliminary tests were carried out on samples of copper-bearing shale. Rock and potassium salts are samples characterized by a relatively simple and homogeneous structure, low variability in composition, and a small amount of impurities. On the other hand, lignite deposits are characterized by high variability of the chemical composition at individual levels of the deposition layers, which significantly

16 Cremers D., Radziemski L., *Handbook of..., op.cit.*

17 Kashif C., Syed Z., Jalil A., 2016. *Laser-Induced Plasma and its Applications, Plasma Science and Technology – Progress in Physical States and Chemical Reactions*, Tetsu Mieno, IntechOpen: https://www.intechopen.com/books/plasma-scienceandtechnology-progress-in-physical-states- and-chemical-reactions / laser-induced-plasma-and-its-applications – accessed on 02/20/2020.

18 Diamond FLQ Operator's Manual, 2017. Nufern, G026DOC Rev. AT; SCANcube, intelliCube leaflet, 2014. SCANLAB GmbH: https://www.scanlab.de/en/downloads/data-sheets – accessed on 02/20/2020.

19 Ocean FX Miniature Spectrometer, 2017. User Manual. Ocean Optics, Inc.

hinders the exploitation, which determined the choice of this mineral for research purposes. The usefulness of the LIBS technique for determining the quality parameters of hard coal by determining the content of individual constituent elements in spectroscopic spectra could improve the mining process. The last of the tested samples, the copper-bearing shale, consists of black or dark gray shale bituminous (tar) clay, clay-dolomite shale, dolomite shale, and marly shale[20]. The samples were tested using the LIBS technique, and the obtained results were compared with the available spectral databases[21] to identify the elements and determine the chemical composition of the material tested.

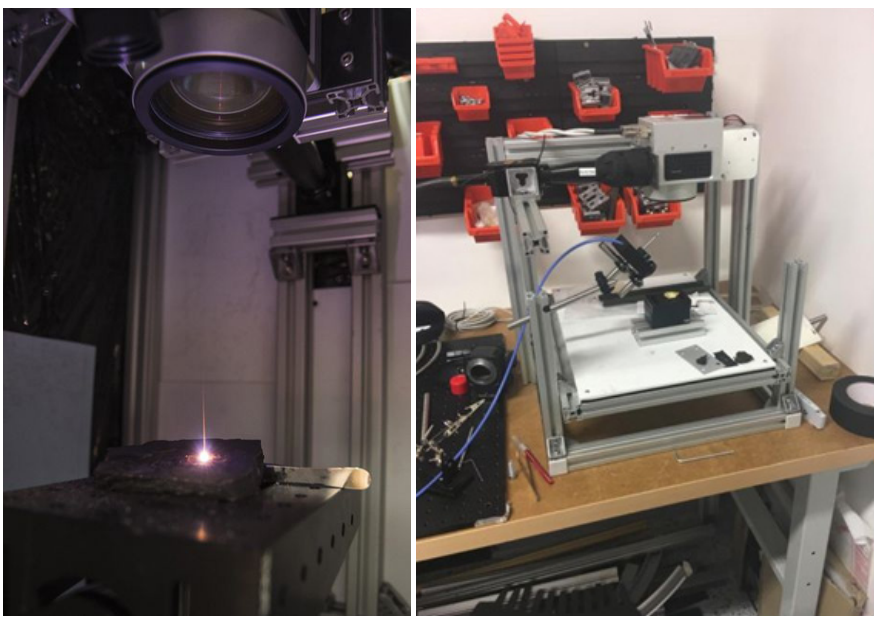

Fig. 1. Measurement station, samples during measurements.

20 Kijewski, P., Leszczyński, R., 2010, *Węgiel organiczny w rudach miedzi – znaczenie i problemy, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk*, no. 79, pp. 131–146.

21 Kramida A., Olsen K., Ralchenko Yu., 2019. NIST LIBS Database, National Institute of Standards and Technology, Atomic Spectroscopy Group, Quantum Measurement Division: https://physics.nist.gov/PhysRefData/ASD/LIBS/libs-form.html – accessed on 02/20/2020.Kramida A., 2019. NIST Atomic Spectra Database Lines Form. National Institute of Standards and Technology, Atomic Spectroscopy Group, Quantum Measurement Division: https://physics.nist.gov/PhysRefData/ASD/lines_form.html – accessed on 02/20/2020.

3. Current results

The main elements of halites (NaCl) are sodium and chlorine. Rock salts can also have small admixtures of such elements as potassium (K), magnesium (Mg), calcium (Ca), or bromine (Br). The interpretation of the obtained results showed that sodium (Na) is the main building element of all the tested halite samples. This element occurred with the highest intensity at the wavelengths of 588.9 nm and 591.4 nm. Small concentrations of Na also occurred at the lengths of 387.3 nm, 498.9 nm, and 570.0 nm. The second most concentrated element is chlorine (Cl). Its highest intensities were observed at the wavelength of 820.4 nm. Small concentrations also occurred at the wavelength of 490.3 nm. As expected, traces of other elements that may be contaminants, naturally occurring in sedimenting salt deposits, have also been observed. Among them, there was potassium and magnesium. Relatively high intensity (as for the accompanying element) is observed at a wavelength of 479.9 nm. The spectrum of potassium or magnesium was probably recorded at this wavelength. At 522.5 nm and 778.9 nm, there were small concentrations of Mg, while at lengths of 767.6 nm and 771.5 nm, slight K intensities were also observed. The results confirmed the chemical composition of all tested halite samples. The obtained characteristic peaks of the elements included in the salt coincide at the wavelengths for each of the tested samples. The obtained intensity plot as a function of wavelength is shown in Fig. 2.

The results obtained for the samples of potassium salts (Fig. 3) showed that the highest intensities were observed for potassium at wavelengths of 768.3 nm and 771.5 nm. The presence of chlorine was recorded at the lengths of 419.2 nm and 695.1 nm. Small amounts of magnesium, sodium, and potassium were also observed in the chemical composition of the tested samples. Reliable results were obtained for sample no. 2 of the white potassium salts. Sample no. 1 did not show the characteristic intensity peaks, thanks to which it would be possible to determine its chemical composition. This state of affairs could have been caused by the laser not hitting the fire.

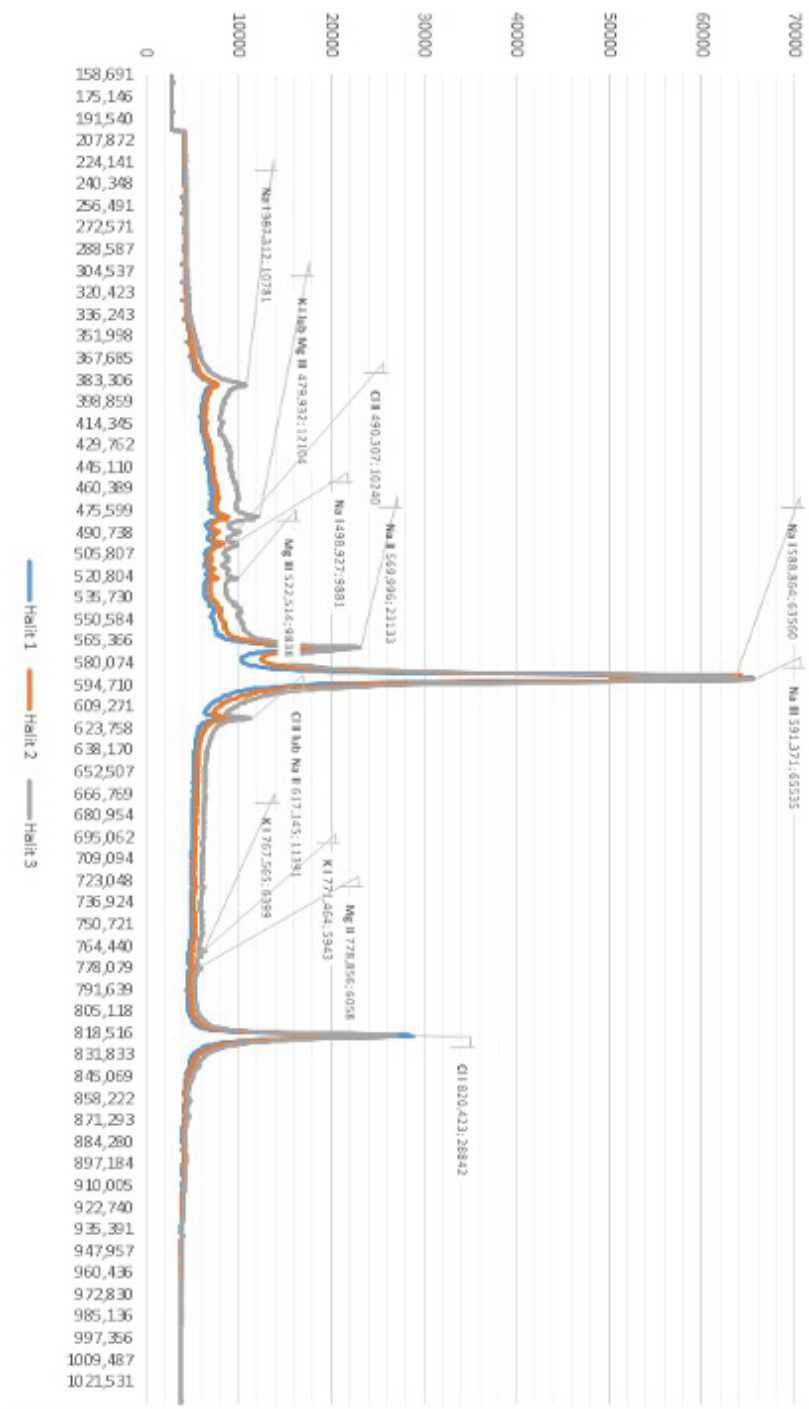

Fig. 2. Intensity versus wavelength graph for halite samples: blue – halite 1, orange – halite 2, gray – halite 3

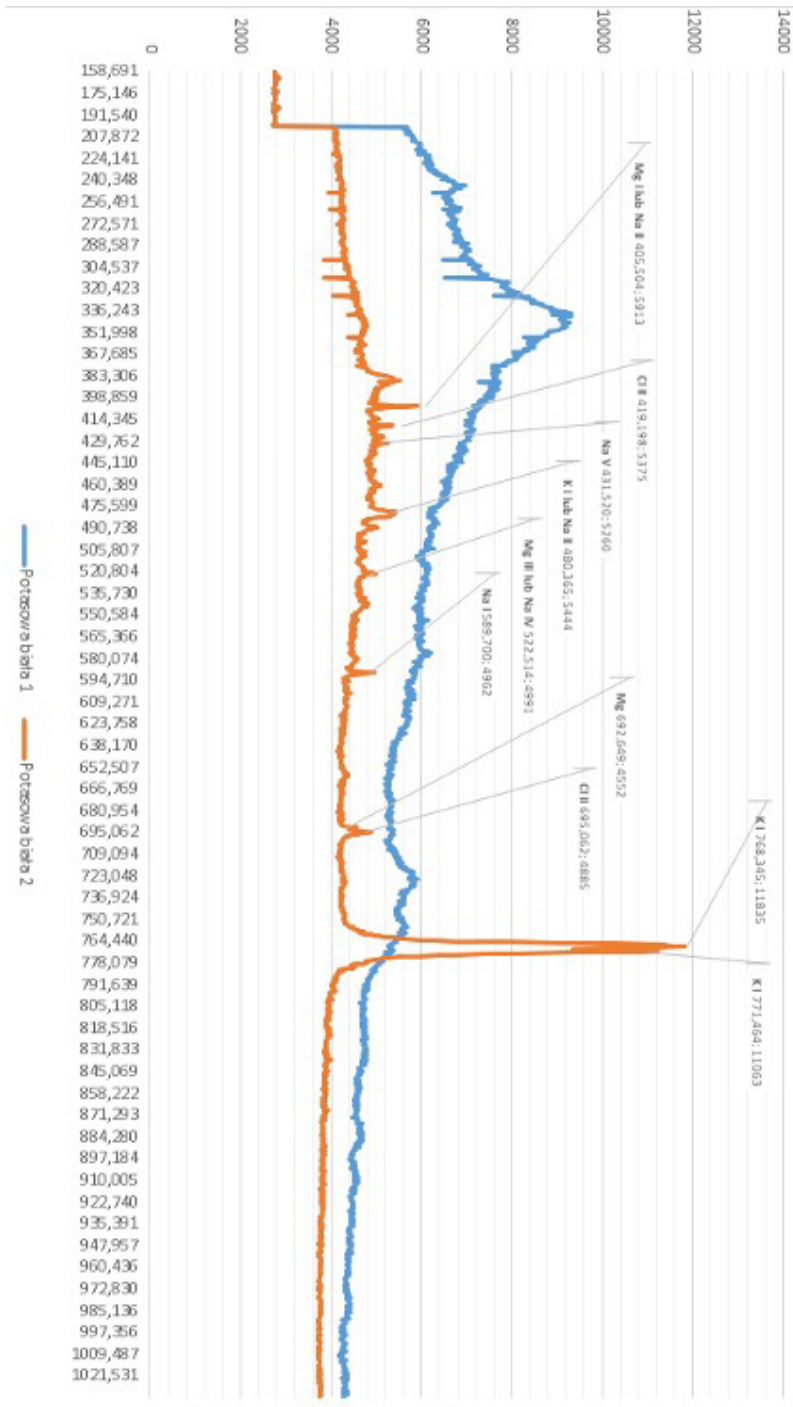

Fig. 3. Intensity versus wavelength, the graph for potassium salts: blue – potassium salt 1; orange – potassium salt 2.

The tests were carried out on five lignite samples of different calorific values, and varying sulfur, and ash content. The parameters varied depending on where the sample was taken in the field. The exact parameters of the samples were previously determined by elementary laboratory methods (Tab. 1) to establish a reference point for further research using the LIBS technique.

Table 1. Parameters of the tested lignite samples (determined using elementary laboratory methods)

Sample no	Calorific value Q [kJ / kg]	Sulfur content [%]	Ash content [%]
Sample 1:	12500	0.18	8
Sample 2:	9400	2,33	22.1
Sample 6	12500	0.18	22.1
Sample 7	13520	0.16	5.5
Sample 8	8300	1.5	25

In the tested samples (Fig. 4–8) the following spectra were recorded: carbon, sulfur, oxygen, and nitrogen. In samples no. 1, 2, 7, and 8, characteristic, intense peaks corresponding to the carbon spectrum were recorded at the lengths of 588.9 nm, 766.4 nm, and 769.9 nm. The minimum shift occurred in sample 6 where, in addition to 588.9 nm, carbon is observed at 766.8 nm and 770.3 nm. In addition, the presence of carbon was recorded in each sample at wavelengths exceeding 890 nm, successively 893.1 in sample 1, 892.8 nm in sample 2, 890.1 nm in sample 6, 892.0 nm in sample 7 and 894.6 nm in sample 8. An oxygen peak at 759.4 nm was recorded in each sample. In addition, slight sulfur peaks were observed at 602.6 nm and 741.7 nm in samples 1 and 2, 602.6 and 774.0 nm in sample 6, 603.5 nm in sample 7, and 605.1 nm in sample 7. sample 8. The low sulfur intensity in each of the brown coal samples may result from the fact that its contents are relatively low in relation to the volume of the entire sample (from 0.16% – 2.33%). Sample no. 1 also shows a characteristic peak for the nitrogen spectrum at a wavelength of 575.0 nm. No distinct nitrogen spectrum was observed in the remaining samples.

In samples 1 and 2 (Fig. 4, 5), the highest intensities of characteristic elements (C, S, N, O) were recorded among all analyzed brown coals. They were the most reliable of the tested samples, thanks to which it was possible to determine the chemical composition. Much lower intensities were recorded in samples 6 and 7 (Fig. 6, 7). However, despite the relatively low intensities obtained in samples 6 and 7, these values corresponded to the wavelengths

recorded in samples 1 and 2, which confirmed the chemical composition of the tested brown coals. In sample 8 (Fig. 7) no intense, characteristic peaks for C were recorded. The only value observed was the peak at 894.6 nm. The remaining peaks obtained corresponded to only S at 605.1 nm and O at 759.4 nm. It was the least reliable sample. This fact may be due to the presence of the highest amount of ash (25%) among the tested brown coal samples, which resulted in the formation of a large amount of pollutants during the interaction of the laser with the surface and had a negative impact on the quality of the generated plasma during ablation.

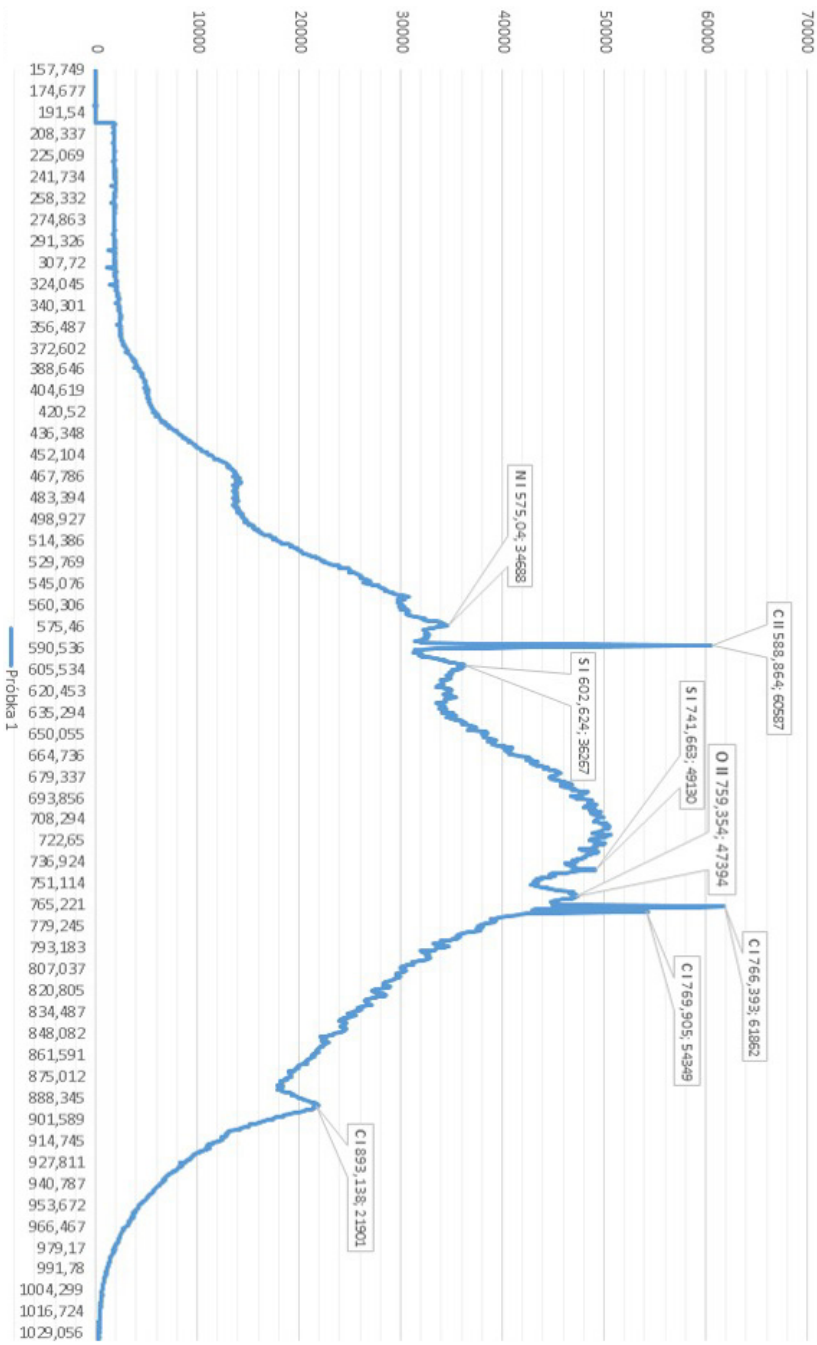

Fig. 4. Intensity versus wavelength, graph for lignite, sample no. 1.

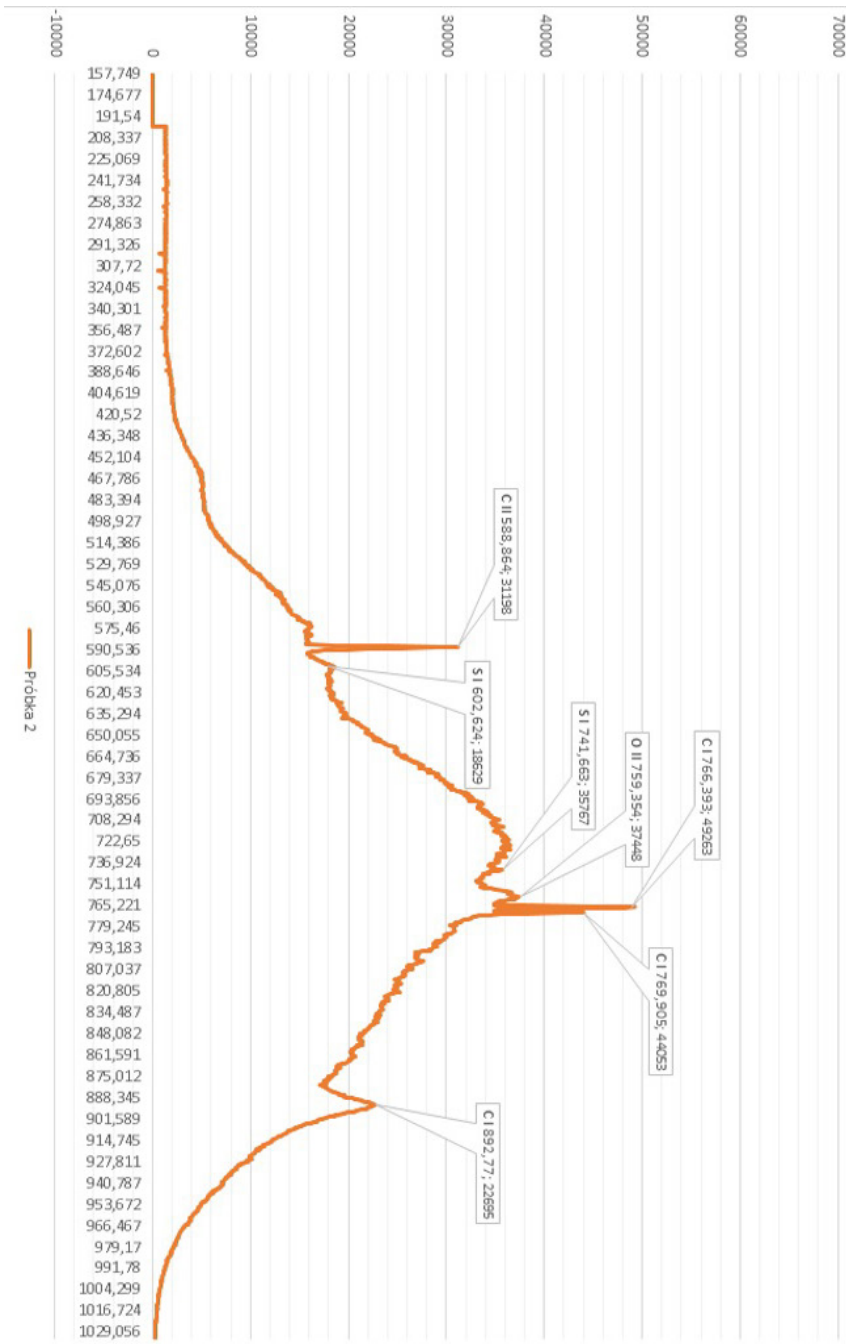

Fig. 5. Intensity versus wavelength, graph for lignite, sample no. 2

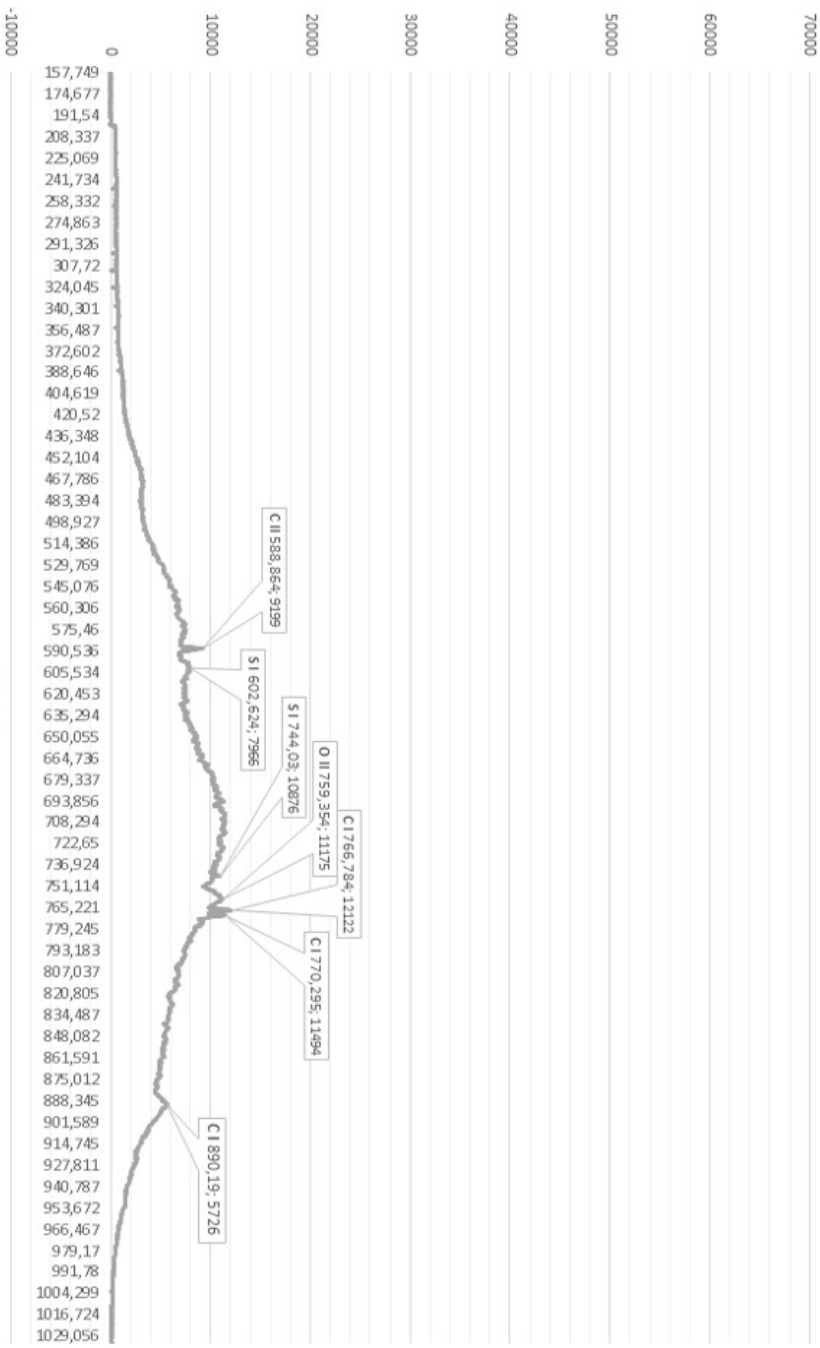

Fig. 8. Intensity versus wavelength, graph for lignite, sample no. 8

Fig. 7. Intensity versus wavelength, graph for lignite, sample no.7

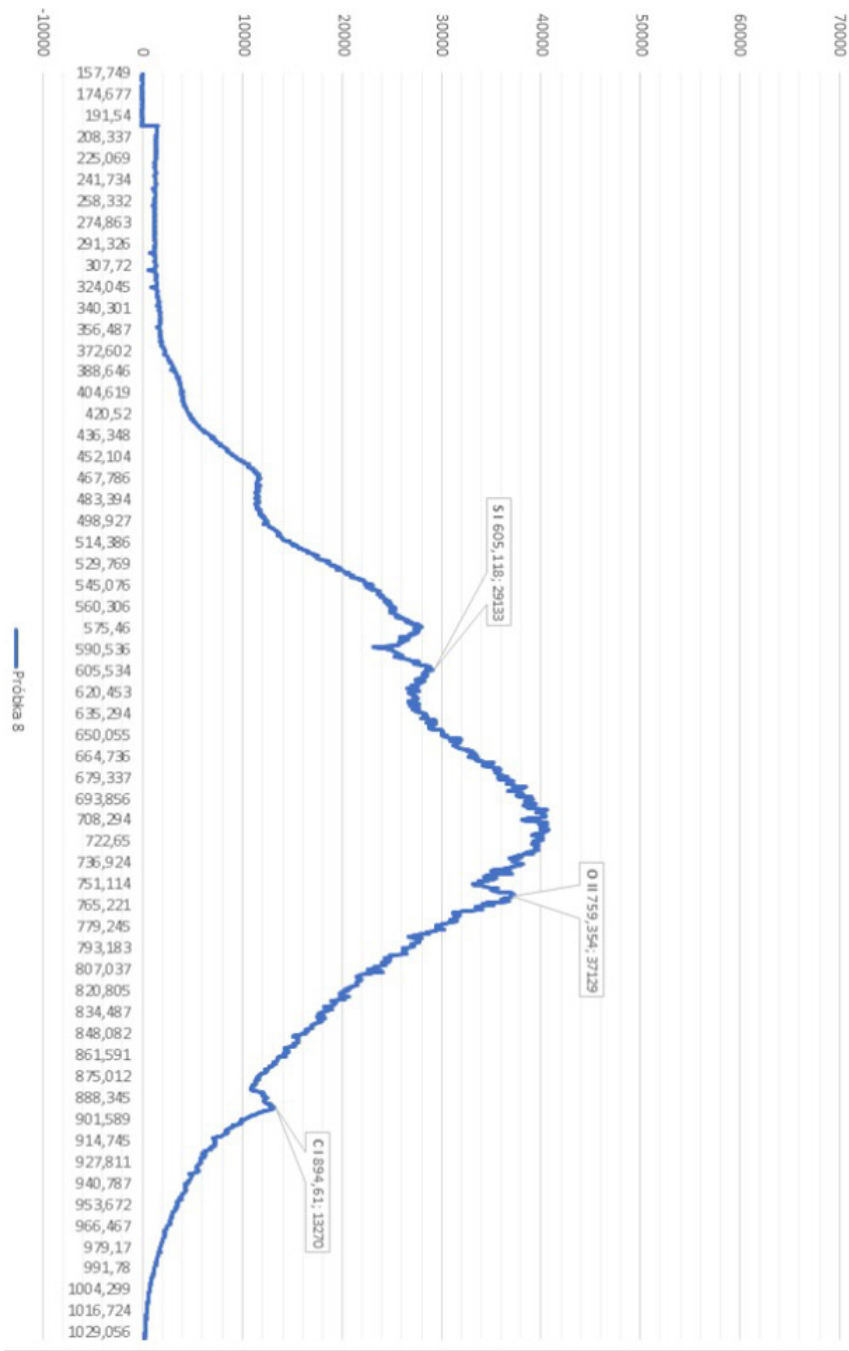

Fig. 6. Intensity versus wavelength, graph for lignite, sample no. 6

4. Conclusions

The obtained results allowed us to determine the chemical composition of the tested salt and brown coal samples from a distance of approx. 12 cm from the source of laser radiation to the surface of the test sample. The presence of the same elements at the same wavelengths in different groups of tested samples confirms the effectiveness of the applied methodology and measuring equipment, as well as the possibility of using it in the study of the chemical composition of useful minerals from a distance. It should be noted that the scattering of spectra on the glassy surfaces of the sample, problems with reaching the laser beam of the focus, the formation of plasma with parameters unsuitable for analytical purposes (the so-called burning phenomenon) may directly translate into the quality of the obtained results, which was the case with sample no. 1 of potassium salt. The sodium and potassium were mainly found in the salt samples. In the examined lignite samples, the highest intensity values were definitely obtained for coal.

Initial measurements of copper-bearing shale were also performed to check the suitability of the method for quick and non-invasive determination of the chemical composition of samples with copper content. The results were initially interpreted (Fig. 9). The peaks that were obtained suggest the possibility of using the method for testing samples of the same type.

The use of a device based on the LIBS technique would be possible to check the quality of the excavated material continuously. The next stage will be a detailed analysis of the obtained results and carrying out measurements on a large number of samples in order to develop a detailed methodology and analyze the obtained measurement data.

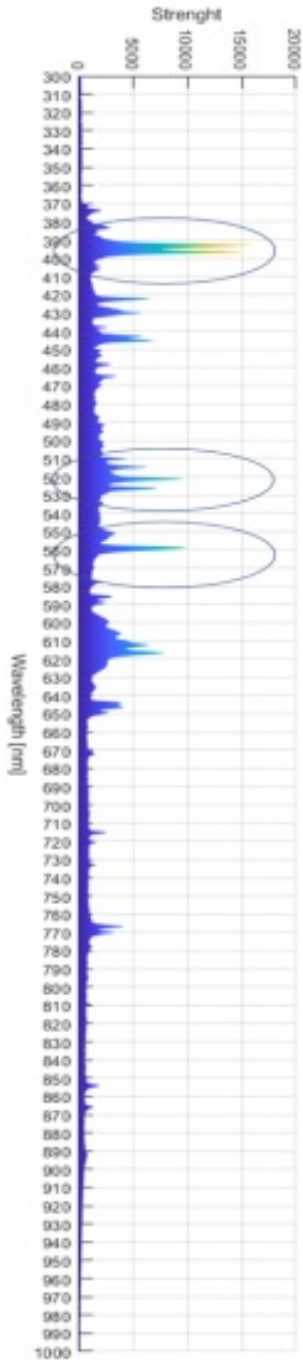

Fig. 9. The spectroscopic spectrum obtained with the LIBS technique for cuprous shale

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Anna Wojciechowicz – PhD in Earth Sciences in the field of geology. A graduate of geology with a specialization in geophysics at the University of Silesia and Geoengineering, mining, and geology with a specialization in underground and open-pit mining of deposits at the Wrocław University of Technology. She has been professionally associated with the Jagiellonian University since 2011, and since 2019 she has been the Dean of the Faculty of the Jan Wyżykowski University. The author of many publications in national and foreign journals, the subject of which concerns the use of geophysical methods in remote studies of the mineral composition of rocks, identification of the quality of road surfaces, or the use of these methods for non-invasive recognition of postglacial sediments. She gained practical experience at work as a GPR research specialist at TPA SA based in Pruszków and is participating in various research projects.

Michał Zięba – Technical Director (CTO) of Scanway, responsible for the technical aspects of solutions developed in the company. A graduate of the Faculty of Mechanical Engineering at the Wrocław University of Technology, where he studied Automatic Control and Robotics. He gained experience in R&D at the university, and later in several projects in the industry.

Mikołaj Podgórski – Operational Director; a specialist in the area of business cooperation. An expert in the areas of space projects – from the management side as well as in the areas of engineering.

Łukasz Buczkowski – A graduate of the Wrocław University of Technology in the fields of Environmental Protection and Occupational Health and Safety and of the Jan Wyżykowski University in the field of Mining and Geology. Co-author of scientific publications on methods of studying minerals and rocks. Member of the Scientific Circle of Miners and Geologists. A man of many interests, currently working in the underground mining of copper ore and the education of future generations.

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Selected aspects of the seismicity of the Upper Silesian Coal Basin

Summary

The Upper Silesian Coal Basin (USCB) is the most seismically active region in Poland. The energy distribution of tremors registered by the Upper Silesian Regional Seismological Network and mine networks shows bimodality. According to the current state of knowledge, most of the low-energy tremors, with a local magnitude below 2, are directly induced by underground hard coal mining. High-energy shocks with a magnitude greater than 2 occur frequently in zones of existing tectonic disturbances. It is believed that their cause may be tectonic stresses, and the mechanism triggering these shocks may be their interaction with local mining stress fields. However, the origin of the tectonic stresses that could cause severe shocks is still not fully settled. The analysis of the temporal, spatial, and energy distributions of strong tremors in the USCB shows that the seismicity associated with them has many similarities to the seismicity observed in areas with increased tectonic activity, where natural earthquakes occur. The tremor epicenters in the USCB are grouped in several areas related to some tectonic subunits of the basin, separated by aseismic areas. The distribution of tremors epicenters shows the features of a fractal distribution with a fractal dimension of approx. 1.18. The activity of strong tremors varies with time and space. Its time variability suggests the possibility of seismic cycles with a period of several years. There is a migration of seismicity in the USCB. The studies conducted so far have shown that the strong shocks are serial. The lines connecting their epicenters show certain privileged directions, which may indicate directional stress transmission. There are several hypotheses explaining the above-mentioned features of the seismicity of the USCB.

Keywords: Upper Silesia, seismicity, tremors, epicenter, seismic activity.

WYBRANE ASPEKTY SEJSMICZNOŚCI GÓRNOŚLĄSKIEGO ZAGŁĘBIA WĘGLOWEGO

Streszczenie

Górnośląskie Zagłębie Węglowe (GZW) jest najbardziej aktywnym sejsmicznie regionem Polski. Rozkład energetyczny wstrząsów zarejestrowanych przez Górnośląską Regionalną Sieć Sejsmologiczną oraz sieci kopalniane wykazuje bimodalność. Według aktualnego stanu wiedzy większość wstrząsów niskoenergetycznych, o magnitudzie lokalnej poniżej 2, jest bezpośrednio indukowanych podziemną eksploatacją węgla kamiennego. Wstrząsy wysokoenergetyczne o magnitudzie powyżej 2 występują często w strefach istniejących zaburzeń tektonicznych. Uważa się, że ich przyczyną mogą być naprężenia tektoniczne, a mechanizmem wyzwalającym te wstrząsy może być ich współoddziaływanie z lokalnymi polami naprężeń górniczych. Nadal jednak nie jest ostatecznie rozstrzygnięte pochodzenie naprężeń tektonicznych mogących powodować silne wstrząsy. Analiza rozkładów czasowych, przestrzennych i energetycznych silnych wstrząsów w GZW wskazuje, że związana z nimi sejsmiczność wykazuje wiele podobieństw do sejsmiczności obserwowanej w obszarach o podwyższonej aktywności tektonicznej, w których występują naturalne trzęsienia ziemi. Epicentra wstrząsów w GZW grupują się w kilku obszarach związanych z niektórymi podjednostkami tektonicznymi GZW, przedzielonych obszarami asejsmicznymi. Rozkład epicentrów wstrząsów wykazuje cechy rozkładu fraktalnego o wymiarze fraktalnym ok. 1,18. Aktywność silnych wstrząsów zmienia się w czasie i przestrzeni. Czasowa jej zmienność sugeruje możliwość występowania cykli sejsmicznych o okresie kilkunastu lat. W GZW występuje migracja sejsmiczności. Dotychczasowe badania wykazały seryjność silnych wstrząsów. Linie łączące ich epicentra wykazują pewne uprzywilejowane kierunki, co może świadczyć o kierunkowej transmisji naprężeń. Istnieje kilka hipotez tłumaczących wymienione cech sejsmiczności GZW.

Słowa kluczowe: Górny Śląsk, sejsmiczność, wstrząsy, epicentra, aktywność sejsmiczna.

1. Introduction

The Upper Silesian Coal Basin (USCB) is located in the most densely populated region of Poland. The area of several thousand square kilometers is inhabited by about 10% of the country's population. Hard coal mining is

still one of the most important branches of the Silesian economy. Its development has been the cause of rapid industrialization and urbanization over the past two hundred years.

There is no doubt that the current level of seismic activity is related to the disturbance of the rock mass by mining works. There are no documented historical records of the occurrence of even single seismic phenomena in the Basin, although references to tremors in the past can be found sporadically in the regions to the east and west of it. Intensive mining activity has led to the initiation of seismic phenomena, which have become a serious problem for operational safety as well as for infrastructure and buildings on the surface. This resulted in the necessity of systematic seismic observations in order to understand the causes of the phenomena and possibly counteract their effects.

The occurrence of seismicity in mining areas is a well-known phenomenon and must be considered as one of the negative environmental impacts of mining. It is also the subject of specially designed seismological, mining and geological surveys conducted in the Upper Silesian Coal Basin since the end of the 1920s. As more and more seismic data was collected, there was a clear evolution of views on the genesis of tremors in the USCB

Initially, the tremors occurring in the GZW were mainly attributed to tectonic origin, stating that the foci of tremors were arranged along certain directions roughly consistent with the course of the main faults in the USCB. However, it should be taken into account that only the strongest of these shocks were recorded then and the accuracy of the location of the foci was low. As the apparatus developed, the observation network was densified and the methods of record interpretation improved, the level of detection of tremors decreased rapidly. Because most of the foci were clearly related to mining operations and moved with the progress of the mining fronts, the view about the exploitation origin of the tremors became popular. However, there were reasons to see tectonic influences in the case of some tremors, the more so as there was independent evidence of tectonic interactions in the area of Upper Silesia or in its vicinity. Currently, both previous views on the genesis of mining tremors were coherently connected by the statement of bimodality of the energy distribution of these phenomena, commonly accepted by seismologists studying the seismicity of the USCB. The essence of this concept is the observation that the energy distribution of induced shocks is the overlapping of two modes – low and high energy. Low-energy mode, representing the overwhelming number of tremors (mainly weaker), is di-

rectly related to mining exploitation and rock mass fracture in the vicinity of workings. High-energy mode may result from the interaction of operational stresses with geology or tectonic stresses, but the genesis of strong tremors has not been fully explained so far. This division is statistical in nature, because among the weak tremors there may be phenomena of tectonic origin, and some stronger tremors may be caused by mining works.

The article presents the characteristic features of the temporal and spatial distributions of strong tremors. Seismicity analyzes were carried out on a set of tremors with energy from 100 kJ, recorded in 1987–2020 by the Upper Silesian Regional Seismological Network, operated by the Central Mining Institute in Katowice. The available data on tremors with energies from 1 MJ also covered the earlier years (1977–1986).

On the basis of energetic distributions of the shock probability, it can be assumed that the phenomena with energy above 500 kJ are mostly generated by regional dynamic processes. As these phenomena often occur at a considerable distance from mining excavations, they are less likely to cause catastrophic effects in mines than shocks that are weaker, but occur near the mining fronts. Instead, they are felt on the surface, and the effects of the strongest of them may be comparable to those of a weak earthquake.

2. Catalog of seismic data from the area of USCB

The Upper Silesian Regional Seismological Network (GRSS) supervised by the Central Mining Institute currently consists of 18 seismometric stations located throughout the area of the USCB, equipped with three-component seismometers, enabling directional registration of seismic waves. The records of the detected tremors are collected and interpreted at the Department of Geology and Geophysics of the Central Mining Institute. On their basis, annual shock catalogs are created covering the period from January 1, 0.00 to December 31, 24.00 of a given year. The catalogs contain information about the time of occurrence of the shock, its energy, local magnitude, and location of the epicenter. Coordinates of the epicenter are given in the local, topographic coordinate system known as the "Sucha Góra system", commonly used in the Silesian mining industry. Due to the network configuration, the determination of the depth of relatively shallow tremors hypocenters is subject to considerable uncertainty, and therefore it is not included in the compiled

catalogs. At the beginning of the operation of the seismological network, it was possible to detect tremors of energy above 1 MJ. From 1987, after the modernization of seismometers, the detection threshold was reduced to 100 kJ. In total, in the years 1987–2020, over 37,600 shocks with energy above 100 kJ were registered, including over 6,260 shocks with energy above 1 MJ.

3. Spatial distribution of tremor epicenters

The distribution of epicenters of strong tremors with energy greater than 100 kJ (i.e. with local magnitude ML > 1,7) in the Upper Silesian Coal Basin is not uniform. Fig. 5 shows a map of the tremors' locations plotted in the local coordinate system.

Although mining is carried out throughout the Basin, epicenters of strong tremors are grouped in separate clusters (Fig. 1.). These clusters are located in various structural subunits of the USCB:

a) Bytom syncline (BS);
b) Kazimierz syncline (KS);
c) Main anticline (MA);
d) Main syncline (MS);
e) Jejkowice syncline (JS).

Clusters of strong tremors are separated from each other by aseismic areas in which tremors of this energy range are not recorded, although there may be low-energy, typically operational tremors, which do not cause any damaging effects in mining excavations or on the surface.

The distribution of epicenters does not depend on the scale in which their location is considered. The fractal nature of this distribution was demonstrated by Idziak and Zuberek (1995). The set of epicenters is self–similar in a statistical sense and forms a random fractal set of the "Sierpinski carpet" type, i.e. epicenters are grouped into larger clusters, in which, in turn, smaller clusters can be distinguished, and so on up to areas comparable to the size of tremor foci (i.e. less than 100 m).

The analysis of the surface density of the probability of epicenter occurrence, carried out on a square area of 50 km x 50 km (including all five quake clusters) in square grids with square sides varying from 50 km to 100 m, showed that this probability distribution is fractal and its fractal dimension is D = 1.18 (Idziak 1996; Idziak at al. 1999). The plot of the probability

of a shock occurrence in a square with side R, depending on the side length, made on a bilogarithmic scale, is shown in Fig. 2. The fractality of the distribution of earthquake outbreaks found in some seismic areas is a manifestation of the chaotic dynamics of the lithosphere, which can lead to the occurrence of a quake even with a minimal change in the state of stresses in the rock mass.

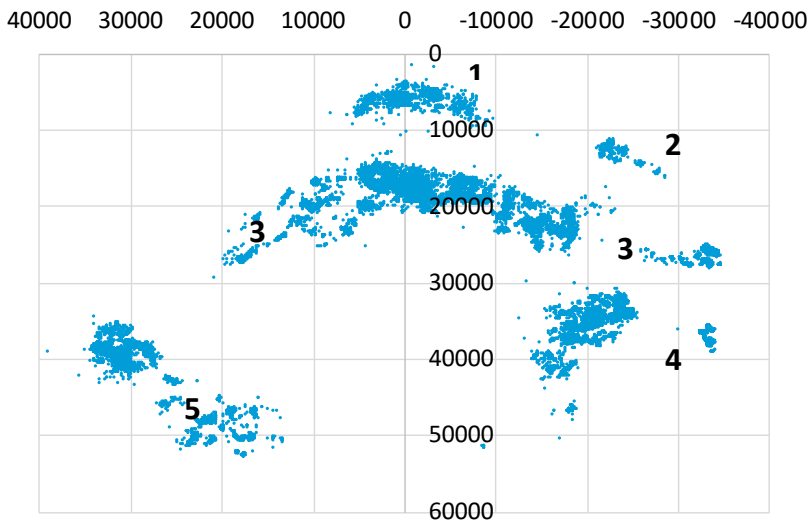

Fig. 1. The distribution of epicenters of strong tremors with energy greater than 100 kJ (1987–2020). The map plotted in the "Sucha Góra" coordinate system. 1) Bytom syncline; 2) Kazimierz syncline; 3) Main anticline; 4) Main syncline; 5) Jejkowice syncline

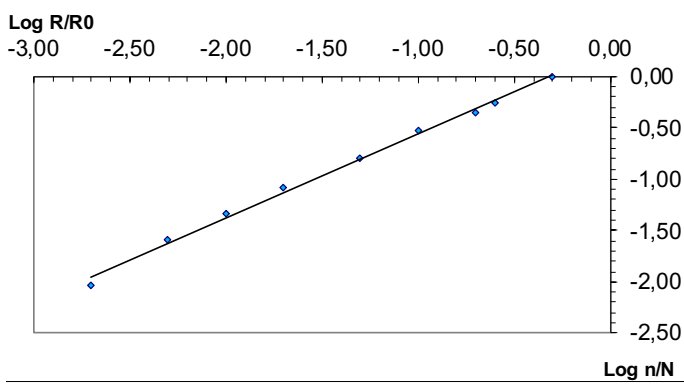

Fig. 2. The analysis of the surface density of the probability of epicenter occurrence. Fractal dimension of the distribution is D = 1,18 (Idziak,1996)

In the second half of the 1980s, seismic activity was around 1,800 tremors per year, which means that there were 4–5 seismic events every day. In the following years, the activity generally decreased, reaching the minimum in 1995 (465 shocks per year). The upward trend took place in 1996–2003 to the level of 1520 shocks per year and then decreased to about 750 shocks in 2009. Another peak was recorded in 2014, when the activity again reached the level from the mid-1980s (1762 shocks). Its slow decline has been observed in the last few years.

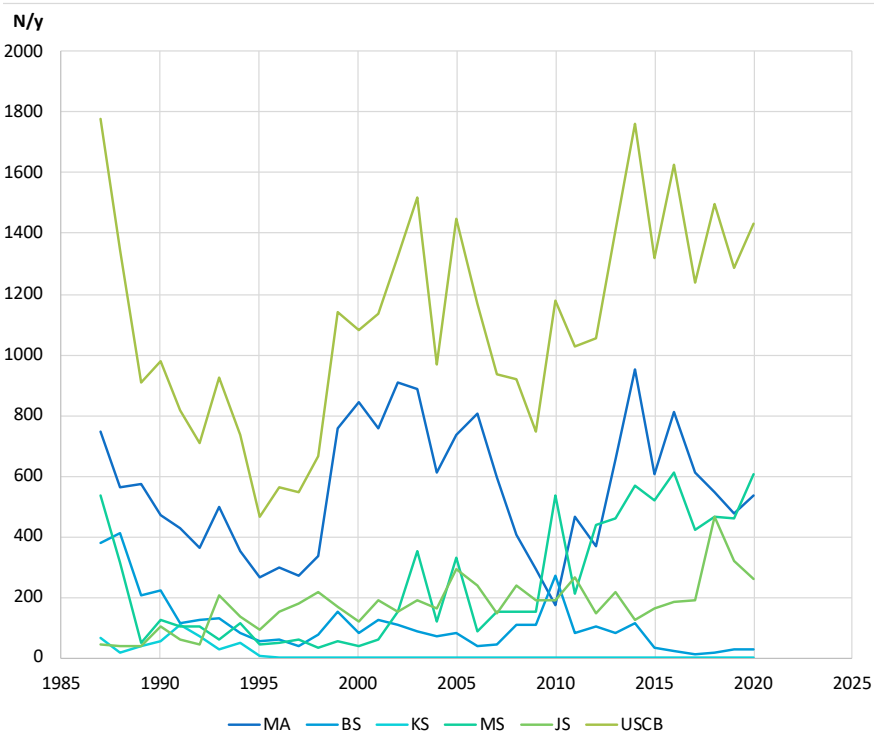

Fig. 3. The annual activity of tremors with energy above 100 kJ (1987–2020) both for the entire USCB and individual structural sub-units

Throughout the observation period, the most seismically active area was the Main anticline bounded to the south by a large fault zone (the Kłodnica Fault). The exception was 2010, when the activity in the Main syncline and the Bytom syncline was greater. In the remaining tectonic sub-units, activity changes took place in various ways. The initial, quite high activity in the

Bytom syncline and the Main syncline began to decline rapidly and in the years 1990–2001 remained at a relatively low level.

After 2001, activity gradually increased in the Main syncline, which is now the second major seismic area, comparable to the Main anticline. The third most active area is the Jejkowice syncline, in which the activity gradually increased throughout the observation period. In the Bytom syncline, a renewed increased activity was recorded in 2008–2014, after which it decreased to the level of 30 shocks per year. Quite low seismic activity in the Kazimierz syncline practically disappeared after 1995.

The catalog of stronger tremors with energy above 1 MJ (local magnitude ML> 2.3) was initiated in 1977 (Fig. 4). Until 1982, the greatest number of such tremors occurred in the Bytom syncline. In the following years, until 2009, the main area of their occurrence was the Main anticline. Since 2010, the activity of such tremors in the Main syncline and the Jejkowice basin has increased significantly.

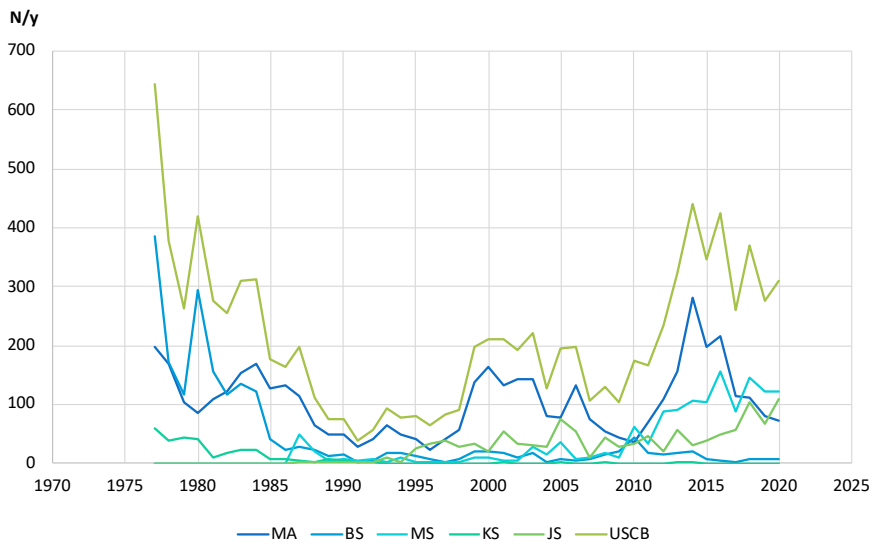

Fig. 4. The annual activity of tremors with energy above 1 MJ (1977– 2020) both for the entire USCB and individual structural sub–units

During the observation period, there was a clear increase in the share of tremors with energy above 1 MJ in the total number of tremors recorded by GRSS (Fig. 5). In 1991 it was only 5%, while in 2015 it reached 26% and is still higher than 20%.

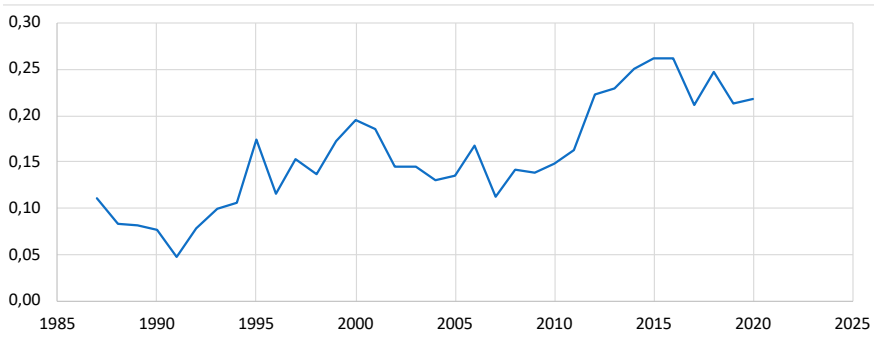

Fig. 5. The share of tremors with energy above 1 MJ in the total number of tremors recorded by GRSS (1987–2020)

4. The strongest tremors registered at the USCB

In the years 1977–2020, 17 shocks with energies of 1 GJ and higher were recorded (Table 1). The strongest of them had an energy of 8 GJ (ML = 4.45). A tremors of this strength are comparable to weak natural earthquakes and causes similar effects on the ground surface. Their location is shown in Fig. 6. Most of them occurred in the Bytom syncline and the Main anticline, but the last two took place in the Jejkowice syncline.

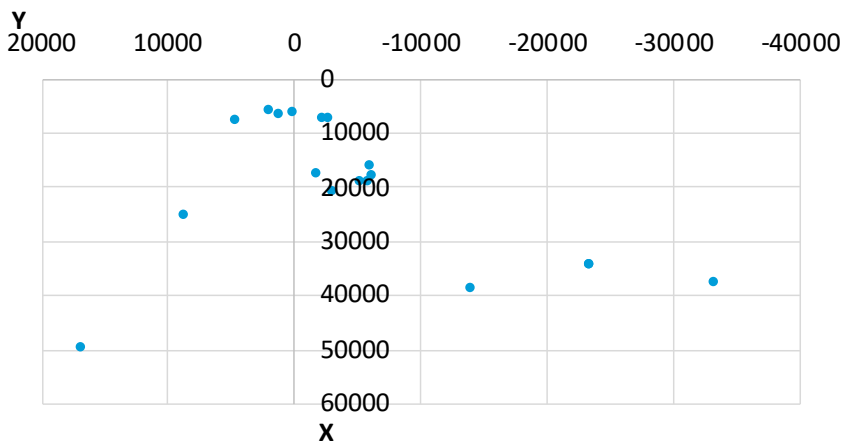

Fig. 6. The distribution of epicenters of strongest tremors with energy 1GJ or more (1977 – 2020). The map plotted in the "Sucha Góra" coordinate system

Table 1. Recorded shocks with energies of 1 GJ and higher (1977–2020)

N	DATE	HOUR	MINUTE	ENERGY (GJ)	MAGNITUDE	COORD.Y	COORD.X
1	10.02.1979	14	24	2.0	4.11	4560	7760
2	12.07.1981	13	59	1.0	3.94	-2210	7320
3	13.04.1983	19	0	8.0	4.45	-6230	18020
4	23.02.1984	23	24	2.0	4.11	-5900	19150
5	20.12.1984	23	8	1.0	3.94	-2670	7240
6	19.04.1985	16	47	5.0	4.33	-5300	19230
7	11.10.1985	21	2	2.0	4.11	-6000	16300
8	05.05.1992	10	0	2.0	4.11	-14000	39000
9	21.04.1993	11	58	1.0	3.94	1940	6050
10	09.12.1993	11	36	1.0	3.94	-1888	17602
11	09.02.2007	14	46	1.0	3.94	50	6420
12	09.02.2010	7	35	3.0	4.21	-23434	34425
13	18.04.2015	0	16	4.0	4.28	-3000	20830
14	18.11.2015	0	27	1.0	3.94	-33241	37619
15	23.04.2018	10	55	2.0	4.11	1120	6620
16	05.05.2018	10	58	2.0	4.11	16770	49720
17	13.01.2020	14	34	3.0	4.11	8717	25331

5. Directional relationships between epicenters of strong tremors

Research on the distribution of epicenters in the temporal sequences of strong shocks occurring in the USCB showed clearly directional tendencies to generate successive shocks both inside and between clusters (Idziak 1999). Lasocki and Idziak (1998) proved that the probability of another tremor is greatest for a specific direction in relation to the epicenter of the previous seismic event. Examples of such directional relationships are shown in Fig. 7.

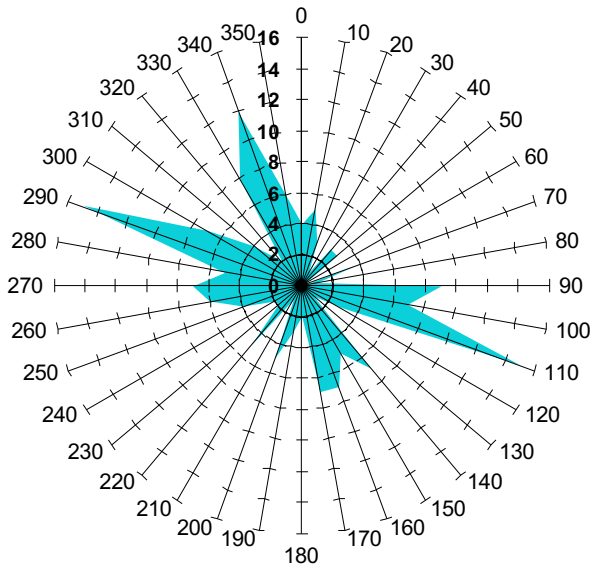

Fig. 7. The example of directional relationships between epicenters of two consecutive shocks (Lasocki & Idziak 1998)

6. Release of seismic energy

Each seismic event causes the release of elastic energy stored in the rock mass. Part of this energy is emitted in the form of a seismic wave, the remaining part is used for inelastic deformations and displacement of rock masses in the area of the shock focus. Summing up the energy of successive seismic phenomena allows to determine what amount of elastic energy has been released from the rock mass from the beginning of the observations (the so-called cumulative energy). Taking into account the increases in accumulated energy in certain time intervals, the average rate of energy release (RER) and its time changes can be calculated.

Based on the catalog of tremors with energy from 100 kJ, the rate of release of seismic energy in individual regions of the USCB was determined. Fig. 8 shows the curve of the cumulative seismic energy released in the entire GZW from 01/01/1987. You can see in the chart that the average release

rate of seismic energy, which was 5 MJ/d for an extended period, had tripled to 15 MJ/d since Q2 2014.

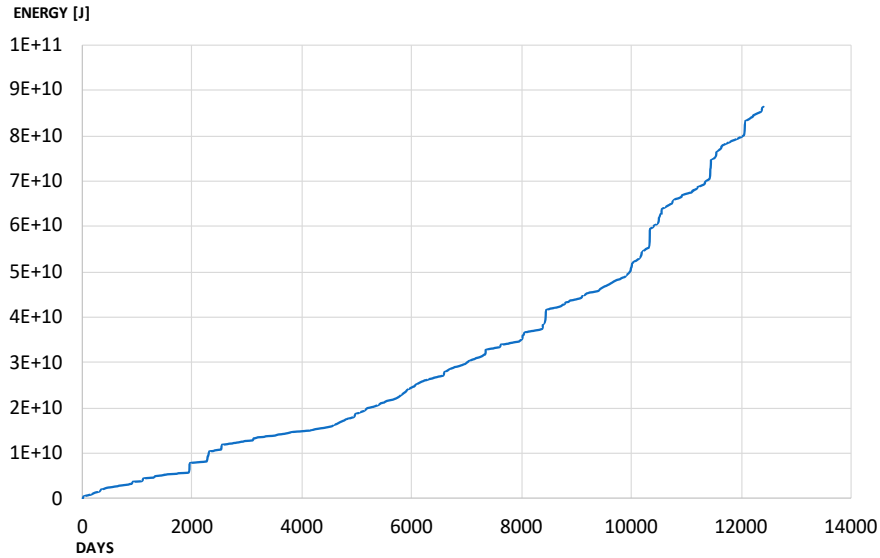

Fig. 8. The curve of the cumulative seismic energy released in the entire USCB from 01/01/1987

The release of seismic energy, however, differs in different structural subunits of the USCB (Fig. 9). In the Main anticline, until the end of 2013, the RER was 2.3 MJ/d. In the short term, from the beginning of 2014 to May 2015, it increased to 18.5 MJ/d (which was caused by the occurrence of several very strong shocks), and then decreased to 3.5 MJ/d. In the Bytom syncline, most of the energy was released in very strong shocks. Between these shocks, the RER was rather low, at the level of 0.4–0.5 MJ/d. In the Kazimierz syncline, the RER was 60 kJ/d until the middle of 1992. After a very strong shock that took place at that time, it dropped to the level of 27 kJ/d, and after 2008 it fell to almost zero. In the Main syncline, the RER was at the level of 300–400 kJ/d for a long time. From 2010 it increased to 2.1 MJ/d. In the Jejkowice syncline, RER systematically increased from the initially low value of 88 kJ d through 0.6–0.9 MJ/d to reach 1.6 MJ/d from mid–2018.

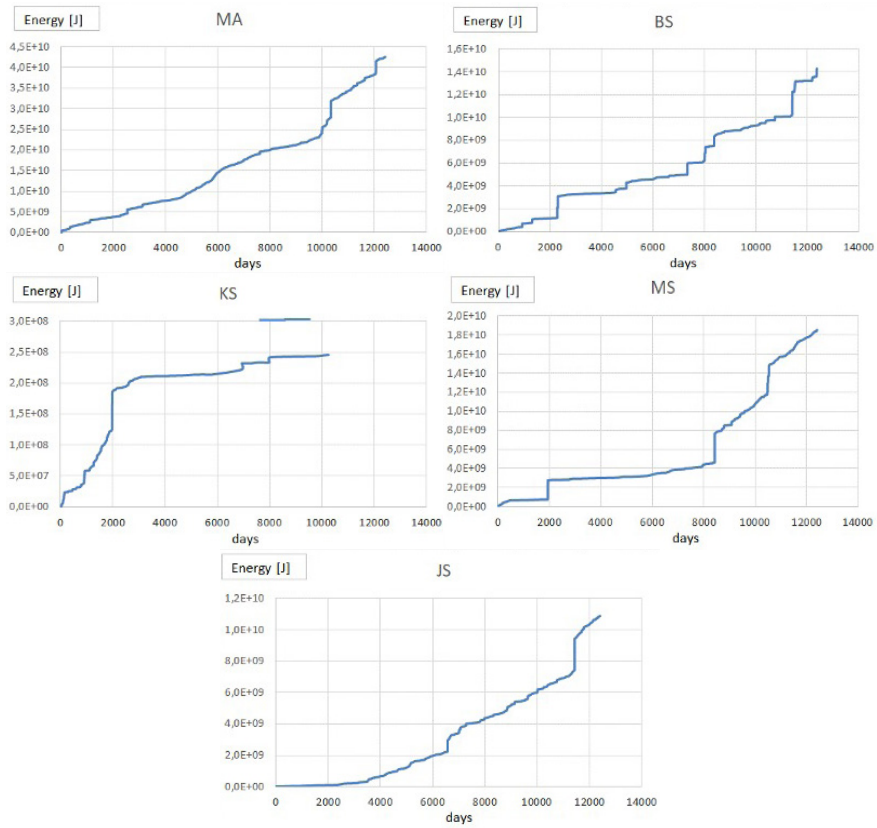

Fig. 8. The curve of the cumulative seismic energy released in the entire USCB from 01.01.1987

The total amount of seismic energy released in 1987–2020 in individual sub–units and in the entire USCB is presented in Table 2.

Table 2. The total amount of seismic energy released in 1987–2020 in individual sub--units and in the entire USCB

Tectonic sub-unit	MA	BS	KS	MS	JS	USCB
Energy [GJ]	42,599	14,264	0,224	18,527	10,872	86,507

7. Conclusions

The above characteristics of the seismicity of strong tremors in the USCB in its various aspects show its similarity to the seismicity in tectonically active areas. Repeated increases and decreases in seismic activity resemble the seismic cycles characteristic of natural earthquake regions. The fractal spatial distribution of the tremors epicenters may testify to the non-linear chaotic dynamics of the Upper Silesia massif. In the USCB, a certain degree of seismicity migration is observed. While in the 1980s and 1990s, strong tremors occurred mainly in the northern part of the Basin (BS, KS and MA), now the activity in the south-west (JS) and south-east (MS) is significantly increasing, as well as the related pace of release of seismic energy. Directional relationships between the epicenters of successive tremors may be the result of the transmission of tectonic stresses between or inside individual subunits of the USCB.

The genesis of high-energy seismic phenomena in the USCB is still under discussion. Some hypotheses link changes in activity with the restructuring of the coal industry – a decrease in hard coal mining, the closure of some mines, concentration and an increase in the depth of mining. However, not all features of seismicity can be explained by these reasons. Other hypotheses indicate the role of neotectonic movements in the crystalline basement of the USCB divided into several latitudinal blocks. Under the pressure of the Outer Carpathians, which are probably still overlapping the Upper Silesian Basin, blocks of the substrate move towards each other along the existing fracture zones, causing changes in the stress distribution in the sediment cover, especially in the zones of tectonic discontinuities, such as e.g. the Kłodnica Fault. Recently, A. Bracławska (2021) presented some statistical evidence of the relationship between the seismic activity of the USCB and the activity of the Carpathian and Pannonian Basin. According to her, the seismic cycles in this area are repeated with some delay in the Upper Silesian Basin. What's more, the increase of the number of weaker tremors in the Carpathians results in an increase of the number of the strongest tremors in the Upper Silesian Coal Basin. Therefore, it can be assumed that the lower the rate of release of seismic energy south of the USCB, the higher it is in the Basin.

There is no doubt that finding out the genesis of the strong tremors at the USCB will continue to be an important research task.

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Biographical note

Professor Adam F. Idziak – was born in 1951 in Chorzów. In this city, he graduated from elementary school and secondary school. In 1969 he began studies at the Faculty of Mathematics Physics and Chemistry at the University of Silesia. In 1974 he obtained a master's degree in physics with a specialization in applied physics. After one year of military service, he started working for "Nitron-Erg" in Krupski Młyn as a research laboratory technologist, where he was involved in testing the strength properties of plastics. In 1977 he changed his place of work to the Faculty of Earth Sciences of the University of Silesia in the Department of Geochemistry. He dealt with the analysis of thermal decomposition products of coal using the NMR method. From 1979 he worked at the Department of Deposit Geology and Geophysics, then transformed into the Department of Applied Geology. He researched the field of seismo-acoustic emission of rocks. In 1983, he began research on the effect of fracture in rock massifs on the velocity of seismic wave propagation in them. This research allowed him to prepare a doctoral dissertation, which he defended in 1986 at the Faculty of Exploration Geology of the AGH University of Science and Technology in Krakow, obtaining a PhD in technical sciences.

After his doctorate, he continued research on the effect of fracture on the anisotropy of elastic and electrical properties of rocks. He also got involved in multidirectional research on induced seismicity in the Upper Silesian Coal Basin. In 1990, he completed a scientific internship at the Institute of Physics of the Hungarian Academy of Sciences in Budapest. In 1992, he prepared for publication a monograph entitled "Anisotropy of the velocity of seismic waves and its relationship with the orientation of the fracture systems of rock massifs", which was the basis for awarding him in 1993 the degree of habilitated doctor of Earth sciences in the specialization of geophysics by the Council of the Faculty of Geology, Geophysics and Environment Protection of the AGH University of Science and Technology. From October 1994 he was appointed head of the Department of Applied Geophysics. In June 1995 he took up the position of associate professor at the University of Silesia. The experiences in the use of geophysical methods to determine the fracture parameters of rock massifs allowed him to start research aimed at identifying the migration paths of groundwater in carbonate fissured reservoirs. In the field of induced seismicity, he analyzed the temporal and spatial distributions of strong tremors occurring in the Upper Silesian Coal Basin and the reasons for their formation.

The result of this research was published in 1999 in a monograph entitled "Seismicity and the tectonics of the Upper Silesian Coal Basin".

He was awarded the scientific title of professor in January 2001. After obtaining the title, in addition to the continuation of the current research topics, he initiated new research directions in his team: the use of geophysical methods to identify the youngest fluvial and glacial deposits and the natural radioactivity of minerals and rocks. Under his supervision and with his active participation, geophysical studies of glacial deposits in Iceland, Spitsbergen, and Western Pomerania, as well as the extent of permafrost in Lapland (northern Sweden) were carried out. Research on the effect of fracture on the physical properties of rock massifs, previously carried out for carbonate massifs, was extended to other types of sedimentary and igneous rocks. In May 2006, he was appointed full professor.

Professor Adam Idziak is the author or co-author of over 100 scientific publications – articles, chapters in monographs, and monographic works, as well as the author or co-author of over a dozen unpublished reports from government research programs. He participated in dozens of international and national scientific conferences and several science schools. For many years, he has maintained close scientific contacts with the Institute of Geonics CAS in Ostrava and the Institute of Rock Mechanics of the CAS in Prague. It also cooperates with research centers in the country: the Institute of Geophysics of the Polish Acad-

emy of Sciences in Warsaw, the AGH University of Science and Technology in Kraków, the Silesian University of Technology in Gliwice, and the Central Mining Institute in Katowice.

He has repeatedly reviewed research projects for the Committee for Scientific Research and the National Science Center. As a member of the NCN expert corps, he chaired the expert panel of the ST-10 Team twice. He was a consultant of the National Atomic Energy Agency for which he reviewed geophysical research projects in the areas of planned radioactive waste repositories. He reviews articles for foreign scientific magazines. He collaborated with the Grant Agency of the Czech Republic, reviewing research projects for it.

Professor Idziak promoted eleven doctors. He has been a reviewer of doctoral and postdoctoral theses many times. In the years 1994-2020, he headed the Department of Applied Geophysics, and from 2011 also the Department of Applied Geology. He was the vice-dean for scientific research at the Faculty of Earth Sciences of the University of Silesia in the years 1999 - 2005, and in the years 2008-2016, he was the dean of this faculty.

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The challenges of analytical chemistry – keeping up with changes in the copper industry[1]

Summary

Any new technology or even a change in an existing process is often a challenge for the existing analytical toolset. The same dependence occurs in the analytical handling of processes taking place in the copper industry. The main trends are the preference for multi-element analytical techniques; simplification and automation of the sample preparation process; the use of direct analysis techniques in the analysis of solid samples; continuous lowering of the limits of quantification for the determination of trace elements; production of certified reference materials for new products and materials of the copper industry; using solutions that allow for in-process analysis online. The study includes a review of examples of development work carried out at the Center for Analytical Chemistry, Łukasiewicz Research Network – Institute of Non-Ferrous Metals for the needs of the copper industry, in which these trends are manifested.

Keywords: analysis, spectrometry, CRM, quality, laboratory

1 The article written as a part of research conducted in Łukasiewicz Research Network - Institute of Non-Ferrous Metals. It include autorship of research group: Tadeusz Gorewoda, Jacek Anyszkiewicz and Jadwiga Charasińska, Zofia Mzyk, Barbara Bolibrzuch, Justyna Kostrzewa, Magdalena Knapik, Sylwia Kozłowicz, Andrzej Hryniszyn, Izabela Maj, Magdalena Grzegorczyk, Marta Wolska, Agnieszka Czech, Ewa Jamroz, Michał Jadwiński and Beata Cwolek under edition of T. Gorewoda, J. Anyszkiewicz, J. Charasińska.

WYZWANIA CHEMII ANALITYCZNEJ – NADĄŻYĆ ZA ZMIANAMI W PRZEMYŚLE MIEDZIOWYM

Streszczenie

Każda nowa technologia lub nawet zmiany w obecnie działającym procesie, stanowią często wyzwanie dla laboratorium analitycznego. Taka sama zależność występuje w obsłudze analitycznej procesów przebiegających w przemyśle miedziowym. Główne trendy to: preferowanie wielopierwiastkowych technik analitycznych; upraszczanie i automatyzacja procesu preparatyki próbek; wykorzystywanie technik analizy bezpośredniej w analityce próbek stałych; nieustanne obniżanie granic oznaczalności, w celu oznaczania pierwiastków śladowych; wytwarzanie certyfikowanych materiałów odniesienia dla nowych produktów i materiałów przemysłu miedziowego; stosowanie rozwiązań pozwalających na analizę w procesie, tzw. on-line. Opracowanie obejmuje przegląd przykładów prac rozwojowych przeprowadzonych w Centrum Chemii Analitycznej Sieć Badawcza Łukasiewicz – Instytutu Metali Nieżelaznych na potrzeby przemysłu miedziowego, w których przejawiają się te trendy.

Słowa kluczowe: analiza, spektrometria, CRM, jakość, laboratorium

1. Introduction

Introducing innovative solutions in the non-ferrous metals industry, whether in the context of completely new technologies or by modernizing existing solutions, is a natural process occurring in many enterprises. The development concerns both the processes of copper production from primary and secondary raw materials, as well as the processing of copper and the production of modern copper materials. All these processes have one thing in common – they require analytical support and efficient provision of information about the composition of process materials as well as product quality control. It should be noted here that each introduction of an innovation, resulting in the creation of a material with a chemical composition different than previously known, is associated with a challenge for the laboratory. It is an accepted fact that there are no universal analytical procedures or apparatus prepared for the analysis of every possible material. Hence, new technologies require new solutions in analytical processes. The selection and development of a sample preparation procedure, appropriate for the new ma-

terial, fine-tuning the details of the measurement application on analytical instruments, selection or production of calibration materials and reference materials for the quality control of results – these are typical operations, the execution of which often involves research work. In addition, there are requirements for a modern analysis process – the shortest possible time, the highest possible accuracy, minimization of the consumption of chemical reagents and the production of laboratory waste, low costs, and operation within standardized quality systems.

The Center for Analytical Chemistry, operating within the Łukasiewicz Research Network, an Institute of Non-Ferrous Metals, has been providing analytical solutions for the non-ferrous metals industry since its inception.[2] A significant part of these solutions is dedicated to supporting processes related to the production or processing of copper. Throughout all the years of its activity, its activities follow global trends and changes taking place on the analytical market. The most important of the observed trends are summarized below.

- Increasing the share of multi-element methods, i.e. instrumental techniques that make it possible to obtain results for many elements (even several dozen) in one measurement cycle.
- Striving to automate the sample preparation process. A special case is the analysis of solid samples, the direct analysis of which is particularly developed.
- Developing analytical methods for the determination of trace elements. Changes in production processes, the development of technologies for the recovery of valuable elements, and the recycling of copper materials require the determination of elements that have not been routinely determined so far.
- Need to produce certified reference materials (CRM) for new materials. In this respect, the development also includes keeping up with the requirements of international standards and ISO guides.
- Increasingly frequent introduction of online analyzers in the production line.

The following sections present examples of solutions developed at the Center for the needs of the copper industry in the last decade, which correspond to the above-mentioned trends.

2 The official website of the Center for Analytical Chemistry Łukasiewicz – Institute of Non-Ferrous Metals, http://www.imn.gliwice.pl/content/506/zaklad_chemii_analitycznej [access: 24/11/2021].

2. Preference for analysis methods equipped with easy to conduct and automated methodology of sample preparation

A simple sample preparation process that requires a minimum number of additional substances generates a minimum amount of waste and can be performed by an unskilled worker in a repeatable manner is an ideal that all laboratories strive for. Unfortunately, it is not always possible to achieve such parameters. It should be noted here that often the simplicity of daily operations and repeatability can only be ensured by high automation. The use of advanced solutions to simplify these operations is not contradictory.

An example of a solution that allows the preparation of a sample for analysis while minimizing the impact of the human factor is an automatic sample preparation line operating in the Polkowice branch of the Quality Research Center. This solution was fully functional after the implementation of the project called "Development and production of a base of reference materials to ensure the control of flotation and geological material analyses using the XRF technique after the preparation of pellets on an automatic line. Development of a new method for the preparation of pellets enabling control and correction of the REMCU graining matrix effect"[3]. Automation of the process of preparation and analysis of geological and flotation samples allowed for a significant increase in the number of analyzes performed by the CBJ and facilitated the work of the laboratory staff. Nevertheless, it was required to produce a very large series of reference materials for the calibration of XRF spectrometers analyzing samples at the end of the line. It was also necessary to develop an optimal methodology for controlling the operation and wear of line elements, such as grinders and automatic presses. As part of this project, 54 flotation materials, 27 geological materials, and 10 materials for Cu concentrates (imported) were produced for the calibration of XRF spectrometers. Additionally, to control the work of the preparative line and spectrometers, 10 CRM grades for flotation materials and 3 CRM grades for geological materials were developed and produced. Moreover, special binder tablets with an internal standard (Innocel 90) have been developed to enable quick inspection of line components, including grinder

3 The official website of the research projects of the Innotech competition, carried out in Łukasiewicz – Institute of Non-Ferrous Metals, http://www.imn.gliwice.pl/projects/category/14/innotech [access: 24/11/2021].

wear monitoring. By introducing these pellets into the sample preparation line, it is possible to detect milling problems by observing the intensity of the strontium analytical lines that are recorded by XRF spectrometers. This solution was described in detail by Z. Mzyk.[4]

Fig. 1. Innocel-90 tablets for control of devices used in the preparation of samples for the XRF technique

3. Searching for methods of analysis enabling determination of lower and lower content of elements

The progressive increase in the quality requirements for copper products goes hand in hand with the growing expectations of analytical methods. Elements that were recently considered irrelevant due to their very low content are now of interest to technologists. There are many examples of such changes that require the development of new analytical solutions. In recent years, this has particularly concerned the development of applications for

4 Mzyk Z., Anyszkiewicz J., Gorewoda T., *Special tablets containing cellulose binder and Sr internal standard for simplifying X-ray fluorescence analysis of powder samples*, "Spectrochimica Acta, Part B" 2015, No. 114, pp. 15–19.

the inductively coupled plasma mass spectrometry (ICP-MS) technique. It is a multi-element technique that enables the determination of trace and ultra-trace levels of more than 70 elements in solution or solid samples after transfer to a solution.[5] The Laboratory of Atomic Spectrometry, operating in Łukasiewicz-Institute of Non-Ferrous Metals, has developed procedures allowing for the determination of a wide range of elements in copper industry materials with this technique. In 2016, analytical procedures were created to determine 14 elements in copper in accordance with the PN-EN 1978: 2000 standard (Ag, As, Bi, Cd, Co, Cr, Fe, Mn, Ni, Pb, Sb, Sn, Te, Zn) and for the determination of 18 elements in silver (As, Au, Bi, Cd, Cu, Fe, In, Mn, Ni, Pb, Pd, Pt, Sb, Se, Sn, Te, Tl, and Zn).[6] In recent years, in response to the needs of technologists, new analytical procedures have been developed, including determination of thallium in copper matte and slags,[7] barium in copper electrolyte and anode slime[7], determination of barium and mercury in electrolytic copper, or determination of arsenic in flotation waste[8, 9] (table 1).

Table 1. Measuring ranges of new procedures for the ICP-MS technique

Chemical element	Material	Measurement range
Ba	Copper electrolyte	0.01–2 mg / l
Ba	Anode slime	200–10,000 mg / kg
Ba	Electrolytic copper	0.1–5.0 mg / kg
Hg	Electrolytic copper	0.5–5.0 mg / kg
As	Flotation solutions	0.01–50 mg / l
As	Flotation waste	1–500 mg/kg
^{203}Tl	Copper matte and slag	0.1–10 mg/kg

The standard of conduct when analyzing technological samples is theoretical recognition of potential interferences that interfere with the measurement of isotopes of the analyzed element. The source of such interference

5 *Methods of Analytical Atomic Spectrometry*, W. Żyrnicki (ed.), J. Borkowska-Burnecka (ed.), E. Bulska (ed.), E. Szmyd (ed.), Warsaw, 2010.

6 *Development of methods for the determination of impurities in copper and silver by inductively coupled plasma mass spectrometry (ICP-MS). Report No. 7551/16* Łukasiewicz – IMN, J. Charasińska, Gliwice, 2016.

7 *Development of analytical procedures ensuring ongoing analytical control of modern technologies developed by IMN research facilities in 2017*.

8 *Development of a set of analytical procedures for the methods implemented at the Department of Analytical Chemistry in 2019. Report No. 7855/19 Łukasiewicz – IMN, J. Charasińska (ed.), Gliwice, 2019.*

9 *Development of new analytical methods for determinations made at the Department of Analytical Chemistry in 2020. Report No. 8061/20 Łukasiewicz – IMN, J. Charasińska (ed.), Gliwice, 2020.*

may be isotopes of other elements present in the sample or multi-element bonds formed in the plasma from the plasma gases and the sample matrix. The research work then consists in checking the qualitative composition of the tested material using an application for the so-called semi-quantitative analysis. Based on the results of this analysis, it can be concluded whether there is a possibility of interference and which elements can be used as an internal standard (they should be practically absent in the sample). An example of this procedure is shown for the determination of thallium in copper matte.[6] It is important to identify possible interferents not only for the thallium isotopes but also for the internal standard isotope (^{195}Pt) – one should look for an isotope for which there will be no theoretically predicted interference. Potential interferences are summarized in Table 2.

Table 2. Potential interferences for thallium isotopes and the isotope of the internal standard – platinum ^{195}Pt

Isotope	Natural content [%]	Interference
^{203}Tl	29.52	$^{187}Re^{16}O$, $^{185}Re^{18}O$; $^{187}Os^{16}O$, $^{189}Os^{14}N$, $^{163}Dy^{40}Ar$, $^{184}W^{19}F$
^{205}Tl	70.48	$^{187}Re^{18}O$, $^{191}Ir^{14}N$, $^{189}Os^{16}O$, $^{186}Os^{19}F$, $^{186}W^{19}F$
IS ^{195}Pt	33.80	$^{179}Hf^{16}O$, $^{176}Hf^{19}F$

Another area where there is a need to use methods with ever lower values of the limit of quantification is the characterization of new reference materials. Increasing the requirements for analytical methods is also associated with the need to produce appropriate certified reference materials. The ICP-MS technique is increasingly used when characterizing materials – candidates for CRM. In 2019, the Center took part in determining the certified values for CRM for the CuZn33Pb1AlSiAs copper alloy produced by the German National Institute for Materials Research with the symbol BAM-M396.[10] On the one hand, the ICP-MS technique allowed the determination of some elements at very low levels of content, and on the other hand, for elements with higher content, it was an alternative method, which is always desirable in this type of production. As part of this work, an analytical application was developed that allows the determination of Fe, Sn, Ni, Mn, Sb,

10 Official CRM BAM-M396 certificate, https://rrr.bam.de/RRR/Content/EN/Downloads/RM-Certificates/RM-cert-nonferrous/Copper/bam_m396de.pdf?__blob=publicationFile [access: 24/11 .2021].

Bi, Cd, Co, and Cr in a wide range of concentrations (Table 3).[11] In addition to determining the characteristic values of CRM, the application is used in the ongoing work of the Center.

Table 3. The results of the determination of elements (mg/kg) in the BAM-M396 alloy and the analytical ranges of the ICP-MS application used for the analysis of the material

Chemical elements	The result of the analysis	Benchmark	Measurement range
Fe	227	235 ± 12	2–500
Sn	355	367 ± 11	1–500
Ni	132	143 ± 17	2–500
Mn	42.9	44.5 ± 1.9	1–100
Sb	6.0	6.1 ± 0.7	0.5–10
Bi	3.0	3.2 ± 0.03	0.5–10
Cd	2.0	2.2 ± 0.2	0.5–10
Co	1.2	1.2 ± 0.1	0.5–10
Cr	7.3	7.9 ± 0.7	0.5–10

4. New Certified Reference Materials – keeping up with the market requirements

The Łukasiewicz Analytical Chemistry Center – IMN continues over 60 years of tradition of producing certified reference materials for materials in the non-ferrous metal industry. In this regard, it cooperates with other research centers of the Institute, which specialize in casting metals and their alloys. Works of this type are most often carried out as part of research projects because the development of a new CRM requires the development of a methodology for casting a perfectly homogeneous material with a specific composition and the development of a full methodology for its analyses. Contrary to appearances, the latter task is a challenge, because usually, the object which is being produced is an alloy with parameters not available on the market so far. Examples of large B+R projects under which copper-

11 Development of new analytical procedures for the methods implemented at the Department of Analytical Chemistry in 2018, *Report No. 7724/18 Łukasiewicz – IMN*, J. Charasińska (ed.), Gliwice, 2018.

based CRMs are created are projects under the acronyms EFROHS[12] and Non-Ferrous CRMs.[13] The former, called "production of reference materials necessary for the analysis of electronic and electrical devices placed on the EU market, regulated by the RoHS directive (financed by the Łukasiewicz Center earmarked subsidy and coordinated by the Łukasiewicz Center for Analytical Chemistry – Institute of Non-Ferrous Metals), covers the production of two new types of CRMs based on copper-containing Cr, Cd, Pb, and Hg – elements covered by the RoHS directive.[14] The planned compositions of these two species are to ultimately enable the creation of a simple calibration using the so-called method of constraining patterns. These will be the first materials of this type containing Hg, whose homogeneous fusion into high-melting copper is a very difficult challenge. These materials are intended for laboratories that check electrical and electronic equipment for compliance with the requirements of the directive. Łukasiewicz – Kraków Institute of Technology is responsible for casting the material for the production of this pattern.

In turn, the determination of certified values will be possible thanks to analyzes carried out with accredited methods in the Center for Analytical Chemistry and in the laboratories of consortium members. Completion of the project and introduction of the materials to the market will be possible by the end of 2022. The Non-Ferrous CRMs project, with the full title "Development, production, and validation of new matrix certified reference materials for selected non-ferrous alloys" is carried out thanks to funding from the LIDER program of the National Center for Research and Development. As part of this project, CRMs will be produced with a chemical composition corresponding to the most common classes of copper scrap. It is a response to the constantly growing share of copper scrap in copper production processes, and hence the need for quick methods of analyzing such scrap, e.g. by X-ray fluorescence spectrometry (XRF). There are many examples of works completed in recent years in which CRMs for copper-based materials were produced. Modern high-speed railways require the use of specific

12 The official website of the projects financed from the Special-Purpose Grant in Łukasiewicz – Institue of Non-Ferrous Metals, http://www.imn.gliwice.pl/projects/category/80/projekty_doffinansowane_ze_srodkow_dotacji_celowej_przyznanej_przez_prezesa_centrum_lukasiewicz [access: 24.11.2021]

13 Official website of projects financed by the LIDER program (NCBiR), http://www.imn.gliwice.pl/projects/category/19/lider [access: 24/11/2021].

14 Directive 2011/65 / EU of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32011L0065&from=PL [access: 24/11/2021].

alloys of copper with silver and copper with magnesium. In 2019, two series of CRMs for such materials were developed.[15] Another example of progress in the CRMs produced at the Center is the standard with the symbol CuS-L, in which the sulfur content has been certified at the level of 4 ppm. Such a low content posed a great challenge to the analytical methods used in the characterization process. CRM producers must keep up not only with the market requirements as to the composition of new CRMs but also with the requirements resulting from the provisions of the current ISO 17025 and ISO 17034 editions. Progress in the field of standardization led to the publication in 2018 of the Polish version of the ISO 17034 standard entitled General requirements for manufacturers of reference material. Meeting the market requirements, in 2021 the Center for Analytical Chemistry was accredited by the Polish Center for Accreditation in the scope of this standard. It required the development of a quality system adjusted to the realities of production of certified reference materials of the matrix type and fully meeting the requirements of the aforementioned standard. The implementation of this system was also closely related to CRM for the copper matrix because the first material fully covered by this system was the B555 bronze standard, currently used, among others, in the production of modern fittings.[16]

5. Introduction of online analyzers in the production line

One of the most interesting challenges that modern technologies pose to chemical analysis is online process analysis. It can be considered as an ideal type as the result of the analysis is obtained in real-time without the influence of the human factor. Online analysis solutions are known, very often based on solutions based on the XRF technique. In 2015–2019, the project Next-generation urban mining – Automated disassembly, separation, and recovery of valuable materials from electronic equipment, with the acronym ADIR, was implemented.[17] A consortium of German, French, Austrian, and Italian companies as well as the Fraunhofer and Łukasiewicz institutes – In-

15 *Development of two series of certified reference materials for alloyed copper: magnesium and silver, Report No. 7750/18 Łukasiewicz – IMN*, J. Kostrzewa (ed.), Gliwice, 2018.

16 *Development of a quality system for the production of certified reference materials in the context of the PN-EN ISO 17034 standard and the requirements of the Polish Center for Accreditation, Report No. 7887/19 Łukasiewicz – IMN*, T. Gorewoda (ed.), Gliwice, 2019.

17 The official website of the ADIR project, www.adir.eu [access: 24/11/2021].

stitute of Non-Ferrous Metals, whose leader was the Fraunhofer Institute of Laser Techniques, developed a technology for the processing of electronic scrap, in the form of PCBs from telephones and servers, such as a significant secondary raw material in the production of copper. The core of the technology is a machine consisting of 4 modules operated automatically by robots. In the first module, all used telephones are pre-sorted and arranged. The second module is a set of devices for automatically disassembling the phone and extracting its PCB and speakers. The third module – which guarantees online analysis of the entire process – enables full laser dimensioning of the PCB and its components as well as quick, semi-quantitative analysis of individual electronic components mounted on the board with a laser-excited optical emission spectrometer (LIBS). Thanks to this analysis, it is possible to select components containing metals, the content of which, in relation to the complete plate, is too small for the recovery processes. In the next, fourth module, the laser desolders or cuts off the elements selected on the basis of LIBS analyzes and allocates them to fractions, which are then directed to the appropriate recovery processes. All unselected components can be removed from the board in a pulse-power device and directed to the precious metal recovery process. The remaining plate containing copper, the content of which is higher than the complete plate before the process, can be directed to the currently implemented pyrometallurgical process. The developed solution is technologically advanced and, as a result, enables the recovery of elements that have not been recovered so far and does not require the involvement of numerous qualified personnel in everyday work. Analytical chemists made a significant contribution to the development of this technology, as described by the authors of this chapter[18, 19].

18 T. Gorewoda, J. Anyszkieiwcz, J. Charasińska, Sylwia Kozłowicz, Magdalena Knapik, *Wkład chemii analitycznej w opracowanie nowoczesnej technologii recyklingowej w ramach europejskiego projektu badawczego ADIR*, "Analityka: nauka i praktyka" 2019, no. 4, pp. 56–63.

19 T. Gorewoda, M. Eschen, J. Charasińska, M. Knapik, S. Kozłowicz, J. Anyszkiewicz, M. Jadwiński, M. Potempa, M. Gawliczek, A. Chmielarz, W. Kurylak, *Determination of metals content in components mounted on printed circuit boards from end-of-life mobile phones*, "Recycling", 2020, No. 20, pp. 1–9.

Fig. 2. ADIR technology machine

6. Increasing the share of instrumental multi-element methods in analytical processes

The use of modern, instrumental analytical methods is a response to the technology demand for fast and relatively cheap methodology providing a full set of analytical information in a short time. This point, although it was mentioned as the first in the introduction to this study, appears as the last one in the text. This is a deliberate move since analyzing the previous points, one can easily notice that in practically every discussed example multi-element techniques such as XRF, ICP-OES, ICP-MS, or LIBS are used. It should be noted here that the implementation of such a technique requires a great deal of laboratory effort, but the subsequent benefits balance it. It is also difficult to come up with a universal solution. An example of a very universal tool for the analysis of a very wide group of copper alloys is XRF spectrometry. In 2019, an application containing calibrations for 14 alloying elements and

impurities found in bronze was developed.[20] The key of the solution was the use of four series of CRMs by Łukasiewicz – IMN and two NIST production patterns (BI1-BI4; BL1-BL5; BJ1-BJ5; BE1-BE5; NIST 1113; NIST 1114). Very well-developed applications that use calibrations based on the correction of matrix effects in the so-called empirical form, allow the determination of Sb, Sn, Pb, Zn, Cu, Ni, Fe, Mn, P, Al, S, Si, Bi, and As in a wide range of contents covering several orders of magnitude of concentration (Table 4).

Table 4. Element measuring ranges in a bronze analysis application

Chemical elements	Analytical range [%]	Chemical elements	Analytical range [%]
Al	0.00052–2.88	P	0.0022–0.70
As	0.00057–0.14	Pb	0.0025–6.97
Bi	0.013–0.12	S	0.0023–0.021
Cu	77.94–96.45	Sb	0.0012–0.58
Fe	0.0061–0.42	Si	0.0038–3.91
Mn	0.0011–1.69	Sn	0.0034–11.05
Ni	0.0074–6.97	Zn	0.0078–10.22

7. Conclusions

Innovative solutions, developed and introduced in the broadly understood copper industry, generate the need to introduce equally innovative solutions in the field of chemical analyses. Hence, a good practice is a close cooperation between technologists and analysts at various stages of creating innovations. Certain trends can be observed that determine the directions of changes in analytical solutions. They result from the requirements imposed on laboratories by new technologies. Short analysis time, quick access to results, reliability of results and their measurement traceability, and finally standardization and normalization resulting in recognition of the results by all interested parties – these are the basic factors that the laboratory and manufacturers of analytical solutions must take into account. The presented examples of works carried out in recent years or currently carried out by the Center for Analytical Chemistry Łukasiewicz – Institute of Non-Ferrous Metals, a unit closely cooperating with the copper industry, confirm

20 *Development of a set of analytical procedures for the methods implemented at the Department of Analytical Chemistry in 2019, Report No. 7855/19 Łukasiewicz – IMN*, J. Charasińska (ed.), Gliwice, 2019.

the trends in this field all over the world. By observing the changes taking place in the industry, one can forecast the changes that will take place in the area of analytics. Industry 4.0 definitely enforces the use of automation and fast data flow, which will result in wider use of online analyzers, and where this is not possible, the use of automated lines for sample preparation and analysis, such as the CBJ line operating in Polkowice. We can also predict an even greater increase in the role of instrumental, multi-element techniques. This is already observed in the industry, where classical analytical laboratories are of less and less importance, and single-element instrumental techniques such as AAS atomic spectrometry are being replaced by multi-element ICP-OES. The high dynamics of changes in the area of standardization will affect the producers of certified reference materials and their recipients. There are more and more materials produced in accordance with the ISO 17034 standard on the market, which laboratories eagerly use. Unfortunately, increasing the requirements for producers results in an increase in the prices of standards all over the world – a trend which will probably continue into the future. It can also be anticipated that the industry will stimulate the development of analytical methods allowing the determination of elements at ultra-trace levels. More and more laboratories are equipped with relatively expensive ICP-MS spectrometers, for which an alternative in the future may be the X-ray fluorescence technique of total reflection TXRF, which allows achieving results parameters comparable to ICP-MS. The progress in the apparatus, patterns, and methodology of analyses is noticeable and natural in relation to the developing industry. Continuous work and research in order to develop analytical instruments for new technologies will always accompany the technological development of mankind.

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– "LIDER" program of the National Center for Research and Development, project no. LIDER / 29/0110 / L-11/19 / NCBR / 2020, *Development, production,and validation of new matrix certified reference materials for selected non-ferrous metal alloys*;
– Horizon 2020 Program of the European Commission, *Next-generation urban mining – Automated Disassembly, separation and recovery of valuable materials from electronic equipment ADIR project, (project No. 680449 within H2020-EU.*2.1.5. – Advanced manufacturing and processing)

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Official CRM BAM-M396 certificate, https://rrr.bam.de/RRR/Content/EN/Downloads/RM-Certificates/RM-cert-nonferrous/Copper/bam_m396de.pdf?__blob=publicationFile [access: 24/11 .2021].

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T. Gorewoda, J. Anyszkieiwcz, J. Charasińska, Sylwia Kozłowicz, Magdalena Knapik, *Wkład chemii analitycznej w opracowanie nowoczesnej technologii recyklingowej w ramach europejskiego projektu badawczego ADIR*, "Analityka: nauka i praktyka" 2019, no. 4, p. 56–63.

T. Gorewoda, M. Eschen, J. Charasińska, M. Knapik, S. Kozłowicz, J. Anyszkiewicz, M. Jadwiński, M. Potempa, M. Gawliczek, A. Chmielarz, W. Kurylak, *Determi-*

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Biographical notes

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Jacek Anyszkiewicz – He completed his master's studies at the Silesian University of Technology in the field of chemical technology, and post-graduate studies in chemical metrology at the University of Warsaw. Since 2007, an employee of the Department of Analytical Chemistry of the Institute of Non-Ferrous Metals (since 2021 Center of Analytical Chemistry Łukasiewicz - Institute of Non-Ferrous Metals), where he professionally deals with analytical chemistry, X-ray fluorescence spectrometry, and certified reference materials. Author or co-author of 21 publications in the field of analytical chemistry, published e.g. in journals from the JCR list as well as other domestic and international journals and monographs. Author and co-author of over 13 research projects financed by the state

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The use of a mobile laboratory to assess the quality of the natural environment and the possibility of its use in measurements in underground mining excavations

Summary

The quality of outdoor and indoor air is now an important issue for the scientific community and the relevant services both in Poland and internationally. Air pollution is one of the causes of an increasing number of deaths worldwide each year. Air, water, soil, and waste quality tests are usually performed in stationary laboratories using standardized or reference research or measurement techniques. However, with the development of new technologies, mobile laboratories are used increasingly often in environmental research, as they allow for quick determination of the state of the natural environment in the studied area. Measurement capabilities of mobile laboratories equipped with unmanned airships (drones), portable air analyzers, or portable gas chromatographs allow them to be used also in underground mine workings, where they can be used in research on air pollution or mine water and can be used during rescue operations in mines.

Keywords: air, mobile laboratory, mine, natural environment, quality, drones

WYKORZYSTANIE MOBILNEGO LABORATORIUM DO OCENY STANU JAKOŚCI ŚRODOWISKA NATURALNEGO ORAZ

MOŻLIWOŚCI JEGO ZASTOSOWANIA W POMIARACH W PODZIEMNYCH WYROBISKACH GÓRNICZYCH

Streszczenie

Jakość powietrza zewnętrznego jak i wewnętrznego jest obecnie ważnym zagadnieniem zarówno dla środowiska naukowego oraz odpowiednich służb w Polsce i innych krajach. Zanieczyszczenia występujące w powietrzu są jedną z przyczyn powodujących każdego roku coraz większą liczbę zgonów na całym świecie. Badania jakości powietrza, wody, gleby czy odpadów najczęściej wykonuje się w laboratoriach stacjonarnych wykorzystując znormalizowane lub referencyjne techniki badawcze lub pomiarowe. Jednak wraz z rozwojem nowych technologii coraz częściej w badaniach środowiskowych wykorzystywane są mobilne laboratoria, które pozwalają na szybkie określenie stanu środowiska naturalnego na badanym obszarze. Możliwości pomiarowe mobilnych laboratoriów wyposażonych w bezzałogowe statki powietrze (drony), przenośne analizatory powietrza czy przenośne chromatografy gazowe umożliwiają ich wykorzystanie również w podziemnych wyrobiskach górniczych, gdzie mogą mieć zastosowanie w badaniach zanieczyszczenia powietrza czy wód kopalnianych oraz mogą być użyte podczas akcji ratowniczych prowadzonych w kopalniach.

Słowa kluczowe: powietrze, mobilne laboratorium, kopalnia, środowisko naturalne, jakość, drony

1. Introduction

The quality of air, both internal and external, and its various pollutants are currently one of the biggest problems of the modern world[1]. The problem doesn't concern only air pollution but also contamination of surface water, groundwater, and soil. In recent years, one of the most important topics of public debate globally is the state of the natural environment and the impact

1 ONU. Transforming Our World: The 2030 Agenda for Sustainable Development. 2015, pp. 12–14. https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E; EEA. Climate Change and Air. 2013, pp. 1–8. https://www.eea.europa.eu/signals/signals-2013/articles/climatechange-and-air; IPCC. Chapter 11. Fifth Assessment Report of IPCC. In Climate Change 2014 Impacts, Adaptation, and Vulnerability; 2015; pp. 709–754. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch11.html; *Integrated Mobile Laboratory for Air Pollution Assessment: Literature Review and cc-TrAIRer Design* "Atmosphere" 4 August 2021 Chiara Boanini, Domenico Mecca, Federica Pognant, Matteo Bo and Marina Clerico.

of human activity on its quality. Many measures are taken to improve and protect it, including monitoring and regular tests and measurements, often using portable or mobile devices.

Air pollution is one of the most common causes of death worldwide[2], and it can come from natural sources or be caused by human activity[3]. One of the main sources of air pollution is the combustion of various types of fuels (oil, gasoline, gas) in industry and agriculture, processes that generate energy or are used to generate heat[4].

Testing air, water, and soil pollutants can be performed in a standard way (tests and measurements in a stationary laboratory) or, if possible, performed at the site of potential contamination. In the latter case, tests and measurements are carried out with the use of portable research and measurement equipment, which enables the determination of the pollutants of interest "online" and "in situ", which significantly reduces the time needed for the analysis. In recent years, manufacturers of various types of mobile measuring devices have developed technologies and various solutions that have enabled the construction of portable devices, compact, fast, and allowing to obtain preliminary results of field measurements, often identical to the results obtained in a traditional way (in a stationary laboratory)[5].

This article presents several different types of measuring devices used in testing the quality or pollution of atmospheric and indoor air, as well as water and soil. Additionally, devices or vehicles used as means of transport (e.g. a car) and unmanned aerial vehicles (drones), which are now increas-

2 WHO. Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease; WHO: Geneva, Switzerland, 2016; pp. 68–70. https://apps.who.int/iris/handle/10665/250141; *Air pollution and health*. "Lancet Public Health" 2017, 2, e4–e5. Landrigan, PJ; *Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter.* "Proc. Natl. Acad. Sci." USA 2018, 115, 9592–9597, Burnett, R.; Chen, H.; Szyszkowicz, M.; Fann, N.; Hubbell, B.; Pope, C.A.; Apte, J.S.; Brauer, M.; Cohen, A.; Weichenthal, S.; et al.

3 AIRUSE-LIFE +: *A harmonized PM speciation and source apportionment in five southern European cities*. "Atmos. Chem. Phys. Discuss". 2016, 16, 3289–3309, Amato, F.; Alastuey, A.; Karanasiou, A.; Lucarelli, F.; Nava, S.; Calzolai, G .; Severi, M .; Becagli, S .; Gianelle, VL; Colombi, C.; et al.; *PM2.5 Pollution in Xingtai, China: Chemical Characteristics, Source Apportionment, and Emission Control Measures*. "Atmosphere" 2019, 10, 121, Hu, J.; Wang, H.; Zhang, J.; Zhang, M.; Zhang, H.; Wang, S.; Chai, F.

4 *Primary emissions versus the secondary formation of fine particulate matter in the most polluted city (Shijiazhuang) in North China*. "Atmos. Chem. Phys. Discuss". 2019, 19, 2283–2298, Huang, R.-J.; Wang, Y.; Cao, J.; Lin, C.; Duan, J.; Chen, Q.; Li, Y.; Gu, Y.; Yan, J.; Xu, W.; et al.; *World air particulate matter: Sources, distribution and health effects*, "Environ. Chem. Lett". 2017, 15, 283–309, Mukherjee, A.; Agrawal, M.

5 *Mobile Laboratory with RapidResponse Instruments for Real-Time Measurements of Urban and Regional Trace Gas and Particulate Distributions and Emission Source Characteristics,* "Environ. Sci. Technol". 2004, 38, 5694–5703, Ch. Kolb, SC Herndon, J. B McManus, J. H Shorter, M. S Zahniser, DD Nelson, J. T Jayne, M. R Canagaratna, D. R Worsnop.

ingly used in environmental and field research were included in the text. Most often they serve as transport platforms for devices that perform environmental measurements. They can also be used for the sampling process, or for taking photos or videos documenting the test sites.

2. Construction and equipment of the mobile environmental laboratory – general information

The research and measurement equipment of a typical mobile environmental laboratory can be divided into two main groups. The first is comprised of fully portable and mobile devices. This group is characterized by the fact that they have their independent power source, for example in the form of batteries or accumulators, and they can be used in real conditions without the use of other power sources. The group includes mainly:

- portable gas chromatographs,
- portable air analyzers,
- mobile versions of spectrometers,
- mobile spectrophotometers,
- unmanned aerial vehicles ("drones"),
- portable weather stations.

The second group includes devices that do not have their own battery power supply. This type of measuring equipment requires an additional source of electricity. This group most often includes:

- auxiliary equipment (scales, evaporators, magnetic stirrers, etc.),
- spectrometers,
- stationary versions of gas or liquid chromatographs.

Due to the fact that a typical mobile environmental laboratory is equipped with devices from both of these groups, it should be planned how to provide a power source for devices that require it in the conditions of field measurements.

When creating a mobile environmental laboratory project, the type and type of measurement and research equipment that will be included in it should be taken into account. An important element is to determine how many and what kind of devices will be used in measurements in real conditions. After the inventory and inspection of the research and measurement

equipment are completed, one can proceed to the selection and design of the "base" of the mobile laboratory, which is undoubtedly a car suitable for this type of activity. The most common choice for this type of project are vans with a large and spacious loading space, with a suitable height that allows you to move freely inside the cabin. Additional equipment may be a towing hook, on which, for example, an additional trailer can be towed, which is a means of transport for measuring devices, or which is a further part of the laboratory space.

In recent years, due to the growing environmental awareness and other requirements, cars that are the backbone of mobile environmental laboratories are equipped with low or zero-emission drives (hybrids or electric cars).

Fig. 1. An example of a car as the base and means of transport for the mobile environmental laboratory (cbj.com.pl)

Another important aspect, after choosing a car, is a properly designed interior that will allow the transport of research and measuring devices and the possibility of conducting tests in real conditions in the field. Most often, cars are equipped with specially designed versions of furniture construction, which allow providing transport places and an appropriate working surface for testing. In most new projects, mobile environmental laboratories are equipped with their own independent electricity supply to allow the operation of devices that are not fully mobile. The most common source of power is the auxiliary batteries inside the vehicle, which can be recharged after being used up in the field.

Other important pieces of equipment are refrigerators or coolers, which are used during the transport of samples to the stationary laboratory. This applies to analyzes that cannot be performed in mobile laboratories or, in the results of preliminary studies, it was possible to determine the source and type of contamination so that samples can be taken for more detailed analyzes in a stationary laboratory. In addition, the cars are also equipped with an air-conditioning system of laboratory space in order to ensure stable and optimal working conditions for the devices and the comfort of work for people staying in it, especially in winter or during a hot summer.

3. Examples of research and measurement equipment used in mobile environmental laboratories

3.1. Portable gas chromatographs

Mobile environmental laboratories are one area where portable gas chromatographs have found their way very well. They come in various configurations and with many different detectors: mass (MS), thermal conductivity (TCD), or flame ionization (FID). The widest spectrum of determined compounds is possible with the use of a mass detector. It allows the determination of organic compounds from many different groups, e.g., aromatic and aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and pesticides, among others. Another advantage is selectivity, which makes it possible to detect and accurately determine the type of contamination with high probability. This makes it suitable for both qualitative and quantitative analysis. This is a great advantage, often used in preliminary field analyses aimed at quick

assessment of the situation and identification of the type of contamination in the tested samples. The latest measurement systems, thanks to appropriately modified dispensers and the column, are able to perform chromatographic analysis in just a few minutes. Thanks to this, after such a short time, it is possible to obtain preliminary results of the analysis, which are used to conduct further tests in a narrower scope, saving time, the number of used reagents or energy, which is extremely important from the point of view of the requirements of "green chemistry". Along with the development of portable gas chromatographs, various methods of preparing samples in real or field conditions have also been developed, which also allowed to significantly reduce the time of taking and analyzing samples of pollutants present in the air, water, soil, and waste. Among the most commonly used sample preparation techniques are microextraction techniques, e.g., the SPME (Solid Phase MicroExtraction) technique. This technique consists in concentrating the marked substances on special fibers, covered with appropriate sorbents. It can be used in virtually all types of environmental matrices.

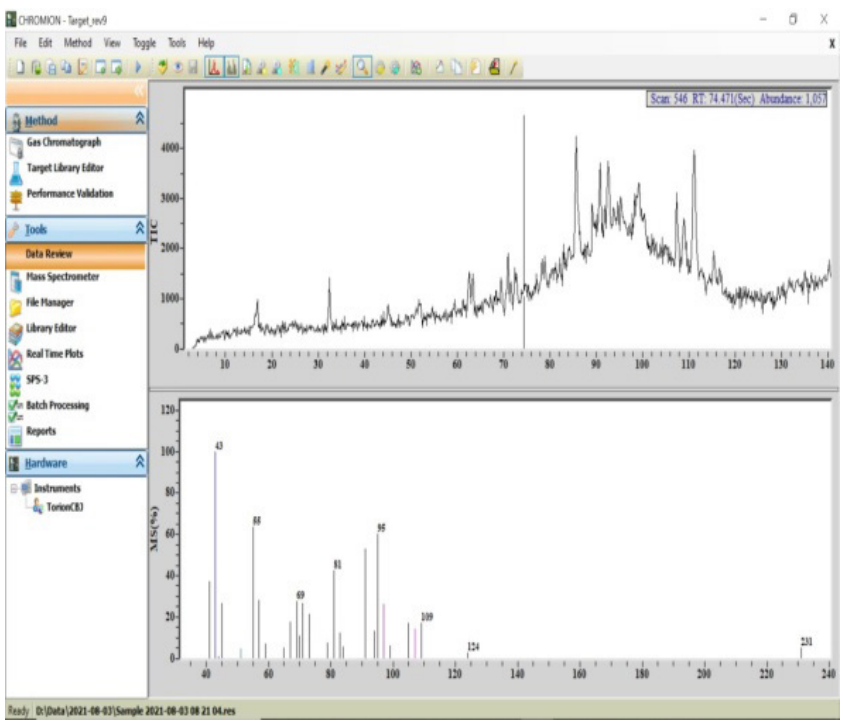

Fig. 2a. An example of a portable gas chromatograph equipped with a mass detector (GC/MS) with an SPME microextraction kit (Torion.com)

Fig. 2b. An exemple chromatogram of the tested environmental sample

3.2. Portable air quality analyzers

Another group of devices used in mobile environmental laboratories are portable air quality analyzers. They can be equipped with various sets of sensors, detectors, analyzers, or particle counters, which are designed to determine the level of air pollution and its quality. They are mainly used for testing the atmospheric air, but they can also be used for indoor air or air monitoring in underground mining excavations. The latest devices in this group are equipped with modules that enable sampling for appropriate sorbents or with the isolation method into appropriate bags, e.g. Tedlar or FlexFoil type. The use of appropriate sorbents or bags allows for subsequent determination of these samples in stationary laboratories. In addition, some devices are also equipped with a Wi-Fi module and have a built-in GPS transmitter, which allows you to later locate and place the obtained results on the map. That way, it is possible to create maps of the levels of individual pollutants, determine their extent and the direction of their spread from their source.

Most often, the analyzers are used to measure air pollution in cities during heating periods. Their task is to pre-define the type and amount of pollutants in the atmospheric air. For this purpose, measurements of parameters such as the concentration of PM 1, PM 2.5, and PM 10, nitrogen oxides, hydrocarbons, ozone, or other pollutants included in the so-called smog are measured.

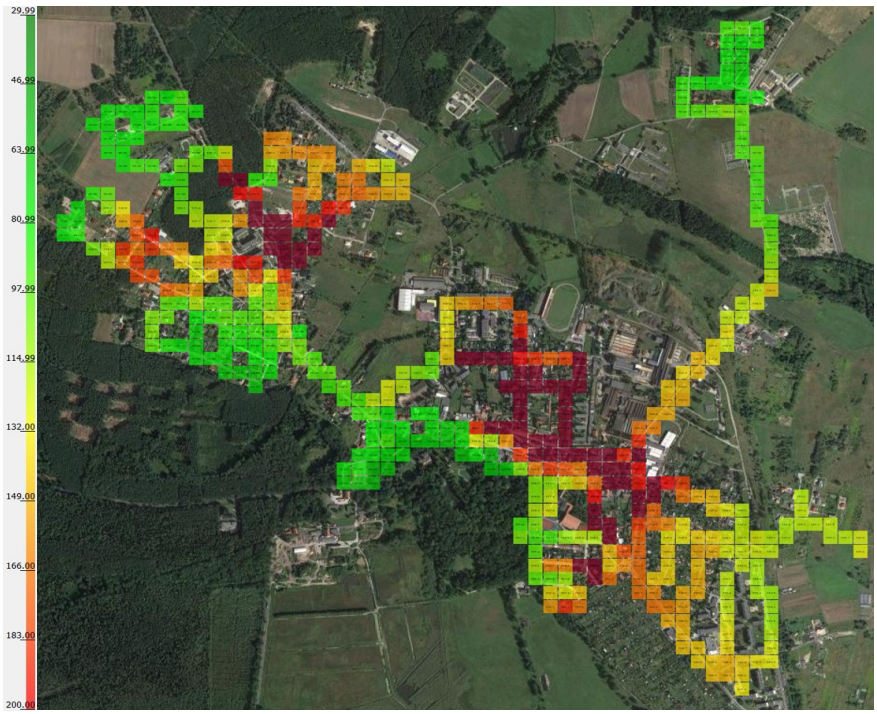

Fig. 3. Sample measurement made with an air quality analyzer. Thanks to the GPS module, after taking measurements, it is possible to accurately determine the location of the most polluted places in the entire measurement area (the darker the color, the higher the level of air pollution)

Fig. 4. An example of an air quality analyzer equipped with a GPS module with a built-in sampling pump – Sniffer 4d (sniffer4d.eu)

3.3. Spectrometers, spectrophotometers, and other mobile measuring devices

Another group of devices are spectrometers, spectrophotometers, and other analyzers used for *online* and *in situ* environmental measurements. The most common area of research is the contamination of water, soil, and furnace waste. The measuring equipment enables the measurement of parameters such as contamination of samples with heavy metals or other contaminants. The analysis of furnace waste makes it possible to check what type of fuel was used during combustion in heating systems, which allows, for example, to select samples and places where waste and garbage were incinerated or co-incinerated. Portable spectrophotometers are most often used during the analysis of drinking, surface, and swimming pool waters. They enable performing basic physicochemical determinations in the field, e.g., during water quality measurements in swimming pools or watercourses.

Fig. 5. On the left, a portable EDXRF spectrometer (xenemetrix.com), and on the right, an analyzer for determining basic physicochemical parameters of water by Horiba (horiba.com)

3.4. Unmanned aerial vehicles – drones

Along with the development of new technologies and the increasing availability of unmanned aerial vehicles – drones, they are becoming more and more frequently used in mobile environmental laboratories. They are used in research and measurement in many different areas. Most often they serve as a transport platform for other research and measurement devices. They enable access to measurement sites that are difficult to access or dangerous for people performing analyzes in the endangered area. Very often they are

equipped with high-resolution cameras, which enable an accurate on-site vision of the test site, help in the preparation of documentation related to the description of the area under study, or enable the determination of the size, range, or directions of contamination spread.

Fig. 6. An example of the use of drone raids equipped with a high-resolution camera. The analysis of photos specialized programs allows you to document the places of sampling or determine the size and location of potential sources of pollution

Another "measurement set" can be a drone armed with a portable air quality analyzer, e.g., Sniffer 4d. A set prepared in this way can be used to test the level of air pollution over any area, including those particularly difficult to access, e.g., cars that are the basis of mobile laboratories. As described in the previous chapter, portable air quality analyzers using the drone as a transport platform allow you to determine the level and distribution of a whole range of pollutants in the studied area, especially those that are part of smog. Measurements with the use of a drone also allow for measurement in three dimensions, i.e., you can additionally check the distribution of a given pollutant at different heights at a given measurement point. Thanks to the built-in air sampling module, you can use appropriate sorbents to take samples exactly in the place and at the height where the limit values have been exceeded. Large drone sets currently offer virtually unlimited room for maneuver when it comes to the use of various measurement sets or sampling systems for sorbents or dedicated bags. The only limitation is the flight time of the drone (you must have the appropriate number of battery packs) and the possible no-fly zones with unmanned aerial vehicles.

Fig. 7. An example of a measurement set – a drone armed with a portable air analyzer with a built-in air sampling module

4. Potential possibilities of using the mobile environmental laboratory for measurements in underground mine excavations

The first mobile laboratory dedicated to measurements in mines was established in 2012 in Australia as a response to the need to quickly respond to emergencies or unexpected gas outbursts that take place in underground mining excavations[6]. So far, the use of this type of laboratory around the world, especially in deep mines, is not a very widespread custom. The development of measuring technology and research equipment, its miniaturization, and the creation of many mobile devices already enable quick and accurate measurements of mine air quality under normal operating conditions of the mining plant, as well as in emergencies. Especially the latter requires making important, responsible, and quick decisions during, for example, a rescue operation. Therefore, mobile laboratories and mobile measuring equipment can provide valuable support during mine air analyses in

6 https://www.australianmining.com.au/news/world-first-mobile-underground-mine-gas-lab-launched/

the area of the rescue operation. Portable gas chromatographs, especially those equipped with a TCD or FID detector, can quickly test the concentration of oxygen, carbon monoxide, and dioxide or methane, i.e. basic gases monitored during operations in underground mining excavations. The advantage of chromatographic analysis over other measurement techniques is the separation of the analyzed gases and minimization of cross-contamination that may come from other gases in the mine air, e.g. during a fire action or after rock and gas ejection. Other gases present in the air may affect the concentration readings on classic gas analyzers equipped, for example, with electrochemical sensors.

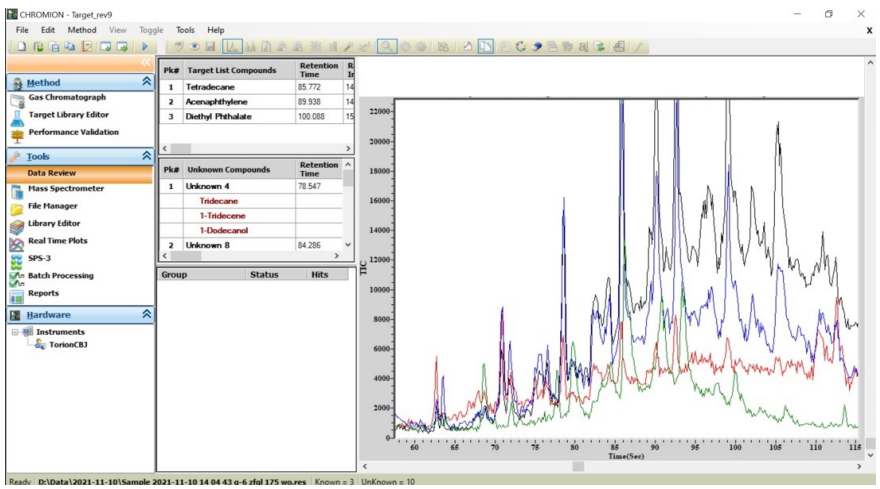

Fig. 6. An example of the use of drone raids equipped with a high-resolution camera. The analysis of photos specialized programs allows you to document the places of sampling or determine the size and location of potential sources of pollution

On the other hand, gas chromatographs equipped with a mass detector, especially when using the SPME sampling technique, can quickly and reliably determine the type and size of contaminants in the mine air. The technique can be used during classic air quality monitoring in underground mine workings as well as during a rescue operation in order to measure toxic or dangerous compounds, e.g., during fires in underground mining workings or during rock and/or gas outbursts.

Portable spectrometers or spectrophotometers can be used to analyze the quality and purity of mine waters used in various processes or works carried out during the mine's operation. Also, portable air quality analyzers, in ad-

dition to the measurements of classic gases present in the mine air, can be used for initial dust measurements by measuring the levels and concentrations of PM 1, PM 2.5, and PM 10 dust.

5. Conclusions

Along with the development of technology and research equipment, mobile environmental laboratories are increasingly used in field research to determine the quality and condition of the natural environment at the measurement site. The use of measurement techniques coupled with drones allows you to perform analyzes that have been difficult or impossible to perform so far. The latest achievements in this area can be successfully transferred to other, so far poorly used research areas, e.g. underground mine workings. Due to the fact that measurements performed in these conditions often require on-site analyzes and results in the shortest possible time from the moment of sampling for testing, mobile measurement laboratories can perfectly complement the previously used measurement methods and techniques.

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Biographical notes

Marcin Przybyła – a graduate of the University of Wrocław in the field of Biotechnology and the University of Banking in Wrocław in the field of Quality Management. Currently, he is carrying out his doctoral research at the Wrocław University of Technology as part of the Implementation Doctorate program. He is a co-author of scientific publications, studies, and expert opinions on the quality of external, internal, and the mine air as well as measurement methods and techniques used during the collection and analysis of samples from underground mine excavations. Member of the Association of Mining Engineers and

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Wacław Szetelnicki – a doctor of humanities, specializing in management, control, PR, CSR, HR, and EB – especially in state and local administration units, corporations, and companies. A graduate of, among others: University of Opole (PhD in history), the University of Economics in Wrocław (management, audit and internal control), the University of Banking in Wrocław (MBA), University of Social Sciences and Humanities in Warsaw (mediation), University of Wrocław (Faculty of Law and Administration – document expertise).
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He also has a ten-year management experience in the KGHM Polska Miedź SA Group (both at the Head Office and at the Companies). Currently, since 2018, he is the President of the Management Board of Centrum Badań Jakości Sp. z o. o., Secretary of the Council of the Polska Miedź Employers' Union.

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Estimation of the Parameters of the Cu Deposit in the "Rudna" Mine Based on the Application of Geostatic Methods with Even Conditioning on the Example of the Mining Side R-1, R-3

Summary

Geostatistical methods, i.e. ordinary kriging, bundled indicator kriging, conditional *turning bands* simulation (**Part I.**) and finally *uniform conditioning* (**Part II.**), aiming for performing of the estimation of copper ore deposits parameters have been applied in the present paper.

Geostatistical studies investigate the variation in the basic geological parameters of the lithologically varied deposit in some selected mining blocks, i.e., R-1, R-3, of the "Rudna" mine (KGHM Polska Miedź, S.A., Copper Basin, in the region of Lubin – Sieroszowice, southwestern part of Poland).

The deposit profiles within two mining blocks (R-1, R-3) comprise of various rock formations, such as: mineralized Whiteliegendes sandstones, intensively mineralized upper Permian dolomitic-loamy and loamy copper-bearing schists and carbonate rocks: loamy dolomite, striped dolomite and limy dolomite, of various thickness. No schists formed in some parts of one studied block (R-1), which are referred to as the schistless area. The deposit series here is considerably less mineralized (comparing with other R-3 block) even though the mineralization thickness of the sandstone and carbonate rocks reaches as much as 20 m. The data from the sampling are the results of chemical analyses of the Cu content in the (recoverable) deposit series, carried out on channel samples and drilled core samples, taken systematically at every 15–20 m in the headings and thickness.

The applied methods, in particular, *indicator kriging* and conditional *turning bands* simulation, allowed to determine anomalous zones for specific

thresholds of deposit parameters values, i.e. Cu content and thickness, within blocks R-1 and R-3.

Uniform conditioning (UC) estimates the conditional distribution of the analyzed metal (e.g. copper – Cu) and tonnage above cut-off within a mining panel. The proposed uniform conditioning is non-linear, very useful, technique, because its results particularly could find use in mine planning.

The combination of application of various geostatistical techniques – ordinary kriging, indicator kriging, conditional *turning ban*ds simulation and uniform conditioning will allow more effective management of mineral resources – copper ore deposits.

Keywords: copper deposit parameters, Cu grade, geostatistics, variogram, ordinary kriging, indicator kriging, conditional turning bands simulation, uniform conditioning

SZACOWANIE PARAMETRÓW ZŁOŻA RUD CU NA OBSZARZE KOPALNI RUDNA, Z ZASTOSOWANIEM METOD GEOSTATYSTYCZNYCH (WRAZ Z RÓWNOMIERNYM KONDYCJONOWANIEM) (NA PRZYKŁADZIE BLOKÓW GÓRNICZYCH R-1, R-3)

Streszczenie

Przedmiotem badań geostatystycznych jest zmienność podstawowych parametrów geologicznych złoża rud Cu, o różnorodnym wykształceniu litologicznym serii złożowej, w obrębie dwóch bloków górniczych: R-1, w zachodniej (W) części i R-3, wschodniej (E) części kopalni Rudna, w rejonie Lubin – Sieroszowice, w SW części Polski. Materiał wyjściowy do analiz przestrzennych reprezentują dane pochodzące z opróbowania wyrobisk górniczych w obrębie bloków R-1, R-3, o liczebnościach wynoszących, odpowiednio, n =708 i n = 998. Są to wyniki analiz chemicznych, dotyczących zawartości Cu w serii złożowej (bilansowej), wykonanych dla prób bruzdowych i rdzeni otworów wiertniczych, pobieranych systematycznie w chodnikach, w odległości co 15–20 m. Pełny profil złoża reprezentowany jest przez piaskowce Białego Spągowca, cechsztyńskie łupki miedzionośne (łupki: dolomityczno-ilaste, ilaste), cechujące się bardzo intensywną mineralizacją i skały węglanowe – wapienno-dolomityczne (dolomity: ilasty, smugowany, wapnisty) o zmiennej miąższości. Na niektórych podobszarach bloku R-1, łupki miedzionośne nie zostały wykształcone, stanowiąc, tzw. *obszar bezłupkowy*, gdzie mineralizacja skał serii złożowej jest znacznie uboższa, jednakże miąższości złoża były duże, osiągając kilkanaście metrów.

Przedstawiono rezultaty oszacowania zmienności parametrów złoża rud Cu, z użyciem takich metod, jak funkcja wariogramu i kriging zwyczajny, wariogram wskaźnikowy i *kriging wskaźnikowy* oraz wariogram Gaussa i symulacja *turning bands*.warunkowa. W efekcie zastosowania krigingu zwyczajnego, wskaźnikowego i symulacji warunkowej *turning bands* wydzielono strefy anomalne, pod względem intensywności okruszcowania Cu i zróżnicowania miąższości złoża, o wysokich i niskich wartościach parametrów złożowych, w obrębie bloków R-1, R-3.

Uzyskane rezultaty analiz geostatystycznych świadczą o przemieszczaniu się roztworów mineralizujących, zachodzącym raz w obręb piaskowców, ale jednocześnie obejmującym spąg utworów wapienno-dolomitycznych, zaś innym razem, w obręb skał węglanowych, z równoczesnym objęciem stropowych warstw piaskowców. Proces formownia się obecnej formy złoża i zróżnicowania mineralizacji miedziowej miał charakter wielofazowy, zaś istotną rolę mogły odgrywać procesy przemieszczania kruszców, zarówno lateralne, jak i w pionie.

Zaproponowano technikę równomiernego kondycjonowania (Uniform Conditioning UC) do wykorzystania jej w prognozowaniu zasobności złoża, przy określonej zawartości Cu. Jest to nieliniowa metoda estymacji, pozwalająca na modelowanie warunkowego rozkładu zawartości metalu w bloku stanowiącym najmniejszą jednostkę górniczą (SMU) w obrębie płyty. Tymczasem technika zlokalizowanego równomiernego kondycjonowania (LUC) umożliwia umiejscowienie jednostek (SMU) w prawdopodobnych lokalizacjach, w obrębie płyty złożowej.

Słowa kluczowe: parametry złoża miedzi, klasa Cu, geostatystyka, wariogram, kriging zwykły, kriging wskaźnikowy, symulacja warunkowych pasm toczenia, kondycjonowanie równomierne

Part I.

The part I of the present paper presents the estimation of copper ore deposit parameters in the area of "Rudna" mine, the blocks R-1, R-3, using different geostatistical methods. Successive stages of applying of variograms analysis (variogram, indicator variogram, Gaussian variogram), ordinary kriging, *indicator kriging*, conditional *turning bands* simulation are discussed in the Part I of the present study.

1. Introduction

Geostatistics offers a wide range of different methodologies adapted to all raw materials and styles of deposits, including Zechstein sedimentary Cu ore deposits occurring in the region of Lubin-Sieroszowice (SW part of Poland) and porphyry copper deposit Rio Blanco (Peru) and is the most efficient framework to characterize, estimate and manage mineral resources. Needs relying in mapping, resource estimation, volume estimation and risk analysis appear for solving.

Geologists or mining engineers can apply geostatistics at all stages of the mine life cycle, i.e. from exploration, through developmentand production to the site remediation. Applying geostatisticsenables obtaining large quality of evaluations at different stages of the development of projects. Geostatistical methods are also useful tools for optimizing reservoir characterization, providing the most efficient framework to build accurate and reliable statistical models of reservoirs (oil and natural gas) and a valuable methodology at all steps of the geomodelling process. Beside mining, oil and natural gas deposits characterization, contaminated sites, geostatistics applies to air quality monitoring, subsurface modeling, natural hazards, biological resources, precision agriculture, not to mention other fields, such as geochemistry, epidemiology, meteorology, forestry, archeology.

Geostatistics provides efficient solutions for spatial data analysis, sampling optimization, 2D/3D mapping and risk assessment.

Risk analysis for mineral resource estimates generally relies on the use of conditional (*turning bands*) simulation and *uniform conditioning*, which, by characterizing spatial variability and producing multiple equiprobable realizations of the orebody, allows to characterize *uncertainty* (*quantitative assessment of uncertainties*).

The basis for the application of geostatistical techniques were: *isotropic variogram* (ordinary kriging), *indicator variogram* (bundled *indicator* kriging), while for the conditional *turning bands* simulation such basis was constituted by the *Gaussian variogram*.

It was important to learn about the general characteristics of the variation of deposit parameters within the post-exploitation mining (R-1, R-3) blocks carrying out the estimation using of ordinary kriging in first stage of spatial analyses.

Application of the presented research approaches permits for finding out, which among the used techniques will be more suitable and effective for more detailed mapping of the variation in the values of the parameters: Cu grade, thickness, accumulation (quantity), as well as, for the determining:

- the highest probability P values of exceeding the assumed cut-offs values (thresholds) (probability to be above and below cut-offs values),
- the determination of subareas with an anomalous mineralization with copper compounds, also characterized by varying thickness, quantity within the mining sections using different research approach.

The basic theoretical assumptions of geostatistics, i.e., of the used research methods have been presented in many positions, books, monographs, articles, papers and reports, both foreign and domestic[1].

The results of applying various geostatistical methods for estimating and simulating of ledge parameters values of stratified Cu ore deposits in the Fore-Sudetic Monocline, in the Lubin – Sieroszowice region, have been presented in many works in an elaborated way, including[2].

1 M. Armstrong, *Basic Linear Geostatistics,* USA. 1998; EH. Isaaks, RM. Srivastava, *An introduction to applied geostatistics*, USA, 1989, p. 561; *Struktura zmienności parametrów złoża. Monografia KGHM Polska Miedź SA,* A. Piestrzyński (ed.), Lubin 1996; J. Mucha, *Struktura zmienności zawartości [Zn] i [Pb] w śląsko-krakowskich złożach rud Zn-Pb*. Kraków 2002, p. 149; B. Namysłowska-Wilczyńska, *Zmienność złóż rud miedzi na monoklinie przedsudeckiej w świetle badań geostatystycznych,*, Serie Monografie 21, Wrocław 1993, p. 207; B. Namysłowska-Wilczyńska, *Geostatystyka: Teoria i Zastosowania..* Wrocław 2006, p. 356; H. Wackernagel, *Multivariate Geostatistics: An Introduction with Applications*, Berlin 1998, p. 256.

2 *Model zmienności złoża rud miedzi Lubin- Polkowice i problemy jego genezy,* J. Kotlarczyk, M. Nieć, B. Namysłowska-Wilczyńska, Kraków 1981; J. Mucha, M. Wasilewska, *Trójwymiarowe modelowanie wartości parametrów złożowych metoda krigingu zwyczajnego 3D,* [in:] Geologia, Kraków 2009; B. Namysłowska-Wilczyńska, *Zmienność…, op.cit.*; B. Namysłowska-Wilczyńska, *Geostatystyka…, op.cit.*; B. Namysłowska-Wilczyńska, *Geostatistical methods used to estimate Sieroszowice copper ore deposit parameters.* "Zeitschrift fur Geologische Wissenschaften" , Berlin 2012, t. 40, z. 6, p. 329–361; B. Namysłowska-Wilczyńska, *Application of turning bands technique to simulate values of copper ore deposit parameters in Rudna mine (Lubin-Sieroszowice region in SW part of Poland)*. "Georisk: Assessment and Management of Risk for Management and Engineered Systems and Geohazards" 2015, Volume 9, Issue 4, p. 224–241; B. Namysłowska-Wilczyńska, *Filtration of Components of Sieroszowice Mine Copper Ore Deposit Variogram Models by Means of Estimation Ordinary Kriging Technique*. "Geoinformatics & Geostatistics: An Overview", 2018, 6:1; p. 1–19; B. Namysłowska-Wilczyńska, *Application of geostatistical techniques for the determining of an anomalous zones of copper ore deposit in the area of Polkowice mine*. "Geoinformatics & Geostatistics: An Overview", 2019, 7:1, p. 22; B. Namysłowska-Wilczyńska, A. Wilczyński, *Prognozowanie powierzchniowe i powierzchniowo-czasowe jako podstawa w podejmowaniu decyzji rozwojowych i operacyjnych organizacji. "*Zeszyty Naukowe Uczelni Jana Wyżykowskiego", Polkowice 2019, p. 117–144; B. Namysłowska-Wilczynska, *Estimation of copper ore deposit parameters – case study of Rudna Mine mining block R-1 (SW part of Poland) using geostatistics.* 2021, https://doi.org/10.5194/egusphere-egu21–12397 [access: 20.12.2021].

The Author has also used geostatistics to solve other problems, connected with mining, environmental protection, geodesy, agriculture, geochemistry, hydrogeology, as well as for estimation of soil-water environment pollution, soils and groundwater[3].

2. Research methods

Spatial analyses of variation of Cu ore deposits parameters, using different geostatistical methods, were carried out in successive stages, relying on estimation, indicator estimation and conditional *turning bands* simulation:

- Estimation,
  - Isotropic variogram modeling,
  - Ordinary (block) kriging,
- Indicator estimation:
  - Indicator variogram modeling,
  - Bundled (block) indicator kriging,
- Conditional *turning bands* simulation, including:
  - Raw – Gaussian Anamorphosis,
  - Gaussian variogram modeling,
  - *Turning bands simulation*,
  - Post-processing simulation,
  - Statistical simulation maps,
  - Iso – cutoff maps of probability distribution.

3 B. Namysłowska-Wilczyńska, *Geostatystyka…, op.cit.*; B. Namysłowska-Wilczyńska, *Studium modelowania i szacowania porfirowego złoża miedzi Rio Blanco w Peru*". *3D modelling and estimating of Rio Blanco porphyritic copper deposit in Peru*. Wrocław 2014; B. Namysłowska-Wilczyńska, A. Wilczyński, *Geostatistical Characteristics of the Structure of Spatial Variation of Electrical Power in the National 110 KV Network Including Results of Variogram Model Components Filtering*, "Acta Energetica" 2015, p. 72–87; B. Namysłowska-Wilczyńska, *Geostatistical studies of space-temporal variation in selected quality parameters in Klodzko water supply system (SW part of Poland).* "Journal of Geological Resource and Engineering" 2015, vol. 3, No. 2, USA, p. 57–81; B. Namysłowska-Wilczyńska, *Space-Temporal Variation in Underground Water Some Quality Parameters in Klodzko Water Intake Area Using Statistical and Geostatistical Methods (SW Part of Poland).* "Journal of Geological Resource and Engineering" 2016, Vol. 4, No. 3, USA, p. 105–124; B. Namysłowska-Wilczyńska, A. Wilczyński, *Prognozowanie Zmienność…, op.cit.*; B. Namysłowska-Wilczyńska, J. Wynalek, *Spatial-Temporal Analysis and Short-Term Forecasting of Hydrotechnical Facility Displacements*. "International Journal of VIBGYOR Earth Science and Geophysics" 2020; A. Piotrowska, J. Dlugosz, B. Namysłowska-Wilczyńska, R. Zamorski, *Field-scale variability of topsoil dehydrogenase and celluse activities as affected by variability of some physico-chemical properties.* "Biol Fertil Soils" 2011, No 47, p.101–109; H. Wackernagel, *Multivariate…, op.cit.*.

3. Scope of research work

The scope of the research work performed was as follows:

1. Situation of the analyzed mining blocks (R-1, R-3) of "Rudna" mine.
2. Lithological profiles of Cu ores deposit in two analyzed blocks of the "Rudna" mine.
3. Applied research methodology:
   - Spatial analyses were performed using linear geostatistics and non-linear geostatistics
4. Evaluation of basic statistics of ledge parameters of whole deposit series.
5. Analysis of (isotropic, directional, indicator) variograms and Gaussian variograms of the deposit parameters and variogram modelling their by means of theoretical functions.
6. Estimation using ordinary and *indicator kriging* (in block modification).
7. Conditional *turning bands* simulation of the deposit parameters.
8. The uncertainty of the estimations and simulations.
9. *Uniform conditioning* simulation.

The data obtained from the sampling (sample sizes: the block R-1, N-708, the block R-3, N-998 and some mining excavations in two blocks: R-1 (in the western (W) part and R-3 (in the eastern (E) of the "Rudna" mine were the input for the spatial analyses.

4. Object and subject of geostatistical studies

Geostatistical analyses were performed for selected post-exploitation blocks in the Lubin-Sieroszowice region (southwestern part of Poland), i.e. the R-1, R-3 blocks in area of "Rudna" mine.

Variation of Cu ore deposits were estimated for two ledge parameters:

- copper grade [%],
- thickness [m].

Two analyzed mining blocks are located in the area of "Rudna" mine, the R-1 – at the western region and the R-3 – at the eastern region.

Localization of the "Rudna" mine was presented in the map of Poland; Lower Silesia Region; N – north of the city of Polkowice (Fig. 1).

A situation map of an occurrence of copper (Cu) ore deposits in Poland was shown in the Fig. 2.

Fig. 1. The localization of. the "Rudna" mine; Lower Silesia Region; southwestern part of Poland

Source: http://mapa.livecity.pl/miasto/Rudna,0367373 [access: 9.9.2021].

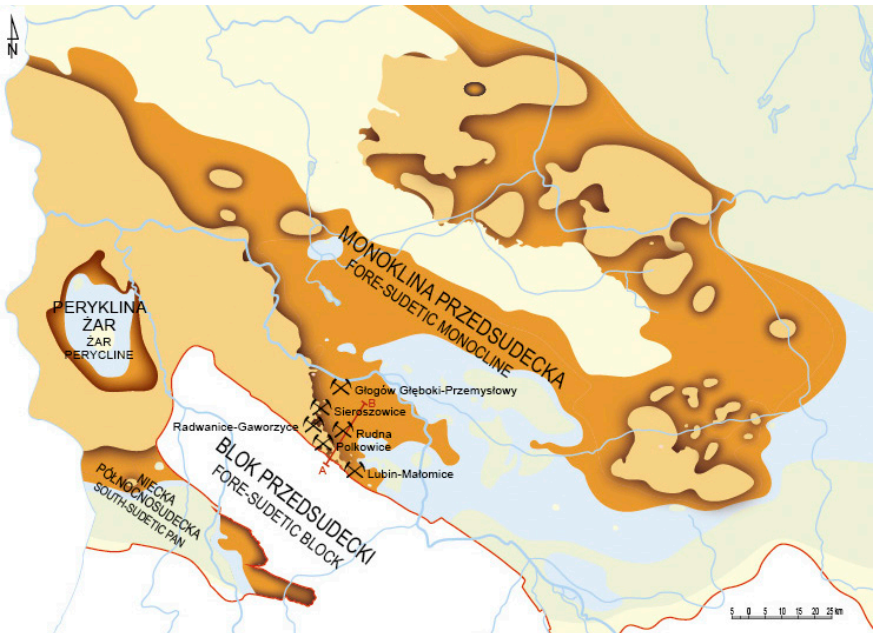


Fig. 2. Copper (Cu) ore deposits are occurred in the Foresudetic-Monocline (Poland) (acc. S. Oszczepalski et al., 2016)

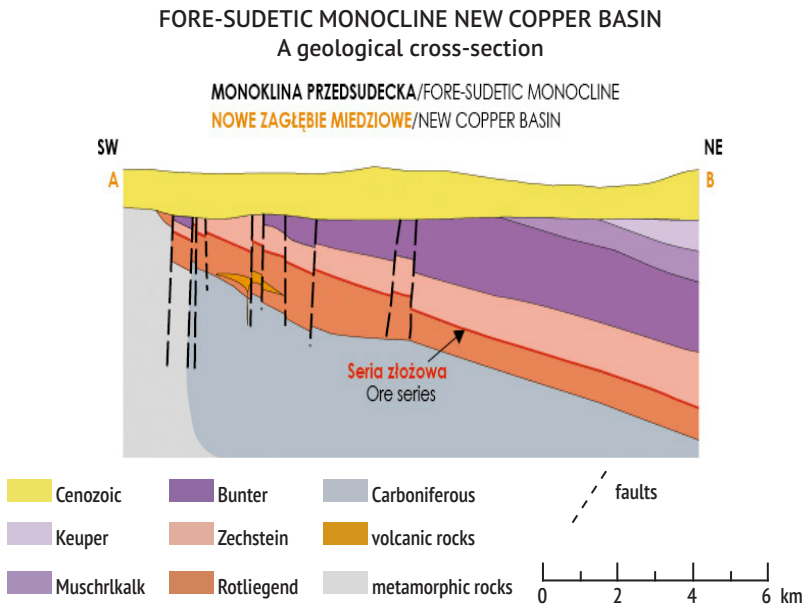


Fig. 3. A geological cross-section; Foresudetic Monocline; Copper ore series deposit is connected with the border of Whiteliegendes and Zechstein (acc. S. Oszczepalski, 1999). The deposit structure of copper-polymettalic ores is of the stratified type

4.1. Characteristics of "Rudna" mine

The industrial resources of the "Rudna" mine (as of December 31, 2017) in the 4 deposits it uses are 384 mln ton of copper ore. The average Cu grade is 1.95%. Among the Polish deposits exploited by KGHM, "Rudna" mine" is distinguished by the greatest thickness, even up to several m. The average thickness of the deposit is currently over 4 m. Ores with a thickness of more than 3 m account for as much as 70% of the deposit.

Sandstone ore has a dominant share, constituting nearly 80% of the resources, carbonate ore constitute approx. 15% and copper-bearing shales – 5% of the deposit's mass. Shales characterized by the highest Cu content constitute over 6%.

The depth of the copper-bearing rocks occurrence ranges from 844 m to 1250 m. Geological resources: 387.5 mln tonnes of ore deposits with an average thickness of approx. 2.2 m and a Cu grade of 2.4%, of which > 99.9% are balance resources.

5. Lithological profile types of copper ore deposit series within the blocks R-1, R-3 "Rudna" mine

Generalized lithological profile of copper-bearing deposit series in the Fig.4. was presented below:

Moving from the bottom (1–3) of the deposit, towards its top is as follows:

- Upper Permian carbonate rocks: loamy dolomite, striped dolomite and limy dolomite (3);
- Intensively mineralized Upper Permian dolomitic-loamy and loamy copper-bearing shales (2);
- *Whiteliegendes* sandstones (1).

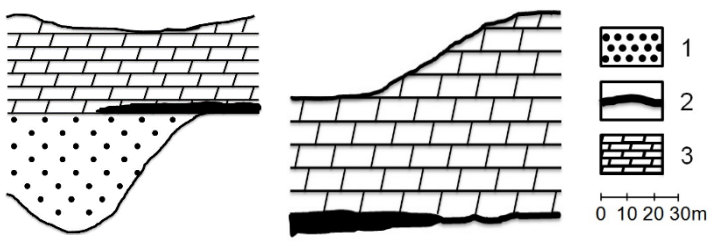


Fig. 4. 1 – Sandstones, 2 – copper-bearing shales, 3 – limestones and dolomites (acc. Barbara Namyslowska-Wilczyńska, *Zmienność złóż rud miedzi na monoklinie przedsudeckiej w świetle badań geostatystycznych,* Mongrafie 21, Wrocław 1993, p. 207)

The sandstone rocks representing the *Whiteliegendes* formations have the greatest share (1.90 m) in the balance series, as well as carbonate rocks which are also characterized by considerable thickness (1.20 m) in the area of block R-1 (Fig. 4; Tab. 1a). Copper shales is characterized by a rich, intense mineralization, with Cu content within the limits 10.76 – 12.85 (Tab.1a).

Table 1a. The weighted mean of Cu grade and thicknesses of individual lithological horizons and for whole deposit series when balance criteria are adopted (0.7% Cu); the "Rudna" mine, whole R-1 block

	Thickness [m]	Cu grade [%]
Carbonate rocks (clay, streaked, limy – calcareous dolomites)	1.20	1.50
Copper-bearing shales (clay, clay-dolomitic, dolomitic, tarry)	0.40	12.85
Whiteliegendes sandstones	1.90	1.75
Balanced deposit series (whole mineralized zone)	3.65	3.02

Table 1b. The weighted mean of Cu grade and thicknesses for individual lithological horizons and whole deposit series when balance criteria are adopted (0.7% Cu); the "Rudna" mine, block R-1; schistless (shalesless) area

	Thickness [m]	Cu grade [%]
Carbonate rocks (clay, streaked, limy – calcareous dolomites)	0.70	2.19
Whiteliegendes sandstones	3.20	1.94
Balanced deposit series (whole mineralized zone)	3.90	3.02

Table 1c. The weighted mean of Cu grade and thicknesses of individual lithological horizons and for whole deposit series when balance criteria are adopted (0.7% Cu); the "Rudna" mine, whole R-3 block

	Thickness [m]	Cu grade [%]
Carbonate rocks (clay, streaked, limy – calcareous dolomites)	1.30	1.93
Copper-bearing shales (clay, clay-dolomitic, dolomitic, tarry)	0.40	10.76
Whiteliegendes sandstones	1.90	2.16
Balanced deposit series (whole mineralized zone)	3.52	3.78

Carbonate rocks are characterized by very small thickness (0.70 m), while the sandstone rocks of *Whiteliegendes* are the dominant components (3.20 m) of the deposit in the shale-free area, within block R-1 (Fig. 4, Tab. 1b). The average thickness of the deposit – 3.90 m is a greater here (Tab. 1b), compared to the entire R-1 block, i.e., 3.65 m (Tab. 1a). Carbonate rocks are slightly stronger mineralized than sandstones ore (Tab. 1b).

Sandstone ore has greatest thickness (1.90 m) in the whole deposit series comparing to other types of ores (carbonate ore – 1.30 m, copper-bearing shales within the block R-3 (Tab. 1c). Shales are characterized by high mineralization – 10.76 % (Tab. 1c).

The block R-3, "Rudna" mine was the other analyzed area. The weighted mean of Cu grade and thicknesses of individual lithological horizons and for whole deposit series (0.7% Cu) for the block R-3 were presented in Table 1c. The main component of the deposit series are mineralized sandstones (1.90 m), but also mineralized carbonate rocks have a significant share (1.30 m) there. Copper-bearing shales are intensely mineralized (10.76%).

Cu grade Thickness

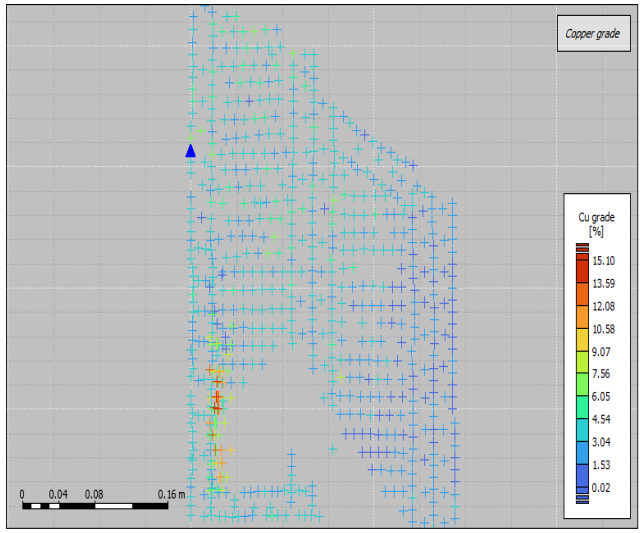


Fig. 5. Basemap with sampling points: Cu grade [%]; size N=708; distance between samples 15–20 m in the headings; The block R-1, "Rudna" mine

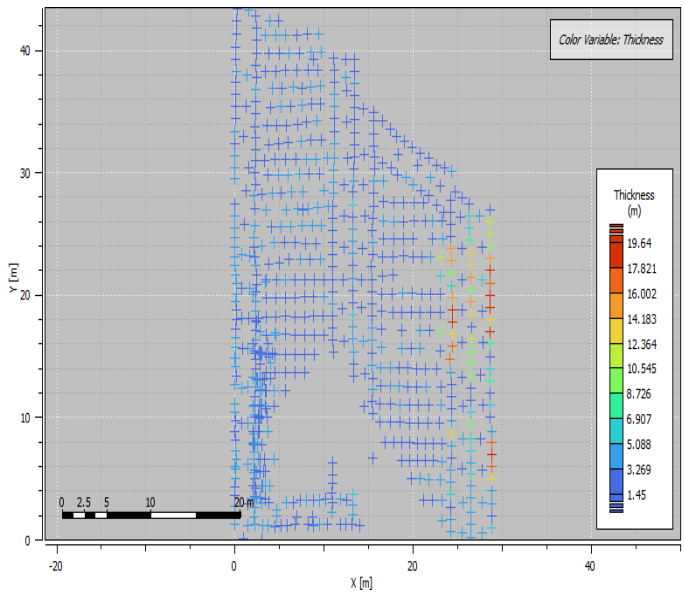


Fig. 6. Basemap with sampling points: thickness [m]; size N=708; distance between samples 15–20 m in the headings; The block R-1, "Rudna" mine

The block R-1, "Rudna" mine. Histograms of distributions of original values Z of ledge parameters

Cu grade Thickness

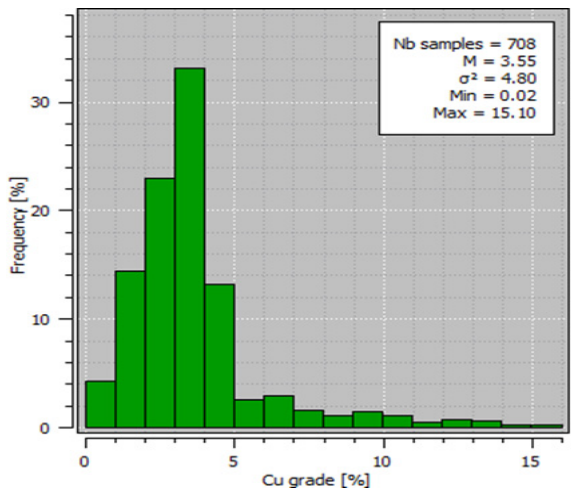


Fig. 7. Histogram of Cu grade [%] distribution in enclosed Cu ore deposit; the block R-1, "Rudna" mine; skewness g_1= 2.09, moderate asymmetry; g_2= 9.18, leptokurtic kurtosis

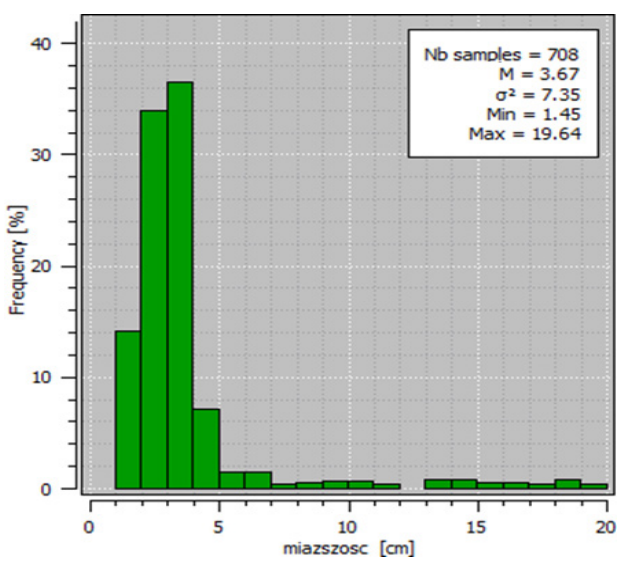


Fig. 8. Histogram of thickness [m] distribution in enclosed Cu ore deposit; the block R-1, "Rudna" mine; skewness g_1= 3.85, strong asymmetry; g_2= 18.62, leptokurtic kurtosis

5.1. The block R-1, "Rudna" mine

The basemaps with sampling points, i.e. original values Z of ledge parameters – copper grade and thickness for the block R-1 are presented in Figs. 5–6. Increased values Z of Cu grade in the western part of the block R-1 (Fig. 5), while of thickness in E part of this block can be noticed (Fig. 6).

Histograms of distributions calculated for original ledge parameters values Z for the R-1 block prove a moderate asymmetry for Cu grade and a strong asymmetry for thickness (Figs. 7–8). A leptokurtic character of histograms, particular for thickness is visible (Fig. 8).

Table 2. Basic statistical parameters of original values of deposit parameters of whole (balance) deposit series; the "Rudna" mine, the R-1 block

Deposit Parameter	Size n	X_{min}	X_{max}	Mean $\overline{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	708	0.02	15.10	3.55	2.19	3.25	61.80
Thickness [m]	708	1.45	19.64	3.67	2.71	3.06	73.82

Weak correlation between the parameters Cu grade/thickness coefficient r = -0.19

Variation coefficients V of Cu grade and thickness reach high values ranging from 61.80–73.82 %, indicating in big variability of these parameters within whole R-1 block. It can be confirmed by a considerable statistical range R of original values Z of both parameters (Table 2.). Means of deposit parameters for the R-1 block amount to: Cu grade – 3.55 [%] and thickness – 3.67 [m].

Table 2a. Basic statistical parameters of original values Z of deposit parameters of whole (balance) deposit series; mining excavation – A51, the R-1 block, the "Rudna" mine

Deposit Parameter	Size n	Mean $\overline{X}$	Std. Dev. S	Variation coefficient V [%]
Cu grade [%]	31	3.40	0.82	24.12
Thickness [m]	31	3.08	0.85	27.60

Variation coefficients V of Cu grade and thickness reach much lower values ranging from 24.12–27.60%, indicating in much smaller variation of both parameters for mining excavation A-51 within R-1 block, comparing to the whole R-1 block (Table 2a). Means of ledge parameters for the excavation A-51, amount to: Cu grade – 3.40 [%] and thickness – 3.08 [m]

6. Research methodology

Spatial analyses of variability of copper ore deposit parameters for the R-1, and R-3 blocks of "Rudna" mine using methods representing linear geostatistics and non-linear geostatistics were performed.

Linear geostatistics:

Analysis of empirical (isotropic, directional), variograms of the deposit parameters and modeling by theoretical functions;
Estimating of the deposit parameters values using ordinary (block) kriging;
The efficiency of the kriging estimations.

Non-linear geostatistics:

Analysis of *indicator variograms* and *Gaussian variograms* of the deposit parameters and modeling by theoretical functions;
Estimating of the deposit parameters using *indicator* (block) kriging;
Conditional *turning bands* simulation of the deposit parameters;
The uncertainty of the estimations and simulations.

6.1. Linear geostatistics

6.1.1. Analysis of variograms of ledge parameters; the block R-1,"Rudna" mine

Isotropic variograms of both ledge parameters (Figs. 9, 15) were calculated and modelled by using of geostatistical models, for the block R-1, "Rudna" mine, in first stage of geostatistical studies connected with using of linear geostatistics.

Variogram of Cu grade shows a distinct increase of $\gamma(h)$ function values along analyzed distance [m]. Some periodicity of variation of this parameter can be traced (Fig. 9). Variogram of Cu grade was modeled by sum of two models, i.e. exponential one and linear one, with ranges of influences *a,* amounting to 16.22 m and even 23.69 m. The nugget effect C_0 is rather small.

Variability of Cu grade has a character of large-scale changes, which are observed along the north-south direction. Strongest variation of Cu grade are connected with direction west-east (Figs. 12a, b, 13, 14a, b).

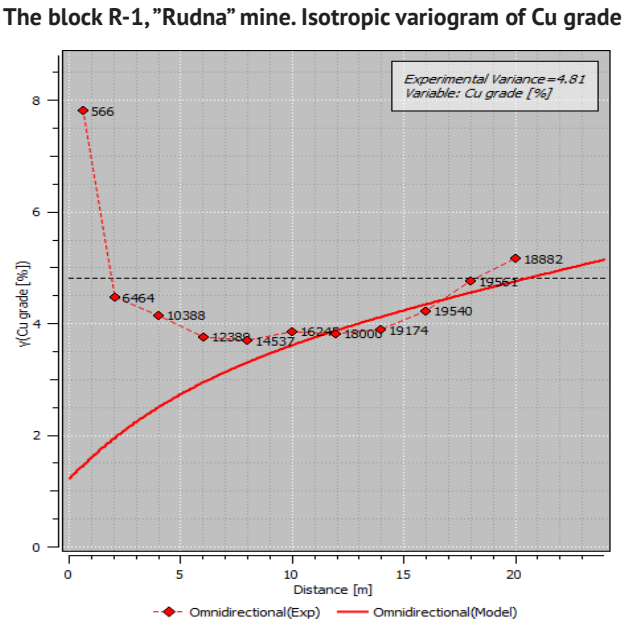


Fig. 9. Isotropic variogram of Cu grade [%]2, approximated by theoretical functions in enclosed Cu ore deposit; with parameters of the assumed model; block R-1: **exponential model**: nugget effect C_o = 1.19 [%]^2, sill variance C' = 1.78 [%]^2; range of influence *a* = 16.22 m; **linear model**: sill variance C' = 2.15, range of influence *a* = 23.69 m, total sill variance C = 3.93 [%]^2

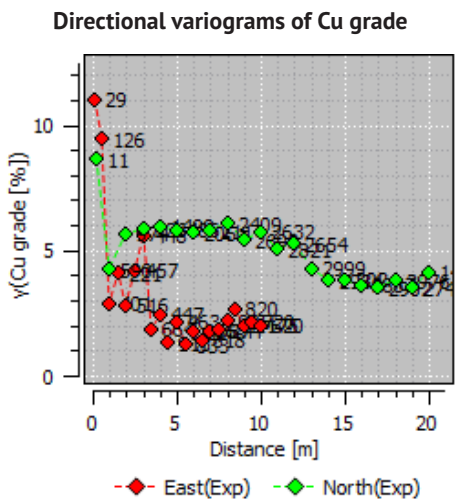


Fig.10. Two directional variograms of Cu grade [%]^2; main geographical directional: N-S, W-E in enclosed Cu ore deposit; the block R-1, "Rudna" mine

Vmap – Variogram map, Cu grade

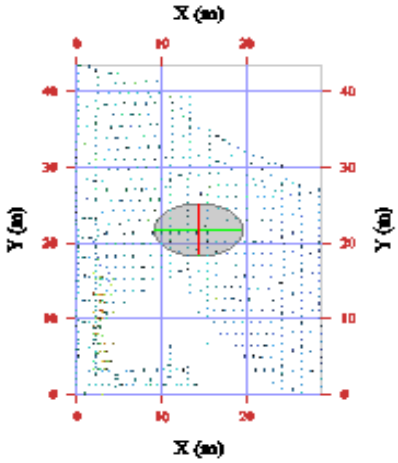


Fig. 11a. VMap of Cu grade [%] in copper ore deposit; R-1 block, "Rudna" mine

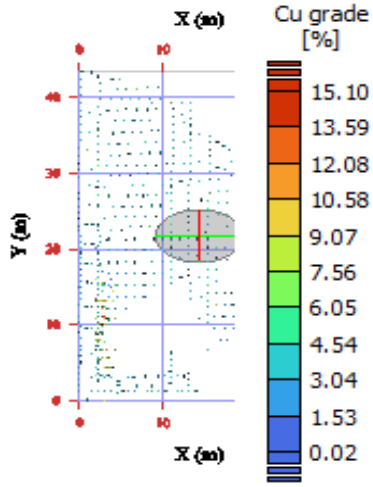


Fig. 11a. VMap of Cu grade [%] in copper ore deposit; R-1 block, "Rudna" mine

Cu grade Thickness

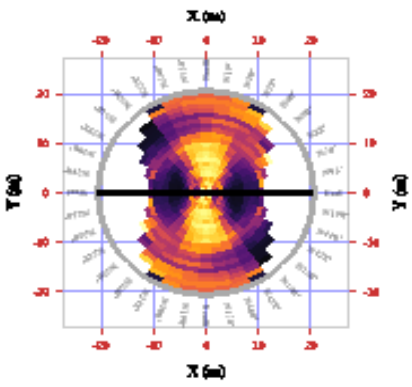


Fig. 12a. V Map of Cu grade [%] in copper ore deposit; R-1 block, "Rudna" mine

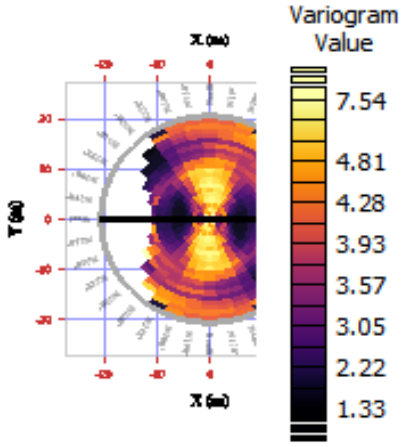


Fig. 12b. VMap of Cu grade [%] in copper ore deposit; R-1 block, "Rudna" mine

The variogram of thickness shows the regular variation of γ(h) variogram values along analyzed distance [m] (Fig. 13). Variation of this parameter can be expressed by two models, i.e. cubic one and spherical one, with short range of influence *a*, suitably amounting to 2.55 m and a little longer 9.57 m, in comparison with a variogram of Cu grade. Nugget effect C_0 doesn't occur at all (Fig. 13).

The thickness variability show large-scale changes along the N-S direction (Figs. 14, 15a,b, 16a,b). Strongest variation of deposit thickness are connected with direction W-E (Figs. 14, 15a,b, 16a,b).

The block R-1, "Rudna" mine. Isotropic variogram of thickness

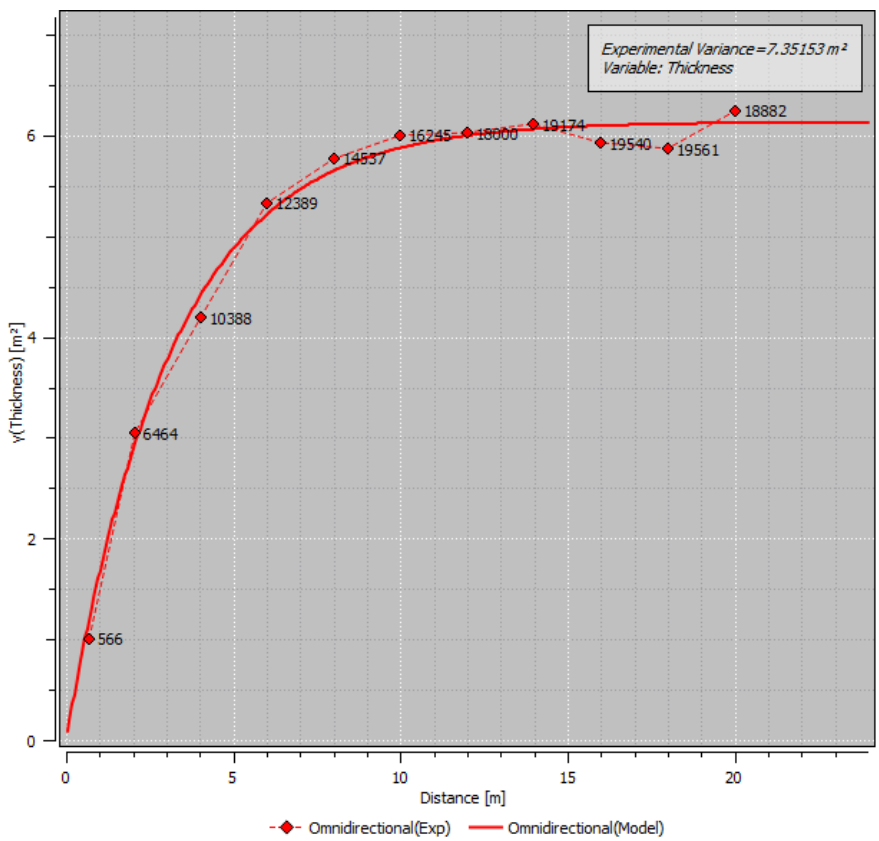


Fig. 13. Isotropic variogram of thickness $[m]^2$, approximated by theoretical functions in enclosed Cu ore deposit; with parameters of the assumed models: **cubic model:** range of influence *a* = 2.55 m, sill variance C = 1.65 m^2; **spherical model**: range of influence *a* = 9.57 m, sill variance C = 4.37 m^2; total sill variance C = 6.02 m^2; the block R-1, "Rudna" mine

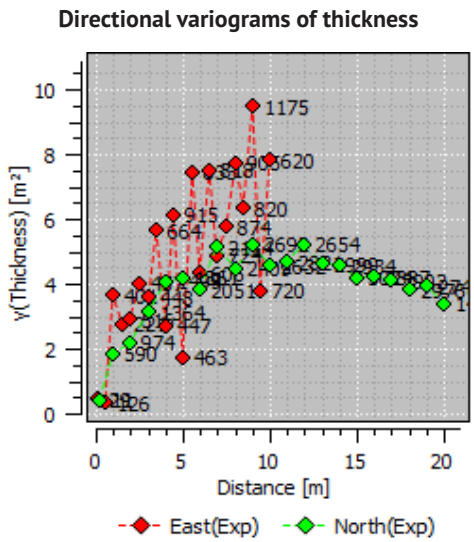


Fig. 14. Two directional mine variograms of thickness $[m]^2$; main geographical directional: N-S, W-E in enclosed Cu ore deposit; the block R-1, "Rudna" mine

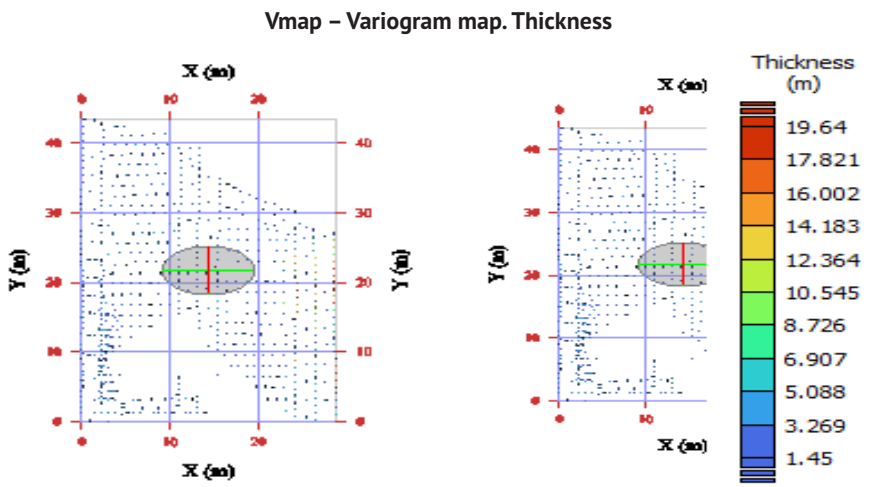


Fig. 15a. VMap of thickness [m] in copper ore deposit; R-1 block, "Rudna" mine

Fig. 15b. VMap of thickness [m] in copper ore deposit; R-1 block, "Rudna" mine

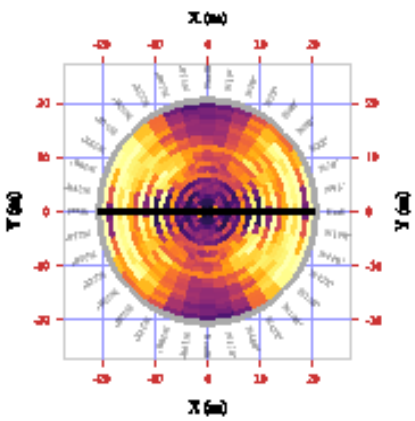


Fig. 16a. Vmap of deposit thickness [m] in copper ore deposit; R-1 block, "Rudna" mine

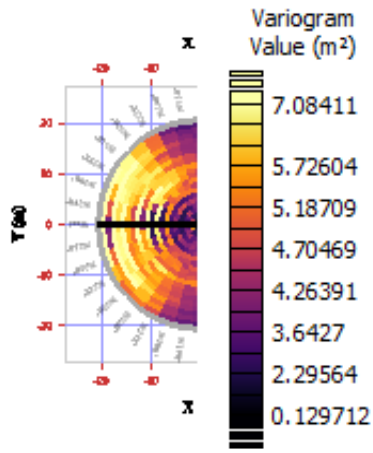


Fig. 16b. Vmap of deposit thickness [m] in copper ore deposit; R-1 block, "Rudna" mine

6.1.2. The results of using of ordinary (block) kriging; the R-1 block,"Rudna" mine

The ordinary (block) kriging technique in order to the estimation of estimated averages Z* (with minimum variance of estimation σ^2) of ledge parameters in a successive stage of geostatistical studies was used. An anomalous zones of increased averages values Z* of copper grade [%] and thickness [m] which were determined for elementary grid within block R-1. It can be traced anomalous zones in raster maps of distributions of averages Z* of ledge parameters.

The subareas of biggest concentrations of Cu grade occurs in western and southwestern parts of area of the block R-1 (Figs.17 a, b, c), while the subareas of the biggest thicknesses are noticed in eastern and southeastern parts of the block R-1 (Figs. 18 a, b, c). The subareas of the lowest values of Cu grade are observed in E and SE part of the R-1 block (Figs.17a, b, c), and in case of thickness in whole area of the R-1, excluding E, SE parts of the R-1 (Figs. 18 a, b, c).

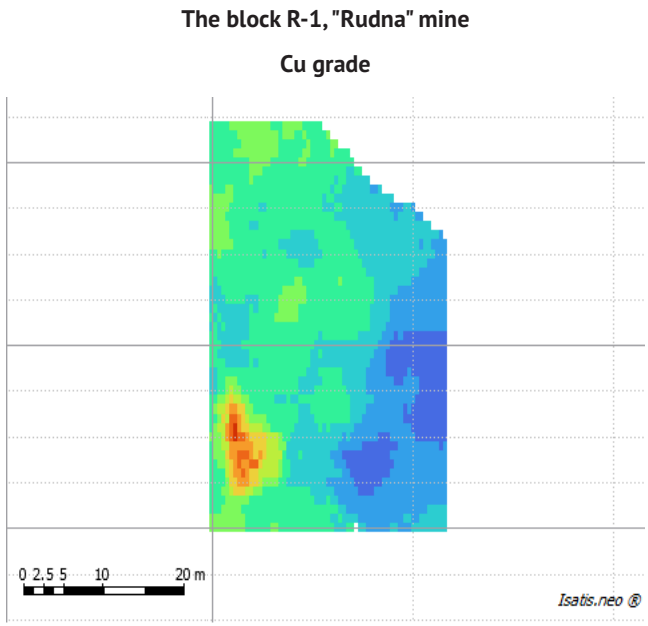


Fig. 17a. Raster map of distribution of estimated averages Z* of Cu grade [%]; the block R-1, "Rudna" mine; the results of ordinary (block) kriging

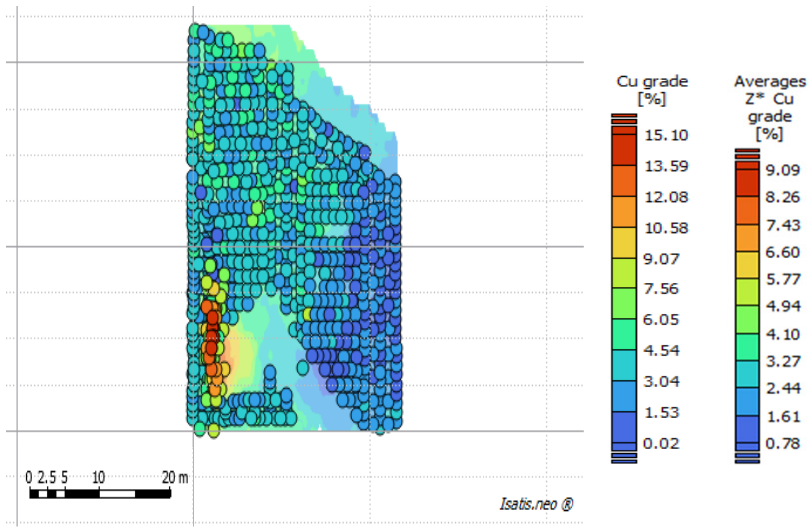


Fig. 17b. Raster map of distribution of estimated averages Z* of Cu grade [%] with sampling points (basemap); the block R-1, "Rudna" mine; the results of ordinary (block) kriging

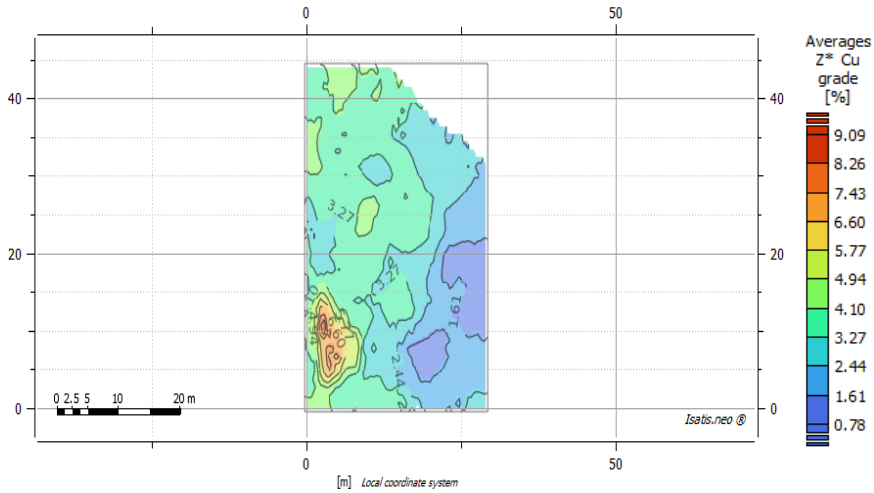


Fig. 17c. Isoline map of distribution of estimated averages Z* of Cu grade [%]; the block R-1, "Rudna" mine; the results of ordinary (block) kriging

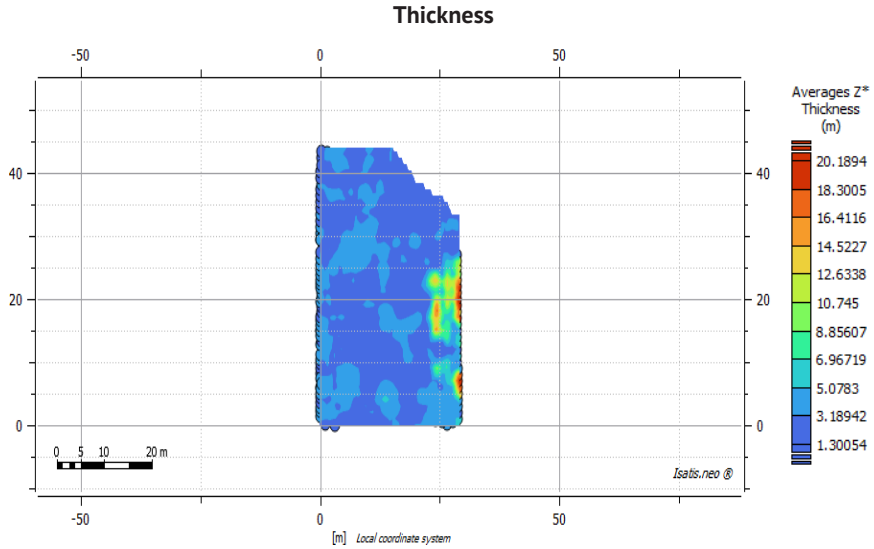


Fig. 18a. Raster map of distribution of estimated averages Z* of thickness [m]; the block R-1, "Rudna" mine; the results of ordinary (block) kriging

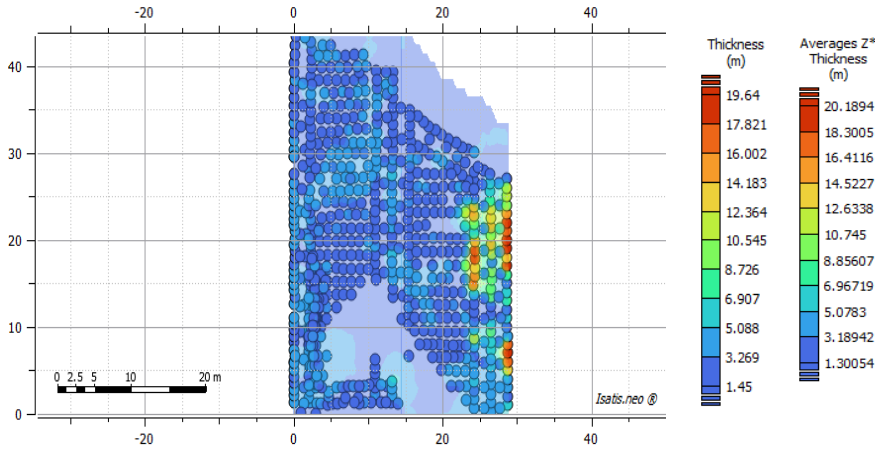


Fig. 18b. Raster map of distribution of estimated averages Z* of thickness th [m] with sampling points (basemap); the block R-1, "Rudna" mine; the results of ordinary (block) kriging

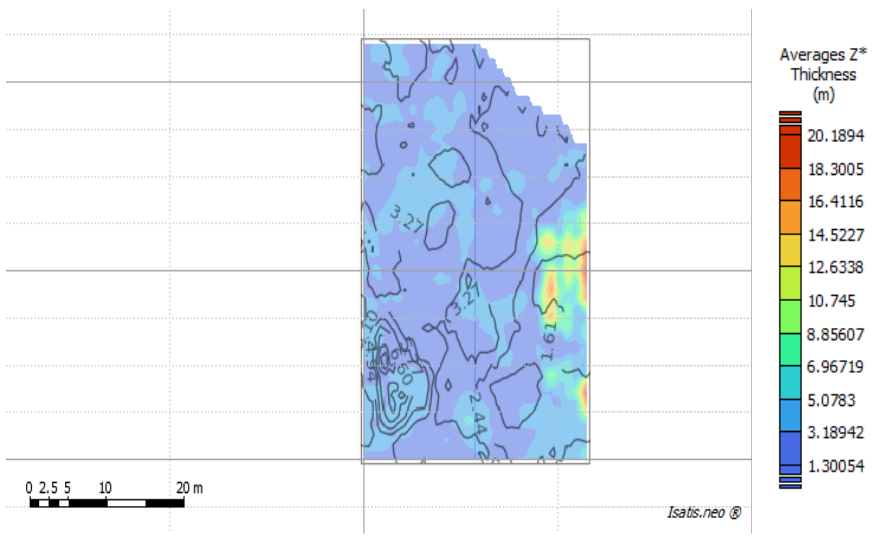


Fig. 18c. Isoline map of distribution of estimated averages Z* of thickness th [m] with sampling points (basemap); the block R-1"Rudna" mine; the results of ordinary (block) kriging

The coefficient of variation V (34 %) of estimated averages Z* of Cu grade indicates in moderate variability of the Cu content, while the coefficient V (59.85 %) of estimated averages Z* of thickness proves a large variability of this parameter (Table 3). Size of estimated nodes of elementary grid has ranged from 2432–2473 nodes (Table 3).

Table 3. Basic statistical parameters of estimated averages Z* of ledge parameters of whole (balance) deposit series; the R-1 block, the "Rudna" mine

Deposit Parameter	Count N	X_{min}	X_{max}	Mean $\overline{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	2432	0.78	9.09	3.22	1.11	3.33	34.00
Thickness [m]	2473	1.30	20.18	3.50	2.09	3.02	59.85

The block R-1, "Rudna" mine. Histograms of distributions of estimated averages Z* of ledge parameters

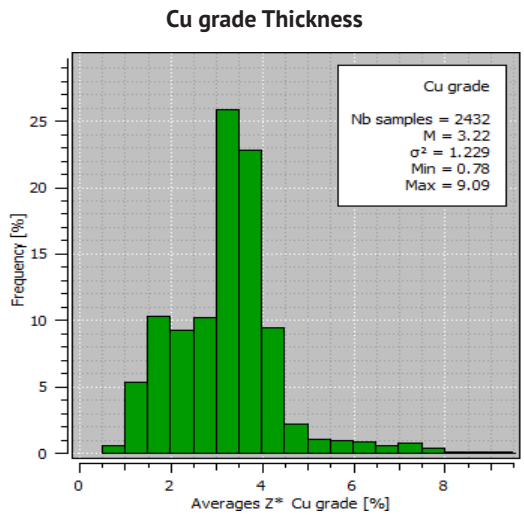


Fig. 19. Histogram of averages Z* of Cu grade [%] distribution in enclosed Cu ore deposit; the block R-1, "Rudna" mine; skewness g_1 = 0.76, moderate asymmetry; g_2 = 5.48, a leptokurtic kurtosis; variation coefficient V = 34.46%

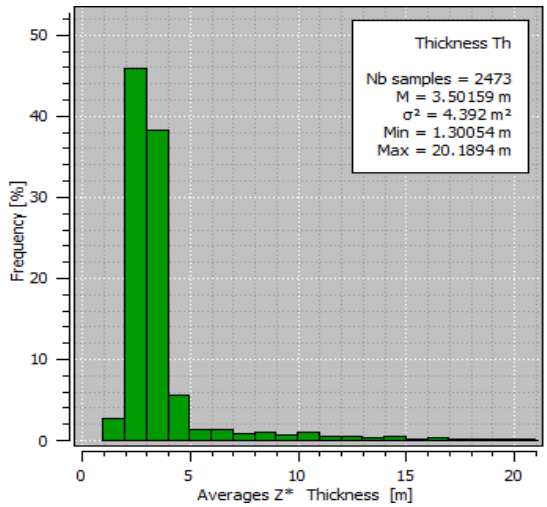


Fig. 20. Histogram of averages Z* of thickness [m] distribution in enclosed Cu ore deposit; the block R-1, "Rudna" mine; skewness g_1 = 4.12, extremely strong asymmetry; g_2 = 22.87, a leptokurtic kurtosis; variation coefficient V = 59.85%

The parameters show asymmetry (Figs. 19–20). One can observe a weak, left–sided asymmetry for Cu grade and an extremely strong, right-sided asymmetry for thickness, in comparison to histograms calculated for original values Z of ledge parameters for the R-1 block, i.e. a moderate asymmetry – Cu grade and strong asymmetry – thickness (Figs. 7–8).

6.2. Non-linear geostatistics

6.2.1. Results of indicator (block) kriging using; the R-1 block, "Rudna" mine

Subsequently, the indicator semi-variograms for the assumed cutoff values of the deposit parameters were calculated. Probabilities P values in the block centers of the elementary grid, covering analyzed block R-1, were estimated using bundled *indicator kriging* – a non-linear technique, taking into account the models parameters of the indicator semi-variograms. As a result of the performed indicator estimations, the images of the P values distributions of the exceeding of different cutoffs were obtained.

Raster maps of distributions of probability P values for the cutoffs: Cu grade > 3.5 % and thickness > 2.5 m in the Figs. 21–22 were shown. Subareas of most intense mineralization, exceeding the Cu grade cutoff > 3.5 %

occur mainly in western and central parts of R-1 block (Fig. 21). Subareas exceeding the thickness cutoff > 2.5 m are observed in many places of area R-1, mostly in W, SW, central and E parts of R-1 block (Fig.22).

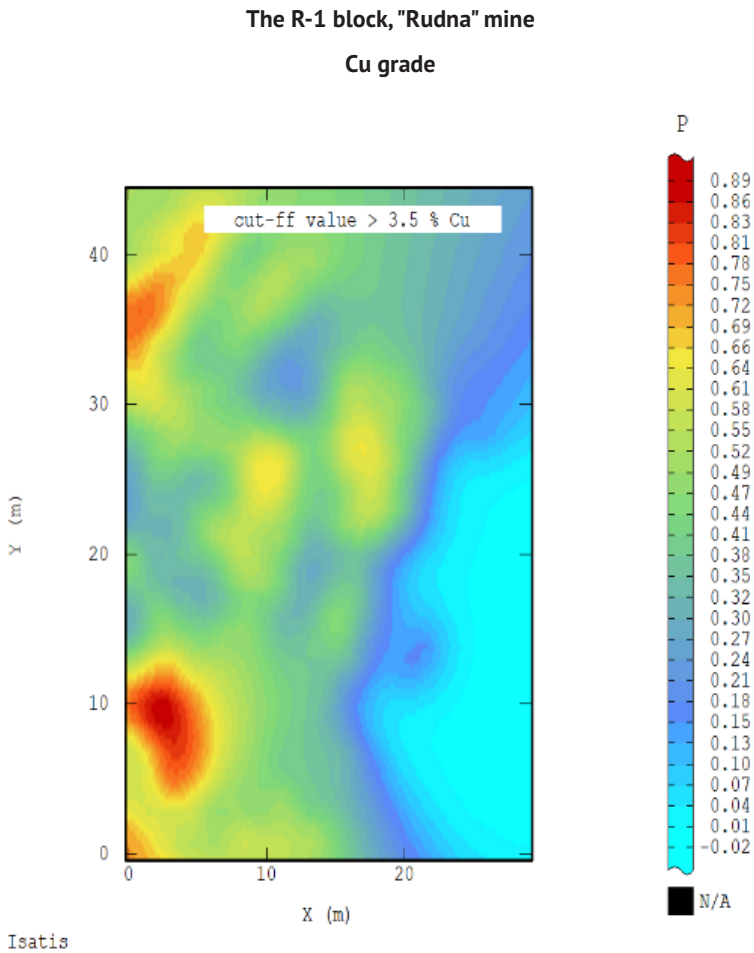


Fig. 21. Raster map of probability P distribution for the cut-off value > 3.5% Cu; copper grade [%]; the R-1 block, "Rudna" mine

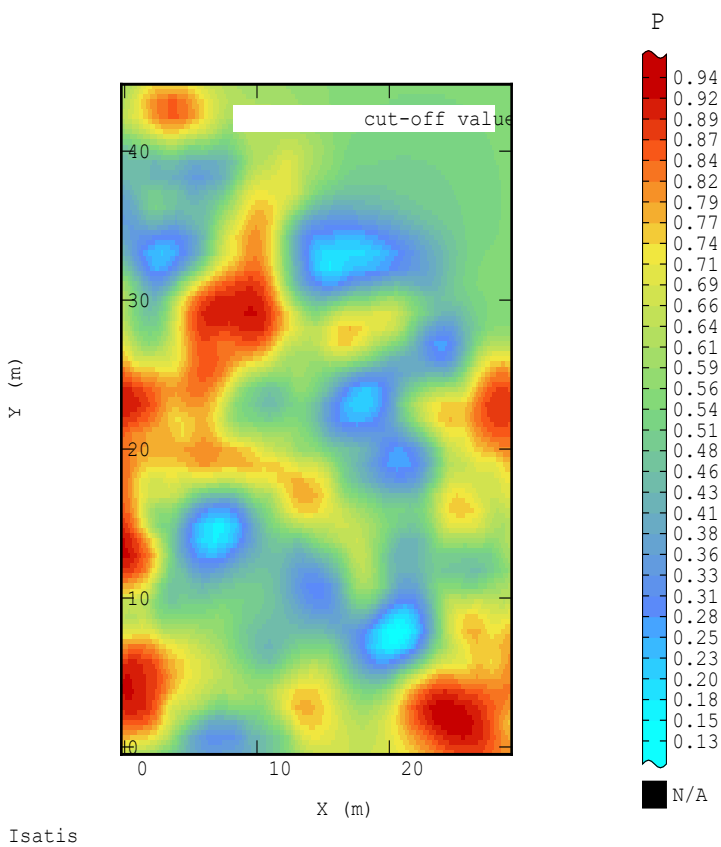


Fig. 22. Raster map of probability P distribution for the cut-off value > 2.5 m; thickness [m]; the R-1 block; "Rudna" mine

Table 4. Basic statistical parameters of kriged indicator values Ind of ledge parameters, the R-1 block, the "Rudna" mine

Deposit parameters Kriged Indicator	Count N	X_{min}	X_{max}	Mean of Ind values $\overline{X}$	Std. Dev. S	Variation coefficient V [%]
Kriged indicator Cu grade [3.5%]	2655	-0.02	0.89	0.35	0.21	58.99
Kriged indicator Thickness [2.5 m]	2655	0.13	0.94	0.58	0.17	29.27

Much bigger variation characterizes probability values P kriged for the cutoff of Cu grade > 3.5% Cu (V – 58.99 %) and much smaller (moderate variability) for the cutoff thickness > 2.5 m (V – 29.27) (Table 4). Indicator estimation was carried out for particular nodes of elementary grid covering R-1 block of "Rudna" mine, i.e. 2655 nodes (Table 4).

6.2.2. The results of conditional turning bands simulation of Cu grade, the block R-1, the "Rudna" mine

The performed conditional *turning bands* simulation was based on the Gaussian variogram model of Cu grade. 100 realizations (simulations) were calculated for particular nodes of elementary grid covering R-1 block of "Rudna" mine, i.e. 2293 nodes (Table 5).

The highest of simulated values Z_s of Cu grade were observed in the south, southwest, north, northwestand, in a smaller extent, in central part of the R-1 block, while the lowest values of this parameter were noticed in the eastern and southeastern of R-1 block (Fig. 23).

The highest of simulated values Z_s of thickness are observed in the eastern, southeastern, northern and northwestern parts and, in a smaller extent, in the central part of the R-1 block . The lowest values of this parameter may be observed in the southeastern and northeastern parts of the R-1 block (Fig. 24).

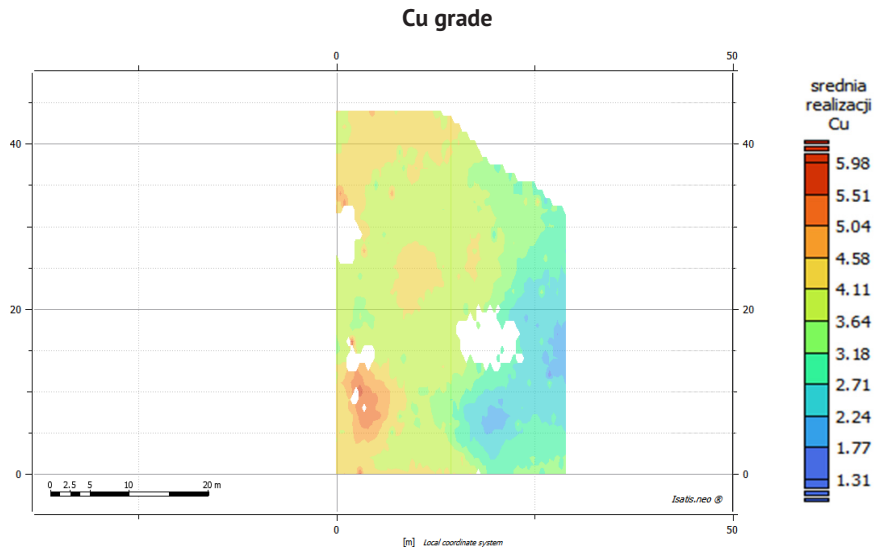


Fig. 23. Raster map of distribution of simulated values Z_S (the mean of realizations Z_S), Cu grade [%]; the R-1 block, "Rudna" mine

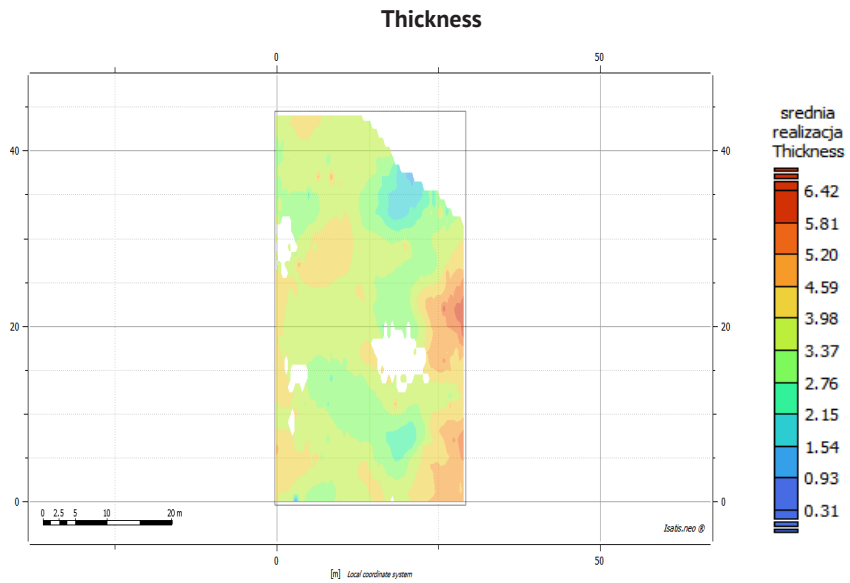


Fig. 24. Raster map of distribution of simulated values Z_s (the mean of realizations Z_s), thickness th [m]; the R-1 block, "Rudna" mine

Table 5. Basic statistical parameters of simulated values Z_s (realizations) of Cu grade, the "Rudna" mine, the R-1 block

Deposit Parameter	Count N	X_{min}	X_{max}	Mean of realizations $\bar{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	2293	1.31	5.98	3.66	0.67	3.86	18.31
Std. deviation σ_s of realizations Z_s [%]	2293	0.00	1.39	0.87	0.12	0.886	14.02

Variation coefficients V of simulated values Z_s of Cu grade indicate in low variability realizations Z_s, (V: 18.31%), as well as, std. deviations σ_s of realizations σ_s (V: 14. 02%) (Table 5). Size of estimated nodes of elementary grid was 2293 nodes (Table 5).

Geostatistical model of copper deposit the R-1 block, "Rudna" mine

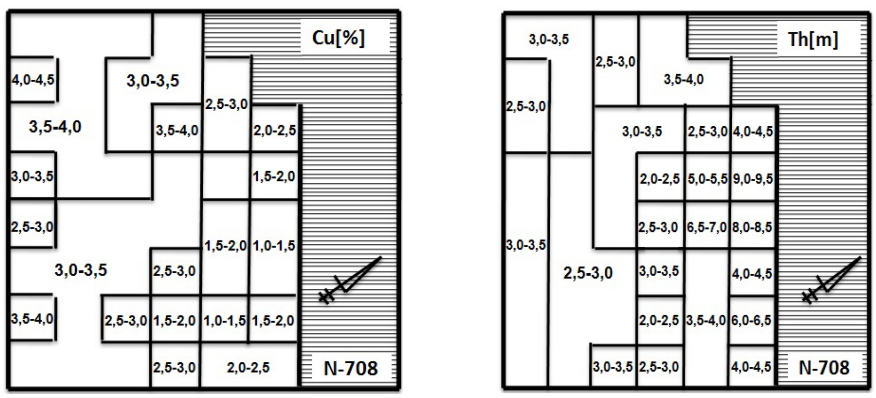
The richer ore is usually in the form of nests (sub-areas) with areas of 1–3 ha* *(1 ha = 10 000 m^2).* The highest estimated averages Z* are ranged from 4.0–4.5% Cu to 5.0 – 5.5% Cu (the W part of the R-1 block) (Fig.25a). In the E part of this block, there some parts of the deposit with poorer mineraliza-

tion occur (averages Z*: 1.0–1.5 %, 1.5–2.00 %) (Fig. 25a). It is the so-called *shale-free area – schistless area. (Out of N = 708 data, a total of 20 samples were found proving that the rocks contained only from 0.02–0.23% Cu).*

The average Cu contents for the entire deposit series were significantly lower from 1.0–2.5%, with the predominance of the values ranging from 2.0–2.5% in the shale-free area. The higher averages Z* for homogeneous blocks in the central part and in the W part of the R-1 section show the extent of copper-bearing shales (Fig. 25a).

The highest estimated averages Z are ranged from of 5–7%. These data relates to 24 samples.*

The results of ordinary kriging, applying spherical model of ledge parameters variograms; (elementary grid 100 m × 100 m)



Global statistics Cu grade [%] Thickness [m]
Number of blocks 45 45
Mean estimated kriged value Z^* 2.94 3.48
Kriging deviation σ_k 0.14 0.07

Fig. 25a, b. Deposit blocks of homogeneous copper grade mineralization (Fig. 25a) and blocks of similar thickness (Fig. 25b); the R-1 block, "Rudna" mine

Rapid variation in the deposit thickness is found (Fig. 25b). The presence of a large number of 1-ha blocks to each other with diametrically different layers thicknesses, ranging from the average Z*: 2.5–3.0 m to much higher, from 6.5–7.0 m and 9.0–9.5 m (Fig. 25b). The greatest deposit thickness, up to several meters, was found in the shales-free area of the R-1 section, and falls in different value ranges (Fig. 25b).

61 samples, out of N = 708: they are characterized by thickness containing from 5–7 m, 7.5–9.5 m and 10–15 m, 15–20 m.

They are connected with the presence of anhydrite binder sandstones in part E of the R-1 block. Anhydrite sandstones are within the block R-1 the main component of the deposit series.

7. Other region of "Rudna" mine, the block R-3

Variation coefficients V of the analyzed parameters prove moderate variability They are ranged from V: 28.07 – 37.50 % for whole R-3 block, "Rudna" mine (Table 6). Similar results can be related to two mining excavations occurring within the R-3 block, i.e., W213 (Table 6a) and B-31 (Table 6b). Coefficients V generally indicate small variability of thickness within the excavation W213 (Table 6a) and Cu grade in the excavation B-31 (Table 6b). Histograms of both parameters are characterized by right-sided asymmetry, but not as strong as it was observed in the case of the block R-1 (Figs. 26–27).

The histogram of distribution of the averages Z* of Cu content is characterized by a tendency to right-sided asymmetry (Fig. 26), while the histogram of distribution of average Z* of thickness shows a tendency to the asymmetry of the right- hand sided (Fig. 27).

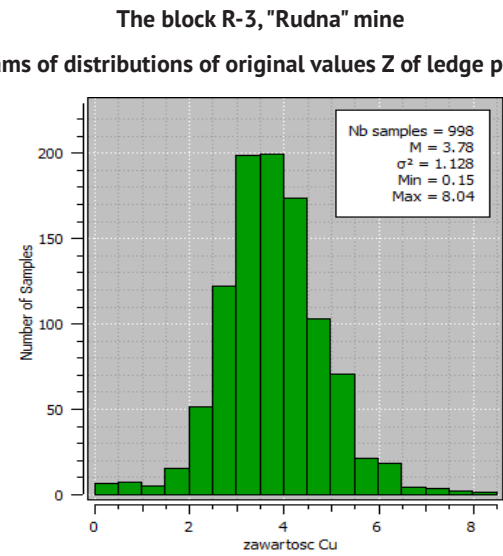


Fig. 26. Histogram of original values Z of Cu grade [%] distribution in enclosed Cu ore deposit; the block R-3, "Rudna" mine; skewness g_1 = 0.163, quasi-symmetry; g_2 = 4.22, a leptokurtic kurtosis; variation coefficient V = 28.07%

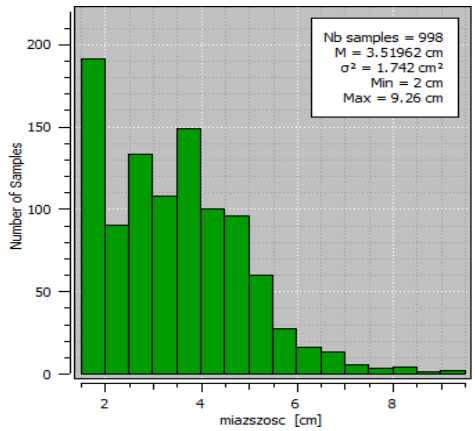


Fig. 27. Histogram of original values Z of thickness [m] distribution in enclosed Cu ore deposit; the block R-3, "Rudna" mine; skewness g_1 = 0.89, weak asymmetry; g_2 = 3.83, a leptokurtic kurtosis; variation coefficient V = 37.50%

Table 6. Basic statistical parameters of original values Z of ledge parameters; of whole (balance) deposit series; the "Rudna" mine, the R-3 block

Deposit Parameter	Size n	X_{min}	X_{max}	Mean $\overline{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	998	0.15	8.04	3.78	1.06	3.71	28.07
Thickness [m]	998	2.00	9.26	3.52	1.32	3.37	37.50

Correlation between two parameters values – copper grade and thickness (Cu/Th) for the whole R-3 block, is weak and coefficient r amounts to: r = -0.19. It is a similar result as this obtained for R-1 block.

Table 6a. Basic statistical parameters of original values Z of deposit parameters of whole (balance) deposit series; the "Rudna" mine, the R-3 block; mining excavation – W213

Deposit Parameter	Size n	Mean $\overline{X}$	Std. Dev. S	Variation coefficient V [%]
Cu grade [%]	38	3.50	1.12	32.00 %
Thickness [m]	38	3.96	0.87	21.97 %

Table 6b. Basic statistical parameters of original values Z of deposit parameters; of whole (balance) deposit series; the "Rudna" mine, the R-3 block, mining excavation – B-31

Deposit Parameter	Size n	Mean $\overline{X}$	Std. Dev. S	Variation coefficient V [%]
Cu grade [%]	48	3.66	0.56	15.30 %
Thickness [m]	48	3.76	0.88	23.40 %

Meanwhile variation coefficients V for Cu grade and thickness reach much lesser values ranging from 28.07 – 37.5 % indicating moderate variation of these parameters within R-3 block (Table 6).

The statistical range for both deposit parameters is much narrower for R-3 block (Table 6) comparing to block R-1 (Table 2). Means of deposit parameters amount to: Cu grade – 3.78 [%] and thickness – 3.52 [m].

It can be concluded that, in general, the variability of deposit parameters in individual mining galleries is lower than estimated for the entire mining block R-3 (Tables 6, 6a, b).

7.1. Linear geostatistics

7.1.1. The results of ordinary (block) kriging using, the block R-3, "Rudna" mine

The determination of blocks with increased copper mineralization (Fig. 28) and thickness (Fig. 29) is the result of using ordinary block kriging. The most enriched zones with increased Cu content are observed in the northern part, along the northwest-southeast line, and to a slightly lesser extent, also in the southwestern part of the block R-3 (Fig. 28). Sub-areas of increased thickness occur in the eastern and middle parts, and also in the northern and southwestern parts, within block R-3 (Fig. 29).

The results of ordinary (block) kriging show very low variability of estimated averages Z* of Cu grade and moderate variability of averages Z* of thickness (Table 7). The kriging results were estimated for 2833 – 2891 nodes of elementary grid covering the R-3 block.

Histograms of distributions of estimated averages Z* of both ledge parameters for the R-3 block have shape, showing a weak asymmetry for Cu grade (Fig. 30) and quasi-symmetry for thickness (Fig. 31) (Table 7).

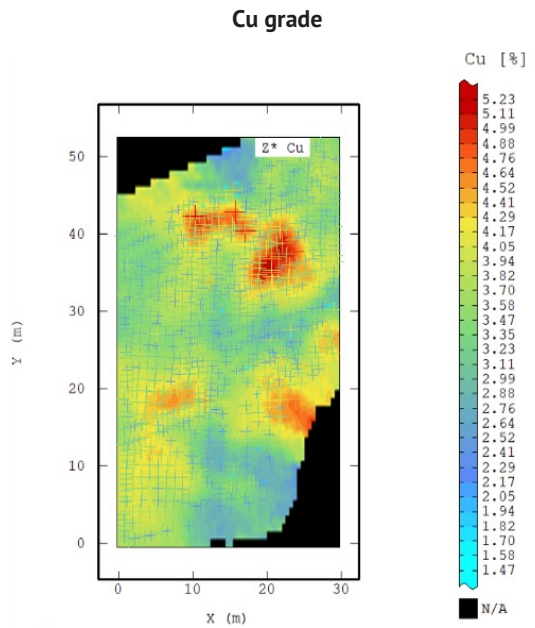


Fig. 28. Raster map of distribution of estimated averages Z* of Cu grade [%]; the R-3 block, "Rudna" mine

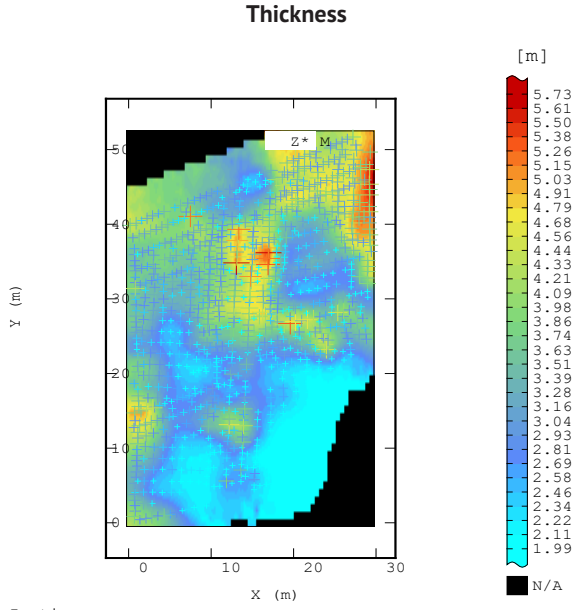


Fig. 29. Raster map of distribution of estimated averages Z*of the thickness [m]; the R-3 block, "Rudna" mine

Table 7. Basic statistical parameters of estimated averages Z deposit parameters of whole (balance) deposit series; the "Rudna" mine, the R-3 block

Deposit Parameter	Count N	X_{min}	X_{max}	Mean $\overline{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	2891	1.36	5.92	3.73	0.59	3.72	15.81
Thickness [m]	2833	1.91	5.73	3.35	0.87	3.36	26.00

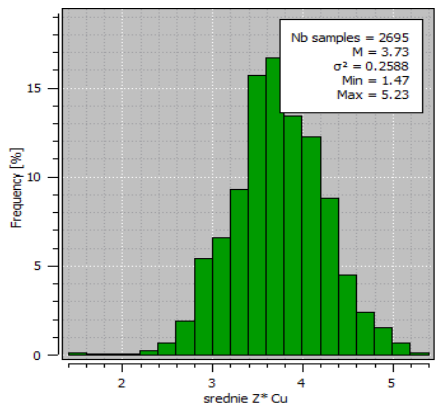


Fig. 30. Histogram of distribution of estimated averages Z* of Cu grade [%]; the R-3 block, "Rudna" mine; skewness $g_1 = 0.76$, week asymmetry; $g_2 = 5.48$, a leptokurtic kurtosis; variation coefficient V = 34.46 %

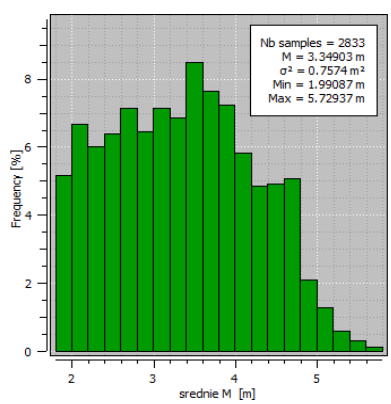


Fig. 31. Histogram of distribution of estimated averages Z* of thickness [m]; the R-3 block, "Rudna" mine; skewness $g_1 = 0.17$, quasi-symmetry; $g_2 = 2.10$, a platokurtic kurtosis; variation coefficient V = 25.99 %

7.2. Non-linear geostatistics

7.2.1. The results of indicator (block) kriging using, the block R-3

Two indicator maps of probability values P calculated for the cutoffs of Cu grade – 4.5 % Cu (Fig. 32) and 5.5 % Cu (Fig. 33) in the block R-3, "Rudna" mine, are presented below.

Simultaneously with the increase of the cut-off value to 5.5% Cu, the boundaries of an anomalous zones with increased Cu content became sharper and marked very clearly (Fig. 33).

Basic statistical parameters of kriged indicator I (Ind) for Cu grade have been inserted in Table 8. Small variation V – 14.39 % for the assumed cutoff – 2.50% Cu was obtained. Moderate variation of this parameter V – 35.41% is connected with the higher cutoff amounting to 3.5% Cu. Variation coefficients V reached higher values, together with increasing of cutoff values to 4.5 % and 5.5 % (Table 8). The V coefficients are contained within wide limits from 77.4 % – 190.20 %. Size of estimated nodes of elementary grid was 2891 nodes (Table 8).

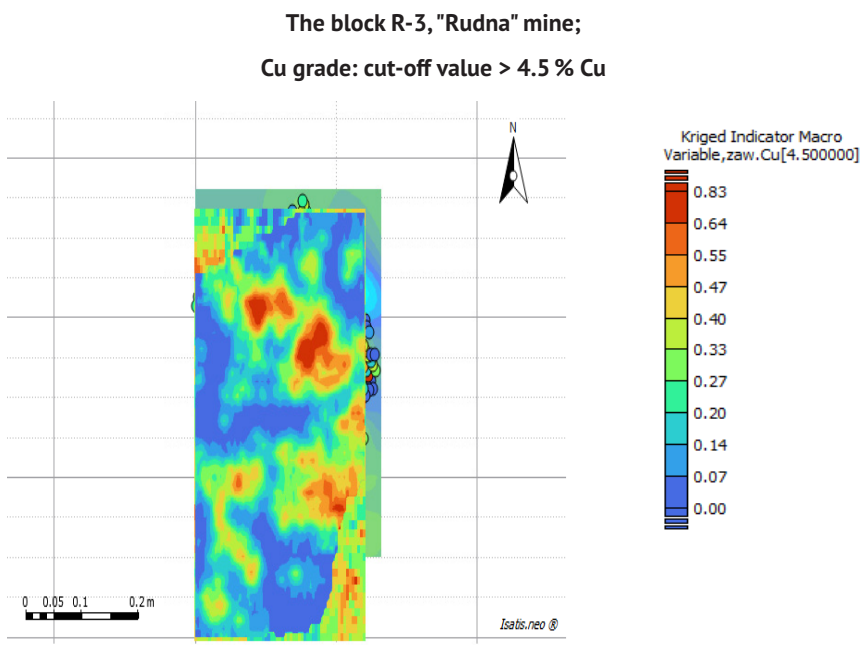


Fig. 32. Raster map of distribution of probability P of copper grade [%]: the cut-off value > 4.5 % Cu; the R-3 block, "Rudna" mine

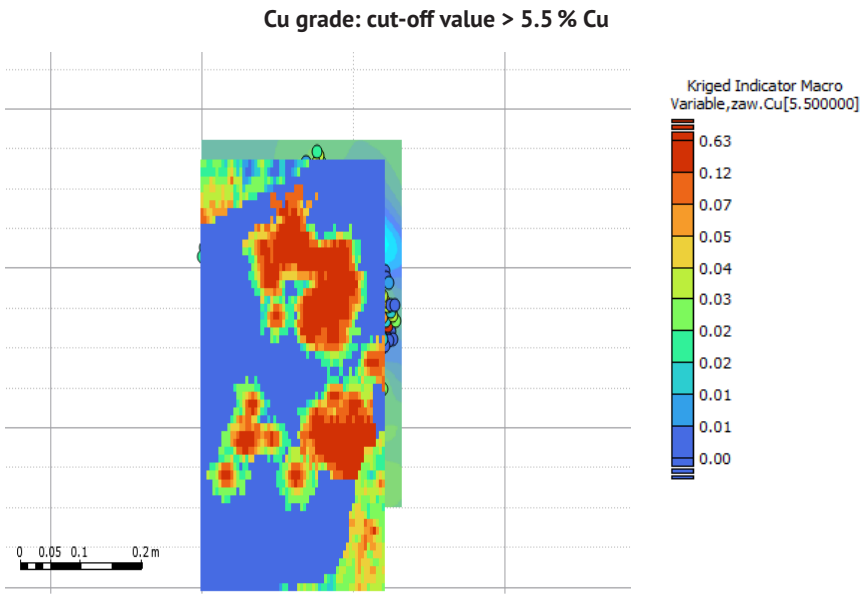


Fig. 33. Raster map of distribution of probability P of copper grade [%]: **the cut-off value > 5.5 % Cu**; the R-3 block; "Rudna" mine

Table 8. Basic statistics of kriged indicator (Ind) values of Cu grade: The R-3 block, the "Rudna" mine

Kriged indicator Ind Cu grade	Count N	X_{min}	X_{max}	Mean of Ind values $\overline{X}$	Std. Dev. S	Variation coefficient V [%]
Kriged Indicator Cu grade [2.50 %]	2891	0.33	1.00	0.90	0.13	14.39
Kriged Indicator Cu grade [3.50 %]	2891	0.00	1.00	0.58	0.21	35.41
Kriged Indicator Cu grade [4.50 %]	2891	0.00	0.83	0.22	0.17	77.64
Kriged Indicator Cu grade [5.50 %]	2891	0.00	0.63	0.05	0.09	190.20

7.2.2. The results of conditional turning bands simulation of Cu grade, the block R-3, "Rudna" mine

In further stage of spatial analyses, a conditional *turning bands* simulation was applied. Conditional *turning bands* simulation, taking into calculations of the theoretical models fitted to the Gaussian semivariograms of the deposit parameters, was performed (Table 9). Gaussian variograms have been computed for the assumed thresholds, i.e. 1.5 % Cu and 3.5 % Cu.

Exemplary statistical maps of the simulated values Z_s distributions in raster maps of probabilities values P of exceeding of the assumed thresholds, e.g.: Cu grade > 1.5 % Cu and > 3.5 % Cu, respectively in the Figs. 34–35. were shown. With the assuming of the 1.5% Cu threshold, P amounting 1 values were obtained for almost entire analyzed area of the R-3 block (Fig. 34). By increasing the threshold value to 3.5% Cu, an anomalous zones with probability P = 1 were distinguished, extending along the NW-SE line, E, SE, also in the W, SW parts of the R-3 (Fig.35).

Variation coefficients V show a small variability of realizations Z_s of Cu grade (V: 15.66 %) and moderate variability of std. deviation σ_s of realizations Z_s (V: 36 %) (Table 9).

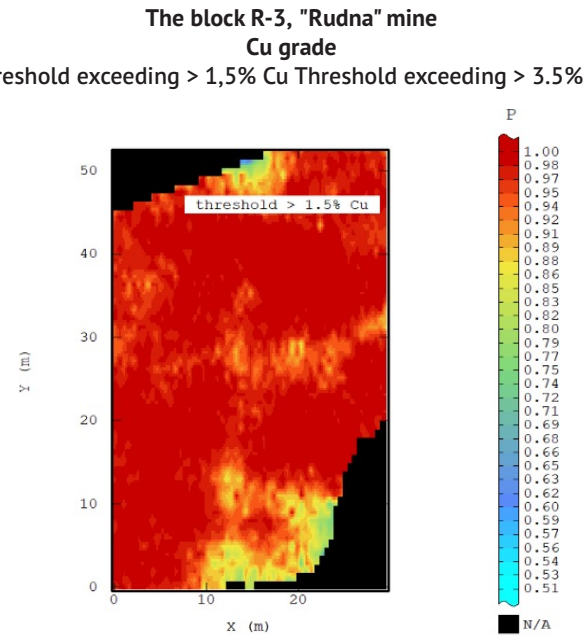


Fig. 34. Raster map of distribution of probability P values of threshold exceeding > 1.5 % Cu; Cu grade in the deposit, the R-3 block, "Rudna" mine

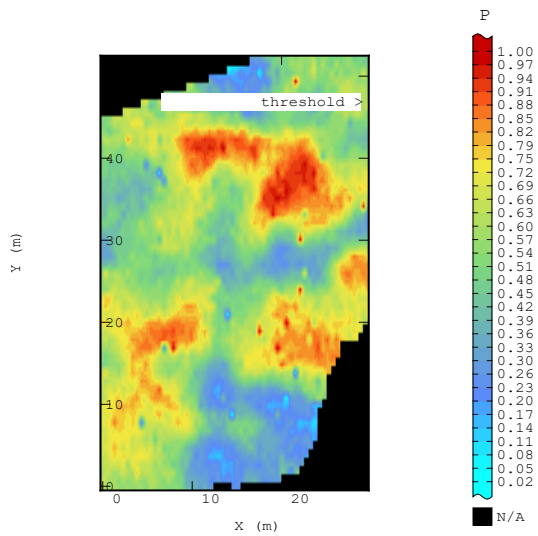


Fig. 35. Raster map of distribution of probability P values of threshold exceeding > 3.5 % Cu; Cu grade in the deposit, the R-3 block, "Rudna" mine.

Table 9. Basic statistical parameters of simulated values Z_s (realizations) of Cu grade; the R-3 block, the "Rudna" mine

Deposit Parameter	Count N	X_{min}	X_{max}	Mean $\overline{X}$	Std. Dev. S	Quantile 50% (Me)	Variation coefficient V [%]
Cu grade [%]	3294	1.48	5.91	3.71	0.58	3.71	15.66
Std. deviation σ_s of realizations [%]	3294	0.31	1.38	0.62	0.22	0.54	36.00

Geostatistical model of copper deposit, the blocks R-1, R-3 "Rudna" mine

Geostatistical model of variation in values of the parameters of Cu ore deposit in its horizontal and vertical extents in the blocks R-1, R-3, "Rudna" mine. The results of the spatial analyses clearly indicate the shifting of the mineralizing solutions, sometimes into the sandstones, while spreading throughout the floor of calcareous-dolomitic formations and sometimes into the carbonate rocks, partly entering the roof layers of sandstones.

In the light of the obtained results of analyzes of the use of various geostatistical methods, it can be concluded that the process of formation of the present form of the deposit and diversification of Cu mineralization had a multi-phase nature, and the processes of ore displacement, both lateral and vertically, could have played an important role in its development. Very strong anisotropy of the variation in overall thickness and Cu grade was established.

The obtained results of the variability of the Cu ore deposit parameters in the area of "Rudna" mine indicatethe processes of a multiphase displacement of metalliferous solutions in deposit formation.

Part II.

Estimation of Cu ore deposit parameters using *uniform conditioning (UC*) for the block R-1, "Rudna" mine was presented in the Part II. Successive stages of using of geostatistical analyses were also discussed in the Part II. of the present study.

Uniform conditioning (UC) is a non-linear estimation method that models the conditional distribution of smallest mining unit (SMU) block grades within panels[4].

Localized uniform conditioning (**LUC**) places these SMU at plausible locations within a deposit panel[5]. The localization process doesn't improve the accuracy of the UC result, but has a more practical meaning, particularly for its application in mine planning.

The theory of uniform conditioning includes the discrete Gaussian model for change of support and block kriging in order to estimate the panel

4 J. Deraisme, J. Rivoirard, C. P. Carrasco, 2008, *Multivariate uniform conditioning and block simulations with discrete Gaussian model: Application to the Chuquicamata deposit*, "Proceedings of the VIII International Geostatistics Congress (Geostats 2008)", Santiago 2008, 1–5. Gecamin, p. 69–78; K. Hansmann, *When should uniform conditioning be applied?* vol. 116, No. 7, Johannesburg, 2016; C. Neufeld, C. V. Deutsch, *Calculating Recoverable Reserves with Uniform Conditioning.* Alberta, 2005.

5 J. Deraisme, W. Assibey-Bonsu, *Localised uniform conditioning in the multivariate case – An application to a porphyry copper gold deposit. "*Proceedings of the 35th International Symposium on Application of Computers and Operations Research in the Minerals Industry (APCOM)", Melbourne 2011; M.G. Millad,. K.M. Zammit, *Implementation of localised uniform conditioning for recoverable resource estimation at the Kipoi Copper Project, DRC. "*Proceedings of the Ninth International Mining Geology Conference", Melnourne, 2014, p. 207–214; C. Neufeld, C. V. Deutsch, *Calculating…, op.cit*.

grades and the calculation of the quantity of metal and proportion of the panel above the cutoff grade.

Uniform conditioning (UC) estimates the conditional distribution of the analyzed metal (e.g. copper Cu) and tonnage above cut-off within a mining panel. It does not directly estimate Cu grade. Metal grade is a typical outcome from the estimated metal-tonnage distribution or there are the results produced by **localized uniform conditioning (LUC)**.

UC results as a recoverable resource above multiple cut-off grades are presented. The advantage of UC is that it can be used on widely spaced data, across domains that are not strictly stationary, provided that there is sufficient data for a conditionally unbiased estimate of the panel mean grade.

UC performs well in terms of estimating grades and tonnages under a condition of a normal underlying grade distribution and good sample coverage relative to the variogram ranges *a,* which result in low conditional biases. A linear estimator can also closely predict recoverable resources and provide a spatially representative grade model, although the UC estimate of tons and grades is slightly better.

When there is an underlying lognormal distribution and a poor sample coverage relative to variogram ranges *a*, conditional biases of a linear panel estimate occur inevitably. This results in UC providing a more accurate global estimate of grades and tonnage than a linear estimate.

8. Uniform Conditioning

8.1. Successive stages of geostatistical studies

Panel estimates

The quality of the panel estimate determines the success of the UC estimation. A panel estimate should be conditionally unbiased.

The UC conditional metal grade distribution will be an accurate estimate of the actual grade distribution. The panel estimate can be carried out using any linear estimator, but conventionally ordinary kriging is used.

The panel size should be chosen appropriately to the spacing of the sample data.

The panel should be as small as possible to ensure an accurate estimate, but large enough for minimal conditional bias of the estimation.

The number of smallest mining units (SMU) within the panel is related to the resolution of the grade-tonnage relationship, as the number of SMU discretizes the grade-tonnage curve of the panel. ***SMU – Smallest Mining.***

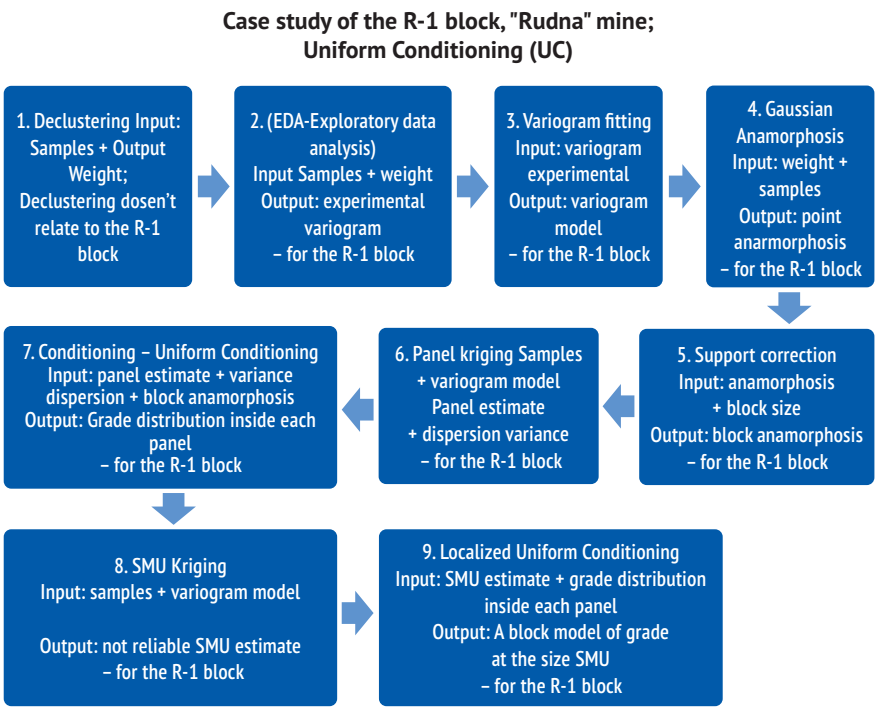


Fig 36. Uniform Conditioning (UC); Workflow; the R-1 block, "Rudna" mine.

Successive steps of Cu ore deposit estimation using uniform conditioning (UC) for the exemplary mining block R-1 in the Fig. 36 were shown and are presented below:

Step 1.

Declustering is not compulsory, depending on whether our data is clustered or not. Data concerning values of Cu deposit parameters (Cu grade, thickness) for mining block R-1 is not clustered.

Step 2.

Exploratory data analysis EDA

For the uniform conditioning (UC), the **raw variogram** is used for estimation, therefore it is necessary to calculate experimental variogram (for the analyzed parameter of mining block R-1).

Step 3.

Fitting this **experimental variogram** by means of theoretical functions – geostatistical models (for mining block R-1).

Step 4.

Gaussian anamorphosis modeling, providing **point anamorphosis** (for mining block R-1).

Earlier the analyzed variable (Cu grade) was transformed into a Gaussian variable.

- Raw Variable – Cu grade (for the block R-1);
- Gaussian Cu grade (for the block R-1),
- Point Anamorphosis Cu grade (for the block R-1),
- 5 assumed **cutoffs:**
- 0.7 by step of 0.5; number of cutoff(s).

Step 5.

Support Correction

Anamorphosis + block size;

Output – Block anamorphosis

- Raw – Gaussian Transformation;
- Point Anamorphosis (for the block R-1),
- Block Anamorphosis Cu (for the block R-1).

Step 6.

Panel kriging

Samples + variogram model

Panel estimate + dispersion variance

Then blocks should be kriged and **one output (result)** of **calculations** will be following: **dispersion variance** (**dispersion variance for the UC**) and it is needed todetermine the number (nb) of dispersion variances classes. Between 5 and 10. classes are recommended so.

Step 7.
Uniform Conditioning (UC)
Block Anamorphosis,
Main Kriged Value – Kriged Indicator Macro Variable **Cu** [e.g. 1.20].
Main Dispersion Variance
The analyzed variable (e.g. Cu grade) earlier was transformed into a Gaussian variable.
Input: **panel estimate + variance dispersion + block anamorphosis**:
Output: **grade distribution inside each panel.**

Step 8.
SMU Kriging
Kriging for Smallest Mining Unit
Input:
samples + variogram model
Output: not reliable SMU estimate.

Step 9.
Localized Uniform Conditioning
Input:
SMU estimate + grade distribution inside each panel.
Output: **A block model of grade at the size SMU**.
First steps **1, 2, 3, 4,** concerning Cu ore deposit parameters estimation for the R-1 block (Rudna mine) have performed yet.

Further steps **5, 6, 7, 8** for the R-1 block, "Rudna" mine will be realized in near perspective of research work. It will be necessary to define: **the size SMU** (Smallest Mining Unit).

9. Panel estimates

Panel grade estimates, using ordinary kriging, could be madefor normal distribution and lognormal distribution with the intent of minimizing conditional bias while retaining some local variability.

In the presented case, taking into account the ranges of influence *a* of isotropic variogram of Cu grade for the block R-1, it should be assumed in

further analyses, relative to the average sample spacing: the size of SMU, i.e. 20 m×20 m (or 25 m × 25 m).

The quality of the panel estimate determines the success of the UC estimation[6]. A panel estimate should be conditionally unbiased[7], so that the UC conditional grade distribution will be an accurate estimate of the actual grade distribution. The panel estimate can be carried out using any linear estimator, but conventionally ordinary kriging (OK) is used.

The panel should be as small as possible to ensure an accurate estimate, but large enough f to minimize the conditional bias of the estimation[8]. The number of smallest mining units (SMU) within the panel is related to the resolution of the grade-tonnage relationship, as the number of SMU discretizes the grade-tonnage curve of the panel.

10. Closing remarks

Uniform conditioning (UC) in final stage of spatial analyses of Cu ore deposits estimation was applied. Point anamorphosis determined during conditional *turning bands* simulation was changed into block anamorphosis, during the realizing of (*UC*).

The individual panel results predict the actual grade and tonnage distribution when there is no evidence for conditional bias for that panel.

Localized uniform conditioning (LUC) results are favorable when there is sufficient closely spaced data, in which case it is likely that a linear estimation could also accurately predict the model grade values. Therefore, the benefit of using a non-linear UC estimator over a linear estimator is more significant when the data is widely spaced.

6 J. RivoirardIn, *Introduction to Disjunctive Kriging and Nonlinear Geostatistics*. Paris 1994.

7 C. De-Vitry, J. Vann, H. Arvidson, A guide to selecting the optimal method of resource estimation for multivariate iron deposits. Proceedings of Iron Ore 2007, Perth 2007, pp. 67–77; J. Rivoirard, *Introduction*…, *op.cit.*

8 C. De-Vitry, J. Vann, H. Arvidson, A guide…, *op.cit.*; J. Rivoirard, Introduction…, *op.cit.*

11. Coclusions

The combination of the application of various geostatistical techniques – ordinary kriging, *indicator kriging*, conditional *turning ban*ds simulation and *uniform conditioning* will allow more effective management of mineral resources i.e. copper ore deposits occurring in the Foresudetic Monocline, in the region of "Rudna" mine, within mining blocks.

The presented results of conducted geostatistical analyses, with the application of various methods, especially *indicator kriging* and conditional *turning bands* simulation, enable the determination of the boundaries of the occurrence of deposit sub-areas with anomalous Cu content – rich or poor ore, their size and shapes, and in particular for the sub-areas with a different probability P of exceeding the assumed threshold values, for Cu grade and thickness. It is possible to track how the boundaries of anomalous zones change with increasing values of the cutoff (threshold) deposit parameters.

The aforementioned method would enable more accurate determination of the costs of mining, exploitation of copper ore deposit and application of different thresholds of exceeding the cutoff values of metal.

For the reasons presented, a proposal of using of uniform conditioning (UC) and localized uniform conditioning (LUC) can be considered, as interesting, valuable and worth of application in the case of Cu ore deposit estimation. Both UC and LUC are promising methods in the mine planning, aiming at predicting of deposit parameters (Cu grade, quantity) for the small deposit blocks within deposit panel.

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https://pl.wikipedia.org/wiki/Zak%C5%82ady_G%C3%B3rnicze_%E2%80%9ERudna%E2%80%9D

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The used geostatistics packet

Isatis 2017.1;

Isatis.Neo 2021.07

Geovariances, Avon- Fontainebleau, France

https://www.geovariances.com/en/

Biographical note

Professor Barbara Namysłowska Wilczyńska – has acquired the master's degree in the discipline of geology at the Faculty of Natural Sciences at the University of Wroclaw, Poland. She received the degree of Doctor of Technical Sciences (PhD), in a scientific discipline of engineering geology and mining on May 5th, 1980., defending a doctoral dissertation entitled *Quantitative analysis of spatial variability of parameters of geological sediments of the lower Zechstein (Permian) in the area of the mine Lubin*, in the Institute of Geotechnical Engineering, Wro-

claw University of Science and Technology, Poland. ., On October 10th, 1994 she completed habilitation at the Faculty of Geology Geophysics and Environmental Protection of the University of Science and Technology in Cracow, Poland, based on the dissertation entitled *The variability of copper ore deposits in Foresudetic Monocline in the light of geostatistical studies* On October 10th, 1994, the resolution of granting her the habilitation degree of Earth Sciences in the discipline of geology was made by the Faculty Council . Prof. B. Namysłowska-Wilczyńska was approved by the Presidium of the Central Control Commission in Warsaw on March 23rd, 1995. On December 30th, 2009 President Lech Kaczynski awarded PhD. B. Namyslowska-Wilczynska with the title of Professor of Technical Sciences. the handing the nomination took place at the Presidential Palace in Warsaw on March 3rd, 2010. On June 28, 2017, B. Namysłowska-Wilczyńska was nominated for the position of full professor at the Wrocław University of Technology.

Selected positions:

1996–1999 – Deputy Director for Education and Development of Research Personnel of Institute of Geotechnics and Hydrotechnics at WUST;

1999–2002 – Deputy Director for Education and Development of Research Personnel of Institute of Geotechnics and Hydrotechnics at WUST,

1998–2014 – Head of Engineering and Environmental Geology Department of Institute of Geotechnics and Hydrotechnics at WUST;

1999–2014 – Head of Engineering and Environmental Geology Laboratory of Institute of Geotechnics and Hydrotechnics at WUST;

2004–2008 – Deputy Head of Center for Modelling Hydrological Processes (CMHP) in Wrocław;

2009–2012 – Deputy Head of Center for Modelling Hydrological Processes (CMHP) in Wrocław;

2013–2016- Deputy Head of Center for Modelling Hydrological Processes (CMHP) in Wrocław.

Basic themes of scientific research in the field:

– ore deposits geology, engineering geology, applied geology, hydrogeology, environmental geology, environmental protection, reservoir geology, energy sector;
– geostatistics, (applied – spatial statistics).

Modelling, estimating, forecasting and simulating (2D, 3D) of the analyzed parameters concerning regionalized phenomenas

Prof. Barbara Namysłowska-Wilczyńska deals with research problems related to modelling, estimation, forecasting and simulating (2D, 3D) of mineral resources

parameters, copper ore deposits, in particular and also copper porphyry deposits. Her works are associated with a variety of applications of statistical and geostatistical methods, i.e. applied spatial statistics, including simulation techniques (turning bands simulation), in the issues relating to mineral deposits geology, mining, environmental engineering, environmental protection, in waste landfill research, climatology, enzymology, geodesy, as well as in the energy sector (power engineering). she is an author of numerous articles and research studies devoted to the area analyses (2D) spatial analyses, as well as spatio-temporal analyses (3D, uncertainty estimation of the estimated averages of deposits parameters, and variability risk analysis of the studied parameters used in the solving of certain issues. Her recent studies include the development of geostatistical (2D, 3D) hydrogeochemical models of variation of underground waters quality parameters for a water intake area, of a treated water and in water supply system, geostatistical description of structure of copper ore deposit parameters variation, filtering of components of copper ore deposit variograms models using ordinary kriging technique, spatial-temporal analyses (3D), i.e. modelling of horizontal and vertical displacements on the basis of data from the geodetic monitoring of a hydrotechnical object, with the sustainable management of water resources and energy.

Prof. B. Namysłowska-Wilczyńska presented the results of the works in various scientific and scientifictechnical national conferences and international conferences, congresses in Poland and abroad, for example in Czech Republic (1981, 1983, 1985, 1987, 1990, 1993, 2011, 2018), Israel (1984), Germany (1982, 1983, 1985, 1986, 1990, 2002, 2004, 2015), Sweden (2011), Great Britain (1990, 2014), France (1988, 2014, 2019), Spain (1997), the Netherlands (1993), Italy (2000), Canada (1986), Chile (2009, 2013), Belgium (1991, 2018, 2018), Austria (2015, 2016, 2021), Australia (2017), Taiwan (Taipei) (2019).

Prof. B. Namysłowska-Wilczyńska is the author or co-author of 173 works: 48 articles published in prestigious journals national (including PAN and PAU) and recognized abroad, 1 professor monograph, 1 habilitation monograph, 1 monograph (edited by B. Namysłowska-Wilczyńska) 1 monograph (co-authored), 58 papers at national and international conferences, 9 book chapters, 3 books, and the 28 papers included in the lists of journals of Ministry of Science and Higher Education and 48 studies carried out in the framework of consortia of academic institutions, as well as from the funds received for the implementation of research grants, EU as well as special orders from the industry.

The number of citations of her scientific papers according to the Web of Science, amounts to 145 (by 10.01.2022).

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Numerical hydrogeological model of copper mine deposits of KGHM Polska Miedź S.A.

Summary

The article presents the results of work on the numerical hydrogeological model of the mines of KGHM Polska Miedź S.A. To develop the size of the inflow of groundwater, a detailed multi-layer, three-dimensional numerical hydrogeological model was built in 2010–2012, along with elements of the water and economic balance. The area subjected to model tests was 3,049 km^2. The model tests were carried out by a team of scientists from the Institute of Geological Sciences of the University of Wrocław in cooperation with geologists and hydrogeologists of KGHM mines. The model takes into account groundwater intakes existing in the mine areas and in their vicinity, river flows, and detailed water balances for 17 aquifers mapped in the study. The volumes of inflows to individual KGHM mines and forecasts for the development of

depression cones for the deposit and adjacent levels were given. Trained mine workers use a modern tool for water management.

Keywords: Groundwater, numerical modeling, KGHM mine model, mine inflows

NUMERYCZNY MODEL HYDROGEOLOGICZNY ZŁÓŻ MIEDZI KGHM POLSKA MIEDŹ

Streszczenie

Artykuł prezentuje wyniki prac nad numerycznym modelem hydrogeologicznym kopalń KGHM Polska Miedź S.A. Dla opracowania wielkości dopływów wód podziemnych zbudowano w latach 2010–2012 szczegółowy wielowarstwowy, trójwymiarowy numeryczny model hydrogeologiczny wraz z elementami bilansu wodno-gospodarczego. Obszar poddany badaniom modelowym to 3049 km^2 . Badania modelowe przeprowadził zespół pracowników naukowych z Instytutu Nauk Geologicznych Uniwersytetu Wrocławskiego przy współpracy z geologami i hydrogeologami kopalń KGHM. Model uwzględnia ujęcia wód podziemnych istniejące na terenach kopalń i w ich otoczeniu, przepływy rzek oraz szczegółowe bilanse wodne dla 17 warstw wodonośnych odwzorowanych w badaniach. Podano wielkości dopływów do poszczególnych kopalń KGHM oraz prognozy rozwoju lejów depresji dla poziomów złożowych i nadległych. Przeszkoleni pracownicy kopalń dysponują nowoczesnym narzędziem dla zarządzania gospodarką wodną.

Słowa kluczowe: wody podziemne, modelowanie numeryczne, model kopalń KGHM, dopływy do kopalń

1. Introduction

Managing groundwater resources, carrying out drainage works and especially forecasting and designing drainage of KGHM mines requires modern tools. Numerical hydrogeological modeling is precisely that kind of tool. In 2010–2012, a team of researchers from the Institute of Geological Sciences, in cooperation with geologists and hydrogeologists of KGHM mines, developed a detailed, multilayer, three-dimensional numerical hydrogeological model with elements of a water-economic balance of an area of the mining

area of approximately 600 km^2 for forecasting and environmental impact assessment, and engineering design. The area subject to model tests was 3,049 km^2 (Staśko et al. 2012). The database for the development of the numerical model was archival data, including the results of drilling 602 wells, 472 measurement points and stationary observations, 192 piezometers, and over 700 wells from hydrogeological maps of Poland.

2. Hydrogeological model

Model studies take into account the entire aquifer system, including the network of major rivers and their tributaries, as well as the Żelazny Most tailings pond. Information was collected on the size of flows and underground outflow. The data came from the observations carried out by the Institute of Meteorology and Water Management and from hydrological studies carried out as part of the groundwater monitoring by KGHM. Long-term observations conducted by the Institute of Meteorology and Water Management allowed for the determination of the characteristic volumes of the outflows (Table 1, 2).

The groundwater supply was determined using the infiltration index method. When constructing the groundwater supply map using the infiltration index method, a numerical soil map on a scale of 1: 500,000, prepared by the Institute of Cultivation, Fertilization and Soil Science in Puławy, was used to distinguish the infiltration classes. The classes of infiltration were adopted in accordance with the analysis of data presented in Table 3.

Based on the calculations, it was found that in 2009 the rainfall in the study area changed slightly – from 594 mm in Polkowice to 625 mm in Rudna, so for the needs of the assessment of the supply, one rainfall value of 610 mm was adopted for the entire area.

The groundwater supply map is presented in Fig. 1.

Table 1. Flows Q [m^3/s] and unit outflows q [$l/s/km^2$] – minimum annual and long-term average amount measured in years 1969–1987

No.	River	Stream gauge	F [km^2]		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean
1	Szprotawa	Parchów	253	Q	-	-	-	-	-	0.22	0.18	0.16	0.29	0.20	0.10	0.10	0.33	0.14	0.30	0.29	0.26	0.22	0.28	0.22	-	-
				q	-	-	-	-	-	0.87	0.71	0.63	1.15	0.79	0.40	0.40	1.30	0.55	1.19	1.15	1.03	0.87	1.11	0.87	-	-
2	Czarna Woda	Bukowna	430	Q	0.54	0.51	0.59	0.51	0.48	0.40	0.18	0.27	0.43	0.35	0.21	0.78	0.28	0.22	0.10	0.47	0.25	0.32	0.62	0.40	0.54	0.51
				q	1.26	1.19	1.37	1.19	1.12	0.93	0.42	0.63	1.00	0.81	0.49	1.81.	0.65	0.51	0.23	1.09	0.58	0.74	1.44	0.92	1.26	1.19
3	Rudna	Krzepów	378	Q	0.26	0.30	0.28	0.31	0.19	0.45	0.11	-	-	-	-	-	-	-	-	-	-	-	-	0.27	0.26	0.30
				q	0.69	0.79	0.74	0.82	0.50	1.19	0.29	-	-	-	-	-	-	-	-	-	-	-	-	0.72	0.69	0.79
4	Cicha Woda	Chełm	191	Q	0.17	0.11	0.13	0.18	0.09	0.11	0.13	0.13	0.13	0.13	0.09	0.15	0.15	0.09	0.02	0.05	0.04	0.13	0.16	0.12	0.17	0.11
				q	0.89	0.58	0.68	0.94	0.47	0.58	0.68	0.68	0.68	0.68	0.47	0.79	0.79	0.47	0.10	0.26	0.21	0.68	0.84	0.60	0.89	0.58
5	Wierzbiak	Kunice	253	Q	0.37	0.37	0.23	0.26	0.05	0.06	0.07	0.08	0.25	0.11	0.07	0.32	0.45	0.16	0.14	0.10	0.08	0.19	0.35	0.20	0.37	0.37
				q	1.46	1.46	0.91	1.03	0.20	0.24	0.28	0.32	0.99	0.43	0.28	1.26	1.78	0.63	0.55	0.40	0.32	0.75	1.38	0.77	1.46	1.46
6	Krzycki Trench	Chociomyśl	359	Q	-	-	0.27	0.30	0.18	0.45	0.11	0.13	0.35	0.15	0.23	0.40	0.44	-	0.35	0.16	0.18	-	-	0.26	-	-
				q	-	-	0.75	0.84	0.50	1.25	0.31	0.36	0.97	0.42	0.64	1.11	1.23	-	0.97	0.45	0.50	-	-	0.74	-	-

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1	Szprotawa	Parchów	253	Q	-	-	-	-	-	0.22	0.18	0.16	0.29	0.20	0.10	0.10	0.33	0.14	0.30	0.29	0.26	0.22	0.28	0.22	-	-
				q	-	-	-	-	-	0.87	0.71	0.63	1.15	0.79	0.40	0.40	1.30	0.55	1.19	1.15	1.03	0.87	1.11	0.87	-	-
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Table 3. Assignment of protective abilities to soil types and species (Witczak et al. 2003, Duda et al. 2004)

Soil protective capacity	Infiltration rate [%]	Type and class of soil
To a very small extent	27	gravel soils; loose sand; loose sand with low clay content; rocky soils; skeletal soils; sandy soils
Weak	20	clay sands; sands with low and high clay content, tertiary rendzinas*, Jurassic rendzinas*, old geological rendzinas*, gypsic rendzinas *, sandy fluvisols ***, muck soils, and mucky soils **
Medium	13	light loam soils, silt soils, loess soils, clay soils, silty soils, chalk rendzinas *, fluvisols ***
Good	8	medium clay soils, heavy clay soils, clay soils (loam), peat soils **, mud-marsh soils

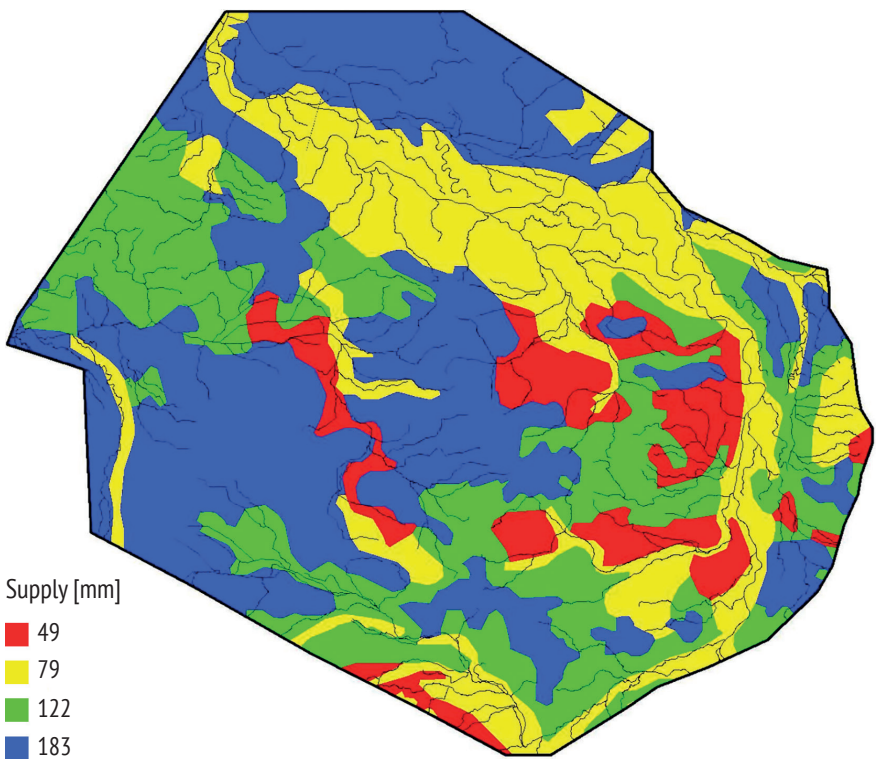

Fig. 1. Map of groundwater supply in 2009

In the mapping of the hydrostructural system, the existence of one heterogeneous Quaternary aquifer and three Neogene horizons built of sand-gravel formations were assumed – the levels of carbohydrate, carbon, and sub-carbon – see tab.4. Below is introduced a system of layers corresponding to the monoclonal collapse of the sequence of the following precipitations: the Muschelkalk, Röt formation, middle Bunter sandstone, lower Bunter sandstone, Zechstein, main dolomite level (Ca2), basic limestone level (W1), and rotliegend. Finally, in the construction of the model, 17 computational aquifers were adopted, adjusted to the separated aquifers (11) and poorly permeable separating formations. The model is by definition very regional and was prepared based on a hydrogeological study on the scale of 1: 50,000.

For the calculations, a quasi-established model of the filtration processes was adopted, and the discretization of the area was made with a uniform square grid of elementary blocks with the sides x = y = 400 m. After the model was verified and detailed, the boundary conditions of the first, second, and third layers were determined for each layer. Type 3, simulated with various Modflow packages in the GMS environment (McDonald and Harbough, 1988). Hydrogeological parameters were introduced to each numerical layer through geostatistical analysis of regionalized variables, including, in particular, the distribution of the filtration coefficient, based on archival data from the wells.

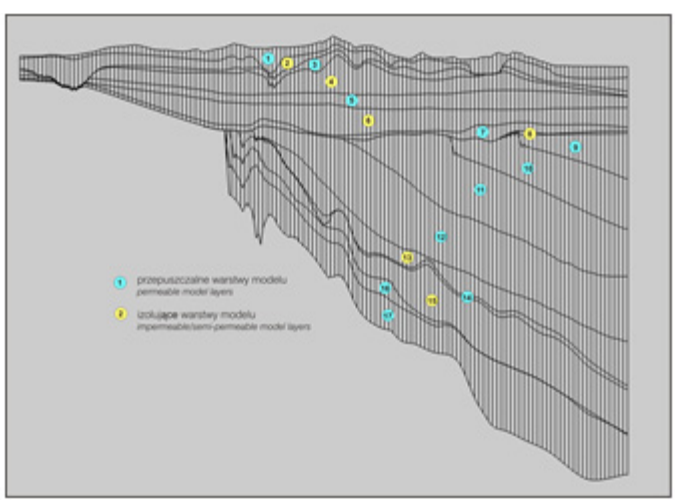

Fig. 2. Schematic system of aquifers and insulating layers separated on the numerical model of KGHM

Table 4. Characteristics of the floors and aquifers in the cup-bearing area of the Fore-Sudetic Monocline (according to Kalisz et al. 2007).

Top floor aquifers	Level Water-bearing	Layer Insulating	Thickness water level. (insulating v-o) [m]	factor filtration [m/min]	Primary pressure hydrostatic [m head of water]
Neogene	Holocene Pleistocene (river-glacial sands and gravels)		20 – 130	$1.0x10^{-2}$ – $8.0x10^{-2}$	water table (slight pressure)
		Pliocene clays	several dozen		
	super-carbonaceous (Pliocene) (sand and gravel formations of the Gozdnica and Mużakowa series)		several – several dozen	$9.0x10^{-5}$ – $3.5x10^{-3}$	110–170
		Pliocene clays	several – several dozen		
	Carboniferous (Miocene) – (sand and gravel formations of the Silesian-Lusatian series)		several – several dozen	$9.0x10^{-6}$ – $3.5x10^{-3}$	115–250
		Miocene clays	several – several dozen		
Paleogene	sub-carbon (Oligocene) – (sand and gravel formations of the Lubuskie series)		a few – a dozen	$2.1x10^{-4}$ – $2.2x10^{-3}$	225–330
Triassic	Muschelkelk (limestones and dolomites)		several – several dozen	$9.7x10^{-5}$	260
	upper Bunter sandstone (Röt formation) (limestones, sandstones)		several – several dozen	$2.8x10^{-4}$	350
Triassic	middle Bunter sandstone (cracked sandstones)		180 – 330	$1.8x10^{-6}$ – $2.7x10^{-4}$	300–360
	bottom Bunter sandstone (sandstones)		a dozen – 280	$1x10^{-7}$ – $1,2x10^{-4}$	350–740
Permski		shale guilds grn.	20–30		
	"Lubin" dolomite (fissure dolomites, cracked, cavernous)		0.5–10	$3,5x10^{-6}$ – $1,5x10^{-4}$	300–350
		Zechstein anhydrites	several dozen		
	Zechstein of Ca_2 main dolomite (fissured, cracked, and cavernous dolomites)		several – 38.5	$5,2x10^{-6}$ – $5,1x10^{-4}$	400–900
		Zechstein anhydrites	several dozen – 300		
	limestones and dolomites of the Ca_1 series (limestones and dolomites, incl. fissured, cracked, cavernous, and porous dolomites)		several – 100	N * pr. not $3,1x10^{-3}$ S**$4,1x10^{-4}$ ***	400–1050
	Rotliegend sandstones		350	pr. not $1x10^{-6}$	700–1200

* – the northern region of the deposit ** – the southern region of the deposit *** – the average value according to model tests

In the modeled area, 12 group intakes of groundwater supplying water to the entire area were taken into account. These are: "Szklary", "Rynarcice", "Lubin I and II", "Koźlice-Gola", "Osiek I, II", "Airport" in the area of the "Lubin" Mining Plant; "Moskorzynka", "Retków-Stara Rzeka", "Grębocice", "Rudna" in the area of "Rudna" and "Potoczek", "Sobin-Jędrzychów" in the area of "Polkowice-Sieroszowice" mining plants

Table 5. Consumable resources of team shots

No.	Shot name	Approved resources [m^3/h]	Depression [m]	Average efficiency expl. [m^3/ h]
1	Szklary	55	8.2 – 15.0	25
2	Rynarcice	70	8.2 – 15.0	43
3	Lubin-city shot I	90	4.6 – 7.3	90
4	Koźlice I Koźlice II	350	0 – 13.0	300
5	Osiek I Osiek II	120 200	6.2 – 6,5 0 – 4.7	120 200
6	Airport	140	8.1 – 10.0	140
7	Moskorzynka	170	2.3 – 11.5	77
8	Retków – Old River	320	5.0 – 7.6	52
9	Grębocice	160	7.6 – 10.0	22
10	Rudna	33	0.4 – 9.5	18
11	Potoczek	350	1.7 – 5.3	85
12	Sobin – Jędrzychów	537	2.0 – 4.3	270

For the hydrogeological model to accurately reflect the actual situation, it is necessary to compare the observed mirrors with the calculated ones. The discrepancy between these values did not exceed 20 m for deep levels, meeting the assumed criteria. On the verified and tared numerical filtration model as of 2013, groundwater flow balance calculations for the entire area and individual deposit areas were carried out. The calculations were carried out with the breakdown of the hydrodynamic system into 11 aquifers and confirmed the reliability of the solutions presented by the model.

The result was the determination of inflows to the workings along with the percentage deviation from the measured values (Fig. 3). The total inflows to the mines amounted to 69,400 m^3/d. The highest tributaries were measured in OG Polkowice and Lubin Małomice. In the total groundwater

balance, mine water exploitation accounted for 7.4% and intake through intakes 2.1% of the water balance of the mine area.

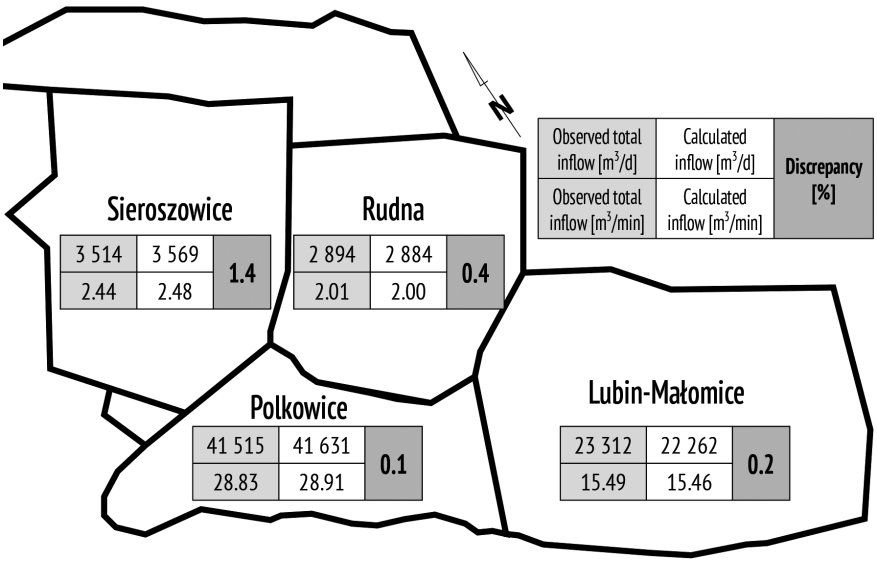

Fig. 3. Summary of the size of groundwater inflows to the workings observed and obtained on the model in m^3/min

Model studies, apart from the analysis of the current hydrodynamic system and the size of inflows to the workings, were used to forecast water failures within individual mining areas. For example, we provide the estimated volume of inflows to the OGP in 2025, Polkowice is 42.9 thousand m^3/d and respectively: Lubin Małomice – 28.3 thousand m^3/d; Rudna – 2,864m^3/day, and Sieroszowice – 3,602m^3/day. It should be emphasized that the forecasts did not take into account the extraordinary intensification of the inflow from the main dolomite level recorded from 2014/2015. More recent studies of the pace of lowering the groundwater table do not show any effect of drainage on the uppermost Quaternary aquifers. On the other hand, in the sub-carbon and inter-carbon horizons, the lowering rate of the groundwater table was observed, respectively, 3 m/year and 0.6 m/year (Staśko and Bylebył 2018).

Table 6. Water balance of the modeled area

Element of the total balance	INFLOWS		OUTFLOWS	
	thousand m^3/d	%	thousand m^3/d	%
Atmospheric power	1 999.3	87.5	0.0	
Side tributaries	183.8	8.0	-483.0	21.2
Rivers	103.0	4.5	-1 723.3	75.7
Mine drainage	0.0	0.0	-69.4	3.0
Capture by shots			-18.5	0.8
	2 286.2	100.0	-2 275.7	100.0
Difference	10.4	0.5		

Detailed simulations on the scale of excavations were also carried out, which confirmed the possibility of modeling in detailed scales.

For over a dozen years, the model has been performing well as a permanent (constantly updated) model, on which new variants of forecasting calculations and simulations can be implemented, depending on the problems reported by the mine's services. incl. training in the use of software and ongoing exchange of opinions on the results and directions of development of work on the model. The authors express their sincere thanks for the cooperation to mgr inż. R. Becker, mgr S. Szumilas, mgr A. Włochy and mgr Z. Krzywański.

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Biographical notes

Stanisław Staśko – Hydrogeologist and full professor at the Department of Hydrogeology of the University of Wrocław, he obtained his doctorate at the Inst. Of Geological Sciences in 1986. His main scientific interests are groundwater in carbonate and fissure scales, hydrogeological mapping, protection of groundwater resources, numerical modeling, and groundwater flow systems. Recently, also interested in research on power processes, sources, and temperature of groundwater.

Jacek Gurwin – Hydrogeologist and professor at the University of Wrocław at the Department of Applied Hydrogeology at the University of Wrocław, head of the Laboratory of Modeling Hydrogeological Processes at ING UWr. He defended his PhD in 1997. Specialized in regional, exploration and environmental hydrogeology; issues related to the resources and protection of groundwater with the use of the integration of modern environmental monitoring systems and GIS/RS techniques in hydrogeological model studies (the impact of mining, models of pollution migration from the area of landfills and post-industrial areas. Moreover, he is interested in the extensive use of geoinformatics tools in the construction of numerical filtration models. An important research stream is also the issues of ecology, monitoring, and assessment of the environmental impact of surface water reservoirs, as well as hydrogeological drought.

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Marek Wcisło – Hydrogeologist. He is an assistant professor at the Department of Basic Hydrogeology, University of Wrocław. He defended his PhD on the aspects of modeling slotted flow systems in 2008 at the Institute of Geological Sciences of the University of Wrocław. His interests include artificial groundwater resources, numerical modeling of flow, contact of groundwater and surface waters, and modeling of tributaries in underground mining conditions.

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Possibilities of sustainable water resources and energy management in mining of the copper deposits

Summary

In the mines of KGHM Polska Miedź SA (Kombinat Górniczo-Hutniczy Miedzi, in addition to the traditionally mined minerals – mainly metals (Cu, Ag, Ni, Pb, Re, Au, S, NaCl salt, etc.) – there are also other useful ingredients and resources, such as thermal energy, or water, which can be utilized. Acquisition of the abovementioned resources could improve the economic efficiency of the mines. In the future, after the exploitation of the copper ore deposit and the partial closure of the mines, selected shaft areas could still function under organized energy systems based on renewable energy sources from RES. The article also indicates some attempts to use the heat contained in the mine water discharged to the surface in the region of the Lubin O/ZG mine. Attention was paid to the essence of the discussed problems related to the necessity to transform the domestic energy sector and, as a result, to protect the natural environment. The presented proposals are in line with the principle of sustainable development, in particular with its three aspects, i.e., economic, environmental and social. The possibility of storing heat and energy was also indicated, which is extremely important in the era of intensive development of unconventional sources of electricity, the main feature of which is the irregularity of work.

Keywords: mines, mineral resources, water resources, energy resources, geothermal energy

MOŻLIWOŚCI ZRÓWNOWAŻONEGO GOSPODAROWANIA ZASOBAMI WODNYMI I ENERGIĄ W KOPALNIACH ZAGŁĘBIA MIEDZIOWEGO

Streszczenie

W kopalniach KGHM Polska Miedź S.A., oprócz tradycyjnie wydobywanych surowców mineralnych, głównie metali (Cu, Ag, Ni, Pb, Re, Au, S, sól NaCl i in.) występują jeszcze inne użyteczne składniki i zasoby, jak np. termalne, energetyczne, wodne, które mogą być przedmiotem zagospodarowania. Pozyskiwanie wymienionych zasobów mogłoby poprawić efektywność ekonomiczną kopalń. W przyszłości, po wyeksploatowaniu złoża rud miedzi i częściowej likwidacji kopalń, wybrane rejony szybowe mogłyby nadal funkcjonować w ramach zorganizowanych systemów energetycznych, bazujących na odnawialnych źródłach energii OZE. W artykule zasygnalizowano także pewne próby wykorzystania ciepła zawartego w wodzie kopalnianej, odprowadzanej na powierzchnię w rejonie LW O/ZG "Lubin". Zwrócono uwagę na istotę poruszanych problemów związanych z koniecznością transformacji krajowej energetyki, a w rezultacie ochrony środowiska naturalnego.

Przedstawione propozycje zgodne są z zasadą zrównoważonego rozwoju, a w szczególności z trzema jego aspektami, tj. ekonomicznym, ekologicznym i społecznym. Wskazano także na możliwość magazynowania ciepła i energii, co jest niezwykle ważne w dobie intensywnego rozwoju niekonwencjonalnych źródeł energii elektrycznej, których zasadniczą cechą jest nieregularność pracy.

Słowa kluczowe: kopalnie, surowce mineralne, zasoby wodne, zasoby energetyczne, geotermika

1. Introduction

In the mines, apart from the traditionally mined mineral resources, there are also other resources not of interest to date, unused, or of practical use. These include energy resources and mine waters. Their acquisition could contribute to the improvement of the economic efficiency of the mines. The authors point to the real possibilities of managing groundwater heat and generating electricity in mines.

The approach presented in the paper is in line with the European Union (EU) policy preferences regarding the so-called critical resources – energy and water. Their implementation would make a certain contribution to solving problems related to the supply of heat and electricity that occur in Poland. Such action would be in line with the objectives of the Polish Energy Policy until 2040[1], assuming, in addition to the certainty of electricity supply, the need for flexibility of the power system, which is to be served by the development of energy storage technologies. In a situation of intensive development of energy production technology, using renewable resources, characterized by high irregularity of work, is necessary.

The main goal of energy policy in the area considered in this paper is to ensure the security of supply while maintaining competitiveness and sustainable development.

The use of the technologies presented in the work in the mining industry could significantly contribute to more efficient use of energy, effective work of both renewable and conventional power plants, as well as sustainable development and sustainable energy.

2. Sustainable development and sustainable energy

Sustainable development is about economic development that takes into account environmental and social values. According to the Brundtland Report: "*Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*".[2]

The goals listed in the[3] Brundtland Report are clearly focused on the social dimension, and in particular concern:

1. changes in the quality of economic growth;
2. ensuring employment, food, energy, water and sanitation;
3. maintaining an appropriate level of the human population;
4. protecting and even enhancing the natural resource base;
5. reorientation of technological processes and management methods;

1 Poland's energy policy until 2040, Ministry of Climate and Environment, Annex to Resolution no. 22/2021 of the Council of Ministers of February 2, 2021.

2 Brundtland, G.H. "Our common future – Call for action". *Environmental Conservation*, 14(4), (1987) p. 292

3 G.H. Brundtland, *op. cit.*

6. integral combination of economics and ecology in the decision-making process.

It is worth paying attention to the fourth goal, namely the proposals presented in this paper regarding the use of resources occurring in mines, not included in business activities so far, and undoubtedly consistent with this aim.

The implementation of the proposals presented in the article, after examining their practical possibilities, would contribute to the implementation of sustainable development, taking into account the three fundamental dimensions – economic, environmental, and social.[4, 5] Their implementation should contribute to the improvement of the economic efficiency of operating copper mines, and in the case of closed mines, which will undoubtedly occur in the future, the use of their water and energy resources. The indicated actions would not have a negative impact on the natural environment, as it is possible to use the already existing technical infrastructure of mines (e.g. drainage installations), which would also significantly reduce investment outlays on the projects in question.

We can talk about sustainable energy when three basic goals are met:
– ensuring universal access to modern energy services,
– enabling activities in the field of improving energy efficiency,
– promoting the development of renewable energy.

The need to develop activities aimed at contributing to the achievement of these fundamental goals by 2030 is indicated in the document entitled "Sustainable Energy for All"[6], which was created as a result of cooperation between the UN Global Compact and Accenture.

An important element of sustainable energy is the development of electricity generation technologies using renewable resources. It is obvious that an energy mix should be created in Poland, in which unconventional sources should find their place, however, in accordance with the other principles of sustainable development and sustainable energy. It is closely related to the observance of the principle of rationality, and this requires stable and clear legal, national, and EU regulations, which are the right signal for investors. When planning the construction of an energy facility, one must have a clear

4 G.H. Brundtland, *op. cit.*

5 J. Malko, A. Wilczyński, H. Wojciechowski, *Bezpieczeństwo energetyczne, dostępność energii i zrównoważony rozwój a strategia unii energetycznej*, "Rynek Energii" 2015 no. 2 (117), pp. 10–17.

6 Sustainable Energy for All: Opportunities for the Utilities Industry. Global Compact ONZ, Accenture, 2012.

perspective ahead – i.e. a clear picture of the profitability and stability of business rules in the long term, while we are still at a legislative crossroads.[7]

3. Basic directions of polish energy policy[8]

The aim of the state's energy policy is:
- energy security,
- ensuring the competitiveness of the economy, energy efficiency and reducing the impact of the energy sector on the environment,
- making the best use-of the EU's indigenous energy resources.

The plans set out in the Energy Policy until 2030 do not indicate the possibility of using energy resources that have not been in the center of interest of politicians or companies so far, and this is about resources located in mines. Yet, there are a lot of mines of mineral resources, still in use in Poland, even though many of these mines are closed. They contain water and energy resources, the use of which could extend the operation time for many years, and in the case of working mines, improve their economic situation

One of the main directions of the country's energy policy is to improve the competitiveness of the national economy. In order to increase this competitiveness, the energy intensity of the economy should be reduced. Poland, meanwhile, uses 2 kWh of primary energy for every dollar of GDP generated, while Germany, France, and Japan use half as much. In the United States, there is 1.32 kWh for $ 1, and in China, for 3 kWh.[9]

Improving energy efficiency in industry and buildings should, according to the National Plan for Energy and Climate, reduce energy demand by 5.3 Mtoe (1 toe = 11 630 kWh. If we do not achieve this goal, it will be necessary to incur additional costs, which by 2030 will reach the level of PLN 11 billion per year.

The achievement of the next goal, i.e. the optimal use of own energy resources, in this case, unused mine resources, could to some extent contribute to the development of the activities discussed in this article.

7 J. Malko, A. Wilczyński, H. Wojciechowski, *Bezpieczeństwo…, op.cit.*

8 *Polityka, op.cit.*

9 Swoczyna B., Zasuń R., *Polak produkuje mniej za więcej – skąd taka energochłonność?* https://wysokienapiecie.pl/21766-polak-produkuje-mniej-za-wiecej-skad-taka-energochlonnosc/. [access: 8.08.2019].

4. Heat and energy resources in the mine water that can be used

The following questions then arise:
- how can KGHM Polska Miedź S.A. fit in with the goals of the energy policy?
- what could be done to meet the problems in Poland related to the provision of electricity and heat?

The article shows the possibilities of managing the resources found in copper mines, in particular regarding such resources as heat in mine water and energy resources. Certainly, such a procedure would be consistent with the principles of sustainable management of the water environment in mines and the use of renewable and waste energy resources"[10, 11, 12].

One may can list the possibilities of the undertaking and implementing such important goals as[13, 14, 15, 16]:
- water storage
- recovery of heat contained in the mine water,
- energy generation,
- storage of generated energy with the use of technological systems using local renewable energy sources,
- post-industrial tourism.

In addition, the possibilities of storing heat in water in selected shafts and galleries of former mines should also be well recognized.

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10 B. Namysłowska-Wilczyńska, A. Wilczyński, *Sustainable management of environment in intensive anthropopressure area for municipal purposes, water quality improvement and utilization of renewable and waste energy sources.* Dusseldorf, Germany, 2015.

11 *Possibilities of using water and energy resources in underground mines of mineral resources.* B. Namysłowska-Wilczyńska, A. Wilczyński, H. Wojciechowski, "Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk", no. 95, Kraków 2016.

12 Namysłowska-Wilczyńska B., Wilczyński A.: *Sustainable management of environment in intensive anthropopressure area for municipal purposes, water quality improvement and utilization of renewable and waste energy sources.* The Congress of the European Geosciences Union General Assembly EGU21, Open session ERE1.1 – Energy, Resources and the Environment, Vienna 2021(online).

13 Ph. Gombert, Ph., et al. *Installation of a thermal energy storage site in an abandoned mine in Picardy (France). Part 1: Selection criteria and equipment of the experimental site.* "Environmental Earth Sciences" 2019, 78 (5).

14 W. Kotowski, E. Konopka, *Aby czasowo nie wyłączać odnawialnych źródeł energii.* "Magazyn energii. Energy Gigawat ", 2013, no. 10.

15 Miecznik M., *Podziemne magazynowanie energii cieplnej – metody i zastosowania.* "Przegląd Geologiczny" 2016, vol. 64, no. 7, pp. 464–471.

16 *Germany will store renewable energy in mines, h*ttps://www.ogrzewnictwo.pl/aktualnosci/niemcy-beda-magazynowac-w-kopalniach-energie-z-oze.pdf [access: 13/12/2021].

Fig. 1 presents various variants of water and energy resources management, among which the most appropriate method for a given mine should be selected.[17]

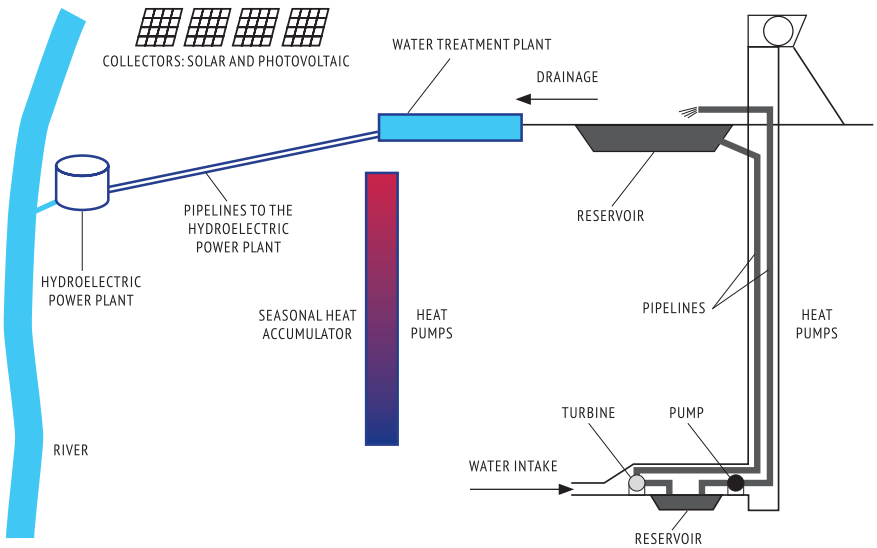

Fig. 1. Conversion of energy from renewable energy sources, using mine water (author's research)

Fig. 1 shows the following options:

- excess electricity generated by a photovoltaic farm can be used in a pumped-storage power plant in a mine and constitute a reserve source of electricity in the technological system. A feature of such a power plant in a mine is a very high head, which, with a relatively low flow, allows for obtaining significant power in a water turbine set. For example, with a water flow of $1 m^3/s$ and a drop of 500 m, the power obtained in a water turbine set will be 3.5 MW, with a head of 1000 m – 7.0 MW;
- drainage of water from mines, through a water purification station, through a pipeline with a slope to surface waters, can be used in a small hydroelectric power plant to generate electricity;
- use of water in a separate part of the mine for seasonal heat storage, obtained in solar collectors in the summer.

An intensive development of unconventional energy sources, in addition to obtaining positive values related to the use of free energy resources,

17 B. Namysłowska-Wilczyńska, *Possibilities*...., op.cit.

is the cause of many problems. The main problem in the case of wind and solar power plants is the instability of their operation, depending on weather conditions. Therefore, this type of energy requires the expansion of energy storage systems.

For example, pumped-storage hydroelectric power plants and heat storage facilities are effective supplements to the operation of unconventional sources of electricity.

5. Examples of the application of the heat and energy storage system

5.1. Heat storage facilities

The most commonly used solution for larger objects is the underground storage of thermal energy in geological formations. UTES – Underground Thermal Energy Storage). Taking into account the spatial characteristics of the reservoir, underground thermal energy storage can be divided into two groups[18]:

- a closed system in which the thermal capacity of rocks is used to store thermal energy;
- an open system that uses the heat capacity of the groundwater, which is pumped and then pumped back into the ground; There are two types of this system: aquifer thermal energy storage (ATES – Aquifer Thermal Energy Storage) and thermal energy storage in caves, artificially constructed caverns (CTES – Cavern Thermal Energy Storage). The facilities used for the storage of thermal energy (e.g. water) may be closed mines, tunnels, underground chambers.

Fig. 2 shows an example of the heat storage system (CTES) in Lyckebo, Sweden,[19] which is produced in solar collectors in summer and used in winter.

18 K. Midttømme, *Ground-source heat pumps and underground thermal energy storage: energy for the future*. http.://eprints.gla.ac.uk/76172/ [access: 5/11/2021].

19 G. Hellström, UTES Experiences from Sweden. Underground, Thermal Energy Storage Seminar, London 2012.

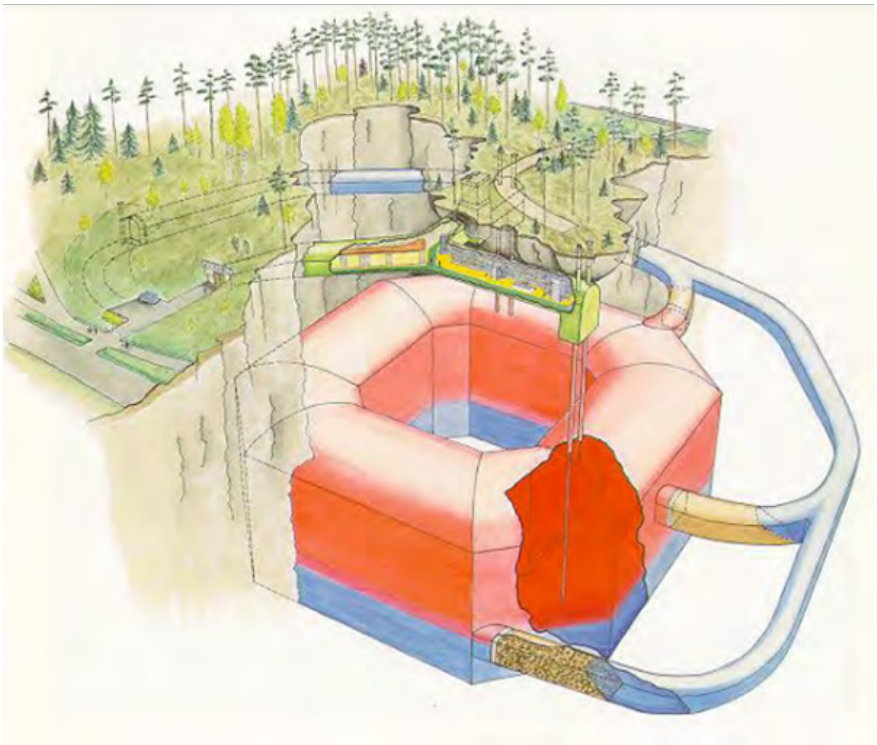

Fig. 2. Diagram of an underground thermal energy storage facility in Lyckebo, Sweden

Source: G. Hellström, *UTES..., op.cit.*

Warehouse parameters:
- tank volume – 104,300 m^3,
- storage capacity – 5.5 GWh,
- storage temperature – 60–90 °C,
- seasonal use of the warehouse,
- Cost 17.5 million SK (1982).

Underground heat storage with a capacity of 105,000 m^3 in Lyckebo, Sweden, cooperating with solar collectors with an area of 4,350m^2, which heat the water in the tank in the summer, allows obtaining 19,800 GJ of heat. The heat accumulated in the tank in summer enables 90% of heating to be supplied to 550 single-family houses in winter. The system is equipped with a heat pump.

5.2. Storage of renewable energy in mines

Energy storage can be the source of many positive effects (consequences) and economic benefits[20]. It enables the release of electricity during peak consumption periods. Importantly, it contributes to better use of technical infrastructure – electric power grids and conventional power plants, in a situation of an increasing share of power plants using renewable resources. The installation of an appropriate number of electricity storage facilities in the power system will affect a more stable power generation in conventional power plants, which will undoubtedly improve their economic efficiency and operational reliability.

Electricity storage facilities are large pumped storage plants, however, they are very expensive investments. Moreover, these types of objects significantly interfere with the natural environment. Hence, the idea of building underground storage facilities and pumped storage power plants in exhausted coal and metal ore mines emerged[21]. Germany plans to use some of the closed mines to implement such an idea. They will serve as electricity storage facilities generated in numerous wind farms in this country. A diagram of the operation of such a hybrid system, i.e. the use of excess electricity to pump water into the upper reservoir, and then use it to produce electricity, is shown in Fig. 2. Since the pumped water in this type of mines is sometimes warm, it pays to pass it through the heat pump heater while it is pumped to the upper reservoir. This heat can be used in facilities in the vicinity of the mine, e.g. in office or residential buildings.

The energy concern RWE Power AG has engaged in the construction of this type of pumped storage power plants. Together with the Societe Electrique de J'Our concern, he has already built such a power plant in the Luxembourg town of Vianden. The lower water reservoir is the closed hard coal mine and the adjacent cavern. The installed capacity of the turbogenerator is 1096 MW[22].

20 A.Wilczyński, H.Wojciechowski, *Magazynowanie energii elektrycznej – marzenie czy konieczność*. XVIII Scientific Conference "Current Problems in Power Industry" Jastrzębia Góra 7–9.06.2017. Zeszyty Naukowe Wydziału Elektrotechniki i Automatyki Politechniki Gdańskiej, no. 53, Gdańsk 2017.

21 *Germany will store renewable energy in mines* https://www.ogrzewnictwo.pl/aktualnosci/niemcy-beda-magazynowac-w-kopalniach-energie-z-oze.pdf. [access: 5/11/2021] www.energiawiatru.eu [access: 10/10/2021]

22 W. Kotowski, *In order not to temporarily switch off renewable energy sources*..., op.cit.

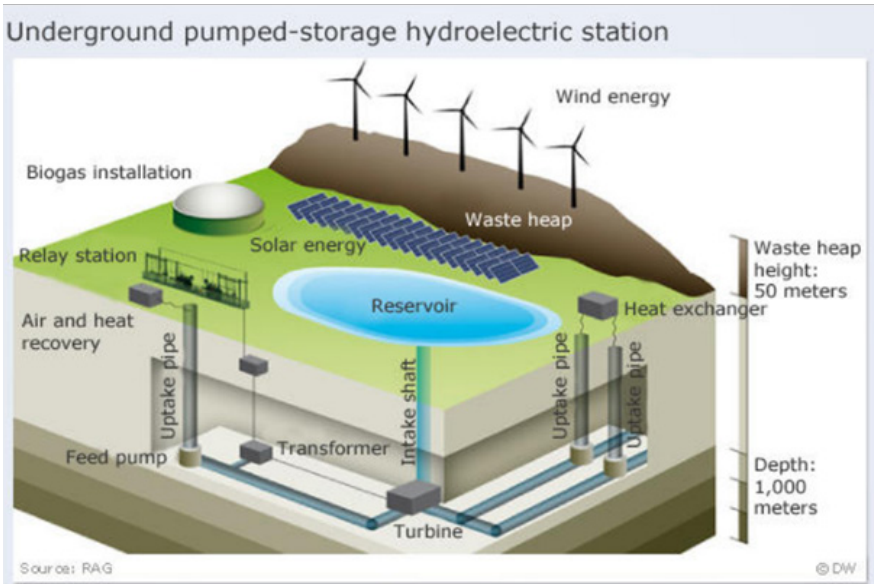

Fig. 3. Scheme of using an exploited, underground hard coal mine as electricity storage

6. KGHM's capabilities relating to the use of underground heat

The maintenance of both active and partially closed mines requires draining water and used air from the mine workings. The temperature of the underground water and the air removed is between 13 and 40 °C. Heating systems, using water heat, recovered from mine drainage, could be used, due to the low heat output, locally for heating purposes, e.g. for heating offices or apartment blocks. If there is a lack of balancing the heat demand with its supply, the geothermal installation could be supported by conventional heat sources and vice versa.

The possibility of creating heat storages requires urgent research, studies, and analyzes, which have not been performed so far. On the basis of many previous, but fragmentary, research results, it is stated that the geological and mining conditions of copper ore mines create a wide range of possibilities for the production of electricity and heat from renewable energy sources.

6.1. Possibilities of managing geothermal heat from mines of copper ore deposits

When considering the possibilities of geothermal heat management from copper ore mines, the basic problem is to determine the resources of thermal energy and the possibility of obtaining it in the period ensuring the effectiveness of the assumed technology in this process.

In the area of copper ore deposits, there are the following heat sources:
- QDT dynamic resources generated from the Earth's interior;
- static QST resources accumulated in the rock mass and groundwater;
- QET exploitable resources, contained in mine groundwater discharged to the surface.

QDT dynamic resources are renewable. These resources constitute the heat flux q, generated towards the Earth's surface from the depths of the lithosphere, with a significant contribution of radiogenic heat, expressed in W/m^2. The flux density decreases to the temperature equalization zone, i.e. about 8.8 °C at a depth of about 8.5 m below the surface area. The average value of this parameter for mining areas, at the depth of the copper ore deposit of existing mines, is $q = 0.065\ W/m^2$. This means that the amount of constantly flowing heat to the rocks of the deposit zone is per 1 ha – $(0.065\ W/m^2) \times 10^4$, i.e. 650 W /ha, and per $1km^2$ – $(0.065W/m^2) \times 10^6$, i.e. 65 kW /km^2. This heat flows through the water-tight layers of deposit rocks in which access and mining pits are drilled, including drainage drilling. After draining the formation water as a heat carrier, the amount of heat, static energy that can be recovered, accumulated in the rock mass, is drastically reduced. Therefore, in the technological systems of obtaining electricity and heat, the separated space must be filled with water in order to constantly receive heat from the rocks.

Static resources QST is the amount of heat contained in a given rock mass, block, or specific lithological facies structure of the Zechstein, Triassic or Cenozoic formation. These resources are determined on the basis of a parameter called heat capacity cp in [kJ/ °C x kg] of a given rock and/or water present in the collector space. Static heat resources QST of rocks, together with water filling dynamic and closed structural discontinuities, increase according to the gradient G [°C/m] and geothermal degrees G [m/°C], determined for a given region and particular geological formations. Static resources of heat contained in the rock mass can be obtained only through the medium in contact with the rock on the natural surfaces of fissures, cracks, caverns, or dynamic pores, or in the space of delamination and fractures of

roof rocks and goafs formed after the exploitation front of the deposit has passed, irrespective of how to liquidate the space after the selected deposit. Part of these resources becomes non-renewable or only partially renewable after the amount of heat supplied by the thermal stream q to the given layers is exceeded, as well as after the discharge of static and elastic water resources present in the considered formations. The layers of the direct floor of the exploited deposit, and in part also the layer of the main floor, after delamination, cracking, loss of continuity, displacement, or collapse, may constitute a favorable collector space for water storage in energy and thermal renewable energy systems.

QET exploitable resources define the possible amount of heat to be obtained from groundwater from a given geological structure with specific parameters: heat flux density q [W/m^2], heat capacity cp [kJ/°C x kg], specific thermal conductivity lambda [W /m x °C], and the coefficient conduction of temperature a [nx10^{-6}xm^2/s] under specific geological, mining, and technological conditions of the assumed industrial geothermal heat recovery system. Under the existing lithological, structural-tectonic, hydrogeological, and geothermal conditions of copper ore mines, at the present stage of exploitation of the deposit, the exploitation resources of geothermal heat are contained in mine waters. These waters (approx. 15%) come from the drainage of Permian aquifers (elastic and static water resources) and indirect drainage, through Zechstein outcrops, from the basal layers of Cenozoic formations, mainly from the Oligocene level (the remaining 85%). After draining the water resources of the Permian complex with access and preparatory workings, at the stage of exploitation of the deposit, the possibility of obtaining heat from high-temperature reservoir waters ends, due to the exhaustion of the above-mentioned elastic and static resources of these waters.

In such a situation, static heat resources contained in the rock mass may be partially obtained, e.g. indirectly from water accumulated in post-mining goaf, in a part of a mine that is closed to traffic, etc. The source of water filling this type of heat reservoirs may be the remains in the rock mass of drained resources, supplied to the mine – technological waters, and in the case of the "Lubin" and "Polkowice" mines – also inflows of Oligocene waters (through Zechstein outcrops) with an intermediate temperature, between cold waters and thermal, i.e. at a temperature of around 20–25 °C. Average temperatures of mixed water in the mines depend on the balance of inflows from the rock mass or the water supplied, and in the mines "Lubin" and "Polkowice" it is approx. 25 °C, and in the "Rudna" mine, approx. 28 °C

and in the "Sieroszowice" mine – over 30° C.[23] In the calculation of the efficiency of heat recovery from mine waters during the operation of mines, their liquidation or after their closure, one should take into account the high mineralization of Permian and Triassic waters and a significant height of their lifting to the surface in the areas of the main drainage: LG – 610 m; PG – 850 m; RG – 1000 m; SG – over 1,200 m.

The main drainage pumping station for the LG Region discharges mine water to the surface, to the Ore Beneficiation Plant. During the year, it pumps itself out, on average approx. 7,900,000 m^3 of water. The mine water, flowing through the pipeline, has a temperature within the range of 24–26 °C. Unfortunately, the heat resources contained in the mine water are not used, and in such a situation one can regret the irretrievably lost heat. In Downorowicz's paper, one reads that "the problem of managing the large heat load contained in mine waters discharged to the surface still remains open. This heat can be used for heating purposes in the shaft areas, which discharge mine water to the surface. These are the regions of LG and LW in O/ZG Lubin, PG in O / ZG Polkowice-Sieroszowice and RG in O/ZG Rudna"[23]. A significant problem of proper energy management is indicated by the data contained in another paper[24], which shows a very large share, amounting to over 50% of the total electricity consumption needed to ensure ventilation of mining plants. Factors such as an increase in the depth of exploitation and the ever-higher price of electricity should encourage actions to reduce the operating costs of mines, by, inter alia, analyzing the possibilities of using the solutions presented in the article and implementing them for practical application. Certainly, the first step in this direction should be the use of mine heat.

One of the attempts to accomplish this task was to use a heat pump with an exchanger immersed in the mine water tank at O/ZG Lubin. This investment has brought measurable economic effects[25]. If the implementation of the proposed solution in one mine would bring positive results, it should be replicated in other mines. It has been shown that the return on investment costs should not exceed 3.5 years.

23 S. Downorowicz, *Waters...*, *op.cit.*

24 Augustyn W., Niechwiej A., *Bilans energetyczny przewietrzania kopalń rud miedzi KGHM Polska Miedź S.A.* [in:], *Aktualne problemy geotermiczne Polski*, S. Downorowicz (ed.), Lubin 2018, pp. 77–84.

25 Kostka T., *Wykorzystanie energii cieplnej zawartej w wodach kopalnianych przy zastosowaniu pompy ciepła w KGHM Polska Miedź O/ZG "Lubin".* [in:], *Aktualne problemy geotermiczne Polski,* S. Downorowicz (ed.), Lubin 2018, pp. 159–168.

7. Conclusions

There are different ways to use waste energy and heat in mines. Their use will certainly contribute to the improvement of the energy efficiency of the mine, as well as to the implementation of energy goals adopted by the government. The indicated actions would also result in the improvement of the country's energy security. Such a combination of ensuring the security and competitiveness of energy and heat supplies would certainly be the right direction for creating a sustainable, effective, but also diversified "energy-mix", and would also be in line with the trend of sustainable development.

The amount of heat discharged to the surface contained in mine waters, given in the article, is significant and should not be ignored in energy balances. Taking appropriate measures to enable the use of mines' energy resources, as well as their storage, is a necessity in a situation of increasing energy prices. This may lead to an increase in the energy self-sufficiency of plants, as well as contribute to the achievement of the state's energy goals.

It is postulated to urgently develop an interdisciplinary, comprehensive concept-project for the energy transformation of copper ore mines in the target approach of individual mining plants, taking into account renewable energy sources.

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Biographical notes

Artur Kazimierz Wilczyński – was born on February 14, 1947 in Włocławek. Prof. dr hab. of economics, PhD in Technical Sciences, eng. electrician, a graduate of the Wrocław University of Science and Technology. He represents two scientific disciplines: electrotechnics and economics. After graduating from the Faculty of Electrical Engineering at the Wrocław University of Technology; was employed at this Faculty in the period between 1971 and 2017. In 1977, he defended his doctoral dissertation, obtaining a degree in technical sciences; and in 1991 the Council of the Faculty of Management and Computer Science at the University of Economics in Wrocław awarded him the post-doctoral degree (habilitation). In 2007 he was awarded the title of professor and in 2010 the position of a full professor. Employed at the Institute of Power Systems Automation in Wrocław (1993–2001 – second work); at the State Higher Vocational School in Nysa (2003–2014 – second work). Since 2017, prof. Artur Wilczyński is employed at the Jan Wyżykowski University.

Prof. Artur Wilczyński is the author and co-author of 166 scientific publications and many scientific studies.
His scientific interests focus, among others, on identification, modeling, and forecasting of electricity and power demand processes, including surface (2D) and spatial (3D) modeling, study, and design of the structure of electricity tariff systems, the impact of tariffs on power and electricity consumption. From 1990, prof. Artur Wilczyński deals with the issues of restructuring the power industry and creating energy markets, as well as the conditions and technical and economic benefits related to cooperation with the interconnected power systems of Western Europe. Since 1998, the subject of his scientific interests is also the issues of distributed, including unconventional, energy sources. These are mainly related to the integration of these sources with the power system and the economic efficiency of their operation.
He has thaught, among others, the following subjects: Electricity networks and systems, Electric load shaping, Marketing basics, Management and marketing, Basics of management, Business management, Power management, Management in the conditions of globalization and regionalization, Economic cooperation in the European Union. He was a member of the T10B Energy Section of the Scientific Research Committee of the Ministry of Science and Information (2003–2005); member of the Scientific and Technical Council for Innovation of ENERGA SA (2016–2018); a member of the Scientific Committees of Conferences organized by the Lublin, Częstochowa, Gdańsk Universities of Technology, Wrocław University of Science and Technology, University of Economics and Jan Wyżykowski University.
Prof. Artur Wilczyński has promoted 6 doctors (PhD in Technical Sciences); he is a reviewer of many doctoral and postdoctoral dissertations and the application for the title of professor.

Professor Barbara Namysłowska Wilczyńska holds a graduate degree in geology from the Faculty of Natural Sciences, at the University of Wroclaw, Poland. She received the degree of Doctor of Technical Sciences (PhD), in a scientific discipline – engineering geology, mining, on 5/3/1980, after defending a doctoral dissertation entitled "Quantitative analysis of spatial variability of parameters of geological sediments of the lower Zechstein (Permian) in the area of the mine Lubin", the Institute of Geotechnical Engineering, Wroclaw University of Science and Technology, Poland. In 10.10.1994, she completed habilitation at the Faculty of Geology, Geophysics and Environmental Protection, University of Science and Technology in Cracow, Poland, based on the dissertation entitled "The variabil-

ity of copper ore deposits in Foresudetic Monocline in the light of geostatistical studies." Resolution habilitation granting a doctoral degree of Earth Sciences in the discipline of geology, dated 10/10/1994. Prof. B. Namysłowska-Wilczyńska was approved by the Presidium of the Central Control Commission in Warsaw, in March 27, 1995. On 30.12.2009 President Lech Kaczynski awarded PhD to B. Namyslowska-Wilczynska the title of Professor Technical Sciences. The nomination took place at the Presidential Palace in Warsaw, on 03.03.2010. On June 28, 2017, B. Namysłowska-Wilczyńska was nominated for the position of full professor at the Wrocław University of Technology.

Some Posts (Positions) held:

1996–1999 – Deputy Director for Education and Development of Research Personnel of Institute of Geotechnics and Hydrotechnics at WUST;

1999–2002 – Deputy Director for Education and Development of Research Personnel of Institute of Geotechnics and Hydrotechnics at WUST,

1998–2014 – Head of Engineering and Environmental Geology Department of Institute of Geotechnics and Hydrotechnics at WUST;

1999–2014 – Head of Engineering and Environmental Geology Laboratory of Institute of Geotechnics and Hydrotechnics at WUST;

2004–2008 – Deputy Head of Center for Modeling Hydrological Processes (CMHP) in Wrocław;

2009–2012 – Deputy Head of Center for Modeling Hydrological Processes (CMHP) in Wrocław;

2013–2016 – Deputy Head of Center for Modeling Hydrological Processes (CMHP) in Wrocław.

Basic themes of scientific research in the field:

ore deposits geology, engineering geology, applied geology, hydrogeology, environmental geology, environmental protection, reservoir geology, energy sector; geostatistics, (applied – spatial statistics).

Prof. Barbara Namysłowska-Wilczyńska deals with research problems related to modelling, estimation, forecasting and simulating (2D, 3D) of mineral resources parameters, copper ore deposits, in particular and also copper porphyry deposits. Her works are associated with a variety of applications of statistical and geostatistical methods, i.e. applied spatial statistics, including simulation techniques (turning bands simulation), in the issues relating to mineral deposits geology, mining, environmental engineering, environmental protection, in waste landfill research, climatology, enzymology, geodesy, as well as in the energy sector (power engineering). Author of a lot of articles and research studies devoted to area analyses (2D) spatial analyses, as well as spatio-temporal) analyses (3D,

uncertainty estimation of the estimated averages of deposits parameters, and variability risk analysis of the studied parameters used in the solving of certain issues. Recent studies include the development of geostatistical (2D, 3D) hydrogeochemical models of variation of underground waters quality parameters for a water intake area, of a treated water and in water supply system, geostatistical description of structure of copper ore deposit parameters variation, filtering of components of copper ore deposit variograms models using ordinary kriging technique, spatial-temporal analyses (3D), i.e. modelling of horizontal and vertical displacements on the basis of data from the geodetic monitoring of a hydrotechnical object, with the sustainable management of water resources and energy.
Prof. B. Namysłowska-Wilczyńska presented the results of the works in various scientific and scientific-technical national conferences and international conferences, congresses in Poland and abroad, as in Czech Republic (1981, 1983, 1985, 1987, 1990, 1993, 2011, 2018), Israel (1984), Germany (1982, 1983, 1985, 1986, 1990, 2002, 2004, 2015), Sweden (2011), Great Britain (1990, 2014), France (1988, 2014, 2019), Spain (1997), the Netherlands (1993), Italy (2000), Canada (1986), Chile (2009, 2013), Belgium (1991, 2018, 2018), Austria (2015, 2016, 2021), Australia (2017), Taiwan (Taipei) (2019).
Prof. B. Namysłowska-Wilczyńska is the author or co-author of 173 works: 48 articles published in prestigious journals national (including PAN and PAU) and recognized abroad, 1 professor monograph, 1 habilitation monograph, 1 monograph (edited by B. Namysłowska-Wilczyńska) 1 monograph (partnership), 58 papers at national and international conferences, 9 book chapters, 3 books, and the 28 papers included in the lists of journals of Ministry of Science and Higher Education and 48 studies carried out in the framework of consortia of academic institutions, as well as from the funds received for the implementation of research grants, EU as well as special orders from the industry.
The number of citations of scientific papers in the Web of Science, amounts to 145 (by 01/10/2022).

Stanisław Downorowicz D.Sc.Eng., is a graduate of the Faculty of Hydroengineering – Geology Department of the Gdańsk University of Technology (1960). He obtained the title of MSc Eng. of geology after defending his diploma thesis on hydrogeological conditions of hard coal mines in the area of the Zabrze Saddle – KWK "Bielszowice", "Makoszowy", "Zabrze-Wschód" and "Zabrze-West", "Ludwik", "Pstrowski", "Concordia. From 01.04.1961 to 31.03.1991 he worked at KGHM in Lubin as a hydrogeologist engineer, deputy chief geologist and chief hydrogeologist, obtaining further OUG approvals and state mining, hydrogeological

and engineering geology licenses, and later – qualifications of an expert President of the WUG in group XVII "Water hazards". In 1973, after defending the thesis entitled: "Geothermics of copper ore deposits of the Fore-Sudetic Monocline" at the Mining Department of the Wrocław University of Technology, he obtained the title of doctor of technical sciences. As part of documenting the copper ore deposit, he supervised and managed hydrogeological, geological and engineering, geophysical, gas, and geothermal research for individual deposit areas, and carried out the identification of usable groundwater resources, geological and mining conditions as well as soil and water conditions for the construction of shafts, etc. mining, hydrotechnical, water management, and flotation waste landfills – "Gilów", "Gilów II", "Żelazny Most", "Wartowice" and others, and drinking and industrial water intakes in the area of LGOM. He is the author of documentation and other geothermal studies and studies of thermal parameters of rocks for the design of ventilation and air conditioning of existing mines, including for prospective copper ore deposit areas. He is the creator of the safe technology for depositing flotation waste, produced in copper ore enrichment plants, used in the years 1976–2022 (patent); is the author of a waste-free technology for the processing of flotation waste into market products (cement, mineral fertilizers with microelements and materials for construction) with the simultaneous recovery of metal residues (3 patents); he is the co-author of the hydrotechnical technology and the author of the hydrogeological (patent) technology for the management of saline mine waters. At KGHM, he was in charge of identifying and combating water hazards in the "Lubin" copper ore mines. "Polkowice". "Rudna", "Sieroszowice" and in the old copper basin "Konrad", "Lubichów" and "Lena" as well as hydrotechnical facilities, damming water, liquid flotation, and metallurgical waste. He was a member of the interministerial Commission for Combating Natural Hazards, et al. commission within the ministry, the union of non-ferrous metals and the copper plant; he was appointed to expert teams at the ministerial level and repeatedly delegated abroad, including for the selection of deposits and the expansion of the national resource base for Huta "Katowice". On numeral occasions to international specialist enterprises, design and research institutes, and mining plants. incl. in Russia (St. Petersburg, Moscow, Tula, Fe deposits in the Belgorod region, non-ferrous metal ore deposits in Central and Western Siberia); to Ukraine (Fe deposits in Kryvyi Rih, Biełoziorka); to Kazakhstan (Cu, Pb-Zn deposits and non-ferrous metal mining and smelting plants – Rudny Altai, Zyrianovsk, Zezkazgan, Balkhash, Alma-Ata); to Uzbekistan (Mining and metallurgical plants: Pb-Zn-Ag-barite in Kentau, Cu, Pb, Au, Ag in Almatyk, Coquettent); to the Kabardino-Balkar Republic (WV-Mo

Mining and Metallurgy Combine in Tyrnauz); to Sweden – mining and hydrotechnical construction; to Austria – radioactive techniques in hydrogeology; to the former Yugoslavia – Belgrade, Cu Bor and Majdanpek fields – consultations (flotation waste management, hydraulic filling); to Bulgaria – lectures in Sofia and color metallurgy plants on the quality control of production and geological maintenance of mines; secondment in 1988–89 to Algeria – as chief geological engineer and deputy construction manager – organization and construction of the metro in Algiers.

In 1992, he organizes the "HYDROGEOMETAL" Consulting Company with a research and implementation profile, periodically employing up to 32 specialists from various industries. During 3 decades, the company performs over 600 research, design, and documentation works, including the construction of research installations and technological facilities (water treatment, liquid thickening, monitoring, etc.) for KGHM Polska Miedź SA, and other domestic and foreign investors: in Albania (Kombinat Cu Albakr), Kazakhstan (Kombinat GH Cu in Żezkazgan), Russia (Kombinat "Norylski Nickel", Kombinaty Fe in Kostomuksza and Kavdor, Kombinat "Apatyt" on the Kola Peninsula).

In 2013, at the Faculty of Geoengineering, Mining, and Geology of the Wrocław University of Technology, he obtained a postdoctoral degree in engineering geology and mining in subjects: Fundamentals of hydromechanics, Hydrogeology, Hydropower, Fundamentals of ecology and environmental protection, Ecology in industrial production, Applied geophysics. In the past six decades, he was the organizer or co-organizer of 31 international and national scientific and technical conferences, where he presented a total of 59 papers important for the development of innovations in the mining of non-ferrous metal ores. He is the author and co-author of over 900 studies, including 199 publications, including 14 books, monographs and collective works, 27 patents. The last 200th publication is a monograph published on the occasion of the 60th anniversary of professional and scientific work – "Polish copper ore mining – environmental changes" (TKP O, Lubin, January, 2021, p. 1200, A4. color).

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Experience in the field of practical use of data from mining machinery monitoring

Summary

Mining machines implementing production processes are highly diversified in terms of construction dedicated to the implementation of specific technological goals. In practice, this means managing a machine park grouping loading and hauling machines, drilling rigs, bolting machines, and bulldozers as well as auxiliary machines carrying out transport work in the field of people and materials. Proper management of these machines means optimization of costs related to their maintenance and obtaining high rates of availability for individual types. Replacement purchases are made in relation to the recommended periods of use and result from the experience of operating machines of various manufacturers interpreted directly from the data warehouse using the TCO total cost method. Direct actions related to the observation of the current technical condition of machines during the implementation of production cycles are carried out with the use of machine monitoring. It covers the main production machines in the field of direct control of measurement sensor indications and their interpretation by the supervision using the control reports obtained within the SAP BusinessObjects software.

Keywords: monitoring, TCO total cost method, mining machinery

DOŚWIADCZENIA W ZAKRESIE PRAKTYCZNEGO WYKORZYSTANIA DANYCH Z MONITORINGU MASZYN GÓRNICZYCH

Streszczenie

Maszyny górnicze realizujące procesy produkcyjne wykazują się dużym zróżnicowaniem pod względem budowy dedykowanej do realizacji określonych celów technologicznych. Oznacza to w praktyce zarządzanie parkiem maszynowym grupującym maszyny ładująco-odstawcze, wiertnice, kotwiarki i spycharki oraz maszyny pomocnicze realizujące prace transportowe w zakresie ludzi i materiałów. Prawidłowe zarządzanie tymi maszynami oznacza optymalizację ponoszonych kosztów odnoszących się do utrzymania ich w sprawności oraz uzyskiwanie wysokich wskaźników dyspozycyjności dla poszczególnych typów. Zakupy odtworzeniowe prowadzone są w odniesieniu do rekomendowanych okresów użytkowania i wynikają z doświadczeń eksploatacyjnych maszyn różnych producentów interpretowanych bezpośrednio z hurtowni danych przy wykorzystaniu metody kosztów całkowitych TCO. Działania bezpośrednie związane z obserwacją bieżącego stanu technicznego maszyn podczas realizacji cykli produkcyjnych odbywa się przy wykorzystaniu monitoringu maszyn. Obejmuje on główne maszyny produkcyjne w zakresie bezpośredniej kontroli wskazań czujników pomiarowych i ich interpretacji przez dozór przy wykorzystaniu raportów kontrolnych uzyskiwanych w ramach oprogramowania SAP BusinessObjects.

Słowa kluczowe: monitoring, Metoda całkowitego kosztu TCO, maszyny górnicze

1. Introduction

Observation of the current technical condition of mining machines is an important factor that determines the maintenance of mining machines so that they remain efficient. Additionally, measuring the indications of control sensors during the implementation of individual phases of production processes allows for concluding the causes of critical loads and the introduction of methods to counteract unfavorable phenomena. Continuous monitoring of machines means observation of the technical condition of a machine by the operator as well as control of the machine operation by mechanical supervision based on monitoring data sent to the data warehouse and processed in

order to obtain illustrative reports on the operation of machines. It should be noted that monitoring understood as the transmission of data from the operation of machines concerns selected units. Due to the purchase costs, sensor maintenance costs, as well as IT support costs, there is a natural necessity to apply this system to machines with the highest rank in terms of maintaining the continuity of extraction.

2. Characteristics of mining machinery monitoring

Monitoring of mining machines is carried out mainly in the field of:
- observation of indications of control parameters and direct signaling of threats due to exceedance of permissible values,
- transmitting data from the current indications of control sensors through transmission stations to the central data warehouse,
- cyclical generation of control reports observed by the mechanical and mining supervision using the functionality of the available SAP BusinessObjects software,
- supporting production processes in the process of automating the drilling cycle with blast hole drilling trucks based on the uploaded blast record.

Observation of the behavior of the measuring sensors during the production cycles of mining machines in real conditions allowed for the detection of atypical states suggesting incorrect cooperation of the main components in the case of loaders of the LK4 class, type LKP 1601B, manufactured by KGHM ZANAM with a bucket capacity of 8.5 m^3.[1] The appearance of undesirable momentary torque of the opposite direction in the drive system was observed. These observations, supported by the assessment of technical services, allowed to isolate the causes of the occurrence of unfavorable load states and allowed to propose technical solutions enabling the blocking of undesirable states by introducing a special APC 312 controller cooperating with an automatic gearbox.[2] The modernization of selected machines showed the effectiveness of the actions taken. The analytical observation regarding maintenance costs and availability efficiency was carried out based on the

1 Lewicki M., Kaniewski T., Śliwiński P. *Wykorzystanie informacji uzyskiwanych z monitoringu parametrów pracy do wprowadzania zmian technicznych w modernizowanych maszynach górniczych*, „Inżynieria Mineralna", January–June 2020, pp. 145–150.

2 *Ibidem*.

TCO total cost method.[3] The current observation of costs presented in the fig. confirms that the decision to modernize machines in the discussed scope was right. Fig. 2 shows the time courses for the LKP-1601B mine loaders in the 6-year operation period. Correct operating conditions of the drive system were achieved, with protection against sudden increases and drops in pressure, temperature, control of the rotational speed of the clutch baskets with simultaneous elimination of changes in the direction of travel under load.

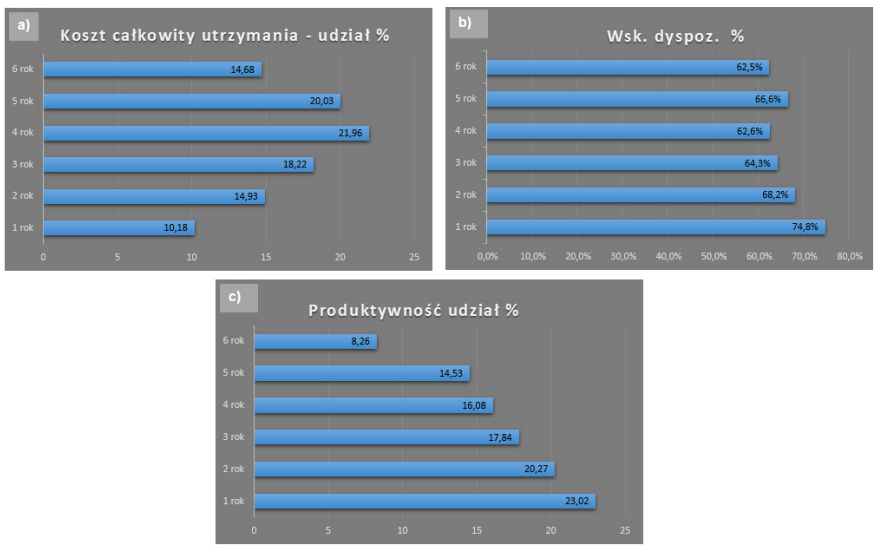

Fig. 1. Analysis of control parameters of 9 LKP-1601B machines in a 6-year operation period a) Maintenance costs, b) Availability index, c) Productivity

The machinery chambers presented are dedicated to the current operation of machines and their periodic inspections OT-1, OT-2, OT-3, are built-in locations favorable for access roads to the mining fields and the crew transport from under the downhill shaft.[4] Fig. 2 shows the LKP-0903 wheel-articulated loader. On the other hand, the technical data of selected loaders manufactured by KGHM ZANAM are presented in Table 1.

3 Lewicki M. *Ocena korzyści z wykorzystania metody TCO w procesie zarządzania samojezdnymi maszynami górniczymi w warunkach podziemnej kopalni miedzi*, „Nauki techniczne i praktyka przemysłowa w Zagłębiu Miedziowym", Polkowice 2017

4 Lewicki M., Kucharski A. *Wpływ trybu realizacji okresowych przeglądów technicznych na prawidłową gospodarkę samojezdnych maszyn górniczych*, „Zeszyty Naukowe Dolnośląskiej Wyższej Szkoły Przedsiębiorczości i Techniki w Polkowicach", Issue no. 4 (2015), Polkowice 2015.

Fig. 2. LKP-0903 wheel-articulated loader by KGHM ZANAM[5]

Table 1. Technical data of selected loaders by KGHM ZANAM[6]

Type	Designation	Length	Width	Height	Total mass	Bucket capacity	Lifting capacity	Internal combustion engine power	Exhaust purity class
		[mm]	[mm]	[mm]	[kg]	[m^3]	[t]	[kW]	Stage
LK2	LKP-0805C	9 970	3 030	1 750 / 2 100	26 800	3.5	8	138	
LK3	LKP-0903	10 600	3 150	1 750 / 2 100	29 500	4 / 4.5	9	181	Stage 3A
LK4	LKP-1601B	11 650	3 300	2 350	47 300	8.5	16	295	Stage 3B

The high quality of the current assessment of the technical condition of the machines determines the proper management of mining machines. Machine management covers technical inspections OT-1, OT-2, OT-3 carried out in mechanical chambers on special stands by a highly qualified mechanical service. It must also take into account the replacement of worn-out units with new ones. It is connected with the necessity to build effective purchase schedules related to the liquidation of used units. This logic results from many years of observation of the maintenance costs of individual machines and the control of several other related parameters, including, for example, availability. The observations carried out with the use of the TCO total cost method showed differences in operating periods depending on the analyzed types of machines.[7] The overall observation of the machine park showed the advisability of operating with the recommended period of operation dedicated to individual types of machines. The possibility of forecasting the ef-

5 https://www.kghmzanam.com/wp-content/uploads/2020/06/LK_0903_PL.pdf
6 *Ibidem;* Lewicki M., Kaniewski T., Śliwiński P., *op. cit.*;
7 Lewicki M. *Ocena korzyści..., op. cit.* ; Lewicki M. *Wykorzystanie monitoringu do bieżącej oceny stanu technicznego SMG*, „Inżynieria Górnicza", no. 4(2018).

fective conduct of production processes was achieved while maintaining low maintenance costs related to high availability and, at the same time, a low failure rate maintained at the permissible control level. Fig. 3 shows the life curve of a mining machine.[8]

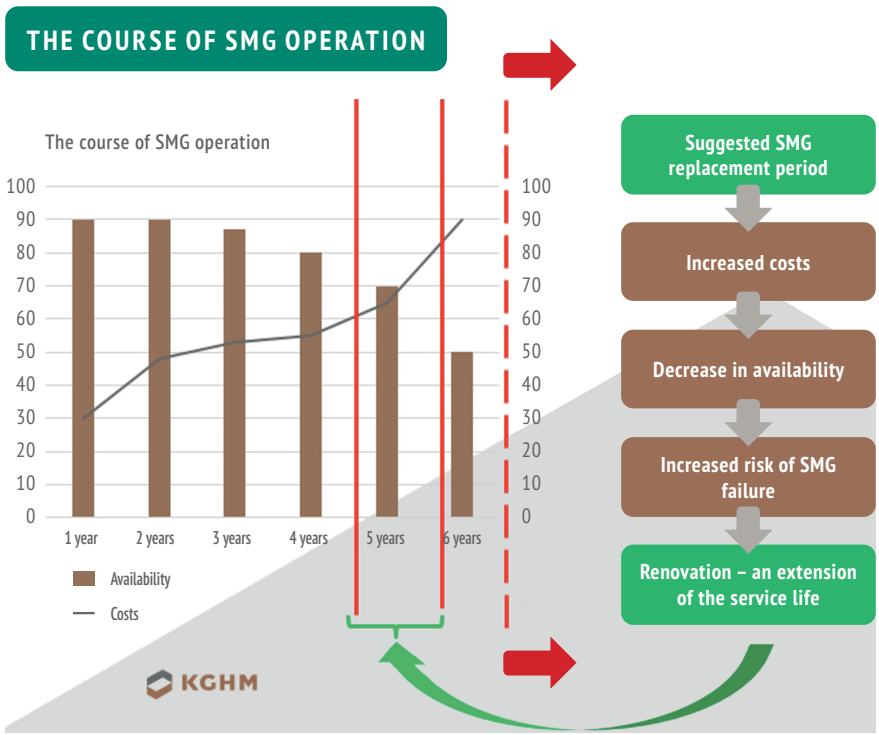

Fig. 3. The course of operation of the machine during its life in terms of the share of the unit annual cost about the total cost[9] [4]

3. Assessment of the technical condition of machines

The technical condition of mining machines is assessed based on ongoing monitoring combined with diagnostics – Fig. 4.

Classic monitoring focuses mainly on collecting data from measurement sensors, efficiently locating these sensors on the machines, which are installed

8 Lewicki M. *Wykorzystanie monitoringu do bieżącej oceny stanu technicznego SMG*, „Inżynieria Górnicza", no. 4(2018).

9 *Ibidem.*

to capture the limit states of loads, sending this data to the analytical center, and building control reports for mechanical supervision. Examples of time series of data from measuring sensors are shown in Fig. 5.[10]

Active monitoring is designed to capture overload states on an ongoing basis and signal them to the operator in the form of a controlled warning – yellow, or critical alarm – red alarm.

The supporting monitoring is based, for example, on the measurements of the readings of sensors installed in the working system of the drilling vehicle and allows for the effective implementation of the process of automatic drilling of blast holes in accordance with the applicable blast certificate.

The effectiveness of monitoring is related to the effective diagnosis of the cause of the increase in the indications of the observed sensors.[11] The designation of the critical component responsible for adverse overloads occurring in the working system and the determination of its technical condition determines an effective preventive service.

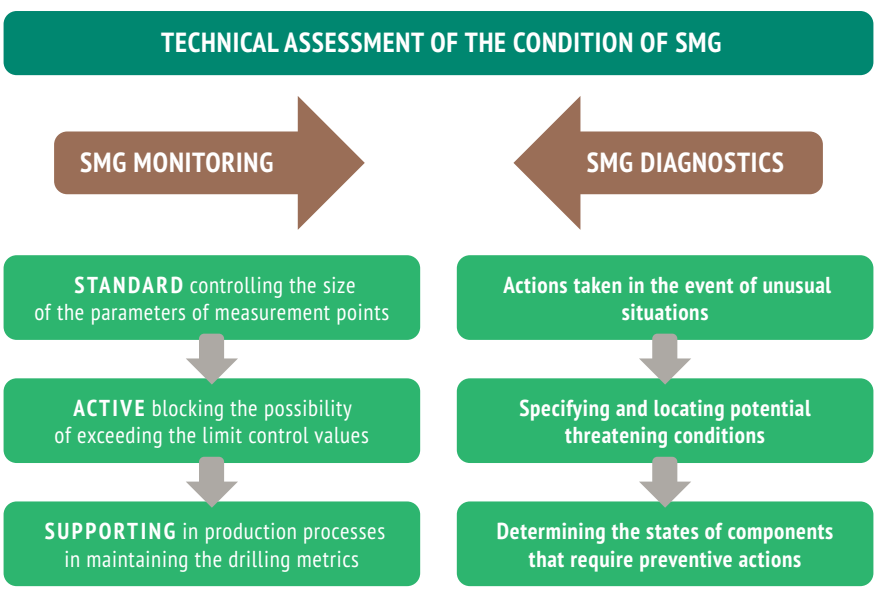

Fig. 4. Current assessment of the technical condition of mining machines

10 Lewicki M., Kaniewski T., Śliwiński P., *op. cit.*;

11 Stefaniak P, Obuchowski J., Sawicki M., Zimroz R., Żak G., Wyłomańska A., Bartelmus W. *Wybrane problemy i wyzwania automatycznej diagnostyki elementów maszyn górniczych*, „CUPRUM – Czasopismo Naukowo-Techniczne Górnictwa Rud", no. 3 (76) 2015, pp. 189–198.

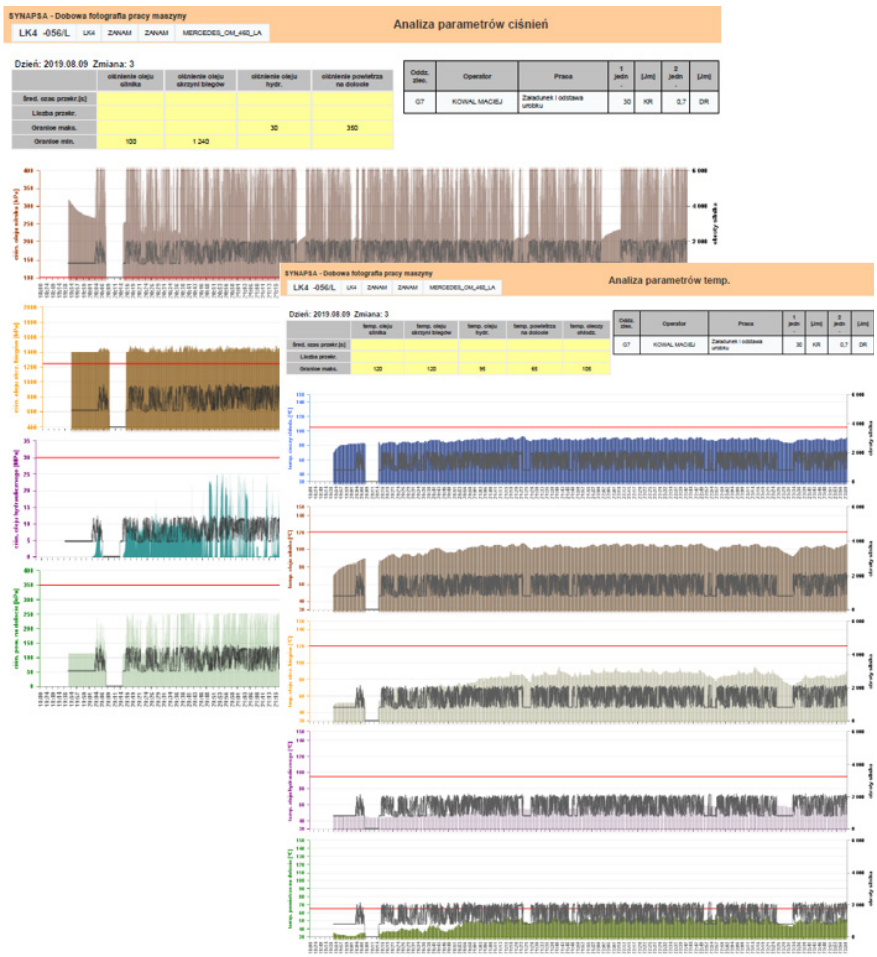

Fig. 5. Examples of time courses obtained for the LK4 during the registration of indications of the main measuring sensors – pressure parameters and temperature parameters

4. Conclusions

The life curve reflects the environmental and technical conditions of mining machinery operations. The period of effective work in terms of availability must correspond to economic conditions. Excessively high maintenance costs combined with a successive reduction in availability discredit the maintenance mode of machines after exceeding the recommended period of operation. The TCO total cost method based on historical data downloaded from

a data warehouse with the specialized SAP BusinessObjects software enables relating control parameters to machines from different manufacturers with different periods of effective use dedicated by companies. The mechanical inspection has a financial and technical instrument that allows the purchase of machines from the best manufacturers and their operation in the periods that allow obtaining the most favorable technical and cost parameters.

The introduction of the current monitoring of the operation of machines allowed for the effective observation of the behavior of operators with the simultaneous transmission of information on the current technical condition of individual machines. Additional data from monitoring may be used during the performance of OT-1, OT-2, OT-3 technical inspections as a current indication of deficiencies that could not be included in the standard procedures of individual inspections.

The successive modernizations based on the observation of control parameters obtained on an ongoing basis from measuring sensors indicate favorable development activities allowing for the conversion of mechanical systems into more favorable ones in terms of failure-free operation over an extended period of operation.

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Building the Image of a State-Owned Company: the Case of KGHM Polska Miedź S.A.

Summary

The present paper is an attempt to show how KGHM Polska Miedź S.A. carries out image building activities in the micro and macro environment. The subject of its considerations is also the analysis of the results of research related to the diagnosis of areas that have the strongest impact on the positive reception of this copper holding.

Keywords: Image, image communication, social responsibility, information management

BUDOWANIE WIZERUNKU SPÓŁKI SKARBU PAŃSTWA NA PRZYKŁADZIE KGHM POLSKA MIEDŹ S.A.

Streszczenie

Artykuł stanowi próbę wykazania, w jaki sposób KGHM Polska Miedź S.A. realizuje działania na rzecz budowania wizerunku w bliższym i dalszym otoczeniu. Przedmiotem rozważań będzie również analiza wyników badań związanych z diagnozowaniem obszarów, które najsilniej wpływają na pozytywny odbiór miedziowego holdingu.

Słowa kluczowe: wizerunek, komunikacja wizerunkowa, odpowiedzialność społeczna, zarządzanie informacją

1. Introduction

The state–owned companies intensify the efforts aimed at building the positive image in its micro and macro environment[1]. The effective brand positioning on the market is no longer determined solely by the implementation of newer and newer products or technologies. Currently, an important role in shaping the image is played by a number of determinants influencing the reception of the company by consumers. According to Jerzy Widerski, the image is not created by an particular entity, which role is limited only to providing some information about itself. It is only on its basis that the environment constructs its specific image[2]. A positive perception of a company is therefore a consequence of a fully conscious strategy implemented on many levels. Image communication plays a special role in this process. Anna Barcik considers it to be the basic public relations tool used in creating an image[3]. Over the years the communication between organizations and their target groups has undergone a particular metamorphosis[4]. These changes are closely interconnected, among others, with the dynamic development of communication technologies, implementation of the concentrated marketing programs or the consumer awareness concerning the area of communication[5]. The abovementioned phenomenon was pointed out by Dominik Lewiński, who perceives image communication in a much broader way. The researcher refers to it as „the complex communication", which consists of, among others, CI programs, public relations, corporate culture, advertisement, marketing, branding, corporate behaviour, internal communication, sponsorship etc.[6] The concept of branding proposed in the text thus embodies a new approach to brand marketing and includes, among others, communication strategy[7]

1 The term „micro environment" is understood here as activities aimed at building a positive image among employees, cooperation with local governments or local entrepreneurs. In turn, „macro environment" is defined as activities of national and international scope.

2 Widerski J., *Komunikacja językowa w public relations*, Wydawnictwo KPSW, Jelenia Góra 2015, p. 30.

3 Barcik A. (2012), *Public relations sztuka zarządzania organizacjami*, „Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego", No. 93, Siedlce, p.10.

4 Wyrwisz J., *Nowe media w kreowaniu wizerunku organizacji, Problemy Zarządzania, Finansów i Marketingu*, No. 41, t. 1, 2015, „Zeszyty naukowe Uniwersytetu Szczecińskiego" No. 875, p. 211.

5 Macnar A., *Moc employer brandingu – jak zbudować skuteczną strategię marki pracodawcy*, „Personel i Zarządzanie", No. 8, 2016, p. 13-16.

6 Lewiński D. (2009), *Komunikacja marketingowa a ideologia. Rzecz o kulturyzacji rynku.*, „Ideologie w słowach i obrazach", Wrocław, p. 164.

7 Under the notion of image communication, we understand all communication activities aimed at micro and macro environment.

and image identity[8]. A right image can significantly influence the interest among investors and increase access to capital markets, which should result with lowering the costs of the capital. It means that the image may be as one of the intangible resources of organization.

Therefore, it seems justified to say – despite the lack of quantitative measures – that the image of an organization is currently one of the most important factors shaping its market position and competitiveness. Economists believe that it has a measurable value, although its quantification is a difficult challenge. Moreover, a positive image of a company affects the probability of certain successes and failures. Experience has proved many times that entities enjoying a favourable image are much better at coping with all kinds of crisis situations[9]. It is one of the reasons why this problem is increasingly often a subject of consideration of researchers[10]. Their interests focus on the particular aspects of image related to, among others, the meaning of logos and advertising slogans[11], the support of enterprises for different pro–ecological programs or the use of social responsibility in creating an image[12]. The companies also put a lot of effort into being perceived as „good employers". For this purpose, they use appropriate communication instruments to influence the external and internal stakeholders. Thanks to a properly developed image projection, the organization informs different groups that it is perceived as a valuable partner, while work or cooperation with enterprises with a good image is a value in itself[13].

The companies shape their image also in other areas as well. Scholars emphasize that knowledge has become the main factor of production[14] and that highlighting the innovativeness of an organization is favourable. Companies

8 Skrzypek E, Pinzaru F., *Marka jako ważny element marketingu*, „Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach", „Administracja i Zarzadzanie" serie, No. 114, 2017, p. 198.

9 Widerski J., *op. cit*., p. 30.

10 Knap-Stefaniak A., *Kształtowanie wizerunku współczesnej firmy – wybrane zagadnienia*, „Zeszyty Naukowe Akademii Finansów i Biznesu Vistula", Warszawa 2015, p. 108-117.

11 Krzysztofek A., *Społeczna odpowiedzialność w kreowaniu wizerunku przedsiębiorstwa*, „Zarządzanie i Finanse", Vol 13, No. 3/2/2015, p. 85-86.

12 Iwacewicz-Orłowska A., *Koncepcja społecznej odpowiedzialności przedsiębiorstw i jej wpływ na wizerunek firmy*, „Przedsiębiorstwo & Finanse", 2016, No. 1(12), p. 31.

13 Czopek M., Kazusek M., *Employer branding – istota, narzędzia, cele, korzyści*, Obraz-Pamięć-Media, „Zeszyty Wydziału Humanistycznego" No. 18, Greń P., Morawski K. (ed.), Wydawnictwo KPSW, Jelenia Góra 2020, p. 195-233.

14 Stefaniuk K., *Innowacyjność i jej znaczenie dla korporacji*, „Zeszyty Naukowe Wyższej Szkoły Humanitas w Sosnowcu", Zarządzanie 2019(1), p. 38.

increasingly undertake initiatives addressed to the members of local communities, support sport events and manage the media coverage[15]. However, the scale of responsibility and number of areas in which the image campaigns are implemented are incomparably greater and more heterogeneous than in the case of non–state companies. The large state–owned companies are special in that they also take under consideration the social and political aspects in their image–building activities. These aspects directly or indirectly correlate with the image of Poland influenced by changing international conditions.

The present paper attempts to demonstrate how the state–owned company KGHM Polska Miedź S.A. carries out activities to build the image in the micro and macro environment. The subject of reflection will also be the analysis of the results of research related to the diagnosis of areas that have the strongest impact on the positive perception of the copper holding.

2. Research methodology and source materials

A quantitative research was carried out for the purposes of the present study. A questionnaire containing closed and semi–open single and multiple choice questions was applied as a main research tool. Their scope included the issues related to:

1. identification of the meaning of the slogan advertising the enterprise,
2. the characteristics of the slogan,
3. areas that most effectively build a positive image of state–owned company
4. diagnosis of the most effective media channels used in the image projection process.

Subsequently, the press materials distributed by KGHM Polska Miedź S. A. became the subject of the analysis. The researchers checked if the information contained therein has met the expectations of stakeholders from the micro and macro environment.

15 Białopiotrowicz G. (2009), *Kreowanie wizerunku w biznesie i polityce*, Wydawnictwo Poltext, Warszawa, p. 12.

3. Research results

The electronic questionnaire was delivered to 1,054 inhabitants of the Copper Basin. 774 respondents correctly completed and returned their questionnaires. The survey was conducted between November 10th and December 20th, 2021. The answers show that the respondents are residents of centers of various sizes, belong to different age groups and have various education. The characteristics of the people covered by the study are presented in the table below.

Table 1. Characteristics of the respondents

Characteristic features	Percentage value
Gender:	
Male	45,4
Female	54,6
Age:	
below 20 years	5,4
20–25 years	10,9
26–30 years	12,2
31–35 years	13,8
36–40 years	11,6
41–45 years	13,4
46–50 years	14,5
over 50 years	18,2
Place of residence:	
A village	21,2
A town of below 5 thousand inhabitants	0,9
A town of 5 to 10 thousand inhabitants	3,6
A town of 10 to 15 thousand inhabitants	6,8
A town of 15 to 25 thousand inhabitants	18,4
A town of 25 to 50 thousand inhabitants	28,3
A town of 50 to 100 thousand inhabitants	20,8
Education:	**Percentage value**
Junior high school	0,9
Secondary or vocational	39,0
University degree (bachelor/ingeneer)	30,6
University degree (Master/PhD)	29,5

Source: own study based on the conducted research

According to over 89% of respondents, an advertising slogan and a persistent logo is an important element of building the image of the state–owned companies. However, only 47% of the respondents were able to name at least one slogan advertising a state–owned company. The most frequently mentioned (probably because of living in the Copper Basin and its vicinity) was the slogan promoting KGHM: „The future is made of copper".

In the next research question, the respondents were to specify what, in their opinion, a good slogan advertising a state–owned company should look like. The respondents could indicate the five most important characteristics, but not all of them took advantage of this opportunity. Some of the respondents listed only two, three or four characteristics. The total number of responses obtained was thus 2516. The table below shows (in absolute numbers) the characteristics of a good advertising slogan of state–owned companies in the opinion of the respondents.

Table 2. Cechy dobrego hasła reklamowego spółek Skarbu Państwa

Characteristic	The number of indications (in absolute numbers)
Easy to memorize	719
Simple language	623
Referring to the characteristic features of a company/its activity	609
Original	243
Witty	170
Bond/building	152

Source: own study based on the conducted research

The next question was to diagnose the areas which, in the opinion of the respondents, have the strongest impact on the positive image of state–owned companies. The respondents had the opportunity to indicate five most important areas. Only some of them took advantage of this opportunity. They most often indicated three areas. That translated into the total number of responses, which amounted to 2,385. The table presented below shows, in absolute numbers, the areas which, in the opinion of the respondents, have the strongest impact on the favourable image of companies.

Table 3. The areas that build the favourable image of the state–owned companies most efficiently

Areas	The number of indications (in absolute numbers)
Activities for the benefit of the local community	632
Ecology	563
Sports sponsorship	428
Innovations	357
Pro/family programs aimed at the employees	305
Involvement in important domestic matters	100

Source: own study based on the conducted research

The survey was also aimed at identifying the most effective communication channels used to promote the activities and building the image of state–owned companies. Therefore, the respondents were to indicate the media (or events) which, in their opinion, were the most effective in promoting companies. The subjects could choose up to five indications. Only a small part of them took advantage of this opportunity. The total number of responses was 2,212. The table below shows (in absolute numbers) the media and events that, in the opinion of the respondents, can be most efficiently used to promote the image of companies.

Tabela 4. Media i wydarzenia o największym potencjale w budowaniu wizerunku

Media	The amount of indications in absolute numbers
Social media	513
Websites	492
Television (nationwide channels)	384
Cultural/sport events	353
Radio (nationwide channels)	217
Billboards	130
Local radio channels	71
Local television channels	52

Source: own study based on the conducted research

4. KGHM as a social responsibility leader

On the basis of the presented results of quantitative research, one can conclude that the offer proposed by KGHM Polska Miedź S. A. corresponds with the expectations of stakeholders from the close and more distant environment. This is especially exemplified by activities for the benefit of the local community (632 indications, see Table 3). The more important events include, among others, the next edition of the interdisciplinary conference entitled „Together for the family", organized by the company together with the local authorities of Legnica. It was attended by the local politicians of the cities and communes of the Copper Basin, school principals, educators and representatives of non–governmental organizations from all over the region. The discussions concerned, among others, challenges in education and recommended programs for children, teenagers and families. As part of this project, other preventive and aid programs, which are implemented and financed by KGHM, were also summarized, including: „School of Parents and Educators", „Leadership Academy of the Top Educators" and „Children in the Virtual Network" guidebooks.

5. KGHM as a patron of science

KGHM Polska Miedź S.A. from the very beginning of its existence has engaged itself in the cooperation with the local schools training for the professions important for the company[16]. From 2018, these activities were specified and significantly intensified. The contents of the curricula were defined as part of the project: „Competent in the mining and metallurgical industry. KGHM – a key partner in vocational education". As part of this project, patronage classes were created in nine schools from the following counties: Legnica, Bolesławiec, Lubin, Głogów and Polkowice. The company also cooperates with universities.

In 2020, KGHM Polska Miedź S.A. signed an agreement with the Jan Wyżykowski University regarding dual education in the direction of studies of Mining and Geology. The university in Polkowice is one of the four

16 https://kghm.com/pl/kariera/dla-uczniow/kompetentni-w-branzy

universities in the country, Which offers a possibility of academic studies in this area. As part of the agreement, both parties developed and modified the contents of the existing curricula. Seminars are conducted by specialist staff who work in a copper holding on a daily basis. KGHM has also offered consultancy and assistance for universities in equipping teaching and research laboratories. Joint scientific conferences and broadly understood activities for the benefit of the region are being organized. The agreement concluded between the Jan Wyżkowski University and KGHM has also opened new forms of development for the students, most of whom are employees of the company. They have the possibility of, among others, undergoing apprenticeships and internships at plants owned by KGHM. Under the agreement, there are also scholarship programs for the best students and graduates of universities, who are to be the competent staff of the copper company in the future.

6. Out of concern for health

The mental health of the region's inhabitants has recently become a subject of special concern for the copper holding. As part of the preventive program „In depression you are not alone", people leaving in the region can get the help of psychologists free of charge, participate in support groups or sessions dedicated to teachers and youth workers. In 2021, KGHM Polska Miedź S.A. celebrated the 60th anniversary of its activity. On this occasion, the company released a jubilee album titled *60 good CSR practices for 60 years of KGHM*. The publication contains a description of KGHM's activities categorized into several topic groups among others around issues related to physical health, education, ecology and social relations. In the introduction to this study, the president of the company Marcin Chludziński emphasizes the essence of implementing social projects dedicated to beneficiaries from the micro environment:

KGHM's social projects are addressed to the employees who are our most valuable capital, but also to the local community: families, friends, neighbors and acquaintances of our staff. Together with them, we build a local community. Only in cooperation with local authorities, with the support of experts and resources of non–governmental organizations, we can move mountains and effectively

respond to socially significant challenges[17].

KGHM Polska Miedź S. A. for many years has been a regular participant of aid actions carried out not only in the region, but throughout the country. Difficulties occurring over the last several months, related with the Covid–19 pandemic, significantly intensified the company's activity in this area. From the beginning of the pandemic, the copper holding supported the government's activities focused, among others, on equipping existing medical facilities or creating new modular hospitals. As part of this project, sanitary materials were transferred to health centers, local government institutions and social welfare homes.

The copper holding also joined the project entitled „Solidarity Corps of Seniors Support" organized in cooperation with the Ministry of Family and Social Policy. The program assumed taking a number of actions to support seniors – a „special risk" group in the context of Covid–19 pandemic. The project included, among others, bringing groceries, care for animals, but also online support in performing official or payment–related activities. KGHM Polska Miedź S. A. donated nearly PLN 400,000 for the latter purpose, and 28,000 seniors in the region benefited from the help of volunteers[18].

7. Conscious sponsorship

Sponsorship of sport by state–owned companies is becoming a more and more frequent form of building a positive image and reaching customers. KGHM Polska Miedź S.A. regularly supports sport at local, national and international level. The company's activity in this area results from the goals set out directly in the Business Strategy. As indicated by the research results presented above, according to the respondents (438 responses, see Table 3), sport is one of the most important areas influencing the positive perception of the company. Financing sport not only warms the sponsor's image, but also facilitates the building of the image of the company as environmentally conscious and maintaining good relations with the local community. This plays an important role, especially in industrial investments (for example, in the energy sector or natural resources exploitation), where the ecologi-

17 www.kghm.com/60praktykCSR

18 https://zdrowie.kghm.com/solidarnosciowy-korpus-wsparcia-seniorow/

cal assessment often determines the success of a given project. In the case of building a positive image in the micro environment, the company supports, among others, football club – KGHM Zagłębie Lubin (playing in Ekstraklasa – the top-level–level Polish league) and local associations through the Polska Miedź Foundation. In recent years, the holding sponsored the sport players from Lubin who represented Poland on the international arena, including tennis player Łukasz Kubot, winner of the Australian Open (2014) and Wimbledon (2017) in doubles and skater Natalia Czerwonka, who won a silver medal of the Olympic Games in Sochi (2014). The support of local champions could contribute to an even more favorable reception of the company by the local community, but also build its positive image in the macro environment.

8. The future is made of copper

In 2021, KGHM Polska Miedź S.A. celebrated the 60th anniversary of its foundation. The ceremonial gala, concerts, scientific conferences, an occasional exhibition and a film promoting the company were parts of the celebration. As we can read in the official announcement of the holding: „The 60th anniversary is an opportunity to emphasize the role of the company on the international stage"[19]. During the celebrations, President Marcin Chludziński emphasized that KGHM has a huge impact not only for the Polish, but also for the global economy:

KGHM Polska Miedź S.A. reminds the world of this on the 60th anniversary of our company, which as a global producer of copper and other valuable metals, thanks to its heritage and strong position, is called an Explorer, Giant and Visionary[20].

As part of the celebrations, also a new slogan promoting the company was presented. It sounds „The future is made of copper". It refers to constantly changing trends in the global economy, the development of electromobility, electronics, renewable energy and medicine. The slogan also contains a message related to the vision of the future, modernity and the guarantee of the

19 https://kghm.com/60praktykCSR

20 https://www.money.pl/gospodarka/60-lat-kghm-koncern-ktory-ma-ogromny-wplyw-na-polska-gospodarke-6634299246508992a.html

company's functioning in the next years – „copper is durable and resistant to rust"[21]. Since ancient times copper have been playing a crucial role in the development of human civilization. Although time has passed, no substitute for copper has been invented in the most of its application. All the aforementioned factors make the copper industry extraordinarily stable, regardless of some natural and inevitable market fluctuations[22]. Referring to the results of quantitative research presented above, it can be stated that the slogan advertising KGHM Polska Miedź S.A. meets the expectations of the respondents. In their opinion, the password should be easy to remember, expressed in simple language and refer to the specifics of the company's operations.

9. Conclusions

The image–building campaigns of statestate-owned–owned companies in Poland are more extensive and involve more aspects than the branding activities of companies whose activities are financed exclusively from private sources. The actions of KGHM Polska Miedź S.A. confirm this statement. The results of the presented quantitative research correspond to the actions undertaken by KGHM and meet the expectations of stakeholders from the micro and macro environment. This means that the image strategy is well thought out, its individual elements harmonize with each other, creating a coherent whole. This fact allows us to draw another conclusion: KGHM Polska Miedź S.A. precedes and supports the implementation of individual image campaigns with the research of expectations and deep analyzes. The company's activities in the field of image–building can be described as effective. An example confirming the above conclusion has been, among others, the new advertising slogan proposed on the occasion of the 60th anniversary of the company in 2021: „The future is made of copper", which after a relatively short period of time became known to the stakeholders, as was shown by the qualitative research. Selected aspects of the image–building of KGHM Polska Miedź S.A. analyzed and cited in the study show the multifaceted nature of the undertaken initiatives and professional attitude in their implementation.

21 https://plus.gazetawroclawska.pl/wierzymy-ze-przyszlosc-jest-z-miedzi/ar/c3-15586400

22 https://www.pb.pl/polska-miedz-na-wszystkich-krancach-swiata-945321

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https://www.pb.pl/polska–miedz–na–wszystkich–krancach–swiata–945321;
https://www.pb.pl/polska–miedz–na–wszystkich–krancach–swiata–945321;
http://www.proto.pl/aktualnosci/swiadomy–sponsoring–spolek–skarbu–panstwa
https://plus.gazetawroclawska.pl/wierzymy–ze–przyszlosc–jest–z–miedzi/ar/c3–15586400
https://zdrowie.kghm.com/solidarnosciowy–korpus–wsparcia–seniorow/

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Selected aspects of innovation activity

Summary

The article describes selected issues related to innovative activity in Poland. It indicates, *inter alia*, the low level of innovativeness of Polish enterprises. Statistical data show that a significant number of Polish companies are not active in the area of innovation, giving the main reasons for the lack of adequate resources – financial, infrastructural, human resources, and know-how, as well as uncertainty about the effects of future activities. Taking into account the above-mentioned Problems, this article attempts to propose possible forms of cooperation that could encourage these companies to start operating in the area of innovation.

Keywords: innovation, strategic alliance, cluster initiative, cluster

WYBRANE ASPEKTY DZIAŁALNOŚCI INWESTYCYJNEJ

Streszczenie

Artykuł opisuje wybrane kwestie dotyczące działalności innowacyjnej w Polsce. Wskazuje między innymi na niski poziom innowacyjności polskich przedsiębiorstw. Dane statystyczne wskazują, że znaczna liczba polskich firm nie jest aktywna w obszarze innowacyjności podając jako główne powody brak odpowiednich zasobów – finansowych, infrastrukturalnych, kadrowych i know-how, jak również niepewność odnośnie efektów przyszłych działań. Biorąc pod uwagę ww. problemy, w niniejszym artykule podjęto próbę zaproponowania możliwych form współpracy, które mógłby zachęcić te firmy do rozpoczęcia działalności w obszarze innowacji.

Słowa kluczowe: innowacja, alians strategiczny, inicjatywa klastrowa, klaster

1. Introduction

The ongoing globalization processes force enterprises to intensify their activities in the field of innovation or broadly understood research and development works. Active activity in these areas leads to an increase in market competitiveness, an increase in sales and profits. As the statistical data show, only approx. 20% of Polish enterprises conduct innovative activities. Statistical data show that a significant number of Polish companies are not active in the area of innovation, giving the main reasons for the lack of adequate resources – financial, infrastructure, human resources, and know-how, as well as uncertainty about the effects of future activities. Taking into account the above-mentioned Problems, this article attempts to propose possible forms of cooperation that could encourage these companies to start operating in the area of innovation.

One can find many definitions of innovation in the literature. The PWN Encyclopedia[1], following PF Drucker, defines innovations as „new, newly introduced things; in the economy, implementing new technologies, creating organizations and institutions". A similar approach was adopted in the European Union and OECD,[2] defining innovation as implementation, i.e., the introduction to the market of a new or improved product (product or service) or the use of a business process in economic practice, workplace organization, or in relations with the environment. It should be noted that the above-mentioned definition of a new product or process is concerned a given enterprise, and not the generally understood market, industry, or segment.

The main breakdown of innovation based on the Oslo Manual 2005[3] is as follows:

– Process innovations: implementation of a new or significantly improved production method or method in the field of logistics, methods of creating, and providing services. These innovations may, apart from the basic

1 Drucker P.F., *Innowacje i przedsiębiorczość. Praktyka i zasady* [in]: Encyklopedia PWN https://encyklopedia.pwn.pl/haslo/innowacje;3914833.html [access: 05/01/2022].

2 *Działalność innowacyjna przedsiębiorstw w latach 2017-2019*, Wegner M. (ed.), Warszawa 2020. https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/nauka-i-technika/dzialalnosc-innowacyjna-przedsiebiorstw-w-latach-2017-2019,2,18.html?pdf=1 [access: 05/01/2022].

3 *Oslo Manual Guidelines for Collecting and Interpreting Innovation Data, Third Edition, OECD/Eurostat* [in:] *Innowacje i transfer technologii. Słownik pojęć*, Matusiak K.B. (ed.), Warszawa 2021, pp.106-109 https://www.parp.gov.pl/component/publications/publication/innowacje-i-transfer-technologii-slownik-pojec [access: 05/01/2022].

activity, concern auxiliary activities (e.g., purchases, accounting, repairs). Process innovations lead to a reduction in the unit cost of production, increase in quality, and process efficiency;
- Product innovations: implementation of a product or service that is new or significantly improved in terms of their functional characteristics or the intended use;
- Marketing innovations: implementation of a new marketing method, which may include significant changes in the field of design and packaging, methods of selling products/services, their promotion and advertising, or methods (strategies) of pricing products and services; the purpose of these innovations is to better meet the needs of customers, enter new markets, change the position of products, which ultimately leads to an increase in sales;
- Organizational innovations: implementation of a new organization method in the field of business practices, workplace organization, or relations with the environment; the aim of this innovation is, inter alia, increasing operational efficiency, reducing administrative costs, increasing employee satisfaction and commitment, and improving the organization's communication and learning ability.

Carrying out innovative activities in an enterprise is always associated with leaving the comfort zone, based on existing knowledge or experience, and opening to new ways of functioning. The above division shows how wide the range of activities may be, which in turn leads to an increase in the effectiveness of the conducted activity. Innovation is the driving force from the point of view of the company and more broadly from the point of view of the economy. Therefore, government administration authorities in Poland, and more broadly also the European Commission, pay special attention to this area by financing research and development activities directly in the form of grants or subsidies or indirectly through the tax relief system, thus encouraging enterprises to incur expenditure on development. Statistical data[4] shows that in 2017–2019, public financial support for innovative activities was transferred to 19.6% of innovation-active industrial enterprises and to 16.1% of service enterprises.

4 *Działalność innowacyjna przedsiębiorstw w latach 2017-2019*, Wegner M. (ed.), Warszawa 2020, p.71. https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/nauka-i-technika/dzialalnosc-innowacyjna-przedsiebiorstw-w-latach-2017-2019,2,18.html?pdf=1 [access: 05/01/2022].

According to the terminology of the Central Statistical Office of Poland, innovatively active[5] enterprises are those „which in the analyzed period introduced at least one product or business process innovation or implemented at least one innovative project during this period, which was interrupted or abandoned during the analyzed period (not successfully completed) or hasn't been completed (i.e., it continues) by the end of this period '. Arguably, this definition is quite broad and may even include companies that have started innovative work and have not implemented it for various reasons. Despite this approach, the statistical data for 2010-2019[6] show that the share of innovative enterprises in the total number of enterprises is not significant – it ranges from 16–19% (the highest indicator is 24% in 2018) – but shows an upward trend.

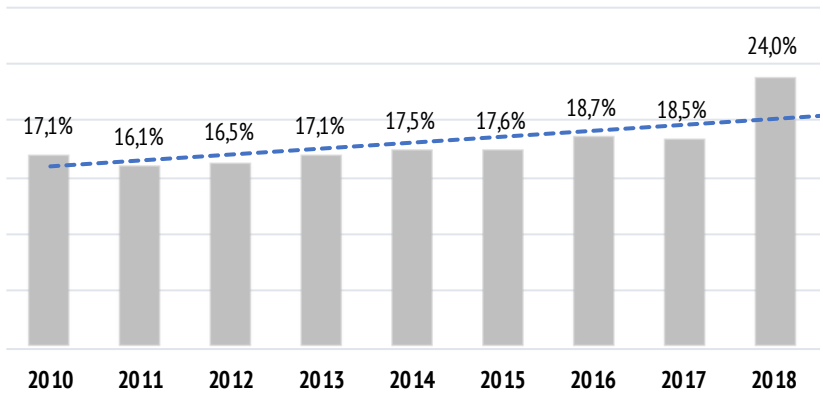

Fig. 1. The share of innovative enterprises in the total number of industrial enterprises (employing 10 people and more)

Source: *Innovative activity of enterprises in 2017-2019*, Wegner M. (ed.), Warsaw 2020, p. 20.

A significant percentage of companies in Poland are enterprises that have not undertaken innovative activity. Research conducted for PARP[7] shows the reasons why companies did not undertake activities in favor of innovation. They are presented in Fig. 2.

5 Wegner M. (ed.), *Activity…*, *op. cit.* p. 27.
6 Wegner M. (ed.), *Activity…*, *op. cit.* p. 27.
7 *Monitoring innowacyjności polskich przedsiębiorstw. Wyniki III edycji*, Warszawa 2020. www.parp.gov.pl/storage/publications/pdf/Raport_Monitoring-innowacyjnosci-polskich-przedsiebiorstw-III-edycja-2020.pdf [access: 05/01/2022].

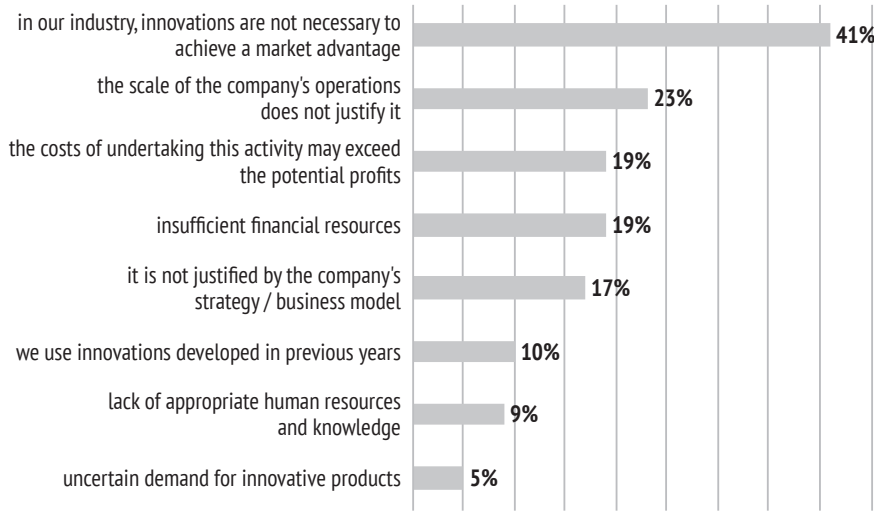

Fig. 2. Share of respondents' responses – enterprises indicating the reasons for not undertaking innovative activity on the basis of PARP research (Companies inactive in terms of innovation, N = 810)

Source: *Monitoring of innovativeness of Polish enterprises. Results of the 3rd edition*, Warsaw 2020.

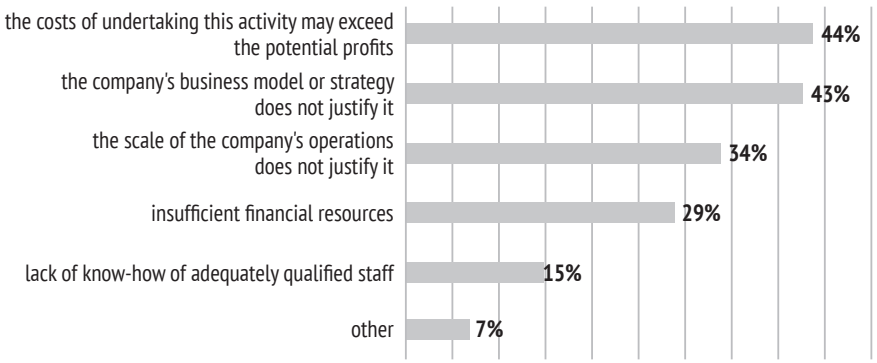

Fig. 3. Share of respondents' responses – enterprises indicating the reasons for not undertaking innovative activity on the basis of KPMG research. N = 430 companies which in the last three years did not understand work on at least one type of innovation. The respondents could choose any number of answers.

Source: *Dojrzałość innowacyjna przedsiębiorstw w Polsce, raport KPMG*, Warszawa 2014, p. 17.

Similar conclusions emerged from research conducted a few years earlier by KPMG in Poland[8]. They are presented in the Fig. 3.

The first reason why companies do not conduct innovative activity is the belief that it does not influence the market advantage in a given industry. It seems incomprehensible, perhaps due to the fact that companies are not precisely specified or not informed about possible innovative changes, e.g. improvement of efficiency in business processes or undertaken marketing activities, which can be improved in each company, which translates into an increase in its competitiveness.

Another reason for the lack of innovative activities is the scale of operations or the size of the company. For example, small, local companies may have a passive attitude to activity in the area of innovation, resulting from the fact that they either do not realize the need for changes or do not see the need to introduce them due to the fact that the current scale is satisfactory for them.

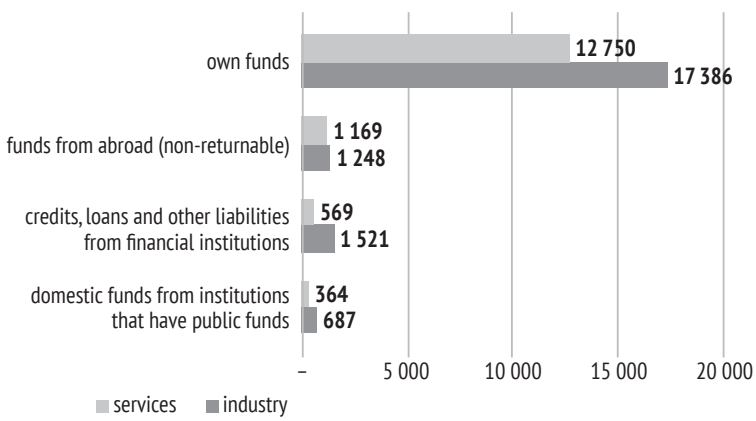

Fig. 4. Sources of financing of expenditure on investment activities in 2019 (in PLN million)

Source: *Działalność innowacyjna przedsiębiorstw w latach 2017-2019*, Wegner M. (ed.), Warszawa 2020, p. 65.

8 *Dojrzałość innowacyjna przedsiębiorstw w Polsce, raport KPMG*, Warszawa 2014, p.5. http://kpmglaw.pl/wp-content/uploads/2014/07/Dojrzalosc-innowacyjna-przedsiebiorstw-w-Polsce-KPMG-2014.pdf [access: 05/01/2022].

One of the reasons mentioned is the lack of sufficient financial resources to cover expenditure on innovation. As the statistical data show[9], despite the wide range of possibilities of financing innovative projects from public funds, it is companies' own funds that are the main source of financing innovative activities (approx. 84. Fig. 4. presents the sources of financing of expenditure on investment activities in 2019 (in PLN million).

As mentioned above, own funds are the primary source of financing investment activities (83% in industrial enterprises, 86% in services), followed by non-returnable funds from abroad (approx. 6%), liabilities from financial institutions constitute 7% among industrial enterprises and 3% in services. The smallest amount of funds for innovations was obtained from domestic institutions with public funds (approx. 3%.)

Another reason why the surveyed companies do not undertake innovative activities is the uncertainty as to the future profits from the expenditure incurred and the uncertain demand for innovative products, which may be related to:

– lack of sufficient knowledge about the effects of innovative activities and, as a consequence, the reluctance to bear the risk of investing in this activity,
– knowledge, supported by market research, that innovative action is unprofitable.

Another reason for not taking up activity in the area of innovation is the lack of appropriate targets in this field in strategic documents, plans, or owners' visions. For this reason, enterprises do not deal with this subject, focusing on current operations and sales.

Another important reason why enterprises do not undertake innovative activities is the lack of staff with sufficient qualifications in areas that could potentially be subject to innovation processes.

Therefore, the question arises what are the possible options that could encourage enterprises to develop within the innovative activities undertaken.

Two conditions for potential cooperation were adopted, which it would have to meet in order for the undecided to be inclined to undertake innovative activity:

– minimal investment in innovation,

9 *Działalność innowacyjna przedsiębiorstw w latach 2017-2019*, Wegner M. (ed.), Warszawa 2020, p.65. https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/nauka-i-technika/dzialalnosc-innowacyjna-przedsiebiorstw-w-latach-2017-2019,2,18.html?pdf=1 [access: 05/01/2022].

– access to resources (human resources, infrastructure), know-how, including in the field of innovative solutions adequate to the conducted activity.

Fulfillment of the above-mentioned conditions is associated with involvement in such projects that would enable:

– co-financing of innovative activities by other entities – diversification of financing sources towards obtaining non-returnable funds or from other business partners;
– exchange of resources, in particular, the knowledge (know-how) – starting cooperation with selected partner institutions, such as:
  - enterprises belonging to the same industry, customers, competitors,
  - consulting companies, commercial laboratories, suppliers of equipment, materials, components or software,
  - scientific institutions (universities, public research institutes (including scientific institutes of the Polish Academy of Sciences),
  - public sector entities (national and local government administration bodies),
  - non-profit organizations

The table below presents the possible forms of innovative activity in the enterprise and their assessment, taking into account the above-mentioned criteria for possible activity in this area.

Table 1. Comparison of possible forms of innovative activity in an enterprise

Criterion: / Form:	co-financing of innovative activities	sharing knowledge
Innovative activities of enterprises at their own expense	(-)	(-)
Ordering the performance of innovative activities to an external entity in the form of a commercial agreement	(-)	(+)
Strategic Alliances	(+)	(+)
Cluster initiative	(+)	(+)
Joint-venture with an entity with the required know-how (capital investment)	(-)	(+)

(-) minus means that the criterion is not met, (+) plus means that the criterion is met

Source: Author's research.

Analyzing the above results, the optimal choice of the form of development towards increasing innovation is a strategic alliance, which has been

losing its importance in recent years in favor of cluster initiatives. It seems that both solutions meet the expectations of companies that have not been innovative so far.

2. Strategic alliances

Strategic alliance in the area of research and development, often the so-called knowledge alliance is a form of cooperation within innovative activities that has existed for many years.

There are many definitions of strategic alliances. According to M. Romanowska, a strategic alliance is a cooperation between competing, current or potential companies, which affects the situation within the same or related sectors, ie competitors, customers, or suppliers[10].

A strategic alliance is also defined[11] as an agreement between many independent entities that decide to jointly implement a project or conduct specific activities, coordinating competencies, methods, and necessary resources for action (B. Garette, P. Dussauge).

The researchers of the topic by Karaś A.[12] and[13] Chwałek J. lead to the conclusions that the development of innovative activity may be the subject of alliances, grouped according to YL Doz and G. Hammel[14] into the following types of alliances:

– Joining forces – an agreement concluded between existing competitors, which is aimed at weakening or eliminating the remaining competition,

10 Romanowska M., *Alianse strategiczne przedsiębiorstw*, Warszawa 1997, p.15.

11 Walas-Trębacz J., *Znaczenie zawieranych aliansów strategicznych dla przedsiębiorstw produkcyjnych w Polsce*, „Ekonomika i Organizacja Przedsiębiorstwa", 2016, No 7, p. 80. https://www.researchgate.net/publication/329786940_Znaczenie_zawieranych_aliansow_strategicznych_dla_przedsiebiorstw_produkcyjnych_w_Polsce [access 05/01/2022].

12 Karaś A .. *Alianse wiedzy i ich wpływ na działalność innowacyjną przedsiębiorstwa*, „Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie", 51(3), 2021, pp. 75-85. https://doi.org/10.25944/znmwse.2021.03.7585 [access: 05/01/2022].

13 Chwałek J., *Alians strategiczny jako droga do innowacji*, „Roczniki Ekonomiczne Kujawsko-Pomorskiej Szkoły Wyższej w Bydgoszczy", 2013, p.84. https://bazhum.muzhp.pl/media//files/Roczniki_Ekonomiczne_Kujawsko_Pomorskiej_Szkoly_Wyzszej_w_Bydgoszczy/Roczniki_Ekonomiczne_Kujawsko_Pomorskiej_Szkoly_Wyzszej_w_Bydgoszczy-r2013-t6/Roczniki_Ekonomiczne_Kujawsko_Pomorskiej_Szkoly_Wyzszej_w_Bydgoszczy-r2013-t6-s79-89/Roczniki_Ekonomiczne_Kujawsko_Pomorskiej_Szkoly_Wyzszej_w_Bydgoszczy-r2013-t6-s79-89.pdf [access: 05.01.2022] .

14 Doz Y.L., Hammel G., *Alianse strategiczne. Sztuka zdobywania korzyści poprzez współpracę*, Gliwice 2006, p.25

thanks to which the Allies have a larger market share. As part of the innovative objectives, the entities of the alliance exchange research and development resources, achieving synergy effects in the implementation of product and process innovations.
- The alliance of combining competencies – creating a partnership network in order to exchange knowledge and skills (know-how), specific and unique at various stages of the production, sales, etc. process; the effect of the alliance is the creation of a comprehensive solution for customers, the creation of a new quality.
- Knowledge acquisition alliance – the acquisition of knowledge and skills from the Allies through observation and direct learning during the cooperation of mixed teams or the exchange of Allied employees; enabling access to knowledge by entities with a stronger market position.

The strategic alliance is one of the ways of co-financing innovative activities by the Allies, thus optimizing the expenditure on this activity. Alliances are concluded by independent entities for closed periods – until the goal of the alliance is achieved. Any number of enterprises, even 2-3 entities, can participate in alliances.

The advantage of a strategic alliance is that it does not bind the partners in an irreversible way, and at the same time increases the sense of security of cooperation in comparison with ordinary market relations.

In Poland, alliances are not popular among entrepreneurs, which may be due to the shortage of social capital and a relatively low level of business ethics[15].

Due to the fact that the possibilities of financing the activities of alliances from public funds are limited, they are losing popularity in favor of clusters.

3. Cluster initiatives

Polish legal regulations do not regulate the concepts of a cluster and a cluster initiative. According to Porter, the[16] cluster is „a geographical cluster of interconnected companies, specialized suppliers, units providing services,

15 Chwałek J Strategic Alliance…, *op. cit*.., p. 88.

16 Porter M.E., *Porter o konkurencji* [in:] Lis A., Lis A., *Klaster, inicjatywa klastrowa, powiązanie kooperacyjne – rozróżnienie pojęć.* https://www.researchgate.net/publication/329590772, 2018. [access: 05/01/2022].

companies operating in related sectors and related institutions in particular fields, competing with each other, but also cooperating". The EU definition for cluster financing is „a group of companies, related economic entities, and institutions that are close together and have a sufficient scale to develop expertise, services, resources, suppliers, and skills"[17]. Therefore, they are ecosystems of enterprises and partner institutions formally linked in order to achieve the goals and ideas for which they have cooperated.

The concept of a cluster initiative is also ambiguous. According to Lis A., a cluster initiative is comprised of organized activities for the development of the cluster undertaken by and in cooperation with various entities. A similar approach is presented by Sölvell, Lindvist[18], Ketelsin a report for PARP, stating that the initiatives serve to strengthen and develop clusters, increasing their competitiveness in the region, including companies operating within the cluster, governmental and scientific-research institutions.

In other definitions, an initiative is referred to as the cluster seed or the cluster itself. Including the definition of a cluster initiative used in GUS reports[19] says that „for the purposes of research on innovation, it is a cooperative relationship, formally established on the basis of a letter of intent, an association agreement, an agreement to establish a consortium, etc.".

An important role in the process of establishing a cluster initiative is played by the initiator or leader, i.e., an inspiring organization in whose interest it is the establishment or development of the cluster. The initiator may or may not be the sponsor of the cluster initiative, or as a consequence the cluster. Most often, the initiator can be:

- An enterprise or a group of enterprises from one industry (most often small and medium-sized enterprises) that perceive the need for development, and their resources do not allow it,
- State administration institutions (public sector), operating on the basis of the adopted goals of national cluster programs or local strategies.

In cluster organizations, it is necessary to emphasize the strong influence of the state policy directions related to the development of specific indus-

17 *Smart Guide to Cluster Policy,* European Commission 2016. https://ec.europa.eu/growth/content/smartguide-cluster-policy-published-0_en.

18 Sölvell Ö., Lindqvist G., Ketels C., *Zielona Księga Inicjatyw Klastrowych. Inicjatywy Klastrowe w gospodarkach rozwijających się i w fazie transformacji,* Warszawa 2008, p. 17.

19 *Działalność innowacyjna przedsiębiorstw w latach 2017-2019*, Wegner M. (ed.), Warszawa 2020, p.82. https://stat.gov.pl/obszary-tematyczne/nauka-i-technika-spoleczenstwo-informacyjne/nauka-i-technika/dzialalnosc-innowacyjna-przedsiebiorstw-w-latach-2017-2019,2,18.html?pdf=1 [access: 05/01/2022].

tries in the regions (including intelligent specialization of regions) and the dependence on this financing of their activities.

Depending on the type of cluster, the number of companies being its members ranges from a minimum of 15 (seed cluster) to a minimum of 51 (KKK – National Key Cluster).

An incentive to set up initiatives, and consequently clusters, are undoubtedly financial incentives under programs financed from EU or other public funds, even despite the fact that the level of financing is decreasing (in 2016-17 it decreased to PLN 23.5 million from PLN 140 million between 2012 and 2014)[20].

The Fig. 5. shows the percentage of industrial enterprises cooperating under a cluster initiative or in other formalized types of cooperation (enterprises employing 10-249 people).

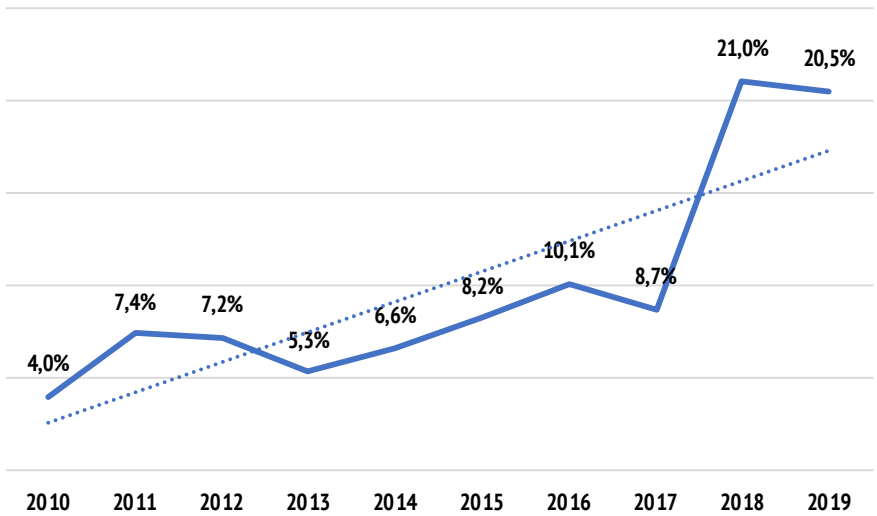

Fig. 5. The chart below shows the percentage of industrial enterprises cooperating under a cluster initiative or in other formalized types of cooperation (enterprises employing 10-249 people)

Source: *Działalność innowacyjna przedsiębiorstw w latach 2017-2019,* Wegner M. (ed.), Warszawa 2020, p. 65.

20 *Benchmarking klastrów w Polsce – edycja 2018*, Wielec Ł. (ed.) Warszawa 2018, p.7. https://www.parp.gov.pl/component/publications/publication/benchmarking-klastrow-w-polsce-edycja-2018 [access: 05/01/2022].

Cluster initiatives most often operate in the form of projects, and their activities are financed by the participants of the initiative on terms mutually agreed between them in the formal documents, such as a letter of intent, association agreement, etc. An important role in cluster organizations is played by the trust and loyalty of partners – companies that often compete with each other.

As mentioned above, cluster initiatives support the activities of clusters and the implementation of their goals. As indicated by the results[21] of the 2019 study, commissioned by the European Observatory of Clusters and Industrial Change on a group of 29 European countries, 49 European regions, and 10 countries outside Europe, respondents (answers to 29 programs) indicated three main objectives of cluster programs as:

- strengthening cooperation structures between companies/industry and science,
- increasing the competitiveness of small and medium-sized enterprises,
- supporting activities in the field of internationalization,
- which indicates that the main idea of clusters is related to the development of their participants towards increased competitiveness on the local market and expansion into international markets.

All of the goals indicated by the respondents are presented in the Fig. 6.

It is worth noting that supporting innovative abilities is the fifth goal indicated by the respondents. Above In its conclusions, the report refers to the issue of innovation in clusters and assesses the activity of clusters in this area very poorly[22] – 50% of the surveyed clusters did not score 0.04 in this sub-area (maximum score 0.46) on a scale of 0–1. The reason for this state of affairs was the lack of highly qualified human resources and significant financial outlays in comparison to other areas of clusters' activity.

21 *European Observatory for Clusters and Industrial Change, Cluster programmes in Europe and beyond* [in:] *Kierunki Rozwoju Polityki Klastrowej w Polsce po 2020 roku*, Citkowski M. (ed.), Warszawa 2020, pp. 20-21, www.gov.pl [access: 05/01/2022].

22 *Benchmarking klastrów w Polsce – edycja 2018*, Wielec Ł. (ed.) Warszawa 2018, p.31. https://www.parp.gov.pl/component/publications/publication/benchmarking-klastrow-w-polsce-edycja-2018 [access: 05/01/2022].

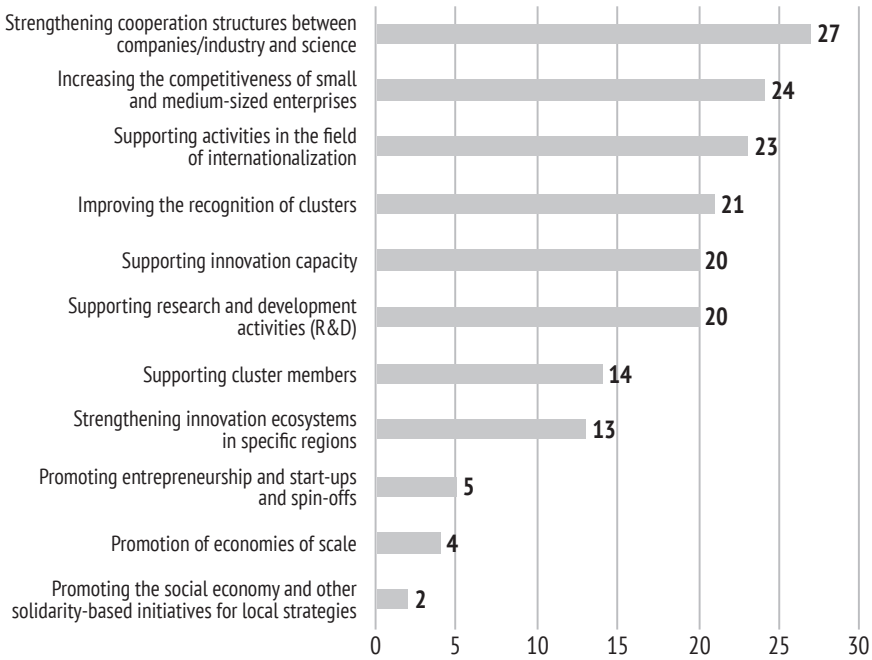

Fig. 6. Objectives of cluster programs on the basis of the European Observatory of Clusters and Industrial Change

Source: *European Observatory for Clusters and Industrial Change, Cluster programs in Europe and beyond* [in:] *Directions of Cluster Policy Development in Poland after 2020*, Citkowski M. (ed.), Warsaw 2020, p. 21.

4. Conclusions

The article analyzes selected aspects of innovative activity in Poland and attempts to indicate possible solutions initiating cooperation of entities, leading to the development of companies in this area in order to increase their competitiveness. Statistical data shows that only approx. 20% of Polish enterprises are innovatively active, which places us in the group of European countries with a moderate level of innovation[23]. A significant percentage of

23 „Moderate innovators", "moderate innovators" – in the European Innovation Scoreboard 2020 (europa.eu)

enterprises is not interested in undertaking innovative activities, motivating it with the following reasons:
- no need to incur expenditures due to the industry in which they operate or the scale of operations,
- lack of adequate resources – financial resources, human resources, know-how, infrastructure,
- lack of sufficient knowledge whether the effects of the innovative activities undertaken will be satisfactory, or whether there will be a high demand for new products.

It seems that the above reasons for the lack of innovative activity could be eliminated as part of the accession of enterprises to strategic alliances or cluster initiatives.

The above solutions can be used both in the case of large companies as well as small and medium-sized enterprises that are not able to conduct research work on their own.

Joining strategic alliances or cluster initiatives in order to implement various innovative plans is beneficial mainly for the following reasons:
- expenditure on innovation is optimized by co-financing projects or free exchange of knowledge; Cluster innovations (clusters) seem to be more beneficial, as they can additionally benefit from public support while implementing the region's policy,
- knowledge and experience are shared in selected aspects related to the increase in innovation, resulting in the development of enterprises and reducing the risk of wrong business decisions.

Strategic alliances are a flexible form of cooperation also for a small number of entities (2-3) that want to benefit from cooperation, not being able to solve their problems on their own. Cooperation in the form of clusters concerns a greater number of entities (minimum 15), but its advantage is the possibility of obtaining non-returnable financing and the implementation of regional policy.

Cooperation in both cases, especially of companies competing with each other, requires compliance with the principles of business ethics.

Qualitative research[24] confirms that the cooperation of Polish entrepreneurs in the innovation process is most often incidental and does not con-

24 *Monitoring innowacyjności polskich przedsiębiorstw. Results of the 3rd edition*, Warsaw 2020, p. 83. www.parp.gov.pl/storage/publications/pdf/Raport_Monitoring-innowacyjnosci-polskich-przedsiebiorstw-III-edycja-2020.pdf [access: 05/01/2022].

dition the technological development of enterprises. The main reason for this is the limited trust in entities and the assessment of the benefits of this cooperation.

The principles of cooperation and the terms of using innovative solutions should be precisely defined in formal documents (letter of intent, association agreement, etc.) before starting cooperation, which should allow for the protection of the interests of individual entities and avoiding possible disputes in the future.

It does not matter which of the above forms a given entity decides to implement in order to implement innovative activities because both provide opportunities for development and optimization of resources for its implementation.

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Biographical note

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Assessment of the organization's maturity to implement innovative solutions in the area of knowledge management and verification of the implemented tools supporting this process in the copper industry, on the example of KGHM Polska Miedź S.A.

Summary

The effectiveness of knowledge management is now one of the key elements determining the success of an organization. Creating a knowledge management strategy and the gradual implementation of its individual components is perceived as a feature of innovative companies. The publication aims to present the results of quantitative and qualitative research concerning the assessment of the organizational maturity of KGHM Polska Miedź S.A. in the field of knowledge management and the assessment of the IT services provided to support information searches in KGHM. The analysis of the research results also allowed to identify the benefits related to the implementation of the KGHM Search application. Moreover, the study shows the diagnosed development barriers in the discussed area, indicating, *inter alia* the need to reduce organizational and technological shortages in the field of communication and information gathered in the organization. The article presents the conclusions of the conducted research and proposes a set of recommendations that may increase the innovativeness of the entire organization.

Keywords: knowledge management, organization maturity, innovation, KGHM Search application, development barriers

OCENA DOJRZAŁOŚCI ORGANIZACJI DO WDRAŻANIA INNOWACYJNYCH ROZWIĄZAŃ W OBSZARZE ZARZĄDZANIA WIEDZĄ ORAZ WERYFIKACJA WDROŻONYCH NARZĘDZI WSPIERAJĄCYCH TEN PROCES W BRANŻY MIEDZIOWEJ NA PRZYKŁADZIE KGHM POLSKA MIEDŹ S.A.

Streszczenie

Efektywność zarządzania wiedzą jest obecnie jednym z kluczowych elementów decydujących o sukcesie organizacji. Tworzenie strategii zarządzania wiedzą i stopniowe wdrażanie jej poszczególnych elementów jest postrzegane jako cecha firm innowacyjnych. Celem publikacji jest przedstawienie wyników badań ilościowych i jakościowych dotyczących oceny dojrzałości organizacyjnej KGHM Polska Miedź S.A. w zakresie zarządzania wiedzą oraz oceny świadczonych usług informatycznych wspomagających wyszukiwanie informacji w KGHM. Analiza wyników badań pozwoliła również na identyfikację korzyści związanych z wdrożeniem aplikacji KGHM Search. Ponadto w opracowaniu wskazano zdiagnozowane bariery rozwojowe w omawianym obszarze, wskazując m.in. na konieczność ograniczenia niedoborów organizacyjnych i technologicznych w zakresie komunikacji i informacji gromadzonych w organizacji. W artykule przedstawiono wnioski z przeprowadzonych badań oraz zaproponowano zestaw rekomendacji, które mogą wpłynąć na wzrost innowacyjności całej organizacji.

Słowa kluczowe: zarządzanie wiedzą, dojrzałość organizacji, innowacyjność, aplikacja KGHM Search, bariery rozwoju

1. Introduction

The enterprises of the copper industry certainly belong to the organizations that operate in conditions determined by changing market conditions, uncertainty, and high risk. This means the need to take actions aimed at increasing efficiency, improving competitiveness, and reaching organizational maturity. The conditions that must be met to cope with this pressure are the ability to adapt to the ongoing and observed changes and an ability to

utilize organizational and technological possibilities. The development of management concepts and information technologies shows the direction of the necessary changes. The implementation of a knowledge management strategy and IT tools supporting its implementation can significantly contribute to maintaining the company's position on the market, strengthening it, and preventing potential crises in the organization at an early stage. Knowledge, which is understood as a sphere that allows one to utilize an idea about reality[1] and implement it, as well as and the information system in which methods, techniques, technologies, and computer tools are used, therefore[2] becoming elements of innovative organizations. Other features of an innovative enterprise are the ability to learn, the ability to forecast, and to effectively and rationally make changes.[3] The degree of innovation depends on how management and employees approach innovation. Continuing the deliberations based on the area in question, it should be emphasized that an innovative enterprise is also one that can use an incentive system to stimulate and enhance the creativity of employees and entrepreneurship of the managerial staff[4]. Developing appropriate attitudes of employees requires a specific organizational culture. In short, knowledge management is a method that allows one to achieve a significant advantage over the competition in an unconventional way. For the implementation of knowledge management to be possible and effective, the organization must be characterized by many important features, including achieving a certain maturity and having effective support tools. The purpose of this publication is to present the results of research on the maturity of KGHM Polska Miedź S.A. to implement the knowledge management strategy and to evaluate the available tools supporting this process. Another aim of the study is to present the identified development barriers of the organization.

1 Flaszewska S., *Projektowanie organizacyjne w zarządzaniu wiedzą*, Warszawa 2017, p. 14.
2 Patalas-Maliszewska J., *Modele referencyjne zarządzania wiedzą w przedsiębiorstwie produkcyjnym*, Warszawa 2019, p. 16.
3 Krawczyk-Sokołowska I., *Kreatywność stymulatorem postaw proinnowacyjnych w przedsiębiorstwie*, „Zeszyt Naukowy SGH w Warszawie", 162/2018, p. 61.
4 Romanowska M., *Innowacyjne przedsiębiorstwo w nieinnowacyjnej gospodarce*, in: „Przegląd Organizacyjny" 2015, no 8, p. 6.

2. Methodology

In the conducted empirical research, the quantitative measurement method was used, in the form of an anonymous questionnaire addressed to employees who have permanent access to the IT tools used at KGHM Polska Miedź S.A. The questionnaire was delivered to 159 respondents, selected randomly from among employees who had permanent access to the dedicated KGHM Search application. Subsequently, the qualitative method was used – a focus group study, in the form of a group focus interview, which was attended by 20 employees of R&D departments. The above methodological triangulation allowed for the collection of knowledge enabling the drawing of conclusions and the development of recommendations. Empirical research was preceded by an analysis of the literature, materials, and documents of the organization, allowing, inter alia, to diagnose behavioral artifacts and the level of compliance with the standards and values in force at KGHM Polska Miedź S.A. This approach also allowed for the identification of barriers delaying the implementation of innovative knowledge management.

The quantitative and qualitative research was carried out from November 30, 2020 – December 21, 2020. The anonymous questionnaire consisted of 16 questions (closed and open questions). The purpose of the survey was to obtain information on the evaluation of the IT system in the form of the KGHM Search application as a tool enabling searching and obtaining information in the KGHM Group. The application acts as a corporate search engine that gives access to connected information resources. The survey was active for 3 weeks, and its availability was preceded by an article published on the intranet, presenting the specificity and capabilities of the above–mentioned application. According to the design assumption, the Search KGHM application was created and implemented to facilitate users' access to the rapidly growing amount of electronic information in the organization. The provided IT service is to serve as a tool for finding information, supporting operation, and maintaining central information resources (repositories). The search engine supports the processes of acquiring knowledge by providing a search mechanism for file and database resources as well as application data used in KGHM by content (websites, Sharepoint applications, file resources, repositories, IBM Case Manager). The project was implemented by the adopted strategy in the field of "Tele–IT for the Capital Group" and

its requirements, replacing the technology of systems losing manufacturer support (SharePoint 2010 technology).

Qualitative research, in the form of an author's interview, including 26 questions, was, due to the pandemic, carried out online using Skype. In the focus study, the participants were first introduced to the process of assessing the organization's maturity and the areas in which it would be conducted. Organizational maturity has been defined as a certain continuum of the company's development towards an objectively considered mature organization. The point of reference was the CMM organization maturity model (an acronym for Capability Maturity Model)[5]. The core of the focus study on the maturity analysis of KGHM Polska Miedź SA was the comparison of the existing status with the recommended (target) status. The maturity analysis, the results of which were integrated into the form of a radar chart, was carried out in the areas of culture and organizational structure, processes, motivation, leadership, and technology.

3. Research results

The survey provided quantitative data showing the area and scale of using KGHM's Search application, its benefits, and showed its functionalities as assessed by the respondents. In the first place, attempts were made to determine how the employees acquired knowledge relevant to the substantive task area before the implementation of the tool? Respondents could choose from three priority sources. After aggregating the responses, four main sources were diagnosed. Almost 73% of respondents indicated that they previously obtained knowledge mainly from colleagues. The detailed results are shown in the Fig. 1.

Subsequently, the research aimed to determine how much KGHM employees use the application prepared for them. One might expect that the tool has become a permanent fixture in the minds of the employees and sup-

5 The CMM model was created directly at the request of the US Department of Defense, which, due to dissatisfaction with the quality of IT products supplied, commissioned the development of a reference list that would help assess the ability of software companies to fulfill government orders. The proposed approach turned out to be simple and effective, so the CMM was quickly adapted (by creating its successive versions) to evaluate companies operating in other industries – Grela G., *Assessment of the level of process maturity of the organization*, in „Social Inequalities and Economic Growth", 2013 No. 35, p 172.

ports the performance of daily tasks. However, the results do not confirm the abovementioned assumption. Over 43% of respondents use the tool less than once a month, and only less than 3% of respondents indicate that the discussed tool supports them in their daily work.

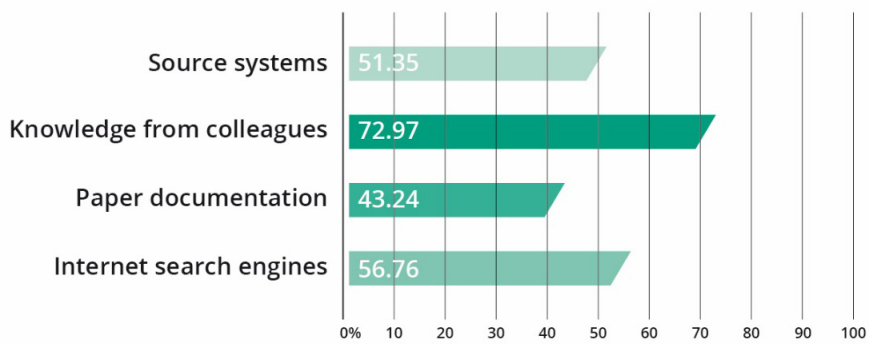

Fig. 1. Sources of knowledge acquired before the introduction of KGHM's Search application

Source: author's research.

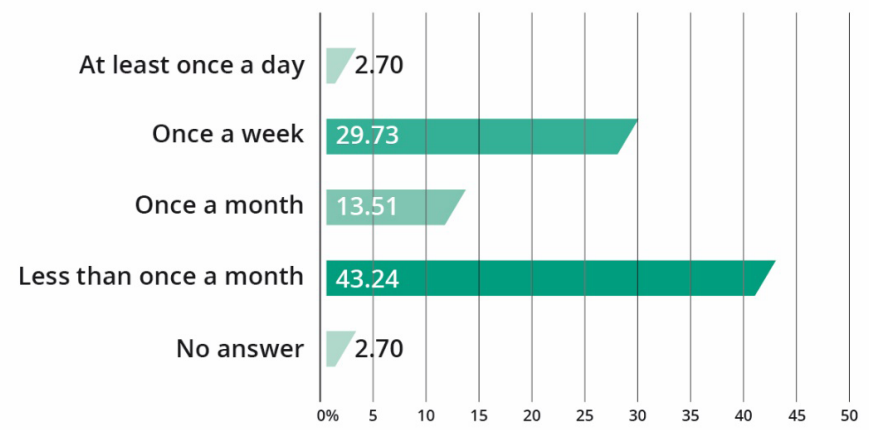

Fig. 2. The intensity of using Search KGHM

Source: author's research.

It was also important to diagnose the benefits of implementing the application and making it available to employees. The respondents had the opportunity to indicate the three most important, in their opinion, benefits.

The collected answers show that the main benefit is saving time instead of wasting it on (often fruitless) searches on the Internet. The pooled data from the studies also identified further benefits, as illustrated in Fig. 3.

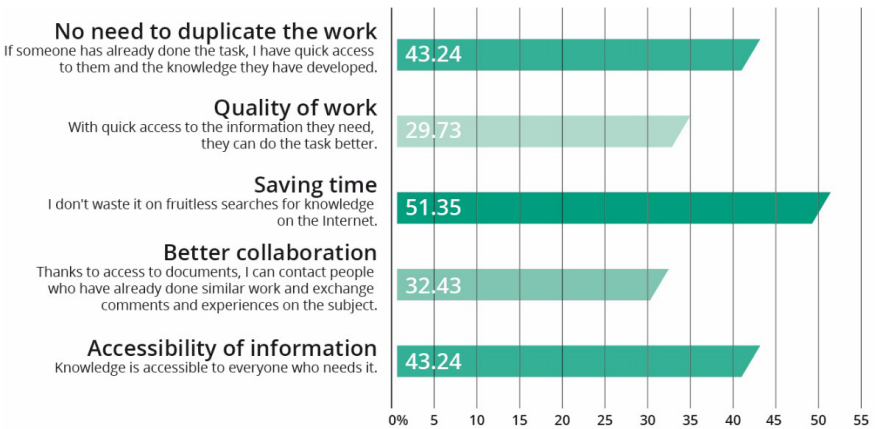

Fig. 3. Benefits of implementing the KGHM Search application

Source: author's research.

Despite the numerous and significant benefits related to the currently used software that had been diagnosed, the respondents indicated that the solutions used did not fully meet their expectations. They indicate that the IT services at their disposal should be constantly developed, especially in the area of further functionalities. The respondents emphasized their expectations regarding the possibility of searching for new resources functioning in the company, including mainly: purchasing areas, file resources, and corporate normative acts.

Qualitative research, conducted in the form of a group interview, was aimed at determining whether the discussed organization is mature enough to implement knowledge management and what areas are related to it? The table below shows a summary of the analyzed areas. For better visualization, the obtained results were also presented in the form of a graph, where the area marked with the inner oval indicates the current level, while the surrounding oval indicates the recommended level.

Table 1. Summary of the results of the focus group studies on the assessment of KGHM's maturity in the area of knowledge management

Area	Current situation in KGHM	KGHM's aspirations
Organisational culture	1.33	3
Organisational structure	1.0	3
Processes	1.25	3
Motivation	1.0	3
Leadership	1.25	3
Technology	1.0	3

Source: author's research.

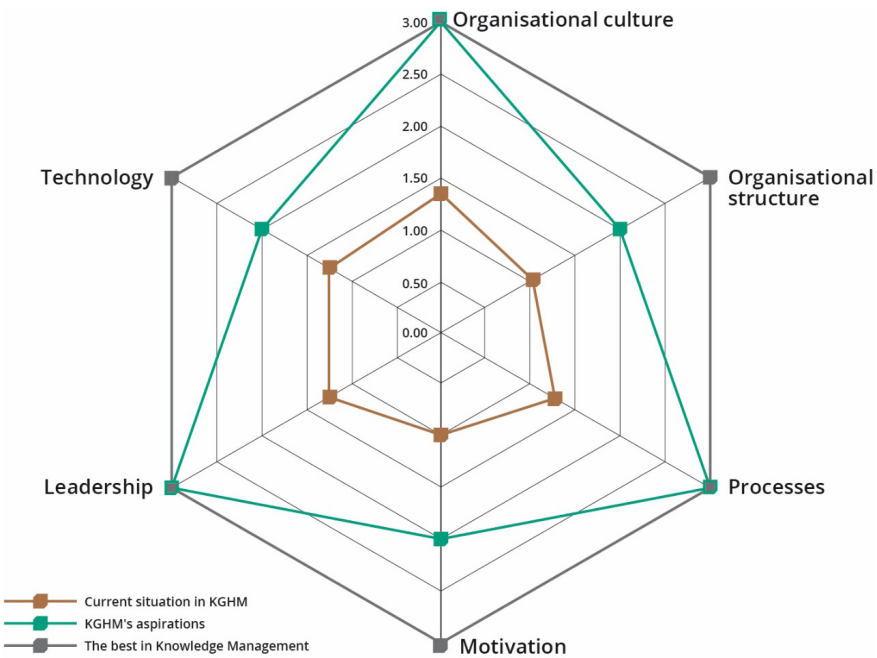

Chart 1. Assessment of KGHM's maturity in the area of knowledge management

Source: author's research.

The conducted analysis shows that in the area of organizational culture, processes, and leadership, the largest gap (58%) exists between the existing state and the target situation defined in strategic assumptions. In other areas, the difference is 50%, but it should be noted here that the level of ma-

turity of the organizational structure and technology does not have to be maximum for the criteria for effective knowledge management to be met. Based on the above results, it is possible to define the directions of strategic support that may allow for closing or minimizing the diagnosed gaps in individual factors that make up the organization's maturity for knowledge management. One can indicate here the precise definition of the methods of collecting, storing, and sharing knowledge, defining the roles supporting the process (e.g. appointing experts, mentors), adjusting the motivation system to the needs of the staff, supporting effective communication and change management, and the evolution of the organizational culture aimed at smoother implementation of the adopted strategy. The implementation of the above–mentioned measures may also have a positive impact on the reduction of negative phenomena that crystallized as a result of the conducted research and which should be considered as development barriers of the diagnosed organization. Among them, the respondents most often indicated:

- strong internal divisions, silos, e.g. headquarters – divisions, departments;
- corporate culture, where the overriding goal is to take care of the formal side;
- ineffective horizontal and vertical communication;
- mental islands – division us and them,
- overly strong security policy of access to internal and external information and
- organizational and technological shortages in the field of communication and access to information gathered in the organization.

4. Conclusions and recommendations

When analyzing the results of the focus research in the area of assessing the maturity of the organization, there are several important issues to pay attention to. Firstly: for knowledge management to be effective, it is necessary to remodel the organizational structure, which would counteract information asymmetry and consist in flattening the organizational structure. The flatter the structure, the lower the tendency to block information.

Secondly: the leadership change should be aimed at reducing formalism, delegating decision–making powers, and introducing employee participa-

tion in the knowledge management processes. The third area that requires modification is supporting the concept of changes through adequate processes describing it and increasing its acceptance among employees. Further, to optimize the organizational structure, it is important to create studies that precisely set the directions of development and define the areas of change so that they become a map for future proceedings. It should also be possible to open up the organizational culture, which in turn will guarantee dialogue between individual cells and contribute to the shaping of mechanisms facilitating cooperation. The motivational system should be seen as a stimulator of the knowledge management process. Therefore, it is worth leading to a situation, through the change of attitude, in which not only financial gratification but e.g. the prestige of work, recognition in the eyes of superiors or development opportunities will become appreciated by employees and will become important elements of the non–financial incentive system. It also seems important to define the priority goals and tasks of research and development teams in terms of systemic support for the implementation of knowledge management strategies in the discussed organization. The figure below shows the authors' proposals that may contribute to increasing the effectiveness of the knowledge management concept implemented by KGHM Polska Miedź S.A.

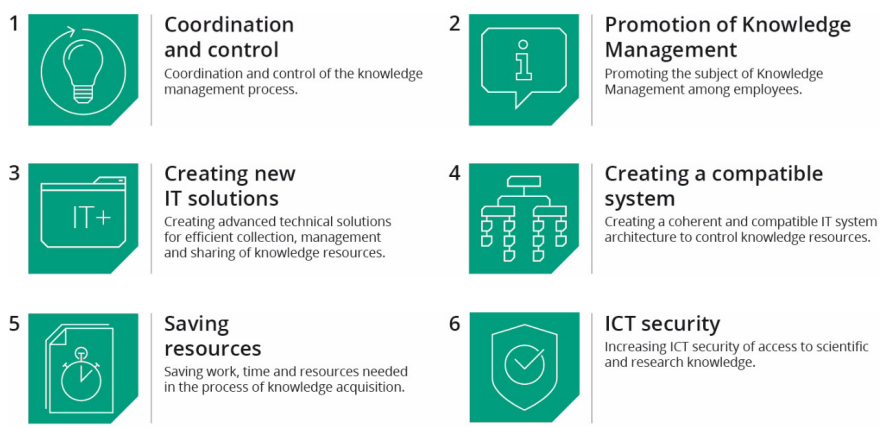

Fig. 4. Goals and tasks for the R&D area in the KGHM ZW process

Source: author's research.

Technology is a factor to support the processes involved in creating tools for collecting and storing knowledge and enabling the effective fulfillment of the roles assigned within the knowledge organization. Based on the analysis of the research results, it can be concluded that the discussed organization, in any of the analyzed areas, is not fully ready to implement the knowledge management strategy. The research results indicate the necessity to change (adapt) the company's organizational culture to the requirements of the concept being implemented. It is extremely difficult as it requires a transformation of employees' awareness and mentality. It's a long process. Therefore, it is necessary to start with equipping employees with IT tools that will enable effective and multi–faceted knowledge search. Adapting such tools can build the habit of sharing knowledge with other members of the organization over time. Based on the information collected from the research survey and the analysis carried out, business goals and further steps in the development of search systems in KGHM Polska Miedź SA can be defined. Business purposes include:

- enabling the employees of KGHM Polska Miedź SA to effectively use the experience of the organization and
- saving time by quickly obtaining the desired results of the information searched for.
- Developing search systems. Among the additional elements that may contribute to the increase in the effectiveness of the search engine, the following can be mentioned:
- expansion of the system with additional connectors, which will allow Search KGHM to search for information in the eKancelaria systems and normative acts in the future, and
- extending the group of users to the staff of the companies of the KGHM Polska Miedź SA Group.

The above goals and the projected development of the system are visualized in the Fig. 5.

In the future, the system should play the role of a corporate search engine that will enable users to quickly and easily gain access to all information resources in the entire KGHM Polska Miedź S.A. Group. In conclusion, the KGHM Search application is an effective tool in the area of knowledge search and thus supports knowledge management. Its widespread use and further development may positively affect the growth of employees' potential and more effective performance of their tasks. Access to corporate knowledge will improve organizational flexibility, due to the experience that shows

that faster adaptation to changing market conditions and turning them into success is possible with quick and full access to knowledge. Easy access and effective use of information resources gathered by KGHM will limit the duplication of tasks under previous projects in the discussed organization. The implementation of the KGHM Search system makes it possible to use the collected data and information both in the basic tasks and in complex proceedings regarding the verification of the legitimacy of the implementation of investment, research and development, and innovation initiatives. All such activities may significantly increase the efficiency of the entire organization.

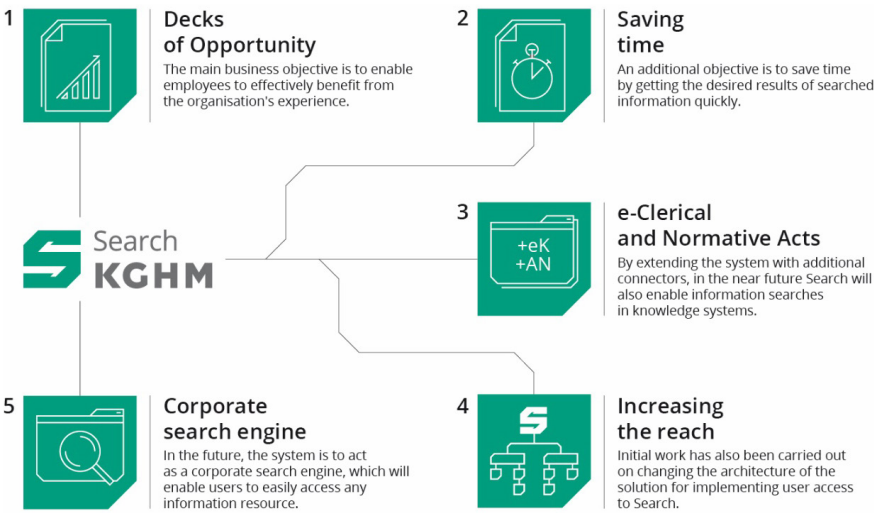

Fig. 5. Search KGHM – business goals and planned system development

Source: author's research.

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Since 2011, he has been working on independent engineering positions at various levels in KGHM Polska Miedź S.A. in the area of R&D.
Knowledge management is of interest not only from the scientific point of view but also from the professional point of view. He has extensive practical knowledge in the field of project management and research and development works. Over the last decade, he has participated in dozens of such tasks, also in the area of knowledge management and IT tools supporting R&D processes.

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The art of improvement. The implementation of process innovations in the areas of production and logistics of business activities

Summary

Improvement can be viewed in many different ways. For some it is almost an art related to the pursuit of perfection, for others, it is normality inscribed in everyday life, resulting from the culture of continuous improvement (Continuous Improvement), yet another may see it as the implementation of the principles of the KAIZEN philosophy, or alternatively, a requirement imposed by the employer or superiors. Improvement may refer to the organization of the enterprise or the processes implemented in the enterprise, but it may also refer to products constituting the subject of the company's activity. An effective method of improvement may be innovation related to various areas of the company's operation.

Keywords: company improvement, innovation, Lean Management, KAIZEN, continuous improvement

SZTUKA DOSKONALENIA – CZYLI RZECZ O IMPLEMENTACJI INNOWACJI PROCESOWYCH W OBSZARZE PRODUKCJI I LOGISTYKI PRZEDSIĘBIORSTW

Streszczenie

Doskonalenie może być postrzegane w bardzo zróżnicowany sposób. Dla jednych jest niemalże sztuką związaną z dążeniem do doskonałości, dla innych normalnością wpisaną w codzienność, wynikającą z kultury ciągłego doskonalenia (Continuous Improvement), dla jeszcze innych implementacją zasad

filozofii KAIZEN, a dla kolejnych wymogiem narzucanym przez pracodawcę czy przełożonych.

Doskonalenie może dotyczyć organizacji przedsiębiorstwa, czy realizowanych w przedsiębiorstwie procesów, ale może być odnoszone również do produktów stanowiących przedmiot działania firmy. Efektywnym sposobem doskonalenia może być innowacyjność odnoszona do różnych obszarów funkcjonowania przedsiębiorstwa.

Słowa kluczowe: doskonalenie przedsiębiorstwa, innowacyjność, Lean Management, KAIZEN, ciągłe doskonalenie

1. Introduction

Improvement is most often defined as all activities aimed at improving the functioning of an enterprise or person. Actions for improvement may be aimed at the enhancement of processes carried out in the enterprise or improvement of the enterprise organization, or they may comprehensively concern all aspects of the enterprise's functioning.

Improvement activities may be focused on a selected aspect of the company's operations, e.g. improving the level of product quality or improving the efficiency of using technical means of production or transport. Often, however, actions for improvement are broader and cover many aspects related to the company's operations.

Depending on the nature and orientation of the enterprise, the improvement actions may be local, e.g. improving the organization of the warehouse (raw materials or finished products); in the case of a silo organization of the company, or comprehensive (global, holistic), e.g. improving the flow in the company's logistic chain, or improving the quality of customer service, or reducing the transition time associated with handling a production order; in the case of a process-oriented enterprise.

Improvement activities may be aimed at improving the functioning of the company's core activity, e.g. improving the course (quality or efficiency) of production processes (in the case of a production company) or may relate to activities auxiliary to the company's operation, e.g. improvement of logistics activities in the area of raw materials warehouse (manufacturing company).

It is very important for the improvement of the company's operations and organization to measure the company's processes and states with appropriately selected and calculated indicators that should form a package (KPI's - key performance indicators) allowing for precise, comprehensive, unambiguous, and easy identification of states and processes carried out in the organization.

The multitude of possibilities to approach the issues of improving the enterprise, the processes implemented in it, and its organization means that, in principle, even though there are some universal features, methods, and principles in the improvement, conducting improvement activities requires an individual approach in each case. It is purposeful, to maintain the quality and efficiency of the activities carried out, to take into account the current situation in which the company is located, the expectations and preferences of the company and the stakeholders of changes, as well as the specificity of processes, organizations and many individual aspects and requirements.

2. Enterprise model

The introduction of the enterprise model presented below allows maintaining a systemic approach to issues related to enterprise improvement. This model transparently illustrates the elements influencing the functioning of the company and the characteristics that are the results of the company's operation.

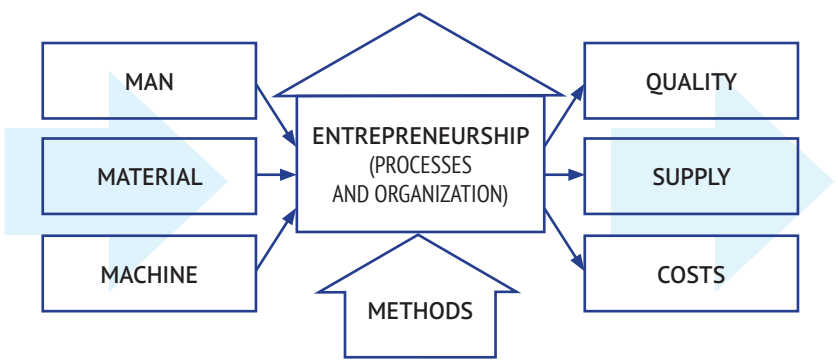

Fig. 1. Enterprise model

Based on the logic of the model presented above, it can be noticed that the results of the company's operation are essentially influenced by three factors, which are: people, materials, and machines.

In the model, the man represents all people related to the implementation of processes in the enterprise, both basic, e.g. production processes, and auxiliary, e.g. related to transport, information flow, quality control, product distribution, etc.

The material in the model means all materials, raw materials, and components used for production, as well as packaging materials, consumables necessary to maintain the continuity of production processes.

A machine is a general term for all machines used in the enterprise, both being technical means of production and means of transport, but also elements of technical equipment of workplaces (all technical facilities operated in the enterprise).

The fourth element constituting the input to the processes carried out in the enterprise is the knowledge that the organization has at its disposal. It translates directly into the company's methods (so marked in the model), procedures, standards, and technologies, sometimes referred to as the organization's "know-how".

The result of the company's operation is a product that, depending on the nature of the company's activity, may constitute a material product or a service. In the presented model, the product is represented by three categories of characteristics: quality, delivery, and costs associated with its creation (or the price for which it is offered). Deliveries mean meeting the logistic requirements for delivering the customer with the right product in the right amount, at the right time, and in the right place.

It should be noted that the improvement may concern the product, affecting the level of meeting the expectations or customer (recipient) satisfaction. Improvement activities may also relate to the processes carried out in the organization, which may translate into its functioning (efficiency, productivity, etc.), and only indirectly affect the product (process implementation costs affecting product costs, or minimizing the level of process and non-compliance with products affecting the quality of processes and possible minimization of the number of shortages of finished products).

3. Innovation

Innovation, issues related to innovative activities, and the implementation of innovations have become very popular in recent years. One can even get the impression that emphasizing the role of implementing innovation and innovation in the context of presenting the nature of activities carried out in business organizations has become a kind of fashion or rhetoric creating the currently desired image of the company. It should be emphasized that this is a very favorable trend, as long as it leads to a real interest in the implementation of innovative solutions and processes, or the development and implementation of innovative products (products and services) as well as process and organizational solutions improving the conditions of people's functioning and the quality of life in general.

Naturally, for many companies, openness to changes and the development and implementation of innovative solutions and processes are normality embedded in the organizational culture for a long time, which in the long-term perspective usually brings very good results in the area of building employee awareness and shaping mentality and attitudes full of openness to the need for continuous improvement.

The practical use of the KAIZEN philosophy, Continuous Improvement, or functioning in accordance with the PDCA cycle, also known as the Deming cycle, allows achievinging a permanent and stable competitive advantage.

It is worth considering what constitutes innovation? There are many definitions of innovation and innovative activities. According to most of them, innovative activities are the development and implementation of new or significantly improved products (products or services), but also processes, methods, and organization of the enterprise. It should be noted that here, new means that something is new for a given company or industry.

This naturally leads to the implementation of innovations through the transfer of knowledge and technology, the source of which are technologically advanced industries and entities, e.g. research centers, the space industry, the aviation industry, or the IT or electronic industry, from which the know-how goes to the automotive industry, or the machine industry, to be further transferred to the household appliances industry, the construction industry, the food industry, or the mining and heavy industry.

Often, R&D activities are also considered innovative, even if they do not lead directly to commercialization through the implementation of the obtained results or developed solutions implemented in business practice.

Therefore, innovation or innovative activities can be referred to in two basic categories: products and processes. As a consequence, it leads to the possibility of formulating two basic types of innovation:

– product innovations,
– process innovations.

The author's experience related to conducting improvement activities in production and service enterprises in the years 1993-2021 allows concluding that in the vast majority of business practice related to improving the functioning of enterprises, the implementation of process innovations is predominant, accounting for 80-90% of all innovative activities. Among product innovations, the most numerous are those relating to the use of innovative products and technical solutions in the field of collectivization, data analysis and information processing.

When considering innovation, it is worth paying attention to the source of innovative activities. Two concepts concerning the origin of the need to develop innovation in enterprises are particularly interesting here. The first one called the demand concept was presented by Jakob Schmookler[1], while the second one was proposed by Joseph Schumpeter and is called the supply concept[2].

The adoption of the above-mentioned concepts of the creation of innovations allows for the identification of areas in which innovative activity of enterprises is conducted. The demand concept presented by Jakob Schmookler shows that the source of innovation is in fact the need on the customer's side, which when communicated to the supplier may be a source of inspiration to take improvement actions aimed at meeting his expectations. Such a mechanism of generating innovative activities indicates that they are embedded in the area of a product (finished product or service), because it is the product that can satisfy the needs (demand) of the customer. Thus, in the case of the Schmookler's demand-driven concept of the occurrence of innovations, the generation of product-related innovations should be predominantly expected.

1 Schmookler J.: *Invention and Economic Growth*. Harvard University Press 1966.

2 Schumpeter J.: *Teoria rozwoju gospodarczego*. Państwowe Wydawnictwo Naukowe, Warszawa 1960.

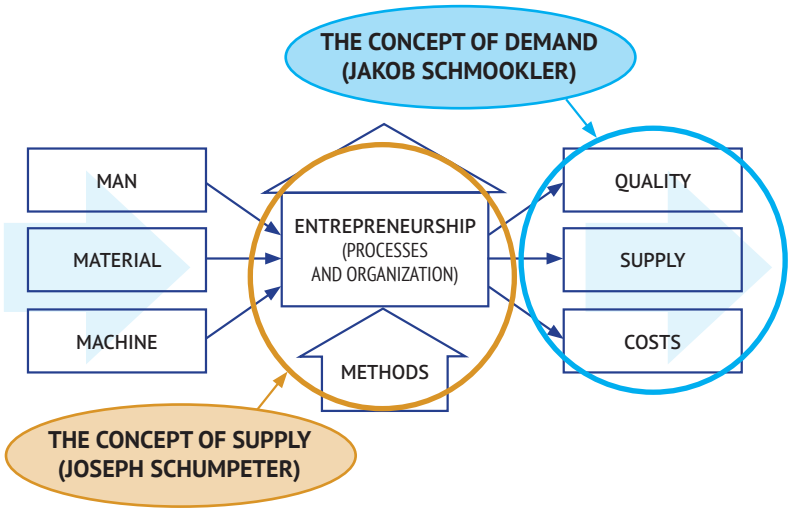

Fig. 2. A place where innovative activities are created and carried out

The situation is different in the case of the supply concept formulated by Joseph Schumpeter, according to which the source of innovation is mainly the creativity of the entrepreneur determining the emergence of innovation. In this approach, the entrepreneur decides about the emergence of innovations and is their stakeholder. Therefore, it can be expected that these changes should be in the nature of improving the processes implemented by the entrepreneur, because it is in this area that the allocated innovations are able to provide the entrepreneur with benefits, such as improving the quality of processes, their efficiency, better use of machines and tools and an increase in the productivity of employees, and better use of materials and raw materials. In the case of the supply concept of the occurrence of innovations given by Schumpeter, innovations of a process nature should be generated to a large extent.

The location of innovative activities in accordance with the concept of their formation and nature is presented in Fig. 2.

4. Four levels of improvement

In the overwhelming number of analyzed cases, the implementation of innovations in enterprises is of a process nature and is related to the improvement of process implementation and organization of the enterprise structure.

A good example of improving company processes can be the implementation of tools used in the Lean Manufacturing methodology.

Effective improvement is possible here on four levels. Naturally, the scheme of improvement activities will not be identical in every case, each time attention should be paid to the individual approach to the improvement activities carried out, taking into account the state and current situation of the company as well as preferences, expectations, and conditions related to the conduct of improvement activities.

Generally, it is possible to define and conduct activities improving the enterprise (its functioning, processes, and organization) at the following four levels of operation:

- solving local problems,
- improvement of areas and production lines,
- improving the flow of value,
- improvement of organizational activities.

Below are examples of improvement activities carried out in the area of implementation of process innovations as well as Lean Manufacturing methodology tools dedicated to improvement at various levels of the enterprise organization.

Solving local problems

It is possible by conducting point improvement dedicated to solving problems occurring locally at the level of individual workplaces or machines used in the implementation of production processes. It comes down to solving technical and organizational problems.

Activities at this level are profiled in order to ensure the stability of the implementation of production processes or the provision of services, which is the basis for further effective implementation of improvement activities and direct implementation of improvement activities. Examples of Lean tools and methods used at this level are:

- the use of the 5S method aimed at improving the stability of tasks performed by organizing workstations in a manner consistent with the

principles of ergonomics and building standards for the organization of positions,
- the use of visual management elements allowing for easy, unambiguous, and understandable identification of any deviations from the adopted standards and the expected values of process monitoring parameters,
- the use of the Poka-Yoke system solution that eliminates the possibility of making mistakes resulting in quality inconsistencies and the necessity to incur costs related to removing the effects of errors,
- the use of the SMED method to reduce changeover times, allowing for the improvement of the use of technical means of production or the reduction of the size of a series of production batches, which translates into a reduction of work-in-progress inventories and a reduction in the costs of implementing production processes.

Improvement of areas and production lines

It is possible by improving the material and information flows. Improvement activities at this level are aimed at creating logistic structures that allow for the implementation of continuous flow and optimization of material flow flows. This can be done, inter alia, by connecting production lines and minimizing or reducing buffers, resulting in the elimination of work-in-progress inventory and shortening the transition time.

Activities at the level of area and production lines improvement also include the optimization of cycle times and cycle times in order to ensure continuous flow, minimize costs and maximize the productivity of the implemented processes.

One of the Lean tools used at this level of improvement activities is Standardization of Work (SOP), which allows for obtaining stable results of implemented processes, creating production scenarios and creating a flexible production system with low sensitivity to disruptions (it concerns both the efficiency and quality of processes and product).

Another Lean tool used to improve the flow is Jidoka, i.e. leveling production in a way that allows meeting the expectations of many customers while maintaining a minimum level of work in progress and the shortest possible waiting times for the implementation of individual production orders.

Improving the flow of value

At this level of improvement, we can already speak of improving the functioning of the entire production system or logistics supply chain of the enterprise.
Systemic improvement is possible, among others, through the use of Value Stream Mapping (VSM), under which current state process maps (process modeling) are developed, which constitute the basis for the creation of future state maps that meet the expectations of the company both at the operational and strategic level.

They can successfully provide guidelines for the creation of long-term improvement plans integrating local improvement activities in a way that allows the use of synergy resulting from the economies of scale of the improvement activities carried out. VSM mapping can cover all processes and products implemented in the enterprise or selected product families characterized by a sufficiently high degree of similarity.

At this stage, it is also possible to introduce the KANBAN system that allows you to manage flows in a trailed system while maintaining the minimum allowable levels of inventory of components and semi-finished products.

Further improvement of the production system can be carried out by introducing One Piece Flow and the implementation of logistics processes in accordance with the JIT and FIFO standards.

Improvement of organizational activities

It constitutes the level of improvement of the entire organization in all its areas and spheres of activity. At this stage of improvement, the improvement "tools" already have the characteristics of systems, projects, or an elaborate structure with a set of rules and a management system.

Improvement at this level may concern, for example, the development of a company's strategy, a group of entities (organizations) or corporations. Another element may be the management of the communication system at the organization level or the system standard of corporate project management.

One of the essential elements of this level of organizational improvement is the creation and management of a production system or a continuous improvement system operating at the level of the entire organization.

5. Conclusions

Effective conduct of activities improving the processes, organization and products of the enterprise plays a very important role in the functioning of the enterprise.

The effectiveness of the organization at the level of opportunities and improvement skills, also based on the implementation of process and product innovations, probably, as never before, determines the possibility of achieving business successes of the organization and influencing its fate in a competitive market. One of the most important features of the business organization and the competences of the management team is the ability to flexibly shape the behavior of the organization in a way that allows for the fastest and most precise adaptation to the dynamically changing environmental conditions, customer needs, and the capabilities of contractors and suppliers.

All this means that the role of a human being (taking into account all its features, advantages, and disadvantages) in a business organization and at its various levels is invariably very important.

It is worth remembering that business is done by people, not companies.

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Biographical note

Robert Kaszuba – doctor of technical sciences, mechanical engineer,academic teacher, practitioner, expert. In academic work related to such areas of knowledge as production and service management, operation of technical facilities, quality management, logistics and operational research.

In her didactic work she uses practical experience gained during cooperation with industrial enterprises. PhD, Eng.Robert Kaszuba has for many years been involved in advisory activities involving the improvement of business processes carried out by production and service companies.

He has extensive professional experience in the implementation of Lean Manufacturing tools and the implementation of improvement projects and process innovations in the areas of production, maintenance, logistics and services, gained during the conduct of projects, workshops, implementations and training for several dozen enterprises and several years of work in an international corporation.

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Recruitment, Onboarding and Training in the Time of the COVID-19 Pandemic in the Enterprises of the Polish Copper Basin

Summary

Acquiring and keeping valuable employees is currently one of the key issues determining the pace of development and the degree of innovation of the organization. This applies, of course, to the same, and perhaps even bigger, extent, to the enterprises of the Polish Copper Basin due to the strategic nature of the industry. One of the conditions enabling the progress of the organization is regular closing the personnel gap, as well as effective onboarding processes and efficient training procedures for new employees. The COVID-19 pandemic has shown once again the importance of adaptative capacity and internal innovations of the companies. The study presents and discusses the results of the research conducted among the companies of the Copper Basin about the influence of COVID-19 pandemic on the number of recruitment processes in 2019 and 2020 years. The scale of the innovative solutions introduced as part of recruitment processes aimed at verifying the knowledge and assessing the competences of candidates, as well as remote onboarding methods of new employees, was also analyzed. The study also discusses the diagnosed changes regarding the introduced new tools used in the training process. The research results made possible formulating conclusions and recommendations.

Keywords: recruitment, remote onboarding, innovation, training, COVID-19

REKRUTACJA, ONBOARDING I SZKOLENIA W DOBIE PANDEMII COVID-19 W PRZEDSIĘBIORSTWACH ZAGŁĘBIA MIEDZIOWEGO

Streszczenie

Pozyskiwanie wartościowych pracowników i utrzymanie ich w organizacji należy obecnie do kluczowych kwestii decydujących o tempie rozwoju i stopniu innowacyjności organizacji. Dotyczy to oczywiście, w takim samym stopniu, a może i większym, ze względu na strategiczny charakter branży, przedsiębiorstw zagłębia miedziowego. Jednym z warunków umożliwiającym progres organizacji jest regularne zamykanie luki personalnej; efektywne procesy onboardingowe oraz skuteczny mechanizm szkoleniowy nowych pracowników. Pandemia COVID-19 kolejny raz pokazała, jak istotne są zdolności adaptacyjne i wewnętrzne innowacje organizacyjne przedsiębiorstw. Artykuł prezentuje i omawia wyniki badań przeprowadzonych wśród przedsiębiorstw zagłębia miedziowego dotyczących wpływu pandemii COVID-19 na ilość procesów rekrutacyjnych w latach 2019/2020. Analizie poddano również skalę wprowadzonych innowacyjnych rozwiązań, w ramach procesów rekrutacyjnych, mających na celu weryfikację wiedzy i ocenę kompetencji kandydatów oraz metod zdalnego onboardingu nowo zatrudnionych. Opracowanie omawia także zdiagnozowane zmiany dotyczące wprowadzonych nowych narzędzi wykorzystywanych w procesie szkoleniowym. Wyniki badań umożliwiły sformułowanie wniosków oraz rekomendacji.

Słowa kluczowe: rekrutacja, zdalny onboarding, innowacje, szkolenia, COVID-19

1. Introduction

The gradual transition from a material-intensive economy to an economy based on knowledge and information is a process typical for knowledge-based economy. As a result of this metamorphosis, intangible assets, in particular human capital, knowledge and new technologies, gain importance. Thereby the pace of development is determined by the intellectual potential of people and the access to knowledge of the achievements of modern science[1]. The aforementioned factors are essential stimulators of the innova-

1 P. Drezdeń, *Innowacyjność a zmiany struktury przestrzennej przemysłu na przykładzie Śląska*, „Rozprawy naukowe Instytutu Geografii i Rozwoju Regionalnego Uniwersytetu Wrocławskiego"

tion. Human potential is not an easily quantifiable value. Regardless of these objective difficulties, however, its growth and future size should be forecasted. Research in the area of personnel controlling shows, among others, that assurance of the inflow of employees, reliable selection of candidates, forging a bond between new staff and the enterprise, adjusting qualifications and organizing further education or making new employees productive as quickly as possible are important sub-goals of personnel controlling, the implementation of which influences the improvement of management efficiency[2]. The meaning of onboarding should not only be understood as introducing a new employee into the organization. It should be emphasized that the purpose of employee adaptation is the implementation of such activities that allow the new employee to perform work in an efficient way as quickly as possible[3]. Another studies take note of the strategic character of employee adaptation[4]. Therefore, it can be assumed that stress reduction of the new employees and increasing their confidence in the organization are important elements[5] the discussed process, which in the first phase should necessarily be supplemented by he means of effective communication, because the amount of information provided in the phase of introducing an employee to work is particularly large.

The arguments given above outline the importance of the constant search for valuable employees and appropriate preparation and carrying out recruitment and onboarding processes as well as acquisition of knowledge and mastering new skills. The economic and social changes that organizations have to face do not always make the discussed challenges easier. Most often, enterprises are forced to adapt management processes to changing economic conditions, price fluctuations or increasing employee expectations. This requires from them a high degree of innovation in many areas. For the first time, businesses in all the economies of the World have had to adapt to the effects of a pandemic. Such a necessity also applied to production, service

2020, no. 46, p. 27.

2 A. Parkitna, Z. Sekuła, *Controlling personalny jako narządzie skutecznego zarządzania zielonymi miejscami pracy*, „Rynek-Społeczeństwo-Kultura" 2018, no. 4(30), p. 58-59.

3 A.I. Tiainen, *New Employee Orientation and Onboarding, SMEREC – New generation recruitment skills for SMES and workforce*, Joensuu 2019, p. 80.

4 M. Karambelkar, S. Bhattacharya, *Onboarding is a Change: Applying Change Management Model ADKAR to Onboarding*, „Human Resource Management International Digest" 2018, vol. 25, no. 7, p. 5-8.

5 G. Svala, L.M. Lundbergsdóttir, *Onboarding Self – initiated Expatriates: The Case of Icelandic Employees Working for the Nordic Cooperation*, „Journal of Workplace learning" 2016, vol. 28, no. 8, p. 510-518.

and trade enterprises of the Copper Basin. The aim of this study is to present the results of research on the impact of the COVID-19 pandemic on the scale of recruitment processes and the innovativeness of solutions assessing the knowledge and competences of candidates and remote adaptation of employees in the group of organizations mentioned above.

2. Research methodology

The quantitative research was carried out using the indirect measurement method in the form of the electronic questionnaire technique. The chosen form made it possible to obtain data with a high degree of standardization. The questionnaire consisted of open-ended, semi-open and closed-ended (both single and multiple choice) questions. The study covers the period from January to October 2021. The questionnaire was sent to the persons indicated by the management division, which were responsible for the diagnosed area, after obtaining a declaration of willingness to participate in the study. The places of residence of the respondents were located mainly in Głogów, Polkowice, Lubin and Legnica counties. The research was conducted on a large scale. The organizations that participated in the survey employ a total of 36,557 workers and represent manufacturing, service and trade companies. The table below presents detailed statistocal breakdown of the type of activity of the surveyed companies.

Table 1. The detailed statistical breakdown of the type of activity of the surveyed companies

Type of activity	Total percentage
Production companies	44,00
Service companies	30,00
Trade companies	26,00

Source: own study based on research.

The empirical research was preceded by an analysis of the literature on the subject in order to identify possible forms of verification of the skills of the candidatesfor the job and the practical activities accelerating the integration of a new employee with the team. In order to diagnose potential dif-

ferences and thus the scale of the impact of the pandemic on the discussed issues, the study collected and compiled data for the years 2019 and 2020.

3. Research results

The research results have indicated that the number of newly created jobs and processes filling the job vacancies has decreased during the COVID-19 pandemic. In 2020, the number of aforementioned processes decreased compared to 2019 from 1719 to 1325. This is tantamount to a decrease of 22.92%. An increase of the number of organizations that suspended a recruitment for vacant positions completely was also diagnosed in 2020. Their share in the researched sample group in 2020 equaled 10%. For comparison, in 2019 only 2% of respondents did not hire any new employee. This means an increase of 8 percentage points in one year. The vast majority of the respondents (74%) indicate the COVID-19 pandemic as the main reason for such a decline in the number of recruitment processes. The remaining respondents oppose that claim. It should be noted, however, that 26% of the surveyed enterprises that do not perceive the negative impact of the pandemic on the recruitment of employees do not employ more than 50 people and thus are classified as small enterprises in accordance with the generally accepted qualification. The new situation that the enterprises of the Copper Basin had to deal with also forced the surveyed entities to undergo profound changes, for example in the way of accepting application documents. As a result of the adaptation processes, over 80% of organizations changed organizational procedures in the discussed area and allowed only the on-line acceptance of application documents. 8.70% of the surveyed enterprises enabled both electronic application and personal or postal delivery of documents. Only a small group of respondents (6.52%) did not introduce any modifications to the application process and still required the personal delivery of documents. The approval of innovative internal solutions has also been perceived in the sphere related to checking and verifying the knowledge and skills of candidates. An on-line interview with the candidate turned out to be the most frequently used form. This solution was introduced by over 33% of the inquired entities. Detailed research results in the discussed aspect are presented in the table below.

Table 2. Applied methods of checking the candidates' skills during the COVID-19 pandemic

Forms	Percentage results
on-line interview	33,71
Standard iterview in the office of the company	26,97
Telephone conversation	22,47
Written tasks to be solved in the employers' headquarters	7,86
Written tasks to be solved on-line	4,49
A task to be solved at home und send or shared electronically	2,25
Others	2,25

Source: own study based on research.

The obtained data also show the degree of social responsibility and adaptation skills of the entities in the copper basin. The vast majority (over 73%) of entities introduced innovations consisting in replacing personal contacts with potential future colleagues with virtual technology or telecommunications technology. This proves a high degree of social responsibility and adaptability to new conditions. Research has shown that new forms of verification of candidates are, in the opinion of the respondents, equally effective. The obtained data also show the degree of social responsibility and adaptation skills of the entities in the Copper Basin. The vast majority of entities (over 73%) introduced innovations based on replacing personal contacts with potential future collaborators with virtual or telecommunications technology. This proves a high degree of social responsibility and a capability to adapt to new conditions. Research has shown that new forms of verification of candidates are, in the opinion of the respondents, equally effective as the traditional ones. Over 26% of the respondents still took traditional interviews in their headquarters. In the course of the conducted analyzes, the authors established that over 66% of this group are enterprises with up to 50 employees. The discussed research was also aimed at diagnosing the preferences of the respondents in the form of checking the knowledge and skills of the candidates. The obtained results clearly show that the business organizations of the Copper Basin approached the issues of safety and health protection of workers in a responsible manner. 37.74% of the members of the researched sample group indicated that the verification of competences should take place remotely in every case. Over half of the respondents (50.94%) prefer hybrid solutions, and only 11.32% of entities, despite the pandemic, support

personal forms of verification and checking the knowledge and skills of future employees. All the surveyed enterprises representing the latter view are small organizations dealing with the broadly understood production activity.

A further important aspect of the research was related to the issue of employee adaptation. The vast majority of the surveyed companies (88%) indicated that they conducted onboarding processes during the COVID-19 pandemic. The respondents also agreed that the coronavirus influenced the adaptation of employees and forced a wide range of changes, including attempts to effectively implement newly hired people into the organization while maintaining the sanitary regime. Hybrid onboarding turned out to be the dominant solution implemented in organizations (over 63% of them). About 18% of enterprises decided to use only on-line solutions. The same percentage share was diagnosed with regard to the use of off-line methods.

Positive relations between a newly hired employee and his collaborators are among the crucial elements of an effective onboarding. Their quality has a major impact on the decision about remaining within the organization. Almost all the surveyed companies (97.73%), as indicated by the responses, are aware of the abovementioned correlation. For this reason, the remote process of adaptation of employees during a COVID-19 pandemic also included getting in touch with collaborators. The most common forms, identified as a result of this research, applied in the enterprises of the Copper Basin in order to form and deepen relationships within a team are presented in the table below.

Table 3. Remote actions used to integrate a new employee with the team

Forms	Percentage results
Telephone conversations/teleconferences	45,74
Distribution of the electronic information about the collaborators and a newly hired employee (Photos, brief descriptions, videos, contact data).	34,05
Videoconferences/webinars	20,21

Source: own study based on research.

Training is another area of onboarding that affects the quality and comfort of work. The vast majority of the surveyed companies (over 84%) are aware of their significant importance, which made them search for the new tools improving knowledge and competences and adapt the existing ones

to the pandemic situation. These respondents started using the virtual environment in order to educate the newly hired employees. However, not all entities were looking for innovative ways to implement this important element of the personnel function. The result of inaction was the resignation of over 15% of the entities of any form of training for new employees. Over 71% of this group are production enterprises, the staff of which does not exceed 50 people.

The modern technologies offer a very wide range of tools which effectively train the new employees. The following chart shows a diagnosed spectre of the applied solutions.

Spectrum of the applied training solutions

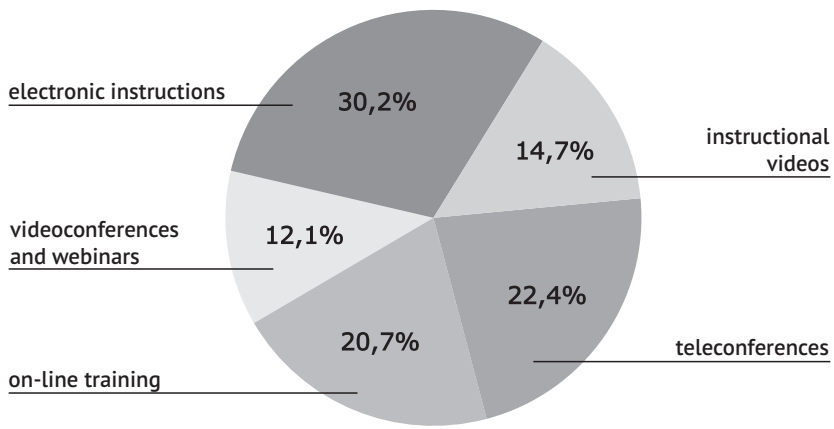

Chart 1. The new generation tools applied in the training process

Source: own study based on research.

Further remote actions implemented by the surveyed entities in the process of adaptation of newly hired employees during the COVID-19 pandemic were identified in the course of the study. Their spectrum is shown in the Table 4.

Table 4. Other remote onboarding activities used by enterprises of the Copper Basin

Activities	Percentage results
Electronic delivery of the necessary information, corporate regulations and company procedures to the employee	21,51
Providing remote assistance on the computer of the newly hired employee	18,28
Appointing an employee responsible for remotely providing necessary assistance for the newly hired person in the process of acclimatization	15,05
Electronic delivery of the documents related to employment	12,90
Electronic training lists	10,22
Electronic work itinerary / list of tasks to be performed within the nearest period (for example, day, week, and month)	9,68
Electronic distribution of the information about the tools being applied at work	8,06
Remote delivery of work tools (e.g. for via courier, mail, company employee)	4,30

Source: own study based on research.

In order to implement remote onboarding processes, the surveyed organizations most often used the following tools:

- applications for providing assistance on the second user's computer – 20.53%;
- electronic mail – 19.20%;
- telephone – 18.75%;
- comprehensive solutions for communication, creating and sharing information and documents – 13.84%;
- on-line communicators – 10.71%;
- intranet / employee portal – 8.93%;
- virtual disks – 8.04%

At the stage of conducting the research, an attempt was also made to identify the form of onboarding activities, which, according to the respondents, should be implemented during the COVID-19 pandemic. The vast majority of entities opted for a hybrid form of introducing employees to the organization (60.38%). Remote methods (20.75%) and personal contacts (16.98%) were ranked on the further places, with a significantly lower number of indications. Only a small percentage of enterprises (1.89%) did not specify the most appropriate onboarding method. The vast majority (about 89%) of organizations that opted for a personal form of onboarding activities are

production enterprises, classified as small and medium-sized organizations from the point of view of the number of employees.

4. Conclusions and recommendations

The COVID-19 pandemic had a negative impact on the number of newly created jobs and delayed actions aimed at closing the personnel gap in the enterprises of the Copper Basin. Compared to the previous year, the number of recruitment processes decreased significantly in 2020. However, copper companies proved to be sufficiently stable and innovative, which allowed them to survive the changes caused by the pandemic. Although development has slowed down, this can be considered a temporary state. The surveyed organizations showed skills in implementing innovative internal solutions. The use of information and communication technologies enabled the transfer the solutions, which were known before and commonly used, on the new stage. Many organizations replaced standard interviews at their headquarters with an on-line form. Additionally, in order to increase the effectiveness of this process, some of the surveyed organizations introduced additional forms of verification of the knowledge and skills of candidates in the form of written tasks to be solved on-line or tasks to be performed at home and shared on-line. These solutions are still not very common, but represent efficient practice and can be expected to gain popularity over time. Regardless of the pandemic, it seems advisable to permanently implement further forms of verification of candidates for the recruitment process, as the appropriate selection and application of selection techniques and methods determine the correctness of choosing the best candidate for a vacant job position in a large extent[6]. The observation of the internal innovations introduced in the copper industry enterprises prompts the expectation that after the end of the pandemic their implementation will not only be continued, but even that its scale will increase multiple times. This thesis is conformed by the results of present study which show that more than half of enterprises are supporters of hybrid solutions in the discussed area. The research also established that despite the organizational difficulties caused by COVID-19,

6 M. Such-Pyrgiel, *Innowacyjne metody i narzędzia badawcze w postaci aplikacji wykorzystywane w procesie rekrutacji i selekcji zawodowej*, „Teka Komisji Prawniczej PAN Oddział w Lublinie" 2018, vol. XI, no.2, p. 419.

the vast majority of organizations did not cease their onboarding activities. Only a small part of the researched entities decided to implement solely the on-line form. The dominantly preferred solution was the application of hybrid activities, with particular use of teleconferences, videoconferences/ webinars or electronic information distribution. The companies of the Copper Basin have also introduced modifications to the training process. They used the on-line metods to a greater extent. Additionally, they supplemented the improvement of qualifications and skills of their employees by preparing and distributing instructional videos and electronic instructions. These instruments have many advantages and should become a permanent part of training programs as a perfect supplement to the traditional methods of knowledge transfer and skills training.

Small production companies seem to be an exception to the diagnosed trend. The vast majority did not change their organizational procedures in any way and did not search for new solutions. This may be related to the quality of their management, their technological level or strongly entrenched habits and determinants of the company owners. Failure to reduce the barriers described above may become the main cause of the future difficulties with the recruitment and keeping of valuable employees and thus would weaken the competitive ability of these enterprises. Therefore, efforts for change the diagnosed way of proceeding are very advisable.

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Layers of possibilities

Thanks to knowledge and experience of our employees we extract and process valuable resources of Earth, enabling the development of a modern world.

The concepts of innovation, industry, and copper – as intended by the editors of the monograph presented to the Readers – define the theoretical field of the discussed considerations. They appear in various research perspectives, in broadly understood engineering and technical sciences, as well as in social sciences. Therefore, they constitute an open area of interpretation that cannot be reduced to a single interpretation or closed within one specific theoretical field. Innovation and issues related to its individual aspects are currently perceived as one of the fundamental issues determining socio-economic development. Globalization, technological and social changes, the constant metamorphosis of the area of production, trade, services, consumption, and the continually growing market awareness of buyers – have become the sources of the intensification of the observed competitive phenomena. Meeting these new conditions forces organizations to search for new, more effective and flexible ways of competing and to constantly identify all possibilities of modeling and rationalizing the market position.

(…) Therefore, regardless of the definition, competitiveness is one of the most important determinants of modern enterprises, and innovative solutions can – and should – be sought in the product, process, marketing and image, and organizational fields.

The monograph titled „Innovation in the copper industry" consists of thirteen chapters, divided into two sections. The first one includes considerations and research results in the field of technical and engineering sciences. The second deals with topics from the area of social sciences. The authors of the texts include, among others, specialists conducting research in the most important academic centers in Poland, employees of research institutes, companies, and management staff at KGHM Polska Miedź S.A.

A FRAGMENT OF THE INTRODUCTION

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