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GIS technology in the geological and technological modeling of iron ore deposits

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SUMMARY

Geological and technological mapping is one of the main areas of activity of the geological service of mining enterprises. It makes it possible to assess the reserves of technological types and varieties of ores, their spatial distribution within deposits, and to carry out rational, complex development and processing with a forecast of geological and technological properties. Technological mapping's efficiency is provided with using of geological and technological models of the deposit. These models were developed in the process of structural and technological mapping of BIF deposits within the Kryvyi Rih region.

To link the structure between the ledges, one of several options is selected: matching using polynomials, polyharmonic functions, or cubic splines. The experience of BIF deposits mapping within the Kryvyi Rih region shows that the most preferable results are obtained using cubic splines.

For deposits with a complex structure, the combination is carried out taking into account the structure of the deposit (the presence of tilted folds, breaking faults). Better results are obtained using interpolation splines. Deposit's models done with this method in the best way describe geological structures. In areas of deposits with highly developed multi-order folding or complicated by folds of drawing, good results are obtained by interpolation using polyharmonic functions. The creation of geological and technological maps and sections using polynomials gives acceptable results only in certain sections of deposits characterized by monoclinic or slightly folded beds of layers of ferruginous quartzites and schists, not complicated by large folds of fractures.

Introduction

Geological and technological mapping is one of the main areas of activity of the geological service of mining enterprises. It makes it possible to assess the reserves of technological types and varieties of ores, their spatial distribution within deposits, and to carry out rational, complex development and processing with a forecast of geological and technological properties. Technological mapping's efficiency is provided with using of geological and technological model of the deposit. This model was developed in the process of structural and technological mapping of BIF deposits within Kryvyi Rih region.

The basis of the model is a database of deposits that includes: 1) data on preliminary, detailed and mining exploration drill holes (hole collar and axle coordinates; chemical, spectral and phase analyzes on sampling intervals); 2) results of structural and geological mapping (measurements of angles at triangulation points from standing points; measurements of angles and distances to the points of determination of structural elements at ledges of the quarry; dip angles of main folded and breaking faults measured in the ledges of the quarry; 3) technology test data (iron content in the source ore, concentrate and tailings, concentrate output; physical and mechanical properties of rocks; quantitative ratios of minerals and granulometric composition by ore types; chemical, phase and spectral analyzes).

Research results

While creating the database omissions of indicators appear. Methods of filling (selection and using regression), weighing, modeling using likelihood functions are implemented in order to process such incomplete data in the geological and technological model. The choice of method of filling depends on deposit's geological structure (Aronov, 1990, Bogdanova et al. 1981, Dmitriev et al., 1989, Plotnikov et al., 2015, Pirogov et al., 1988).

In the process of structural mapping, the coordinates of the standing points are determined using a program that implements the Potenot problem. Ledges of the quarry with structural elements are contoured using interpolation splines with nodes at the measurement points. Coordinates of points are determined by the calculated coordinates of the standing points, as well as the angles and distances to them.

To link the structure between the ledges, one of several options is selected: matching using polynomials, polyharmonic functions, or cubic splines. The experience of BIF deposits mapping within Kryvyi Rih region shows that the most preferable results are obtained using cubic splines.

The next step in creating a geological and technological model is the selection and contouring of natural varieties of ferruginous quartzites. Varieties are distinguished according to the information available in the bank about mineral and chemical composition of quartzites, their structural and textural features (thickness of ore and non-ore layers, grain sizes and aggregates of ore and non-mineral minerals) and physical state.

Since the dimension of data matrices is large, then before dividing the glandular quartzites into natural varieties, it is necessary to reduce the dimension and select the most informative signs. This procedure is carried out by the method proposed by D.A. Rodionov (Rodionov, 1981), based on likelihood relationships, the algorithm of which consists of three parts. In the first part the signs are ranked according to their informativity: from more informative to less informative in value *d*:

$$d_j = \frac{x_{j1} - x_{j2}}{S_{jj}^{1}} \qquad (1)$$

where: x_{j1}, x_{j2} - vectors of mean values along the j variable for the first and second objects;

S^1_{jj} - diagonal element of the covariance matrix calculated in assuming inequality of expectation vectors

In the second part, the criteria is calculated:

$$\lambda = \left(\frac{\left| S^0_{qq} \right| \times \left| S_{m-q,m-q} \right|}{\left| S^1_{qq} \right| \times \left| S^0_{m-q,m-q} \right|} \right)^{\frac{n_1+n_2}{2}} \qquad (2)$$

where: q - the number of the property (sign), which sequentially changes from 0 to m.
S^0 , S^1 - covariance matrices calculated in the assumption equalities and inequalities of vectors of mathematical expectations.

In the third part, objects are compared using the multidimensional average Rao method or, in the case of covariance matrices, with the help of James criterion. Criterion Rao has the form:

$$U = -(n_1 + n_2 - \frac{r}{2}) \cdot \ln \left[\frac{\left| S^1_{rr} \right|}{\left| S^0_{rr} \right|} \right] \qquad (3)$$

where: n_1 and n_2 - the number of observations in the first and second objects respectively.

The calculated criterion value is compared to that taken from tables according to the significance level and the number of degrees of freedom. Depending on the results of the comparison, a combination of the most informative features is selected.

Creating the geological and technological model of the Valyavkinske BIF deposit showed that the most informative signs for unoxidized quartzites are the iron content (general and magnetic) and mineral composition. For oxidized quartzites, textural and structural features (thicknesses of ore and non-ore layers) and the physical state estimated by the coefficient of strength according to Protodyakionov are added to these signs.

Division of ferruginous quartzites by informational attributes into natural varieties is carried out by various methods of cluster analysis. Optimal results are obtained when applying a complex of cluster procedures to the same data. During structural-technological mapping of Valyavkinske deposit composition in low-volume technological tests, textural characteristics, physical state were processed by agglomerative method of cluster analysis using, as a measure of similarity, the usual Euclidean distance, the Mahalanobis distance and the coefficient of race similarity, the k-averages method and factor analysis. As a result of such complex classification, the selected samples were divided into 10 natural species: magnetite (Fe total .- (Fe magn. + CO_2) <2.3 for CO_2 <3%), carbonate-magnetite (Fe total- (Fe magn. + CO_2) <2.3 for CO_2 > 4%), magnetite with carbonate (Fe total (Fe magn. + CO_2) <2.3 for CO_2> 3-4%), magnetite-carbonate (Fe total (Fe magn. + CO_2) <2.3 for CO_2 >> 4% (Fe magn./7.2) <(CO_2 / 4)), silicate-magnetite (Fe total - (Fe magn. + CO_2)> 2.3 for CO_2 <4 FeO> 0.5 Fe magn.), magnetite-silicate (Fe total - (Fe magn. + CO_2) >> 2.3 for CO_2 <4 FeO> 0.5 Fe magn., carbonate-magnetite-silicate (CO_2> 4% and (CO_2 / 4) <(Fe magn. / 7.2) << (Fe total - (Fe magn. + CO_2) /2.3)), magnetite-carbonate-silicate (CO_2> 4% (Fe magn. / 7.2) <(CO_2 / 4) <(Fe total - (Fe magn. + CO_2) /2.3), hematite-magnetite (Fe total - (F total + CO_2)> 7 for FeO = 0.5 Fe magn., CO_2 <4%), magnetite with hematite (Fe total - (Fe magn. + CO_2) = 5-7 for FeO = 0.5 Fe magn. and CO_2 <4%.

The same comprehensive approach to classification is also used for the division of ferruginous quartzites into technological varieties. Unoxidized ferruginous quartzites of the Valyavkinske deposit were classified into eight technological varieties characterized by different mass fractions and the extraction of iron into concentrate. According to the extraction of iron into concentrate, the ferruginous quartzites were divided into two groups: with the extraction of iron more than 70% and less than 70%. When extracting more than 70%, four grades of iron content in the concentrate are distinguished: 1 - more than 63%, 1 - 61-63%, 2 - 59-61% and 5 - <59. When extracting iron into a concentrate of less than 70%, similar mass fractions of iron in the concentrate have 3, 3a, 4, and 6 grades, respectively.

The final stage of a geological and technological model is creating of geological and technological map, forecast plans and sections. For this purpose, the results of documentation and testing of ledges of the quarry and exploration drill holes are used. However, the intervals for testing holes do not exceed one meter. Therefore, graphic modeling at a scale of 1: 2000 requires generation with the identification of geological and technological boundaries. Good results are given with using the Rodionov's criteria for linearly ordered observations:

$$U(r^2) = \frac{n-1}{n \cdot k(n-k)} \sum_{j=1}^{m} \frac{\left[(n-k)\sum_{i=1}^{k} x_{ij} - k \sum_{i=k+1}^{n} x_{ij} \right]^2}{\sum_{i=1}^{n} x_{ij}^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_{ij} \right)^2} \quad (4)$$

where: r - number of partition (index 2 indicates that the partition is performed on two groups); n - number of linearly ordered m-dimensional observations.

The initial data for the generation with the Rodionov's criteria are the results of phase analyzes and technological tests for exploration drill holes in profiles. The task is to find significant geological and technological boundaries with the integration of sampling intervals into them. This generation was performed for each drill hole in the profile. For correlation of nearby drill holes the following criteria are used:

$$U(\Gamma_{1s}, T_{2l}) = \frac{n_{1s} + n_{2l} - 1}{n_{1s} \cdot n_{2l}(n_{1s} + n_{2l})} \sum_{j=1}^{m} \frac{n_{2l} \sum_{i \in T_{1s}} x_{ij} - n_{1s} \sum_{i \in T_{2l}} x_{ij}}{\sum_{l \in T_{1s} \cup T_{2p}} x_{ij}^2 - \frac{1}{n_{1s} + n_{2l}} \left(\sum_{i \in T_{1s} \cup T_{2l}} x_{ij} \right)^2} \quad (5)$$

where: T_{1s} - homogeneous observation group with number *s* for the first object;
T_{2l} - homogeneous observation group with number *l* for the second object.

Using the likelihood method, it was shown [4] that those parts of drill holes for which:

$$U(T_{1S}, T_{2l}) \to \min \quad (6)$$

If $U(T_{1S}, T_{2l})_{\min} > \chi^2_{\kappa p}$, then in two nearby drill holes there are no correlated parts. If $U(T_{1S}, T_{2l})_{\min} < \chi^2_{\kappa p}$,then the parts *s* of one drill hole and *l* other are considered to be similar in terms of a complex of attributes and are combined in section.

For deposits with a complex structure, for example, the Valyavkinske deposit, the combination is carried out taking into account the structure of the deposit (the presence of tilted folds, breaking faults). Structural and technological sections are realized according to the generalized sections of drill holes and maps using several methods.

Better results are obtained using interpolation splines. Sections, maps and block models done with this method in the best way describe geological structures (Fig. 1). In areas of deposits with highly developed multi-order folding or complicated by folds of drawing, good results are obtained by interpolation using polyharmonic functions. Creation of geological and technological maps and sections using polynomials gives acceptable results only in certain sections of deposits characterized by monoclinic or slightly folded beds of layers of ferruginous quartzites and schists, not complicated by large folds of fractures (Fig. 2).

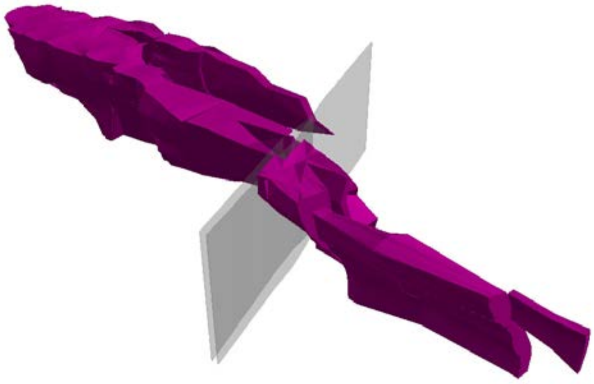

Figure 1 *Block model of the Petrovsky deposit done using interpolation with cubic splines*

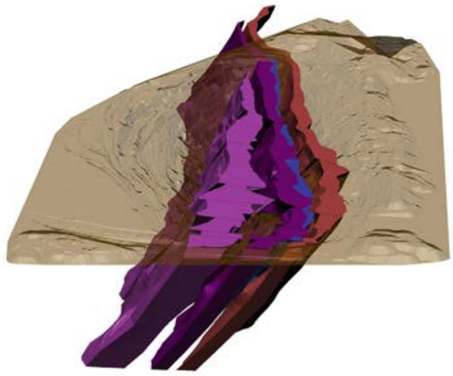

Figure 2 *Geological and technological model of the Velyka Gleevatka deposit done using polynomial interpolation*

Conclusion

Geological and technological models of deposits can increase the reliability of the prediction of technological properties of ferruginous quartzites to unexplored sections of deposits, increases quality of graphic modeling when creating geological and technological maps, plans, sections. The model makes it possible to develop the most optimal geological and technological classification for a specific deposit and rationally outline technological types and grades of ore with the most suitable algorithm in a given geological situation.

Using the geological and technological model, it is possible to most fully identify the relationship of geological and structural features with enrichment and to define main factors affecting the enrichment of ore's quartzites with their quantitative assessment. The model makes it possible to quickly obtain and process geological and technological information on any site of deposits with the issuance of predicted geological, mineralogical and technological indicators using a data bank.

References

Aronov V.I. [1990] Methods for creation for maps of geological and geophysical attributes and geometrization of oil and gas deposits on a computer. Nedra, Moscow (in Russian).

Bogdanova I.P., Gritsay Yu.L., Finvarb S.M. [1981] Creation of computer technological memory based on the example of ferruginous quartzites Krivbass and KMA. *Mineral processing of ferrous metals*, 10, 66-71 (in Russian).

Dmitriev E.V., Chernovsky M.I., Zhuravlev A.S., Bogdanova I.P., Gritsay Yu.L. [1989] Geological and technological mapping of oxidized ferruginous quartzites of the Valyavkinske deposit in the Krivorozhsky basin. *Geology of ore deposits*, 5, 80-87 (in Russian).

Plotnikov A., Kurylo M. and Tokar M. [2015] Application of GIS in reserves estimating of iron ore deposits with complex structure. *Conference Proceedings 14th EAGE International Conference on Geoinformatics. Theoretical and Applied Aspects*. European Association of Geoscientists & Engineers, 2015, 1 - 5.

Rodionov D.A. [1981] Statistical problem solving in geology. Nedra, Moscow (in Russian).

Pirogov B.I., Porotov G.S. Kholoshin I.V., Tarasenko V.N. [1988] Technological mineralogy of iron ore. Nauka, Leningrad, (in Russian).