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SUMMARY OF THE DOCTORAL DISSERTATION.

The structure of variability and methodology for estimating the resources of the selected accompanying elements in the Cu-Ag deposits in the Lubin-Głogów Copper District (LGCD)

The main aim of this thesis is to broaden the knowledge of the spatial distribution of the selected elements accompanying the Cu-Ag LGCD deposits (the Cu-Ag deposits of the Lubin-Głogów Copper District) in the economic ore deposit and in the main lithological series, including arsenic (As), cobalt (Co), nickel (Ni), lead (Pb), and vanadium (V), on the example of the Rudna deposit. The research have been focused on elements that seemed to be particularly interesting due to their locally high content. Arsenic was selected due to its negative impact on the metallurgical processes and the environment. Cobalt, and vanadium are included in the list of critical raw materials for the EU (The European Union). Nickel is recovered from the Cu-Ag LGCD deposits in the form of nickel sulfate ($NiSO_4$) despite the generally low contents (close to the Clarke values). Lead was subjected to the analysis for two main reasons: its negative impact on the copper concentrate and the environment and the imminent depletion of resources in the currently exploited deposits of zinc and lead ores in Triassic formations in Poland.

The work summarizes the previous studies on the selected accompanying elements in the Cu-Ag deposits in the LGCD. The variability of their unit accumulation index has been described in detail, the possibility of using the two available indirect methods for estimating the resources of trace elements (referred to as correlation and mineralogical methods) has been verified, while a modified method for estimating their resources has been proposed. It has been confirmed that the current sampling network used for the accompanying elements is sufficient to estimate their resources with an accuracy corresponding to at least the C_2 grade of deposit exploration. Based on the analysis of the variability of the examined elements, the methodology for determining their enrichment zones within the deposit was proposed. It was suggested to change the current method for collecting samples from mine workings for the purpose of assessing the resources of accompanying elements.

The use of classical and geostatistical statistical methods allowed meeting the objectives set. The statistical description included the calculation of basic statistical measures, the development of histograms and box-and-whiskers plots, the tests of the normality of the distribution of the examined elements, and an attempt to fit the optimal distribution with the theoretical one. The correlation between the accumulation index of both Cu and accompanying metals and their mutual relations were analyzed using the Pearson's linear correlation and Spearman's rank correlation coefficients. Based on the statistical analysis, it was found that the variability of the accumulation index of the analyzed elements (As, Co, Ni, Pb, and V) ranges from high to extremely high. The highest variability has been observed in the case of As and Pb (their highest coefficients of variation are 163% and 229%, respectively). The distributions of the probability of the accumulation index of the analyzed elements are characterized by a positive asymmetry ranging from moderate to extremely strong; the consequence is the inability to fit the normal distribution to the empirical distributions of the accumulation index of the analyzed elements. The rational selection of the optimal theoretical model of the probability distribution of the accumulation index of the accompanying elements was possible only for some of the lithological series. Extremely complicated forms of empirical distributions of the Pb

accumulation index, both in relation to the economic ore deposit and the main lithological units of the ore, are the reason why their approximation using any of the 30 theoretical distributions of the Statgraphics program is impossible. The analysis of the linear correlation between the accumulation index of the examined elements has shown no clear relationship between the accompanying elements in the Cu-Ag deposits in the Lubin-Głogów Copper District (As, Co, Ni, Pb, and V) and the main metal - copper (Cu). For this reason, the possibility of using the correlation method for assessing the resources of accompanying elements in the Cu-Ag LGCD deposits has been rejected.

When analyzing the geostatistical structure of the variability of the accumulation index of the analyzed accompanying elements in the Cu-Ag deposits the so-called semivariogram cloud has been used in order to determine and eliminate anomalous values, blurring the true picture of the variability of a given parameter, from the data set. Due to the complex nature of the variability of the accumulation index of the examined elements, the three types of the empirical (sample) semivariogram estimators were calculated; then, they were fitted to geostatistical models, which were used in estimation techniques. In order to investigate the directional variability of the examined elements, the maps of relative directional semivariograms were constructed. The experimental sampling, aimed at examining the variability of the local accumulation index of As, Co, Ni, Pb, and V, and the vertical variability of these elements in the economic ore deposit and beyond the boundaries of the economic ore deposit, was carried out.

When it comes to the variability structure of the analyzed accumulation indexes of the accompanying elements in the Cu-Ag LGCD deposit, the geostatistical analysis has shown that the share of the random component is generally higher than the share of the non-random component. The use of two types of relative empirical (sample) estimators, both classical and "non-ergodic", has shown a significant variability when considering the accumulation index of some of the analyzed elements in the Rudna mining area, both in the economic ore deposit and in the main lithological series. The highest resemblance in the course of both types of relative estimators of semivariograms is observed in the case of accumulation indexes of cobalt and nickel within the boundaries of the economic ore deposit. The accumulation indices of the analyzed elements are usually characterized by a poor directional variability. The use of anisotropic semivariograms in order to estimate the average value of the analyzed parameter has not contributed to a significant reduction in interpolation errors. The analysis of local variability of the examined elements has shown a very large variability in their accumulation index; this has been observed even in the case of adjacent samples. With the exception of the arsenic accumulation index, it has been found that natural factors have greater influence on the local variability than the sampling errors. The highest level of local variability was recorded for lead, while the lowest for nickel and vanadium. Due to the high local variability of the analyzed accompanying elements, a different method for collecting samples from mine workings in the Cu-Ag deposits in the Lubin-Głogów Copper District (LGCD) for the purpose of assessing their resources was proposed.

The accumulation indices of the analyzed elements were assessed while the errors of these estimates were estimated using the following geostatistical methods: ordinary kriging, indicator kriging, lognormal kriging, and the Turning Bands Simulation. Based on the conducted research, a two-step method for estimating resources was proposed. It has been shown that the current method for collecting samples of accompanying elements from the discussed deposits is the reason why the assessment of their resources is inaccurate and subject to considerable error. The determined amounts of resources should be treated as estimates and qualified to category D.