PROSPECTIVES OF ZHAYLMINSK GRABEN SYNCLINE FOR POLYMETALS IN CENTRAL KAZAKHSTAN

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ABSTRACT

The Zhaiylma graben syncline where large iron (Karazhal) of ferromanganese (West Karazhal, Ushkatyn-III) and polymetal (Zhairem) deposits are located, reveals a rift structure formed in the Upper Devonian - Lower Carboniferous and is complicated by the subsequent orogenesis processes. Its length is 140 km with a width of 10-30 km. Iron, ferromanganese, zinc-lead-barityc ores are developed at the deposits of Zhaiylma graben syncline. They are enclosed in the clay-carbonate deposits of the Upper Famennian and are interstratified with the products of the underwater basaltoid volcanism of jasper-diabasic formations. Limestones of the lower tour lie on them. The listed rocks are covered with loose Cenozoic deposits with a thickness of up to 60 m. The ores are spatially combined and their ratios are different. Some deposits are iron (Karazhal) and ferromanganese (West Karazhal, Ushkatyn-III), others are barite-lead-zinc with lenses of ferromanganese ores (Zhairem), some are ferromanganese-lead-zinc (Arap). Iron and ferromanganese deposits are located on the graben syncline edges, and zinc-lead-barytic deposits are located in its axial part, where the magnetite to hematite ratios are different: it is more in "near edge" than in "axial" pasts, which is a consequence of the geothermal process of dislocation metamorphism. This ratio led to the discovery of all "near edge" deposits by magnetic prospecting, and Zhairem deposit – by gravity prospecting. Such a situation should become a criterion for the search for deep-lying deposits of Zhairem type in the axial part of the graben syncline under the thick mass of limestones of the lower tour by modern electromagnetic (WTEM) and audio-magnetotelluric (ZTEM) aerogeophysical methods.

KEYWORDS

Central Kazakhstan, Zhaiylma graben syncline, polymetal, Zhairem.

Polymetallic ores may become one of the sources of income in the Karaganda region of Kazakhstan, in connection with the commissioning of Zhairem deposit. Among the similar facilities in the region, only the Akzhal mine operates on the basis of the same-named deposit, where intensive mining is taking place, which will lead to the depletion of its reserves in the nearest future.

The works on strengthening and expansion of the raw materials base of polymetals in the region in recent decades have not been successful due the lack of effective criteria and methods for forecasting hidden deposits located at considerable depths, since the stock of deposits located on the surface or at shallow depth in the region is completely depleted. Therefore, to identify hidden deposits, we focused on the geological and prospecting models based on geological and paleotectonic positions, spatio-temporal and genetic connection with specific structural-material formations by using and combining modern geological, geochemical and geophysical methods for the Zhaiylma graben syncline area.

The Zhaiylma graben syncline is a multiple-dissected graben-like trough limied by intersecting deep faults of the north-west and east-west trending. Its length is 140 km with a width of 10-30 km. The rift laying was preceded by a ground lower-middle Devonian volcanism of andesite-basalt and rhyolite composition. With the development, the rift was performed by the association of continental and marine formations, including products of contrast-differentiated ground and underwater basaltic-rhyolitic volcanism, red-molasse, marine siliceous-carbonate and carbonaceous terrigenous formations of the Upper Devonian - Lower Carboniferous (see Figures 1 and 2).

Iron, ferriferrous manganese, zinc-lead-barium ores are developed at the deposits of the Zhaiylma graben syncline. They are enclosed in the clay-carbonate deposits of the Upper Famennian and are interstratified with the products of the underwater basaltoid volcanism of jasper-diabasic formations. Limestones of the lower tour lie on the deposits of the Upper Famennian. The listed rocks are covered with loose Cenozoic deposits with a thickness of up to 60 m. The ores are spatially combined and their ratios are different. Some deposits are iron (Karazhal) and ferromanganese (West Karazhal, Ushkatyn-III), others are lead-zinc with lenses of ferromanganese ores (Zhairem), some are ferromanganese-lead-zinc (Arap). As for the content of metals, iron and manganese ores in zinc-lead-barytic deposits are non-industrial

Lead-zinc-barytic ores are closely related to the clay-siliceous-carbonate formation. Ore bodies are represented by bedding plane deposits of sedimentary genesis, on the one hand, and by cross-cutting lens-and vein-like bodies formed in disjunctive disturbances in the process of dislocation metamorphism of primary sedimentary ores, on the other hand. As a rule, these and other ore bodies are present on all deposits, but their relative number is different. They are being a part of the rocks of the siliceous-carbonate formation of the Famennian age, forming the ore-bearing association of formations, transgressively lie on the older deposits and overlapped by rocks of the Carbon-terrigenous-carbonate formation of the Turney and Visean Stage of the Lower Carboniferous. In this association facies of various depths are noted: near-shore terrigenous carbonate, reef, silt-hollow siliceous-carbonate with relicts of the products of basalt-liparitic volcanism. Mineralization tends mainly to the deposits of silt-hollow facies and their facial joints with shallow deposits.

Among the barite-polymetallic facilities, the Zhairem deposit is of practical value in the region, confined to the brachianticlinal structure (fenster) in the central part of the graben syncline and consisting of three sections: East, West and Far-West. The ores of the deposit are represented by bedding plane deposits, relevant to the host rocks with a thickness from the first tens of centimetres up to the first tens of meters. As for the strike-length, the ore bodies can be traced for kilometres, as for the down-dip – up to 500-900 m. Their boundaries are usually unclear and are set according to the sampling data. Cross-cutting lens-and vein-like ore bodies have a very whimsical shape, but clear boundaries; their thickness is within the range of several centimetres to several meters. The near-ore changes are relatively weak, expressed by baritization and silicification. Barite-lead-zinc ores are of industrial value and form the main reserves. The average content of lead (in %) – 1.7, zinc – 3.75, barite – 37. The main minerals are sphalerite, galenite and barite. There are also about 60 minerals in the ores that do not form clusters. Reserves are estimated in industrial categories (in thousand tons): lead – 2602, zinc – 5620.

A characteristic feature of the Zhailma graben-syncline is that the ferromanganese deposits are confined to both rift edges, and lead-zinc deposits – to the axial part. They come out on the erosion cut (under the silts), so they were available for search and prospecting by common methods. However, the main part (about 90% of the area) of the ore-bearing rocks of the Upper Famennian, except for the fenster where the Zhairem deposit is located, overlain by the thick mass of limestones of the lower tour, with a thickness in the axial part of the rift up to 1200 m, has not been studied due to the impossibility of unambiguous determination of the deep structure by the methods used at the end of the last century.

It should also be noted, and this is especially important for the search criteria - the unevenness of the concentration of magnetite in hematite ore. In the ores of deposits confined to the rift edges, the amount of magnetite is greater than in the deposits in the axial part. In our opinion, the reason for this is the thermodynamic transformations under dislocation metamorphism that arise during the orogenesis, where they manifest themselves strongly in the areas of tectonically disturbed zones, i.e. on the rift edges or in the junction of faults, rather than in undisturbed blocks located far from them. This leads to the rifting of rocks with new formation of minerals, the formation of rich ore columns in the ore fields of similar polymetal Akzhal and Uzunzhal (Kaskaygyr, Zhundy) and manganese Zhezdy (Naizatas) deposits and the transformation of hematite into magnetite. The quantitative relationship of these minerals depends on the intensity of the metamorphism.

As a result, all "near edge" deposits were discovered by magnetic anomalies, and the Zhayrem deposit, located far from the edges in the axial part, is not marked by magnetic prospecting; it is discovered by gravity prospecting. This was also facilitated by finding them near the day surface.

Such a situation can not be transferred to deep-lying ore facilities, especially under the thick mass of the Lower Taurus limestones, as it is impossible to unambiguously identify the weak gravity and magnetic anomalies as ore because of the depth. Accordingly, searches by magnetic prospecting and gravity prospecting methods that led to the discovery of all near-surface deposits and ore occurrences within the Zhaiylma graben-syncline are not effective for the search for deep-lying deposits. Their integration with high-frequency ore seismic prospecting also did not produce the desired effect due to the thick cover of loose Cenozoic deposits.

Thus, in order to search for polymetal deposits under the Lower Utrannian deposits that cover the ore-bearing Upper Famena rocks throughout the Zhaiylma graben-syncline, it is necessary to apply modern technologies for the purpose of studying the spatial structure and accurate forecasting of the desired facilities.

These include aerogeophysical research, namely:

- electromagnetic survey by the WTEM system in the class of transient processes in combination with high-precision magnetic gradiometry for studying the spatial structure of the anomalous magnetic field and geoelectric sections of known deposits and establishing a search "image" for them for the purpose of forecasting similar facilities over the entire area according to the received characteristics;
- audio-magnetotelluric method ZTEM in combination with aerogravimetric gradiometry for structural spatial mapping up to 1-2 km in depth and localization of sources of anomalies for the purpose of task-specific performance of drilling operations.

The application of these methods in combination with the results of earlier geological prospecting works will undoubtedly lead to the discovery of large deposits like Zhayrem in Zhaiylma graben syncline, and the multiple expansion of the mineral resource base and improvement of the investment climate in the region.

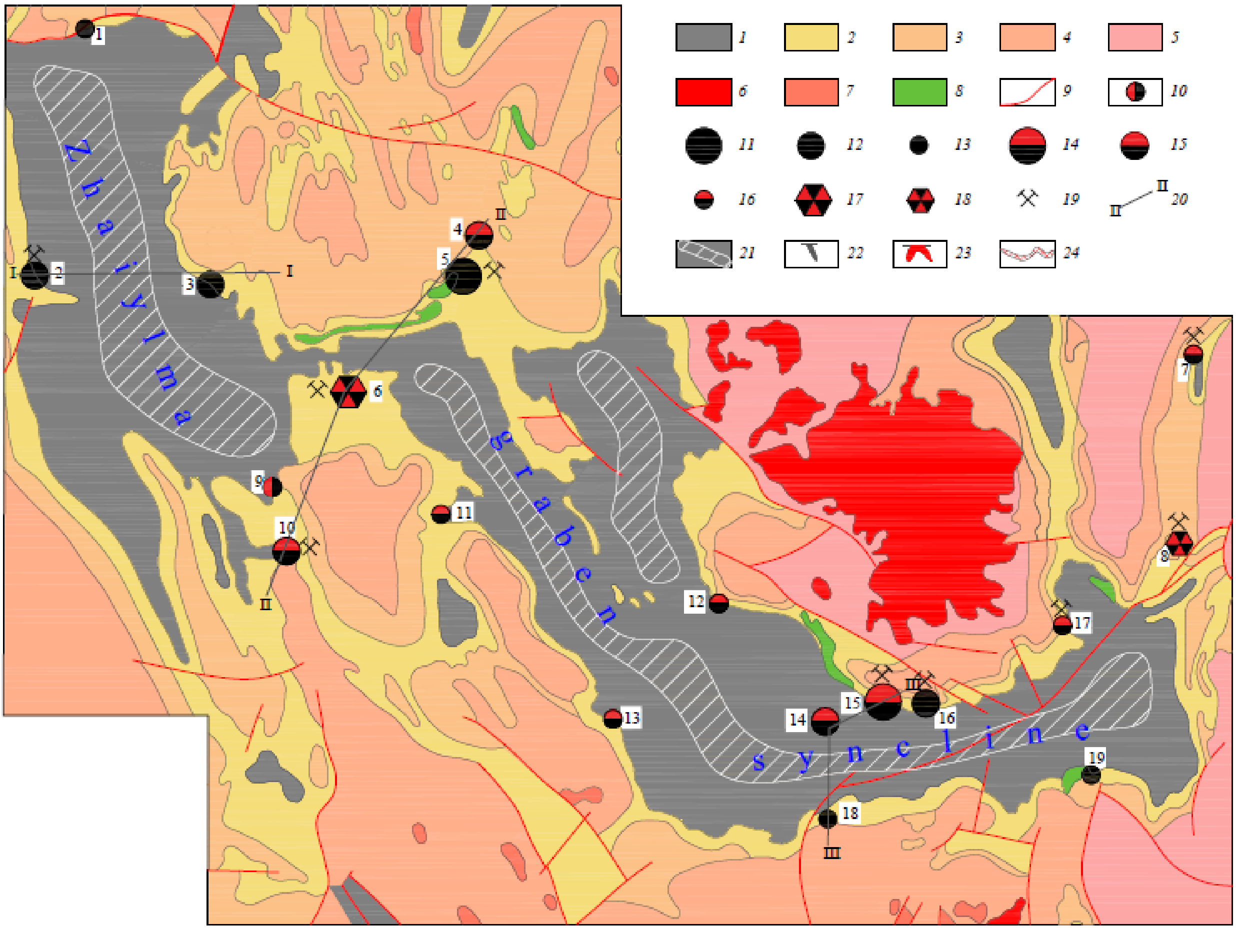

Fig. 1 Schematic geological map of Zhaiylma graben syncline

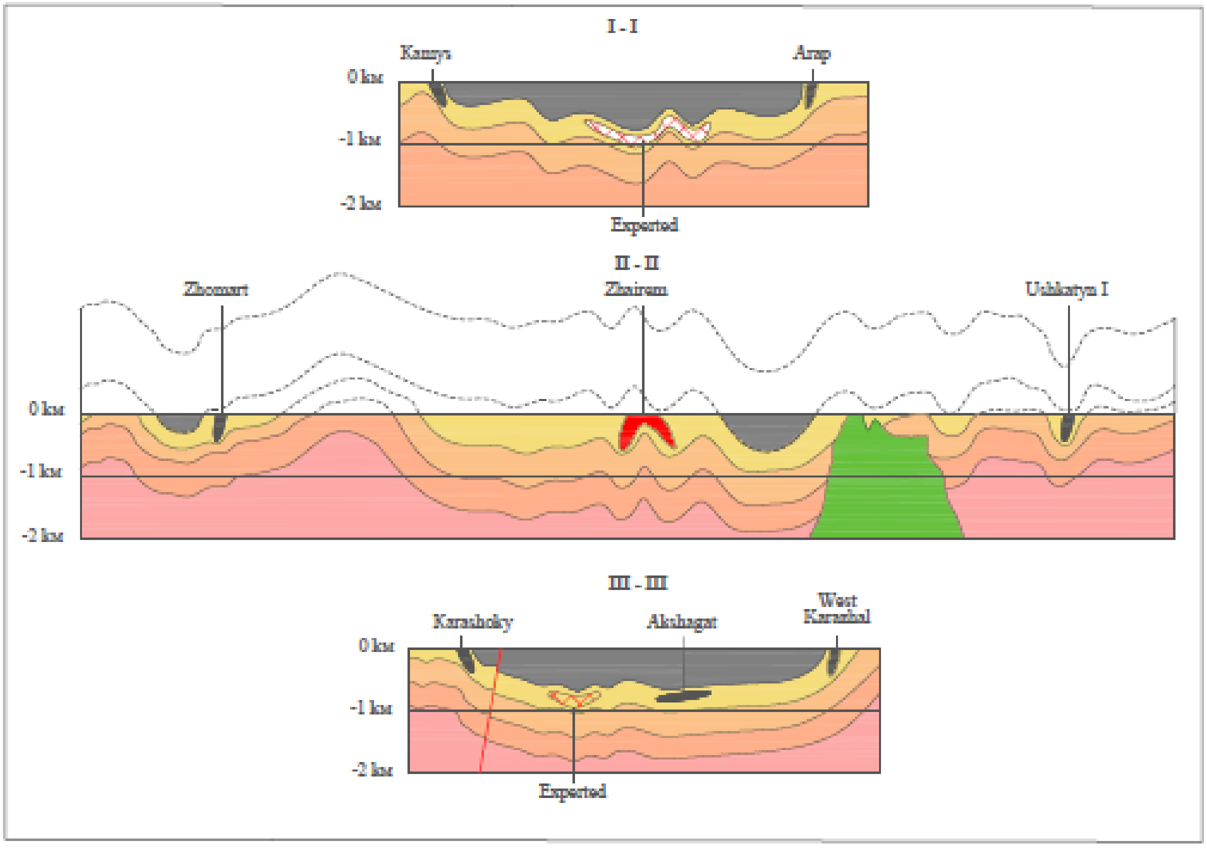

Fig. 2 Schematic geological sections by lines: I-I, II-II, III-III

Legends:

a) Fig. 1: *1* - Lower Carboniferous - limestones, mudstones, sandstones; *2* - Famennian Stage - limestones, clay-siliceous-carbonate rocks with layers of ferromanganese and barite-polymetallic ores, tuffs, tuffites; *3* - Darin suite of the Upper Devonian - red conglomerates, sandstones, siltstones, lenses of trachidaceous porphyrites; *4* - Lower - Middle Devonian - terrigenous-volcanogenic deposits; *5* - Lower Paleozoic - metamorphosed volcanogenic-terrigenous deposits; *6* - granites of the upper Permian; *7* - Devonian granitoids; *8* - gabbro-diabases; *9* - discontinuous faults; *10* - *18* - stratiform volcanogenic-sedimentary deposits (Atasui type): *10* - iron ore - small; *11* - *13* - manganese ore: *11* - large, *12* - medium, *13* - small; *14* - *16* - ferromanganese: *14* - large, *15* - medium, *16* - small; *17* - *18* - barite-polymetallic: *17* - large, *18* - medium; *19* - deposits being developed; *20* - cutting line; *21* - area of possible localization of barite-polymetallic deposits under the cover of the Lower Carboniferous deposits.

b) Fig. 2: deposits: *22* - ferrous metals and *23* - polymetals (known), *24* - polymetals (expected).

The list of deposits marked on the map: 1 - Kartobay, 2 - Kamys, 3 - Arap, 4 - Ushkatyn I, 5 - Ushkatyn III, 6 - Zhairem, 7 - Keregetas, 8 - Kentobe, 9 - Tamara, 10 - Zhomart, 11 - Akkuduk, 12 - Altynshoky, 13 - Karaoi, 14 - Akshagat, 15 - West Karazhal, 16 - East Karazhal, 17 - Bolshaya Ktay, 18 - Karashoky; 19 - Klych.

GEOSTASTISTICAL MODELLING OF GEOMETALURGICAL VARIABLES TROUGH TURNING BANDS APPROACH

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ABSTRACT

Geometallurgical variables have a significant impact in downstream activities of mining projects. Reliable 3D spatial modelling of these variables play an important role in mine planning and mineral processing, in which it can maximize overall viability of the project. This interdisciplinary paradigm involves geology, geostatistics, mineral processing and metallurgy, needs enhanced techniques to model these variables. In some circumstances, these geometallurgical responses demonstrate a good intrinsic correlation that motivates one to use co-estimation or co-simulation approaches. The latter allows to reproduce that dependency characteristic in the final model. Among others, total and soluble copper grades as two important geometallurgical variables in copper deposits show some complex interrelationship characteristics. The reason is that the total copper grade in the material processed by heap leaching is not in complete agreement with the expected recovered grade and one can see a significant variation in different oxide minerals. In such cases, the current approaches of probabilistic modelling such as independent simulation gives poor results. In this paper, turning band simulation methodology in combination with minimum/maximum autocorrelation factor (MAF) used to reproduce this kind of behaviour and compare with those results obtained from conventional co-simulation approach.

KEYWORDS

Geometallurgical modelling, Geostatistics, multi-Gaussian distribution, Co-simulation, Turning bands, Geomatallurgical variables.

INTRODUCTION

Geometallurgical mapping allows the integration of metallurgical responses of a deposit into 3D block models for the purpose of mine planning activities. Considering these parameters into resource modeling complements traditional geology and grade-based attributes, enabling a more comprehensive approach to the economic maximization of mineral production through better mine scheduling, planning and reduced associated risk and uncertainty (Macfarlane and Williams, 2014). Most of the time, geostatistical algorithms are applied for producing the high resolution of geometallurgical variables (Brissette et al. 2014; Deutsch et al. 2014; Tolosana-Delgado et al. 2015). However, in some circumstances such as oxide copper deposits, the complexity of these random functions requires consideration of enhanced geostatistical techniques. For instance, soluble copper is a fraction of total copper grade that recovered by heap leaching in these type of deposits (Emery, 2012; Hosseini and Asghari, 2015). Two difficulties often arise for joint spatial modeling of these two geometallurgical variables. The first difficulty for geostatistical simulation of total and soluble copper grades is inequality constraint, as soluble copper grade is always less than or equal to total copper grade. Conventional co-simulation approaches are not sufficient to reproduce such a crucial condition. To overcome this impediment, several avenues have been suggested (Mallet 1980; Dubrule and Kostov 1986; Leuangthong and Deutsch 2003; Emery, 2012). Emery et al. 2004 proposed change to the variables free of inequality constraint. In this context, the data should be converted to a new space and then after co-simulation, back-transferred to the original space. The second difficulty commonly met in practice corresponds to derive the theoretical cross-variogram structure for co-simulation. Such an inference can be implemented by linear model of coregionalization (Journel and Huijbregts 1978). Fitting this function to the experimental direct and cross-variograms is somehow demanding (Goovaerts 1993; Leuangthong and Deutsch, 2003). One alternative is based on transformation of converted cross-correlated variables into the factors that have no spatial interrelationship continuity. Principal component analysis and minimum/maximum autocorrelation factors (MAF) are the methods that eliminate the use of cross-variograms between correlated variables by decorrelation techniques (Bandarian et al. 2008; Swither and Green, 1984). The aim of this study is twofold: 1) following Emery et al. 2004, change of variables to the new variables free of inequality constraint has been applied for a dataset composed of total and soluble copper grades in a porphyry copper deposit (converting the total and soluble copper grades to total copper grade and solubility ratio, respectively); 2) apply MAF factorization methodology for joint simulation of the underlying converted variables; 3) comparing the proposed methodology (via MAF) with conventional co-simulation.

METHODOLOGY

Performance of MAF

Minimum/maximum autocorrelation factor (MAF) is a decomposition approach in geostatistical context that was first coined by Switzer and Green (1984) for image analysis. In this technique, it is of interest to convert the k spatial cross-correlated variables $\mathrm{Y(u)} = \{\mathrm{Y_1(u)}, \dots, \mathrm{Y_k(u)}\}$ to k uncorrelated factors (orthogonal) $\tau(\mathrm{u}) = \{\tau_1(\mathrm{u}), \dots, \tau_\mathrm{k}(\mathrm{u})\}$ through the linear transformation based on principal component analysis (PCA).

The MAF can be classified into two main families. In first family, model-driven MAF, the transformation matrix for obtaining the orthogonal factors $\tau(\mathrm{u})$, is based on the fitting the linear model of coregionalization (LMC) on the direct and cross-variograms calculated from the primary variables $\mathrm{Y(u)}$ (Vergas-Guzman and Dimitrakopoulos, 2003). However, a critical hypothesis in construction of this version is its restriction to the number of structures in LMC fitted model in order to ensure the independency between the factors for all the lag separations (Tran et al., 2006; Bandarian et al., 2008). In addition, the procedure for inferring a proper LMC model is somehow tedious (Davis and Greenes, 1983; Suro-Perez and Journel, 1991). An alternative can be the second family, the data-driven MAF, which originally, proposed by Switzer and Green (1984). The factors in the latter case are obtained without the requirement to fit a linear model of coregionalization, in which the transformation matrix is computed directly from input data through two successive PCA decompositions (Rondon, 2012; Desbarats and Dimitrakopoulos, 2000; Desbaratas, 2001). In this study, the following steps are presented to obtain two data-driven MAF factors:

1. Transform the original variables to normal score values with a mean of zero and variance one $N(0,1)$: this can be implemented by normal score transformation methodologies such as Gaussian anamorphosis (Rivoirard, 1994) or quantiles-based approach (Deutsch and Journel, 1998).

$$Z(u) = G^{-1}(F\big(Y(u)\big)) \qquad (1)$$

   where $G^{-1}(.)$ is standard normal cumulative distribution function, $F(.)$ is the cumulative distribution function of the original variable $Y(u)$ and $Z(u)$ is the normal score value.

2. Compute the experimental variance-covariance matrix at lag 0: since we are dealing with normal score values, this matrix is identical to the sample correlation matrix. In the case of two variables, this matrix (V) is as:

$$V = Corr\{Z(u), Z(u)\} = \begin{bmatrix} \rho_{11}(0) & \rho_{12}(0) \\ \rho_{21}(0) & \rho_{22}(0) \end{bmatrix} \qquad (2)$$

   where the principal diagonal element equals one which is identical to the total variance, upper and lower diagonal elements $\rho_{12}(0)$ and $\rho_{21}(0)$ equal the linear correlation coefficient between two normal score variables $Z_1(u)$ and $Z_2(u)$, respectively.

3. Perform the spectral decomposition of above matrix (V) to derive the orthonormal eigenvectors matrix (M_1), associated with the underlying diagonal eigenvalues matrix (E_1), such that:

$$V = M_1 E_1 M_1^T \qquad (3)$$

   It is necessary to check that the entries of E are in decreasing order.

4. Calculate the PCA transformations at locations u by:

$$PCA(u) = E_1^{-1/2} M_1 Z(u) \qquad (4)$$

   where PCA(u) are the scores with normal standard distribution due to the priori multivariate Gaussian assumption.

5. Choose a proper nonzero lag distance h and calculate the sample covariance and cross-covariance matrices $\widehat{\Lambda}_{PCA}(h)$ over the PCA scores, so its related spectral decomposition with diagonal eigenvalues matrix (E_2) and orthonormal eigenvectors matrix (M_1) is:

$$\widehat{\Lambda}_{PCA}(h) = M_2 E_2 M_2^T \qquad (5)$$

   It is worth mentioning that since the PCA scores are normal values, the variance-covariance matrix is identical to correlogram matrix.

6. Finally, the MAF factors at location u can be derived:

$$\tau(u) = M_2 PCA(u) \qquad (6)$$

   The back transformation is performed through the inverse of matrix M_2:

$$Z(u) = M_2^{-1}\tau(u) \quad (7)$$

Joint Simulation with MAF

In this study, it is of interest to apply MAF transformation on the cross-correlated variables combined with independent geostatistical simulation. The method allows one to independently simulate the factors without the need to fit a linear model of coregionalization while all direct and cross-covariances have been taken into account. Nevertheless, prior to this paradigm, the approach based on changing the original variables to the new variables free of inequality constraint has been employed to mitigate the impediment of modeling the total and soluble copper grades (proper explanation to do so is presented in subsequent section). Joint simulation with MAF is then performed over the converted variables in order to show the capability of this combined method. First of all, the conventional co-simulation is utilized to multivariate spatial modeling the two cross-correlated converted variables. Second, through the same converted variables, the proposed algorithm (joint simulation with MAF) is used in combination with independent simulation. Finally, the results of first and second steps are validated and compared to verify the relevancy of the proposed algorithm to multivariate spatial modeling of cross-correlated variables. The simulation algorithm in both steps can be on the basis of any Gaussian simulation approach. The first step is very straightforward as thoroughly explained in Madani and Ortiz, 2017. For the second step, following algorithm is proposed:

1. Convert the original cross-correlated variables to the new variables free of inequality constraint
2. Transform the declustered converted variables into normal score data (Gaussian random field with mean 0 and variance 1) (Eq. 1)
3. Transform the normal score data into orthogonal MAF factors (Eq. 6).
4. Calculate the experimental variograms for each MAF factor
5. Independent Gaussian simulation of MAF factors
6. Back-transformation of the simulation results (realizations) into normal score space (Eq. 7)
7. Back-transformation of the normal score realizations into the original space in order to restitute the intrinsic cross-correlation

APPLICATION TO A REAL CASE STUDY

The dataset is composed of 3866 samples obtained from blast holes belonging to a porphyry copper deposit. The dataset is homotopic, means that the data is available for each variable at all sampling points (Wackernagel, 2013). Total copper (tCu) and soluble copper grades (sCu) have been measured at sampling locations (the pattern is illustrated in Figure. 1). In the following subsection, the original values are multiplied by a constant scale factor in order to preserve the confidentiality of the dataset. Table 1 shows the statistical parameters obtained after applying the cell declustering (Goovaerts, 1997). The scarcity of data in some regions makes the sampling patter irregular and statistical parameters possibly biased. The idea of declustering is to account for the weights of each location by cell-based technique to correct the pseudo skewness in the global distribution of the dataset (Deutsch and Journel, 1998).

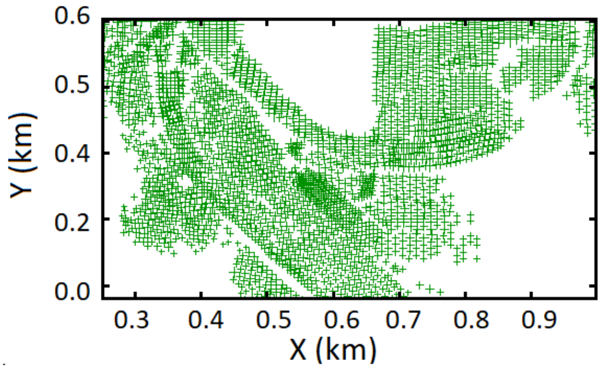

Figure 1 – Base map for the location of samples in the plane (the coordinates are local)

Table 1. Statistical properties of tCU and sCu

Variable	Original mean	Declustered mean	Max values	Min values
tCu(%)	0.83	0.87	4.76	0.11
sCu(%)	0.65	0.68	4.55	0.59

Multivariate analysis between these two variables by computing the linear correlation coefficient $\rho = 0.97$ explicitly indicates that those random attributes are highly correlated. This positive correlation implies that total copper grade increases as the soluble copper grade increases and vice versa. Therefore, this characteristic motivates one to jointly estimate or simulate the total and soluble copper grades in the specified domain. However, as explained the soluble copper grade is always less than or equal to the total copper grade (inequality constraint) (Figure 2), in which it makes difficult the process of co-simulation by conventional methodologies. In this study, these two original variables have been changed to other two variables free of inequality constraint. In this context, the solubility ratio (SR) can be calculated through dividing the soluble copper grade by total copper grade. As this value has no unit, it can be reported as percentage:

$$\mathrm{SR}(\%) = \frac{\mathrm{sCu}}{\mathrm{tCu}} * 100 \tag{8}$$

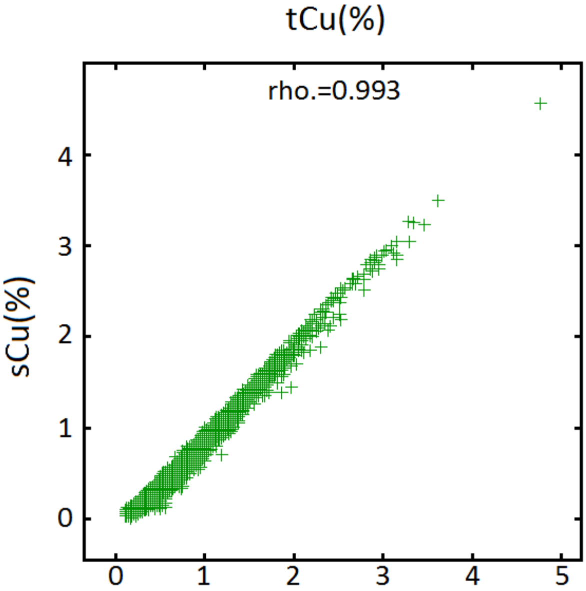

Figure 2 – scatterplot between total and soluble copper grades

Conventional co-simulation

After convert the cross-correlated variables (tCu and sCu) into the variables free of inequality constraint (tCu and SR), following the steps explained in above section, it is of interest, first co-simulate the total copper grade and solubility ratio by conventional Gaussian algorithm. All the Gaussian simulation methodologies can be applied. However, turning bands co-simulation (Emery, 2008) has been employed in this study because of its versatility and straightforwardness (Pravarzar et al. 2015). Prior to the modeling, the converted variables need to be transformed to the normal score values (Figure 3). This transformation guarantees that the values have standard Gaussian distribution $N(0,1)$ and can be used in Gaussian simulation algorithms (Figure 4, right). It is worth mentioning that, the scatter plot of normal scored original data without conversion to the new variables do not convey any multi-Gaussianity assumption, for which it restricts using the Gaussian simulation (Figure 4, left). Corroboration of multi-Gaussian assumption can be visually checked by elliptical shapes appear in scatterplot of two converted Gaussian random fields.

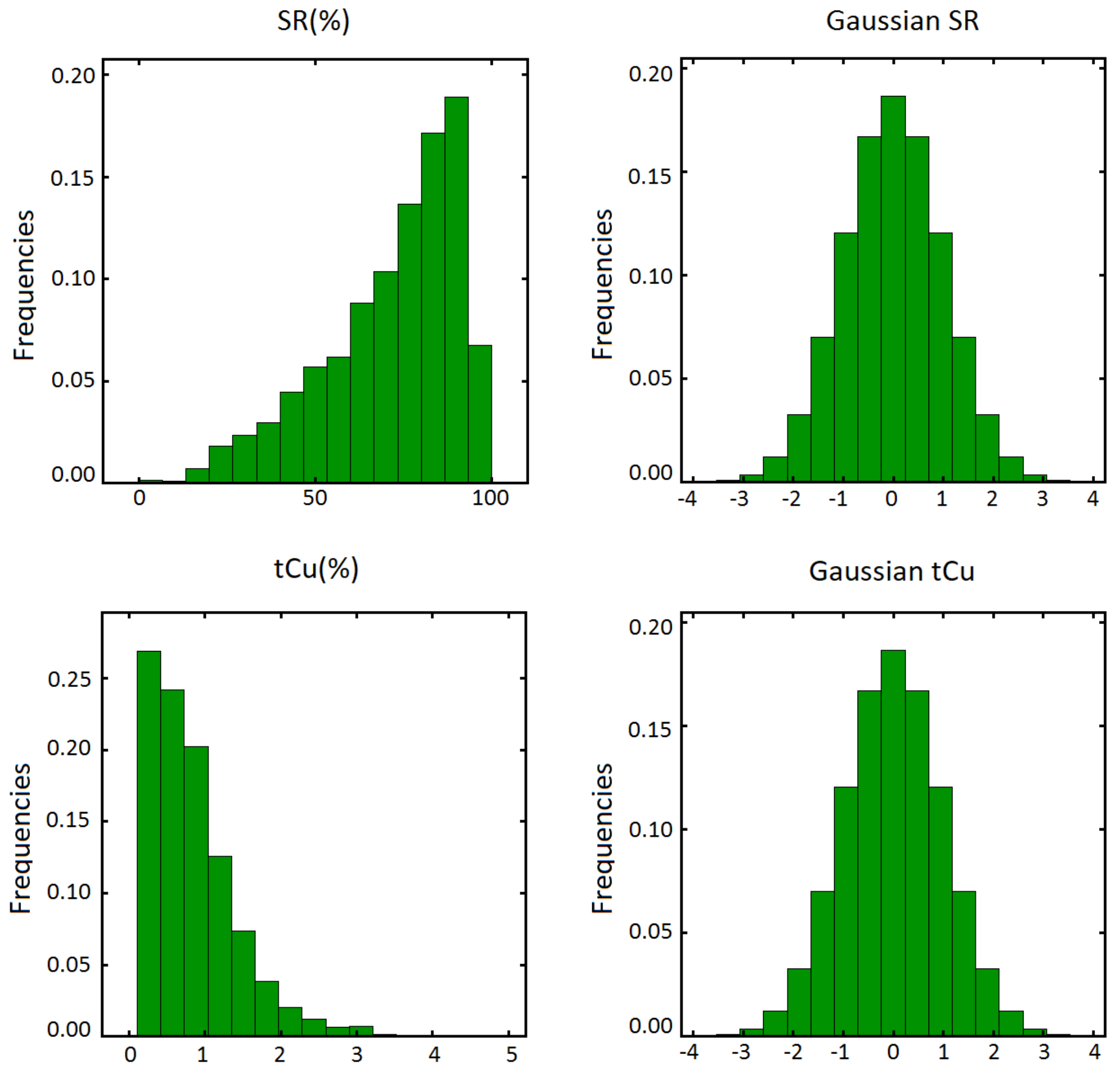

Figure 3 – normal score transformation (left: declustered histogram of the original data and right: histogram of the normal score values

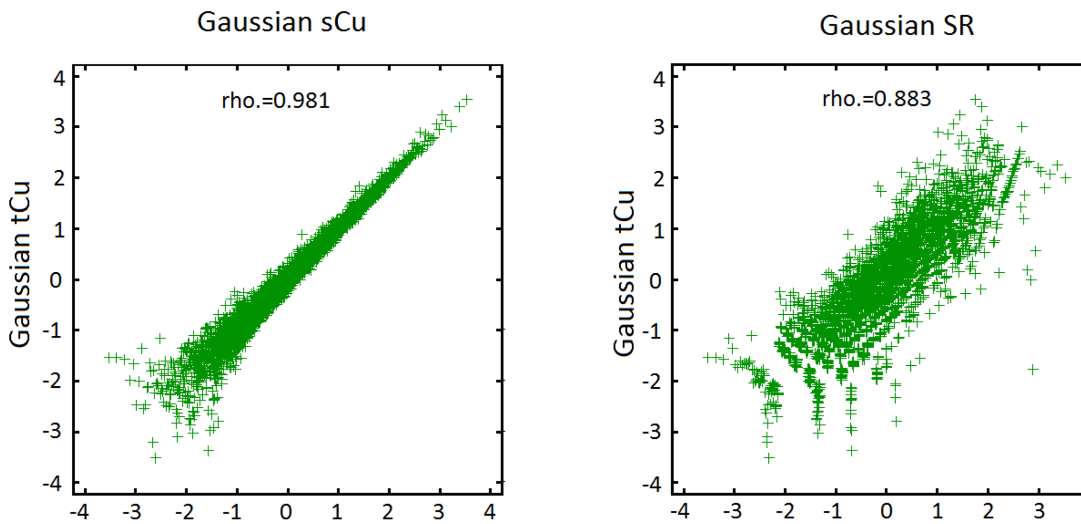

Figure 4: scatter plot of the data before and after conversion

Co-simulation methodology requires that the spatial continuity is primarily modeled by calculation of direct and cross-variograms of the transformed variables. The experimental direct and cross-variograms should then be fitted by manual or semi-automatic fitting approaches. Since, no anisotropy detected in the region, the fitted model (LMC) consists of nugget effect and two omni-directional spherical structures:

$$\gamma_{tCu}(h) = 0.27 + 0.32Sph(51.97) + 0.41Sph(252.88)$$

$$\gamma_{SR}(h) = 0.31 + 0.33Sph(51.97) + 0.41Sph(252.88)$$

$$\gamma_{tCu-SR}(h) = 0.20 + 0.30Sph(51.97) + 0.37Sph(252.88) \quad (9)$$

Having the theoretical fitted spatial continuity, simulation is then performed on a regular grid with dimension of 25 m × 10 m ×0.5 m. Simple co-kriging is utilized for the process of conditioning to the hard data (sampling locations). The proposed approaches can be substituted for ordinary co-kriging where the uncertainty is significant in mean value of the random fields (Emery, 2012). The neighborhood is moving with conditioning to 10 surrounding data characterized by isotropic distance equal 170 m derived from the variogram analysis. The number of lines for turning bands should be as large as possible (Emery 2008). Henceforth, it is set to 1000 lines for elimination of stripping effects and the number of realizations is considered to be 100.

Joint simulation with MAF transformation

The MAF factors are derived from the same normal score values (NS_{tCu} and NS_{SR}) explained in conventional c-simulation section. To do so, since in this study, data-driven MAF is used, it is necessary to consider an arbitrary lag separation distance except 0 for calculation of cross-correlation matrix. So, 10m is chosen based on sampling spacing and range of spatial continuity. In order to check whether the factors are spatially decorrelated, cross-correlogram has been plotted. This shows that the spatial correlation between two factors τ_1 and τ_2 is close to zero (Figure 5). The histogram of the factors can also be checked whether they follow $N(0,1)$. Figure 6 shows that the global distributions of the factors follow a standard normal distribution.

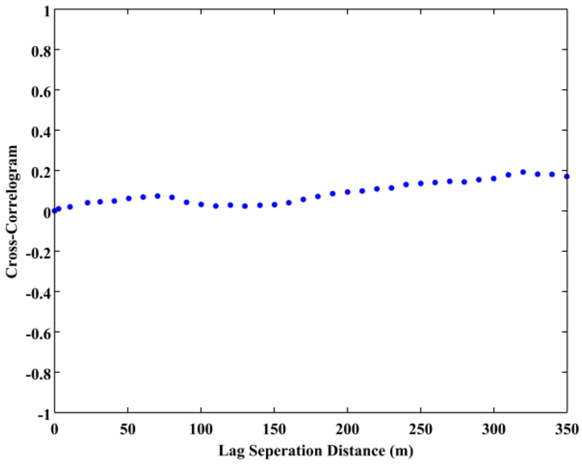

Figure 5 – Cross-correlogram between MAF factors using the data-driven approach

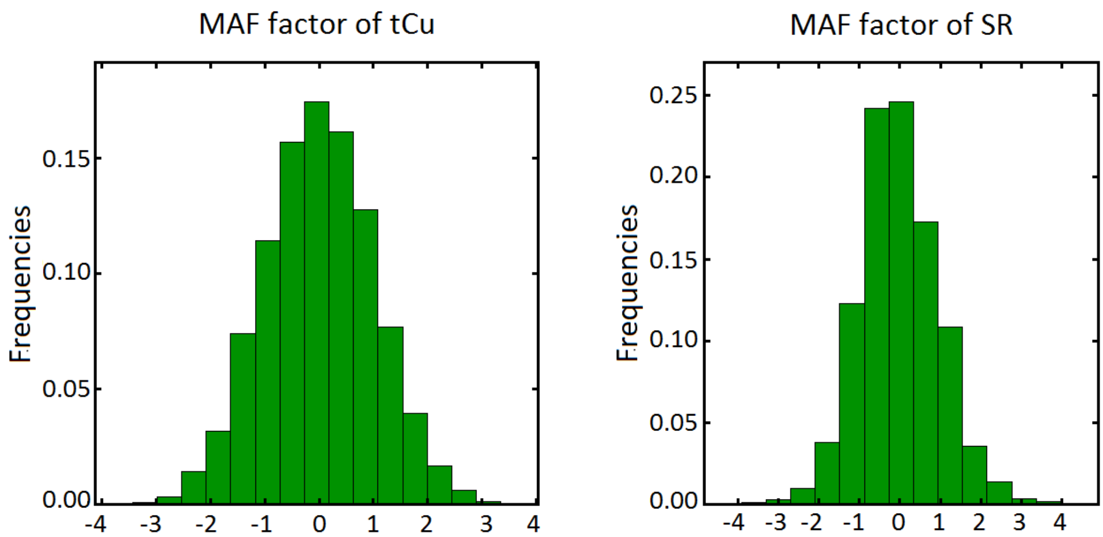

Figure 6 – Histogram of factors

Once the spatial decorrelation of factors is validated, the experimental direct variogram for each factor is computed and fitted:

$$\gamma_{\tau_1}(h) = 0.28 + 0.31Sph(51.97) + 0.42Sph(252.88)$$
$$\gamma_{\tau_2}(h) = 0.52 + 0.22Sph(51.97) + 0.27Sph(252.88) \qquad (10)$$

The fitted model to each factor is nugget associated with two spherical structures. The spatial continuity direction is omni-directional, same as the previous normal score variables (Figure 7).

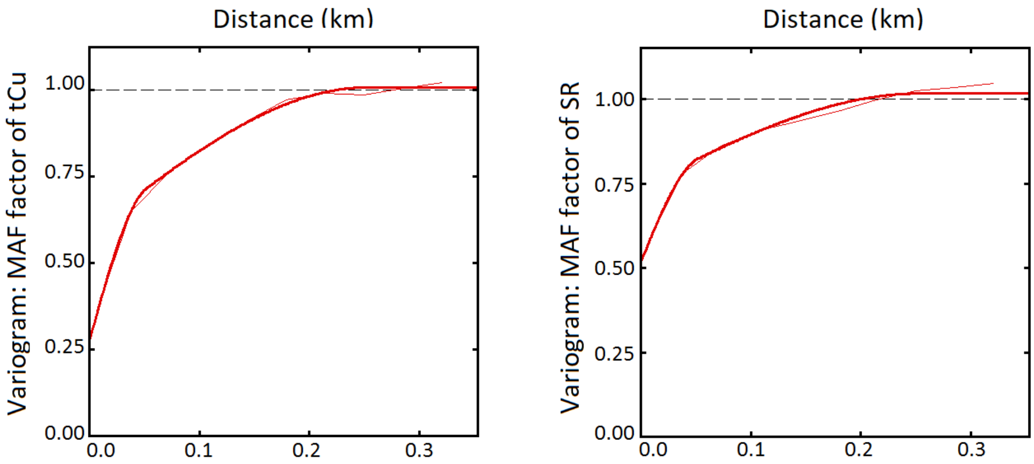

Figure 7 – Variogram analysis for each factor

Having the fitted variogram structures over the factor τ_1 and τ_2, the turning bands simulation algorithm (Emery and Lantuejoul, 2006) is employed to generate 100 realizations conditioned to two random fields of interest (factors). The size and dimension for independent simulation are the same as mentioned in section above. After simulation, it is necessary to back-transform the realization within two successive steps. The first back-transformation is from factor to normal score values; the second is from normal score values to total copper grade and solubility ratio. Since the aim of this research is to jointly simulate the total and soluble copper grades, the realizations so obtained are then back-converted by Eq. 8 to desired space. The maps of the average of 100 realizations produced from both methods: conventional cosimulation and joint simulation with MAF are illustrated in Figure 8 and 9.

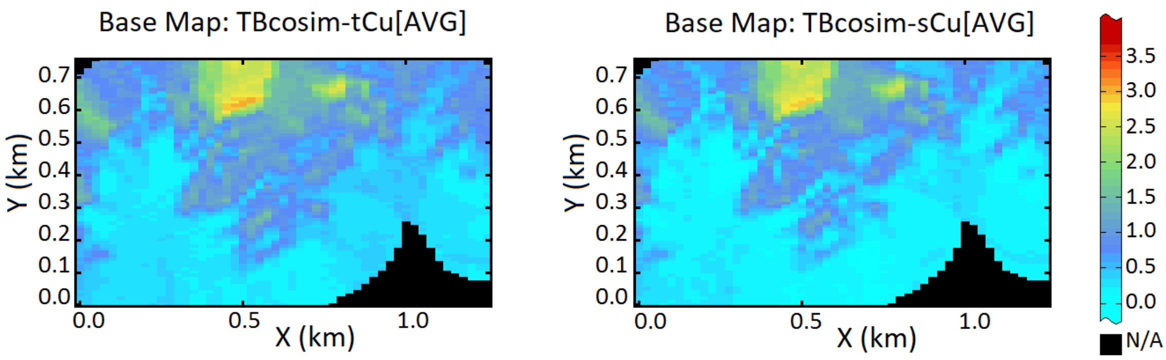

Figure 8 – Maps of simulated total and soluble copper grades for the average by co-simulation approach

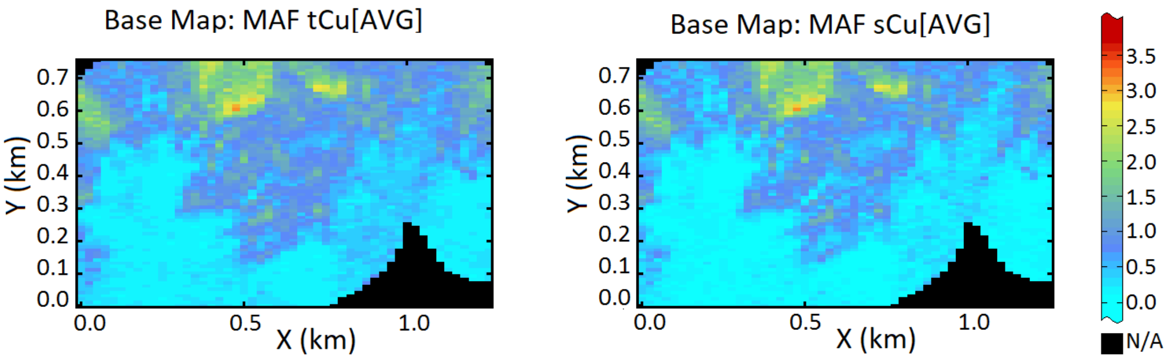

Figure 9 – Maps of simulated total and soluble copper grades for the average of realizations by MAF transformation approach

RESULTS AND DISCUSSIAN

The correlation coefficient is calculated for both results among total and soluble copper grades. The average correlation computed from 100 realizations obtained from MAF transformation and conventional cosimulation ($\rho_{MAF} = 0.994$ *and* $\rho_{Co-sim} = 0.992$) comparing to the declustered original correlation coefficient ($\rho_{tCu-sCu} = 0.993$) indicates that although the LMC is sufficient for re-establishing the data correlation, but the proposed algorithm (joint simulation with MAF) is also capable of restituting the desired correlation and can be applied to multivariate spatial modeling in the case when there is an inequality constraint among the variables. Figure 10 shows the scatter plot among these two variables. The shape of cross-correlation (dependency) between total and soluble copper grades and inequality constraint are satisfactorily reproduced. These results imply that the proposed algorithm does not show loss of accuracy.

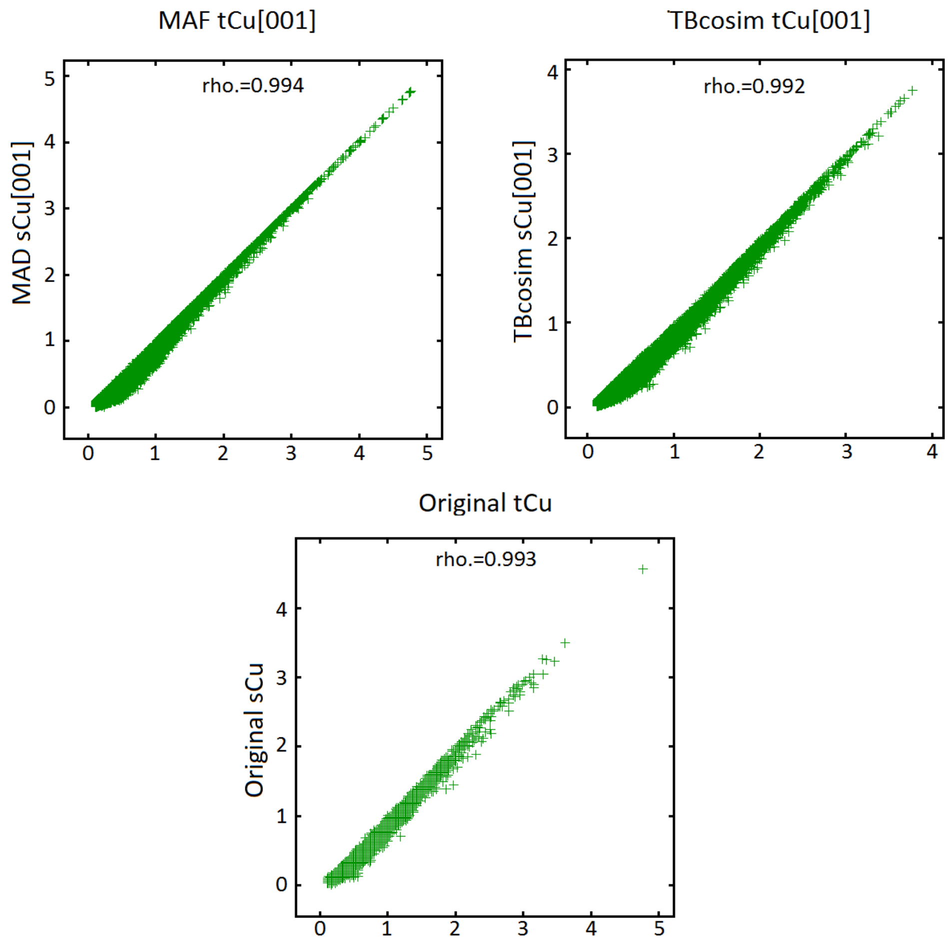

Figure 10 – The scatter plot of tCu(%) and sCu(%) obtained by MAF transformation (left-up); conventional so-simulation (right-up); original dataset (center-down)

CONCLUSIONS

Geostatistical modeling has been widely used in spatial modeling of geometallurgical variables. However, since those variables inherent complex characteristics, one needs to consider the improved methodologies. In this study, a new algorithm is proposed to jointly simulate the total and soluble copper grades with inequality constraint. In order to show the versatility of the presented technique, the results are compared with those obtained from conventional co-simulation that is based on inferring the linear model of coregionalization. The results approved that the correlation coefficients between total and soluble copper for both algorithms (conventional co-simulation and proposed algorithm) are reproduced extremely well, and multivariate complex interrelation of variables is regenerated without any deviation from the primary inequality constraint. The results of the proposed algorithm for joint simulation with MAF shows also the similar results as in co-simulation. Consequently, the use of LMC can be eliminated in order to build simpler geometallurgical modeling through factorization approach, which requires less computational time and resources.

ACKNOWLEDGEMENT

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PROBABILISTIC DOMAINING OF ALUMINUM AREAS IN IRON DEPOSITS

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PROBABILISTIC DOMAINING OF ALUMINUM AREAS IN IRON DEPOSITS

ABSTRACT

Geostatistical modeling of Iron grade (Fe) in metalliferous deposits is a rationale stage in further analysis of mine design such as mine planning and mineral processing plant optimization. This procedure is becoming important in the case when Fe is controlled by a co-variable that impacts negatively or positively the mechanical characteristics of the steel production. For instance, AL2O3 in most of the iron deposits in a certain level of concentration is helpful to increase the mechanical properties of the steel and in some other level plays as a gangue material which leads to prolonging the mineral processing procedure. Therefore, its 3D modeling is as significant as spatial modeling of Iron, in which it can give the idea of spatial distribution for aluminous areas in a mineral deposit. Geostatistical simulation is a powerful tool that able the practitioners to come up with the uncertainty quantification and consequently the probabilistic description of those areas. However, independent simulation in such a case that there exists a reasonable correlation between these two variables doesn't guarantee that the generated outputs preserve this correlation. Conditional co-simulation instead can be applied to check whether this intrinsic characteristic is reproduced properly. In this study, turning band co-simulation algorithm is applied to generate the iron and aluminum spatial distribution in a metalliferous deposit located in Brazil. The results then compared to those produced by independent simulation.

KEYWORDS

Iron deposits, Aluminum, Geostatistical modeling, co-simulation, Turning Band simulation

INTRODUCTION

With depletion of appropriate ores with proper grade distribution, for instance, high concentrations of iron with fewer trace elements which is acceptable for steel production (Mukherjee and Whiteman, 1985), new multivariate geostatistical techniques and approaches are used for constructing of block model which is based on complex multi element deposits with grade uncertainty. In blast furnace operations, presence of such the elements in iron deposits can have either negative or positive impact on mechanical property of iron processing and operation of smelter. Despite the fact that blast furnace burden composed of iron ore sinter, which is suitable for blast furnace performance, depletion of ores with high-grade iron leads to high concentration aluminum or other trace elements (Mukherjee and Whiteman, 1985). One of the co-variables that presents in many metalliferous deposits is aluminum oxide (AL2O3). High concentration of this element in sinter can lead to reduction of strength and negatively affects characteristics of prepared sinter (Das et al. 2001; Kumar et al. 1995). Furthermore, heavy of aluminum loading to the blast furnace results in large slag volume in furnace which leads to high consumption of coke (Hino et al. 2003). Experiment done by Okazaki et al. (2003) showed that concentration of aluminum oxide should be less than 1.5% in adhering fines to obtain proper pore structure, which is important in coalescing and reshaping process. Therefore, depending on market demand for quality of iron, existence of trace elements such as aluminum oxide with desired range of iron leads to better performance in furnace operation procedures. Mentioned negative factors can be partly neutralized by the addition of calcium wire (FeCa) or other number of solutions. However, the first solution to be implemented is avoidance of high aluminum concentration in iron deposit (Rosenqvist and Terkel, 1983). Geostatistics offer a range of methods, techniques for estimation, analysis and mapping of multivariate information or elements distributed in a particular region (Wackernagel, 2003; Chile and Delfiner, 2012). Geostatistics was initially originated in mining engineering for mathematical computations of ore deposits in the early 1950s (Sichel, 1952) and still has wide application of improvements in mining engineering for its significant role in determination of useful zones in deposits that can be considered from economical side. Basically, geostatistical simulations propose more reliable evaluation of grade distribution due to the fact that it produces many possible scenarios of each block, while the other deterministic geostatistical approaches such as kriging provides only one unique value for each block (De-Vitry, Vann and Arvidson, 2010). Existence of a good correlation among the elements motivates one to use co-estimation or co-simulation for the purpose of spatial modeling. These multivariate Geostatistical approach are useful for reproducing the intrinsic correlation after modeling. Among others, turning bands co-simulation algorithm can be applied for such a spatial modeling. In this paper, it is of interest to employ the turning bands co-simulation for two cross-correlated variables (Fe and Al2O3) obtained from a Brazilian iron deposit to define the beneficial probabilistic area of iron with aluminum less than 1.5%. The results are then compared with those resulted from turning bands simulation, in which these two random functions are independently simulated.

METHODS

Turning bands (co)-simulation

Turning bands simulation is an approximate algorithm based on multi-Gaussianity assumption of the underlying random field that first introduced by Matheron (1973) and then extended in some organized program codes (Lantue´joul, 1994; Emery and Lantue´joul, 2006). The principal concept of this algorithm is based on first, drawing plenty of lines with random orientation and second, simulating a one-dimensional Gaussian random field along each line (Lantuéjoul, 1994, 2002). Having the covariance model fitted to the primary declustered normal score variable, the covariance function is derived in one-dimensional random fields. Turning bands simulation provides a non-conditional multi-dimensional random field compatible with the target covariance model, in which the simulated values are practically standard Gaussian (Emery and Lantue´joul, 2006). In order to generate the conditional realizations, the non-conditional simulation so obtained should be progressed through one post-processing kriging step (Chilès and Delfiner, 2012; Emery, 2008; Journel and Huijbregts, 1978). The steps to perform the conditional turning bands simulation are as follow:

1- Exploratory data analysis: this step is needed to detect the possible errors and outliers.
2- Declustering: the scarcity of data in some regions makes the sampling patter irregular and statistical parameters possibly biased. One idea is to account for the weights of each location by cell-declustering technique to correct the pseudo skewness in the global distribution of the dataset (Deutsch and Journel 1998; Goovaerts 1997).
3- Transform the variable to normal score standard: since the turning bands simulation algorithm is based on the multi-Gaussianity assumption of the input data, the variable should be transformed to standard Gaussian with mean 0 and variance 1. The step can be done through Gaussian anamorphosis (Rivoirard, 1994) or quantiles-based approach (Deutsch and Journel, 1998).
4- Variogram analysis: direct experimental variogram is computed over the normal score values and the proper models are fitted by means of either manual or automatic paradigms.
5- Independent simulation: turning bands simulation first, non-conditionally simulates the values in a specified region by the information obtained from spatial continuity analysis in step 4 and then, back transform the realizations to the original space.

In turning bands co-simulation, it is of interest to stochastically simulate the cross-correlated variables (more than two). In this case, the cross-covariance function is needed to construct such a one and multi-dimensional Gaussian random fields in the region. The non-conditional step is the same as tuning band simulation, however, in part of the conditioning mechanism, the co-kriging must be used rather that kriging in order to hold the multivariate characteristics (Carr and Myers, 1985; Myers, 1989; Gutjahr et al., 1997; Emery, 2008). The general workflow is similar to turning bands simulation previously explained except that the items 1, 2 and 3 should be implemented for each variable separately. In variogram analysis, since the co-kriging system is established on the basis of cross-covariance matrix, it is necessary to calculate the experimental cross-variogram along with direct variograms. For n variables, $n(n+1)/2$ experimental variograms should be considered (Journel and Huijbregts, 1978). In order to fit the theoretical direct and cross-variograms models, linear model of coregionalization (LMC) should be fitted to all n(n+1)/2 experimental variograms as a linear combinations of equivalent structures together with the identical ranges, but different in sills, (Chiles and Delfiner, 2012; Wakernagel, 2003). The most tedious part of this job is to construct the permissible positive semidefinitness conditions in fitting the sill matrices. Once this constraint corroborated, the model can be used in variance-covariance matrix in the co-kriging system required in the conditioning process (Goovaerts, 1994).

RESULTS

3. Presentation of dataset

3.1. Case study

The study area, Carajás Mine, is located in Parauapebas municipality, state of Para in the Northern Brazil. The case study provided by Vale, is based on data set of iron deposit which includes iron

(Fe) and trace elements as aluminum oxide (Al2O3), manganese (Mn) and phosphorus (P). Geological and lithostructural setting of the Carajás deposits refers to Grao-Para Group's metasidementary and metavolcanic rocks which has two formations; Parauapebas Formation's volcanic rocks (Meireles et al., 1984) and Carajás Formation's ironstones (Beisiegel et al., 1973).

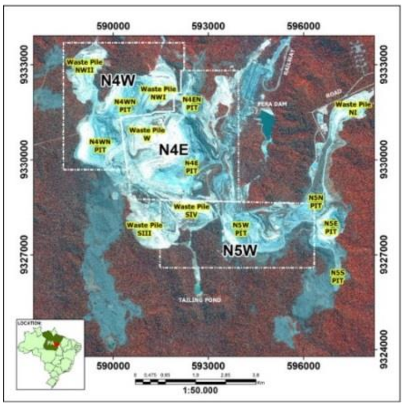


Figure 1 - Top view of mine study area in Para state, Brazil (Paradella et al., 2015).

3.2. Exploratory Data analysis

The dataset consists of 1380 samples obtained from boreholes campaign. Initial step for all mineral resource estimation projects is exploratory analysis of data. First of all, possible outliers should be detected. In this case, they can be removed or replaced by a top-cut value. Second step is identifying duplicated samples and to "mask" them. Declustering as the third step is to assign the weights to the sample points in order to make the global distribution representative (David, 1977 and Deutsch, 1989). To do so, no outlier and duplicated samples detected in the dataset. Declustering has been done in a dimension of $100m \times 400m \times 15m$ and the univariate statistical parameters have been calculated (Table 1).

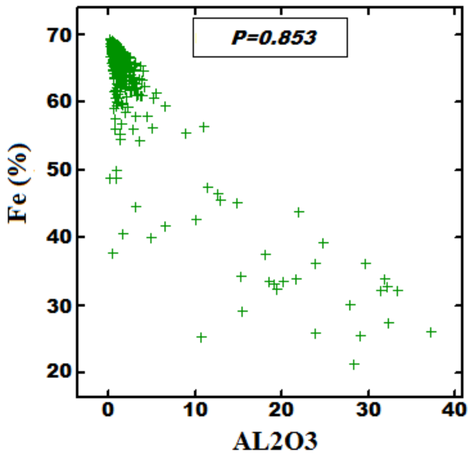


Figure 2 - Correlation between the declustered Fe and Al2O3.

In the case of multivariate analysis, the correlation coefficient parameter is a good measure of dependency. As it can be seen from figure 2, the correlation between declustered original Fe and Al2O3 is 0.853 which encourages one to use co-simulation rather than independent simulation. Beside of that, the heterotopic characteristic of sampling points implies that the co-simulation methodology turns out much satisfying results. Heterotopic data means that some of the variables share some locations of samples in the data set (Wakernagel, 2013).

3.2 Transformation of the Variables into Normal Score Standard

In geostatistical simulation methods, it is required to map the data to Gaussian space. Transformation of the variables to normal score standards is necessary in order to get Gaussian distribution, in which the mean and variance are 0 and 1, respectively (Deutsch and Hournel, 1998). This can be implemented by Gaussian anamorphosis through Hermite polynomial expansion (Rivoirard, 1994). In figure 3, transformation to normal score for Iron (Fe) and Aluminum oxide (Al2O3) is shown. Table 1 shows the statistical descriptions of the declustered and transformed values of Fe and Al2O3.

Table 1 – Statistical parameters of Fe and Al2O3 before and after transformation

	Fe declustered	*Fe transformed*	*Al2O3 declustered*	*Al2O3 transformed*
Number of samples	996	996	615	615
Minimum	4.80	-3.04	0.10	-2.92
Maximum	69.17	3.04	37.20	2.92
Mean	52.78	0.00	2.06	0.00
Standard Deviation	20.76	1.00	4.79	1.00

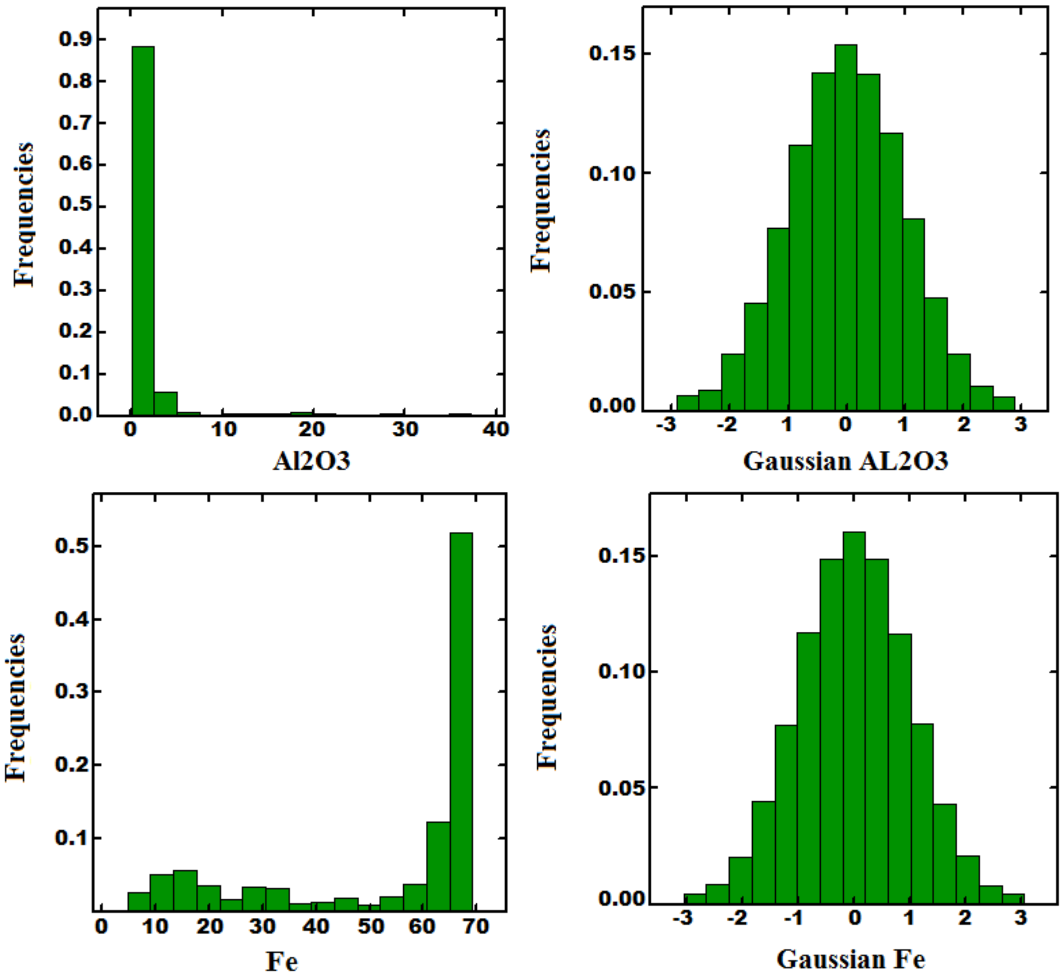


Figure 3 - Original declustered (left) and Normal Score Transformed (right) histograms of Al2O3 and Fe.

3.3 Examination of the multivariate and bivariate Gaussianity

The presence of an interesting positive correlation coefficient among the variables and its univariate transformation (Fig 3) to Gaussian random field does not ensure that the multivariate distributions are also Gaussian (Leuangthong and Deutsch 2003) (a critical assumption for implementing TBCOSIM). One important specification is to examine the multivariate Gaussianity by checking the homoscedasticity and linearity among the transformed cross-correlated variables (Johnson and Wichern, 1998). As an example, Figure (4) illustrates the scatterplot between two underlying elements (Fe and Al2O3) and one can see that the bivariate character is somehow in agreement with homoscedasticity and linearity definitions at small lags. However, the recognition of bivariate normality is somehow demanding in large lags (Emery, 2005).

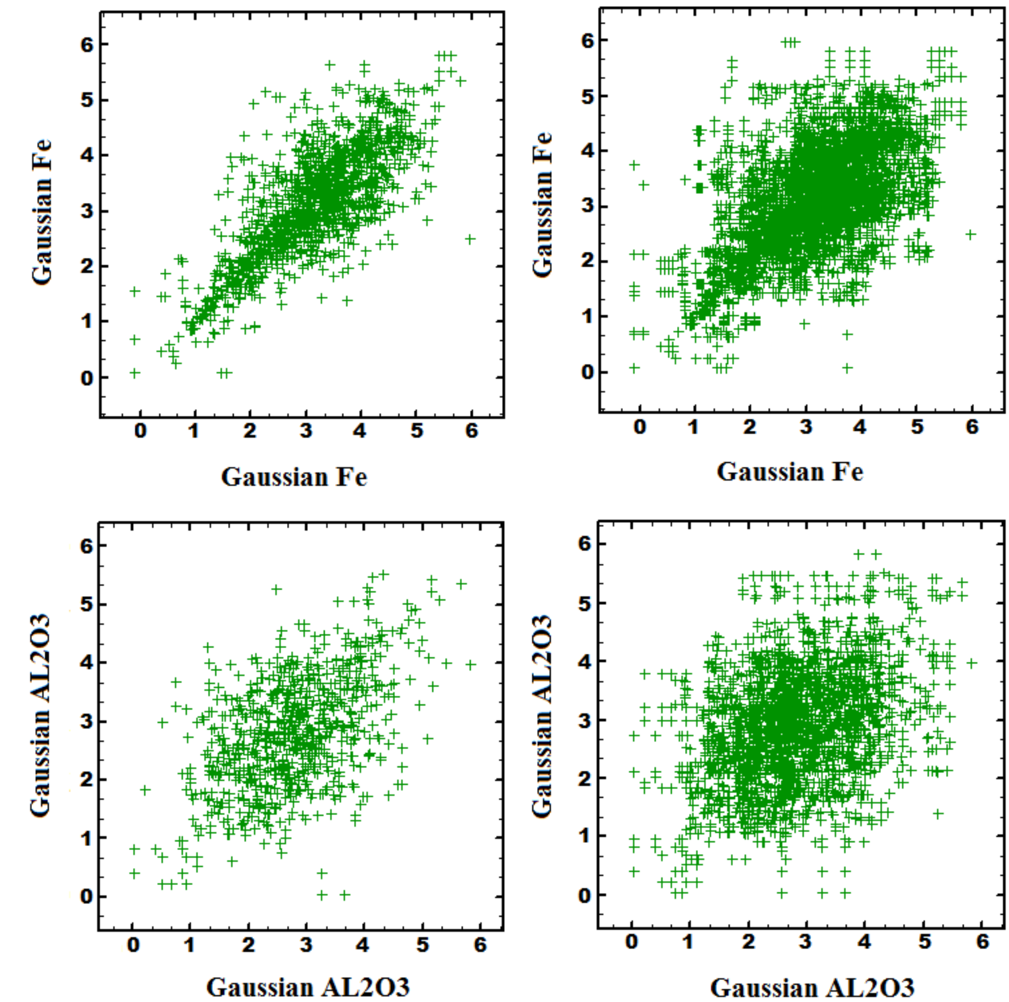
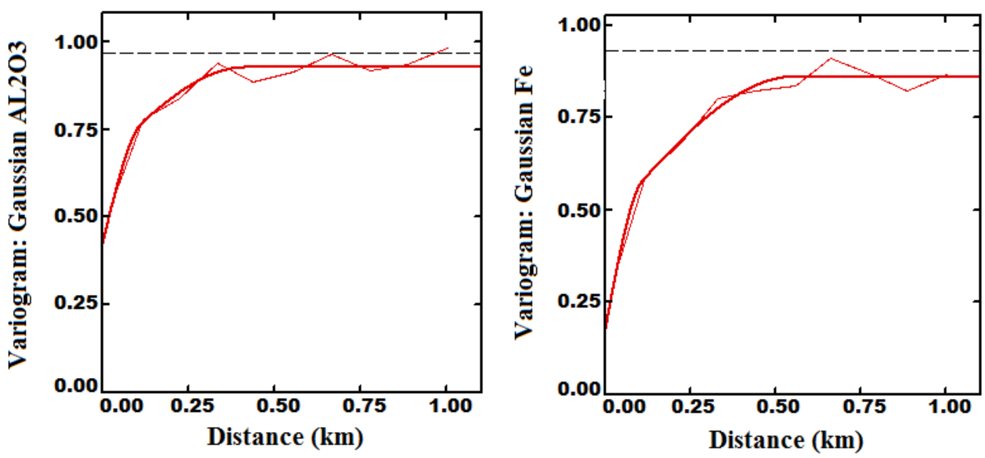


Figure 4 - Bivariate Gaussianity examination at lag (30 m) (left and lag (100 m) (right).

3.4 Spatial Continuity

Direct variograms were calculated for independent Turning Bands Simulation and cross-variograms were computed for Turning Bands Co-Simulation over normal scored aluminum oxide (Al2O3) and iron (Fe). Variogram fitting was done semi-automatically based on linear model of coregionalization (Journel, A. G., & Huijbregts, C. J. (1978)). For the sake of simplicity, the isotropy is considered for both variables. Therefore, the omni-directional variogram taken into account for whole direct and cross-variograms. Figure 5 shows the fitted direct and cross-variogram for Al2O3 and Fe. The equation for the cross-variogram is shown in equation 1:



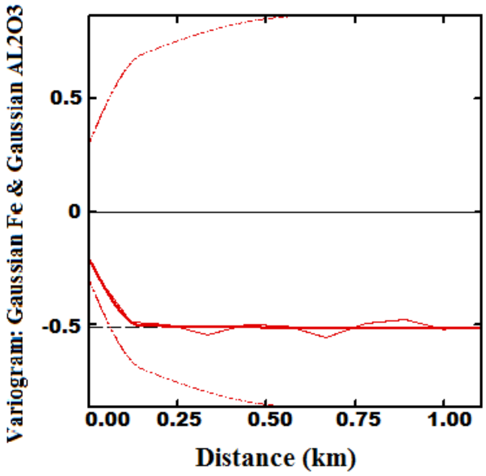


Figure 5 - Direct (upper) and cross-variogram (lower) for the Al2O3 and Fe.

$$\text{Spatial continuity: } \begin{pmatrix} \gamma_{Fe}(h) & \gamma_{Fe-Al2O3}(h) \\ \gamma_{Fe-Al2O3}(h) & \gamma_{Al2O3}(h) \end{pmatrix} = \begin{pmatrix} 0.4402 & -0.2129 \\ -0.2129 & 0.2149 \end{pmatrix} Nugget + \begin{pmatrix} 0.3041 & -0.2906 \\ -0.2906 & 0.2811 \end{pmatrix} Spherical(149.53m, 149.53m) + \begin{pmatrix} 0.1929 & -0.01285 \\ -0.01285 & 0.368 \end{pmatrix} Spherical(598.62m, 598.62m) \quad (1)$$

3.5 Turning Bands Simulation and Co-Simulation

All simulations were conducted on a grid with 10 m * 10 m * 10 m dimension. Type of neighborhood for conditioning process by kriging and co-kriging is moving with maximum distance of 800 m, larger than the maximum range in variography. The number of realization is 100 giving more reliability to conduct the methods with more confidence. Figure 6 shows the E-type maps reproduced by taking average of all realization within each block obtained from co-simulation and independent simulation after back-transformation to original space.

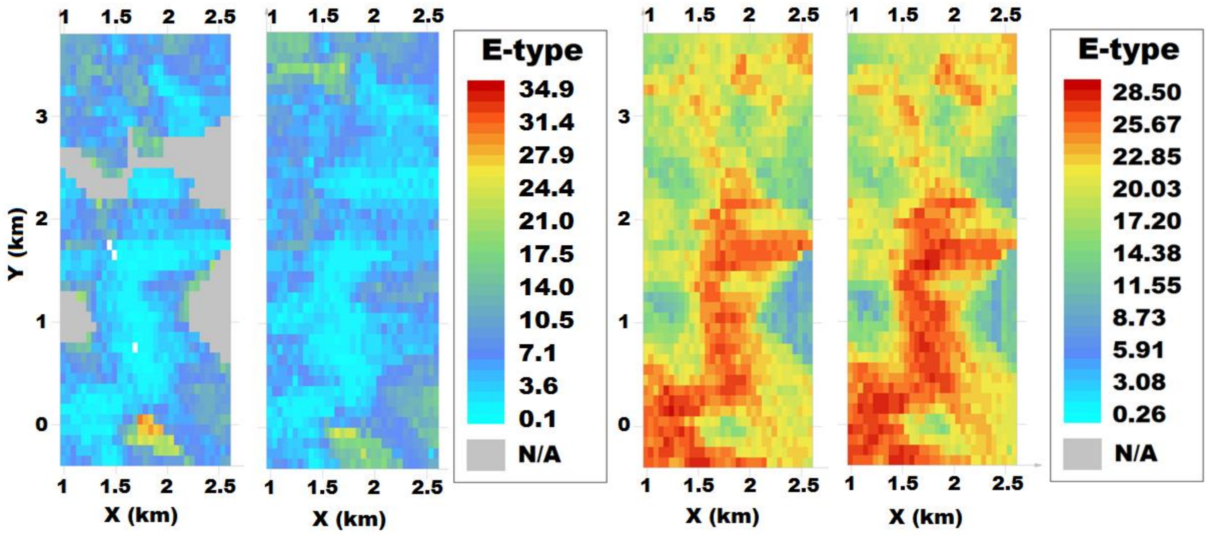


Figure 6 - E-type map of TBCOSIM and TBSIM of Al2O3 (left) and Fe (right). (Elevation 805 m)

3.6 Validation

This section focuses on the comparison between correlation coefficient calculated over the 100 realizations of both independent and co-simulation methods. Correlation coefficient that restitutes by turning bands simulation is 0.105 which is very different from original correlation (0.853, figure 2), while turning bands co-simulation is 0.498 which is 5 times closer to original correlation coefficient. In case of turning bands simulation, the small correlation coefficient based on realizations can be explained in virtue of the fact that independent simulation do not take into consideration the intrinsic correlation between co-variables in multi-element deposits (Madani and Ortiz, 2017).

Table 2 - Correlation coefficient between Al2O3 and Fe through 100 realizations.

	TBCOSIM	*TBSIM*	*Original dataset*
Correlation Coefficient	0.4918	0.105	0.853

3.7 Probabilistic illustration of Al2O3

As it was mentioned earlier, in order to obtain proper pore structure of iron for processing, the concentration of aluminum should be less than 1.5% beneficial in mineral processing system for coalescing and reshaping (Okazaki et al. 2003). Therefore, it is of interest to identify the possible target areas with small amount of aluminum. Since these areas are not deterministic, the geostatistical simulation methodology provides this opportunity to probabilistically detect those regions. To do so, the output of tuning bands co-simulation (100 realizations) is taken into account for computing such a probability. Probabilistic illustration of Al2O3 below 1.5 % is shown in Figure 7.

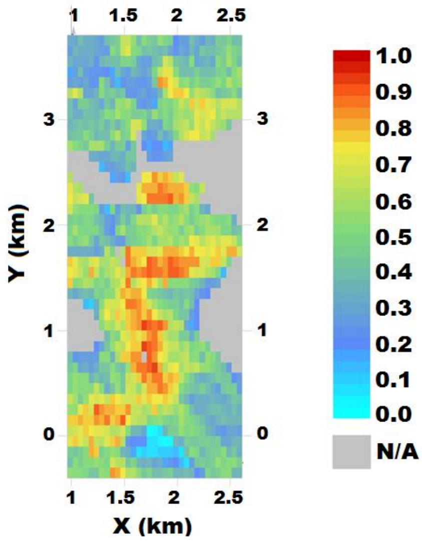


Figure 7 - Probabilistic illustration of Al2O3 below 1.5%. (Elevation 805 m)

DISCUSSION

The depletion of metalliferous deposits with high content of iron leads mining industry to mine metalliferous deposits with higher concentration of other trace elements which sometimes makes the processing less efficient or makes the quality of iron lower. However, geostatistical methods such as estimation and simulation can be applied to identify the blocks with interest of range for trace elements. For instance, trace element, aluminum can lead to high viscosity of slag which can cause unfavorable effect on furnace processes where metals are smelted.

Comparing to estimation (kriging), simulation methods generate more reliable results of spatial grade distribution as it can reproduce multiple scenarios of a deposit, whereas estimation only turns out one scenario of a deposit (De-Vitry, Vann and Arvidson, 2010). Reproduced spatial variability of the variable is another interesting characteristics of geostatistical simulation, which is not guarantee in the case in traditional interpolation such as kriging. The simulation can also be employed in determining the uncertainty in the recoverable resource above or below cut-off grades, Net Present Value (NPV) calculation, and cash flows of a project, geometry of the optimal open pit and identification of useful blocks.

CONCLUSIONS

Geostastical estimation and simulation methods are used for analysis of univariate and multivariate data in space. However, depending on the data distributed, estimation methods are not sufficient to provide with reliable results for constructing the block model. One of the main reasons is that estimation (kriging) methods are biased as they produce only unique realization for analysis, while geostatistical simulation methods provide with multiple realizations giving more reliable evaluation of grade distribution. Another issue occur when independent simulation and co-simulation methods are compared. First of all, independent simulation do not consider the intrinsic correlation between co-variables in the given data, while co-simulation takes into account interdependency between co-variables. Consequently, the results of correlation coefficient computed for independent simulation is much lower than co-simulation. Secondly, as it can be shown in figure 6, the E-type map of TBCOSIM shows higher grades at the bottom area of the map, while E-type of TBSIM shows with less grades. So, it can be stated that TBCOSIM is more reliable than TBSIM. Geostatistical simulation methods can produce the probabilistic determination of areas of interest with specific cut-off grade as in an example in figure 7. Because of mentioned different results for both methods, it is encouraged to use co-simulation in multi-element deposits with good intrinsic correlation among the co-variables. However, other factorization methods such as Projection Pursuit Multivariate Transform (PPMT) or minimum/maximum autocorrelation factors (MAF) can also be applied for better reproduction of global and spatial correlation.

ACKNOWLEDGEMENT

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APPLICATION OF THE STRUCTURAL-GEOCHEMICAL CRITERION FOR EXPLORATION OF OVERLAPPED ENDOGENOUS MINERALIZATION

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ABSTRACT

The article shows the theoretical model of paleovolcanic structures with the allocated zones of pyrite and porphyry copper mineralization. This model is constructed by authors on the basis of research carried out in the Urals, Chukotka, Gornaya Shoriya (Russia) and in Kazakhstan of long-term works. Structural and geochemical criteria of search of the blocked endogenous fields are defined. The example of use of criterion across the territory of South Ural (Russia) is given.

KEYWORDS

Paleovolcano, paleovolcanic structure, criteria, prospecting, facies, covered mineralization, geochemistry

INTRODUCTION

By these days issues of survey of blind and covered deposits are very actual. In course of such survey some significant difficulties associated with technological and intelligent matters used to be appeared. High affectivity of geological and prospecting abilities could be achieved only when complex studies have been done. These studies offer indicate structural elements of explores area and evaluate geological and geochemical potential of prospective areas. Structural and geological parameters of explored area are determined applying unique method of paleo-volcanic reconstruction.

METHODS

Theoretical conception of paleo-volcanic structures

For areas with a cover of igneous rocks, the basic structural unit is a volcano or paleo-volcanic structures. The theoretical concept is presented in articles by authors [1, 2, 3, and others]. Paleo-volcanic structure consists of pyroclastic, lava and volcanic-sedimentary, sedimentary and intrusive rocks. Combination of rocks forms facies. Each of the facies takes its spatial position and accumulates on the entire time interval of the structure. Facies are classified: vent; slope; distant or far distant (see Fig. 1).

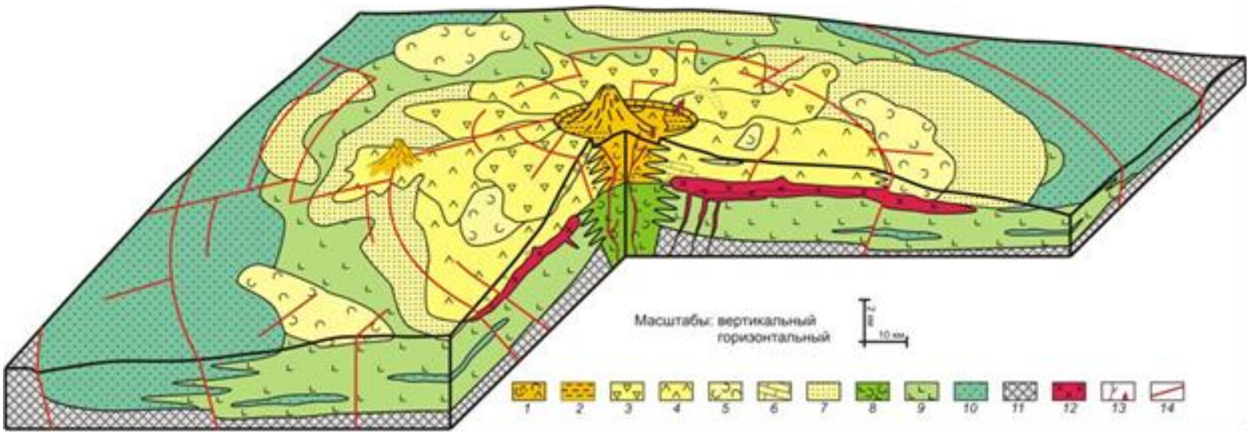


Figure 1 – Allocation scheme of paleo-volcano facies (by Dyakonov V.V., Kotelnikov A.E., 2011)
Legend: 1-10 - group facies of paleo-volcano: 1-7 - facies of the second stage of development (1 - vent, 2 - vent and near the vent, 3 - pyroclastic slopes, 4 – effusive slopes, 5 - ignimbrite slopes, 6 - reef (carbonate), 7 – distant); 8-10 - facies of the first stage of development: (8 - vent, 9 - effusive-pyroclastic slopes, 10 – distant); 11 - bedrock of the volcano; 12 - intrusive; 13 – hypabyssal (or subvolcanic) rocks; 14 - tectonic faults.

Paleo-volcano formation occurs in two periods, including three consecutive stages (Table 1):
- First period – volcanic period – is characterized by extrusive (or effusive) structures development. Volcanic period includes two stages. First stage – eruption of effusive products of basic chemical composition, leads to the creation of a shield volcano; Second stage – the subsequent eruptions of effusive rocks of acidic composition, out of the same magmatic channel, lead to the creation of stratovolcano. Formation of a stratovolcano associated to the same volcanic pipe (conduit), so stratovolcano forms on shield volcanoes, this is due to the change of the chemical composition of the magma at a significant time interval (more than 100 million years). Hypabyssal (or subvolcanic) rocks are formed predominantly within vent from end of first stage to end third stage. Third – the third stage is the formation of intrusive bodies within the paleo-volcano.
- Second period – Intrusive period - is characterized by intrusive (or post-volcanic) structures development. Intrusive period includes third stage. During this stage intrusive bodies (lopolith, laccolith, etc.) introduced into the border of shield volcano and stratovolcano.

Таблица 1 – Stages and Time interval of Paleo-volcano formation

Periods	Stages	Structural elements	Composition	Time interval (Ma)
Intrusive	3 stage	lopolith, laccolith, etc.	mafic-felsic	~10
Volcanic	2 stage	stratovolcano	intermediate-felsic	~50
Volcanic	1 stage	shield volcano	mafic-intermediate	~70

During volcanic period in each stages can distinguish three structural-facies zones: vent, slope and distant. The rocks of this zones form a terrigenous-volcanic-plutonic association reflecting homodromous direction of magmatism (from mafic to felsic).

Vent facies - consists of a vent and near the vent zones, composed of lavas, tuffs. Liquid, semi-liquid, viscous lava or pyroclastic flows with great thickness, are localized in area near the outpouring channels. Tuffs are usually coarse-grained (agglomerate, blocky, bomb), and characterized by the absence of gravitational separation of debris. The presence of ignimbrites, sintered tuff, pumice slag indicates sintering, secondary remelting and viscous flow, so there are traces of fluidal, vesicular. Often, there are arrays of secondary quartzite, located annularly or arcuately around the caldera.

Slope facies - characterized by roughly equal proportions of lavas and pyroclastic deposits (respectively volcanogenic and volcanogenic-sedimentary deposits). Lava flows and covers have a small thickness, but occupy a large area; pyroclastic material is characterized by medium- to coarse-grained, often lapilli-tuffs, which are formed of pyroclastic material transported in the submarine conditions over long distances.

Distant facies - composed of volcanic, volcanic-sedimentary and sedimentary rocks. Volcanic rocks consist of various clast size pyroclastic materials (tuffs of fine ash and coarse ash, with size less than 2 mm). Volcanogenic-sedimentary rocks are ignimbrites formed by black clouds (or glowing clouds). Sedimentary rocks are as terrigenous (sandstone, siltstone) and chemogenic (mainly carbonate and salt-bearing deposits) origin.

In the coastal marine environment, depending on the water level in all areas of facial paleo-volcanic structures can be formed reef structures.

In intrusive (second or post volcanic) period of structures development formed intrusive bodies. Intrusive massifs are large sheet-like bodies - lopolity, graptolite, laccoliths, etc., covering an area of hundreds of square kilometers, which are formed inside of rocks of slope and distant facies. In the vent zone formed large hypabyssal (or subvolcanic) bodies. Supply channels approximation to vents the volcano. Massifs are multiphase. The composition changes from mafic to felsic.

Development of paleo-volcanic structures accompanied by the formation of hypabyssal (or subvolcanic) rocks. It begins at the end 1-st stage of volcanic period and ends at the end of the intrusive period. The bodies of vent zone associate with the supplying channel of the structures and are mainly represented by stocks, obelisks, necks, extrusive domes. The bodies of outside the vent zones are formed during introduction of lava substance into fissures, crushing zones, cavity of intrastratal flaking, flexure bends. These bodies are mainly represented by dikes, veins, sills, and other bodies of complex forms.

The average diameter of the base of paleo-volcanic structure exceeds 100 km. The diameter of the volcanic center is 10-20 km. Volcanic center contains vent and near the vent facies. The width of slope of the structure, formed by covers of lava and pyroclastic material, varies between a few tens of kilometers to tens of kilometers (it depends on the degree of erosion). Rocks of distant facies accumulate on the periphery of paleo-volcano, length of n*km - 10n*km (this ring locates about 50 km from the center). The height of the structure from the foundation to the top of the stratovolcano is the first kilometers but not more than 10 km.

The homodromous sequence of formation of volcanic structures, their size, and time intervals, when magmatic products are accumulated, are constant during the whole Phanerozoic epoch. During the Paleozoic era the structures are formed in course of 3 sequential epochs of tectonic and magmatic activization, namely: Salairic (V-S); Caledonic (D); Hercynic (C-P). The epoch boundaries of tectonic activizations have uncertainty intervals for different regions.

Should be noted that the size (dimension) of the actual volcanic structures corresponds this description. For example, there are two shield volcanos within Hawaii archipelago, namely: Mauna Loa with the width about 120km and the alteration more than 9km (including about 4km elevation above the sea level) and Tamu massif situated in NW part of Pacific ocean (1600km to east from Japan) has 450×650km dimension and 4.5km elevation.

Position of the mineral deposits within paleovolcanic structures (structural and geochemical criteria)

There are two structural and facial types of mineral deposits within paleo-volcanic structures, namely: 1. Volcanogenic within vent and slope facies; 2. Intrusive associated with significant intrusions, formed during final – 3rd stage of the paleo-volcano development, allocated within slope and distant facies. Based on the time of paleo-volcano formation, it should be noted, that massive sulphide deposits with significant resources are common for Salairic and Caledonic structures, while porphyry copper deposits and small massive sulphide deposits are common for Hercynic structures (figure 2).

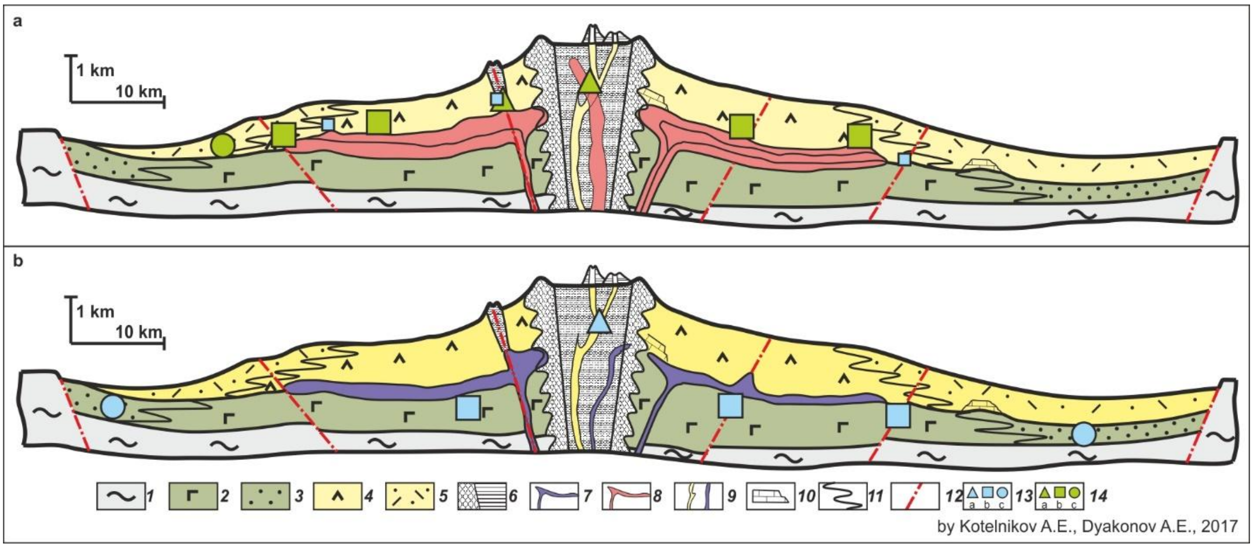


Figure 2 – Conceptual section of the model of paleo-volcanic structures with mineralization zones (by Dyakonov V.V., Kotelnikov A.E., 2015)

a – Hercynic type of paleo-volcanic structures; b – Salairic-Caledonic Hercynic type of paleo-volcanic structures. Legend: 1. bedrock; 2-8 facies of paleo-volcanic structure: 2. Basic sediments of the slope facies (1st stage); 3. Sediments of the distant facie (1st stage); 4. Acidic sediments of the slope facie (2nd stage); 5. Sediments of the distant facies (2nd stage); 6. Rocks of vent and slope facies; 7. Subvolcanic bodies (ultrabasic); 8. Intrusions (acidic and intermediate); 9. Subvolcanic bodies (intermediate); 10. Reef (carbonate) complexes; 11. Boundary of facies; 12. Tectonic faults; 13. Porphyry copper mineralization zones within facial zones (a. vent, b. slope, c. distant); 14. Sulphide mineralization zones within facial zones (a. vent, b. slope, c. distant).

Vent zone. Vent facies of the central type calderas are least studied by this moment. Because they are basically represented by depressive landforms and, thus, are covered by weathering products of vent facies. The central caldera diameter has a wide range from 10meters up to several tens of kilometers. Usually they are represented by a ring structure with numerous volcanic cones and subvolcanic necks inside of them. Performed studies have shown that some unique, well known copper deposits (massive sulfide and porphyry types) and also gold and other mineral deposits are situated within central calderas. This circumstance determines the high interest of the search and reconstruction of these calderas with the final aim of the discovering of blind and covered deposits. Generally, high-grade mineralization of different types is allocated within vent facie rocks. As an example, further deposits might be considered: Ural-type massive sulphide deposits (Blyavinskoe, Yaman-Kasinskoe, Gayskoe, Urup), porphyry copper deposits (Los Pelambres and El Salvador [Chile], Pebble [Alaska], Kounrad [Kazakhstan], Leky-Tal'bey [Polar Ural]), gold deposits (Vorontzovskoe [Ural], Kupol [Chukotka]) and gold deposits of Pebble ore cluster [Alaska]. The mineralization is, generally, associated with numerous subvolcanic bodies and necks within central collapse caldera and nearby its periphery.

Slope zone. There are also different types of mineral deposits within slope zone. The mineralization associates with small lateral (parasitic) vents which contain copper and poly metallic deposits of Cyprus and Kuroko type. Significant amount of commercial mineralization is accumulated within the apical parts of large intersole injections and inside of the sheets. As an example further deposits might be considered: porphyry copper deposits - Aktogay (Kazakhstan), Chucicamata (Chile); gold deposits – Novogodneye-Monto (Polar Ural), Petropavlovskoe (Polar Ural), Kvarkenskoe mineral belt, Aidarlinskoe, Bereznyakovskoe, Kochkarskoe (Southern Ural), Vasil'kovskoe (Kazakhstan), Fort-Nox (Alaska), Republic ore cluster (USA); copper and nickel deposits – Norilsk ore cluster; chromite deposits – Tzentral'noe (Polar Ural), Kimpersay (Kazakhstan).

Distant zone. The sedimentary type deposits (copper sandstone) are formed within distant part of volcanic structure due to weathering of mineralized rocks of the vent and slope zones and further resedimentation at the distant zone. As an example, further deposits might be considered: mineralization of Kungur suite (Western Ural), Mansfield (Central Europe), Lake Superior copper province (Michigan, USA). Also, injection of granitic intrusions lead to formation of the big deposits within the distant zone such as Udokan (Transbaikalia region) and Zhezkazgan (Kazakhstan). In case of such deposits volcanogenic sedimentary and sedimentary rocks are ore bearing.

The method of application of structural and geochemical criteria

Application of the structural-geochemical criteria is based on a unique methodology of paleo-volcanic reconstruction and geochemical evaluation of certain areas of the paleo-volcanic structure. Specialized paleo-volcanic mapping of the area studied is carried out at a scale of 1: 500 000 and 1: 200 000. It results in a map of paleo-volcanic structures. Based on relationship of copper mineralization with specific elements of the structure, there are allocated perspective areas within which prospecting and evaluation work is carried out. It includes detailed geological mapping at a scale of 1:50 000.

Also, both conventional and deep geochemical surveys are carried out to outline primary and secondary dispersion halos over the expected hydrothermal feeding channel. An area of several square kilometers may host several perspective targets. Processing of the data obtained allows to rank prospects of the areas and plan subsequent exploration, including mandatory core (diamond) drilling.

Usage of atmogeochemical survey is recommended as an initial stage. Atmogeochemistry is based on use of halogen, hydrogen sulphide, methane, radioactive and other gases with high volatile and migration ability as indicator elements of hydrothermal mineralization. Such technique makes it possible to draw up a detailed scheme of tectonic dislocations, to reveal areas of intensive degassing over hydrothermal channels, to outline the contours of prospective areas, and to reduce the volume of subsequent lithogeochemical survey.

The main advantages of such technique are:

- high probability to discover blind and overlapped mineralization zones varying from ore occurrences to unique deposits;
- lower cost of exploration versus traditional methods.

RESULTS

Let’s have a look of the implementation of the structural and geochemical criteria for prospecting of covered endogenous mineralization on the example of Mednogorskiy ore cluster (Southern Ural, Russia).

First of all, stock and published literature should be reviewed, with the aim to find out the aspects referring to geological position of the studied region and age dating of its rocks. Mednogorskiy ore cluster consists of volcanogenic, volcanogenic-sedimentary, terrigenous and sedimentary rocks, accumulated during time interval from Cambrian up to Devon. Younger terrigenous and sedimentary rocks are considered as covering (‘conservation’) blanket. Based on this data, paleofacies analysis was carried out. As a result, with a high degree of reliability, division of vent, slope and distant facies was done. Formation of these facies took place during time interval from Cambrian up to Devon. Accumulation of the sediments of low suite took place during early Cambrian up to early Ordovician (Є1-O1) time, when volcanism of the 1-st stage (basic) occurred. On the 2-nd stage (riolitic) (O2-S2) effusive rocks, represented by acidic differentiates of magmatism were accumulated. During the final intrusive phase (S2-D1), when formation of paleo-volcanic structure was accomplished, intrusions of serpentinites injected along the boundaries of the products of magmatism of basic and riolitic stages. Volcanism epoch had been replaced for intensive denudation epoch. This fact is confirmed by accumulation of the terrigenous of early-late Devonian sediments.

The decoding of space images allows distinguishing linear and ring tectonic disturbances of several orders. Their spatial arrangement emphasizes structural elements and dimensions of Mednogorsk paleo-volcanic structure. An example of decoding of volcanic center is demonstrated on the figure 4, where relicts of volcanic cones of 1-st and 2-nd stages of forming of paleo-volcanic structure are placed within the volcanic center. As an example of modern analogues of such volcanic center with a similar size and structure could be Krenitzyn volcano (Onecotan island, Kuril Archipelago, Russia), Mount Rinjani (Lombok island, Indonesia), Teide volcanic cone (Tenerife, Canarias islands, Spain), Creyter caldera lake on the top of Mount-Mazama (Oregon, USA) with 10×15km diameter and about 1km depth with a few volcanoes (diameter of each is up to 1.5km).

This sort of activity lead to create so-called working version of the map-scheme of the territory structure, including the paleo-volcanic structure. These assumptions are confirmed during the field work, including specialized geological routes. The result of such routes is geological sections, determination of zones of facies contours, refined boundaries of structural elements of the paleo-volcanic structure. On the basis of these works, a refined map-scheme of the facies of the paleo-volcanic structure is compiled (fig. 5).

The next stage of work includes determination and evaluation of the prospect areas. Based on the described above criteria of the correspondence of mineralization zones to the specific elements of the structure, prospects are selected ranging in size from 4 to 50sq.km. Lithogeochemical survey is conducted on these prospects, applying 200×500m, sometimes even more detailed. Statistic and graphical analysis are used for assay sample data processing. Each type of mineralization zone is characterized by its specific grade and spatial distribution of chemical elements. These zones are related to direct tectonic conditions and are associated with hydrothermal processes. All these offer to apply advanced atmogeochemical study to allocate zones with high joint density and determine gas indicators.

Determination of the prospect areas or anomaly zones with indication of geochemical parameters and evaluation of its perspectivity is considered as a result of geochemical study. Recommendations are also formulated for further detailed geophysical and geochemical studies or for designing of drilling program.

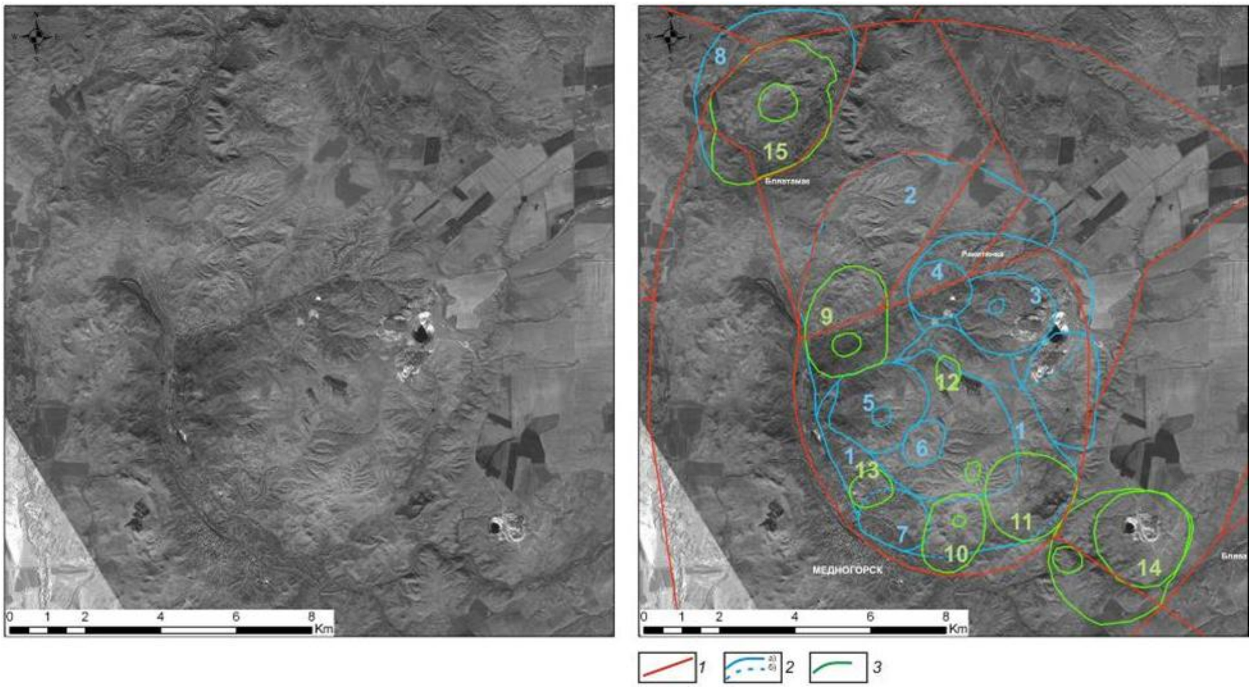
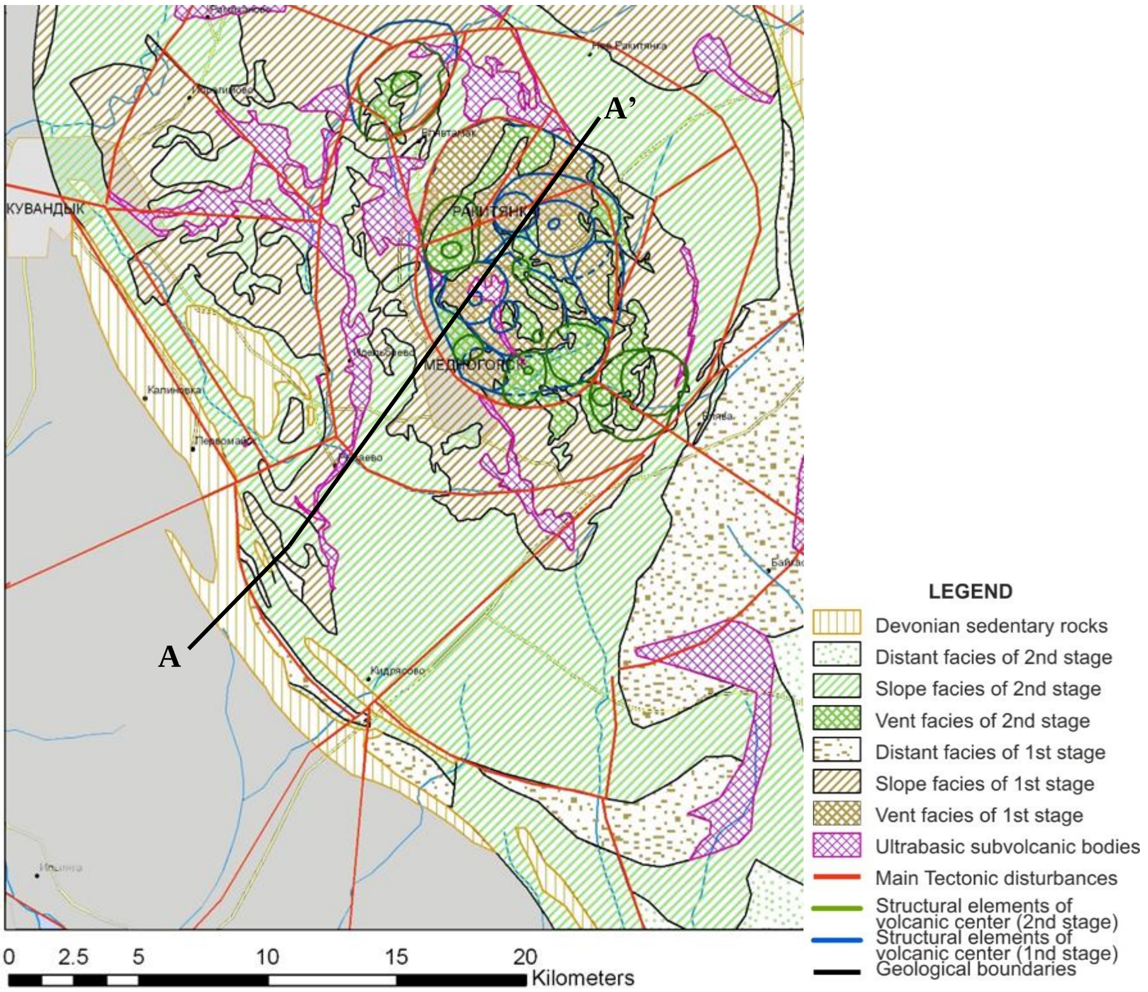


Figure 4 – Volcanic center of Mednogorsk paleo-volcanic structure (satellite image from Roscosmos Geoportal) Legend: 1 – main tectonic disturbances; 2 – boundaries of first stare structures (a. visible, b. covered by second stage structures); 3 – boundaries of second stage structures)



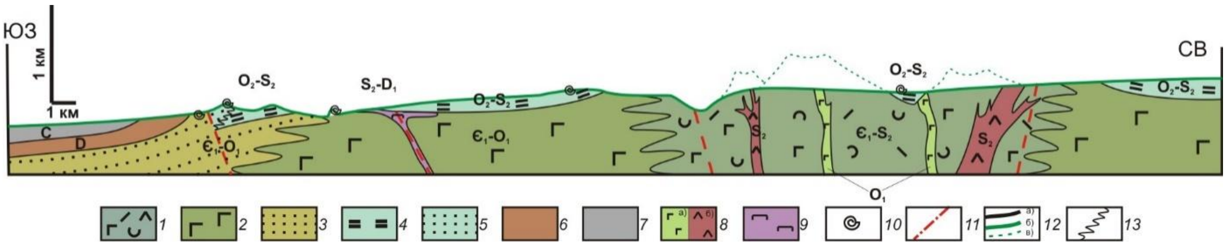


Figure 5 – Schematic map of facies of paleo-volcanic structure and its section

Legend: 1. Vent facies of 1^{st} and 2^{nd} stage (Є1-O1 + O2-S2); 2. Slope facies of 1^{st} stage (Є1-O1); 3. Distant facies of 1^{st} stage(Є1-O1); 4. Slope facies of 2^{nd} stage (O2-S2); 5. Distant facies of 2^{nd} stage (O2-S2); 6. Terrigenous Devonian sediments of after volcanic age; 7. Carboniferrous sediments; 8. Subvolcanic cones (a. basic, b. acidic); 9. Serpentinites; 10. Fauna; 11. Tectonic disturbances; 12. Boundaries (a. geological, b. Earth ground, c. assumed volcanic structure dimensions), 13. Facial boundary.

CONCLUSIONS

On the example of Ural region might be said, that paleo-volcanic studies have shown the existence within Polar Ural and Middle Ural Subregions of structures belonging to two types of tectonic and magmatic cycles, namely Salairic and Caledonic; within Southern Ural Subregion structures belong to Salairic cycle (Mednogorskoe and Gayskoe paleo-vocanic structure), Caledonic cycle (Valeryanovskaya paleo-volcanic zone) and Hercynic cycle (Ghetykolskoe paleo-vocanic structure). Well known massive sulphide and porphyry copper and gold deposits are associated with these structures. Conducted paleo-volcanic reconstruction within different areas with wide sheets of magmatic rocks corresponding to the position of discovered deposits lead to determine prospecting criteria. The most prospective for the prospecting of endogenous mineralization nonferrous and precious metals are zones of vent facies and cover part of the large sheetlike intrusive massifs.

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PUBLIC SOCIETY «PROFESSIONAL SOCIETY OF INDEPENDENT EXPERTS OF THE SUBSURFACE RESOURCES» (PONEN) – FORMATION OF THE INSTIITUTE OF COMPETENT PERSONS IN THE MINING AND GEOLOGICAL INDUSTRY OF KAZAKHSTAN

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ABSTRACT

The PUBLIC SOCIETY «PROFESSIONAL SOCIETY OF INDEPENDENT EXPERTS OF THE SUBSURFACE RESOURCES – known as PONEN, established in November of 2015, at the beginning of its activity, the formation of the institution of Competent Persons of Kazakhstan, which determined the most important strategic tasks.

At the moment, there are almost 150 members of the society, more than half of which are full members of PONEN, who have extensive experience in the industry. About 10% of the total number of PONEN members are experienced geologists and mining engineers from other countries. PONEN has a mutual recognition with SAMREC, PERC, NAEN, and this work continues.

The work on the preparation of Competent Persons, in accordance with the Code of the KAZRC, has been held since 2016 by conducting, jointly with the Association of KAZRC, training seminars of different levels. The programs of the seminars are aimed both at acquaintance with international standards (for managers of profile companies) and on the technical aspects of preparing public geological reporting (for specialists of various levels and profiles). More than 200 specialists and managers of profile companies have already completed their training. Including, at the end of 2017, such seminars were held in Astana, under the auspices of the European Bank for Reconstruction and Development.

For today, the list of Competent Persons, posted on the sites of the PONEN and the Committee for Geology and Subsoil Use, has 40 professionals - professional members of the PONEN. This list included leading experts of the mining and geological profile of Kazakhstan, as well as other countries.

The Executive Committee of PONEN and the Association of KAZRC understand that after the introduction of the Code on Subsoil and Subsoil Use, starting from July 2018, the demand for the preparation of public geological reports will increase significantly. In this connection it is necessary to intensify the work on the formation of the Corps of Competent Persons.

The Executive Committee of PONEN positively assesses the tendencies in the formation of the institution of Competent Persons in Kazakhstan, due to the strengthening of the activities of the profile commissions of PONEN, and the expected increase in demand for the preparation of geological reports in accordance with the Code of the KAZRC.

KEYWORDS

PONEN, Competent Person, public reporting, Executive Committee, professionals, member, experts.

The public association of independent experts of the PONEN mineral resources was established at the end of 2015 in the framework of the preparation of the Republic of Kazakhstan for joining the CRIRSCO. In the first period of PONEN's activity, its Executive Committee (EC), together with the Association of KAZRC, focused on the preparation of the Kazakhstan Code of Public Reporting on the Results of Exploration, Mineral Resources and Mineral Reserves - KAZRC, as well as preparations for joining CRIRSCO, which took place in June 2016 year.

Work on attracting industry experts to PONEN members began by mutual recognition of the KAZRC Association and PONEN by other members of CRIRSCO, and also conducting introductory seminars for specialists of the mining and geological industry on international standards for public geological reporting began after joining the CRIRSCO.

The potential for growth in the number of PONEN members is about one thousand geologists, geophysicists, hydrogeologists, mining engineers of the Republic of Kazakhstan, as well as foreign specialists, both from CIS countries and from other countries working in our country. The most active of these specialists are already professional members of PONEN, and more than two dozen also have membership in other organizations: RPO (AIG, AusIMM, GSL).

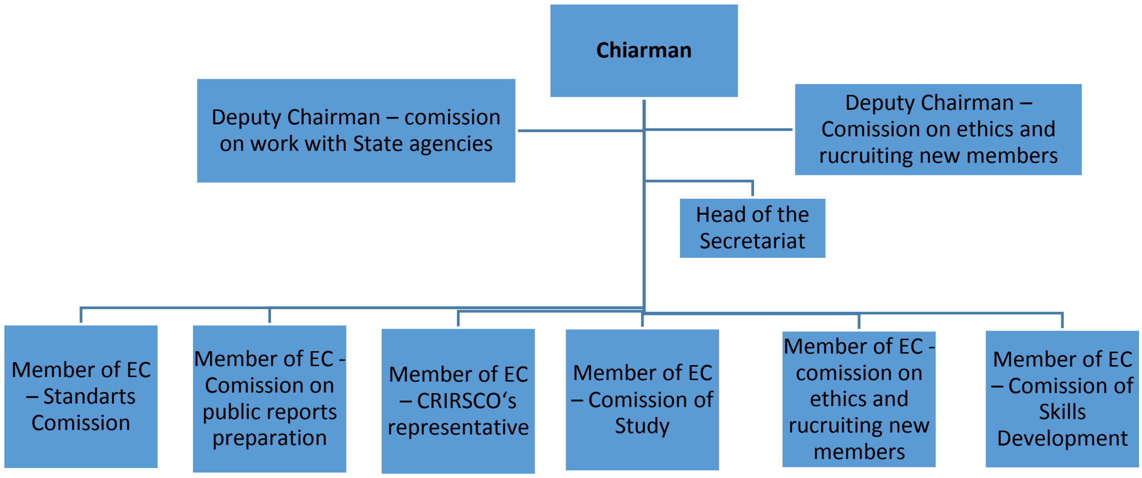
The presence of a significant number of foreign mining and geological specialists working in Kazakhstan indicates a shortage of domestic personnel. This is due to a multiple reduction in the volume of geological exploration in Kazakhstan during the last 20-25 years, as well as the decline in the quality of profile education. As a result of such crisis phenomena, the number of Kazakhstani qualified industry specialists has decreased several times.

In connection with these negative factors, the task of forming the Corps of Competent Persons of Kazakhstan, which is the priority objective of the PONEN, should not be limited to increasing the number of members of the Public Association, but also contribute to the solution of issues of improving the quality of training specialists in universities, providing students with full-fledged production practice, the involvement of undergraduates in PONEN, in the category of a member of the student.

The first stage of the work of the PONEN was held for two years (2015-2017) from the moment of legal registration until the adoption of the Mining Code (December 27, 2017). The second stage began after the adoption of the Mining Code. This stage will last until the end of the transition period, when a full transition to the KAZRC standard (2018-2023) will be implemented in accordance with the Code.

In the second period, EC of PONEN assumes that the number of PONEN members will increase manifold and a corps of Competent Persons (CP), working in accordance with the KAZRC Code, will be formed. Also during this period, methodological recommendations on the application of the Code will be developed, since without such documents, Kazakh specialists who are accustomed to using GKZ methodological recommendations in their practice will find it difficult to adapt to new requirements for public geological reporting.

The structure of the EC of PONEN was changed at a new stage of work in accordance with the tasks set. Seven commissions have been established that cover the main activities of the organization, including: ethics and attracting new members, training specialists, improving the qualifications of PONEN members, interacting with state authorities, and working with CRIRSCO, on public reporting, and on standards (pic. 1).



Pic. 1 - The structure of the EC of PONEN, in accordance with the objectives of the second period of activity

Each commission is headed by one of the members of the Executive Committee, other members of the PONEN are also involved in the work of the commissions.

Reports on the current results of the work of the commissions are heard at regular meetings of the EC, corrections are made to the plans for their work. Even a small amount of experience in attracting members of the PONEN and forming the corps of the CP has objectively demonstrated that the minimal five-year experience for the Member category taken in the initial version of PONEN documents, taking into account the low level of university training, is clearly insufficient, and therefore at the next general meeting it was decided to raise this minimum requirement to 10 years.

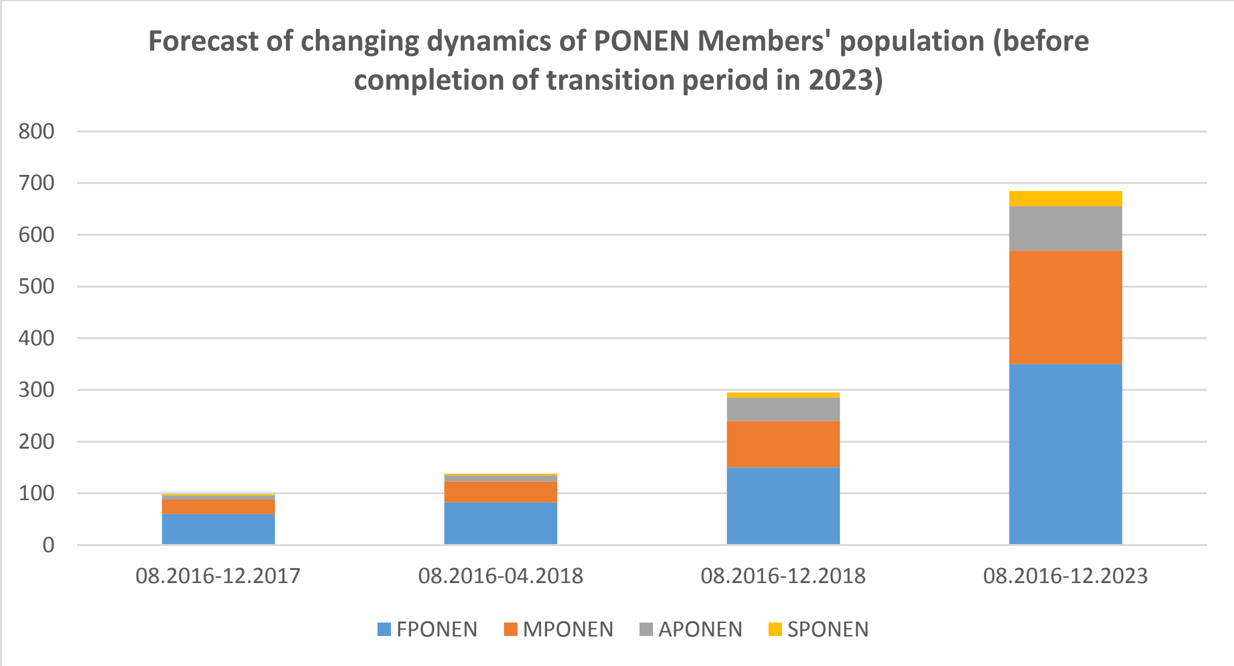
At the moment, there are almost 150 members in the society, more than half of which are full members of PONEN (Fellow), with extensive experience in the industry, 13% of which are experienced geologists and mining engineers from other countries.

It should be said that after the signing of the Code "On Subsoil and Subsoil Use", the number of those wishing to become members of the PONEN has doubled, compared to the previous period. Based on this trend, it is expected that after the implementation of the Mining Code, starting from the second half of 2018, this trend will become even more pronounced. The number of PONEN members may increase to 280-300 people by the end of this year, according to the preliminary assessment of the Executive Committee (pic. 2).

The distribution of PONEN members across the regions of Kazakhstan is uneven, almost half of them are specialists working in companies located in Almaty, and most of them are employees of consulting firms that ensure the evaluation of deposits in all regions of the country (pic. 3).

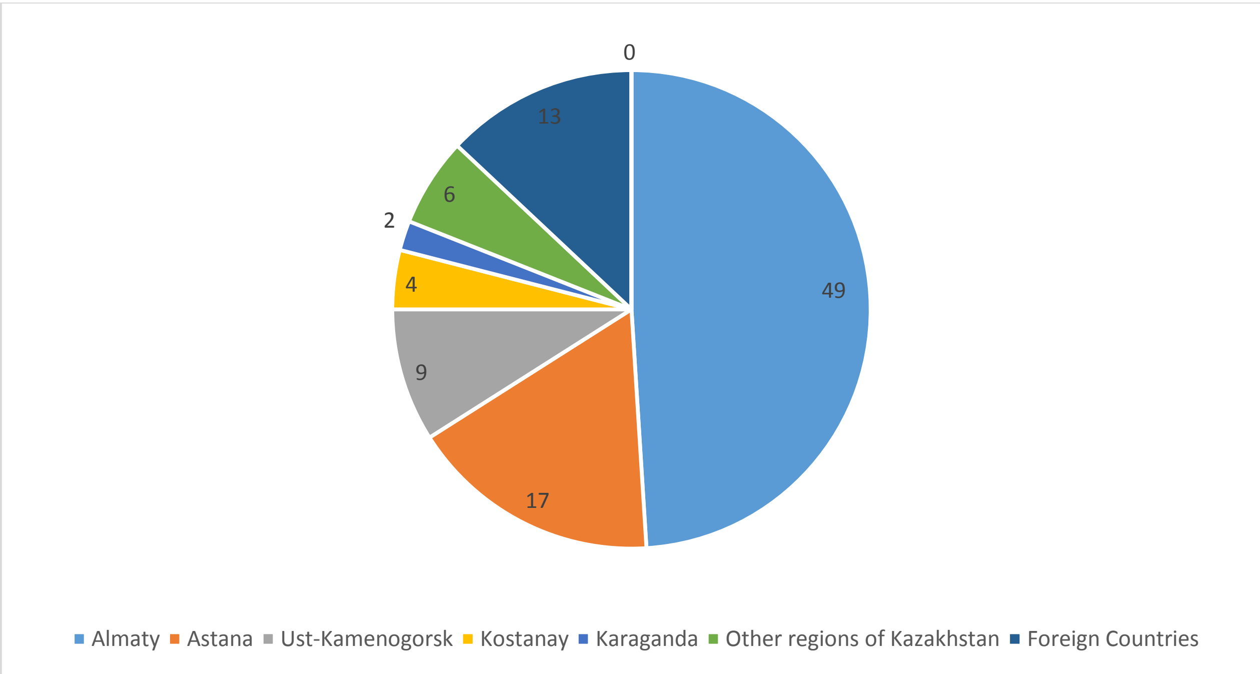
At the moment PONEN has mutual recognition with SAMREC, PERC, NAEN and this work is actively continuing.

The Competent Personnel training activities have been carried out since 2016, by conducting, jointly with the Association of KAZRC, training seminars of different levels in according with the KAZRC Code. The programs of the seminars are aimed both at acquaintance with international standards (for managers of profile companies) and on the technical aspects of preparing public geological reporting (for specialists of various levels and profiles).



Pic.2 Forecast of changing dynamics of PONEN Members' population

During last two years, more than 250 specialists and executives of relevant companies have already studied primary training of international standards of public reporting. Among them, at the end of the year 2017, similar seminars were held in Astana city, hosted by European Bank for reconstruction and development.



Pic. 3 Percentage of PONEN Members by regions.

The key elements of training are their distinctive features with regard to GKZ standards in addition to the basic principles of international standards, which Kazakhstani specialists are used to implement. The most important fundamental issue is the concept of personal responsibility of the Competent Person for the reliability of the assessment of resources and reserves, which, when passing to the KAZRC Code, should replace the collective responsibility of the state expert examination according to the GKZ standard.

The principle of self-certification of Competent Persons is also unaccustomed to the listeners, since by the standard of the GKZ specialists are accustomed to the fact that experts of the SCC appoint the Competent Authority in the field of geological study of subsurface resources. It is also not easy for Kazakhstan geologists to trust the historical geological materials, which according to the GKZ standard are a priori perceived as satisfactory, proceeding from the principle that "if the materials were examined at different times by the State Reserves Committee (in particular the State Committee of the USSR) they are automatically considered reliable."

Today, the list of CP, posted on the sites of PONEN and the Committee for Geology and Subsoil Use, has more than 40 professionals - professional members of PONEN. This list included leading experts of the mining and geological profile of Kazakhstan, as well as other countries.

Competent Persons are the dominant in the list, specializing in the main mining industries of Kazakhstan - non-ferrous metals, gold, iron ore. However, these specialists can ensure the performance of work and the assessment of resources not for all geological and industrial types of deposits, which in our country are many. To lesser extent experts on non-metallic raw materials, rare metals, and colored stones are represented.

All these specialists have extensive experience in geological exploration and reserves calculation according to the GKZ standard. A certain problem is the absence in accordance with international standards of public reporting requirements on the form of reporting, because Kazakhstani specialists are accustomed to working within the framework of a strict reporting format, in accordance with the GKZ standard. To provide methodological assistance in this matter, the Executive Committee of the PONEN has prepared recommendations on such forms, taking into account the experience of preparing public reports in other countries.

Today, the common problem is the absence (with rare exception) of these specialists of experience in preparing public geological reports in accordance with international standards. There is no reason to assume that the process of becoming Competent Persons as signatories will be rapid. Experience comes gradually. The specialist needs to gain the appropriate portfolio for such an experience in order to be able to assess it as Competent Person providing a reliable and objective assessment of the facilities in compliance with the basic requirements of the KAZRC Code of Transparency, Importance, and Competence.

The Executive Committee of PONEN and the Association of KAZRC expect that the demand for the preparation of public geological reports will increase significantly after the introduction of the Code on Subsoil and Subsoil Use, starting from July 2018. This factor initiates the activation of practical actions by the Competent Persons in obtaining experience in the preparation of such reports, probably at the initial stages, as co-executors, of such works, and eventually as "signatories".

The Executive Committee of the PONEN understands the need to intensify the work on the preparation of Competent Persons in connection with objective trends in the promotion of the introduction of the KAZRC Code.

CONCLUSIONS

During the five-year transition period, the Executive Committee of the PONEN should carry out significant work on training Competent Persons and industry specialists in general, on the development of normative and methodological documents for the application of the KAZRC Code, for the improvement of the qualifications of the PONEN members.

The Executive Committee of PONEN positively assesses the tendencies in the formation of the institution of Competent Persons in Kazakhstan, due to the strengthening of the activities of the profile commissions of PONEN, and the expected increase in demand for the preparation of geological reports in accordance with the Code of the KAZRC.

MODERN ELECTROMAGNETIC TECHNOLOGIES ARE HIGHLY EFFECTIVE TOOL IN SEARCHING AND MINERAL EXPLORATION

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SUMMARY

One of the key stages of exploration works is geophysical surveys. Efficiency of their use in most cases has a direct influence on success of all the complex of exploration works implemented at the particular site. Their role will be constantly growing with increasing of propagation distance. Land geophysical surveys primarily include gravity survey, magnetic survey, and one or several electric exploration methods. Besides, the first two methods are basically directed at mapping and structural problem solving, while electric exploration is the basic searching method for many ore minerals.

Over the past decade, land geophysical methods have significantly expanded technical possibilities:

-Introduction and large-scale implementation of computer technologies, GPS navigation and application of the most modern achievements of microelectronics in mineral exploration area has resulted in new category of compact high precision geophysical equipment;

-Introduction and use of specific software, analysis tools, interpretation and 3D picture of data received, as well as algorithms of physic and mathematic object modeling (2D and 3D inversions) with abnormal physical features;

-Introduction of high-precision equipment and effective software has resulted in qualitative improvement of excising technologies and introduction of brand new geophysical methods;

-Over the past decade, the ration of applicable electric exploration methods has significantly changed. Specific gravity of induction methods has significantly increased, and, primarily, the methods based on the use of natural alternating magnetic fields of the Earth (magnetotelluric (MT) and magnetic-variation profiling (MVP)).

KEYWORDS

Magnetotellurics (MT), magnetic-variation method (MVP), induced polarization (IP), dipole soundings (DS), poly-metallic mineralization, porphyry copper type, electric tomography (ET), and ore geophysics.

BASIC DEVELOPMENT TRENDS OF ORE GEOPHYSICS

Nowadays, when studying the deposits of very complicated geological structure, the role of geophysical methods often is not in direct search of mining facilities, but in solving of searching problems of different indirect ore control factors (analysis of structural and tectonic formation, detection of zoning elements and indirect control factors of mineralization). In this regard, currently there is an intensive introduction in practice of mining magnetotellurics (in conjunction with magnetic-variation methods) which is an effective tool of direct detection of mineral facilities and solving of problems of structural mapping and forecasting of different types of mineral deposits, particularly structure controlled (Ingerov, A, 2004; Berdichevsky, M.N and Dmitriev, V.I., 2009; Ingerov, A, 2014). Introduction of magnetotelluric methods for solving of mining problems in Kazakhstan significantly increases the distance of electric exploration surveys, and provides an opportunity to detect deep-lying large deposits according to geophysical data (Kogay, S,G., & Iskakov, K.I., 1996). Besides, the important problems for effective application of mining magnetotellurics are transition to area forms of collection of field survey data with subsequent tree-dimensional analysis of spatial information and joint application of magnetotellurics with other geophysical methods (magnetic survey, TDIP electric survey, TDEM) depending on type of required mineralization and specific conditions for specific areas.

For effective use of different technologies of mining electroprospecting, the problem of complexing of induction (AMT, MT, frequency electromagnetic sounding-IP, TDEM sounding) and geometric soundings (DS-IP) is the highly relevant. It allows to increase uniqueness of integrated interpretation and reconstruction of open-pit mine according to parameters of specific electrical resistance and polarizability. It is important, that software for integrated interpretation of induction and geometrical soundings has finally introduced (Kulikov, V.A., Kaminskiy, A.Ye., Yakovlev, A.G., 2016). It should be marked, that methods of geometric soundings have increased sensitivity to the objects with high resistance and allow to detect boarders of high-resistivity bodies more correctly. The basic disadvantage of the method is limited depth of investigation of survey and strong impact of high-resistivity shields. However, the depth of investigation of magnetotelluric and magnetic-variation methods is limited only by the length of record time at the measuring point. MT-parameters have high sensitivity to conductive bodies and not shielded by high-resistivity horizons. Joint analysis of TDIP and AMT data opens great prospects for creating of polarization model at the great depths. Complexing of two different types of soundings allows to solve wide range of geological problems, from direct search of mining bodies to detection of indirect ore control factors.

It should also be taken into consideration that ~~in~~ searching for low contrast areas of interests, including porphyry copper, golden, rare metal, uranium mineralization the strategy based on detection of abnormal indicators in most cases become ineffective i.e. simple increase of precision and resolution of the instrument does not guarantee the success. In this situation for mapping of indirect control factors of mineralization it is necessary to use the wide complex of methods based on studying the whole range of different parameters of the medium (magnetic features, electrical conductivity, radioactivity) and application of target oriented technologies of data interpretation. Worldwide in recent years very effective searching and mapping complex of Electroprospecting techniques has been created. This complex includes AMT (MT) and DS-IP methods. Over the last years "Qazgeology" has successfully used this complex over the number of prospective facilities. It became possible due to successful usage of the most modern field equipment and software for processing and interpretation of field survey data.

Electric exploration by dipole soundings and induced polarization TDIP

Currently, one of development directions of mining geophysics is the use of specific multi-electrode methods of sounding which allow to increase propagation depth by induced polarization method (TDIP). TDIP technology is a time domain induced polarizability based on registration of effects of induced polarization of earth materials and ores. It is widely applied in searching of problems related to search for the objects with embedded structure (many sulphide and oxide minerals). Methods of this group is nearly always included in searching complexes in solving of mining problems: search for different types of the deposits of gold, metals of platinum group, uranium, ferrous, non-ferrous, rare and trace elements (sulphide); of the deposit of polymetal, skarn and porphyry copper type, detection of increased concentrations of ore minerals related to carbonation processes. Beside the solving the tasks of mining geophysics this method is successfully applied for such applications as hydrogeology, engineering geology and geoecology.

Particular Features of TDIP:

- High discretion of record point due to high density of observation network;
- Correct definition of the boarders of high-resistivity bodies;
- Parallel registration of 2 parameters of resistance and polarizability.

AMT+MT electrical exploration

Application of AMT+MT technologies in 5 component version realizes 2 groups of methods at the same time: magnetotelluric and magnetic-variation methods. The first group is effectively maps the subhorizontal boarders in geoelectric section while the second group has a unique sensitivity to vertical heterogeneity and capability to detect abnormal objects far away from observation profiles. AMT+MT approach can solve geological problems in complicated geological conditions, which identifies this approach as effective tool of exploration surveys in solving problems of structure mapping and forecasting of different types of mineral deposits, particularly structure controlled deposits of solid minerals, hydrocarbons and geothermal sources. Moreover, the propagation distance may be comprised from first dozen of meters to hundreds of kilometers. The most important peculiarities of technologies of this group are their increased sensitivity to electrical conductive objects that often are analogue of loosen, deep structures and splits; also, they are not able to steadily differentiate geological foundations which differ according to resistance, at least 1:3 and almost in any range in dozen of thousands Ohm*m and in units Ohm*m and their shares. It opens wide possibilities of technologies in searching for many types of the deposits of gold, elements of platinum group, uranium, non-ferrous, rare and trace elements, cupriferous sandstone and the objects of porphyry type, the confirmation of which is many examples of detection of new, previously unknown objects all over the world by these technologies over the last years.

Particular Features of AMT+MT+MVP:

- The propagation distance depends only on record time on ~~gage~~ recording point;
- High sensitivity to conductive bodies, no shielding effect in a form of high-resistive horizons;
- Precise detection of conductive objects in the subsurface media, even that one which is aside from observation line.

It is clear that joint application of innovative technologies is significantly increases effectiveness of exploration works and reduces the cost and risks of subsequent drilling operations.

It is clear that the use of modern geophysical technologies allows to solve wide range of problems in searching and exploration of different types of deposits: ferrous, non-ferrous, rare and trace elements (related to sulphides), gold and noble metals, polymetals, deposits of skarn, porphyry copper type, placer mines. Moreover, the use of complex methods facilitates the detection of mining objects at the deep distances and performing more reliable forecast, blind ore body and weak developed mineralization.

Practical application of complexing of modern geophysical methods

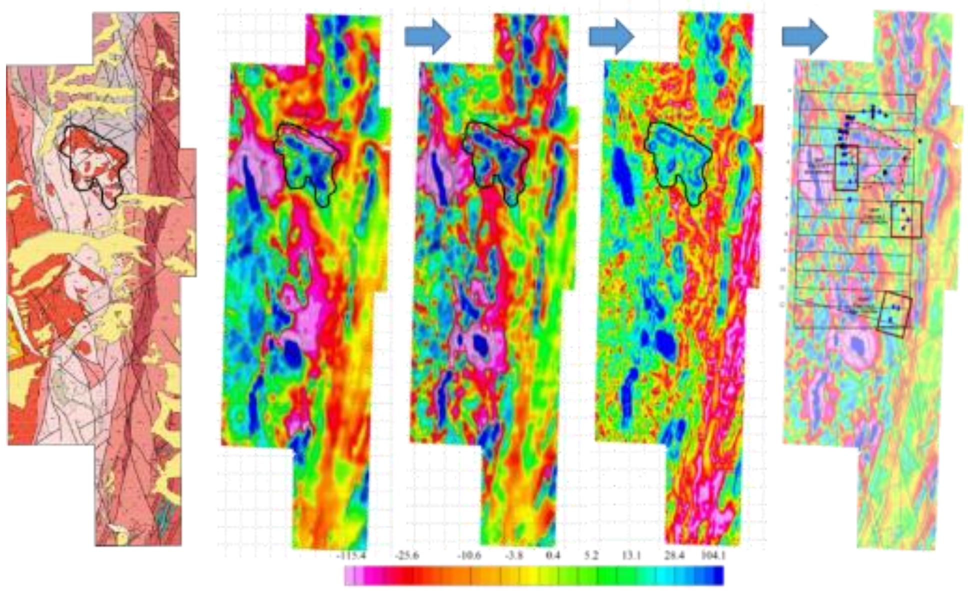
In a complicated geophysical situation, usually it is impossible to obtain a satisfactory solution of searching problem by any one method.

The problem of optimal combination consists of selection of methods that have specific sensitivity to other features of the environment which are important for finding the solutions of given tasks, complementary to each other providing as a result reliable geological interpretation of complex of geophysical surveys and acceptable cost of works. Strict selection of geophysical methods is necessary in conditions of solvable geological problem and its full effective realization. Unjustified bunch of poorly selected methods is harmful as well as negligence to the aggregation of techniques (Andreeva, Ye.V., Bobachev, A. A. Varencov, Iv. M., Vereschagin, M. P., Kulilov, V. A., Yakovlev, A. G., Yakovlev, D.V., 2006).

Good examples of successful complexing of modern geophysical technologies are the results of surveys for polymetal mineralization and searches for facilities of porphyry copper type in Central Kazakhstan implemented by JSC "Qazgeology" during 2015-2017.

Complexing of modern geophysical technologies in searching of polymetal mineralization in Central Kazakhstan

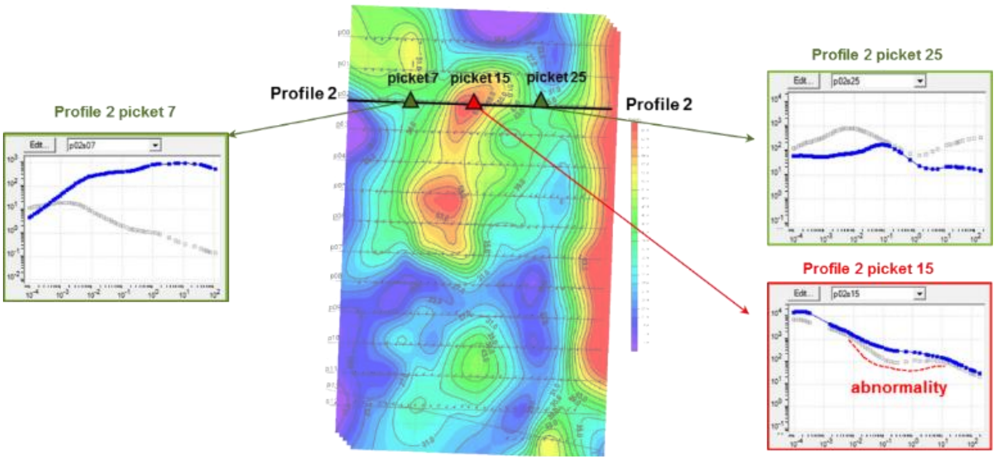
Data from magnetic survey allowed to specify information regarding structural and tectonic formation of the site, to detect structural elements and high intensive magnetic anomalies detected as a result of presence of iron-containing objects at survey site, to mark prospective areas for performing of further electro-magnetic surveys.



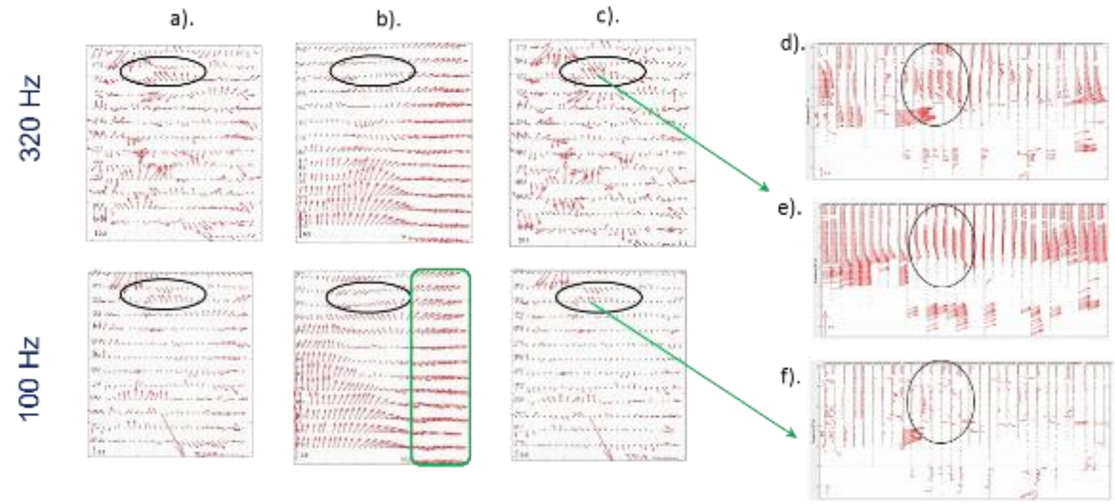
Picture 1 – The use of advanced aerial surveys. Obtaining of high-precision digital data (a-geological map; b – observation map of magnetic field; c – reduction of magnetic field to the pole; d – map of horizontal gradient; e – planned prospective areas for performing of EM researches on the map of local component of magnetic field)

Field works by AMT+MT method have been performed in 1000x250m spacing, «Phoenix Geophysics Ltd.» and «Advanced Geophysical Operations and Services inc.» (Canada) equipment has been used (Ingerov, A., 2011). When analyzing obtained field data of AMT+MT+MVP, one of the important stages is correct reduction of amplitude-phase curves that allows effective estimating of data and preliminarily to identify places of possible location of conductive bodies.

Picture 2 shows a map of invariable phase created at 300 Hz frequency, where conductive body is clearly shown in the central part of the site. In geological plan this zone is connected with bunch of porphyroid and shales PR_2gl. Special attention should be paid to the elongated zone in north-south direction along the east boarder, where there is a conductive body (picture 2). The localization of conductive bodies also possible, by quick estimation of maps of inductive vectors (picture 3). Outlined on the east of the site on maps and vertical sections of induction vectors, the zone is confined to a pack of porphyroids R_2km; which comprises graphite phyllite with lowered values of apparent resistivity.

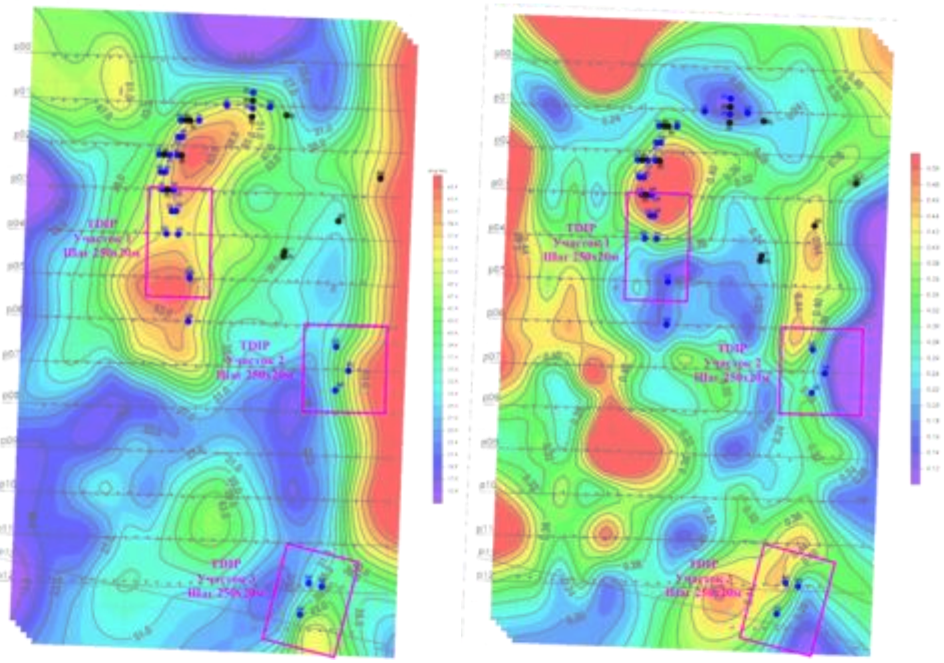


Picture 2 – Express estimation of AMT+MT data that is in conjunction with map of invariant phase at 300 Hz

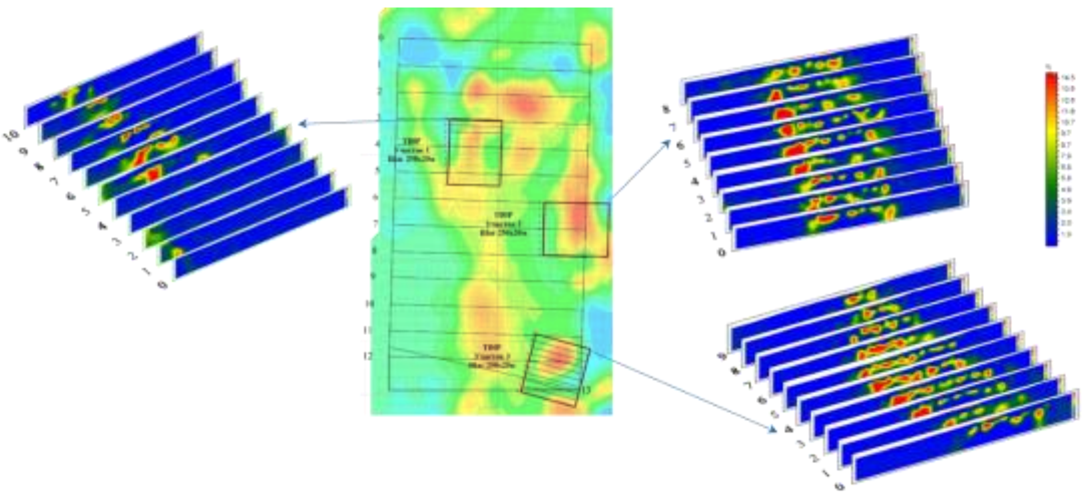


Picture 3 – Induction vectors - additional type of information when analyzing and forecasting. Initial ReWint (a), regional ReWreg (b) and local ReWloc (c) induction vectors in Parkinson convention at 320 (top) and 100 Hz (bottom) frequency. d, e, f - Induction vectors, from profile 2 (vectors are pointing to conductor)

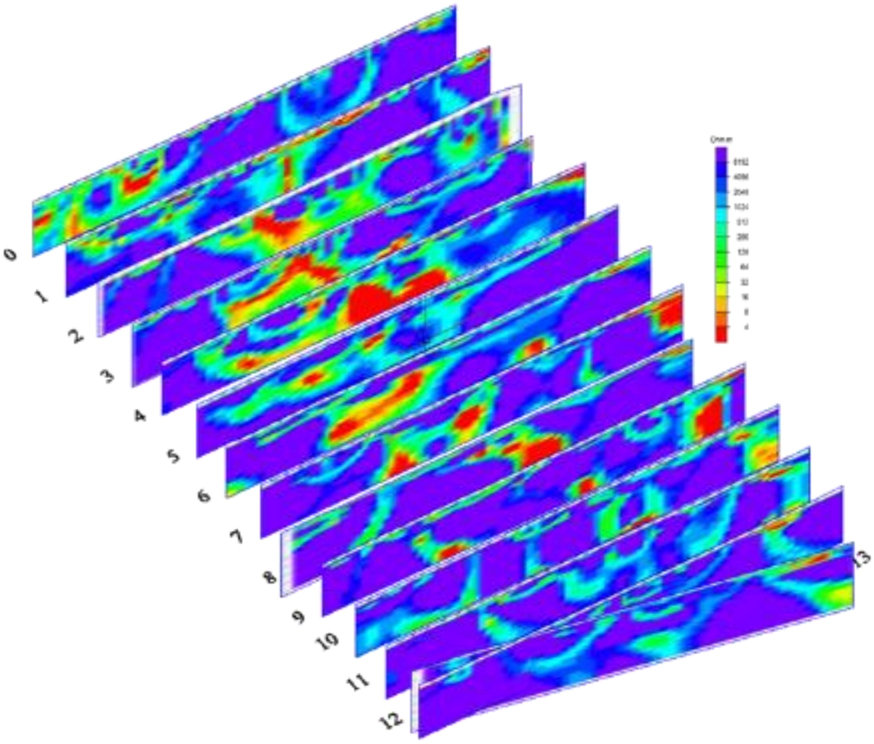
Upon completion of analysis of obtained electromagnetic AMT+MT data (picture 6), detailed electroprospecting TDIP surveys were designed and performed on the three most perspective local survey areas (picture 4). Spacing: 250x25m, total scope of work is 50 linear km (picture 5).



Picture 4 – Qualitative analysis of AMT+MT data. Map of invariant phase at 300 Hz frequency on the left; Map of Tipper magnitude at 300 Hz frequency on the right. Lines in violet color are the boarders of the areas of TDIP works



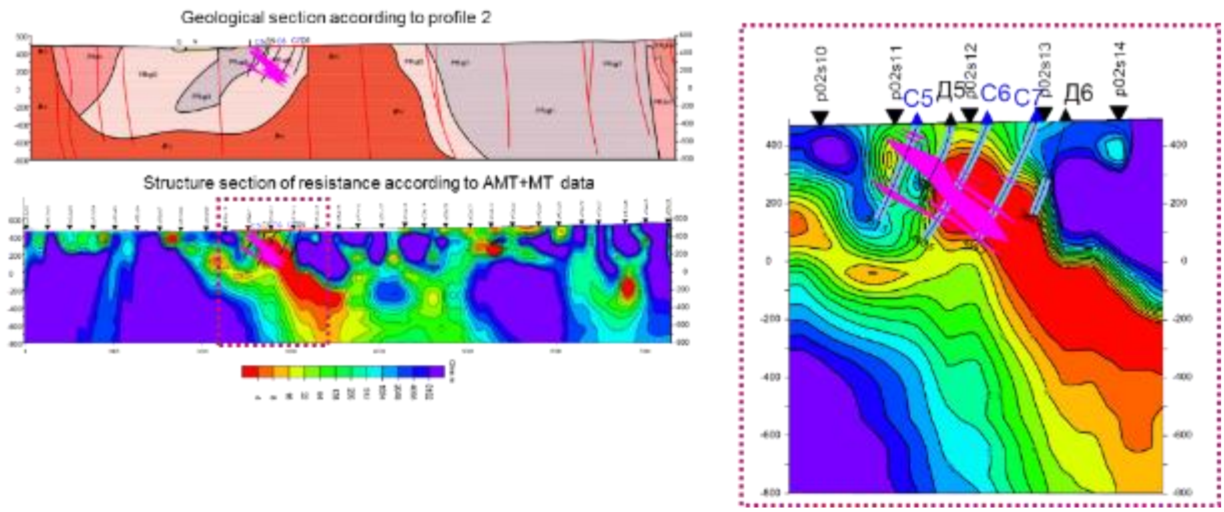
Picture 5 - 3D TDIP data by polarizability



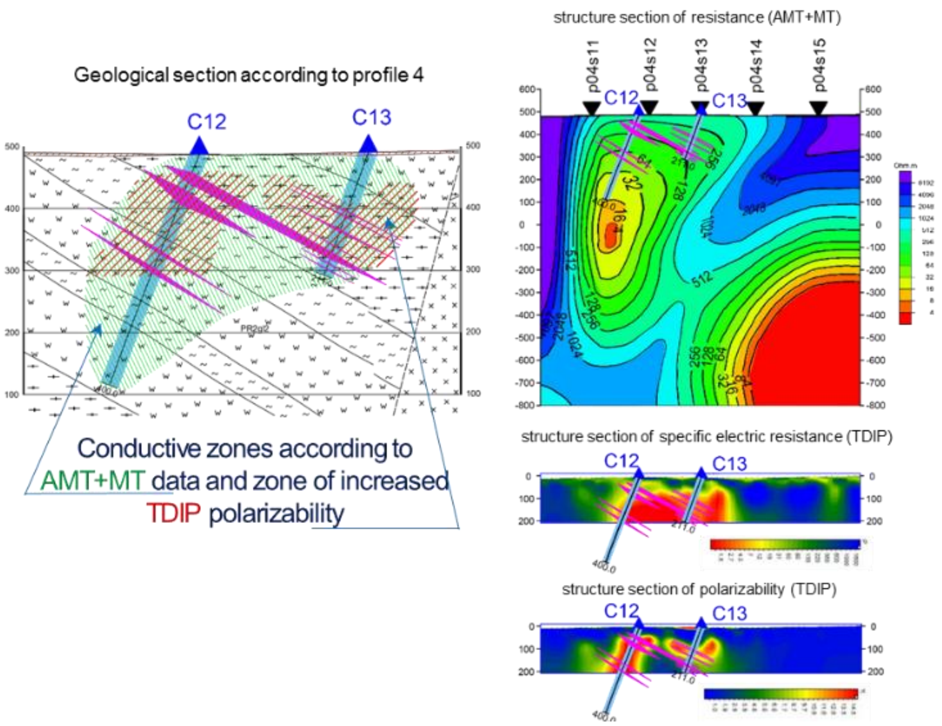
Picture 6 – 3D presentation of AMT+MT model data. Detection and tracing of conductive bodies correlated with polymetal type of mineralization according to AMT+MT technique

Pictures 7 and 8 show the results of joint geological and geophysical interpretation taking into consideration results of drilling the exploration holes and distinguishing spaces with rich polymetal mineralization and industry content of lead and zinc according to the results of analytical researches. According to obtained data it is obvious, that the joint application of AMT+MT and TDIP data is well correlated and complement each other, decreasing non-uniqueness when analyzing geophysical information. It is safe to say that this method of joint application of EM technologies is sufficiently effective.

Based on the results of performed mining and drilling works, subsequent analytical researches the estimation of forecasting resources of the site has been performed for the P_1 category and preliminary economic calculations which show the possibility of commercial acquisition of detected facility with high total content of polymetals (lead, zinc) and accompanying silver.



Picture 7 – confirmation of conductive bodies by reconnaissance drilling

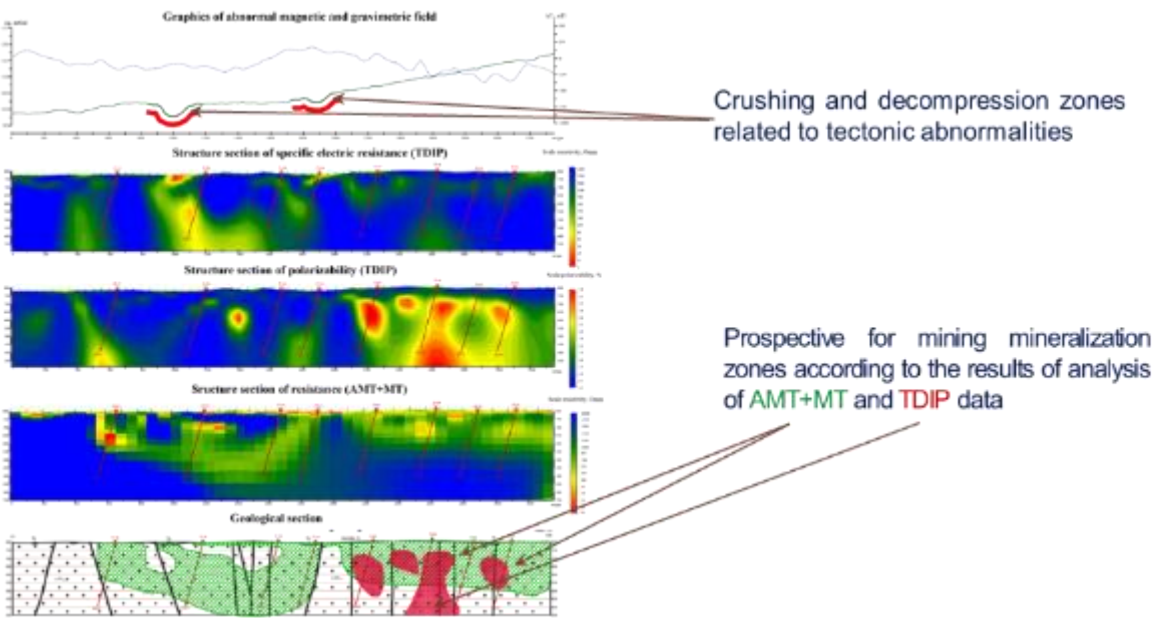


Picture 8 – Complexing of TDIP and AMT+MT data

According to preliminary estimation the specific mineralization value for known resources of P_1 categories are (lead – 2 877 236:4 sq.km=719 309 t/km^2, zinc – 4 391 940:4=1 097 985 t/km^2 and silver – 2525:4=631.25 t/km^2).

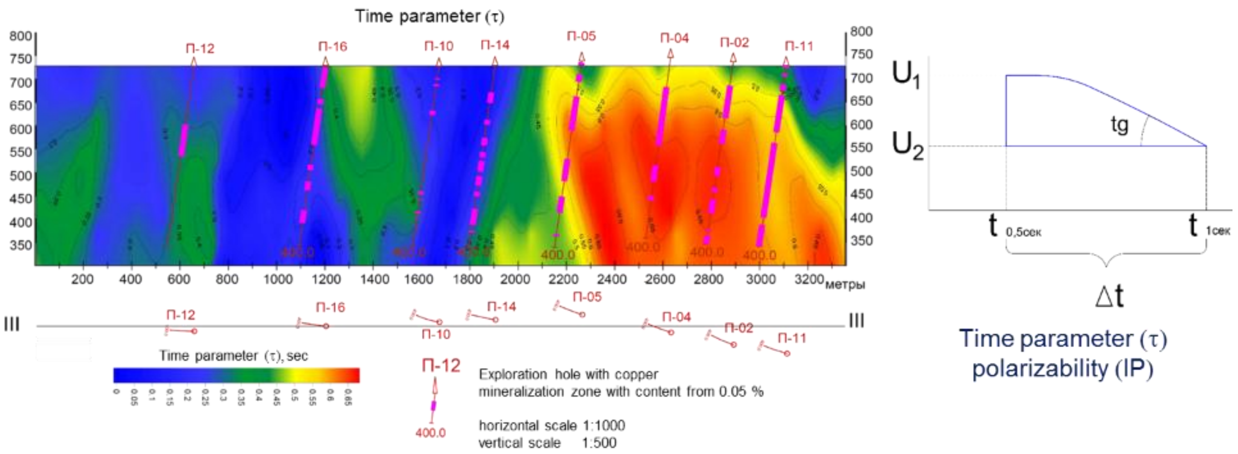
Complexing of modern geophysical technologies in searching porphyry copper mineralization

Researching facility is a typical porphyry copper type of mineralization with strong presented zoning. Ore-hosting primary rocks for sulphide mineralization are diorites and granodiorites of acid and average compositions. To detect zoning elements and specifying of structural and tectonic picture “relatively simple geophysical methods”– gravity and magnetic surveys have been performed first. It’s well known that tectonic disturbances on copper-porphyry objects can often be ore-controlling and ore-supplying factors.



Picture 9 – Complexing of geophysical technologies

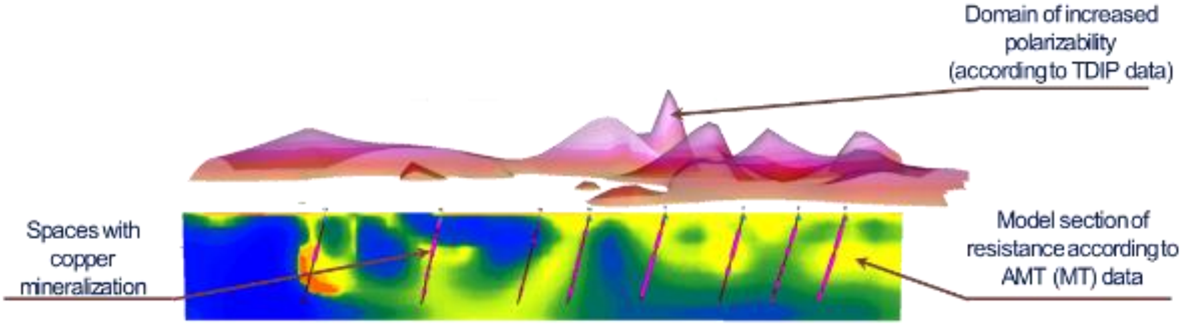
The most interesting for detection of useful sulphide mineralization are zones of increased conductivity and polarizability detected within profile III (picture 9). South-east part of profile according to AMT+MT data are characterized by reduced values of resistance, in average around 200 Ohm*m. Zone of low values has a shallow, close to the horizontal occurrence with the exposure on the surface. West part of the zone has a north-east steeply dipping wing. Zone of low resistivity spatially coincides with the area of increased polarizability. The average values of polarizability here is about 2%, within it several local zones with increased polarizability up to 4.8% (Belyakov, S.N., Yessimkhanova, N.D. & Kononov, A.V. 2018).
In addition, to separate the "false" and "useful" anomalies of polarizability based on the temporal characteristics of the IP decline, a time parameter was calculated that allowed to most accurately define the most promising zone with the assumed presence of copper mineralization (picture 10).



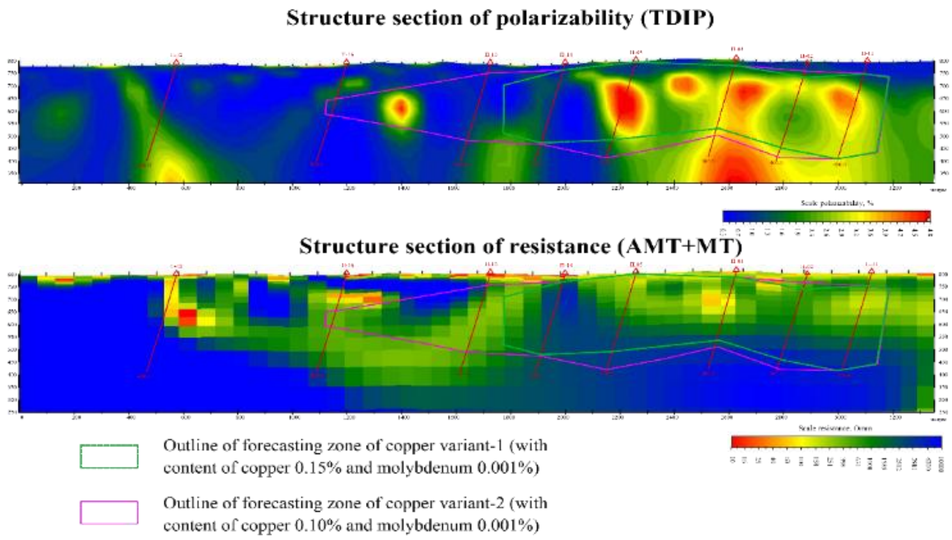
Picture 10 – time parameter of decrease of induced polarizability (IP)

For more complete spatial representation of areas with increased polarizability (TDIP) and decreased resistance (AMT+MT) the corresponding 3D model has been formed. The area of increased polarizability showed in pink color on the model according to TDIP data (level of 200m) located under the model section along the line III according to AMT+MT data. There is a position of exploration holes and zones with increased copper mineralization (picture 11).
Obviously, the two technologies complement each other, significantly increasing the effectiveness of the whole complex of works in general.
In the five wells drilled in the above described zone (Picture 11, 12), ore intersections with sulphide mineralization, represented by small sockets, veins of pyrite and chalcopyrite with an average copper content in the range of 0.12-0.28% and molybdenum from 0.001 to 0.003%. The thickness of the ore crossing ranges from 4 to 53 m.

Ore zones have a close correlation with the geophysical data and are located in the contour of the anomaly of the lowered resistance (AMT + MT). The south-eastern fall of the ore zone is established according to the configuration of the anomalies (picture 12).



Picture 11 – Volume representation of geophysical TDIP and AMT +MT data for line III



Picture 12 – Line III. Wells of exploratory drilling, combined with the sections of apparent polarizability and resistance (1-result of inversion of TDIP data; 2 – result of inversion of AMT+MT data)

The use of modern geophysical technologies allows to solve a wide range of problems in prospecting and exploration of various types of deposits. At the same time, the use of complex approaches promotes the identification of signs of ore objects at the greater depths, and more reliable forecast of hidden and poorly presented mineralization.

The use of effective and relatively inexpensive geophysical methods, as a rule, allows to significantly optimize subsequent mining works and operations and drilling, drastically reducing their volume, which ultimately affects significant savings and a reduction in total costs for the facility.

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NEW DATA ON THE GOLD-MOLYBDENUM-COPPER-PORPHYRY MINERALIZATION OF THE SARYSU-TENIZ BRANCH OF THE DEVONIAN VOLCANOPLUTONIC BELT (CENTRAL KAZAKHSTAN).

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ABSTRACT

Data on the geological position of the gold-molybdenum-copper-porphyry ore manifestation "Zhumbak", revealed in the process of complex geological and geophysical prospecting works, are given. Based on geological, geochemical and geophysical criteria, the Zhumbak copper-porphyry system is distinguished, within which it is recommended to carry out complex prospecting works in order to reveal the unopened erosion of an industrially significant copper-porphyry object.

KEY WORDS:

VOLCANOPLUTONIC BELT, TARANSHY SUITE, SUBVOLCANIC ANDESITES, TUFACEOUS CONGLOMERATE, QUARTZ-SERICITE METASOMATITES, PYRITIZATION, EXPLOSIVE (BOULDERY) BRECCIAS, GOLD, MOLYBDENUM, COPPER.

This article is written according to the results of prospecting works performed by “Azimut Geology” LLP in 2015-2017.

The works have been performed within the program 089 “Provision of intelligent and multipurpose subsoil use and raising of state of geological exploration within the Republic of Kazakhstan” and sub-program 102 “Regional and geological surveying, prospecting and evaluation, and exploration works”.

The works have been intended to explore geological aspects of the area, to define main regularities for location and mode of occurrence of identified mineralization types, to detect ore zones and to define their parameters, morphology and internal structure, and to evaluate mineralization scale.

For the purposes of the tasks set, the following package of basic works has been performed: prospecting traverses, IP-MG and NTES exploration, trenching, RCC holes drilling, core drilling of exploration wells, testing and laboratory works.

The search area is located in the south-east part of the Sarysu-Teniz elevation, and its administrative location is within the Ulytausskiy district of Karaganda region.

The nearest major population centers are Kyzylzhar and Shubarkol, located in 60 km to the south-west and 40 km to the north-west respectively.

A industrial center, Zheskazgan city is located in 160 km to the south-west of exploration area (pic.1).

In regards to geology, the ore manifestation “Zhumbak” is located in the west part of the Sarysu-Teniz branch (segment) of the Devonian volcanoplutonic belt (DVPB) (pic.2).

In current structure of Central Kazakstan, the Sarysu-Teniz DVPB segment is a large and east-west trending anticlinal fold, fractured with fault system of mainly east-west and north-west directions into the series of blocks. Vertical movements in the Late Devonian period alongside this faults resulted in formation of block foldings, which are alternation of upstanding and buried foundation blocks, corresponding to horst-anticlines and graben-synclines.

Among such large structures in the described region are the Shubarkul graben-syncline, the Shubarkul horst-anticline and the Taldysai graben-syncline.

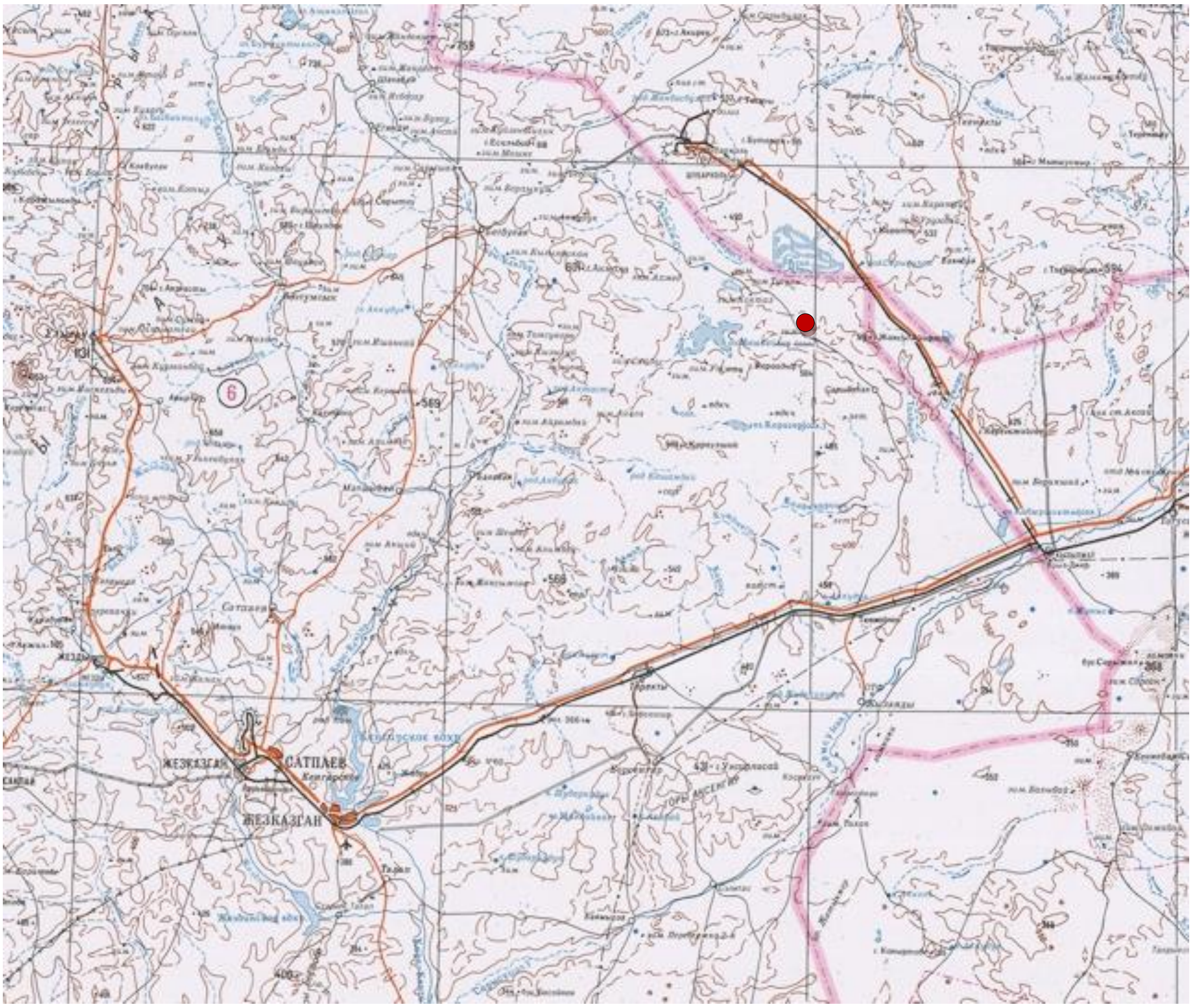
The Shubarkul graben-syncline (sometimes called “depression”) has been formed by sea carbonate rocks of the Famennian and the Lower Carboniferous, which are changed to continental Upper Paleozoic deposits north-west.

The Shubarkul horst-anticline in its upstructure part and north wing is formed by granitoids of the Early Devonian Karamendy, the Middle Devonian Terekty and the Late Devonian Kokkuduktyubinsk complexes forming large Shubarkul pluton. The south wing of the structure is formed by monoclinal folding of the Lower Devonian igneous-sedimentary and volcanic deposits of the Utzhan, the Taranshy, the Zheltymes and the Uronsau suites.

The Taldysai graben-syncline is formed by sea carnonate deposits of the Famennian and the Lower Carboniferous.

The ore manifestation “Zhumbak” is located on the south wing of the Shubarkul horst-anticline.

Geological structure of the ore manifestation includes volcanic deposits of the Taranshy suite (D_1tr), the Early Devonian subvolcanic and vent andesite-basalts and andesites, granodiorite-porphyries of the Karamendy complex supposedly ($\gamma\delta\pi\ D_1km$), exposed in C-2 prospecting well, and felsites of the Terekty complex ($\gamma\pi_3\ D_2t$) (pic. 3).



The ore manifestation "Zhumbak"

Picture 1 – Location map

Volcanites of the Taranshy suite form the main part of the ore manifestation and are exposed with tufaceous conglomerates and tuff rhyolites.

Tufaceous conglomerates form eluvial disintegration of light brown and yellowish brown pebbles of mainly dacitic composition, up to 10-15 cm in size. Tuff rhyolites are also mapped in original outbreaks, as well as in eluvial disintegration. Rocks has light grey, lilac-grey and pinkish grey color.

In the south-west part of the ore manifestation, the Early Devonian subvolcanic andesite-basalts, andesites and vent tuff andesites of greenish grey and grey are well-developed. Subvolcanic bodies have breaking contacts with the Taranshy suite deposits.

In the east part of the ore manifestation, the Taranshy suite tuffs are intruded by dyke-like felsite body of the Terekty complex. Felsite body has the north-west trend with the width up to 30 m.

In the central part of the ore manifestation, tuff rhyolites and andesites are exposed to quartz-sericite metasomatism. Beyond this contour, superimposed epidotization is distinguished in the rocks. Metasomatically altered rocks are accompanied by disseminated pyritization, which is recorded from surface with IP anomaly of up to 12.5% in intensity (pic.4). Besides that, according to the results of electrical exploration with NTES method, longitudinal conduction anomaly > 2,5 cm is evidenced in this part at a depth of 300 m (pic.5).

Within this anomaly, in the area of quartz-sericite metasomatism and intensive pyritization, two prospecting wells C-1 and C-2 has been drilled, of 500 m and 1000 m in depth respectively.

When drilling the C-1 well, quartz bearing and sericitized crystal-lithoclastic tuff andesites have been exposed. In their sections, tuffs are turned into sericite-quartz metasomatites, which thickness varies from 5 to 50 m.

The rocks are intensively pyritized along the whole well bore. Pyrite content amounts up to 15%.

In intervals of 172.4-231.3 m, 247.0-281.0 m, 328.0-343.0 m, and 370.0-425.0 m disseminated and vein-disseminated chalcopyrite mineralization have been observed. Disseminated mineralization is connected with narrow (from 1-3 mm to 1-3 cm) sericite-quartz runs, creating typical stockwork pattern. Copper content in these intervals varies from 0.03% to 0.29%.

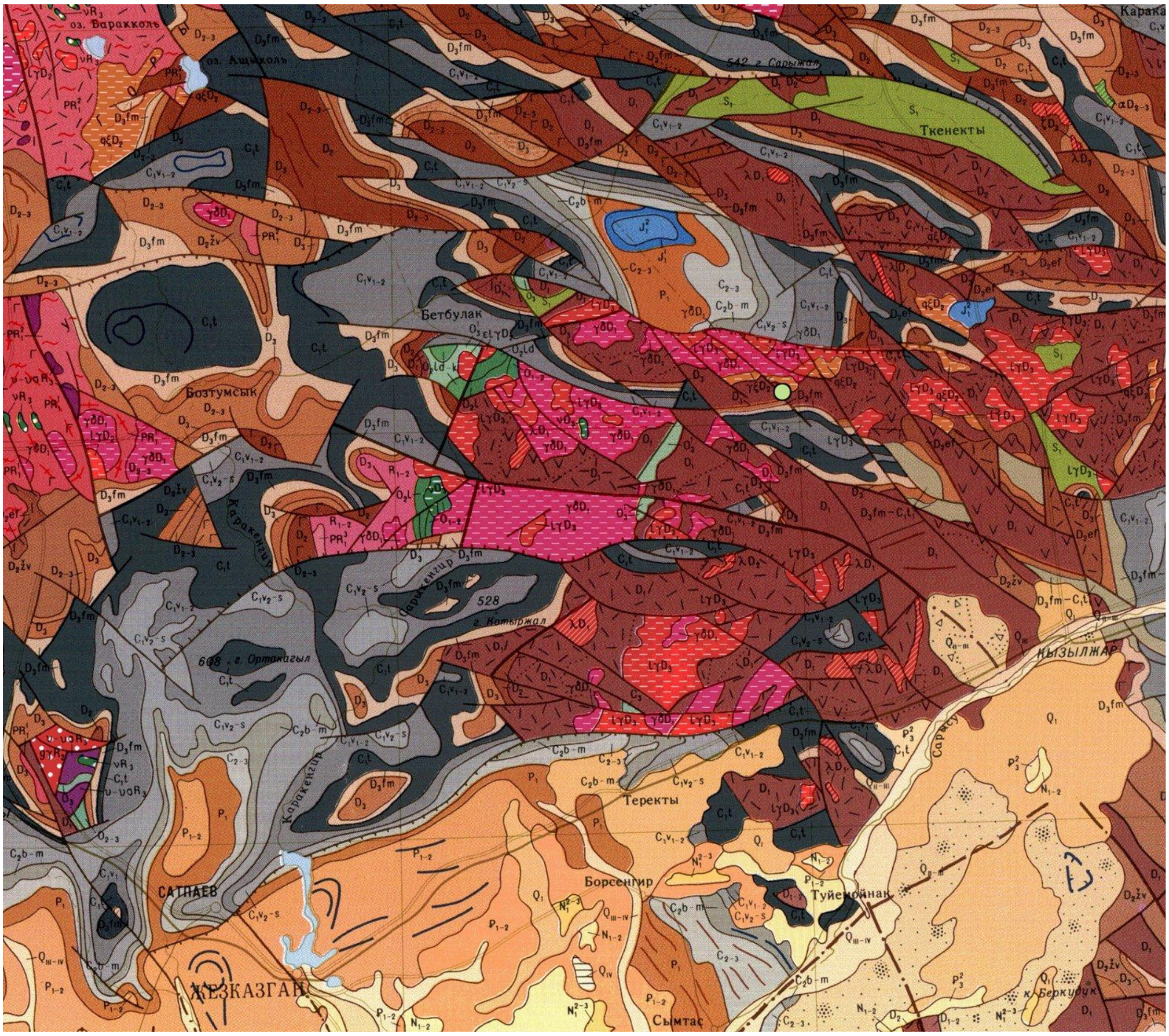
The C-2 well, located in 270 m north-east from the C-1 well, has exposed volcanic section of the Taranshy suite, represented with tufaceous conglomerates, dacites and tuff rhyolites, rhyodacites, dacites and andesites.

In intervals of 71.0-277.0 m and 294.6-322.3 m, the Taranshy suite volcanites have been intruded by explosive (“bouldery”) breccias (pic.6), and in interval 621.0-837.6 m, they have been intruded by the granodiorite-porphyry dike swarn with apparent thickness from 2.3 to 15.6 m.

In the upper part of the section (up to a depth of 400 m), the Taranshy suite volcanites include areas of sericite-quartz metasomatism with thickness from 4 to 50 m, and starting from a depth of 700 m and to the bottom, the area of epidote-chlorite-sericite-quartz metasomatites is well-developed.

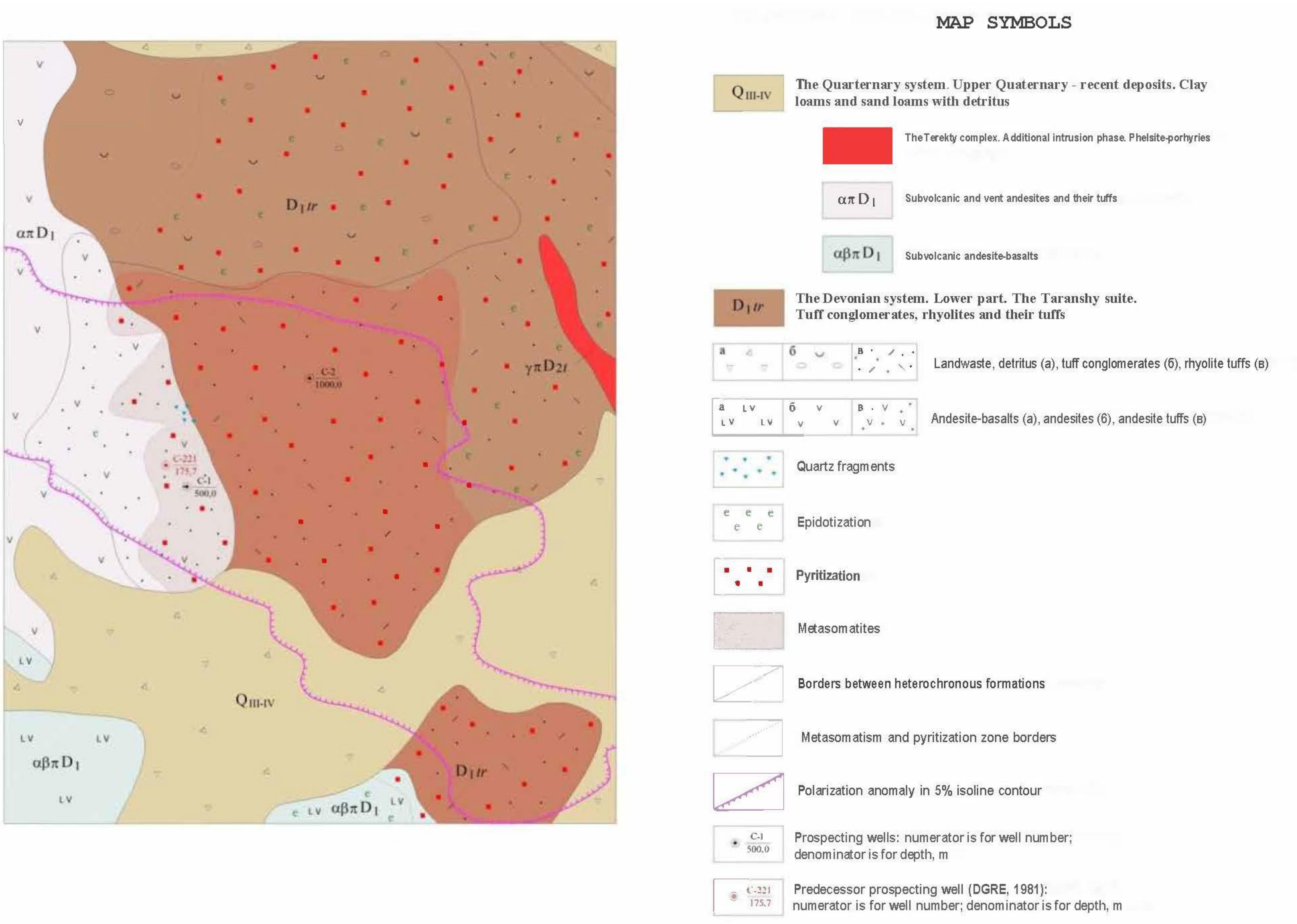
All the rocks exposed by the well are intensively pyritized. Pyrite content in them amounts up to 15%. Apart from pyrite, copper and molybdenum mineralization in the form of a shot and rare runs of chalcopyrite-pyrite-sericite-quartz and molybdenite-pyrite-sericite-quartz composition is distinguished. Copper and molybdenum mineralization is split extremely irregularly in the rocks and forms two mineralized zones.

The first zone is distinguished in int. 277.0-308.0 m with average copper ratio of 0.05% and average molybdenum ratio of 0.002%. The second mineralized zone is distinguished in int. 588.0-1000.0 m and characterized with high copper ratios from 0.04% to 0.66%, and molybdenum ratios from 0.002% to 0.019%.

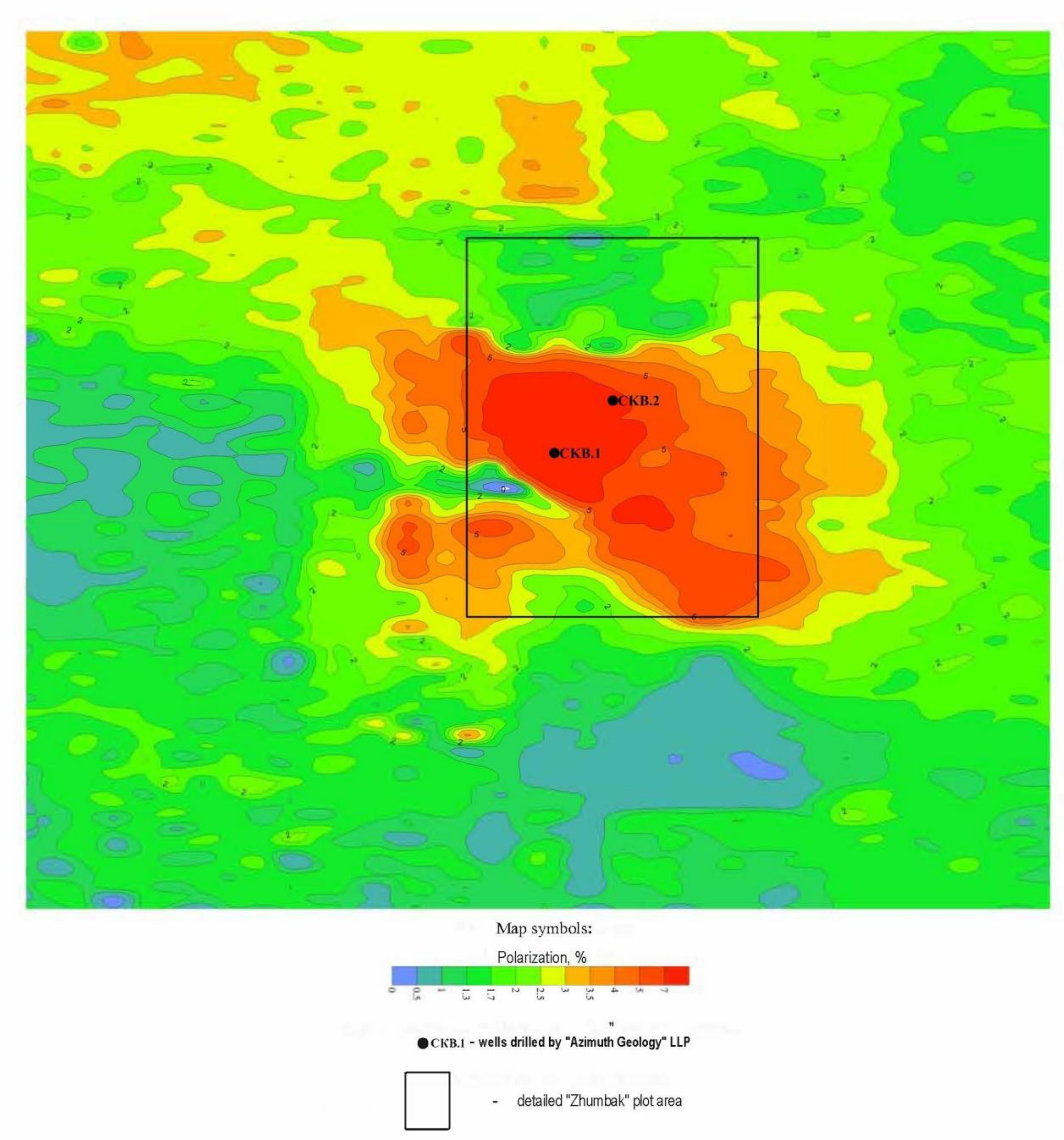


The ore manifestation “Zhumbak”

Picture 2 – Geologic location map



Picture 3 – Geologic map of the ore manifestation “Zhumbak”



Picture 4 – Apparent polarizability map of the ore manifestation “Zhumbak”

Besides that, according to the sample data among explosive (“bouldery”) breccias two intervals with high gold content have been distinguished. The first interval is 116.0-121.0 m with 2.87 g/t gold content, and the second interval is 188.4-193.0 m with 0.94 g/t gold content.

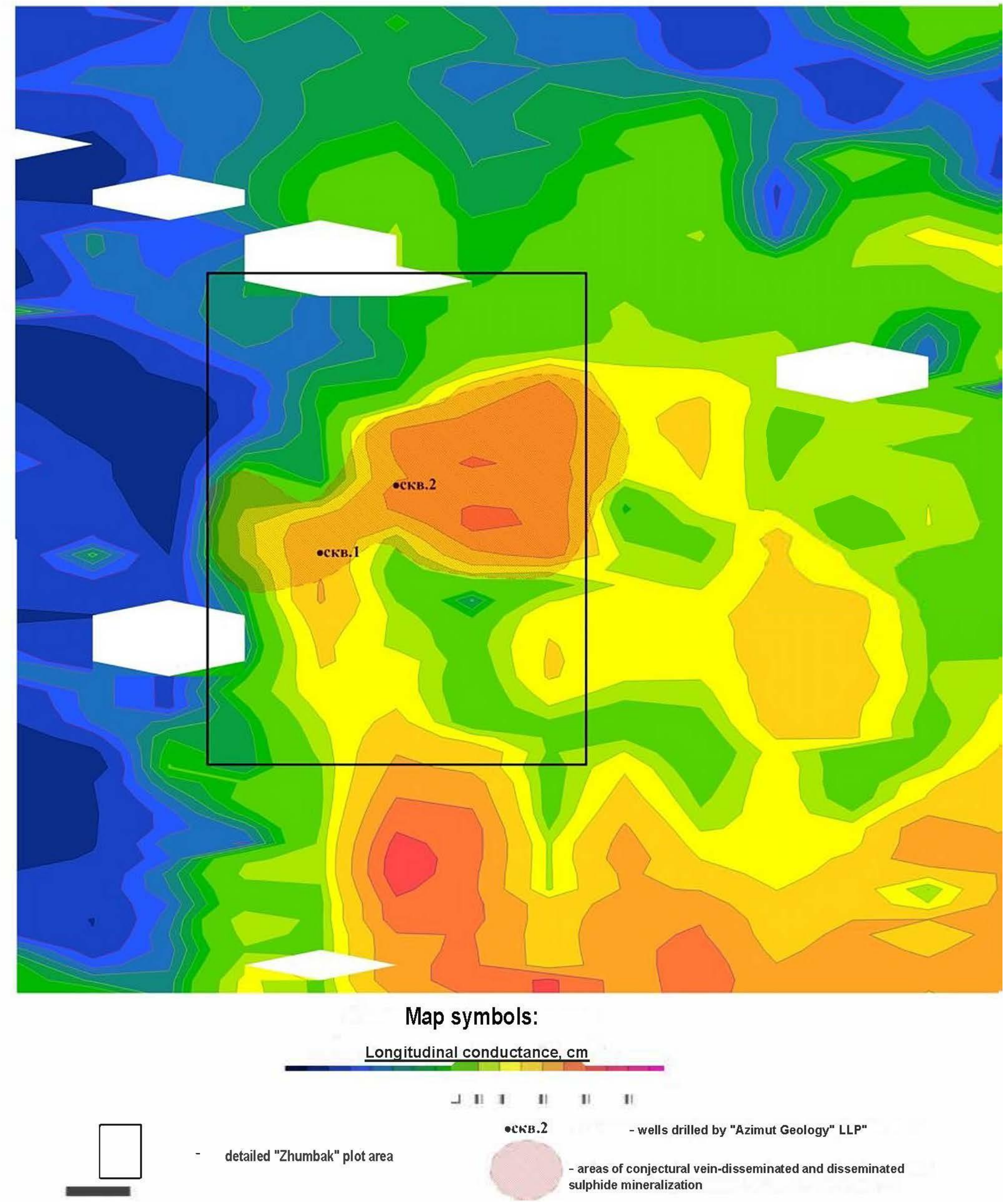
We associate future prospects of the prospecting area with reveal of the object of copper-porphyry genetic type within the ore field “Zhumbak”, located in its south part and elongated north-westward and south-eastward alongside the Tagyloby fault at a distance up to 5 km.

Geological structure of the ore field includes volcanic deposits of the Taranshy, the Zheltymes, and the Uronsai suites, which are intruded by subvolcanic andesite and andesite-basalt bodies of the Early Devonian period. In their sections, volcanites have been altered to sericite-quartz metasomatites and intensively pyritized. Besides that, narrow quartz veins and runs are well-developed among volcanites, which are fixed on the surface as significant quartz disintegrations.

Due to poor exposure and in order to confirm secondary dispersion halos, mapping drilling locations has been performed within the ore field. According to its results, complex buried gold, copper, molybdenum, boron, lead and zinc dispersion halos have been revealed.

In the north-west part of the ore field, in order to confirm intensive polarization anomaly, the C-1 and C-2 prospecting wells have been drilled, which exposed zones of vein and vein-disseminated molybdenum-copper mineralization with depth intervals of 172.0-1000.0 m. Copper ratio in the wells varied from 0.005 to 0.66%. Molybdenum ratio varied from 0.0002 to 0.019%.

When drilling the C-2 prospecting well, granodiorite-porphyry dike swarm has been revealed, of the Early Devonian Karamendy complex supposedly, with which metasomatic alterations of host volcanites are connected, concentrating higher chalcopyrite and molybdenite contents. Besides that, the well has exposed the body of the so-called explosive ("bouldery") breccias, which are important element of copper-porphyry systems. In intervals 116.0-121.0 m and 188.4-193.0 m, these breccias demonstrated high concentration of gold, 2.87 g/t and 0.94 g/t respectively.



Picture 5 – Longitudinal conductance map of the ore manifestation "Zhumbak" at a depth of 300 m

Picture 6 – Explosive (“bouldery”) breccias

Basing on the above-mentioned data, we recommend the ore field “Zhumbak” for carrying out high-priority prospecting works, for the purpose of reveal of commercial copper-porphyry object.

The prospectivity of the ore manifestation “Zhumbak” is characterized by the range of direct and indirect indicators.

The following may be identified as direct indicators:

- extended fields of disseminated pyrite mineralization among the Taranshy and the Zheltymes suite volcanites;
- presence of sericite-quartz metasomatites within pyritization areas;
- presence of explosive (“bouldery”) breccias and porphyry intrusive bodies of grandiorite-porphyries;
- presence of zones with disseminated and vein-disseminated molybdenum-copper mineralization in prospecting wells C-1 and C-2.

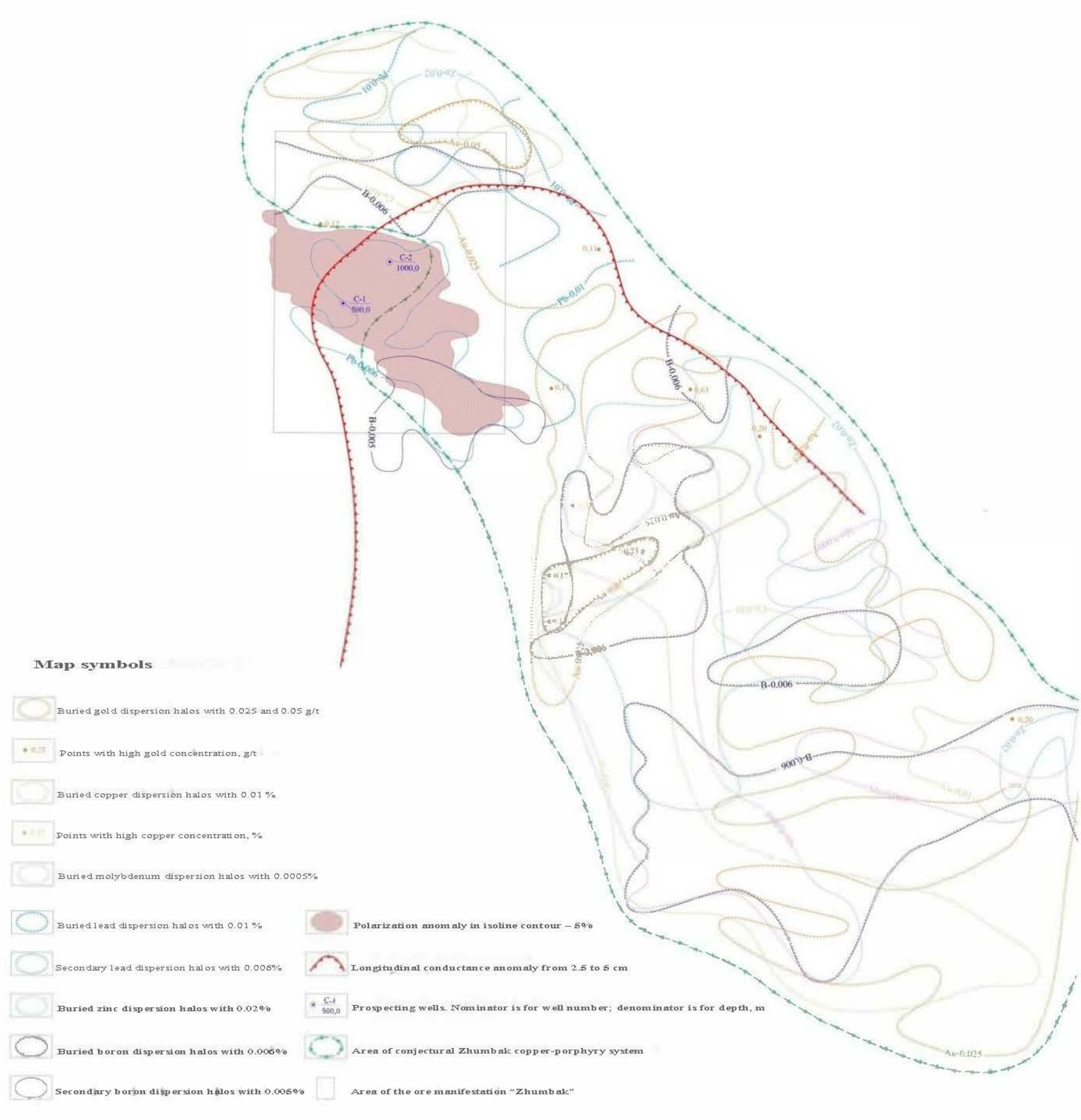
Indirect indicators in the ore field “Zhumbak” include the following:

- high-intensity (up to 12.5%) polarization anomaly;
- deep-seated longitudinal conductance anomaly with intensity > 2.5 cm;
- decreased magnetic signatures, typical of metasomatic rock changing processes;
- complex secondary and buried gold, copper, molybdenum, lead, zinc and boron dispersion halos;
- presence of numerous narrow quartz veins and quartz reefs, with gold mineralization shown in their sections.

Within this area, we recommend the following:

- carrying out high-accuracy and detailed gravity prospecting, in order to expose ore parent intrusive porphyry bodies;
- carrying out geophysical exploration with NTES and MT sounding methods to reveal deep-seated conducting objects;

- drilling holes of up to 1000 m in depth, to evaluate extent of ore mineralization within the ore field.



Picture 7 – Area of conjectural Zhumbak copper-porphyry system

AN EXPLANATORY PAPER ON IMPACT OF STUDYING DIFFERENT GEOSTATISTICAL UNCERTAINTIES TO ALLOCATE MEASURED, INDICATED AND INFERRED CLASSES IN ORE RESERVE CLASSIFICATION (IS IT BEST IN TERMS OF ACCURACY TO ADOPT DIFFERENT CRITERIA THAN TO STICK A FIXED SINGLE STANDARD?)

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ABSTRACT

This paper aims to review and prioritize the classification methods in ore reserve estimation. It also tries to present a quick review of geostatistical tools available to estimate regionalized variables. Firstly, the importance of classification is presented in the article. Since there are inevitable uncertainties in the model obtained by the geostatistical methods, some challenging issues in estimating a regionalized variable are reviewed and some methods are proposed to tackle the challenges and achieve more reliable results. Then, parameters and their relationship to each other applied for quantifying uncertainties have been introduced. finally, it is discussed whether the given uncertainties should be classified based on some established fixed standards or it is much better to consider different criteria and parameters. A short, brief review is made on these criteria and parameters. A statistical method based on cumulative distribution function (CDF) is also introduced to recognize the identical patterns of uncertainty parameters. These criteria combined with the statistical patterns enable a better understanding of the uncertainty of the estimation. A copper deposit is also used as a case study to apply the above mentioned methods. Based on the results, it is concluded that the combination of different methods with a statistical consideration and interpretation can be a better tool to classify an ore reserve than a fixed and single standard which have already been established in some mines so far.

KEYWORDS

Ore reserve classification, Geostatistical uncertainties, Pattern recognition, Quantifying uncertainties

INTRODUCTION

An accurate evaluation of an ore reserve is so important to all mining operations no matter their size or commodity (Stone and Dunn, 1996; Stephenson and Vann, 2001; Goldsmith, 2002). This is especially challenging for porphyry and stockwork and strata bound deposits where grades often fluctuate.

The uncertainties associated with mining are complex (Snowden et al., 2002). As getting the knowledge of geological models is essentially based on estimates, which by their very nature include a degree of uncertainty, it is much important to quantify the uncertainties of the estimates.

The classification of mineral resources depends on different methods of ore reserve estimation. There are several methods of estimating ore reserve grade and tonnage; however, all of them are not able to provide suitable parameters to evaluate accuracy and reliability of a block which grade has been assigned to it. So, determination of errors and uncertainty in the estimation phase is important to mining engineers undertaking these projects during a feasibility study as well as short and long term programming. Therefore, different methods and algorithms have been expanded during short time programming.

A reliable mineral resource model should integrate several databases called geological databases (drilling, mapping, etc.). The database should be interpreted in a way that long and short time programming can be organized with the least uncertainty.

This paper reviews all the steps to make a grade model and define common errors and uncertainties involved in the estimation process.

Also an emphasis is placed on ore reserve classification in this paper. Several parameters and criteria are utilized to quantify the uncertainty of estimating the grade of each individual mining units which are due to be exploited. However, in the previous articles ((Diehl and David, 1982), (Krige, 1996b), (Rivoirard, 1987, Krige, 1994; 1996a), (Arik, 1999a), (Yamamoto, 2000), (Arik, 2002) (Khosrowshahi and Shaw, 2001; Snowden et al., 2002)), fix standards have usually been presented to allocated measured, indicated and inferred classes. This paper discusses whether it is a good decision to use the standard which had been determined by the geoscience researchers or it is wiser to analyze the uncertainty parameters statistically for each project and classify measured, indicated and inferred blocks exclusively for the project since the number, distribution, and dimension of data are different in each project.

MINERAL RESOURCE AND IMPORTANCE OF ORE MODELING AND CLASSIFICATION

Classification of ore bodies are usually based on geological features (e.g. geneses, grade continuity, structural geology features), data quality (e.g., sampling and assay quality, etc.) and sometimes feasibility studies and economic viability as a function of money are taken to be account (Stephenson, 2000; Stephenson and Stoker, 2001).

Geological uncertainties usually depend on factors like sampling density and distribution. Based on these uncertainties, resources should be classified in order to determine measured, indicated and inferred classes. These classes are mentioned in the 1999 JORC code explaining as a report standard for Measured Mineral Resource: "...that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence. It is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are spaced closely enough to confirm geological and/or grade continuity."

Several interesting researches have been put forward to determine guidelines and standards for the classification of resources and reserves based upon measuring the uncertainties. These are generally supposed to be qualitative in nature, based on consideration of all the factors that might impact on an estimation about which you can be confident. So far, several researchers determine valuable equations for classifying the reserves or grade computational efficiency such as kriging variance (Diehl and David, 1982), kriging efficiency (Krige, 1996b), regression slope (Rivoirard, 1987, Krige, 1994; 1996a), Combines variance (Arik, 1999a), Interpolation variance (Yamamoto, 2000), Resource classification index (Arik, 2002) or the results of conditional simulation studies (Khosrowshahi and Shaw, 2001; Snowden et al., 2002).

This paper wants to shed a light on some challenging issues on ore reserve estimation and see if it is best to use standard quantities to classify reserves. It is important to note that if no appropriate preprocessing steps take place, the results will be really biased. So, the paper starts with reviewing pre-processes needed for geostatistical estimations and clarifies some challenges which geostatistician always face. It continues with a short summary of estimation method. Finally, it focuses on some numerical relationships to quantify the uncertainties and errors of estimating each block leading to the classification of a deposit. At this stage we suggest some simple statistical notification in order to classify Measured, Indicated and Inferred blocks in a convenient way. We also keep this discussion open in the conference so that all geostatistician can put forward their opinion as well. A strata-bound copper deposit is also considered as a case study to make all the mentioned issues easy to understand.

WHAT IS UNCERTAINTY AND THE IMPORTANCE OF STUDYING UNCERTAINTIES IN ORE RESERVE ESTIMATION? (WHY MEASURED, INDICATED AND INFERRED)

Uncertainty is a parameter, associated with the outcomes of an estimation that characterizes the dispersion of the values that could reasonably be attributed to the measured value. As far as estimating mineral reserves and resources are concerned, all uncertainties related to geological phenomena are closely related to resource/reserve classification. State-of-the-art methods or processes determining geological uncertainty can bring about reliable resource/reserve classification which a mine planner can indicate the level of accuracy he/she works on. The following issues are underlying factors which have significant influence on identifying the uncertainties: (a) poor sample and assay quality data (b) a lack of detailed mine geology and fundamental understanding of the deposit (c) poor interpretation of grade distribution characteristics (d) poor understanding and application of computer-assisted estimation techniques (e) the failure to recognize effect of selectivity and the change of support or volume-variance effect.

This paper does not try to discuss all above issues but issues mentioned at (c), (d) and (e) are the issues which focuses on it as key factors to determine the uncertainties more reliably. Based on this policy and in a nutshell, we have summarized the parameters and criteria contributing to quantify the uncertainties in Table 1 and 2.

Table1 - The parameters giving rise to quantifying the uncertainties

Parameters type	Parameters Group
Data Quality	Sample preparation errors

Parameters type	Parameters Group
	Non-Normality of distribution and Its effect on the estimation Regularization and composite making
Number of Points to be used in the estimation for each block	Number of points implicated in the estimation Number of search octants Number of points situated in each octant Number of points within a block Number of discretization points
Distance and arrangement of points	distance between points (two point based algorithm, variogram theory) Ratio of nearest point distance to the range of variogram Interpolation/Extrapolation
Purpose of estimation	Block size Orientation of blocks and spatial structure Sub-cells Number of Discretization points Variance of Dispersion
Spatial Correlation	Parameters (nugget effect and Range of variogram as well as Sill) Anisotropies Spatial continuity of the geology Robustness of variogram model
Local Variation	Local variation of mean Dispersion of contributors sample's grade Local non-continuity of geology
Quality of Estimation	Validation of variogram model Validation of search parameters Validation of estimated block model
Conditional Simulation	Variation of block simulated value Conditional probability

Table2 - The criteria which should be considered on determining uncertainties

Criteria	The related issues
Sample Density	Number of sample per unit area Number of sample per block
Production planning	Planned production period
Distance and arrangement of points	Minimum distance (Nearest point) Number of points situated in each octant

Criteria	The related issues
	Ratio of nearest point distance to the range of variogram Interpolation/Extrapolation Weighted average of point distances (weighted by kriging)
Purpose of Estimation	Ratio of target size to the range of variogram Dispersion variance Dispersion variance ratio (Variance of Selective Mining Unit)
Spatial Correlation	Range of variogram Spatial continuity of the geology
Local Variation	Lagrange multiplier Standard deviation of neighbour points Relative variability Index Interpolation Standard deviation
Quality of data	Skewness Nugget Effect Ratio
Estimation Quality	Variance of kriging error or Confidence level Kriging variance PDF Relative kriging error Block efficiency Isobel Clark's classification index Linear regression slope
Conditional Simulation	Standard deviation of the realized values for each block Relative standard deviation of the realized values for each block Confidence interval 90% of local block grade distribution

MATERIAL AND METHOD

Picking up a good geostatistical method (Geostatistics (Avoid! Damn Lies) OR (Wow, Avoid Damn Lies))

The estimation method must be able to reflect the appropriate grade/tonnage relationship for a given mining scenario. Confidence level in an estimated resource depends on the resource estimation technique utilized (e.g.the geological mineralisation model, the limits or constraints applied, the mathematical modelling procedure and the specific geostatistical parameters). No single or fixed method can be appropriate for all orebodies (Snowden, 2001).

The importance of evaluating the accuracy of estimated ore reserve has always been recognized and highlighted in the past. Mining companies obviously need accurate ore reserve estimates since the quality of the estimation may directly effect a company’s profitability.

Some geologists working in this field are still of the opinion applying classical statistics in ore reserve estimation on the basis that the assay values are not random but generally are correlated to some degree, as it is well known to geologists. They added that the geostatistical process can be really a pain in a neck and is not worth at all since this method only provides fake results! Research by Matheron focused on the study of data that exhibit spatial correlation, a typical example of which is geologic data. The resulting method developed by Matheron (1963) which is commonly referred to as geostatistics has special appeal to geologists and mining engineers. One reason is that it does explicitly take into account the spatial correlations between samples. Another reason is that it makes better use of available data and provides confidence limits for the estimate (Knudsen, 1975). However, still some geologists have been complaining about the uselessness of geostatistical methods and blaming the method to reveal fake and tricky results. The geologists are sometimes right! If some considerations have not been taken in to account before starting the geostatistical process the results are far from the reality. So there are some important pre-processing steps to be done before starting the geostatistical process otherwise as some geologist truly mentioned the geostatistics are damn lies!

As is clear for all the ore model experts there are several interpolation methods to measure a value (most probably grade) in geoscience. However, geostatistics has been considered as a promising method for ore reserve estimation of deposits especially those which are stockwork or show a specific degree of variability. It is important to note that if the appropriate preprocessing steps do not take place, the results will be really biased. Based on this challenging fact, the processes leading to an appropriate and reliable model will be summarized here and some contentious issues about each of these steps have been highlighted.

Preprocessing processes

The processes which should be carried out on a variable which is required to be estimated and modeled in an ore block are reviewed here. If these steps are not undertaken, the result will probably show some significant biased values. The most important frequently asked questions are:

Does the study of distribution really make sense? Working with row data or normalized data? What should be done with outliers? Why studying trends are so critical? (So, to love geostatistics or not, that’s the question)

In estimating mineral resources, it is necessary to apply statistics in order to achieve reliable results since quantifying uncertainties is the best way to analysis and predict risks in all phases of mining. Although the main target in mineral resource estimation is almost inference, numerous descriptive statistics are usually utilized for viewing, understanding, and evaluating data.

Several reasons have been suggested to use statistical tools, the most important issues are:(1) making a sound prediction about a domain which is going to be evaluated for mineral potential (2) getting a greater understanding of databases and mineral deposits in order to interpret deposits not only geologically but also mathematically, (3) accurately ascertain data quality, (4) analyzing disparate information to identify relevant data among different sources of information Moreover, reliable visualization of data is a fundamental step of mineral resource estimation to help validate spatially distributed models (Rossi and Deutsch, 2014).

<u>Gaussian distribution and Data Transformations</u>

Gaussian distributions are commonly utilized since they have convenient statistical properties. The Gaussian distribution stems from the Central Limit Theorem. A univariate Gaussian distribution is fully presented by its mean and standard deviation. It is common to transform data to a Gaussian distribution. There are many instances where the prediction of uncertainty at un-sampled locations becomes much easier with a Gaussian distribution.

<u>Extreme Values (Outliers)</u>

Extreme low or high values in a database may greatly influence central or dispersion statistical parameters like mean or variance, or even it can also affect the correlation coefficient, and measures of spatial continuity.

High-grade intercepts are challenging if they are given too much weight which may lead to a possible overestimation or underestimation, or if kriging is the method of choice; a negative weight, which may lead to an unrealistic negative estimate (Sinclair and Blackwell, 2002). Krige and Magri (1982) warned that presence of these values may mask continuity structures in the variogram. If they are proven to be erroneous values, then they should be removed from the data. For extreme values that are valid samples, there are different ways to handle them, such as classifying the extreme values into a separate statistical population for special processing, or use robust statistics, which are less sensitive to extreme values.

Trend

The distribution of minerals can exhibit very unusual behaviour in terms of sudden boost or reduction in grade in a space domain as one moves from one point to another. This behaviour of mineralization is known as a drift or trend. Trend modeling is applied when a trend has been detected and is assumed to be well understood. While some geostatistical estimation methods are quite robust with respect to the presence of trends, such as Ordinary Kriging (Journel and Rossi 1989), there are many others, most notably simulation that are quite sensitive to trends. However, it is important to remove trend in databases so that uncertainties related to the trend can be reduced significantly.

Sometimes a simple cross-plot of the data versus longitude, latitude and altitude can reveal a trend. If there are notable changes in the local mean and variance of reasonably large subdivisions within the domain, then a spatial trend model may be required.

This sometimes can be derived from the experimental directional variograms. The experimental directional variograms continue to fluctuate as the lag distance increases (Journel and Huijbregts 1978).

Compositing process

Compositing of borehole assay intervals is a primary step to make a constant support effect in orebody modelling and mineral resources estimation. Compositing is defined as the process of establishing an appropriate sample interval or support and splitting the original measure length intervals into these regularized intervals. Compositing can be considered as re-cutting the drill core into pieces of equal length. This is required so that samples will have the same weight or influence when used to calculate block values (Hustrulid and Kuchta, 2006).

Compositing of borehole intervals is an essential step in orebody modelling because the resulting ore composites represent orebody limits along boreholes and subsequently determine the outlines of an orebody model (Ma et. al, 2010).

Geostatistical processes

Geostatistics is a set of models and tools developed for statistical analysis of continuous data. If data are independent, it makes little sense to analysis them geostatistically. The most important step in geostatistical processes is modeling spatial dependency, variogram modeling.

Variography process (a straightforward process or a real pain in a neck!)

In a nutshell, variogram can be explained like a variance (in statistics science) but in a spatial domain. The variogram parameters can be the most fundamental inputs to start geostatistical studies. Variography is the most widely used tool to investigate and model spatial variability of grade, lithofacies, and other geological properties. In addition, vast majority of geostatistical reserve characterization studies have applied variogram-based geostatistical modeling methods. Furthermore, the variogram can reflect level of understanding about the geometry and continuity of reserve properties and have an important effect on predicted grade behavior and consequently reserve management decisions (Gringarten, Deutsch, 1999).

The variogram function, was originally defined by Matheron (1963). Variogram is a description of the spatial continuity of the data. The experimental variogram is a discrete function calculated using a measure of variability between pairs of points at various distances. Anisotropy of the mineralization can be significantly identified by variography process in different direction.

Confidence level in classifying a mineral resource is affected by the nugget effect, sill and ranges. Nugget effect presents the efficiency rate of sampling process usually provided by duplicated sampling at the same location. It reflects both the natural inherent variability of the deposit as well as variability due to sample size, sample preparation and analysis. The more homogeneous the mineralization, the lower the nugget effect. Sill also presents the variogram values when samples show no spatial regression to each other, so it can be defined as a statistical variance of a dataset. Interestingly, in an appropriate interpretation, it should be neither higher nor lower than the statistical variance in all directions. If it happens, the interpreter should carefully consider possible trends in the dataset or the results are revealed by high unbiased values. Range, a distance which samples have significant influence on each other, also plays significant rule in the estimation process since this parameter is directly used to determine the diameters of a search ellipsoid applied for picking up appropriate samples for estimation.

Post processing

A fix standard for ore reserve classification (Is it a best practice?)

The methods of classifying resources have always been a topic of discussion. There are both traditional and geostatistical methods applied to classify resources. As no two ore deposits are identical completely, establishing a single industry-accepted standard for resource classification is almost out of the question. Therefore, some geoscientists have proposed or of the opinion that should be the methodologies to suit the deposits they are working on. Another reason for the existence of different classification methodologies is the lack of an easy and established way to accurately calculate the estimates. Therefore, their classification becomes a subject of debate. In a nutshell, the main purpose of classifying is to assign three classes called measured, indicated and inferred to a reserve. In the measured class, the confident level of the estimation is the highest so that it is the best, the most reliable class for mine planners focusing on making the best mining method.

Over the past decades, a number of resource/reserve classification codes have been developed to provide the classification principles and reporting guidelines in the mineral industry. The main ones being the American USGS Circular 531 (USGS, 1980) and SME Guide (SME, 1999), the Australian JORC Code (JORC, 1999), the Canadian CIM Guidelines (CIM, 1996) and National Instrument 43-101 (CSA, 2001), the South-African SAMREC Code (SAMREC, 2000) and the European IMM Code (IMM, 2001).

In a traditional method, geoscientists usually apply qualitative parameters. For example, in the Russian standard the part of a reserve which the information is available from all around it except one side is considered as a measured reserve. Or in the Iranian standard those parts explored by a drilling pattern which the distance of boreholes is less than 50 are considered as a measured class.

In contrast, geostatistical methods provide some parameters which help a geoscientist to quantify the uncertainty. By this uncertainty, the accuracy level of assigning grade for each block can be assessed and mine planner can make a better decision to start mining. The parameters used for quantifying the uncertainties are kriging variance, block variance, Lagrange coefficient (which all of them calculated based on variogram parameters and geostatistical relationship).

Based on the parameters mentioned above, many methods of classification have been observed. Not all of them are valid, as pointed out by Glacken (1996) and it may be worth noting a few poor practices. However, as kriging variance like variance depends on dimension of a regional variable (e.g. for grade (percent, ppm)), using a fixed standard to assign the class for each block is out of question. If the distribution of kriging variances is used, some of the resource would automatically and erroneously be classified Measured. The kriging variance should thus not be used without reference as to how well the drillhole spacing addresses the geometry and spatial continuity of the deposit and to the overall integrity of the input data and security of the interpretation of the geological controls on mineralisation. Confidence in the geological framework is all important and generally takes precedence over any mathematical indicator of confidence (Snowden, 2001). Based on the mentioned problems, other relationships such as Block Error (BE), Kriging Efficiency (KE), and regression slope (R) have been purposed to quantify the uncertainty and classify a reserve.

MADAN BOZORG (A CASE STUDY TO BE CONSIDERED)

The Abbas Abad copper district is located in NE Iran, close to the highway from Tehran to Mashad. Exploited from pre-Islamic times till 1982, it is thought to have produced about 10,000 t Cu from shallow mining at five main deposits and in numerous smaller occurrences found within a ca. 300 sq. km area.

As far as geology is concerned, the style of mineralisation and its regional setting are considered as well identified: it consists in 'manto-type' stratabound chalcocite stockwork and dissemination over ca. 10 m thickness at the margins of Tertiary andesite sheets which plunge gently (40 to 50° on average) below sedimentary or volcanic country rocks. Oxidised parts have been almost entirely removed by erosion or ancient workings, and remaining ore is mainly sulphide mineralisation. Mineralised veinlets and spots contain several percent copper up to 45% Cu (as indicated by selective chip sampling) and average ore grade depends on their relative frequency within the host andesite: its varies from less than 0.1% to 6% along metric drilling intercepts and is usually in the order of 1±0.2% Cu over the total mineralised thickness. Extension of mineralisation ranges between 400 and 800 m along strike in the main deposits and has been tested downdip to 100 m depth by reconnaissance drilling at a few locations. New mining projects have started since 2013 by digging 94 boreholes.

Most of the samples obtained from boreholes are about 2m long and the distribution of Cu grade, as is shown in Figure 1(a), is positively skewed. Since prediction of uncertainty at un-sampled locations becomes much easier with a Gaussian distribution, as is illustrated in Figure 1(b) an nscore transformation is used to transfer data to a Gaussian distribution.

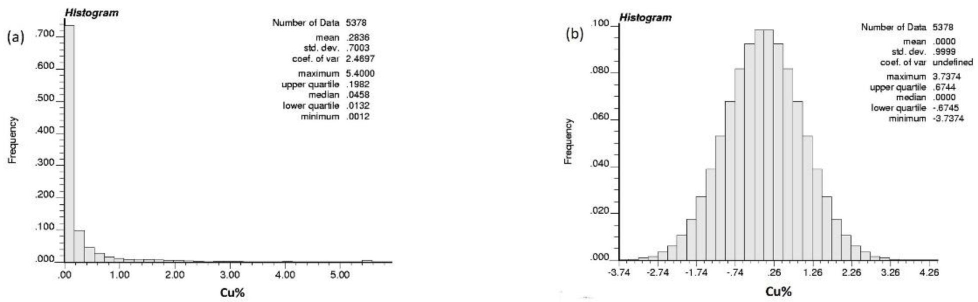

Figure1 - (a) Positively Skewed Distribution of Cu. (b) Nscore transformation to transfer data to Gaussian distribution

To avoid the effect of outliers on statistical parameters or on correlation coefficient, and measures of spatial continuity, graph shown in Figure 2 is used to determine these extreme values. Generally, box plot is a tool used for detecting outliers. However, cumulative distribution function, CDF, can reveal better results. Based on this Figure, a point which a significant discrete happens on it can be considered as an outlier threshold. As illustrated in Figure 2 there are a major point making a disconnection on CDF (5.4%). 21 samples have more value than 5.4% (less than 0.4% of all samples). According to this result, more than 99 percent of the samples have the value less than 5.4%. Therefore, all the data more than 5.4% have been changed to 5.4%.

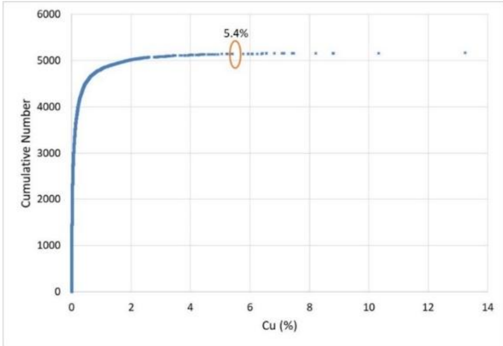

Figure2 – CDF of Cu grade used for detecting extreme values

Cross-plots of the data against longitude, latitude and altitude are illustrated in Figure 3 that reveal there is no trend in database, so there is no concern about increasing uncertainties related to the trend in geostatistical processes.

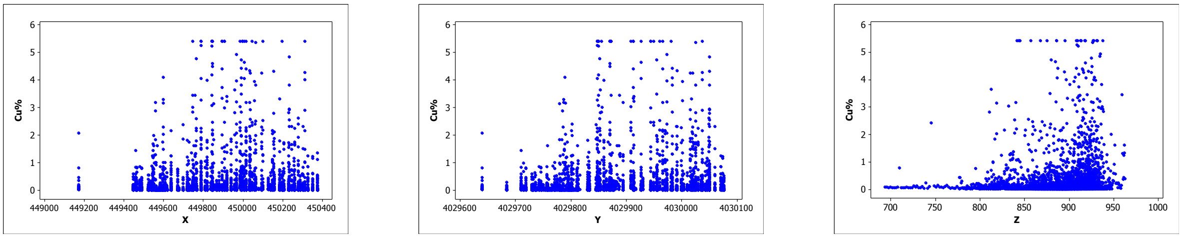

Figure3 - Cross-plots of the data against longitude, latitude and altitude

The term compositing is a procedure leading to a same sample support. In all reserve estimation process, dealing with samples provided by boreholes with different length is absolutely out of question. Therefore, it is important to make all samples with same length. Of course there are other challenges negatively or positively influenced on this process which should be carefully considered. For example, combination between ore and waste samples which trickily increase or decrease grades or combination between grades within different lithology types are among the most critical challenges which really deserve an article to be fully considered. As the purpose of this article is to focus on classification, we only shed light on this issue and we will focus on this procedure in another article. Sample lengths in this mine vary from 0.10m to 2m. Figure 4 shows a histogram depicting the distribution of sample lengths.

For geological modeling, the samples must have the same length, or rather, be on the same support, to make physical or statistical distances the only variable affecting the weights assigned to each sample. Although the maximum number of length equals to 1, the interval of 2 has been considered as a composite length size due to a limitation of exploitation machinery. Other factors which are important in picking up an appropriate composite length include the close value of mean and variance between the actual and composite data. Also, the total length of borehole which is inevitably ignored in the process of compositing (lost length) plays a deciding rule on the composite length. This challenges usually happens (a) at the end of each borehole (b) at the depth which lithology or alteration or zone changes.

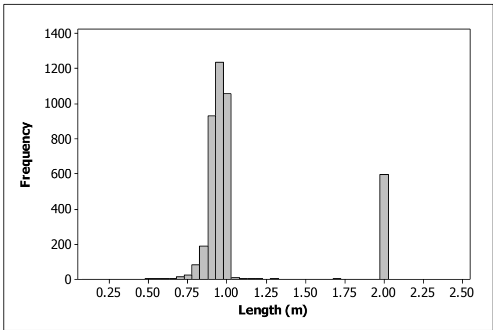

Figure4 - Histogram of interval lengths of samples

As is mentioned before, the most important step in geostatistical processes is modeling spatial dependency, variogram modeling. To attain a reasonable model of 3D spatial variability, 30 or so directional sample variogram have to be examined in most cases. These variograms should be in different directions. In this case study, a total of 144 variograms were calculated by increment angle of 10 for dip angle from 0° to 90° and the azimuth angle from 0° to 360°, with increment of 10°.

The experimental variograms and fitted theoretical models on three perpendicular directions are recognized and presented in Figure 5. It seems that all of the variograms level off at a variogram value of 0.627 namely the variance of the samples, but varying with different ranges showing a geometric anisotropy.

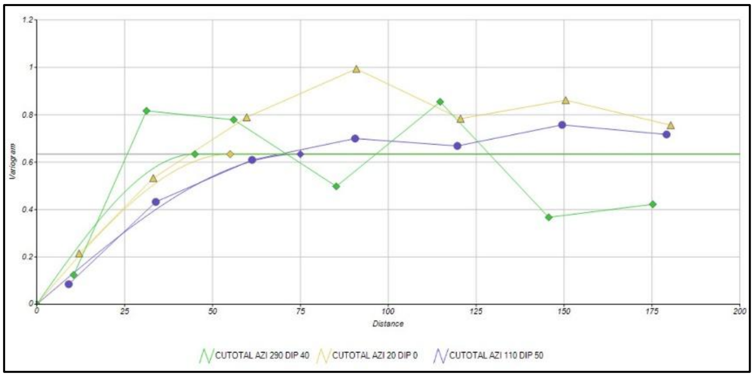

Figure5 - Three perpendicular experimental variograms and fitted theoretical models

Table 3 is containing the variogram model parameters.

Table3 - Variogram model parameters

VANGLE1	VANGLE2	VANGLE3	NUGGET	RANGE1	RANGE2	RANGE3	SILL
200	-40	180	0	45	55	75	0.634

An important issue in variography process is to define an area which limited to ore dataset as much as possible. By limiting the estimation domain to a wireframe where the probability of ore variable is as high as possible, not only does the variography can better highlight the spatial regression in the domain but also the ore reserve estimation process can be carried out with less dilution. Figure 6 shows the wireframe fitted to the ore dataset in the boreholes in Madan Bozorg. As seen some samples which have a grade more than 0.1% are also ignored to take in to the wireframe to counteract with the problem of smoothing effect.

Based on this wireframe, the variography and estimation will no longer have the permission to get any data from outside the domain.

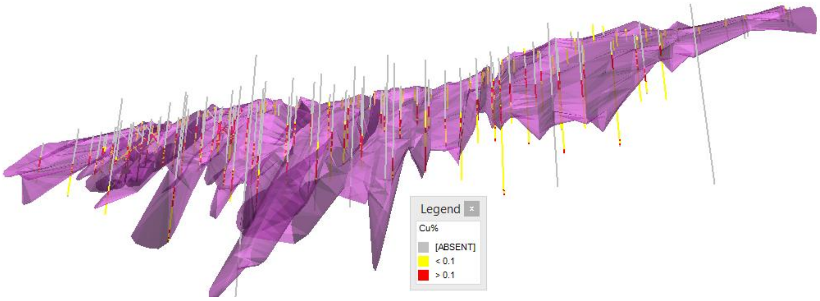

Figure6 - The wireframe domain prepared to restrict the variography and estimation process

Based on the variogram parameters, a geostatistical method, ordinary kriging, has been performed. There have been always different debates about the most appropriate estimation method which should be used to achieve the best results. As this paper focuses on the challenges of pre and post estimation, it has not gone in to detail about the estimation process. No matter what the estimation process is, it is essential to validate the model. Visual validation is one of the process used for ore model validation. Visual validation is a process of checking the block model with the boreholes in some vertical sections. Based on this process, the block model should show almost similar value to the value of boreholes in the same location (Figure7).

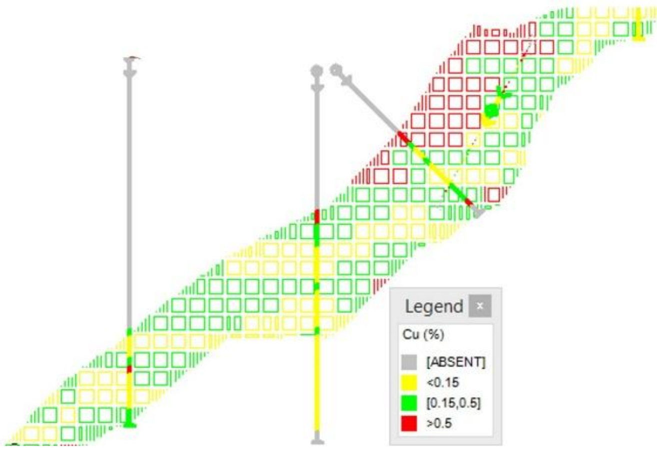

Figure7 - Visual validation in a vertical section

RESULTS AND DISCUSSION

Under the assumptions which the variogram is valid and the regression is linear, it is possible to calculate the main parameters of the regression between estimated and true block grades. Also, the actual scatter plot cannot be plotted as the individual true block grades are not known! An expression for the regression slope determined for each block is estimated as follows (Pan, 1998):

$$a = \frac{(\sigma^2{}_V - \sigma^2{}_K + \mu)}{(\sigma^2{}_V - \sigma^2{}_K + 2\mu)} \tag{1}$$

Where

a is the regression slope

$\sigma^2{}_V$ is the block variance

σ_K^2 is kriging variance

μ is the absolute value of the Lagrange multiplier for each parent cell.

The (sample variance – within block variance) term is what we known as the block variance of all block values. Within block variance is defined as the variance of point data within a block of a certain dimension. It can be calculated by taking the average value of the variogram between all points inside the block. Most geostatistics software packages can easily perform this calculation known as FVALUE. It also can be obtained from standard diagrams known as F-Function which can be found in classic geostatistics textbooks.

Ideally, the slope of the regression a should be very close to 1.0 and thus imply conditional unbiasedness. In these circumstances, the true grade of a set of blocks should be approximately equal to the grade predicted by the kriged estimation. The slope and its interpretation are discussed more fully by Krige (1994; 1996a) and Rivoirard (1987).

Quantifying uncertainties and statistical methods to classified ores (from fix standard to dynamic standard)

When using the regression slope approach, values of a could be arbitrarily selected to correspond to the measured, indicated and inferred classes by examining the probability density function of a for the estimated blocks (Mwasinga, 2001).

Fractal analysis is an important branch of nonlinear mathematical sciences widely applied in different fields of sciences since the 1980s. Though numerous scholars have used fractal analysis in order to separate background and anomaly in the geochemical processes; however, few researchers have paid significant attention on applying this method in field of Ore Resource Classification. Based on fractal analysis, a researcher working on a set of database can be able to separate classes according to the fractal dimension of each subset. In a nutshell, each point where the slope of a trend line fitted on (cumulative frequency (CF)-Variable) figure changes, it is considered as a class with different fractal dimension. As is shown in Figure 8, purple lines show the points which the fractal dimension of CFD changes. These lines coincide with SLP=0.44 and SLP=0.84. Based on this result SLP > 0.84, 0.44<SLP<0.84 and SLP<0.44 can present blocks which can be candidate to be considered as measured, indicated and inferred class, respectively. It should be noticed that it is one of the criteria utilized to determine measured classes and other criteria should be accounted in order to reduce the uncertainty of the estimation significantly.

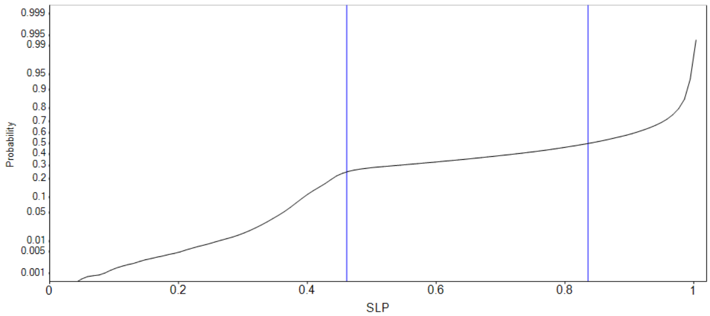

Figure8 - Cumulative frequency of the regression slope values in Madan Bozorg

Figure 9 shows the visual output of the block model that the regression slope value has been presented. As it is obvious, blocks which have been surrounded by actual dataset (borehole samples in this study) can be candidates for the measured class while other blocks which the borehole distribution has the less density show less SLP value. It is important to notice that this criterion is one of the issues used for classifying the ore in this article. Therefore, SLP value is considered as one of the criteria to account the uncertainty and classify the ore estimation. This parameter takes three geostatistical parameters (i.e. kriging variance, block variance and Lagrange coefficient) describing the accuracy of the estimation to determine the uncertainty more reliably. As is shown in Figure 9, SLP for the blocks in a vertical section presents the estimation uncertainty of each block. As the parameter gets close to 1 the uncertainty decrease and the estimation is more reliable. SLP shows low uncertainty (higher value) for the blocks surrounded by more boreholes. As the borehole density decreases, the SLP value decreases either.

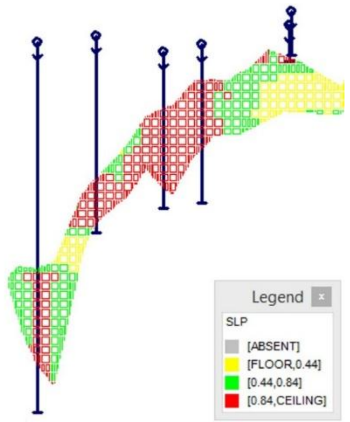

Figure9 - Distribution of regression slope in estimated block model

It should be noticed that the uncertainty can be evaluated more significantly, if other factors (summarized in Table 1 and 2) are taken in to account. One of the criteria taken into account, for instance, is the number of boreholes (NBH) taken part to estimate a block. The blocks which have been estimated by more boreholes may present the estimated grade with lower uncertainties. Also another parameter accounted as a tool to describe the uncertainty is Dynamic Search Volume (DSV). Search volume is an ellipsoid which its diameters and their angles are defined by the ranges of three perpendicular variogram (Figure 5). Based on the theory of DSV, the diameters can be enlarged by a factor for the blocks which have been given no estimation since there is no significant data to be used for the estimation of those blocks. Therefore, the blocks estimated by DSV number one (the ellipsoid without any enlargement factor) have been estimated with a lower uncertainty than those estimated by the DSV 2 and 3. Last but not least, it should be noticed that the uncertainty may decrease if all these criteria are taken to account simultaneously. In other words, applying only one criterion for quantifying uncertainty cannot lead to an accurate estimation.

Therefore, based on all the parameters describe above, we used the following criteria to define measured, indicated and inferred classes:

A block is considered as measured class if SLP >0.84 and NBHID>3 and DSV=1 and minimum number of data taken part in the estimation is 4 and also the minimum octant number which must be filled to classify the block as a measured is 3.

A block is considered as indicated class if 0.44<SLP <0.84 and NBHID>2 and DSV=1 or 2 and minimum number of data taken part in the estimation is 3 and also the minimum octant number which must be filled to classify the block as an indicated is 2.

Other blocks which have been estimated without taking the mentioned criteria in to account can be considered as inferred blocks.

Based on the above criteria provided above a code has been written to assess each block so that the blocks can be allocated as measured, indicted or inferred (Figure 10). As discussed and reviewed, it is not really useful to stick only to one standard and keep away from statistical processes utilized to determine the uncertainty more reliably. The methods and criteria described above are the tools which can help Grade Control unit of each mine to make more reliable block model.

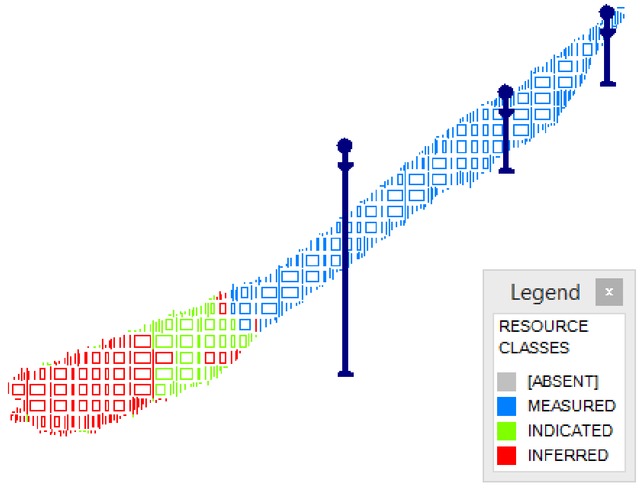

Figure10 - The outcome of the block model in a vertical section

CONCLUSION

The concept of applying different criteria to quantify the uncertainty of Ore Reserve Estimation has been discussed here. The uncertainty is used to allocate appropriate class (measured, indicated, or inferred) to each estimated block. This paper not only did take a look at the resource classification process, but also it provides some fundamental issues to reduce the uncertainty prior to the process of estimation.

Several different and important formulas to classify a resource have been reviewed in this study. This paper shows that the combination of the introduced criteria can give a better understanding of the block errors and risks playing a deciding factor in evaluating a block model which should be a model which can be approved for the exploitation process. Therefore, any criterion which may reduce the uncertainty would be really promising.

This paper also has opened a discussion if it is adequate to use a fixed standard to classify an ore model. Some statistical processes recognizing and determining different patterns have been discussed and it has been noticed that it is worth using statistical process and reviewing all the geostatistical parameters rather than using a fixed standard.

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PERSPECTIVES OF THE TEKELI ORE SITE

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ABSTRACT

Potential ore structure was identified in the Tekeli ore region by employees of LLP "Two Key" in cooperation with LLP "LATON-GEOSERVICE" and "Tien-Shan". The presence of geophysical, geochemical anomalies, as well as a number of other search preconditions and signs, corresponds to the R.Sillitoe concept and speaks of a high probability of a large copper-porphyry object in the Tekeli ore site.

Also, the spatial relationship of copper-porphyry deposits within the Pribalkhash-Ili edge volcanic belt such as Aktogay, Kounrad, Koksay, indicates the prospect of discovering the deposit.

KEYWORDS

Tekeli Mining Region, geophysical and geochemical anomalies, electrical prospecting, geophysical studies, geological mapping, secondary quartzites

Based on the "Geological characteristics of Birinshi gold-silver-polymetallic deposit and the ore mine of the same name" report (August 2017), according to the results of drilling and field works conducted in the Tekeli Mining District in 2016-2017, "Two Key" and "Laton-geoservice" companies laid geophysical profiles for the purpose of delineating the potential ore structure, the rationale of which was given in the above mentioned report.

These works were conducted under the leadership of "Two Key" LLP with the direct participation of "Laton-geoservice" and "Tien-Shan" companies.

The "Tien-Shan" company provided magnetic filming and electrical reconnaissance of the induced polarization in the modification of the dipole-dipole. Also, when carrying out electrical prospecting, the data of the electrical resistivity of the section were obtained. The depth of the method for even profiles Pr_02; Pr_04; Pr_06; Pr_08; Pr_10; Pr_12; Pr_14; Pr_16; Pr_18; Pr_20; Pr_22; Pr_24; Pr_26; Pr_28 was 350 meters, according to profiles Pr_05; Pr_07; Pr_27 - 700 meters. The distance between the profiles was 100 meters, but at the first stage of the odd profiles, it was decided to conduct geophysical surveys based on the results of interpretation and verification works.

In addition, topographic work was carried out on the profiles on which geophysical surveys were conducted, with the determination of the geographical and altitude coordinates of each picket, on which the measurement was carried out, as well as a litho-geochemical survey with a step of 40 meters and geological mapping.

Litho-geochemical filming is currently under processing. The geological mapping data is subjected to office studies.

Identified prospects

During the geological mapping, samples of secondary quartzites were selected, the photographs of which are shown in Fig. 1-3, which bear the signs of the porphyry system of the ore formation.

Fig. 1 secondary quartzites with ore mineralization

Fig. 2 secondary quartzites with ore mineralization

Fig. 3 secondary quartzites with ore mineralization

It should be noted that during geophysical studies, contrast anomalies were obtained for both induced polarization and resistance.

In combination with the field under investigation, it is possible to identify several types of potential objects that require verification by drilling operations, including:

Anomalous zones of increased polarizability, under conditions of reduced cut resistance and negative magnetic field;

Anomalous zones of increased polarizability under conditions of increased resistance and negative magnetic field;

Anomalous zones of increased polarizability, under conditions of reduced cut resistance and positive magnetic field;

Anomalous zones of increased polarizability, under conditions of increased cut resistance and a positive magnetic field.

The first type of objects can be attributed to the anomalous zones in the middle part of the Inverse geomagnetic-electric section of the polarizability %, the magnetic field nT, the electrical resistivity Om / M along the profile PR_28 at depths of about 300 meters and below, in the pickets area 97-122, 30-40; (Fig. 4).

After 100 meters to the east on the profile PR_27 on pickets 30 - 80, you can also trace the first type of anomalous zone at greater depths - about 600 meters and deeper. (Fig. 5).

On the PR_26 profile, this type of anomaly is not so prominent, but on the profile of the polarizability anomaly clearly gravitate toward a lower resistance (Fig. 6).

On the profile PR_22 also in the northern part, there is a similar type of anomalous zone (Fig. 7).

On the anomalous zone of the first type (Fig. 8), the middle part of the profile PR_16 (Fig. 9), the middle part of the profile PR_12 (Fig. 10) are fixed on the profile PR_18 in the middle part. The same type of anomalous zones are presented on the PR_10 profile.

All of the above anomalies, as a rule, are characterized by a vertically elongated structure, sometimes located at a slight angle to the vertical, and having a small spreading zone in width, usually within the first tens and up to hundreds of meters.

Taking into account the peculiarities of reflection of the field of induced polarization, rich low-grade veined ore bodies are predicted in these places, having a subvertical fall.

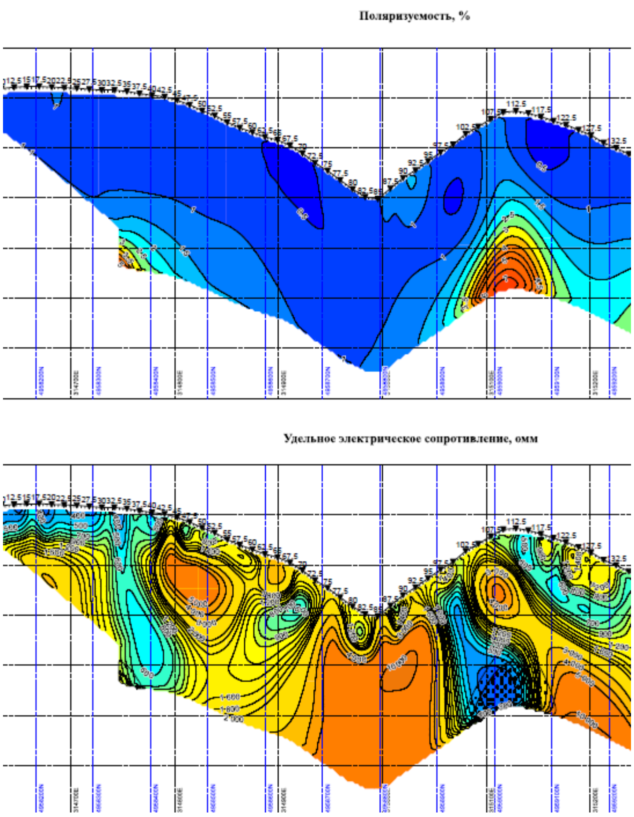

Fig. 4 inverse geoelectric section along profile 28

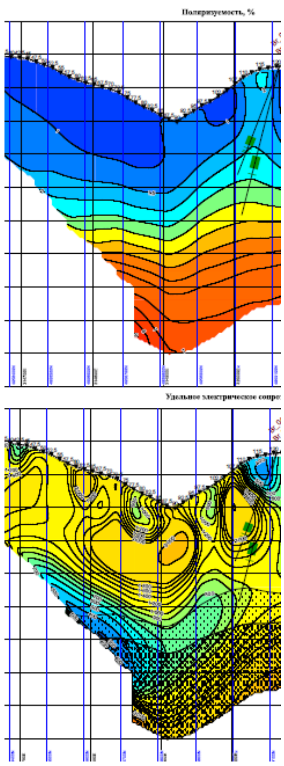

Fig. 5 inverse geoelectric section along profile 27

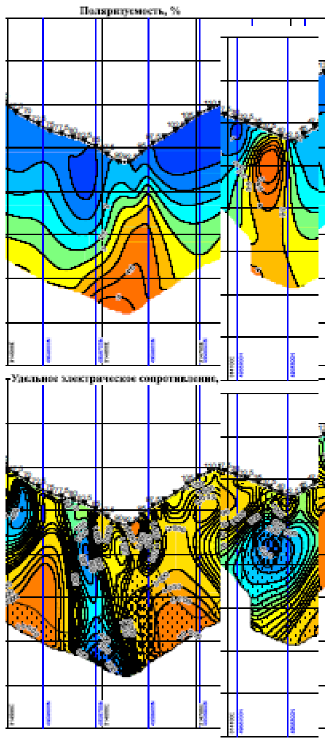

Fig. 6 inverse geoelectric section along profile 26

Fig. 7 inverse geoelectric section along profile 22

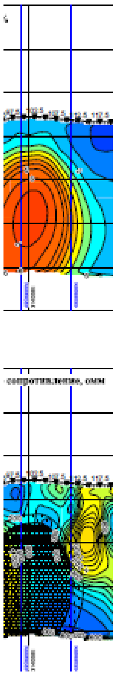

Fig. 8 inverse geoelectric section along profile 18

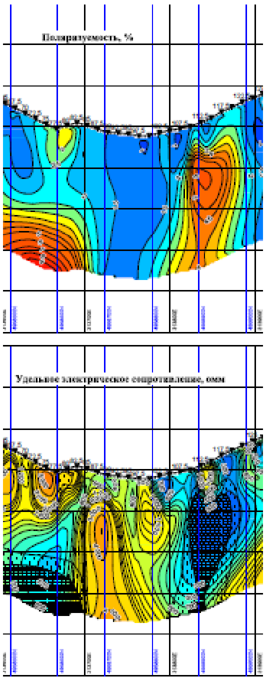

Fig. 9 inverse geoelectric section along profile 16

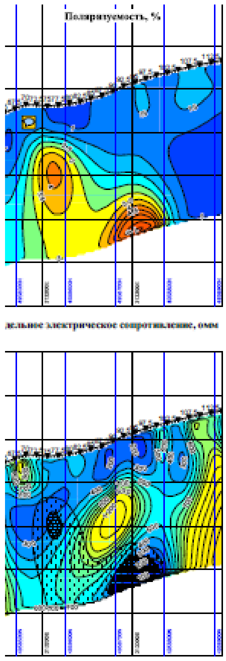

Fig. 10 inverse geoelectric section along profile 12

The second type of anomaly has, as a rule, a more extensive horizontal distribution. This type of anomaly is well traced in the PR_27 profile (Fig. 11), in the PR_08 profile (Fig. 13), in the PR_18 profile (Fig. 14), in the PR_20 profile (Fig. 15), in the PR_22 profile (Fig. 16).

This type of anomaly can characterize small-grained ores, sulfide ores with a much larger volume of distribution than the first type ore.

Here, ore bodies can be expected in a span up to the first hundreds to 800 meters in width, but with ores with a much smaller content of useful components than predicted by anomalous zones of the first type.

In this regard, the data obtained from the 27th profile is interesting, in the area of which similar work was carried out in 2008 with a depth of 200 meters, see the inverse geoelectric section along the 5_Br profile. Figure 11 and the results of drilling wells BR_02, BR_04 see Fig. 12.

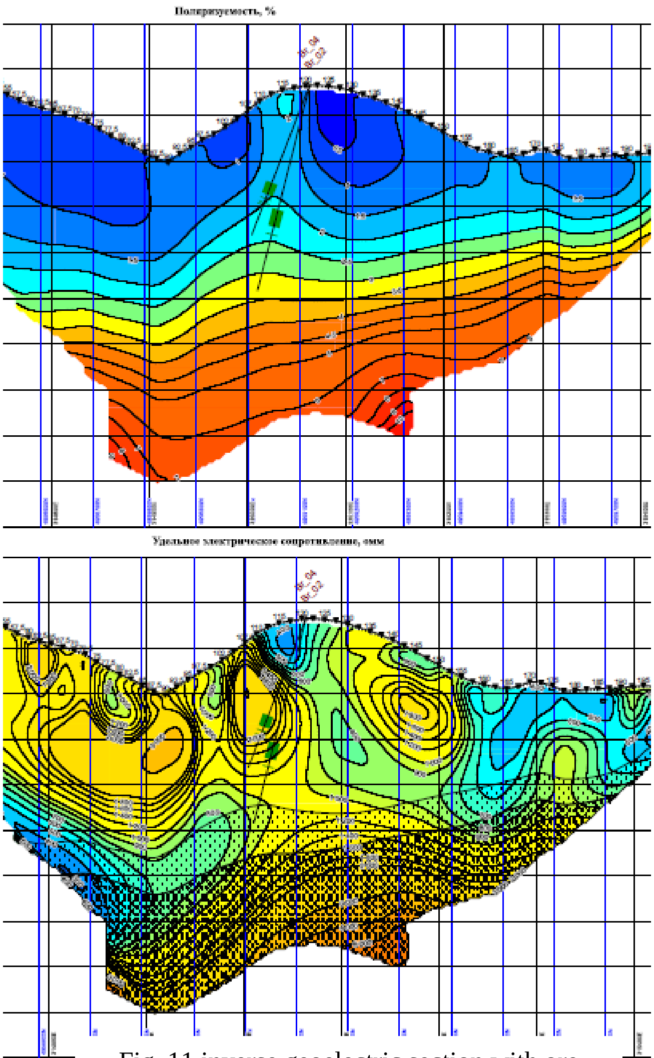

Fig. 11 inverse geoelectric section with ore intervals along the profile 27

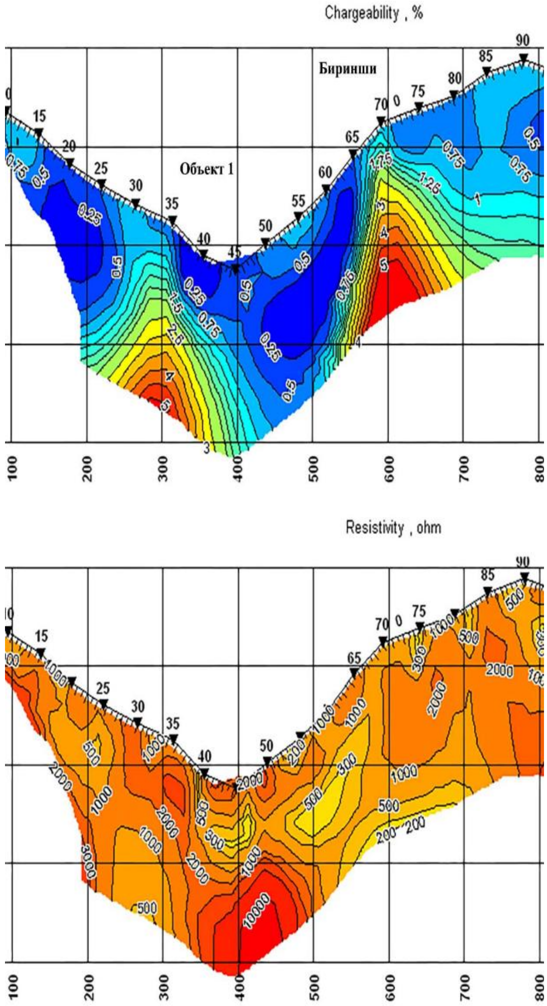

Fig. 12 inverse geoelectric section with ore intervals along the profile of 27 precursors

The results of drilling of BR_02, BR_04 wells (see Fig. 11), low-power, but rich, steeply dipping ore bodies of polymetallic ores with a silver content of up to 1800 g / t, copper to 16%, lead to 6%, zinc to 4% have been identified. At the same time, in geophysics with a depth of up to 200 meters these low-power, but rich bodies are reflected in the form of a volume polarization zone that spreads horizontally up to 100 meters and polarizability to 5%. When shooting at a depth of 700 meters with a loss of detail in the upper horizons, we have a small, slightly pronounced subvertical zone with a polarizability of only 1.5%, and having much less horizontal distribution. Also in this section, the contrasting polarizing zone of subhorizontal extension on the server starting from the low-resistance section is clearly visible and smoothly converting into the high-resistance section. Perhaps we are dealing with a source of ore mineralization of the upper horizons, but the wells laid and drilled in 2016-2017 did not reach the detected horizon, although downhole geophysics instruments also recorded an increased polarization field at the bottom of the BR_04 well.

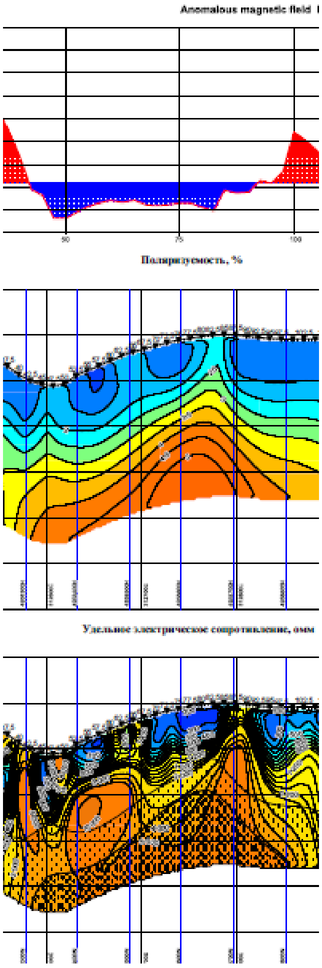

Fig. 13 inverse geoelectric section with ore intervals along the profile 8

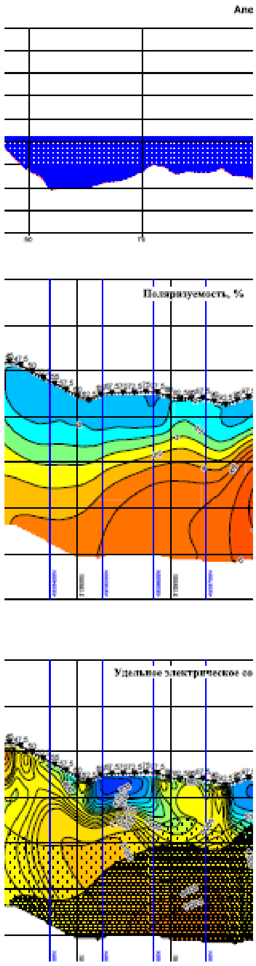

Fig. 14 inverse geoelectric section with ore intervals along the profile 18

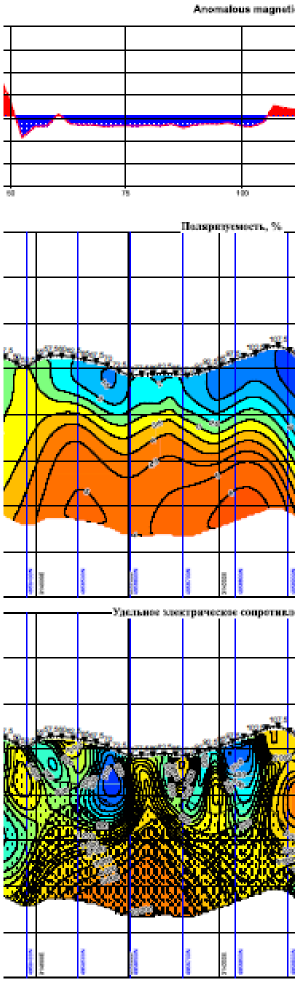

Fig. 15 inverse geoelectric section with ore intervals along the profile 20

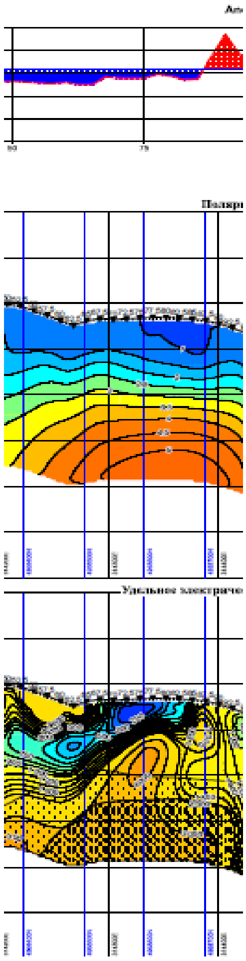

Fig. 16 inverse geoelectric section with ore intervals along profile 22

Anomalous zones of 3 and 4 types do not have a geological justification for the increased magnetic field yet, possibly after a completion of processing of geochemical data and data obtained during geological mapping, a clearer answer will be given to this question. The working version of the factor giving a positive magnetic background, a version of the presence of magnetic iron minerals is accepted.

The magnetic field at the site of work fixed the ring structure, which is also a favorable search sign, indirectly confirming the possible presence of large, ore-bearing porphyry type.

CONCLUSIONS

For the verification of geophysical anomalies of potential objects, search drilling will be performed in two stages:

1 turn – 5 wells (1800 lm), will be completed to verify geophysical anomalies, crossing of the proposed ore body. These wells will help establish the morphology of ore bodies, and the industrial genetic type of ore-bearing property.

2 turn – wells will be passed to clarify the geological structure.

GEOSTATISTICAL MODELLING OF GOLD GRADES BY CO-KRIGING-BASED APPROACH FOR PRESERVING THE OUTLYING VALUES

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ABSTRACT

Geostatistical modeling of Gold grade (Au) is challenging since the presence of outliers makes the distribution long-tailed and impacts significantly the process of mineral resource evaluation, the mine design and financial optimization. Capping is a widely used technique consisting of truncating the data to some top-cut grade. However, this procedure is likely to omit the most important part of a deposit that probably is economically considerable. In this research, a co-kriging-based approach is applied in a gold deposit to preserve the upper quantile of the Au distribution while improving the precision of the estimation. The rationale of this idea is to divide the grade of Au into: truncated grade, a weighted indicator above the top-cut grade and a zero-mean residual. After this decomposition, the co-kriging is able to jointly estimate the truncated grade and the indicator. The benefit of this approach is to provide unbiased grade estimation and choosing the optimum top-cut value while avoiding the outlying values for spatial continuity calculation and implementing the spatial prediction.

Keywords: Gold deposits, Co-kriging, Geostatistical modeling, Geostatistics , Open Pit Mine Design.

INTRODUCTION

Geostatistical modeling of geo-related attributes have been widely used in mining industry for mineral resource estimation and evaluation (Journel and Huijbregts, 1978; David, 1988; Krige, 1999). However, some variables showing the long-tailed distribution which makes the process of modeling challenging. In particular case, precious metals such as gold contain some extreme values that should be treated before any spatial continuity analysis and block modeling (Krige and Magri, 1982; Armstrong, 1984, Paravarzar et al. 2014). Ignoring those values make bias in the process of producing the block model and impact the economical consideration of a mining project. To tackle this issue, some methodologies proposed to reduce the influence of those extreme values (Journel and Arik, 1988; Parker, 1991; Arik, 1992; Costa, 2003; Machado et al., 2011, 2012). A straightforward method is to cap the high grades and reduce them to a certain value (Sinclair and Blackwell, 2002; Rossi and Deutsch, 2014). This technique is accepted in conventional international standards for reporting mineral resources and ore reserves (SAMREC, 2007; JORC, 2012). However, reset the high values ignore remarkable part of the dataset provided by bore holes or blast holes and is likely to advocate a bias in the block modeling (Maleki et al., 2014). Furthermore, there is no strong mathematical or geological concept behind detection of treating the extreme values (Sinclair and Blackwell, 2002). Rivoirard et al. (2013) proposed a methodology based on dividing the dataset into truncated, indicator and residual, for which the variogram analysis is more robust since the new variables do not keep high values. The estimation process is then based on co-kriging of truncated grade and indicator. The aim of this research is twofold: a) presentation the theory of capping and top-cut methodologies; b) resource estimation and quantification of recovery functions by two approaches and show the capability of decomposition approach (top-cut model) in comparison with capping through a real gold deposit.

METHODOLY

Capping

The high values in the long-tailed distribution are usually interpreted as outliers. Those values should be treated before estimation and mineral resource modeling in order to reduce their impact in the further analysis of a mining project. A convenient method termed capping is to detect the outlier value and then reduce other values higher than the defined outlier to the outlier itself. Choosing the optimum outlier value is somehow questionable. However, there are some statistical tools to investigate it (Rossi and Deutsch, 2014). Those tools are related to the global distributions (e.g. probability plot) which help to identify the extreme values (Parker, 1991). The procedure for capping is:

1- Choose an outlier value
2- Reset the high values higher than that outlier to the outlier itself
3- Variogram analysis of the capped variable and fit a theoretical variogram model
4- Implement simple or ordinary kriging based on the decision of stationary of the random function
5- Further analysis of the obtained block model for resource estimation

Top-cut model

Spatial interpolation of long-tailed distribution by combination of top-cut model and truncating the original variable was first introduced by Rivoirard et al. 2013. In this methodology, it is of interest to preserve the influence of high values by defining an equivalent measures identified by an indicator value. The steps are as follow:

1- Choose an optimal top-cut value.
2- Divide the original variable into truncated, indicator and residuals.
3- Variogram analysis of the new variables: in this case, direct and cross-variogram are required for measure the co-spatial continuity of truncated and indicator values. Linear model of coregionalization (Journel and Huijbregts, 1978) can be used to fit a positive semidefinitive condition in deriving the sill matrices. Since two variables in this research are considered, the three experimental direct and cross-variograms should be computed along the pre-specified anisotropy (Chiles and Delfiner, 2012; Wakernagel, 2003). For residuals, it is necessary only calculate the direct variogram.
4- Apply co-kriging for jointly deterministic modeling the truncated grade and the indicator. Use the kriging for separately estimation of the residual. Variance-covariance matrices in co-kriging and kriging systems are constructed on the basis of spatial continuity models so obtained from item 3. Simple or ordinary kriging can be used in both cases.
5- Back-transform the estimated values (truncated, indicator and residuals) in each block into the original variable (backward of item 2)
6- Further analysis of the back-transformed values for resource estimation

Therefore, the first method is dealing with only the block modeling based on capped values, while the top-cut model also considers the extreme values for estimation by defining an indicator value without loss of accuracy. In the following, it is of interest to compare these two methods through a gold deposit.

CASE STUDY

Presentation of the dataset

The dataset consists of 2544 samples composited in 1m length belonging to a gold deposit located in Australia. Location map of the samples and borehole locations can be seen in figure 1. The drilling pattern is regular with approximately 10 m spacing toward north. Statistical parameters calculated revealed that the gold grade shows a heavy-tailed distribution (Figure. 2; above). Consideration of high values indicates that they are not erroneous data and should not be discarded (Table 1). In this study, it is intended to apply above mentioned methodologies: capping and top-cup model for underlying gold grade estimation and compare the results for mineral resource estimation.

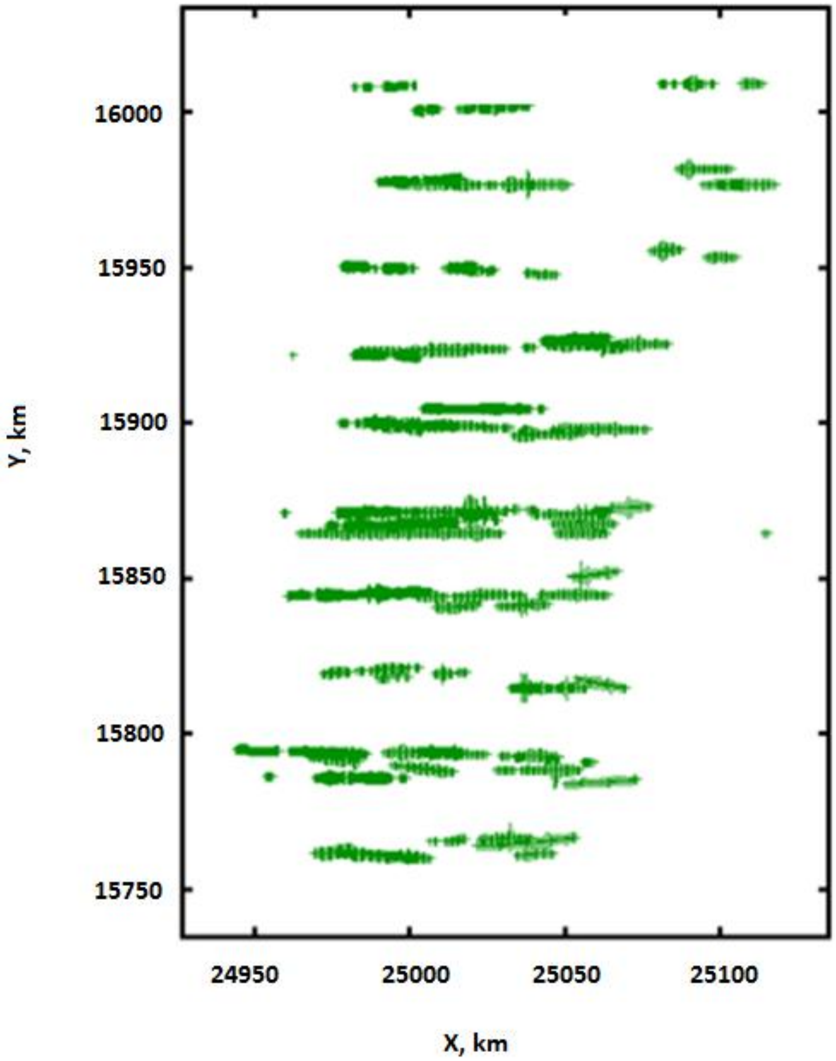


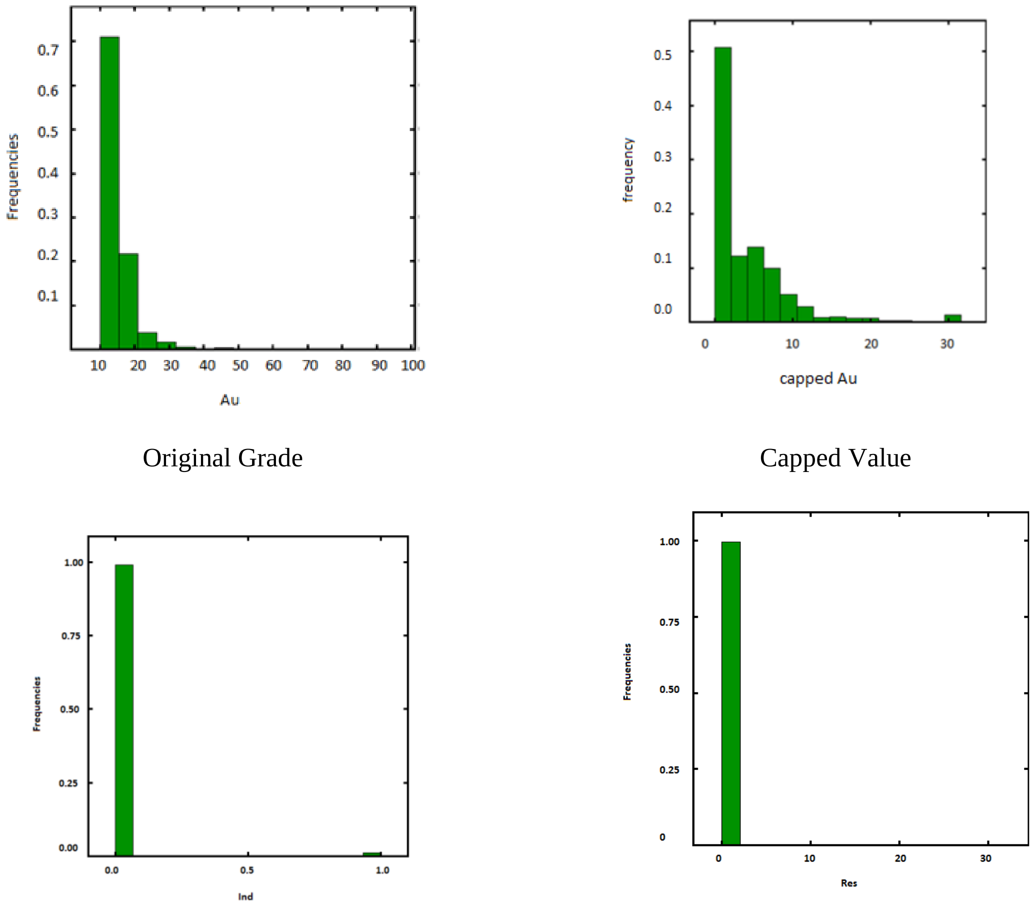
Figure 1 - Location map of the borehole data, green crosses are the sample locations

Table 1: statistical parameter calculated over the original gold grade

Variable	Mean	St. Deviation	Variance
Original grade	4.16	6.98	48.78

Choosing the outlier value

There are some techniques to detect the suitable outlier value required for both capping and top-cut model. Maleki et al. 2014 following Rivoirard et al. 2013 proposed to choose alternative thresholds as the candidate outlier values and compute the ratios between the indicator direct and cross-variograms alongside with successive thresholds. The first threshold that its ratio is approximately constant shows the minimal acceptance value for choosing the top-cut and capping value. However, in this research, for the sake of simplicity, the threshold “30” for gold is defined according to visual inspection of histogram (figure 1). The dataset is ready to be capped and truncated following above methods. Figure (2) shows the histogram of gold capped variable and furthermore the truncated values therewith the indicator and residual.



Original Grade

Capped Value

Indicator

Residual

Figure 2 - Histogram of treated values after indicating the outlier value associated with indicator and residual

Variogram modeling

The direct variogram for capped and residuals, direct and cross-variograms of truncated values and indicators are computed. The proper linear model of coregionalization is fitted with three spherical structures and nugget effect. The continuity is considered to be onmi-directional and isotopic (Figure 3).

Variogram formula for truncated and residual values, accordingly:

Truncated gold values:

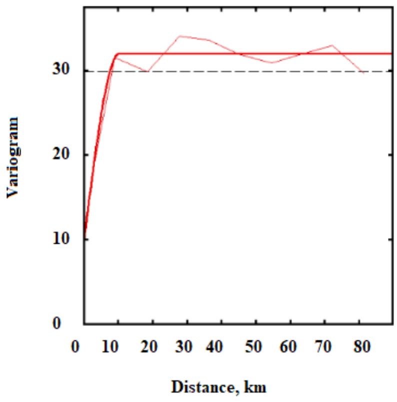
$$\gamma(h)=5.11\,Nugget + 25.39\,Sph\,(7.4m, 7.4m, 7.4m) + 1.542\,Sph\,(29.6m, 29.6m, 29.6m) \quad (1)$$

Residual values:

$$\gamma(h)=0.874\,Nugget + 0.614\,Sph\,(7.4m, 7.4m, 7.4m) \quad (2)$$

Cross variogram of truncated and indicator values:

$$\begin{pmatrix} \gamma_{Au\ trunc} & \gamma_{Au\ trunc-Ind} \\ \gamma_{Ind-Au\ trunc} & \gamma_{Ind} \end{pmatrix} = \\ = \begin{pmatrix} 9.6640 & 0.1378 \\ 0.1378 & 0.0067 \end{pmatrix} nugget \\ + \begin{pmatrix} 22.32 & 0.2452 \\ 0.2452 & 0.0071 \end{pmatrix} Sph(10.28km, 10.28km, 10.28\ km) \quad (3)$$



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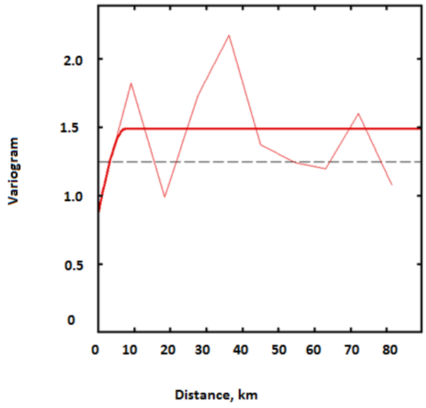

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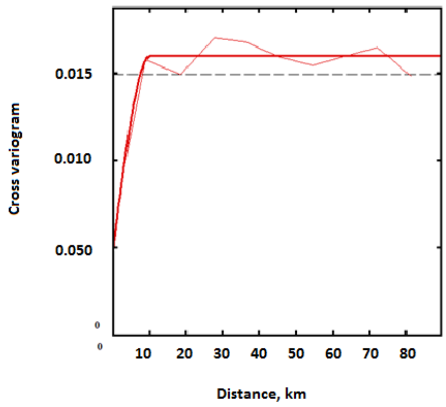


c

Figure 3 – a) Direct variogram of the truncated values; b) direct variogram of the residual values; c) cross variogram ot the estimated truncated value

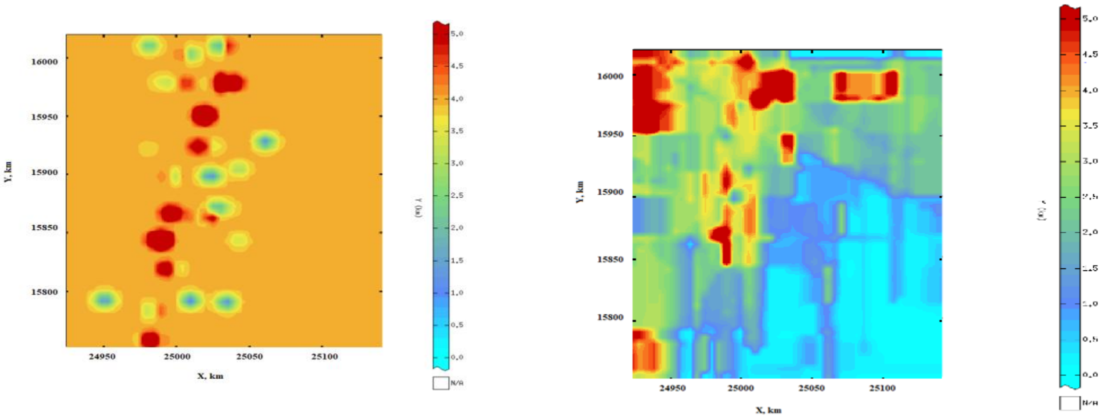
Spatial modeling

According to the previous models of spatial continuity so obtained, estimation of gold grade by two methodologies are implemented and compared:

1- Kriging: simple kriging has been applied for estimation of capped values and residual (capped method)

2- Co-kriging: simple cokriging has been applied for co-estimation of truncated value and indicator (top-cut model)

In both case, moving neighborhood is considered to select a part of sample location for estimation and co-estimation. In this method, the neighborhood surrounding the block is divided into sub-sectors and from each part, the pre-identified number of conditioning data are taken into account for (co)-estimating that block. This neighborhood is then moved from one block to another block in order to cover all region (Chiles and Delfiner, 2012). To do so, the search ellipsoid is selected as 800 m, higher than range of variogram; the number of participating points for estimation is minimum 4 and maximum 8 per sector. After co-kriging of truncated values and residual, it is necessary to back-transform the estimated values to the original space. Figure 4 shows the map obtained from two approaches. Top-cut model better reproduces the variability of high values while the capping is failed to estimate the reliable variability of gold grade.



a) Capping method b) Top-cut model

Figure 4: the estimation maps obtained from two methodologies; the high grade values are more distributed reasonably by top-cut model

The differences between the two approaches can be assessed globally, by calculating the mean grade above cut-off (Table 2 and Figure 5). It is seen that, for all the cut-offs, the traditional approach (kriging of capped grades) yields biased estimates in higher cut-offs while in lower cut-offs, this difference is not very distinguishable in comparison with the top-cut model.

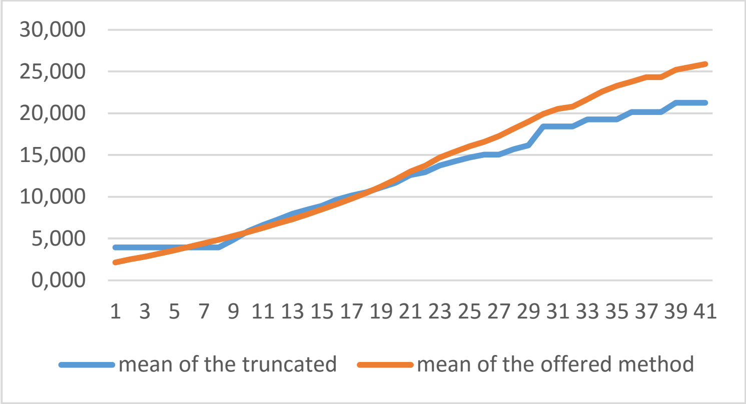


Figure 5 - The mean grade above cut-off

Table 2 - Statistical visualization of mean grade above cut-offs

Cut-off (g/T)	Mean grade above cut-off (g/t)	
	Truncated gold	According to the approached method
0.0	3.934	2.128
0.5	3.934	2.532
1.0	3.934	2.839
1.5	3.936	3.206
2.0	3.938	3.597
2.5	3.941	4.013
5	6.609	6.296
7.5	9.665	9.095
10	12.594	13.033
15	18.410	20.512
20	21.260	25.881

CONCLUSIONS

Geostatistical estimation methodologies are very applicable for reliable resource estimation and ore reserve evaluation based on international standards. The input data for such a spatial modeling obtained from exploratory drillholes. Presence of high values make the statistical analysis of the underlying grade non-robust and advocates one to use treating methodology to alleviate the influence of those values. In this study, two common and widespread used methodologies based on capping and truncation of high values are employed for resource modeling in a gold deposit with heavy-tail distribution. Comparison of results show that since top-cut model preserve the influence of high values in the dataset by contribution of indicator data, it is more reliable comparing to capping that only reduces the high values to a certain threshold and omit the extreme values.

ACKNOWLEDGEMENT

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RESERVE ESTIMATION COMPLICATIONS IN A HETEROGENOUS IRON ORE BODY AND ITS MITIGATION-A CASE STUDY

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ABSTRACT

Mineral deposits are nature given and can be excavated from the location where they occur only, they cannot be moved to a location that is convenient for resource planners. Once a deposit is found, it can be developed over time into a mining Project. Computation of reserves is recognized by the mineral industry as a distinct operation of increasing importance in the evaluation of mineral deposits in all stages of their development. Mine planning process starts from the geological model of the deposit and computation of the ultimate pit limit as a first step in open pit optimization. The special focus of this paper is estimation of reserve for large iron ore operations which is a complex and time-consuming process and study of practical problem associated with the re-estimation process. Often the volume of data and the large range of different conditions make the process complicated. The implementation of a dedicated re-estimation system requires a number of existing practices to be changed, Data sources are to be clarified and validated, terminology has to be standardized, processes needed to be documented and some methodologies needed to be updated. This is a task that requires significant effort by mine planning personnel so that the system could be successfully implemented.

An attempt has been made in this paper to highlight two common problems that arise during the process of reserve estimation and the solution to it. To accomplish these objectives field studies and field data acquisition were conducted at Deposit-A, an open pit iron ore mines of NMDC Ltd. India.

Key Words: Author, Mineral Deposit, Evaluation, Estimation, Mine Planning Process, NMDC Ltd.

1.0 INTRODUCTION AND OBJECTIVE

India is an important producer of iron ore in the world contributing more than 5% of the production and ranking fourth in terms of quantity produced following Australia, Brazil and China. Hematite and magnetite are the most important iron ores in India. About 59% hematite ore deposits are found in the Eastern Sector. About 92% magnetite ore deposits occur in Southern Sector, especially in Karnataka. Of these, hematite is considered to be superior because of its higher grade. Indian deposits of hematite belong to the Precambrian Iron Ore Series and the ore is within banded iron ore formations occurring as massive, laminated, friable and also in powdery form. As per UNFC system, the total resources of hematite as on 1.4.2010 are estimated at 17,882 million tonnes of which 8,093 million tonnes (45%) are under 'reserves' category and the balance 9,789 million tonnes (55%) are under 'remaining resources' category. Major resources of hematite are located in Odisha - 5,930 million tonnes (33%), Jharkhand - 4,597 million tonnes (26%), Chhattisgarh - 3,292 million tonnes (18%), Karnataka - 2,159 million tonnes (12%) and Goa - 927 million tonnes (5%). The balance resources of hematite are spread in Andhra Pradesh, Assam, Bihar, Madhya Pradesh , Maharashtra, Meghalaya, Rajasthan and Uttar Pradesh . Magnetite is another principal iron ore that also occurs in the form of oxide, either in igneous or metamorphosed banded magnetite-silica formation, possibly of sedimentary origin. As per UNFC system, the total resources of magnetite as on 1.4. 2010 are estimated at 10,644 million tonnes of which 'reserves' constitute a mere 22 million tonnes while 10,622 million tonnes are placed under 'remaining resources'.

The production of iron and steel has significantly expanded in recent years, particularly in developing country like India. The New Steel Policy 2017, by Ministry of Steel Government of India, projects crude steel capacity of 300 million tones (MT), and a robust finished steel per capita consumption of 158 Kgs by 2030 - 31, as against the current consumption of 61 Kg. To achieve this target, availability of raw materials at competitive rates is imperative for the growth of the steel industry and accordingly the indigenous demand of Iron Ore is going to increase from 160 MTPA to 437 MTPA by 2030-31.

Keeping in view the above target and in present competitive scenario, enhancing the performances and cost competitiveness of mining industry becomes an essence for survival and sustenance. The survival of mining industry lies in production and productivity and evaluating the performance regularly. Mining industry emphasizes on the best possible utilization of its resources to increase the productivity (Behera and Chakravarthi, 2006). Opencast mine production scheduling deals with the quest for most economic mining sequence over the life of a mine to ensure uniform grade and targeted tonnage based on the plant requirements so that the life of the mine and net present value are maximized.

The process of development of the mine is highly adaptive in as much as fairly complete plans are made before any mining commences, but these plans will require adjustment in response to steadily increasing information of the ore body, unforeseen technical problems and changes in the financial and economic conditions under which the mine is planned and subsequently operated. Central to the planning process is a block model of the prospect, comprising probabilistic data as to the prospect's composition. The block model is refined as the project develops; enabling partially informed decisions whose outcomes further enhance the block model.

In literature namely "Computing reserves of mineral deposits: principles and conventional methods", Popoff (1966) has stated that reserves is recognized by the mineral industry as a distinct operation of increasing importance in the evaluation of mineral deposits in all stages of their development. Previously, valuation was based on facts, experience, and intuition; methods have improved because our knowledge of mineral deposits, sampling, and mining techniques has increased. Advances in earth sciences and engineering resulted in the modification of old and introduction of new methods.

The purpose of reserve computations of a mineral body is to determine the quantity, the quality, and the amenability to commercial exploitation of raw material (ore, rock, coal, etc.). Computations are made during all stages of the life of a mining enterprise from discovery to closing. These are the most responsible and irreplaceable tasks in the valuation of a mineral deposit. Efficiency in extraction and productiveness is impossible without accurate reserve computations. Reserves are computed to determine the extent of exploration and development; distribution of values; annual output; probable and possible productive life of the mine; method of extraction and plant design; improvements in extraction, treatment, and processing; and requirements for capital, equipment, Labor, power, and materials.

Popoff (1966) further stated that for reserve computations of the mineral deposit, reduced and distorted by mapping, is converted to an analogous geometric body composed of one, several, or an aggregate of close-order solids, that best expresses the size, shape, and distribution of the variables. Construction of these blocks depends on the method selected. Some methods offer two or more manners of block construction, thus introducing subjectivity. In such a case a certain manner of construction is accepted as appropriate, preferably on the basis of geology, mining, and economics. Depending on the criteria used in substituting the explored bodies by auxiliary blocks and on the manner of computing averages for variables, the conventional methods may be classified into following four groups: -

- **Group1, average factors and area methods**, embraces analogous and geologic blocks methods. Areas are delineated by geologic and, in part, by mining and economic criteria, and the basic elements (thickness, grade, and weight factors) are determined directly, computed, or taken from other portions of the same or similar deposits.

- **Group 2, mining blocks method,** involves delineation of block areas by underground workings and by geologic and economic considerations; the factors for each block are computed in various ways. As the name implies the method is used mainly for extraction.
- **Group 3, cross-section methods,** includes standard, linear, and isolines. The mineral body is delineated and the blocks are constructed on the basis of certain principles of interpretation of exploration data; the parameters of blocks and the entire body are determined in various ways.
- **Group 4, analytical methods**, divides the mineral body graphically into blocks of simple geometric forms triangular or polygonal prisms. The factors for each block are determined directly, computed as an arithmetic average, or in other ways.

Castañón, Arias , Diego , Martin-Izard and Ruiz (2017) in their study narrated that once the geological, geochemical, and structural information of a mineral deposit are known, it must be represented in 3D in order to obtain sufficiently accurate estimates of its mineralogical content, which will lead to the estimation of both mineral resources and mineral reserves, as is explained in international standards such as those from the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) . According to CIM standards, a Mineral Reserve is the economically mineable part of a Measured or Indicated Mineral Resource demonstrated by at least a Preliminary Feasibility Study. Resource estimation study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified. A Mineral Reserve includes diluting materials and allowances for losses that may occur when the material is mined.

Despite the existence of several resource estimation methodologies, from traditional to geostatistical ones that use the block model as a geometrical representation, in the particular case of tabular or seam-shaped deposits these methods do not allow a sufficiently accurate representation or interpolation. Hexahedral block models are widely used to simulate and classify resources. References shows a study of 120 recent NI 43-101 mineral deposit technical reports, where kriging was the most elaborate one, although used in only seven of the reports. Other more refined methods, such as the sequential indicator simulation (SIS, a pixel-based model) or indicator kriging, are mainly usable in reserve simulations. Implicit modeling is starting to be implemented in commercial simulation packages, e.g., Leapfrog Radial Basis Functions, Surpac Dynamic Shells Module or Minesight Implicit Modeler, but is recommended for use as an additional tool to provide initial and quick resource analysis, not as a complete replacement of block models. State-of-the-art software uses algorithms that sequentially divide each block into smaller blocks in order to follow the geological structures (sub-blocking), but this approach does not achieve the level of precision required and results in models with an extremely high number of blocks. Additionally, sub-blocking uses the composition of the samples surveyed, but does not make an interpolation using the intersections between the surveys and the mineral structure, considering a cutoff, or a minimal thickness, or even considering lateral dilution due to over-excavation.

Sinha (2014) in his study stated that the basic aims of estimation are to: measure performance of the operation against targets; confirm grade and tonnage estimation efficiency; ensure valuation of mineral assets is accurate; and provide key performance indicators in particular for grade control predictions.

1.1 Objective:

The main objective of the study is to uncover the main reserve estimation complications in a heterogenous iron ore body and its mitigation. The present paper tracks the stages of development of the block model and ore selection and sequencing, from exploration through to production, and in doing so examines the complex adaptive features that are likely to be encountere.

2.0 METHODOLOGY OF WORK

Keeping in view the objectives of the study a detailed study was undertaken for Deposit-A of NMDC Ltd. The Research methodology adopted is shown in Figure 1.0.

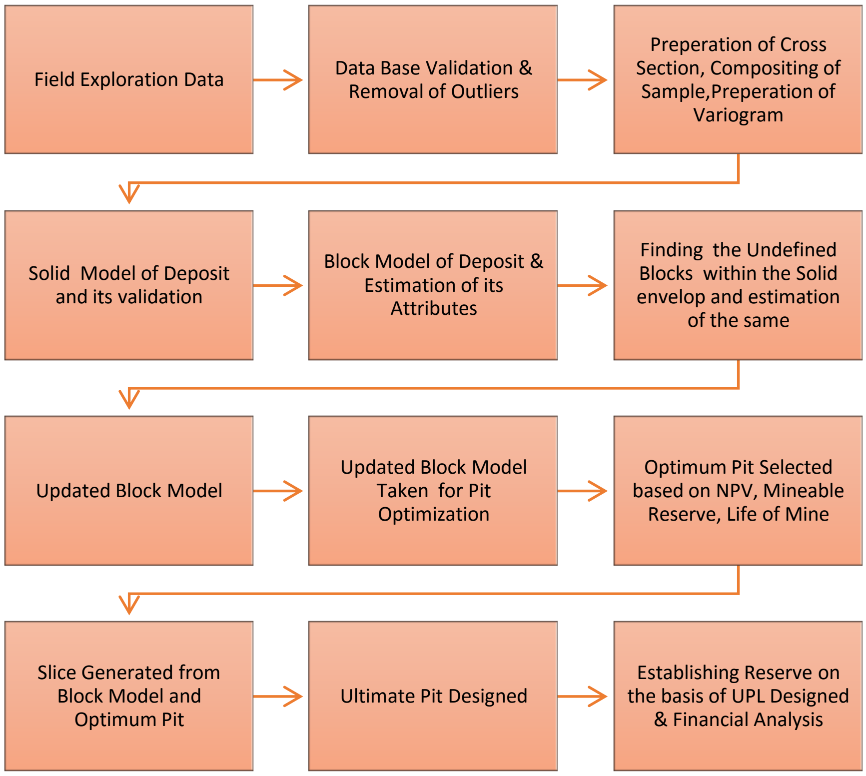

Fig.1.0: Research methodology

3.0 FIELD DETAILS

Deposit-A is on the eastern ridge of folded mountain range of Bailadila Chhattisgarh India. The deposit is bounded by Deposit- B to the north and Deposit C to the south. Towards the east, the deposit slopes steeply to Bacheli plain and to the west to Galli valley. The mineralization is mainly concentrated on the top of the hill range. The deposits are characterized by undulating ridges.

The ore body occurs as an elongated tabloid body 2600 m in length out of which about 1100 m forms the south block between cross section 9 and 16. The average width of the deposit is about 400-500 m and the maximum width of 860 m encountered is at cross section 14. The ore occurs from 1206 MSL to less than 960 MSL. The ore concentration is mostly towards the east of central axial line comprising out crops of massive, laminated lateritic ores. The ore body is underlain by flaky ore/blue dust at depth which in turn overlie transition zone and banded hematite quartzite's. The boundary of the ore body is limited by shale on western side and BHQ on the eastern side. Division of the deposit A has been made in to two blocks on the basis of geology and ore characteristics. The North Block is between CS1 and CS9 while South Block is between CS9 and CS16. Major mineral types of the ore body has been given in Table1.

Table 1.0: Major Mineral types (Litho Type) of the ore body

Ore Type (Litho Type)	Mineral Type Name	Density	Average Fe Content

1	Steel Grey Hematite (SGH)	4.3	67.01%
2	Blue Grey Hematite (BGH)	4.2	66.61%
3	Laminated Ore / Blue hematite (BH)	3.2	63.46%
4	Lateritic / Limonitic (Lat.)	3.1	57.33%
5	Blue Dust / Flaky Ore (BD)	3.0	66.54%
6	Shale (Sh.)	2.5	34.42%
7	Banded Hematite Quartzite (BHQ)	3.3	43.01%
8	Ore Transition Zone(TZ)	3.1	56.59%

Initial exploration was conducted by Geological Survey of India (GSI) in early 1960s. Subsequently Diamond Core (DC) drilling was carried out in 1960-62 by the Indian Bureau of Mines (IBM) with 23 drill holes (19 vertical and 4 angular) over a depth of 1427.25m on 150m x 150m grid. 70 shallow pits and 30 deep pits (1417.07m depth) and 2 adits (219.60m long) were made and a total of 1318 samples were collected and analyzed. Out of the 1318 samples, 612 were drawn from drill holes, 268 from deep pits, 20 from outcrops, 282 from adits and 56 from shallow pits and analyzed for Fe. 14 samples were run for complete chemical analysis consisting of 13 radicals. NMDC explored the deposit during 1978 with 3 vertical drill holes, covering a total length of 150.60m and collected 70 samples for chemical analysis. NMDC subsequently continue drilling with 63 vertical drill holes during 1991 to 1995 with a total length of 6540.35m and collected 3569 samples and analyzed them for Fe, SiO2, Al2O3 and LOI. One in 10 samples was analyzed for Phosphorous. Check samples were collected in the ratio of one in 10 samples and analyzed for Fe, SiO2, Al2O3 and LOI. During the same period, 9 vertical holes with total length of 389.25m were also drilled by NMDC to confirm the area for utilization of dynamic stockpiles. During 2004-05, NMDC drilled 92 vertical drill holes on a 75m x 75m grid with total length of 7712.55m and 5436 samples were analyzed.

Number of works like geological plan, contour plan, cross sections, and longitudinal sections were drawn manually on 1:2000 Scale to ascertain the ore persistence. The chemical analysis data was used for delineating the limits of the ore body envelope and various litho types within it. Slices were extracted at 12m vertical interval from the geological sections. In each slice plan, area of each ore type polygon was measured with Planimeter and its grade was computed from the 12 m composite sample data by simple arithmetic average of the samples data by simple arithmetic average of the samples falling in the domain. Polygon area of similar ore types were summed up separately to determine the area of each ore type in each slice plan and the average grade was estimated by weighted average method by weighting the grade with their respective areas. Tonnages were arrived at by multiplying the areas with slice interval and the ore type wise in-situ bulk density.

4.0 BLOCK MODELLING AND COMPLICATIOMS OBSERVED

A block model is a representation or an interpretation of a mineral deposit. The deposit could be any commodity. Prior to the 1970's many geologists and engineers would build 3D models of the ore body and mine workings to visualize or understand the deposit. The model would often be a set of Perspex cross-sections hanging in a wooden frame. Computers have given the power to build those models electronically, and view in 3D or in sections and plans. The models can be updated as new data becomes available and most importantly guide mine planning. Computer models produce volume and grade reports that reconcile production information and measure mining efficiency and performance. A software model is a numerical arrangement of data that can readily be displayed and used for volumes. The model values or attributes (called

'Q' for quality) are stored at the centroid of a block. The block has a location and size in XYZ space and the Q is stored is 3D space, hence the term 3D model. Further block model estimation involves detailed variogram analysis and selection of appropriate variogram parameters.

In 3D models, the wire frame shapes are filled with blocks and sub-blocks to represent the ore body. By selection of a reasonable block size, which trades accuracy and speed, the ore body can be well represented. These blocks are then filled as attribute values from the drill hole data and other required values can be estimated later for the calculation of input like partial percentage. These attributes could be Fe, Silica, Alumina or LOI.

In this ore body model, the ore body is divided into fixed-size blocks. The block dimensions are dependent on the geo-physical characteristics of the deposit and exploration database. Number of block models is designed for various block size and one best suited block model is selected after estimation and geostatistical analysis. After creating block model (parent or mother block), constrained block models are generated for each litho types using respective litho solid model.

As Solid models are generated for each Litho type separately, ***there is possibility of two complicated situations that arise while creating the block model: -***

1. ***Overlapping of areas by two or more litho type***
2. ***Identification of Gap Blocks***

4.1 Solution of Overlapping of Areas by Two or more Litho Type and formation of Constraints

First situations that arose was overlapping of areas by two or more ore types while making constraints for each litho type. To overcome this problem, priorities are set while generating constraint block model of each litho type. In Deposit-A, blue dust (Litho-5) having the maximum volume, has been given Priority-1. This mean that first of all, constrained block model of litho-5 is first generated from the mother block model. The least priorities have been given to Litho-6 & Litho-7 i.e waste blocks.

- **Constraints**

Using the priorities as discussed above, constraints are generated. A constraint is a logical combination of one or more spatial objects on selected blocks. Objects that may be used in constraints are plane surfaces, DTM's, solids, closed strings and block attribute values. Constraints may be saved to a file for rapid reuse and may themselves be used as components of other constraints. Fig. 2 to 8 illustrates the constraints of the block model according to litho type wise solid.

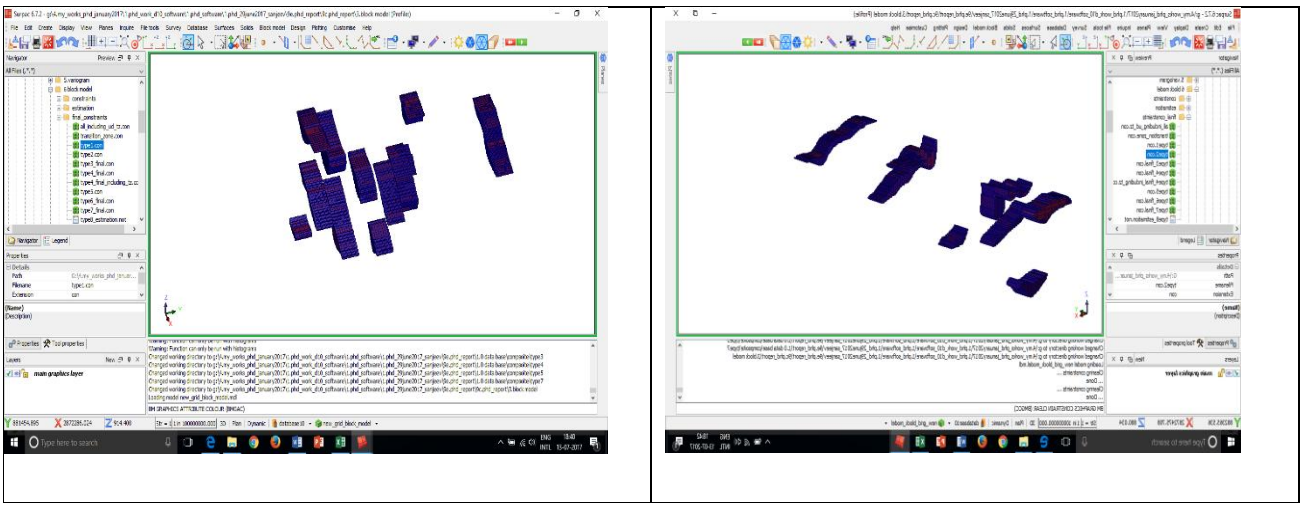

Fig. 2: Litho Type-1 Constraints

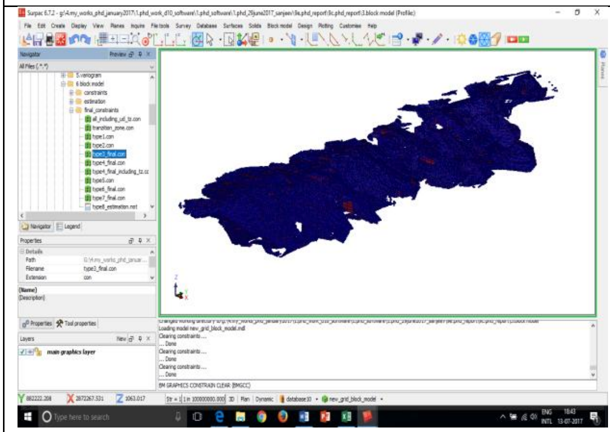

Fig.3: Litho Type-2 Constraints

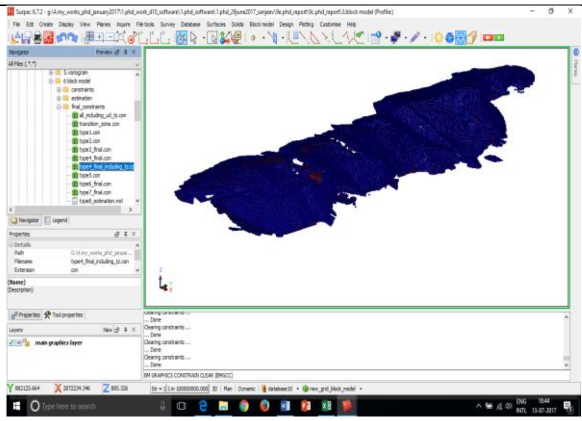

Fig. 4: Litho Type-3 Constraints

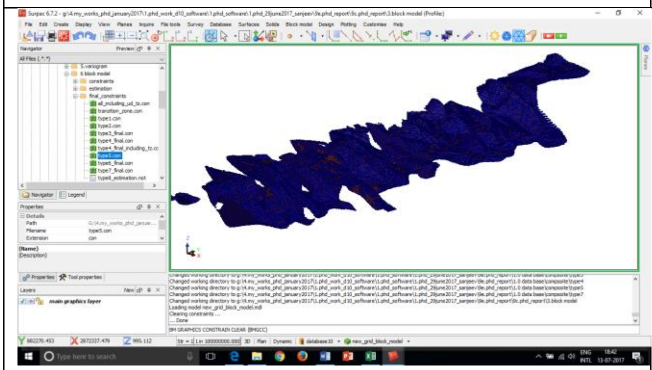

Fig. 5: Litho Type-4 Constraints

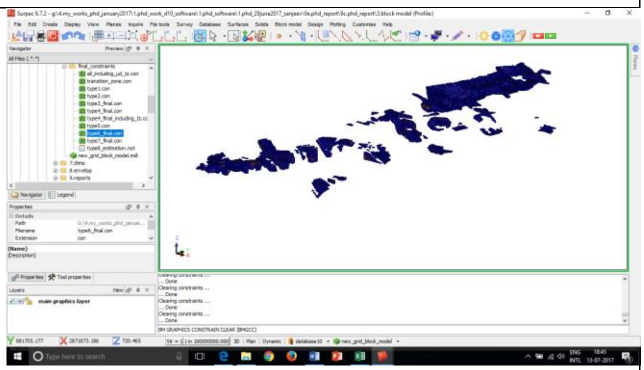

Fig.6: Litho Type-5 Constraints

Fig.7: Litho Type-6 Constraints

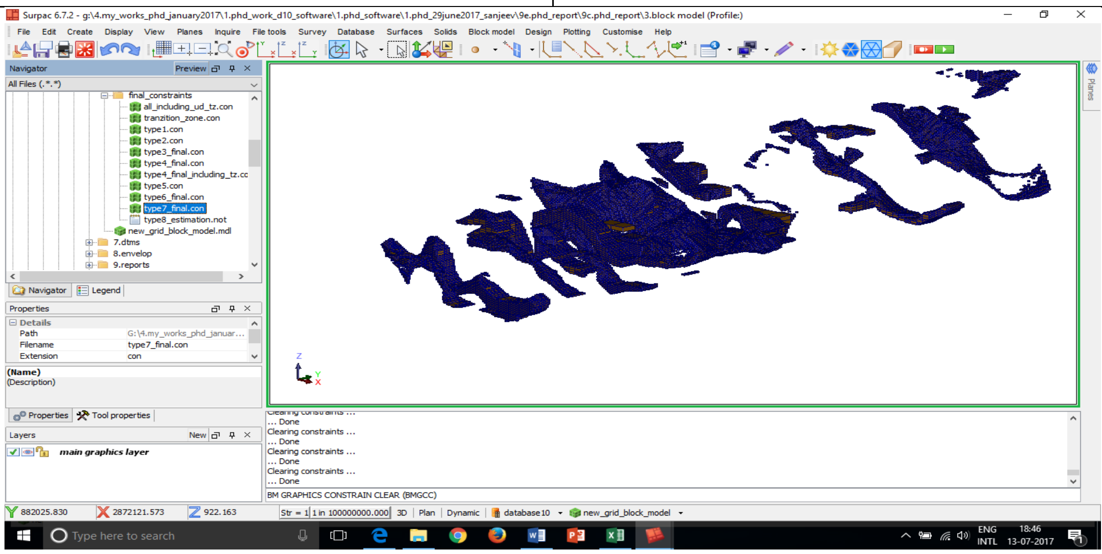

Fig. 8: Litho Type-7 Constraints

4.2 Solution to Gap Blocks

Second Situation that arose is the Gap Blocks, which are, blocks within envelop of the solid ore body but outside the solid model of all litho type combined. Several Gaps or undefined blocks within different litho-type and between the ore body & topography are observed. These gaps occurs because it is not possible to create sections containing different litho type, which can create solid without any gaps between different litho types. Such gaps block may be in the range of 8-12% of the estimated blocks.

Solution: The steps followed for identification of such gaps and further estimation of the same are as follows: -

- Step: 1:- The outer line of each of the sections (36 no.) are digitized to generate string, which is shown in Fig.9.

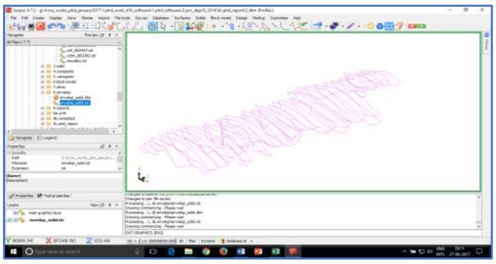

Fig. 9: Display of outer string of 36 No. of Sections

- Step: 2:- Using the same outer string of each of the section, an envelope is made which accommodates all blocks coming within the defined sections as well as gap blocks (Fig.10).

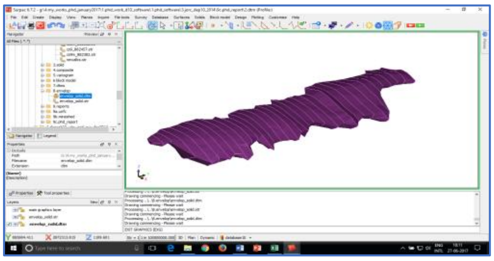

Fig. 10: Display of envelop or void created using outer string of 36 No. of Sections

- Step-3: Using the above envelop & the original constraints model of each litho type, gap blocks are identified by giving the logic of "Inside the envelop and outside the original constraints model of each litho type. The Gaps Blocks identified is shown in Fig.11.

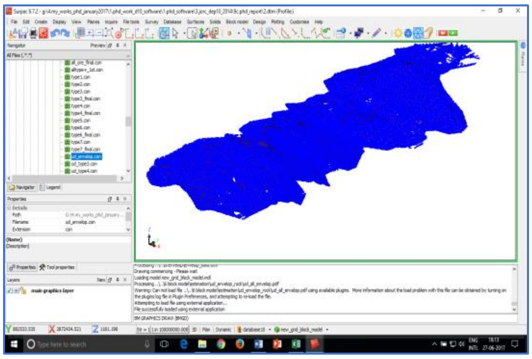

Fig. 11: Display of Gap Blocks identified

- Step: -4: The Gaps blocks are further estimated for grade of different radicals using nearest neighbor method of estimation. Determining the nearest neighbor includes a 3D search ellipsoid and maximum search distance to limit the blocks that are affected. The source of sample data for estimation is a string file.
- Step:-5: The estimated gaps blocks is further divided into waste and ore blocks by using a cut-off of Fe @ 45%. The waste blocks is further divided into Type 6 (Sh.) & Type 7(BHQ) blocks using a cut-off of Silica@10% i.e waste blocks having Silica more than 10% is considered as BHQ blocks and other are

considered as Shale blocks. These new BHQ & Shale blocks are further are added to the original BHQ & Shale blocks and the final constraints of the waste blocks is finalized.

- Step:-6 : Further the Gap Blocks having ore is divided into Type 2, Type3,Type 4 & Type 5 blocks using statistical analysis using average Fe% ,Alumina% & Silica% content as a basis of bifurcation.
- Step:-7: The additional different litho type established from the Gap block is added to the original litho type wise constraints and a new litho wise constraints is arrived at.
- Step-8: The final constraint of all litho type is finalized by adding the above new constraints and used for pit design and mine scheduling.

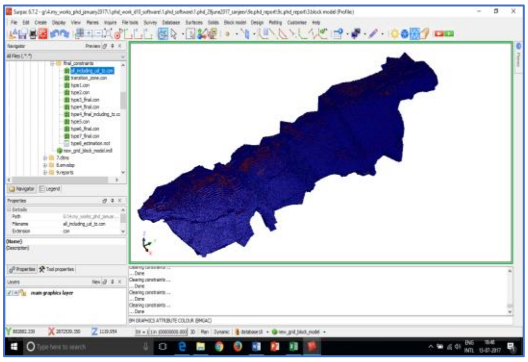

Fig.12: Display of final constraints of Litho Type

5.0 CONCLUSION

In this Study, first situations that arose was overlapping of areas by two or more ore types while making constraints for each litho type. To overcome this problem, priorities are set while generating constraint block model of each litho type. In Deposit-A, blue dust (Litho-5) having the maximum volume has been given Priority-1. This mean that first of all constrained block model of litho-5 is first generated from the mother block model. The least priorities have been given to Litho-6 & Litho-7 i.e waste blocks.

The second situation arose during ore reserve re-estimation process are the Gap Blocks, which were within the envelop of the solid ore body. These Gaps or undefined blocks exists between different litho-type and topography. These Gaps occurs because it is not possible to create sections containing different litho type, which can create solid without any gaps between different litho types. Theses blocks have been further estimated using the nearest neighbor method of estimation and further assigned as various litho type based upon the estimated grade value and the total quantity is found to be in the range of 8-12% of the original estimated blocks.

The complications observed during the process of re-estimation of the ore body and its mitigation discussed can be utilized judiciously however it is further suggested that effort shall be made to obtain as much data as possible from field so as to generate a true representative block model and reduce the possibility of occurrence of the undefined blocks to the maximum possible extent.

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PRECIOUS AND RARE METALS IN SOME COAL DEPOSITS OF KAZAKHSTAN

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SUMMARY

Complex processing of coal deposits at the present time is given considerable attention not only from the point of view of energy, but also from the position of the associated extraction of rare and precious metals.

The study of the composition of impurities in brown coal and the technology of their extraction has been devoted to a number of works in which the significant content of such noble and rare metals as: Au, Pt, Pd, Ag, and also Ge, Zr, Nb, W, Ta, Ti and other elements. However, an economically acceptable technology for their extraction has not yet been developed. In our work, the composition of brown coals of the deposits of Kazakhstan “Kulan”, “Shoptykol”, “Oy Karogay”, “Sarykum” was studied.

KEYWORDS

X - Ray fluorescence energy dispersive analysis, atomic emission analysis with direct injection of powder samples into the arc discharge, scintillation method, Compton scattering, USB microscope, atomic emission spectra, X - ray spectra, and temporal resolution.

INTRODUCTION

The issues of complex processing of mineral raw materials, including coal, are paid a lot of attention in terms of extracting useful components, both from the coal itself and during the processing of ash from its combustion. Problems associated with the integrated use of coals are described in many works [1-9]. In these studies, the results are presented for the elemental and mineral composition of coals and ashes from their burning mainly in various regions of the Russian Federation. Information is given on valuable elements - impurities and toxic elements - impurities in brown coals and ash from their combustion, prospects for their extraction. However, similar information on brown coal deposits in Kazakhstan is not enough. For this reason, the study of the composition and elements - impurities of brown coal in Kazakhstan and the prospects for their complex processing is an actual task.

EXPERIMENTAL PART

The composition of elements - impurities in brown coals of the following deposits in Kazakhstan was studied: “Shoptykol”, “Kulan”, “Oy-Karogay” and “Sarykum”. The X-ray radiometric spectrometer RLP 21 produced by Aspaz Geo LLP with CDD detector (Kazakhstan) and the Atomic Emission Complex Grand Potok, produced by OOO VMK Optoelectronics, was used in the research process in the Russian Federation. This equipment is included in the accreditation area of the analytical laboratory of Centre Consulting LLP, which is accredited in accordance with GOST ISO 17025 - 2009. The composition of surface inclusions was also studied on the X-ray microanalyser M4 Tornado by BRUKER with a locality of 0.3 mm. Photographs of the surface of the coals were made by a USB microscope with magnification of up to 200 and a resolution of 5mp. Samples for research were selected as point (ore) and core (point, furrow, sectional). Samples before measurements were rubbed up to 200 mesh. The worn out samples were spilled into special cuvettes and measured on a X-ray spectrometer RLP 21 without compression. Simultaneously, up to 9 samples were measured and up to 44 elements were determined in the concentration range from 0.0001% to 90%. Gold, platinum metals, and also light elements such as B, Be, Li, and F were determined at the Grand Potok complex with a fast MAES analyser (Multichannel analyser of atomic-emission spectra of the MAES) (Multichannel analyser of atomic-emission spectra of the MAES). The determination of gold and platinum metals at the Grand Potok complex with a fast MAES analyser (Multichannel analyser of atomic-emission spectra of the MAES) used the scintillation method - Scintillation atomic emission spectrometry (SESP) [10]. The method is based on the fact that a powder sample weighing up to 150 mg wakes up in an electric arc for 15 seconds. In this case, the intensity of flashes of gold particles on the 267.595 nm line is measured every 3 ms when they are burned in an arc discharge. As a result, the intensity distribution of the gold signal at the 267.595 nm line is recorded during the time the sample enters the arc discharge (13 s) with a discreteness (time resolution) of 3 ms. The total number of particles and their total intensity in standard samples are recorded. Based on the measured Au intensities in standard samples, the dependence of the signal intensity on the 267.595 nm line on the concentration is plotted. Based on these dependences, the Au content in the samples is determined. The method makes it possible to determine Au in coal samples with detection limits up to 0.007 g / t, Ag up to 0.03 g / t.

RESULTS AND ITS DISCUSSION

Gross analysis of the main elements in brown coals

Abraded samples of brown coal, standard samples of coal and ash were measured at the X-ray radiometric spectrometer 21 in the range of Al to U. The results are given in Table 1. For the analysis of single samples were collected from the middle layer containing the largest amount of carbon and the smallest amount of impurities by visual estimates and in accordance with procedures developed by the company “Consulting Centre” LLP, which is based on an analysis of the Compton scattering from the sample and allows to determine the carbon content and ash content of coal. The table gives the averaged data from different layers and different depths. It can be seen that the total content of impurities in different deposits varies from 7% to 30%. Larger iron and sulphur content in coal deposits of Oy Karogay (25.14% and 9.5%, respectively) indicates the presence of pyrite. However, according to Table 2 in coal deposits Oy Karogay, pyrite does not contain gold and silver 0.03 g / m. Coal deposits Kulan and Sarykum also do not contain gold and silver more than 0.03 g / t.

Table 1 - elements of an impurity in some coal deposits of Kazakhstan according to X-ray analysis (X-ray radiometric laboratory instrument 21)

Element	Coal deposit of Kulan,%	Coal deposit of Shoptykol%	Coal deposit of Sarykum%	Coal deposit of Oy Karogay%
Al	2.9	0.79	1.7	<0.2
Si	4.35	<0.06	2.0	<0.04
P	0,035	0.15	0,065	<0.01
S	1.7	1.29	5.86	9.5
K	<0.02	2.18	0.54	<0.02
Ca	0.73	1.62	1.9	0.83
Ti	0.76	<0.003	0.1	<0.005
V	0,017	0,024	<0.001	<0.002
Cr	<0.0007	<0.0008	<0.0007	<0.001
Mn	<0.0007	0.0031	0,015	<0.001
Fe	0.47	0,667	1.4	25.14
Co	0,006	0.0032	0,003	<0.0001
Ni	0.0018	<0.0003	<0.0003	0.0055
Cu	0.0072	0.0009	0.0016	0.0028
Zn	0,002	<0.0002	<0.0002	0,020
Ga	0.73	0.0006	0.0007	0.0008
Ge	<0.0002	<0.0002	<0.0002	<0.0005
As	<0.0001	<0.0001	0.0006	<0.0001
Se	<0.0001	<0.0001	<0.0001	<0.0001
Sc	0.02	0,031	0,008	0,025
Br	0.0014	0.0026	0.0023	0,031
Rb	<0.00007	0.00042	0.0003	<0.0001
Sr	0.0025	0.11	0.0056	0,024
Y	0.0013	0.00055	0.0007	<0.0001
Zr	0.0076	<0.0001	0.0022	0.0002
Nb	0.0003	<0.00001	0.00009	<0.0001
Mo	0.00054	0.00009	0.00017	0.0024
Pd	<0.00005	<0.00005	<0.00005	<0.0001
Ag	<0.00005	<0.00006	<0.00005	<0.0001
Cd	<0.00008	<0.00009	0.00022	<0.0001
Sn	<0.002	<0.002	0,043	0,025
Sb	<0.0009	<0.001	<0.001	<0.003
Ba	0,013	0,017	0,022	<0.01
Ta	0,018	0.0086	0,004	0.0064
W	<0.001	0,004	0,002	<0.001
Re	<0.0001	<0.0001	<0.0001	<0.0001
Hg	<0.0001	<0.0004	<0.0004	<0.0009
Pb	0.0019	<0.0003	<0.0003	<0.001

Bi	<0.0002	<0.0003	<0.0002	<0.001
Ce	0,018	0,010	<0.003	<0.007
Nd	<0.0001	<0.0001	<0.0001	<0.0001
Th	<0.0001	<0.0004	<0.0001	<0.0001
U	0.00209	<0.0001	<0.0001	<0.0001

Table 2 - precious metal content in the brown coal of some deposits of Kazakhstan from the measurements on the complex "Grand - Potok"

Element	Kulan coal deposit, g / m	Shoptykol coal deposit, g / m	Sarykum coal deposit, g / m	Coal deposits Oy Karogay%
Au	<0.01	0.003 - 3	<0.03	<0.03
Ag	<0.03	0.03 - 0.1	<0.03	<0.03
Pt	<0.4	<0.4	<0.4	<0.4
Pd	<0.5	<0.5	<0.5	<0.5
Ir	<0.4	<0.4	<0.4	<0.4
Os	<0.4	<0.4	<0.4	<0.4
Ru	<0.03	<0.03	<0.03	<0.03

In the brown coals of the Shoptykol deposit, gold and silver are contained in different parts of it from 0.003 g / t to 3 g / t or more. The silver content is from 0.03 g / t to 0.1 g / t. The bulk of gold and silver is contained in inclusions on the surface of cracks in the coal, as evidenced by photographs in a USB microscope with an increase in × (100-200). X-ray spectrometer RLP 21 allows measuring gold, platinum, iridium and osmium with (10-20) g / t, which is the detection limit for this device. For this reason, we do not give the results for the above elements in Table 1. Research of the surface and composition of coals. At examining the surface of coals, we used USB microscopes with different magnification x (100-200). It was found that on the surface of the fragments of the samples of the Shoptykol deposit, inclusions of a circular shape, of various sizes and different densities (from individual particles up to 1 mm in diameter and continuous clusters of particles of several square centimetres in diameter, including particles of circular shape up to 10 μm or less) are seen. Photographs of coal surfaces of the Shoptykol deposit are given in Figures 1, 2. It can be seen that inclusions have a circular shape, and these formations are not uniform in thickness, the centre thickness is smaller than at the edges. Figure 3 shows a photograph of the incorporation of the pyrite crystal on the surface of the Kulan coal deposit. Inclusions on the coal surface of the Oy Karogay deposit also represent pyrite crystals as a result of X-ray analysis. To study the composition of inclusions on the surface of coal from the Shoptykol deposit, they were scraped off the surface of the coals and measured on an X-ray spectrometer. The material thus enriched (scraping) showed 68 g / t gold and 17 g / t silver. At studying the material of scraping under a microscope, it turned out that inclusions retained initially a circular shape. To verify that the inclusions in the coals of the Shoptykol deposit contain gold and silver, they were studied on the surface of the coal using an X-ray microanalyser with a locality of 300 μm, which confirmed our assumption. Local analysis of inclusions also confirmed gold and silver in coals of the Shoptykol deposit. The scraped material was also heated at 1000 ° C for an hour to restore gold to metal. After calcination of the scraping, no round inclusions were seen in the microscope, including particles of coal. However, yellow irregularly shaped particles appeared that were selected under a microscope and measured on an X-ray spectrometer. The measurements showed that it is gold and silver (alloy). Samples of coals of all deposits were analysed on the atomic - emission complex “Grand Potok” with an analyser of the MAES for the purpose of determining gold and platinum metals in them. Unique possibilities of this complex for the analysis of precious metals in various objects are described in [10]. The advantage of the method (SAES-scintillation atomic emission spectrometry) over other methods of atomic emission analysis is that a powder sample with a particle size of 100 μm or less is subjected to analysis, which is introduced directly into the arc discharge for 10 -15 seconds by means of a conveyor belt. The result of the analysis is obtained after this time. That is, it is a method of direct injection of a sample that does not dissolve, is not compressed and does not change. From backfilling the sample to obtaining the result, it takes about 20 seconds. Presence of the sample can be up to a gram, if you analyse (strew between) 5 to 6 parallels.

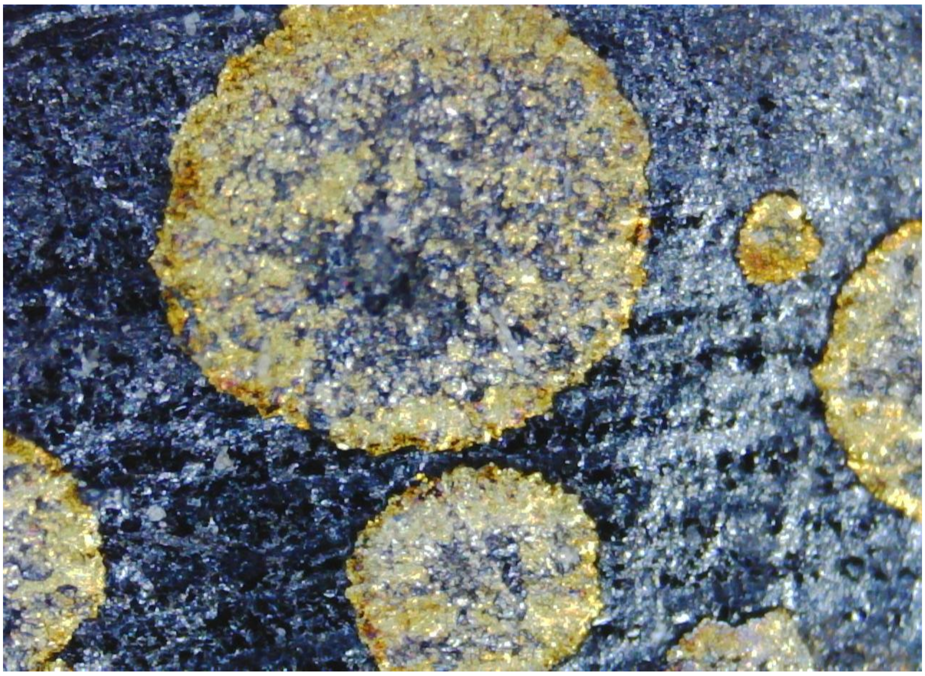


Figure 1 - individual inclusions on the coal surface of the Shoptykol deposit (from 1 mm or less)

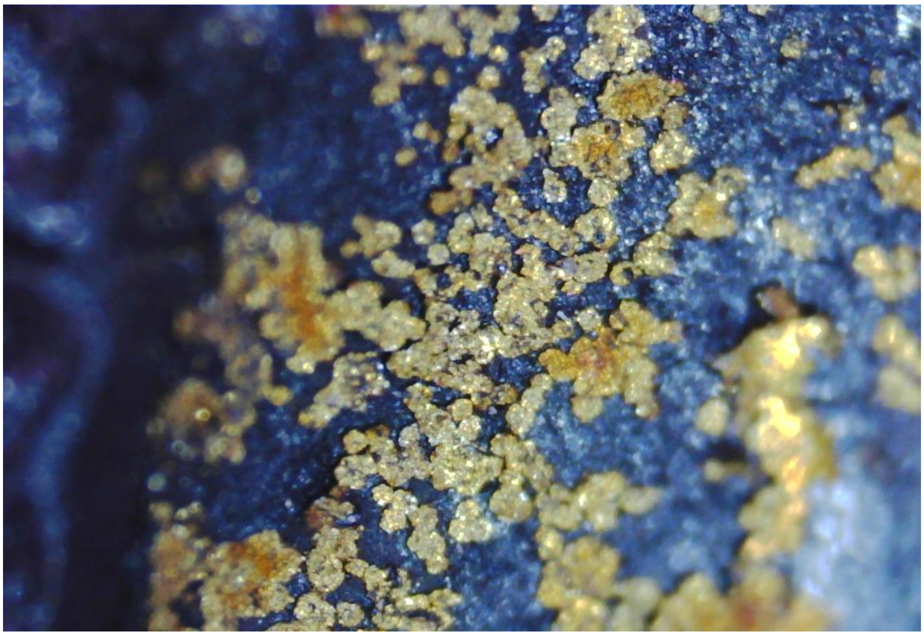
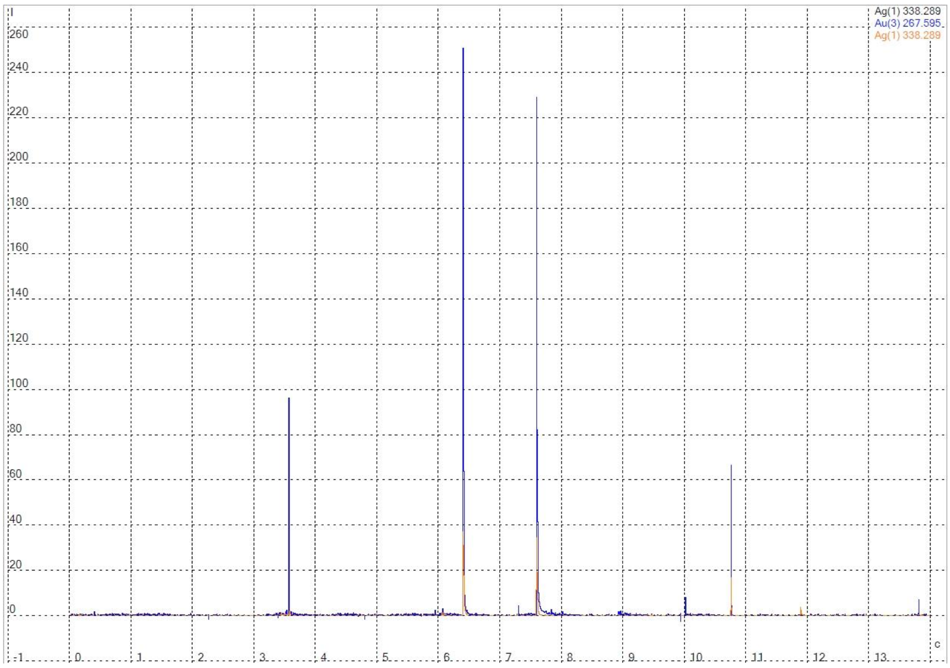


Figure 2 - inclusions on the coal surface of the Shoptykol deposit (splices of individual inclusions)

Figure 3 - a single crystal of pyrite from Kulan coal deposit's surface

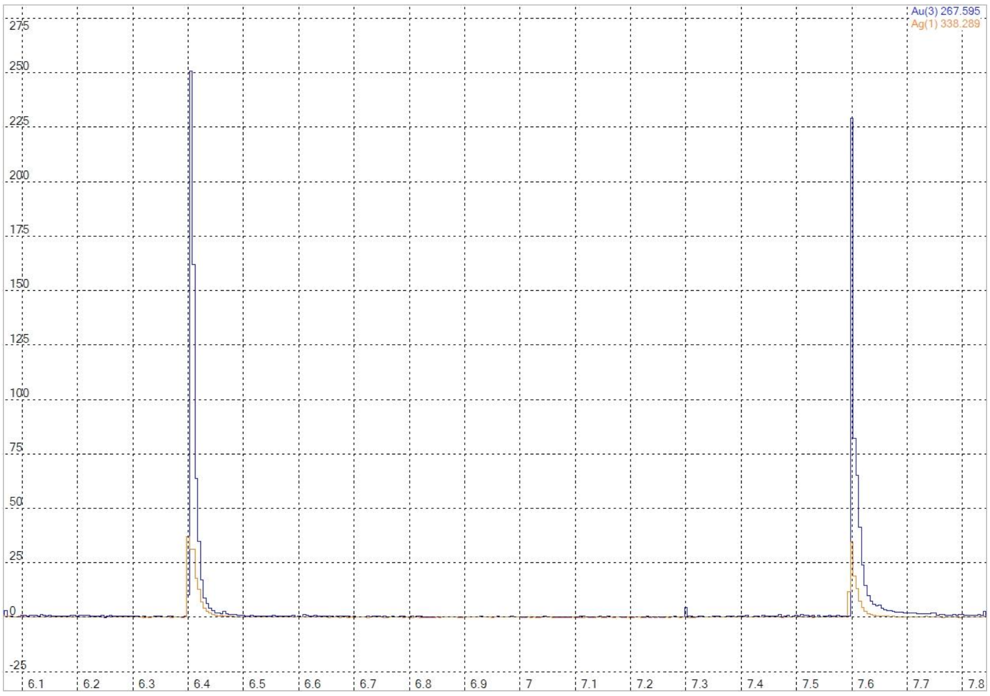
The intensity of the peak, rel. u



Burnout time, sec

Figure 4 shows the spectrum of scintillations of gold particles obtained after calcination of inclusions at a temperature of 1000 ° C and their spilling into the arc discharge of the atomic-emission complex Grand-Potok

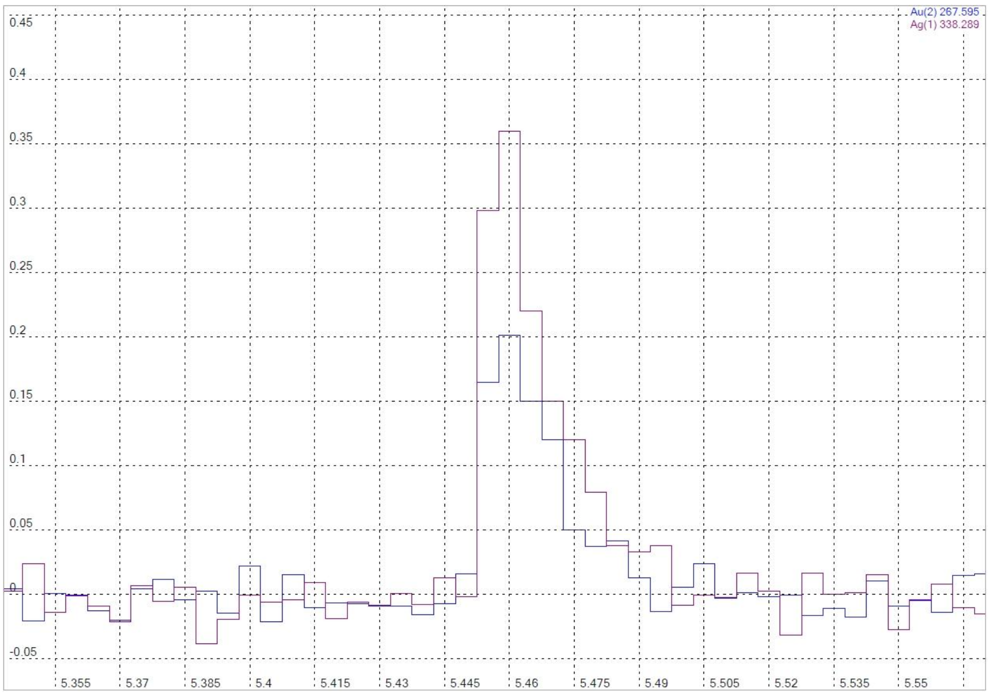
The intensity of the peak, rel. u



Burnout time, sec

Figure 5 - spectrum of scintillations of particles containing gold and silver in the coal of the Shoptykol deposit, obtained after scraping off inclusions from the coal surface and spilling them into the arc discharge of the atomic-emission complex Grand Potok

The intensity of the peak, rel. u



Burnout time, sec

Figure 6 - spectrum of scintillations of coal of Shoptykol localization, spilled into the arc discharge of the Grand Potok complex and measured with a time resolution of 3 ms. It can be seen that the particles consist of an alloy of gold and silver, since they burn out simultaneously with an accuracy of 3 ms.

Thus, the method with its rapidity provides detection limits for gold in virtually all matrices of 0.01 g / t or less with minimal sample preparation. The results for platinum metals are approximately the same. These quantities often depend on the matrix, as in any technique using the atomic-emission method. In works [1,2,9,10], difficulties in the analysis of precious metals in coals, associated with dissolution methods and assay melting, were noted, since carbon is a sorbent for gold. This causes a wide spread of gold results, both in coals and in black shale ores containing precious metals. The method (SAES- scintillation atomic emission spectrometry) used in the Grand Potok complex, using the powder spilling-injection method, is free from these shortcomings and, in this connection, is preferable in prospecting and exploration, and, as indicated in [10], the method provides good repeatability of results on standard samples. Therefore, the application of this method in the analysis of precious metals in coals is a promising task. Figures 4, 5 show the spectra of scintillations obtained by calcining inclusions from the surfaces of coal from the Shoptykol deposit in a muffle furnace at a temperature of 1000 ° C. At the same time, as the photographs of the calcined material show, the inclusions on round coal particles disappeared and separate particles of irregular shape appeared (presumably gold), which is confirmed by the results of registration of scintillations. The spectra show that the particles are very large (the intensity of the signals is very high) and they burn out for more than 10 ms. The size of gold particles from the photographing data is tens of microns. As can be seen from the figures, the scintillation spectra of gold and silver coincide in the arc-discharge time with an accuracy of (3-5) ms, which indicates the genetic connection of gold and silver in these particles (the particles are an alloy of gold and silver). Figure 6 shows the spectrum of scintillations of the ordinary coal powder of the Shoptykol deposit. It can be seen that the scintillations (flashes) of gold and silver coincide in time with the accuracy (3 - 5) ms. It means that the particles are an alloy of gold and silver in the original coal, and their content is .0.03 g / t.

CONCLUSIONS

1. The composition of elements - impurities in brown coals of the deposits of Kazakhstan is determined: Kulan, Shoptykol, Sarykum, and Oy Karogay;

2. It is shown that such elements - impurities as gold, silver, and sulphides are contained in the coal in the form of inclusions of both crystalline and other forms

3. Inclusions in the coal of the Shoptykol deposit have a round shape from 1mm to 10 microns or less. Inclusions include gold and silver, while the crystal structure is not visible. Inclusions are not uniform in thickness and can be hundreds of nanometres

4. At calcinating coal particles, metallic gold is formed in the form of separate particles of irregular shape. The mechanism and nature of the formation of circular inclusions are not known to us.

5. Inclusions in coal deposits Kulan and Oy Karogay have a crystalline structure, the composition and form of microcrystals refer to pyrites which do not contain precious metals;

6. Ash from coal combustion can contain precious metals at a level of less than 0.1 g / t, it also does not contain a noticeable number of rare and scattered elements.

7. The use of the Grand Potok complex with an analyser of the MAES using the method (SAES) and spilling-injection of powder samples into an arc discharge proved to be more effective than the methods providing for dissolution and other, more sophisticated sample preparation with the minimum (clark) limits of detecting precious metals in coals.

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CHEMICAL AND MINERALOGICAL CHARACTERIZATION OF POLYMETALLIC ORE

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ABSTRACT

This paper presents the unprecedented geological study of the kamafugite found at the Cretaceous rock of Mata da Corda group, Minas Gerais, Brazil, which is formed by mafic alkaline, ultramafic volcanic, pyroclastic and epiclastic rocks. The studied kamafugite was first divided into four distinct lithotypes, k-fresh, k-intermediate, k-purple and k-white, which have differences in color and mineral structure. They were analyzed using optical microscopy, x-ray diffraction and Mineral Liberation Analyzer (MLA) and the results were cross-checked with geochemical analysis. The MLA technique is a scanning electron microscope with specific mineral liberation software and a coupled energy dispersive X-ray spectrometer that allows defining the specificities of the ore, such as the mineral content and its association and liberation. The study showed the high potential of these technics, mainly MLA, that indicated the presence of Ti-oxides, perovskite, apatite, monazite, Fe-oxides, and others potential minerals. Furthermore, the mineral association reveals that minerals have different correlations and liberation. These characteristics will enable, in an unprecedented way, the verification of the economic potential of the kamafugite, providing a better use of the mineral riches.

KEYWORDS

Geological study, Kamafugite, MLA, mineral riches.

INTRODUCTION

In recent years the Mineral industry has observed the decline of global scale deposit discoveries as well as the depletion of high-grade ores already in operation. It is also noticed a decrease of the deposits contents and an increase in the complexity of the minerals, both in relation to the mineralogy and the rock fabric (Edwards and Westhuizen, 2014). With this, companies have increasingly sought to know the ore intrinsic characteristics to be processed in order to obtain the best ore recovery. The ore characterization focuses on the understanding of rock mineralogy and the specificities of these minerals, such as granulometric distribution, association, and liberation, which directly influence mineral processing.

Kamafugite is a set of ultrapotassic volcanic rocks, subsaturated in silica, that occur in the oceanic and/or continental setting, mainly in continental rift zone (Sahama, 1974, Bates & Jackson, Edt. 1987 Wilson, 1989, Yu et al., 2001). The occurrence of kamafugitic spills in the world is quite rare, but in the Brazilian context there are several extensive spills and pyroclastic deposits, which form two of the largest kamafugitic provinces on the planet, namely: Alkali Province of Goiás and Alto Paranaíba, which corresponds to the province where the deposit under study is located (Junqueira-Brod et al., 2002).

The Mineral Liberation Analyzer (MLA), developed in the 1990s at The University of Queensland, Australia, is a scanning electron microscope (SEM) with energy dispersive X-ray (EDX) coupled spectrometers and a mineral liberation software that enables the acquisition and the classification of data in an automated way (Sylvester, 2012; Pires e Souza, 2014). The technique allows the acquisition of data such as modal mineralogy, porosity, grain size and mineral association and release (Sylvester, 2012, Pires e Souza, 2014).

The present work consists in a physical, chemical and mineralogical characterization of Kamafugite rock, it aims to understand the polymetallic ore characteristics and indicate the modal mineralogy and the mineral association and liberation which will allow the verification of the economic potential of the kamafugite, providing a better use of the mineral riches.

Geological Settings

The deposit is located on the western border of the São Francisco Craton, near the Brasília Orogenic Range (Fragoso, 2011). According to Fragoso et. al. (2011) and Fragoso (2011), the outlying lithotypes are inserted in the geological context of the São Francisco Basin and consist of Neoproterozoic rocks of the Bambuí Group and of Cretaceous age belonging to the groups Areado and Mata da Corda.

The deposit studied in this paper is related to the Mata da Corda Group and is associated with slopes of plateaus ranging from 850 to 1000m of height (Fragoso et. al. (2011). The group is formed by the alternation of volcanic and epiclastic rocks, which belong to the Patos and Capacete formations, respectively. The volcanic rocks are alkaline mafic to ultramafic with aphanitic fabric, sometimes porphyritic, of effusive and pyroclastic nature. Subvolcanic conduit rocks also occur (Fragoso et al., 2011). According to Moraes et. al. 1987, these lithotypes can be classified as kamafugite and present dark gray color when fresh, and reddish and greenish tones when weathered (Fragoso et al., 2011). A schematic profile made by Mapear Engenharia e Geologia at the request of Magnor is present in Figure 1, where it is possible to verify the weathering profile of the samples.

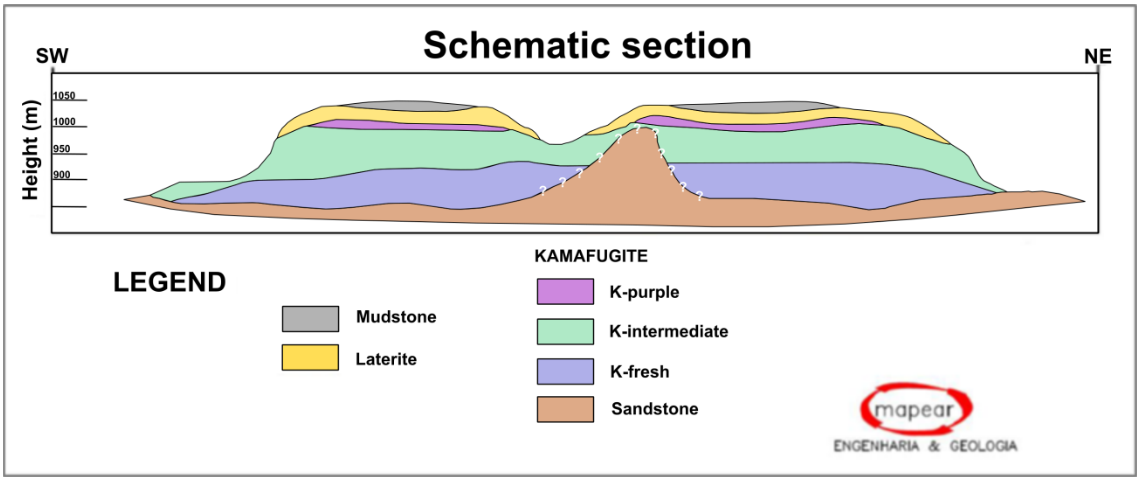


Figure 1 – Schematic profile of kamafugite deposit (modified after Mapear)

It is possible to identify perovskite and pseudomorphs of olivine phenocrystals, and xenoliths emerge in a very thin matrix, composed mainly of clinopyroxene. The perovskite crystals occur in varying amounts, while the olivine pseudomorphs are altered mainly for serpentine in its central portion and chlorite on the edges. Xenoliths are rare and correspond to pyroxene accumulations with possible feldspathoid alteration in the center (Fragoso et. al. (2011).

OBJECTIVES

The aim of this paper is to perform and analyze the physical, chemical, and mineralogical characterization of kamafugite samples. These results will contribute to decide the better process routes in order to obtain concentrates of interest minerals.

METHODOLOGY

The items below describe the phases of studies in the present paper

Sample preparation

The samples were previously prepared (crushing and milling did by the drilling team) and delivered to SENAI Innovation Institute for Mineral Processing team in 397 individual packages. The mineralogical classification was performed by the visual observation of the field geologist. The packages were composed of four different sample types as shown in Table 1 for a detailed study. These samples were homogenized and divided into representative aliquots to the characterization study.

Table 1 – Sample kamafugite classification

Sample	Name	Composition	Description
A1	K-purple	KR	Weathered kamafugite with red and purple color
A2	K-intermediate	KV	Weathered kamafugite with pistachio green color
		KE	Kamafugite of green matrix
		KM	Kamafugite of brown matrix
		KC	Kamafugite of gray matrix
A3	K-fresch	K {blue}	Less weathered kamafugite with preserved structures and minerals
A4	K-white	K {white}	Weathered volcanic rock

Physical Characterization

Particle size distribution by wet sieve tests was done in the apertures 0,600mm (28#); 0,425mm (35#); 0,212mm (65#); 0,150mm (100#); 0,106mm (150#); 0,075mm (200#); 0,053mm (270#); 0,045mm (325#) and 0,038mm (400#). In order to complement the study, particle size distribution by cyclosizer was done with the finer fraction of the sieve tests.

Laboratory milling tests was done with the Sample 2 to determine the P90 on the apertures 0,106mm (150#); 0,075mm (200#); 0,053mm (270#); 0,045mm (325#) and 0,038mm (400#). Test to determinate de Bond Work Index (BWI) in the aperture 0,150mm (100#) was done using a ball mill with the Sample 2.

Density determinations for both head sample and the finer fraction of the sieve tests were done using a helium stereopicnometer.

Chemical Characterization

Chemical analysis of the head samples and particle size fractions (sieve and cyclosizer tests) were performed to determine SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, P_2O_5, Na_2O, K_2O, MnO, BaO, Co, Cr_2O_3 and NiO by fusion with lithium tetraborate and X-ray fluorescence (XRF); Rare Earth Elements (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, U, and Y) were determined by fusion with lithium metaborate and ICP-OES; determinations of Loss On Ignition were yet performed at 405°C and/or 1000°C.

X-ray Diffraction

It was realized one analysis by composite sample thus totaling four analyzes. For this work it, was used a Rigaku / Smartlab equipment, from the SENAI Institute of Innovation in Metallurgy and Special Alloys, which presents X-ray tube with CuKα radiation ("= 1.5418Å). The analytical conditions were:

- Analysis range: 10º to 80º (2θ), with the exception of sample 1 that was 5º to 90º (2θ);
- Step: 0.02 (2θ);
- Reading Time: 0.5 second.

Optical microscopy

The analysis was performed in order to contemplate a range of samples, which was studied during the project (Table 2). The studies aimed at the identification of the minerals rocks, the previous evaluation of the fabric/structural relations and the interest minerals associations. For this, was used an optical microscope with a coupled imaging system, model Leica DMLP of the Mineralogical Characterization Laboratory of SENAI Institute of Innovation for Mineral Processing located in the Center for Innovation and Technology.

Table 2 – Relation of analyzed samples by optical microscopy

ID	Classification
FS31-A021	KE
FS31-A032	KE
FS31-A036	KV
FS33-A038	KC
FS36-A042	KM
FS41-A033	K {white}
FS42-A010	KR
FS43-A048	K {blue}
FS43-A055	K {blue}

MLA

The mineral release studies were carried out in a FEI scanning electron microscope, model Quanta 650F, with energy dispersive X-ray (EDX) and coupled mineral liberation software, located at the Microscopy Center of the Federal University of Minas Gerais (CM-UFMG). The focus of these studies was the modal distribution of the minerals, the mineralogical association and the liberation/exposure of the interest minerals. The analysis was performed in polished sections of the samples distributed by size fractions, except for Sample 4, which did not present sufficient amount and it was necessary to recompose the sample in the range (-100#/+400#) and the classification for the other fractions via software (Table 3).

Table 3 - Relation of analyzed samples by MLA

ID	Size fraction
Sample 1	(-100#/+200#)
	(-200#/+270#)
	(-270#/+400#)
Sample 2	(-100#/+200#)
	(-200#/+270#)
	(-270#/+400#)
Sample 3	(-100#/+200#)
	(-200#/+270#)
	(-270#/+400#)
Sample 4	(-100#/+400#)

For the mineral list, were used previous data instruments of X-ray diffraction and optical microscopy, as well as literature. The results for a global sample were obtained by means of calculations, taking into consideration the masses of each aliquot to be used, as shown in Table 4. For a better results understanding, as fractions as named as coarse (for the fraction -100 # / + 200 #), medium (for the fraction -200 # / + 270 #) and fine (for the fraction-270# / +400#).

Table 4 – Relation of analyzed samples and fractions and their weight

Sample	Size fraction		
	(-100#/+200#)	(-200#/+270#)	(-270#/+400#)
1	283,1g	153,3g	179,4g
2	775,0g	307,9g	357,6g
3	519,0g	165,5g	171,1g
4	334,2g	35,9g	53,1g

The protocol of the automated analytical routine predicted EDS spectra in a minimum area of 100 frames and additionally at least 2000 particles for the coarse and medium samples, and 5,000 particles for fine samples. For the fractions (-100#/+200#) and (-200#/+270#), 225 frames were used, while for the fraction (-270#/+400#), 289 frames. Sample 4, because it was not separated by size fractions, had to be analyzed in a larger area to effect its representativeness, thus using 2350 frames. The calibration of the gray tones is a function of the atomic number Z and the used standard was galena. Overlay of the same gray tone, with differences in the EDS spectrum, were solved with the GXMap correction.

RESULTS

Physical Characterization

The density determinations provided the results showed (in g/cm^3):

- Sample 1: 2.66 (head sample) and 2.64 (fraction below 38 microns);
- Sample 2: 2.19 (head sample) and 2.31 (fraction below 38 microns);
- Sample 3: 2.29 (head sample) and 2.32 (fraction below 38 microns);
- Sample 4: 2.22 (head sample) and 2.33 (fraction below 38 microns);

The BWI determined for the Sample 2 was 11.9 kWh/short ton in a test with fourteen milling cycles and circulating load in 250%. The F80 was approximately 0.300mm (48#) and the P80 was approximately 0.075mm (200#). The laboratory milling tests for the Sample 2 provided milling curves showed in Figure 2.

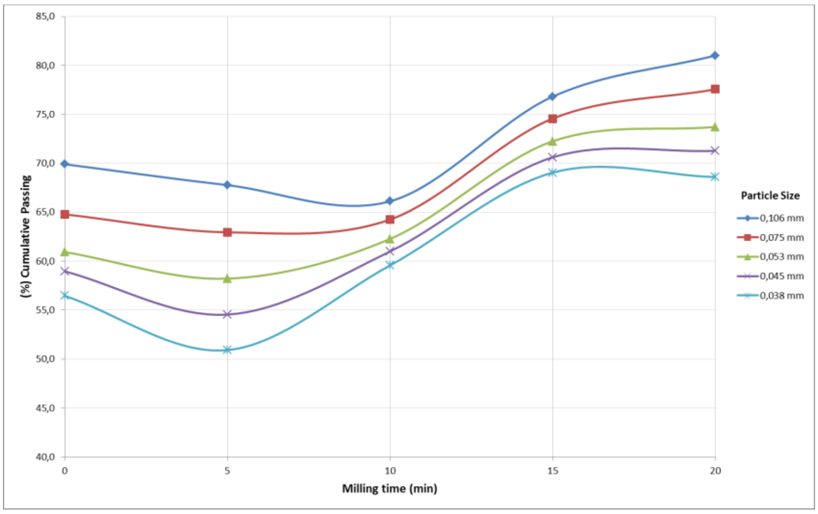


Figure 2 - Sample 2 milling curves in laboratory tests

The results showed in Figure 3 highlight the global mass distribution below 38 and 20 microns.

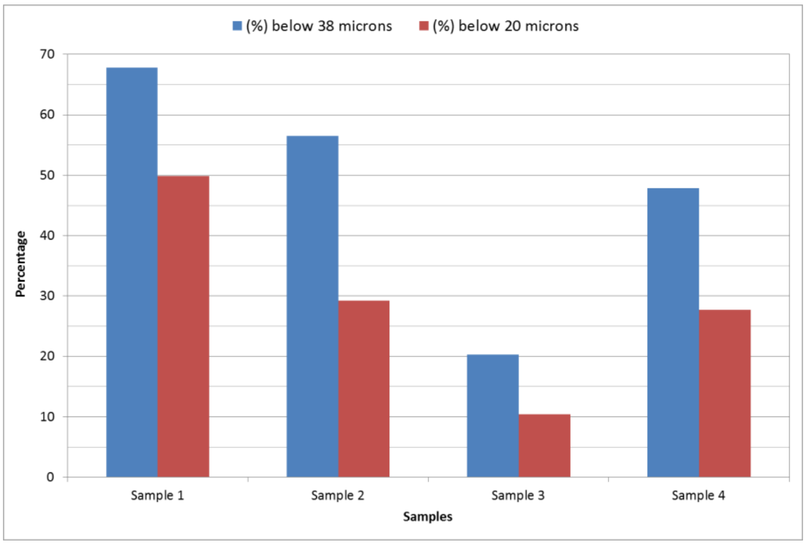
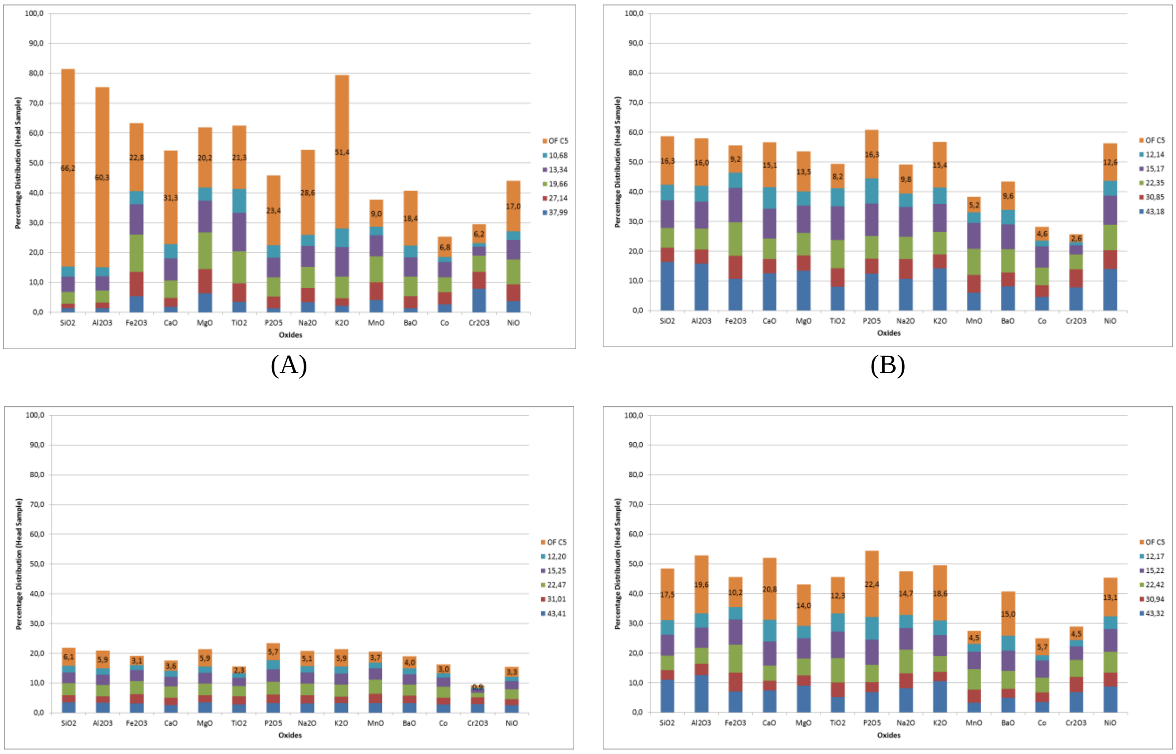


Figure 3 - Samples global mass distributions in the particle size distribution tests

Chemical Characterization

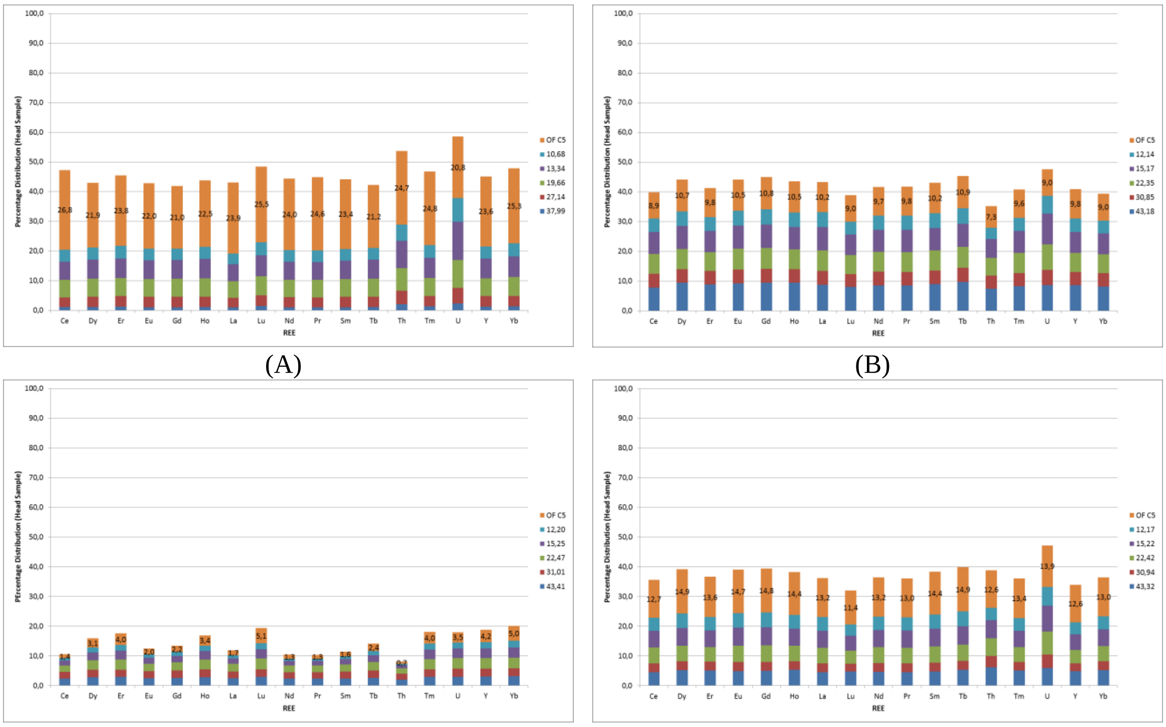
The Figure 4 and the Figure 5 show the results of the Oxides and REE metallurgical distributions in the finer fraction of the sieve tests.



(A) (B)

(C) (D)

Figure 4 - Oxides percentage distributions for the samples in the fraction below 38 microns. (A) Sample 1; (B) Sample 2; (C) Sample 3; (D) Sample 4.



(A) (B)

(C) (D)

Figure 5 - Rare Earth Elements percentage distributions for the samples in the fraction below 38 microns. (A) Sample 1; (B) Sample 2; (C) Sample 3; (D) Sample 4.

X-ray difraction

The diffractograms obtained by the XRD analyzes (Figure 6) allowed to obtain the mineralogy of samples. Minerals such as clay minerals and magnetite occur in all samples. The anatase and fluorapatite phases occur in almost all the samples and cannot be identified in one of them because they do not present the three characteristic peaks.

The phosphate phases identified by the technique are: apatite (samples 2, 3 and 4), goyazite and gorceixite (samples 1, 2 and 4). Titanium phases are anatase (sample 1, 2 and 4), ilmenite (samples 1 and 2) and perovskite (samples 2 and 3). The identified Fe oxide/hydroxide phases are: magnetite (samples 1, 2, 3 and 4), hematite (samples 1 and 2), goethite (sample 1). Other minerals detected are diopside and calcite (sample 3), and quartz (sample 4).

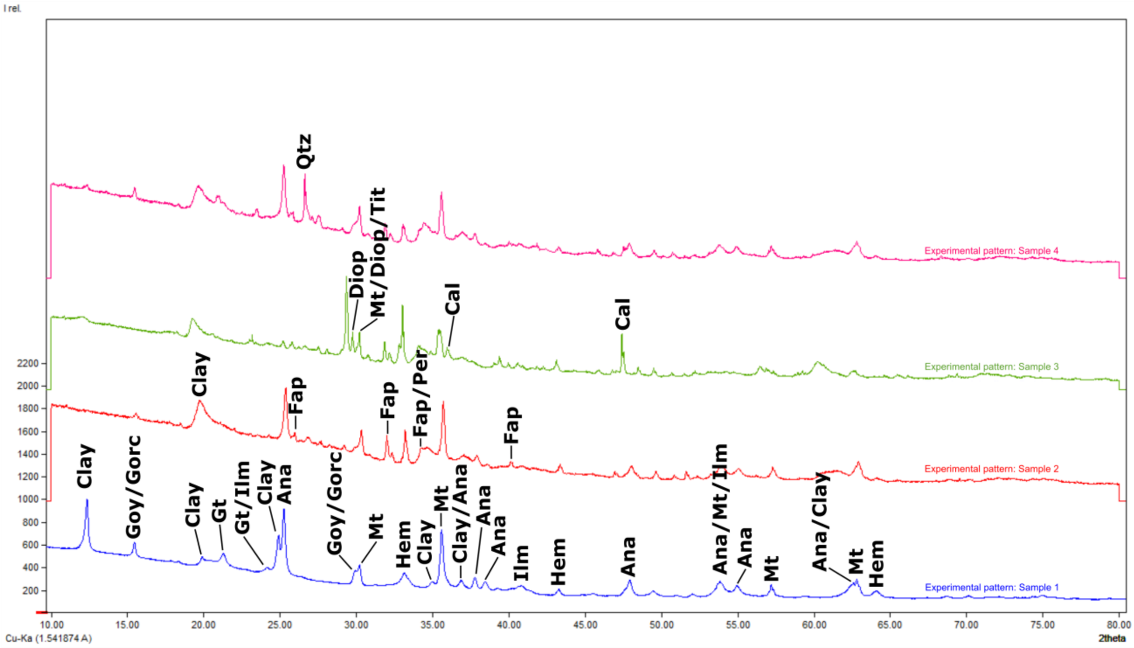


Figure 6 – Samples diffractograms patters with phase identification

Optical Microscopy

Sample 1

Formed by altered olivine pseudomorphs, iddingsite (a cluster of smectite, goethite/hematite and chlorite), anatase, perovskite, magnetite, hematite and reddish clay matrix (Figure 7A). The minerals are very altered giving the sample an earthy appearance. Olivine pseudomorphs have a relatively preserved form but have few optical characteristics of this mineral, being replaced by other minerals such as iddingsite, possible serpentine and clay minerals. The reddish tone is possibly related to the presence of iron oxides and hydroxides associated with clay minerals. The sample fabric is porphyritic with phenocrysts of olivine and well-formed crystals of magnetite and perovskite surrounded by the reddish clay matrix.

Sample 2

Formed by pseudomorphs of olivine and clinopyroxene, possible original phenocrysts, and by euhedral crystals perovskite and magnetite/hematite. The olivine pseudomorphs are greatly altered to serpentine, chlorite, iddingsite, goethite/hematite and possible muscovite (Figure 7B and C). Locally the pseudomorphs show optical characteristics of olivine, indicating the presence of relicts of this mineral. The pyroxene prismatic pseudomorphs change to chlorite, muscovite, clay minerals and possible feldspathoid potassic. The matrix of the rock has an earthy appearance, surrounds the others more well-formed (Figure 7C) and presents fine crystals similar to muscovite.

Sample 3

It consists of olivine and clinopyroxene pseudomorphs, and euhedral to subhedral crystals to perovskite and magnetite/hematite, all surrounded by a clayey matrix of greenish-beige color. The shape of olivine pseudomorphs is preserved, but are altered mainly to serpentine, chlorite, iddingsite, muscovite and goethite/hematite. The Fe oxide is usually found in the center of the crystals. Locally the pseudomorphs show optical characteristics of olivine, indicating the presence of relicts of this mineral. Apparently, olivine pseudomorphs are associated with perovskite crystals. Clinopyroxene pseudomorphs occur as well-formed crystals, with prismatic habit and, similarly to olivine, altered for other minerals, possibly amphibole and chlorite (Figure 7D). They present dirty-looking film covering the crystals. The accurate determination of the secondary minerals is not possible due to the presence of this film and the granular characteristic of the sent sample. Is noted the presence of calcite as anhedral to euhedral crystals through the fragmentation of crystal. The determination of the calcite association with the others minerals is unclear due to rock fragmentation. Could be noted the presence of prismatic apatite. The presence of potassic feldspathoids was not ruled out mainly associated with pseudomorphs of pyroxene.

Sample 4

Formed by olivine and clinopyroxene pseudomorphs. The olivine weathering to serpentine is more easily determined. The sample particles are covered by the thin earthy-looking film, formed by a clay matrix and microscopic and opaque crystals, possibly Fe (magnetite or hematite) oxide. The main difference of this rock to the others is the presence of quartz and absence of calcite.

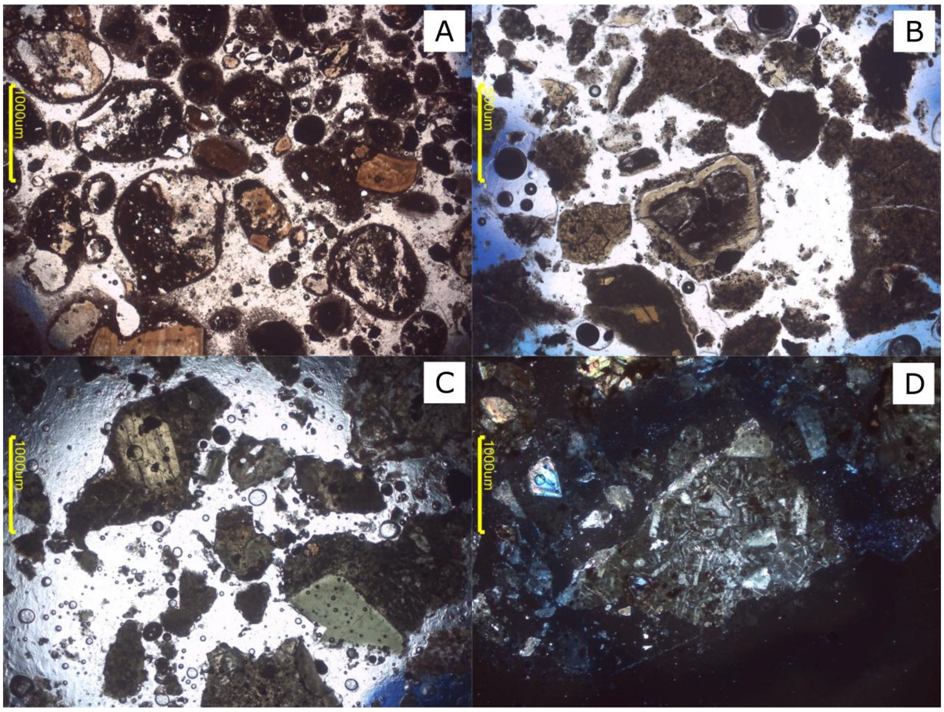


Figure 7 – Photomicrography obtained by optical microscopy: A) Sample formed by particles rich in a reddish clayey matrix with light brown olivine pseudomorphs. Transmitted light and parallel nicols; B) Altered olivine pseudomorphic crystal (center of the image) with central portion rich in goethite. Transmitted light and parallel nicols; C) Pseudomorph crystals of olivine (in beige and green), surrounded by brown clay matrix. Transmitted light and parallel nicols; D) Particle of the sample with pyroxene pseudomorphs (light gray prismatic crystals), completely altered, surrounded by clayey matrix, indicating possible original porphyrite texture. Transmitted light and crossed nicols.

MLA

The minerals calibration for analysis by MLA is shown in Figure 8. Some phases are classified according to the EDS spectrum analysis, such as "Silicate with Al, Mg, and Fe" and "Fe-oxide with Ti" owing to the technique does not generate quantitative data of mineral chemistry and the fact that the sample presents weathered minerals with similar compositions, as observed by optical microscopy. In a similar way, the phases "Mix Ox Fe + clay minerals" and "Mix clay minerals + Ox Fe" are mixed phases which the spectrum presents the greater influence of the first minerals and that cannot be individualized, as well as "Aggregate" phase.

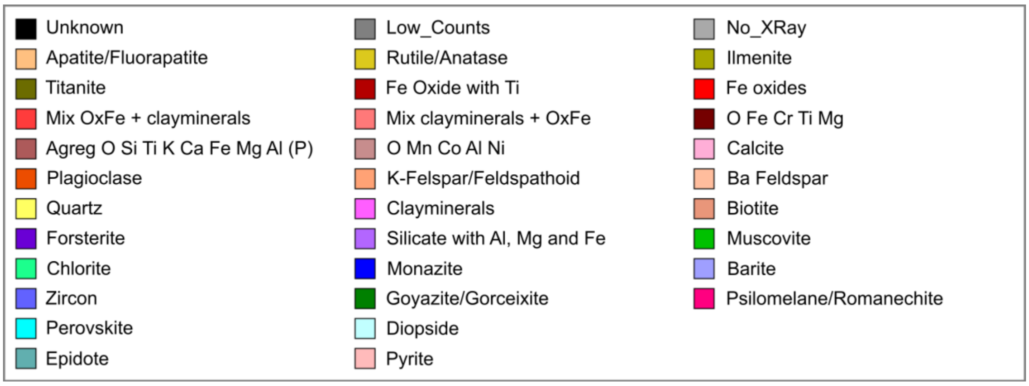


Figure 8 – Mineral list used in the MLA calibration

<u>Modal Distribution</u>

The samples are essentially formed by silicate with Al, Mg and Fe, Ti-oxide, Fe-oxide, Fe-oxide with Ti and perovskite, having their proportions (by weight %) varying according to the analyzed sample (Table 5 and Figure 9). For the global sample, the other mineral phase's present concentrations are lower than 5%. The results presentation was performed in the order from Sample 1 to Sample 4, as well as in the particle size order from the coarsest to the finest (coarse, medium and fine ranges), except when the sample presents results equal to or close to zero.

Apatite: present in samples 2, 3 and 4, as in Table 5 and Figure 9. For sample 2 the results obtained are 5.61%, 5.49%, and 3.70%. Sample 3 has the highest values of 7.49%, 8.03%, and 7.53%. Sample 4 is formed by 2.99%, 2.53%, and 2.35%. In the global sample, the result is 4.50% (Table 6 and Figure 10).

Rutile/Anatase: identified in all samples, the highest results being associated with Sample 1 (Table 5 and Figure 9). For this sample, the values obtained are 26.05%, 21.70%, and 20.84% in the focus ranges of the study. Sample 2 shows the contents of 17.13%, 16.50%, and 17.26%. Sample 3, which has the smallest values, is formed by 0.35%, 0.60%, and 0.90%. Sample 4 is composed of 9.80%, 11.40%, and 12.27%. The global sample presents a result of 13.39% for this mineral (Table 6 and Figure 10).

Monazite: is the main REE-bearing mineral. It is mainly related to samples 2 and 4, as can be identified in Table 5 and Figure 9. Sample 2 shows the values of 0.12%, 0.43%, and 0.31% in the study granulometric ranges. Sample 4 has 0.23%, 0.22%, and 0.16%. For the global sample, the obtained result is 0.13% (Table 6 and Figure 10).

Table 5 – Modal distribution of minerals for the Kamafugite sample compositions by size fraction

Mineral	Sample											
	Sample 1			Sample 2			Sample 3			Sample 4		
	-100# +200#	-200# +270#	-270# +400#	-100# +200#	-200# +270#	-270# +400#	-100# +200#	-200# +270#	-270# +400#	-100# +200#	-200# +270#	-270# +400#
Apatite/Fluorapatite	0,00	0,07	0,01	5,61	5,49	3,70	7,49	8,03	7,53	2,99	2,53	2,35
Rutile/Anatase	26,05	21,70	20,84	17,13	16,50	17,26	0,35	0,60	0,90	9,80	11,40	12,27
Ilmenite	4,36	5,75	7,48	1,25	1,51	2,94	0,05	0,06	0,25	2,37	2,84	3,08
Titanite	0,00	0,00	0,00	0,10	0,24	0,33	1,94	2,07	3,27	0,11	0,12	0,11
OxFe with Ti	11,32	12,94	15,89	8,26	11,50	13,74	2,80	2,83	4,23	10,32	10,92	10,42
Fe Oxide	40,06	41,98	41,16	10,84	14,13	17,54	4,61	5,15	6,70	14,69	15,37	15,49
Mix OxFe + clay minerals	2,82	2,79	2,39	0,56	0,49	0,69	0,07	0,16	0,21	0,96	0,94	1,11
Mix clay minerals + OxFe	3,75	3,35	3,02	0,40	0,25	0,22	0,02	0,03	0,06	1,38	1,39	1,48
O Fe Cr Ti Mg	0,33	0,32	0,68	0,38	0,47	0,60	0,21	0,09	0,12	0,72	0,78	0,63
Agreg O Si Ti K Ca Fe Mg Al (P)	0,94	0,92	0,96	4,92	5,07	4,99	0,85	0,84	1,17	3,39	4,07	4,69
Calcite	0,00	0,06	0,00	0,01	0,00	0,00	7,37	9,29	7,85	0,00	0,00	0,00
K-Feldspar/Feldspathoid	0,01	0,06	0,07	4,57	2,32	3,33	0,65	1,63	1,04	17,19	11,86	9,16
Quartz	0,29	0,33	0,49	0,28	0,07	0,10	0,02	0,02	0,03	4,33	3,91	3,32
Clay mineral	3,57	3,73	2,95	0,03	0,18	0,05	0,03	0,02	0,03	0,37	0,39	0,32
Aluminious silicate of Mg and Fe	1,44	1,84	0,96	36,33	35,09	26,99	29,77	28,12	27,37	24,78	28,47	31,43
Chlorite	0,10	0,09	0,01	2,25	1,52	1,33	5,75	6,20	3,50	0,48	0,55	0,49
Monazite	0,01	0,01	0,00	0,12	0,43	0,31	0,01	0,01	0,01	0,23	0,22	0,16
Barite	0,00	0,00	0,00	0,47	0,00	0,00	0,07	0,07	0,52	0,04	0,00	0,00
Zircon	0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,73	0,27	0,12
Goyazite-Gorceixite	3,95	3,50	2,74	1,00	1,22	1,17	0,13	0,00	0,02	1,65	1,48	1,48
Psilomelane/Romanechite	0,56	0,33	0,22	0,22	0,27	0,09	0,00	0,00	0,00	0,26	0,12	0,08
Perovskite	0,00	0,01	0,02	4,31	2,35	3,83	26,78	22,99	19,23	2,82	2,01	1,43
Diopside	0,01	0,01	0,00	0,39	0,32	0,26	10,70	11,17	15,46	0,01	0,01	0,01
Epidote	0,01	0,00	0,00	0,03	0,05	0,01	0,13	0,24	0,18	0,01	0,02	0,01
TOTAL	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**	**100,00**

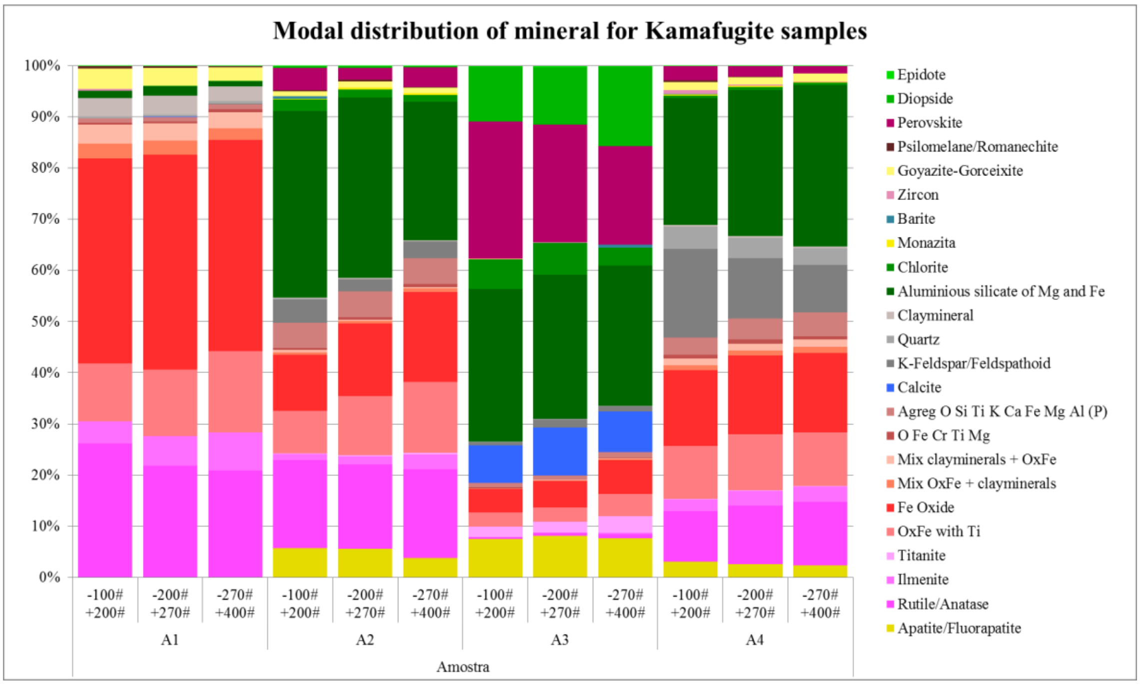


Figure 9 - Modal distribution of minerals for the Kamafugite sample compositions by size fraction

Table 6 – Modal distribution of minerals for global sample of Kamafugite

Mineral	Global
Apatite/Fluorapatite	4,70
Rutile/Anatase	16,19
Ilmenite	2,04
Titanite	0,34
OxFe with Ti	9,99
Fe Oxide	15,54
Mix OxFe + clay minerals	0,78
Mix clay minerals + OxFe	0,67
O Fe Cr Ti Mg	0,43
Agreg O Si Ti K Ca Fe Mg Al (P)	4,18
Calcite	0,67
K-Feldspar/Feldspathoid	3,39
Quartz	0,31
Clay mineral	0,43
Aluminious silicate of Mg and Fe	29,71
Chlorite	1,93
Monazite	0,19
Barite	0,21
Zircon	0,02
Goyazite-Gorceixite	1,27
Psilomelane/Romanechite	0,20
Perovskite	5,05
Diopside	1,25
Epidote	0,04
TOTAL	**100,00**

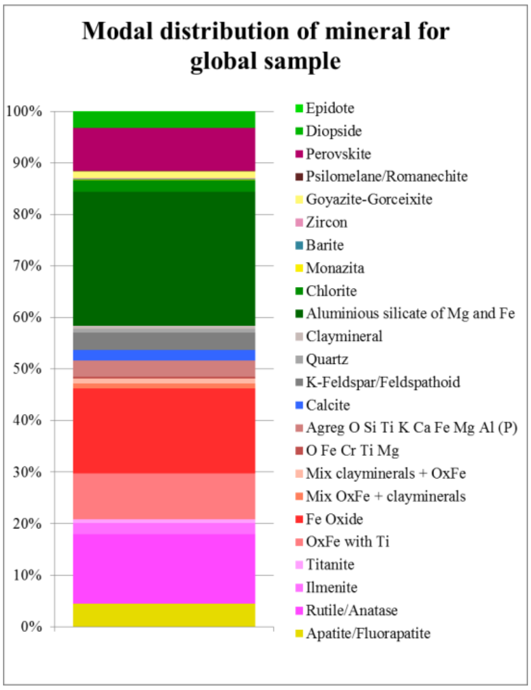


Figure 10 – Modal distribution of minerals for global sample of Kamafugite

Mineral association

These results show the relationship between the mineral phases present in the analyzed samples. The oxides are preferentially associated with other oxide phases. The Ti-oxide phase in Sample 3 has an important association with perovskite, which in turn is associated with others oxides and aluminous silicate of Mg and Fe. Monazite is mainly associated with Ti-oxide (samples 1, 2 and 4, discretely in Sample 3), goyazite/gorceixite (sample 1) and apatite/fluorapatite (sample 3). Apatite is associated with the aluminous silicate of Mg and Fe.

Apatite: the association results per sample and range are shown in Figure 11. All samples have an average free surface result between 20 and 40%, with the exception of sample A1 (-200#/+270#) which presents approximately 73%. The main mineral associated with apatite is the aluminous silicate of Mg and Fe, with an average of 42%. The samples A1, with the exception of the range (-200#/+270#), A2 and A4, show the association of the apatite to the "agreg O Si Ti K Ca Fe Mg Al (P)" phase in the order of 7%. In samples A1 (-270#/+400#), A2, A3 and A4 the apatite is also associated with Fe-oxide with Ti, with values around 4%. The association of apatite with calcite, on the order of 3%, can be observed in samples A1 (-200#/+270#) and A3. In this last sample it is also associated with diopside, with an average result of 8%, and perovskite, with an average value of 2%. Minor associations and classifications of these by the global sample can be seen in Figure 11.

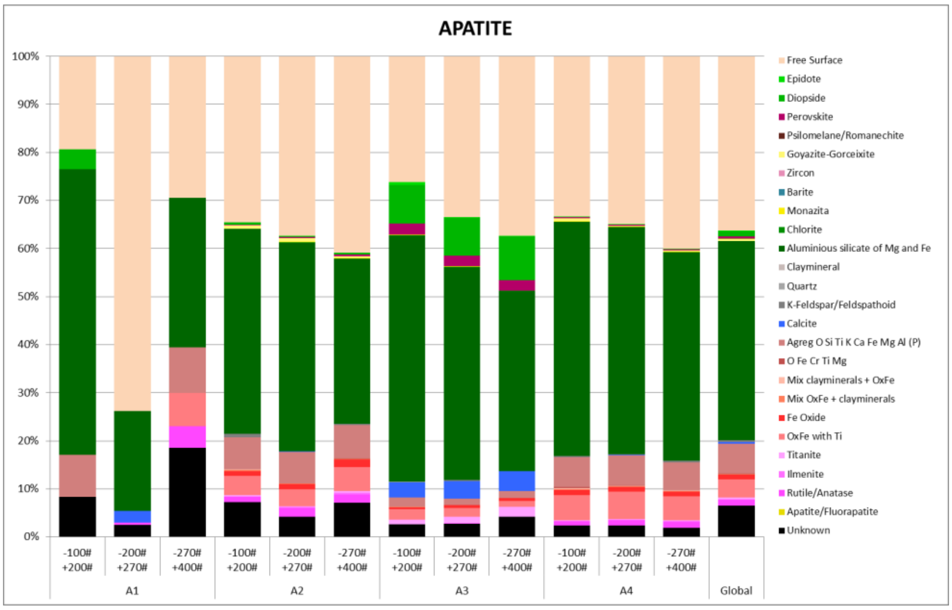


Figure 11 - Mineral association distribution of apatite for the Kamafugite sample compositions by size fraction and by global sample

Rutile/Anatase: the association results per sample and range are shown in Figure 12. The free surface results vary between 30% and 58% approximately. The main mineral association of rutile/anatase is "agreg O Si Ti K Ca Fe Mg Al (P)", with an average result of 21.4%. Other associations observed in all analyzes are Fe-oxide with Ti and ilmenite, with average values of 8.3% and 7.1%, respectively. In samples A2, A3 (which has the highest values) and A4, an association with aluminous silicate of Mg and Fe is found with an average of 3.7%. Association to the perovskite phase is observed mainly in sample A3 with average value of 17,2%. Other mineral associations, such as monazite and goyazite/gorceixite, as well as global sample results, can be observed in Figure 12.

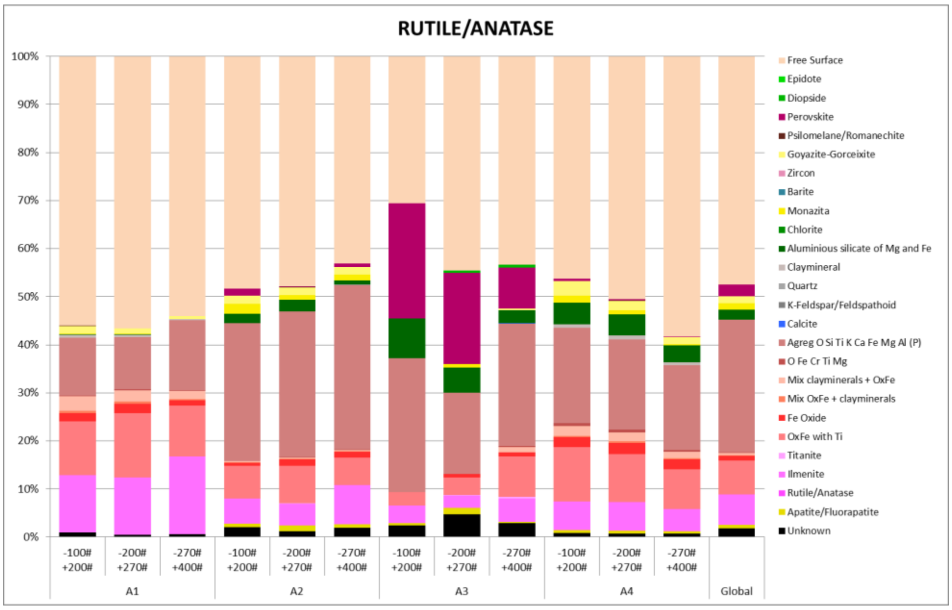


Figure 12 – Mineral association distribution of rutile/anatase for the Kamafugite sample compositions by size fraction and by global sample

Monazite: the association results per sample and range are shown in Figure 13. It occurs as a free surface with an average value of 27.3%, being that the samples A1 and A3 having the lowest and highest mean results, with 11.9% and 45.2%, respectively. The main association is Ti oxide with a mean of 32.4% observed in samples A1, A2, A3 (-200#/+270#), and A4. Apatite/fluorapatite occurs mainly in sample A3, with an average of 27.8%. Furthermore it is verified in samples A2 (-200#/+270#), A2 (-270#/+400#), and A4 with lower values. The association of monazite to goyazite/gorceixite is detected in samples A1, A2 and A4 with a mean of 19.7%. The samples A1 (-200#/+270#) and A1 (-270#/+400#) presenting the highest results for this association, with 66.7% and 41.9%, respectively. Other associations such as aluminous silicate of Mg and Fe, psilomelane/romanechite, ilmenite, perovskite, clay minerals, “agreg O Si Ti K Ca Fe Mg Al (P)”, barite and unknown can be seen in Figure 13, as well as results for global sample.

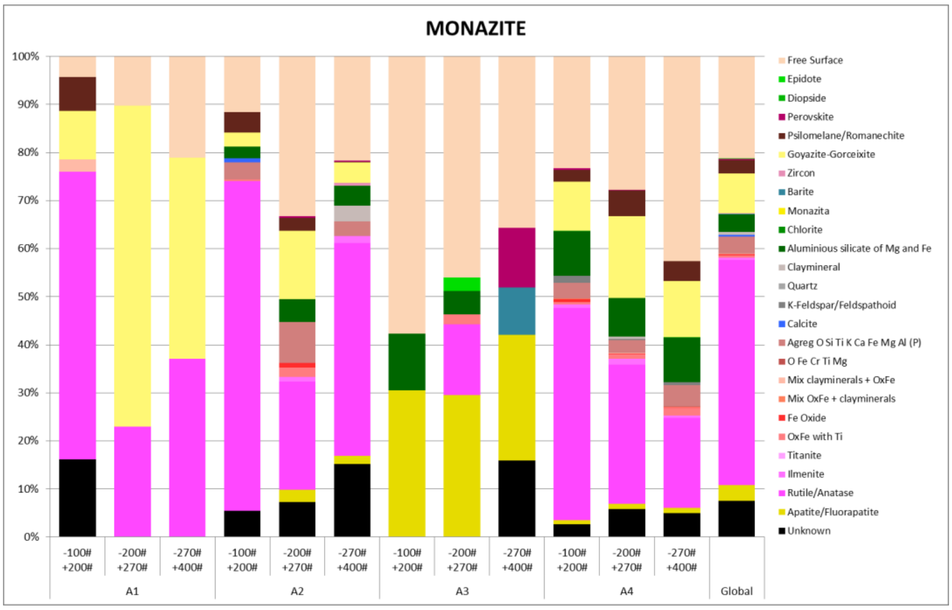


Figure 13 - Mineral association distribution of monazite for the Kamafugite sample compositions by size fraction and by global sample

Mineral Liberation by particle composition

The mineral liberation results are essential for the mineral processing in order to determine which routes could be used and the possible behavior of the ore. According to the method developed by Gaudin (1939), liberated particles are those that present results above 90% of the particle of interest. Table 7 presents these results (liberation > 90%) for the major minerals of interest. The distribution of the liberation classes can be seen in Figure 14 and Figure 15.

Table 7 – Result of mineral liberation by size fraction and by mineral

Sample		Mineral phase		
		Apatite	Rutile/Anatase	Monazite
A1	-100#/+200#	3,79	57,08	0,00
	-200#/+270#	1,25	50,20	0,00
	-270#/+400#	7,93	43,19	0,00
A2	-100#/+200#	40,58	62,89	4,95
	-200#/+270#	55,72	50,98	63,74
	-270#/+400#	43,88	41,53	37,92
A3	-100#/+200#	36,10	3,79	15,33
	-200#/+270#	50,82	57,89	25,71
	-270#/+400#	44,74	29,28	0,00
A4	-100#/+200#	63,19	44,65	54,72
	-200#/+270#	46,72	43,21	48,11
	-270#/+400#	43,37	47,42	56,01

Apatite has the best liberation results for samples A2, A3, and A4 as shown in Figure 14A. The liberation presented by sample A1 is low, with proportions less than 8%. For rutile/anatase the samples A1, A2 and A4 present results above 40% (Figure 14B). Sample A3 has proportions of approximately 4%, 58%, and 29% respectively, for the coarse, medium and fine fractions, respectively. Monazite presents results of approximately 5%, 64% and 38% for sample A2 (Figure 14C). Sample A3 has values of 15% and 26% for fine and medium fractions. The best average results are associated with the A4 sample with 53%.

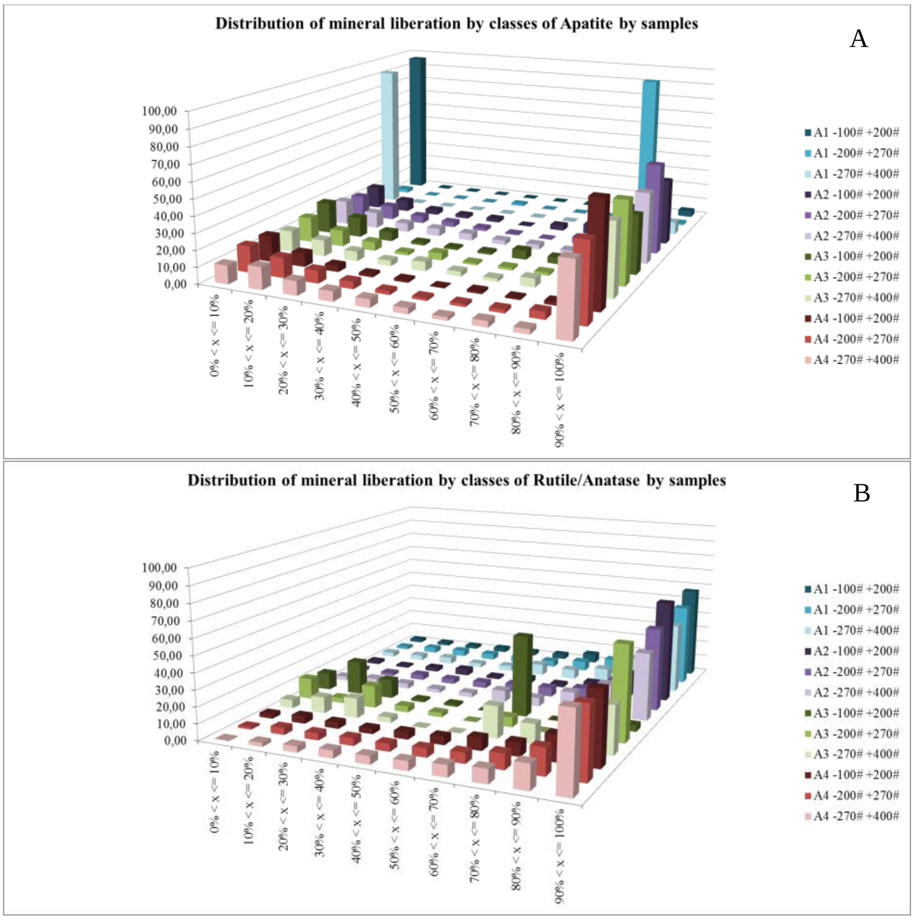


Figure 14 – Mineral liberation diagram by classes: A) apatite; B) rutile/anatase

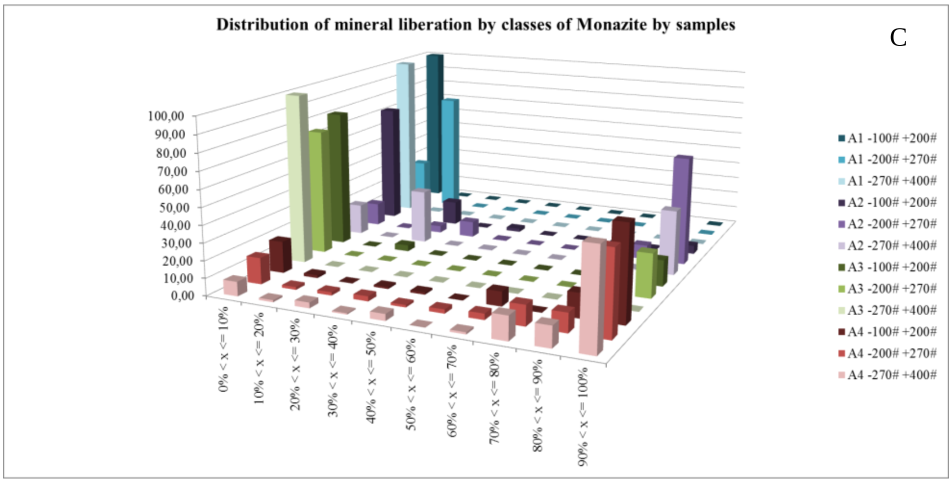


Figure 14 continuation – C) monazite

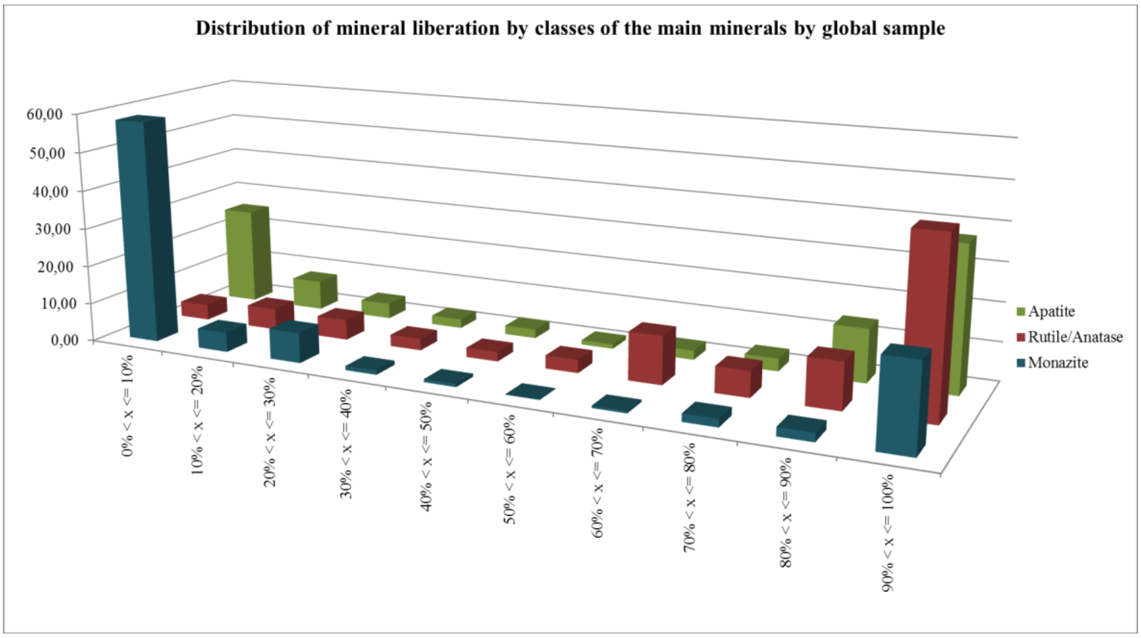


Figure 15 - Distribution of the mineral liberation of interest minerals by global samples

DISCUSSIONS

Physical and Chemical Characterization

The BWI obtained in the test was considered high, even for a previously comminuted sample. The milling test provides a time of 20 minutes of milling to achieve a P80 in 0,106mm (150#) to the Sample 2. Tests with the other samples have not been done since they do not have enough mass. It is necessary to carry out tests to investigate the milling times to obtain a P80 to the other apertures and samples studied.

The particle size distributions by sieve tests show a considerable mass percentage below 38 microns for all samples. The cyclosizer tests with the fraction below 38 microns show the production of fine particles in the comminution procedure carried out by the drilling team.

The chemical analysis of the size fractions indicates that both Oxides and REE metallurgical distributions are of the order of 40 to 50% in the fractions below 38 microns for the Samples 1, 2 and 4, and of the order of 10 to 20% for the Sample 3. It was possible to observe yet that in the ultrafine fractions (below 10 microns) to the Samples 1, 2 and 4 that both Oxides and REE metallurgical distributions are of the order of 10 to 20%.

The results indicate that there was a production of fines in the initial comminution process and this fact has a significant impact on the metallurgical distribution of the main elements investigated in this paper. It is recommended the development of a new study that includes a controlled comminution stage in order to achieve an interpretation of the results that is not compromised.

Mineralogical Characterization

The samples mineralogy is quite similar, diverging in the proportions and the weathering degree. Pseudomorphic crystals of olivine and clinopyroxene occur in all samples and are quite altered. For olivine could be noted alteration to serpentine, chlorite, iddingsite, possible muscovite and goethite/hematite. Relics with original optical characteristics are observed in some samples. The pseudomorphs of pyroxene, with prismatic habit and different granulations, are altered to chlorite, muscovite and possible amphibole and potassic feldspathoid. Crystals of granulation thicker than the matrix, and forms that may be preserved are formed by perovskite and magnetite/hematite. However, due to the granular characteristic of the samples, it is not possible to determine the genetic/temporal relationship of these crystals.

The classification Ti-oxide as anatase is possible only by the XRD characterization, due to the fact that the distinction between this mineral and rutile is not possible by MLA, considering that both have the same chemical composition. The presence of ilmenite and titanite, identified by XRD in samples 1 and 3, respectively, were confirmed by MLA analyzes. The same can be observed for perovskite, which occurs in greater quantity in sample 3.

The different stages of weathering alteration in the analyzed samples, related mainly to the positioning of the rock in depth, can be observed by the difference in the mineralogical proportion. The presence of perovskite in a greater proportion in sample 3 and of anatase in the other samples may indicate the substitution of the first by the last, as already presented by Araújo (2016). The same can be inferred for diopside and chlorite.

The XRD technique did not identify the presence of the OxFe with Ti phase (magnetite with Ti content in its crystalline lattice), only magnetite. On the other hand, by analyzes by MLA/EDS can be detected the Ti element. This can occur due to the presence of microinclusions of titanium minerals in Fe oxides, such as anatase or ilmenite, which cannot be individualized due to the limit of detection of the technique, or the presence of Ti in the mineral crystalline structure.

The presence of calcite in sample 3 and quartz in sample 4 is possibly associated with late events. This inference can be made due to the fact that these minerals do not occur in kamafugites. However, this definition can only be made from petrographic analyzes in rocks, not granulated, thus allowing the identification of textures, structures and real forms of minerals.

The results of mineral association and liberation by MLA show that the interest phases have liberation around 40% and 50%. However the presence of some associations may contribute to obtaining of concentrates from specific processes, which can be observed for apatite and anatase. The phosphate is mainly associated with the aluminous silicate of Mg and Fe, while the Ti-oxide is associated with Fe, Fe and Ti, Ca and Ti oxides or aggregate. Thus the concentration of these interest mineral phases can be done with the application of different routes. The best liberation results for monazite are found for samples 2 and 4, which also correspond to samples with the best modal concentration. In the other samples, the low proportion may lead to associations and liberation that are very disproportionate to the others, considering that small quantity of mineral may not have enough particles to obtain statistical results.

CONCLUSIONS

This unprecedented study made it possible to identify different minerals of interest in the kamafugite samples. The studied samples present a high proportion of fines, possibly due to the comminution process previously realized. This characteristic apparently results in consequences to the chemical distribution in the size fractions, concentrated in the fine and ultrafine portions. It is emphasized that additional studies are necessary in order to control the comminution process parameters.

The main minerals of interest identified are apatite, anatase, and monazite. In addition, was also identified the presence of ilmenite, titanite, OxFe with Ti, Fe-oxide, K-feldspar/feldspathoid, clay mineral, zircon, goyazite-gorceixite, and perovskite. The main minerals of interest present free surface liberation results ranging from 20 to 60%, approximately. The core associations are oxides with other oxides. Apatite is associated with aluminum silicate of Mg and Fe. Anatase is mainly associated with “agreg O Si Ti K Ca Fe Mg Al (P)", Fe-oxide with Ti and ilmenite. In sample 3, there is an important association with perovskite. The monazite is associated with anatase, goyazite/gorceixite, and apatite, depending on the sample. The mineral liberation results show that the phases of interest usually present values above 30%. Results below this value are associated with samples/size fractions with a low modal proportion of these minerals.

Thus, the results presented in this article indicate the possibility of applying specific routes for the concentration of the interest minerals in order to obtain a pre-concentrate. At that point, this sample can be reprocessed to provide products with a higher proportion of these minerals.

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CONTEXT MODEL OF STUDYING MINERAL RESOURCES OF KAZAKHSTAN FOR ORE MINERALS

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The object of modeling is geological exploration of the subsoil. The purpose of the simulation is to set about feasible this process to ensure the replenishment and development of the ore mineral resource base (MRB) of the Republic of Kazakhstan. Knowledge of the subject area indicates the possibility of solving the problem of development of MRBs at the expense of new ore objects with a high probability of their detection on the territory of Kazakhstan. The main difficulty in solving this problem is associated with a change in the geological exploration situation as a result of the almost complete depletion of a fund of easily discovered ore objects. The complication of the geological prospecting situation has led to a significant increase in the cost of work to identify new deposits. So in 1965, the average world cost of opening (in comparable prices) of one non-ferrous metal field was 13-14 million dollars, and now - 40-50 million dollars (according to some data, even significantly more). In general, the study of subsoil is considered as an information process, including obtaining new information about the subsoil, its processing (the transition from observations to models and knowledge), accumulation and storage, management of methods of obtaining and target transformation of information with estimates of forecast resources.

In Kazakhstan there are two areas, a kind of technological "mainstream" in assessing the subsoil for new ore objects in recent decades:

- a continuous geological survey of areas (GSA), geological and mineragenic mapping (GMM) and deep geological mapping (DGM) on a scale of 1: 200000;

- carrying out of large-scale prospecting and search-and-estimate operations on sites with "underestimated" ore objects or allocated on the basis of some other considerations specific for each site.

The results of the study of Kazakhstan's mineral resources are estimated differently, but the lack of discoveries of new significant ore objects is a fact. And this fact clearly indicates the need for the formation of new approaches to the organization and technology of subsoil assessment when carrying out forecasting and prospecting works.

Any real objects, systems and environments, in particular geological ones, can be described by an almost infinite number of characteristics of the 1 st and 2 nd genera, i.e. characteristics directly measured (estimated) and constructed by some rules on the basis of measurable. The initial choice of characteristics is determined by the knowledge available in a particular subject area and the accumulated practical experience of solving specific problems. If we consider the study of subsoil as a task to identify ore minerals, then knowledge of the solution of this problem and the initial choice of characteristics describing the geological environment is formed by metallogeny, the science of movement, association, the differentiation of chemical elements (in particular, metals with low clarkes), as well as patterns formation and placement of ore objects of different hierarchical level (ore regions, ore sites, deposits) [1,2].

The roadmap of the transformation of metallogeny from descriptive qualitative to predictive quantitative is based on adequate physical models of the processes of formation of ore objects and objective information about geological environments and ore-forming systems. Now it has become clear that the movement, association, differentiation of elements in the geological environment is characterized by coherent, self-consistent behavior. Systems with such behavior of the constituent elements are described on the basis of the principles of synergetics and lead to the emergence of different-scale stationary states, the formation of a wide range of dissipative structures and low-entropic objects [3-5]. From the physical essence of the formation of ore objects, it is clear that metallogeny should be based on the study of one- and multidimensional fields of concentration of elements, the allocation of different-scale structures of these fields. At the same time, the ore objects themselves are specific structures of concentration fields, the attributable features of which are sharply increased contents of one or several chemical elements in the macrovolume.

A simple and meaningfully clear basic model for the formation of ore objects is the model of redistribution of elements "in place" [2]. Such a redistribution leads to polar structuring of concentration fields, where ore deposits are located in the regions of accumulation of elements (or their nearest periphery). The possibilities of practical use of the redistribution model with the isolation of metallogenic (ore-forming) systems are associated with the interposition of the regions of removal and deposition of ore matter in space. At present, the trend is dominating the field of mobilization and removal to great depths. In principle, such an approach is nothing but an explanation of ad hoc, that is, an "explanation for a given case". But now there are many facts that indicate that the formation of ore objects occurs due to metals extracted from the surrounding ore objects of rocks (this question was considered in more detail in many works [6,7 and others]. Hence, a fairly obvious consequence: the most simple, fundamental and informationally important characteristics of the geological environment in the search for ore objects are the concentrations of chemical elements. Mapping of concentration fields is the most direct and natural way of forecasting and searching for ore objects. It is important that the concentrations of elements are real physical quantities that allow their objective measurement, a formal description, demonstration of reproducibility, the definition of systematic and random deviations. It is important that the concentrations are determined in the ratio scale in which all algebraic transformations and logical operations are possible, and also that the analysis of concentration distribution allows deterministic and probabilistic interpretation, allowing to flexibly use a wide range of mathematical methods and models, which opens the way to digital metallogeny and digital forecasting.

It is on the mapping of the fields of concentration of ore, accompanying and antagonistic elements, on the allocation in these fields of geochemical structures and geochemical systems of ore objects, IONEX [8,9] technology is based, which can be used as a base for studying the mineral resources of Kazakhstan for ore minerals. Solved problems and applicability of IONEX technology are:

• application technology for forecasting and searching for ore objects of a hierarchical level from ore regions to deposits lying at a depth of up to 500-1000 m or covered with a cover of loose sediments up to 200-300 m thick;

• the technology consists in mapping the fields of gross contents in indigenous and / or loose rocks, the content of mobile element forms in soils (MPF analysis); isolation of geochemical structures on the constructed fields, especially geochemical systems of ore objects;

• the technology is implemented on several scale levels, realizing the principle of sequential detailing of geochemical structures and sharp "squeezing" of allocated potentially promising areas (approximately 6-10 times after each stage of work).

At each scale stage of work on IONEX technology the following works are performed:

1) Preparatory work. The area of reference for forecasting and prospecting works is determined, the scale is adjusted (depending on the size of the area), a network of sampling points is determined with the assignment of coordinates to them, and the necessary information (geological, geophysical, geochemical) is collected.

2) Sampling. Two or three samples are sampled at each sampling point: soil sample (for phase analysis of MPF), samples of loose and bedrock rocks (for gross analysis of element contents). The sample of bedrock is selected in the presence of outcrops of bedrock. Special instructions have been drawn up for the sampling of soils, loose and bedrock rocks.

3) Analysis of samples. At present, IONEX technology uses 2 types of analyzes:

• a phase method for analyzing the content of mobile (weakly fixed) element forms in soil samples (MPF analysis);

• highly sensitive analysis of gross contents of elements in samples of loose and bedrock rocks.

Phase analysis of MPF provides selective extraction of weakly fixed forms of metals in the form of fulvates and humates from soils. The distribution of Me / C on the surface is determined by the distribution of the content of the elements at depths, i.e. geochemical structures are fixed at depths of up to 500-700 m (in particular, under loose sediments with a thickness of more than 100 m). The mobile forms of the following elements are analyzed: Au, Ag, Sb, As, V, Mn, Co, Ni, Zn, Pb, Cu, Mo, Bi, Ba, Sc, Li, Y, Ce, Te (if necessary, the list of elements can be expanded).

The main requirement for analyzing gross contents is sensitivity 3-5 times lower than the clarke of the corresponding element. The gross contents of the following elements are analyzed: Zn, Pb, Cu, Mo, W, Sn, As, Sb, Ba, Ni, Co, Ti, Mn, Bi, V, Sc, Re, U, Li, Y, Ce, In, Te, Au, Ag, Pt, Pd, Ir.

4) Special data processing. It includes the following operations:

• Structural statistical analysis of the distribution of content of elements with the allocation of "concentration levels" and natural boundaries between levels;

• construction of "generalized" and "normal" models of 2D distribution of elements by area of work;

• non-linear correlation analysis of model contents of elements;

• Clustering and zoning of multidimensional geochemical data;

• construction of a multidimensional nonlinear predictive function using the technology of the "multimodal prediction method" (if prediction standards are available).

Data processing and modeling are carried out with the help of programs included in the author's software complex ELAN [10]. In addition, the data processing uses standard Excel, Surfer, MapInfo.

5) Interpretation and recommendations for further work. Interpretation of the results of data processing and modeling is based on the idea of the formation of ore objects in ore-forming systems and the methodological consequences of the development of systems with self-organization. When interpreting, it is necessary to use information about the geological structure, geophysical fields and other data. In the interpretation on which recommendations are based on the direction of further work, it is necessary to formulate the interpretative positions adopted and the main factors on which the allocation of potentially promising areas is based. It is not excluded and various interpretations of the results obtained and, accordingly, various (multivariate) recommendations on the direction of further work.

Geochemical technology IONEX as a basic method of forecasting and prospecting works was used in the following regions of Kazakhstan:

• Leninogorsk and Zyryanovsky districts of the Rudny Altai. The area of the works is 24000km2, the scale is 1: 500000 and 1: 100000. The customer works: KazZinc LLP, 2005-2007.

• Western Torgay. The area is 11000km2, the scale is 1: 500000 and 1: 100000. The customer works: LLP "KazTsink", 2007-2008.

• Zhezkazgan ore district. The area is 137,000 km2, the scale is 1: 1,000,000. Customer works: Committee of Geology and Subsoil Use, MIR RK, 2014-2015.

• Spassk copper ore zone (Central Kazakhstan). The area of work is 12000km2, scale 1: 200000. Customer works: LLP "JV" Tau-Ken Project ", 2015-2017g.

In all regions, work on mapping geochemical fields and their interpretation made it possible to reveal new regularities in the location of ore objects and to identify new potentially promising areas for gold, copper and polymetallic mineralization [9, 11, 12].

The accumulated experience allowed to develop the concept of studying the mineral resources of Kazakhstan and digital forecasting of ore minerals based on the geochemical technology of IONEX [13]. The stages of the planned works are shown in the table.

Table. Stages of planned work

STAGES	Primary scale	Approximate area, km2	Cost of 1 km2 (DUS)	Selectable objects	Received knowledge	Notes
1	2	3	4	5	6	7
I	1:2 500 000 (regional)	1 200 000 – 2 000 000	0.8	Ore regions, large ore sites	New knowledge on the metallogeny of Kazakhstan	The entire territory of Kazakhstan is studied, where the thickness of loose deposits is less 200–400 м
II	1:500 000 (regional)	15 000– 40 000	11	Ore sites, areas of large deposits	New knowledge on the metallogeny of ore and potentially ore areas	9-12 squares are studied, corresponding to ore areas or large ore sites (20-30% of the area of Phase I works)
III.	1:200 000– 1:100 000 (local)	500 – 1500	45-150	Small ore sites, areas of deposits	New knowledge about the quantitative regularities of the localization of deposits and ore zones	4-10 sites are studied in each area, identified as promising in Phase II (a total of 40-60 sites)
IV	1:25 000 (detailed)	60 – 120	1400	Deposits, ore zones for drilling operations		It is studied on 1-3 objects on each of work sites phase III

The most important and in many respects determining the successful implementation of the entire program is the I-st regional (global) stage. At present, the design and estimate documentation for its implementation has been developed and approved.

Estimate the expected results of the program can be done by analogy with similar searches in China (with the introduction of amendments to the incompleteness of information). Probably, we can expect to find out within a period of 5-15 years several dozens of new deposits of nonferrous, noble and rare metals. In addition, studies on the proposed program will make it more reasonable to select sites for prospect evaluation and revaluation of poorly studied ore objects.

The effectiveness of the results of the IONEX forecasting and search technology increases (almost without increasing costs), if the interpretation of results uses already accumulated geological, geochemical, geophysical information. Active interaction and interpenetration of new information about the subsoil (in particular, on the elements content fields) with the traditional information already available in the bank (for example, geological maps) will stimulate the emergence of new metallogenic models and knowledge, and they, in turn, guide the processes of obtaining a new target information about the subsoil. The use of new and already accumulated information is supposed to be carried out within the framework of the formation of the National Bank for Geological Data and Knowledge.

To form a bank it is necessary to solve the following tasks:

- Classification of description objects;
- Classification of information on objects of description, scales, accuracy of objectivity of definition, a priori target value;
- Classification and systematization of knowledge;
- The method of presentation and use of knowledge for the selection of information;
- Ways of formalized description and coding of information;
- Schemes for filling the Bank with information and knowledge;
- Methods for determining the value of information and knowledge, how to extract knowledge from information when solving specific problems;
- Adaptation of technologies for subsoil assessment to the use of the Bank of Data and Knowledge.

In the 21st century, the trend of sustainable development of organizations, production and scientific processes is related to effective digitalization of the processes of interpretation and management of information and knowledge. In Kazakhstan, for this purpose, real prerequisites have been created:

- the state program "Digital Kazakhstan" was adopted;

- national standards of ST RK ISO 21500, 21504, 2831 have been adopted, which regulate tools and methods of project management, including for projects in the field of subsoil research [14].

- Academic preparation of masters and PhD doctors on project management is conducted. By now about 300 masters and PhD doctors in project management have been trained;

- to adopt the Code "On Subsoil and Subsoil Use", which expands opportunities in attracting investments in the study of Kazakhstan's mineral resources to ore minerals;

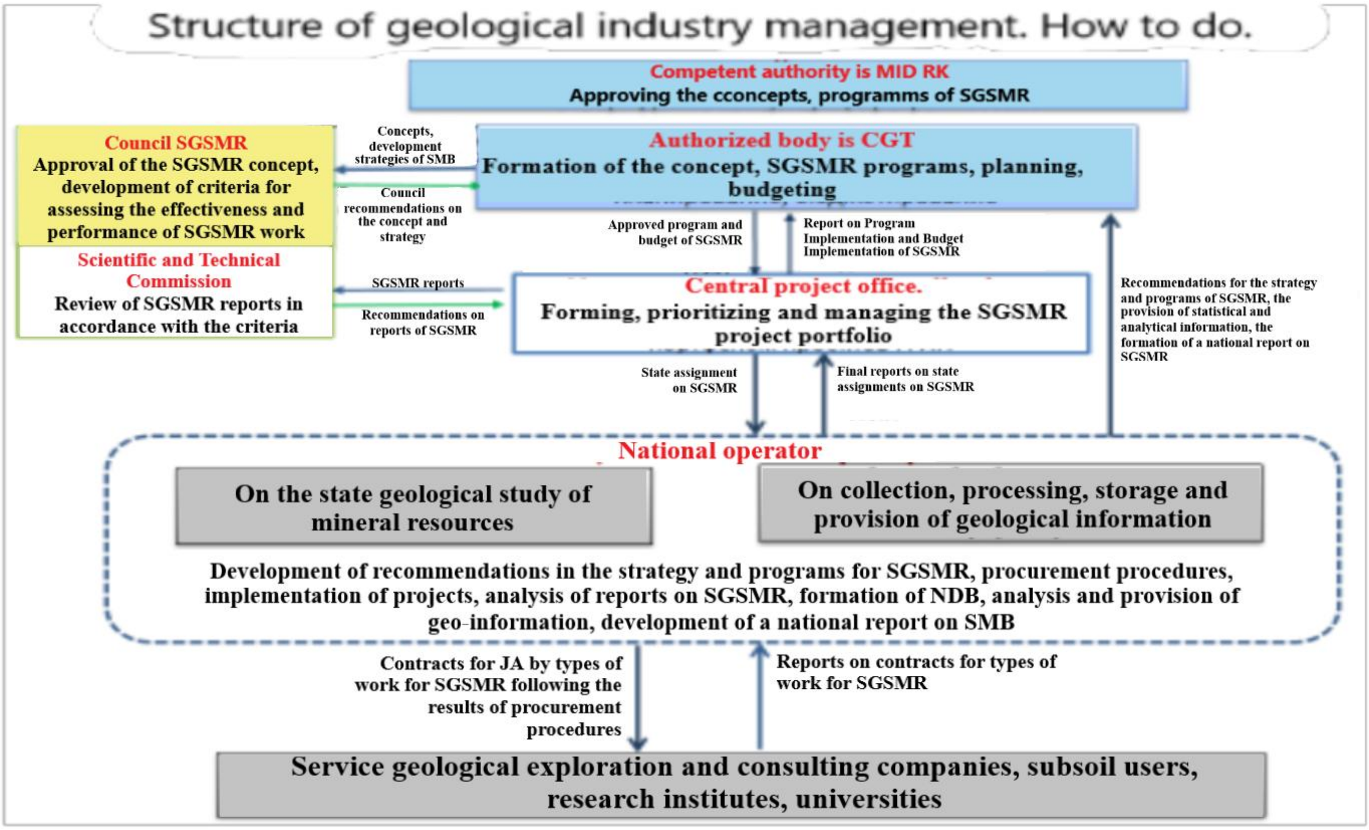
- developed a set of measures aimed at implementing the Concept of the development of the geological industry until 2030 [15, 16].

In particular, the introduction of project management will allow:

- ensure the validity, timeliness and further development of subsoil research;
- more effectively use the resources of the state budget;
- to achieve the planned results in a shorter period;
- improve vertical and horizontal intra- and inter-agency links.

As part of the implementation of the set of measures, a modernized structure for managing the geological sector of the Republic of Kazakhstan is proposed (see pic.).

The proposed contextual model for the study of subsoil contains new elements that together can ensure the development of Kazakhstan's mineral and raw materials base for ore minerals in a new geological exploration situation and taking into account the tasks of increasing the global competitiveness index of our country.



Picture. Structure of the management of the geological branch of the Republic of Kazakhstan

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DEVELOPMENT OF POM-1 – PORTABLE DETECTOR OF MINERALS

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ABSTRACT

Employees of Center Consulting LLP, Two Kay LLP, and Aspap GEO LLP have developed a project to create a portable optical X-ray fluorescent energy dispersive micro analyzer that allows the determining the elemental and mineral composition of the samples directly on the working site with a detail of up to 100 microns. The device provides opportunity to identify not only the chemical, but also the mineral composition of the samples. This is especially important and valuable in geology when carrying out prospecting and exploratory work that requires a prompt identification of the elemental and mineral composition of geochemical and core samples without carrying out expensive laboratory tests. An experimental prototype of the portable mineral identifier, POM-1, was created and tested.

KEYWORDS

X-ray fluorescence analysis, elemental composition, mineral composition, microanalysis, Compton scattering, Rayleigh scattering

INTRODUCTION

The urgency and need to create a portable device

At present, there is a great need for small-sized multichannel spectrometers that allow working outside the laboratory, at the site where the object of analysis is located. They are easily integrated into complex technological processes, operate at the level of microanalysis without destroying the object in real time, and are not particularly demanding of environmental conditions. This is especially important in geology during prospecting and exploratory work, which requires a prompt identification of not only the chemical (elemental) composition of core, geochemical and other types of samples in the field, but also of the mineral composition without running expensive laboratory tests. The availability of such equipment will shorten the period of exploratory operations, improve their quality in the confirmation of reserves, and optimize and improve the technology of processing explored reserves. Foreign companies, including those in the geological industry, actively work on the creation of analogues of such instruments. This determines the relevance and timeliness of this topic.

Market analogues of POM-1

Laser spark emission spectrometers. LIBS technology

There are analogues of the developed device on the market; among them are laser spark emission spectrometers, e.g. LAZER-Z500-AURIS or SCIAPS LAZER Z100, of which operation is based on a technology called LIBS. It essentially measures atomic emission when a sample substance vaporized by a laser beam gets excited by laser breakdown (excitation). A pulsing laser beam (Q-switched Nd: YAG) focuses on the surface of the analyzed material. With pulse duration of the laser beam, which is usually 10 nanoseconds, the power density on the surface can reach 1 GW/cm2. With such a very high specific energy density, a temperature on the surface of the studied material instantaneously reaches over 30000°C, and plasma is formed. Plasma is basically an electrically neutral combination of neutral and exited atoms, ions, and electrons. During the process of recombination of excited ions with electrons and the return of atoms of the investigated substance to low-energy states, photons with wavelengths in the range of 190-1100 nm, depending on atoms of different elements, are emitted [1].

Radiation by means of an optical system is sent to a sensitive CCD spectrometer, which registers the lines of all the elements present in the analyzed substance simultaneously. The resulting optical spectrum is characteristic for this substance. Their intensities are related to the concentrations of the elements in the material under study. In the wide optical range, it is always possible to choose not the interfering lines of most of the chemical elements, even light elements (B, C, Si, Al, P) that are necessary for the researcher in complex mineral bases, including, for example, those containing a large amount of Fe and Cl. This makes it possible to use LIBS in a variety of industries [2,3]. Instruments provide locality of the analysis up to 50 μm, are able to determine chemical elements from Be to U when the sample is evaporated (destructive analysis method). The instruments are mainly oriented to analyze alloys, welds, sorting of metals and any solid samples.

The LIBS method is destructive, because the laser beam makes the sample evaporate to form vapors and aerosols, while thin samples (up to 100 μm) such as microcrystals and small inclusions are completely destroyed. Atomic-emission spectra are very complex even for pure substances, since they contain hundreds of lines. For substances of complex composition, such as ores, the spectra contain thousands of lines. As a consequence, compact (handheld devices) have poor resolution and, subsequently, a large number of overlays that make it difficult to identify chemical elements, and often give incorrect interpretation of the analysis results. Argon purging is required to determine light elements. For light samples, the power of a miniature laser may not be sufficient due to reflection of the original laser radiation from the sample (as a result, weak lines will not be registered), that is, certain elements will not be identified, which also leads to errors in the interpretation of the sample composition. The optics of the spectrometer is very sensitive to vibrations and shocks, so the life and reliability of optics and a miniature laser are not sufficient for fieldwork. In addition, manufacturers mainly focus on the analysis of metals and alloys, welds, etc.

Raman spectrometers

Recently, compact spectrometers of combinational light dispersion (Raman spectrometers) have appeared on the market. Their work is based on the scattering of laser light by molecules of a substance and the registration of this scattering by a compact atomic emission spectrometer. The intensity of the Raman spectrum is very low and requires a very stable and powerful laser light source, high-speed optics to collect light scattered by the sample and high-sensitivity light detectors [4]. An example of the most advanced and modern Raman spectrometer is the Inspector Scope (300-500) of the American company SciAps. The device is equipped with a laser with a wavelength of 785 nm and a beam diameter of 25 μm, as well as a three-coordinate table and a video camera with 100-fold magnification. There is a database of substances and materials for their determination. The device is mainly focused on the definition of narcotic drugs, medicines, explosives and the simplest minerals. The method for determining substances is based on comparing the scattering spectra with the reference spectra of pure substances available in the library (https://www.sciaps.com).

Portable Raman spectrometers do not have sufficient resolution for recording the scattered spectrum; because of their compactness, in addition, many minerals luminesce under the laser radiation and do not allow identifying their composition. Dark samples (dark-colored minerals) completely absorb laser light, so they do not emit a signal from the Raman radiation. For this reason, dark minerals cannot be identified by Raman scattering. The quality of the Raman spectra depends on the stability of the laser, its resolution (line width), and the quality of the filters for removing Rayleigh scattering, which is difficult to ensure in portable devices. Since the intensity of the Raman spectrum is very low, very high-speed optics and highly sensitive scattered-light detectors are required. It also requires high-resolution optics, which is also difficult to provide for a portable device. The identification of substances is based on the principle of comparing the measured spectra on a specific instrument with library spectra measured under different conditions, which also introduces additional uncertainty in the identification of the substance. The Raman spectrum corresponds to vibrational states of molecules of a substance that does not reveal the chemical composition of the substance. This is the fundamental difference between X-ray and Raman spectroscopy.

X-ray fluorescence analyzers

There are also prototypes of the developed device on the market; among them are an X-ray fluorescent (XRF) XGT-7200 analytical microscope from NYTEK Instruments, TORNADO M4 X-ray fluorescence micro analyzer from BRUKER, and FOCUS-M2M (Russia). These micro analyzers ensure the locality of the analysis from 10 μm to 1.2 mm, 0.3 mm, 80-150 μm, respectively, using X-ray optics. The devices are equipped with optical video cameras that allow analyzing a required point on the sample in the range of detectable elements from Na (with evacuation of the sample chamber) to U. The instruments use X-ray tubes with a Rh anode at a voltage of up to 50 kV and a current of 1 mA, as well as SDD silicon detectors. Traditionally, raster electronic micro analyzers (SEM) are also widely used for microanalysis purposes. The principle of operation of RF spectrometers is based on recording the X-ray fluorescence of the sample material. RFS devices consist of an X-ray source, a sample holder and a spectrometer (Figure 1). The spectrometer measures the wavelength (λ) or energy (E) and the intensity of the fluorescent radiation emitted by the sample. Depending on the parameter directly measured by the spectrometer (λ or E), devices with a wave (VD) and energy dispersion (ED) are distinguished, the arrangement of which is fundamentally different. X-ray sources used to excite atoms in the sample, as a rule, do not differ in principle from devices with HP and ED. The most widely used source of primary X-ray radiation in the RFS are X-ray tubes [5].

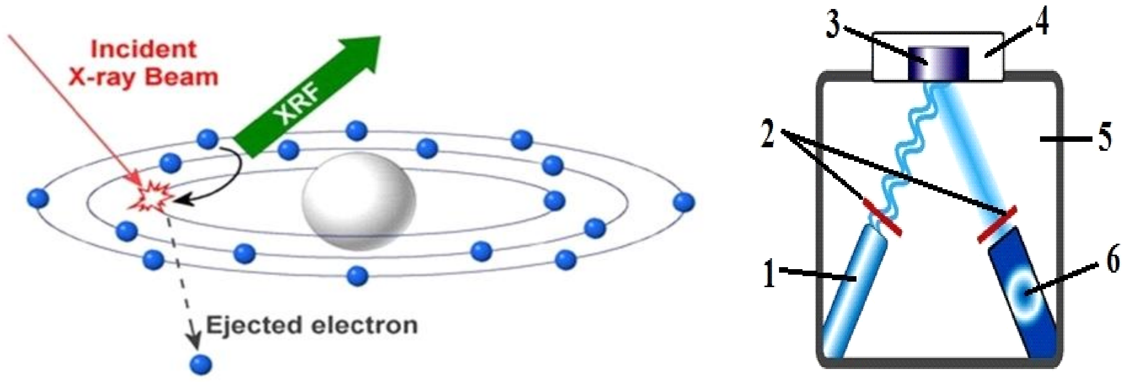

Figure 1 - Principle of operation and diagram of X-ray fluorescence devices
1 - X-ray tube, 2 - filters, 3 - sample, 4 - chamber, 5 - vacuum chamber, 6 - semiconductor detector

Most devices are not compact (portable) and are used in laboratories under special operating conditions, mainly for analysis of the composition of various materials, micro-objects, alloys, metals, electronic equipment boards.

Disadvantages of POM-1 analogs

The shortcomings of similar POM-1 devices include the following:

- Almost all instruments available on the market are stationary laboratory instruments that require special conditions for temperature, humidity, dust;
- To ensure local analysis, X-ray optics are required, which immediately imposes restrictions on excitation energy (up to 15-17 keV) and, as a consequence, the determination of elements from silicon to molybdenum;
- The devices use excitation systems that use direct radiation from X-ray tubes to provide the necessary statistics for the intensity of the characteristic radiation. This increases the background from the anode material, which limits the detection limits
- X-ray micro analyzers conjugated with electron microscopes have good locality (an electron beam that excites the characteristic radiation of a sample has a diameter of several microns). However, these devices are cumbersome, very expensive; they require special operating conditions, facilities and special maintenance. In addition, the electron beam excites only light elements, which is not enough to determine many minerals.
- In many prototypes, when excitation of the characteristic radiation by the direct spectrum of the X-ray tube, the excitation system does not allow changing the spectrum of the exciting radiation to effectively determine the light, medium and heavy elements in different matrices, which limits the sensitivity and determination of the composition of many minerals.
- Excitation systems of many prototypes using X-ray optics to ensure local analysis require special operating conditions and cannot be used in the field;
- The software of prototypes allows identifying mainly the chemical (elemental) composition of the investigated objects, but does not allow identifying their mineral composition.
- Portable instruments are mainly intended for analysis of the composition of metal alloys and various materials. However, their software does not allow you to determine the mineral composition of the analysis objects.

STRUCTURE OF POM-1

The X-ray fluorescence energy dispersive spectrometer RLP 21T of the Kazakhstan Company AspGeo LLP was used as a basis for the developed instrument. RLP 21T is designed to determine the chemical composition of any solid samples, alloys and small samples (2 mm or less), contains a video camera for aiming at the analysis point. The software allows to carry out quantitative analyzes of samples of unknown composition, thickness of coatings within a few seconds. The device does not have X-ray optics and is easy to operate. The appearance of the device RLP 21T is shown in Figure 2. A distinctive feature of the entire spectrum of the equipment manufactured by the company is a powerful methodical and software, which largely determines the basic analytical characteristics of devices. Delivered products fully meet international standards and are maximally adapted to domestic operating conditions. An extremely important factor is a much more effective process of training, warranty and post-warranty maintenance of equipment when working with domestic manufacturers. Instruments since 1992 have been successfully operated by dozens of enterprises of the Republic (Kazakhmys Corporation LLP, Kazzinc LLP, Volkovgeology, Two Kay LLP, Lanton-Geoservice LLP, Customs Committee of the RK, Center for Cash Operations and Storage of Valuables NB RK, Mint of the NB RK, etc.).

The purpose of the work was the creation of a small-sized multi-channel X-ray spectrometer, a microanalyzer that allows to work outside the laboratory, in the locations of the object of analysis. POM-1 should work at the level of microanalysis without destroying the object in real time. Also, the device should not be particularly demanding of environmental conditions. The device should determine not only the chemical, but also the mineral composition of the objects of analysis. According to the goals, the following design features and equipment were determined:

- Metal case;
- A chamber for placing the samples and a sample plate;
- X-ray tube;
- Energy dispersive silicon - a lithium detector of the SDD type, with an area of at least 25 mm2 and a resolution not worse than 130 eV, cooled by a thermoelectric refrigerator at Peltier effect, which does not require liquid nitrogen;
- Excitation system for characteristic radiation providing the necessary counting rate from the sample for real-time operation, as well as the possibility of changing the tube parameters when studying objects with light, medium and heavy matrices;
- The system of forming an exciting X-ray beam that provides a beam diameter not worse than 100 μm and allows to study objects up to 100 μm in real time;
- Electronic optical microscope with magnification no worse than 200, containing a color video camera with a resolution of 5 megapixels or better. The optical axis of the microscope intersects with the axis of the x-ray spot on the sample to provide analysis of the selected point on the object of the study;
- Three coordinate plate for precise guidance of the X-ray and optical microscope on the selected point of the test sample;
- Program of identification of minerals from measurements of spectra and quantitative analysis of the composition of the investigated objects (large and small crystals up to 100 μm and larger, various inclusions, etc.);
- The electronic base of X-ray spectra of the chemical composition of pure minerals, taking into account the Compton scattering occurring in the deposits of Kazakhstan, under the excitation conditions specified in the TOR. The POM-1 scheme is shown in Figure 2. The results of the comparative analysis of the characteristics of POM-1 with analogues are presented in Table 1.

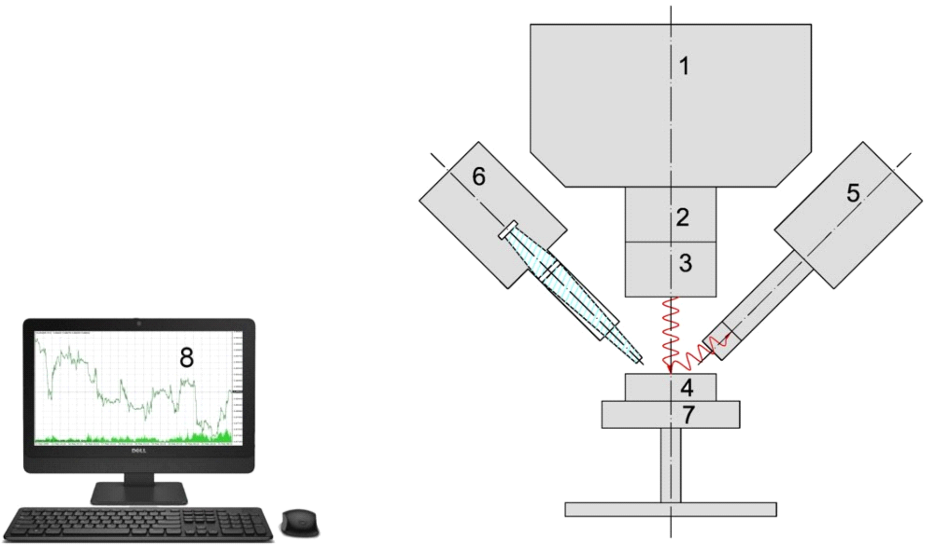

Figure 2 - Diagram of the POM-1 device:
1 - Spectrum processing and registration system, 2 - X-ray tube, 3 - X-ray excitation and formation system, 4 - Sample, 5 - X-ray SDD detector, 6 - Digital microscope with 500x magnification and camera 5 mp, 7 - three-coordinate plate for samples, 8 - PC.

EXPERIMENTAL RESULTS OF PROTOTYPE POM-1

Taking into account the requirements, the model of the POM-1 device was created. The created layout was successfully tested. On the POM-1 model, the x-ray spectra of various materials were measured (Figures 3, 4). The elemental analysis of the sample was carried out according to the existing approved methodology and using ready-made software developed by Aspap Geo LLP. Used technique allows simultaneous 44 elements analysis of a sample from magnesium (Mg) to uranium (U). It is planning to improve the methodology and software to determine the mineral composition of the sample in the future. To analyse the mineral composition the existing libraries of mineral spectra will be used, however it is necessary to create our own libraries by measuring samples of various minerals. In addition, the software should be upgraded to obtain results on the mineral composition of the samples under study. For example, in Fig. 3, experimental results of measurements of brown coal are presented for the purpose of working out a technique for determining carbon. Carbon is not detected by the device,; however, the ratio of the Compton and Rayleigh peaks is unambiguously determined by amorphous carbon. Also, according to the intensity ratio of the Compton and Rayleigh peaks, it is possible to determine the heavy matrix of the tungsten concentrate (Figure 4). Thus, having libraries of the spectra of minerals and spectra of the measured samples, by comparing and calculating the obtained values of the concentration of elements, Compton and Rayleigh scattering, one can obtain results on the mineral composition.

The results of a comparative analysis of the characteristics of POM-1 with analogues are presented in Table 1.

Table 1 - Comparison of the characteristics of analogs, prototypes and the intended working prototype of the device

Characteristics of methods	Raman	LIBS	RFA-spectrometer	RFA-spectrometer	RFA-spectrometer (working prototype)
	Inspektor Scope 300-500 SkiAps	Lazer Z 500	Portable spectrometer Tracer5i Bruker	M 4 Tornado Bruker	RLP 21 Kazakhstan
Destructive/ non-destructive	non-destructive	destructive	non-destructive	non-destructive	non-destructive
Mobility yes/no	yes	yes	yes	нет	yes
Microanalysis	yes (50 µm)	yes (50 µm)	no (3 mm - 5 mm)	yes (300 µm)	yes (100 µm)
Measured parameter	Molecular spectra (combinational dispersion)	Atomic emission (spectra)	Characteristic X-ray radiation spectra	Characteristic X-ray radiation spectra	Characteristic X-ray radiation spectra и scattering*
Chemical composition	no	yes	yes	yes	yes
Dependence on the excitation system	yes (stability and laser resolution)	yes (laser wavelength and argon purging)	yes (helium purging, evacuation for light elements)	yes (helium purging, evacuation for light elements)	no
Sensitivity for signal	Very low (weak signal, combinational dispersion)	satisfactory (argon blowing for light elements)	satisfactory	satisfactory	high
Stability of the excitation source	requires stabilization	requires stabilization	good	good	high
Effect of the sample on the results	affects (luminescence)	reflection from light objects	no	no	no

Sensitivity to vibrations, etc.	satisfactory	satisfactory	satisfactory	high	satisfactory
Identifiable substances and materials	organic substances, drugs, medicines, substances, minerals.	organic and inorganic substances	Solid substances, liquids, metals, alloys, films, etc.	Solid substances, liquids, metals, alloys, films, etc.	Solid substances, liquids, metals, alloys, films, minerals

In addition, the Compton scattering analysis, as well as the program for reconstructing the spectrum from the measured one, is possible using the POM-1 analyzer.

CONCLUSIONS

The developed analyzer POM-1 does not have the shortcomings inherent in analogs and prototypes, since along with the definition of the chemical composition at the level of microanalysis (the size of the X-ray beam 100 μm combined with an optical microscope) and the reference database on the chemical composition of known minerals, it allows to determine the mineral composition of rocks in the field. Measurement of the monomineral spectra with allowance for Compton and Rayleigh scattering makes it possible to determine with a high degree of reliability minerals that include such light elements as H, Li, Be, B, C, N, O, F and other heavier elements by comparison with library spectra monominerals and their measured chemical composition. This is an innovative part of the analyzer, which has no analog and gives it a greater competitive advantage over other prototypes.

The largest companies operating in the subsoil use sector of the Republic of Kazakhstan, such as Kazzinc LLP, NAC Kazatomprom JSC, Kazakhmys Corporation, NGC Kazgeologiya JSC and their subsidiaries, as well as scientific institutions of Kazakhstan and the Eurasian Union, working in the geological industry and mineralogy, may be interested in this device manufactured in Kazakhstan using domestic technology.

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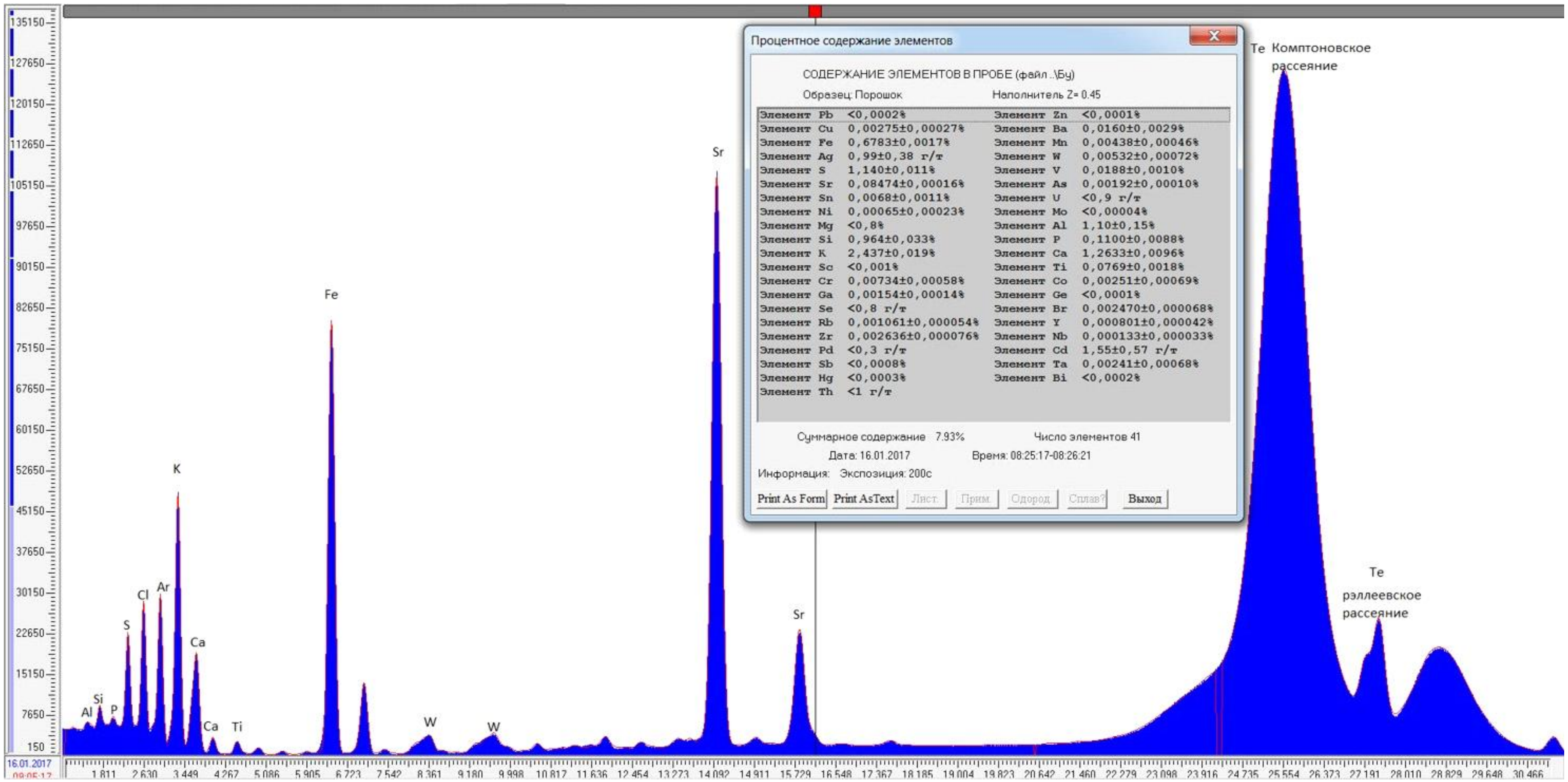

Figure 3 - Examples of X-ray spectra with Rayleigh and Compton scattered radiation on amorphous carbon (brown coal).

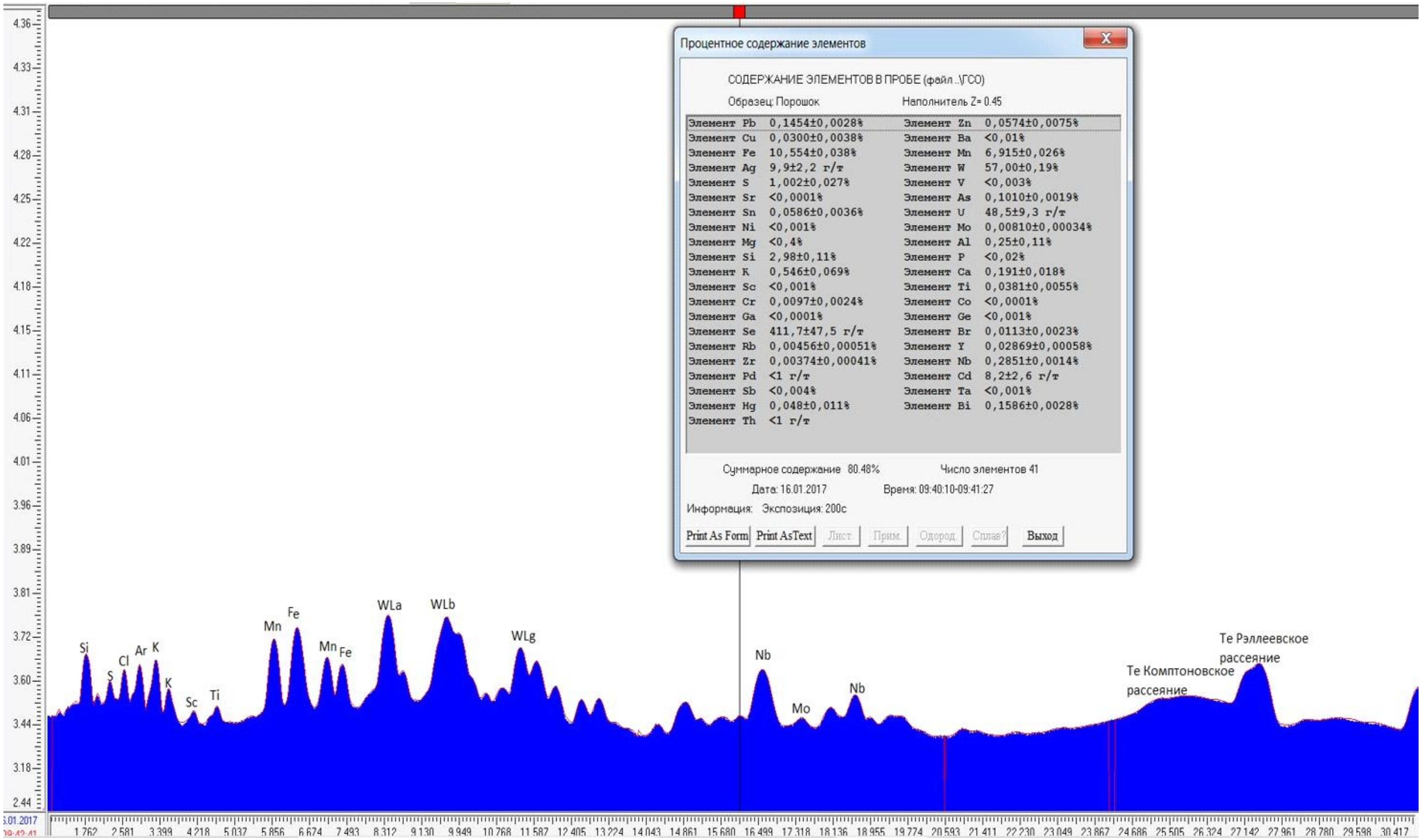

Figure 4 - Examples of X-ray spectra with Rayleigh and Compton scattered radiation on tungsten concentrate.

IRIS ONLINE NEW (INTERACTIVE RAW MATERIALS INFORMATION SYSTEM), AN EXAMPLE FOR A WORLDWIDE UNIQUE NATIONAL RAW MATERIALS INFORMATION SYSTEM

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25th World Mining Congress
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ABSTRACT

The authors present the new Austrian digital Interactive Raw Materials Information System IRIS-Online NEW, allowing to display geological, tectonical, geochemical, aerogeophysical maps, maps of metamorphic events, mineral deposits / occurrences a.s.o. simultaneously. The data base comprises more than 5700 entries of Austrian mineral deposits / occurrences and more than 17.000 references. Special queries (groups of minerals, deposits, geochemical anomalies a.s.o.) are possible. The mineral deposits / occurrences are subdivided into appr. 200 metallogenetic districts (mineral deposits / occurrences within a clearly defined tectonic unit, a specific stratigraphic or facies unit, characterised by both similar shape and mineral content of the individual deposits / occurrences). All deposits / occurrences of a metallogenetic district are supposed to be cogenetic. IRIS Online NEW is not only an important expert tool for exploration, but for scientists as well, allowing to synthesise their own metallogenetic concepts.

KEYWORDS

Digital Interactive Raw Material Information System, geology, tectonic, geochemistry, aerogeophysics, metamorphic events, mineral deposits / occurrences, Austria

INTRODUCTION

Minerals policy requires a tailored made legal base on the one hand and a sound information base on the other hand. Therefore fundamental information concerning mineral deposits is a duty of the public administration. Mining companies should be able to set up their special exploration concepts on a public reliable and sufficient information base.

Raw material information systems are essential for science as well. Those systems should allow to get quick information regarding the distribution of mineral occurrences of particular tectonic units, detailed information about type of deposit, minerals content a.s.o.. The information system should also facilitate to display the mineral deposits / occurrences on proper tectonic and / or geological maps, geochemical maps, aerogeophysical maps and other information bases.

The publication of the printed "Metallogenetic Map of Austria" in 1997 was a first milestone (WEBER, L. 1997a, b). For a first time mineral occurrences, itemised by shape of the ore bodies, group of minerals, size and orientation have been displayed on a newly compiled tectonic map 1:500.000 by F. EBNER. The disadvantage of a printed map is, that by far not all mineral deposits /occurrences can be displayed due to the scale of the map. A further disadvantage of a printed map is that simultaneous combinations with geochemical and / or aerogeophysical base information are impossible. However, the results have been summarised in the "Handbook of mineral deposits of ores, industrial minerals and energy fuels in Austria" (WEBER. ed. [1997 c]).

Subsequently for the very first time a digital Interactive Raw Materials Information System („IRIS") has been developed, which allowed detailed queries concerning mineral deposits / occurrences. Contrary to the printed („static") map this CD ROM based system enabled the user to visualise geology, geochemistry, aerogeophysics and mineral deposits / occurrences simultaneously (WEBER et al. 2001, 2002a,b). In 2009 the system has been published as an Internet version as well. To run the program use: https://www.geologie.ac.at/services/webapplikationen/geofast/iris-interaktives-rohstoffinformationssystem/

Fundamental findings concerning the tectonic architecture of the Eastern Alps with remarkable implications to the metallogenetic concept of the prealpidic basement were reasons for the compilation of a new tectonic map and the revision of the entire data base. In a multi-year exercise the new information have been compiled by the experts of the Mineral Deposits Experts Group of the Austrian Mining Association and the staff of the Geological Survey, merging the data base of both the classical IRIS and the Austrian mining- and mine-dump register.

The latest perceptions of the tectonic structure in particular of the Eastern Alps led to the compilation of a new tectonic map (scale of compilation 1: 1 Mio) as well of maps of the variscian, permian and eoalpidic metamorphic events (scale of compilation 1: 1 Mio) by R. SCHUSTER. Based on the new results and findings more than 5700 mineral occurrences have been allocated to more than 200 metallogenetic districts.

A metallogenetic district is defined as the entity of all those mineral deposits / occurrences within a clearly defined tectonic unit, a specific stratigraphic or facies unit, characterised by both similar shape and mineral content of the individual deposits / occurences. All deposits / occurrences of a metallogenetic district are supposed to be cogenetic. Those findings are important for company-based exploration campaigns, assuming that presumable deposits / occurrences are more likely in the center of the district rather than outside.

The numerous deposits / occurrences of construction materials (sand and gravel, hard rocks) have not been considered in IRIS-Online NEW, as other concepts for metallogenetic districts are to be applied and there is a need for a special geological base map (lithological map rather than a tectonic map). This important mineral deposits / occurrences will be compiled in a separate system (IRIS – construction materials), managed by M. HEINRICH.

One of the main targets of the staff of the Geological Survey was the programming of a user friendly operability and screen performance. Up to now IRIS Online was a „cold fusion" version, and therefore static. Each amendment required a new upload of the entire data base. The new version allows the immediate access to the actual data base („hot fusion"). Furthermore the Geological Survey implemented the definitions of the metallogenetic districts and mineral commodities into their thesaurus. Special attention was payed to the screen-performance, as most applicable extent of the screen, explicit function-buttons, dynamic and suppressible legends to avoid any visual restriction of the results on the screen. The masterscreen of IRIS Online NEW illustrates all mineral deposits / occurrences (except construction materials) as rhombs. In the general scale there is only a differentiation by groups of minerals (red: iron-ores and steel alloying metals, blue: base metals; green: pyrites, yellow: precious metals, purple: special metals; orange: industrial minerals; brown: lignites; black: hard coal; grey: grafites).

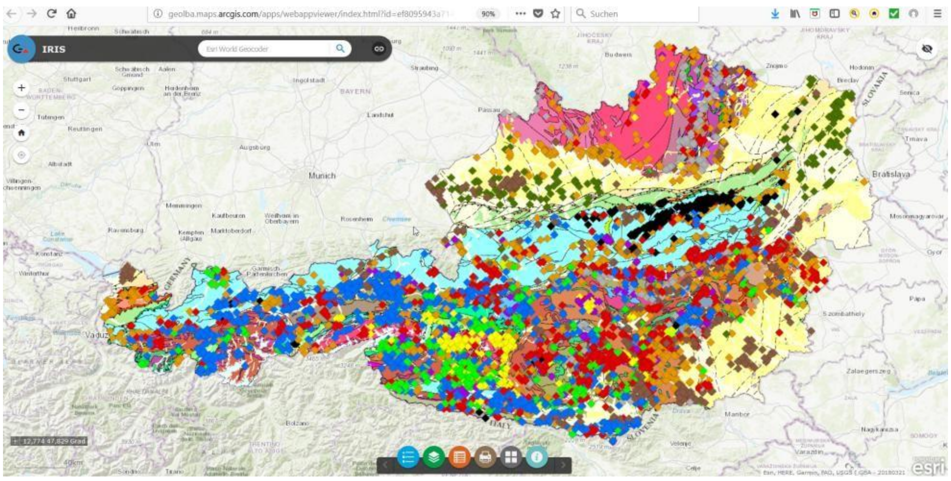


Figure 1 - masterscreen (lithological basemap and mineral deposits / occurrences, topography as layers only)

The single layers, legends, queries can be switched on or off by the buttons, located at the lower part of the screen (from left to right: legend, layer-list, attributes, print, basemaps-gallery, info). To control the visibility of the results, the transparency of each layer may be changed any time. The results are either directly printable (printer button) or saved as screenshots (via info button).

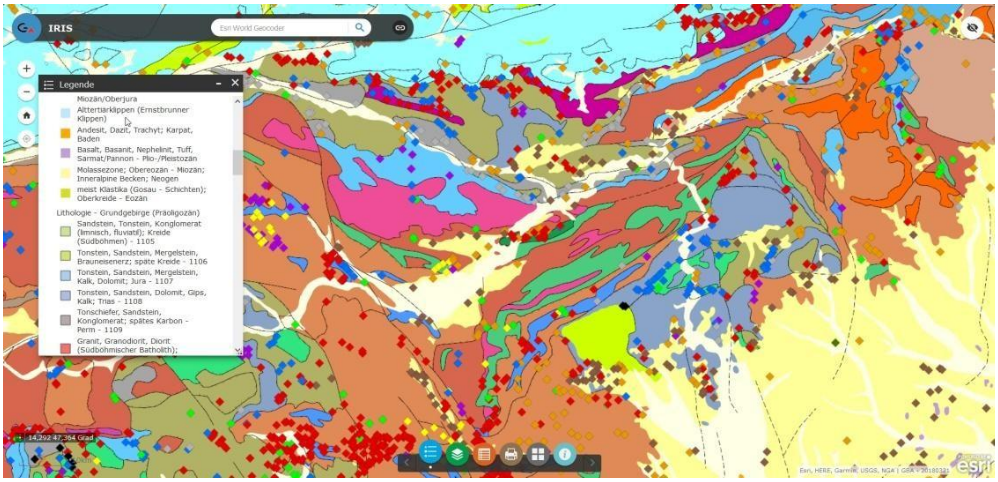


Figure 2 - example for a shiftable dynamic legend (explanation of those elements, which are visible on the current screen only)

Geological / tectonical basemaps

The newest findings of the tectonic structure of the Eastern Alps have been compiled in the scale 1: 1 Mio. To avoid any misunderstandable blurring, the scale of the display on the screen was limited to 1:250.000 only (Fig. 3). Further zooming leds to the display of more detailed maps automatically (geological maps in the scale 1:200.000, 1:50.000, if available). Additional selectable maps in an overview scale are the lithological map (“multi-thematical map”) and the lithological and tectonic maps in the scale 1:500.000 (F. EBNER 1997).

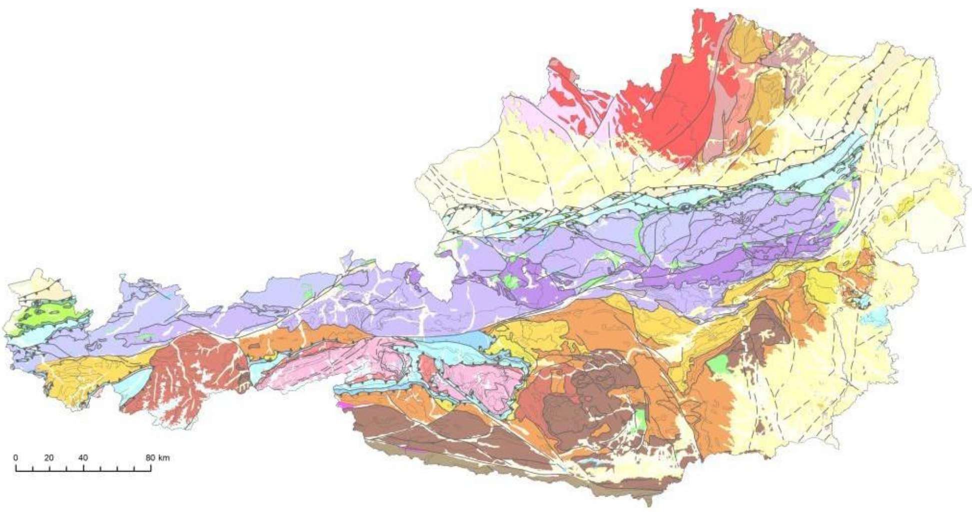


Figure 3 - example for base map layers: new tectonic map 1:1 Mio (R. SCHUSTER)

Maps of metamorphic events

For the very first time maps of the main metamorphic events are applicable. Maps are available for the main three metamorphic events (variscian, permian, cretaceous [eoalpidic] metamorphism).

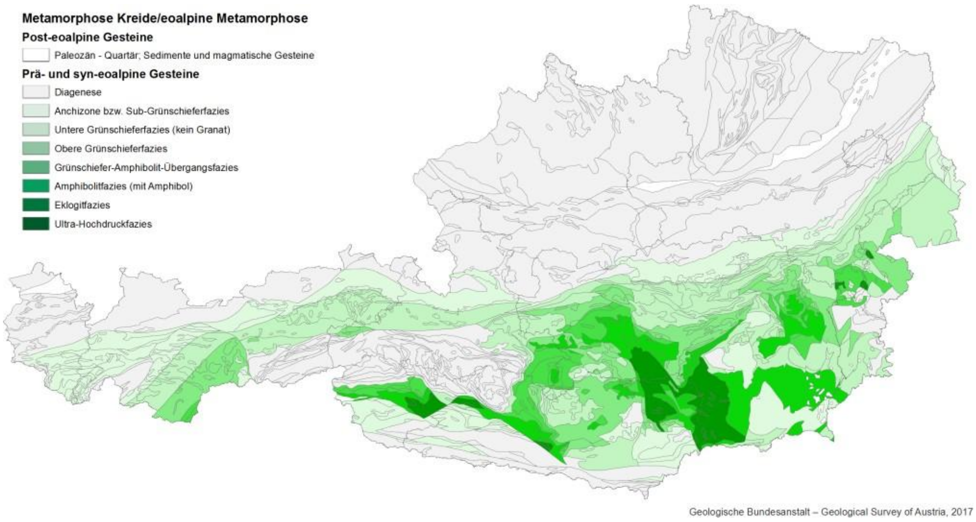


Figure 4- example for a map, displaying the cretaceous (eoalpidic) metamorphic event

This does not necessarily mean that there is a direct relation between a mineralisation and the metamorphic event. However mineralisations can be overprinted with remarkable changes in the shape and the mineral content of the occurrences. In any case a critical interpretation is up to the expert.

Streamsediment-geochemistry

Since 1978 Austria has been sampled with stream sediments systematically. More than 34.500 samples were analysed for 35 elements. The results have been published in a comprehensive publication recently (PIRKL, SCHEDL & PFLEIDERER [2015)]). IRIS Online NEW allows to visualise the results of the streamsediment-geochemistry either in an overview scale (pixels) or in a detailed scale as classified single symbols. Furthermore it is possible to display the anomalies as residuals only. As the anomaly limits differ from element to element, a distribution histogram is available as well.

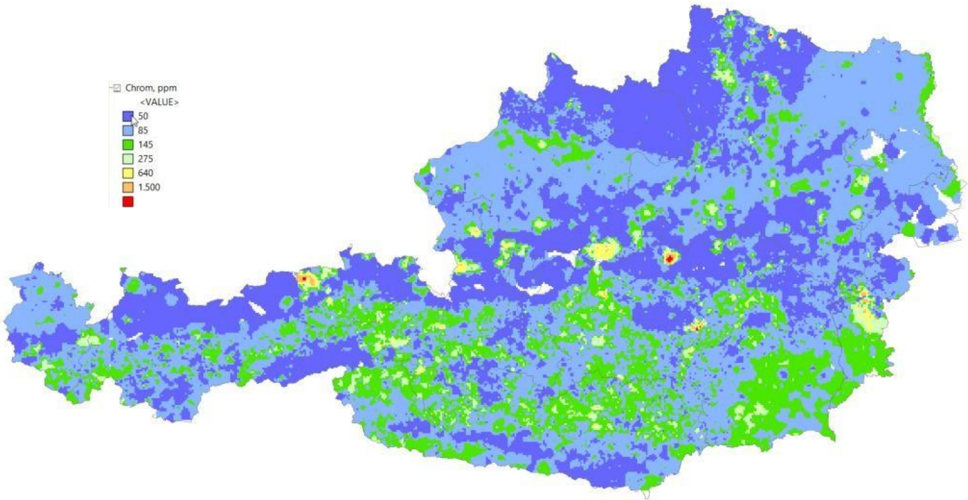


Figure 5 – example for a geochemical map: pixelised map of Cr (overview scale)

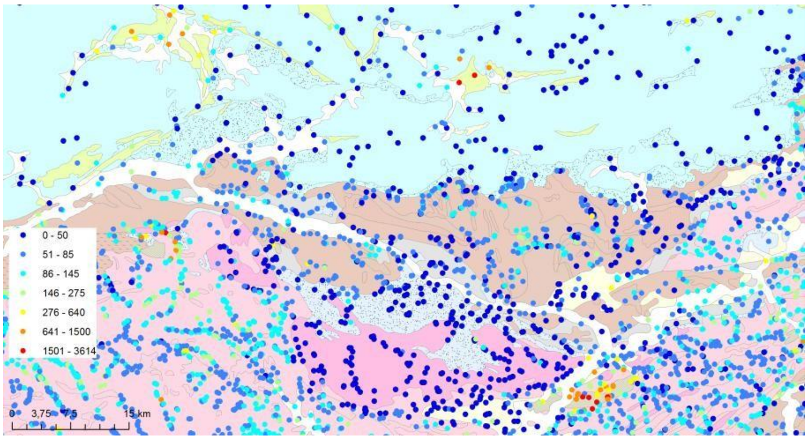


Figure 6a – detail: geochemistry (tectonic map, Cr)

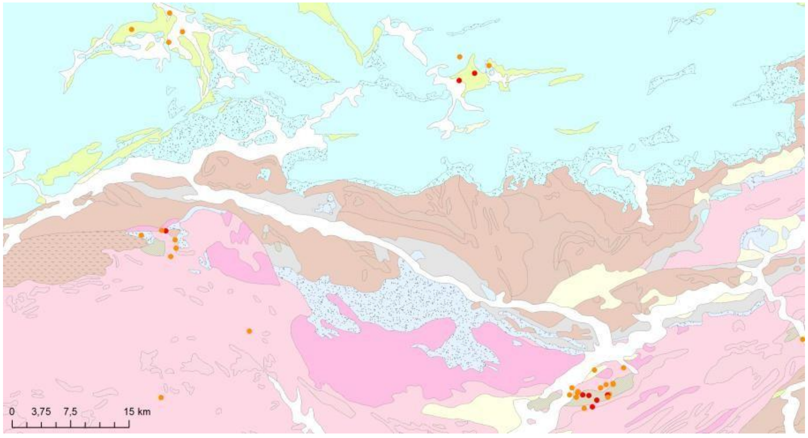


Figure 6b – detail: residuals (Cr-anomalies only)

The geochemical results have been processed for principal components as well. The results the most important principal components including the loadings of the elements can be inserted optionally.

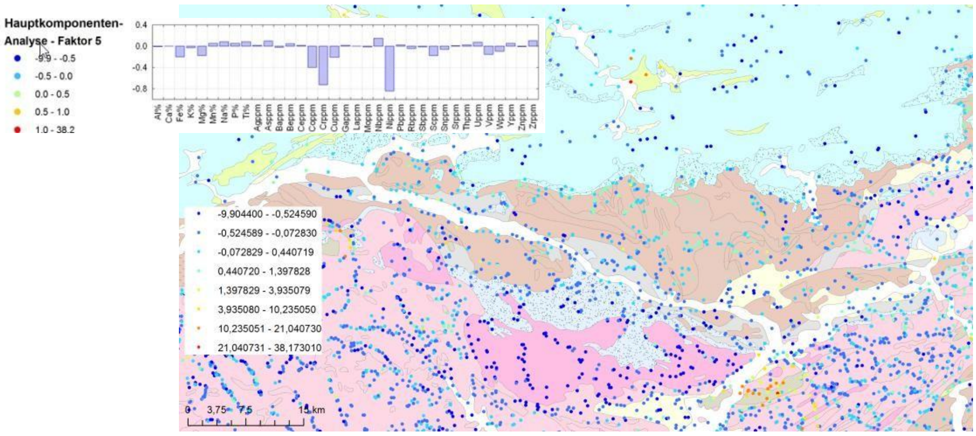


Figure 6c - detail: principal component analysis (PC 5) with element loadings

Aeromagnetic Survey:

In the early 1980-ies Austria has been aeromagnetically surveyed (SEIBERL [1991]). The results are available either as a pixelised map (overview-scale) or as isolines in a more detailed scale.

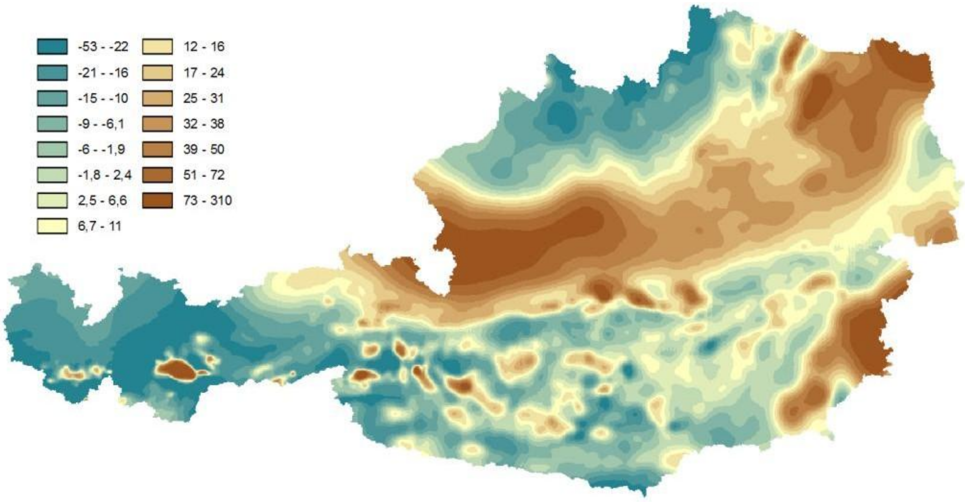


Figure 7 - pixelised aeromagnetic map; all other information layers omitted

Topography, situation

For showing topography, morphology or situation several maps of public domain are available, which can be used optionally.

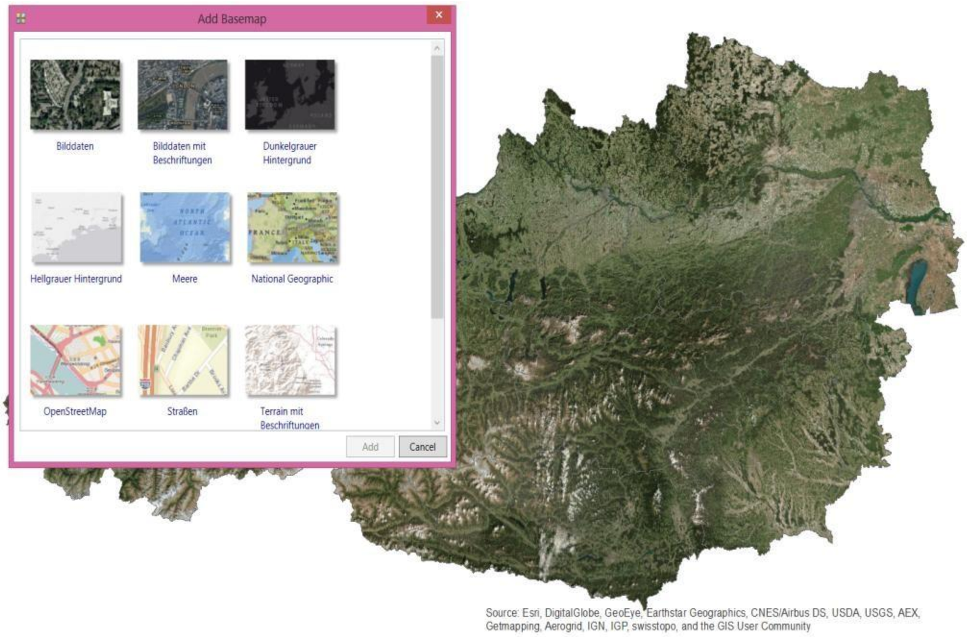


Figure 8 - different topographic or morphologic base maps

Mineral deposits / occurrences

Contrary to simple „mineral deposit maps", showing the location of mineral deposits / occurrences only, a metallogenetic map visualises the basic metallogenetic information as well, so that experts can extract their own genetic interpretation from the symbols directly.

<u>Symbols:</u>

There are six different particular symbols for the shapes of orebodies and one undetermined symbol (e.g. orebody only intersected by a drillhole)

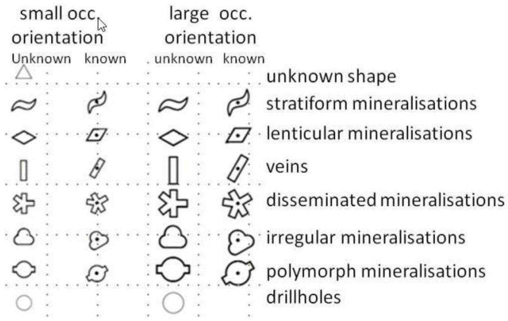


Figure 9 - different symbols for the shape of the orebody

The main mineral content of the deposits is characterised by color of the symbol:

- red: Iron ores and steel alloying metals
- blue: base metals and other non ferrous metals
- green: pyrites
- yellow: precious metals
- orange: industrial minerals
- purple: special metals
- brown: lignites
- black: hard coal
- grey: grafites

The striking direction of a particular mineral deposit / occurrence (as far as known) is displayed by the rotation of the symbol. Rotated symbols are characterised with a dot in the center as well. Mineral deposits of commercial interest are displayed by the larger size of the symbol. In total more than 5700 mineral deposits / occurrences have been attributed with the basic information.

As the genesis of a mineralisation is discussible, an attempt was made not to describe the genesis of a mineral deposit in detail. The genesis of a mineral deposit may be undiscussible or sacrosanct for one scientist but not for anothers. Therefore IRIS Online NEW provides only a value free documentation, allowing any scientist to derive his own (genetic) interpretation.

Multiple possibilities for queries

As each of the data set entries is specially attributed different queries and combinations of queries are feasible, e.g. the presentation of

- all deposits / occurrences of a particular group of minerals
- all deposits / occurrences of a particular commodity
- all deposits / occurrences of a particular metallogenetic district (Fig. 7)

- all deposits, which have been mined within a certain period (Fig. 8)
- all active mines
- all museum mines
- search for a particular mineral deposit / occurrence

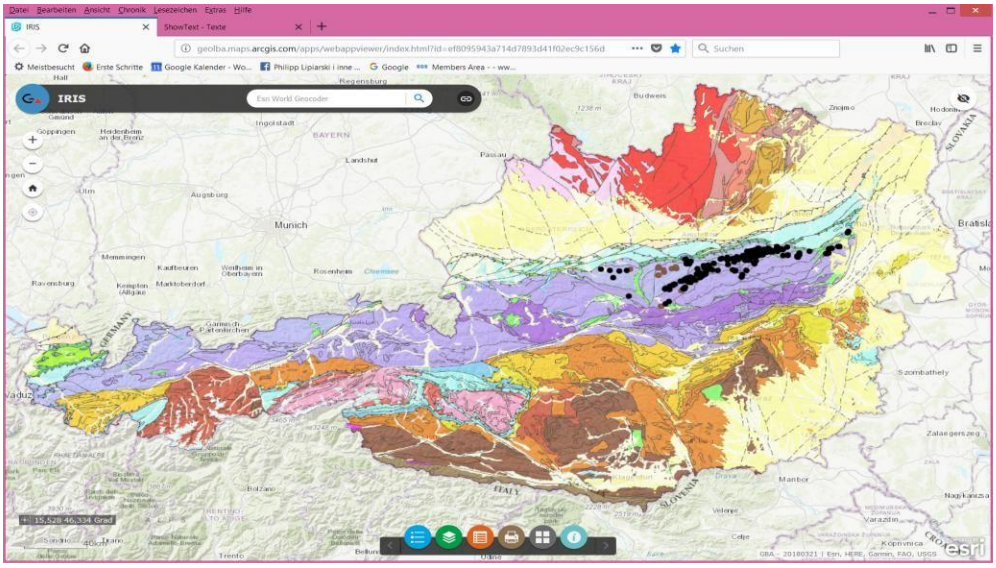


Figure 7 - display of the „Hardcoal (lignite) district of the Tirolic-Noric Nappe system - Lunz-Fm (Schrambach)"

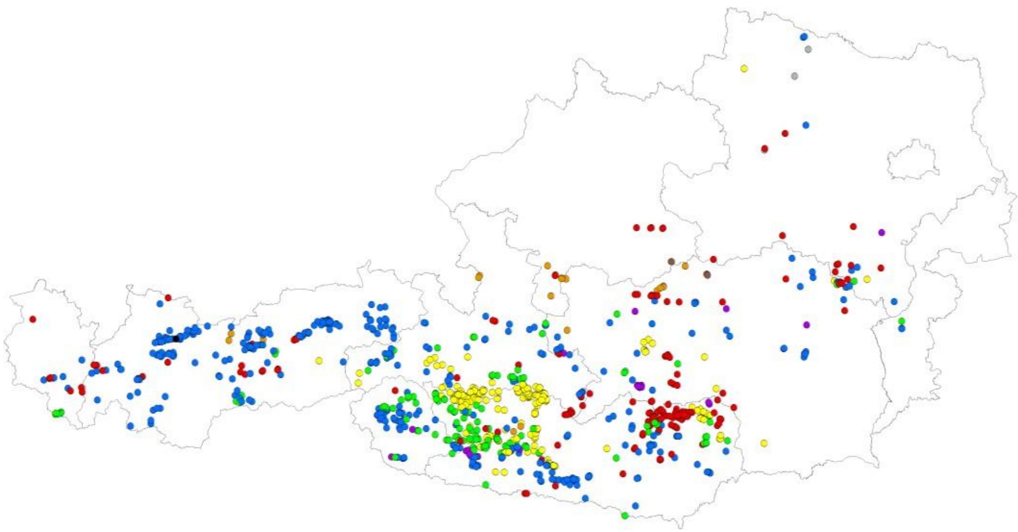


Figure 8 –example for historic queries: Mineral deposits, mined in the 16th century only (all other layers omitted. Color of dots reflect the minerals group only

Isotope-maps

In the past isotope geology made a huge progress. From numerous deposits / occurrences detailed isotope data are available. Currently only the locations of the deposits / occurrences, where data are available, are displayed, due to the heterogenity of the single data.

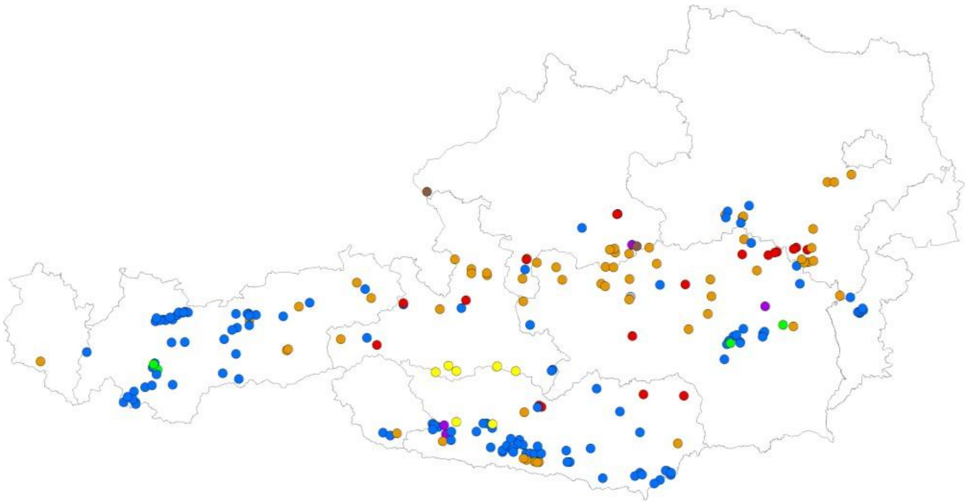
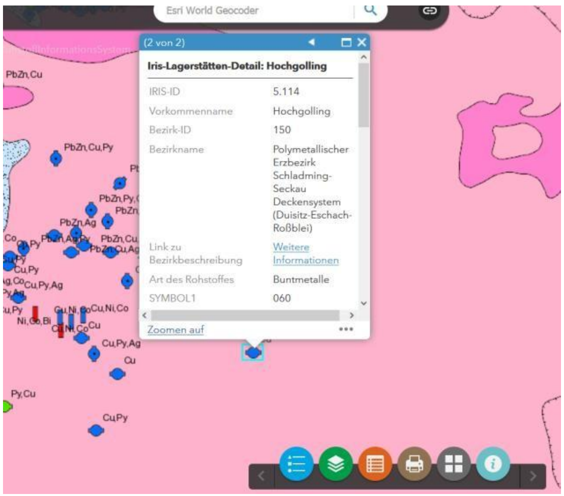


Figure 9 - results of retrieval of locations, where isotope data are available. The color of the symbols reflect the group of minerals only.

Detailed information of a mineral deposit / occurrence

Activating a particular symbol by a mouse-click results in opening of a window with detailed information, e.g.: name of deposit / occurrence, metallogenetic district (with link for detailed explanation), tectonic unit, group of minerals, minerals mined, shape, orientation, isotopes, mining periods, a.s.o.. Besides the general information also pictures, cross sections or other graphics are retrievable.



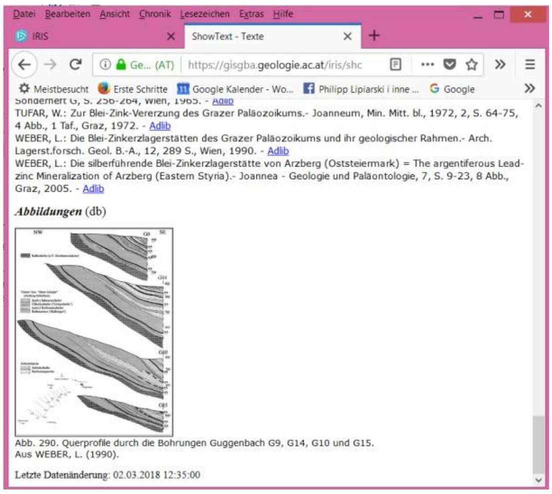
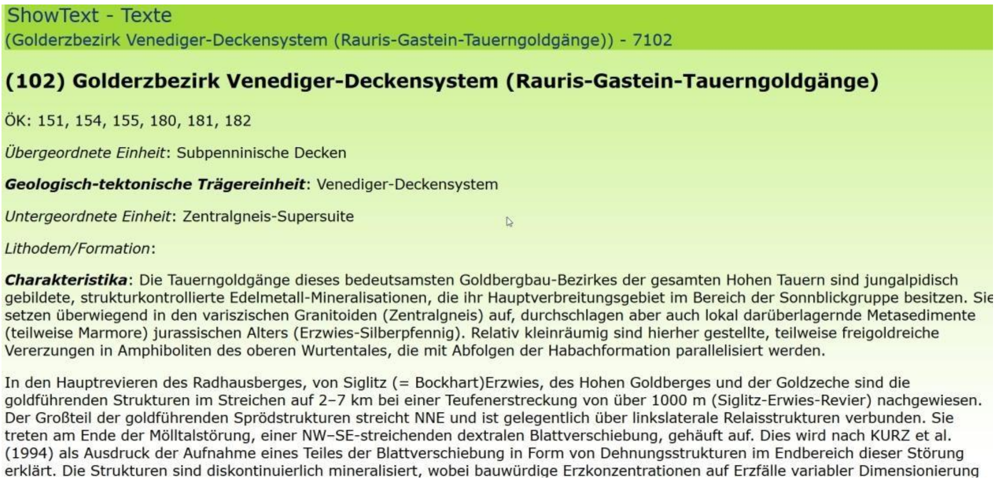


Figure 10 - Detail-information window concerning a particular mineral deposit / occurrence

Figure 11 – continued: detail description incl. cross-sections and references

The detailed description of the respective metallogenetic district is available as well (Fig. 12).


ShowText - Texte
(Golderzbezirk Venediger-Deckensystem (Rauris-Gastein-Tauerngoldgänge)) - 7102

(102) Golderzbezirk Venediger-Deckensystem (Rauris-Gastein-Tauerngoldgänge)

ÖK: 151, 154, 155, 180, 181, 182

Übergeordnete Einheit: Subpenninische Decken

Geologisch-tektonische Trägereinheit: Venediger-Deckensystem

Untergeordnete Einheit: Zentralgneis-Supersuite

Lithodem/Formation:

Charakteristika: Die Tauerngoldgänge dieses bedeutsamsten Goldbergbau-Bezirkes der gesamten Hohen Tauern sind jungalpidisch gebildete, strukturkontrollierte Edelmetall-Mineralisationen, die ihr Hauptverbreitungsgebiet im Bereich der Sonnblickgruppe besitzen. Sie setzen überwiegend in den variszischen Granitoiden (Zentralgneis) auf, durchschlagen aber auch lokal darüberlagernde Metasedimente (teilweise Marmore) jurassischen Alters (Erzwies-Silberpfennig). Relativ kleinräumig sind hierher gestellte, teilweise freigoldreiche Vererzungen in Amphiboliten des oberen Wurtentales, die mit Abfolgen der Habachformation parallelisiert werden.

In den Hauptrevieren des Radhausberges, von Siglitz (= Bockhart)Erzwies, des Hohen Goldberges und der Goldzeche sind die goldführenden Strukturen im Streichen auf 2–7 km bei einer Teufenerstreckung von über 1000 m (Siglitz-Erwies-Revier) nachgewiesen. Der Großteil der goldführenden Sprödstrukturen streicht NNE und ist gelegentlich über linkslaterale Relaisstrukturen verbunden. Sie treten am Ende der Mölltalstörung, einer NW–SE-streichenden dextralen Blattverschiebung, gehäuft auf. Dies wird nach KURZ et al. (1994) als Ausdruck der Aufnahme eines Teiles der Blattverschiebung in Form von Dehnungsstrukturen im Endbereich dieser Störung erklärt. Die Strukturen sind diskontinuierlich mineralisiert, wobei bauwürdige Erzkonzentrationen auf Erzfälle variabler Dimensionierung

Figure 12 - Example for the characterisation of a particular metallogenetic district

The references of a mineral deposit / occurrence are cited. In total more than 17.000 references are available. Already digitalised papers can be downloaded directly (Fig. 13).

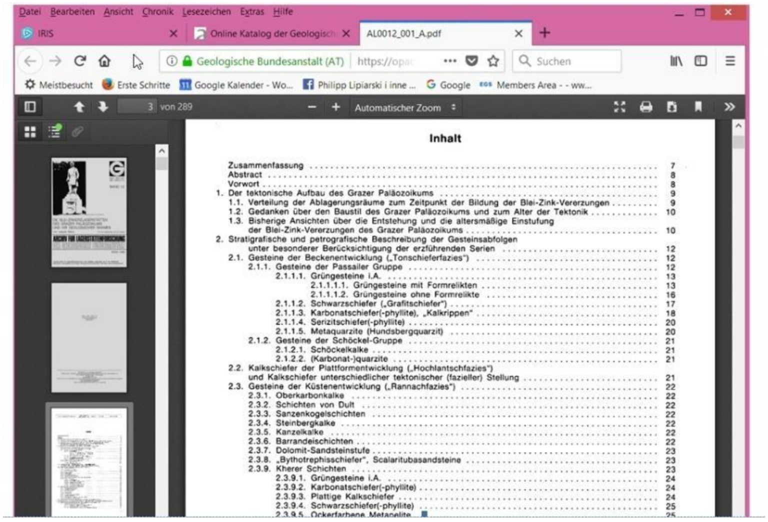


Figure 13 - Example for the retrieval of a full text of a digitalised paper

IRIS Online NEW as an instrument for detailed metallogenetic queries

IRIS Online NEW is not only an important tool for the basic work for mineral exploration, but for scientific purposes (metallogenetic analyses) as well. IRIS Online NEW allows the simultaneous display of geological or tectonic maps, geochemistry, aerogeophysics of areas of interest. However expert judgement is indispensable to avoid misinterpretations.

In the general scale of the pixelised map of the element chromium some „hot spots“ (red colors) are evident (Fig. 5). Figure 14 shows the scales results of the stream-sediment geochemistry in detail.

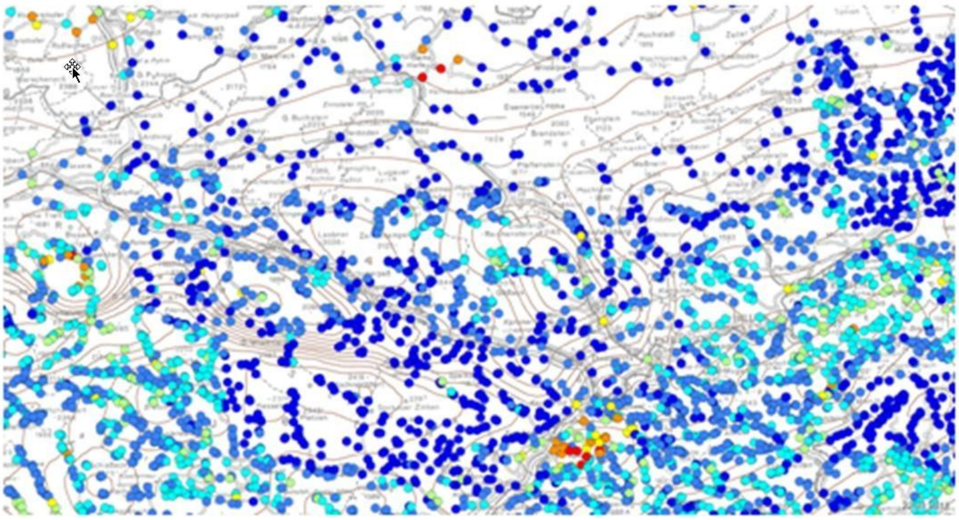


Figure 14 - active layers: streamsediments (Cr) (dots), aeromagnetics (isolines), situation

However chromite deposits / occurrences are only known within the ultramafic Kraubath-complex (Fig. 15). Within the Gosau-sediments where chromium anomalies are developed as well, no chromite occurrences are known. As a matter of fact this anomalies are the result of heavy-mineral placers only.

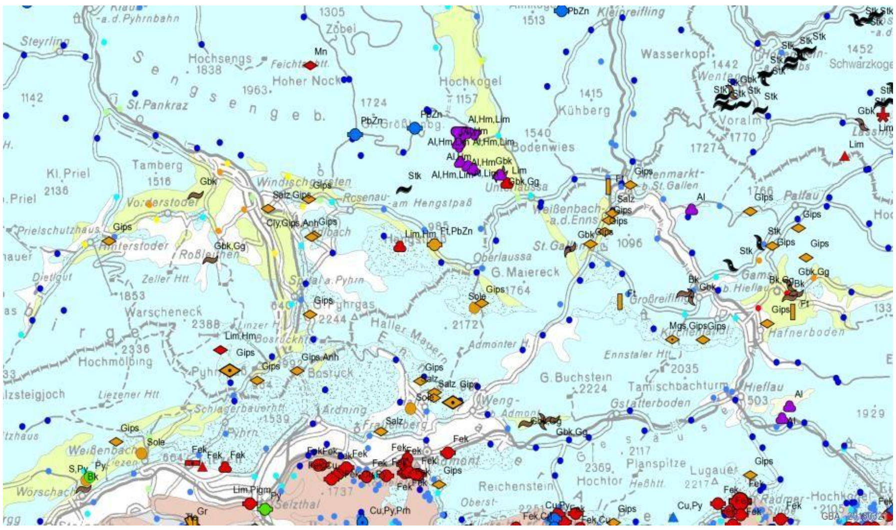


Fig. 15 - active layers: streamsediments (Cr) (dots); tectonic map; mineral deposits (symbols), situation; in detail scale mineral deposits are characterised by special symbols (explanation of symbols see subchapter symbols above). Detailed legend (geology, tectonic) omitted for full screen display for example. Legend can be inserted any time.

Further remarkable chromium anomalies are situated in the penninic rock sequences of the Rechnitz Window. However no chromite mineralisations are known within this area. The anomalies are the result of the chromium content in form of discretely dispatched chromite crystals in the countryrocks or a higher chromium content in some host-minerals as amphiboles a.s.o. This is a clear indication that there have been no suitable conditions for the segregation of chromite (e.g. poor oxygen fugacity or poor viscosity of the melts).

Table 1 – differences between IRIS Old and IRIS Online NEW

	IRIS Old	IRIS Online NEW
base maps:	tectonic map F. EBNER (1997)	tectonic and lithological map R. SCHUSTER (2017) tectonic map (F. EBNER 1997) geological maps 1:200.000 geological maps 1:50.000
maps of metamorphic events	--	variscan event permian event cretaceous (eoalpidic) event
captured deposits / occurrences	ca. 3600	ca. 5700 (without construction material deposits / occurrences)
metallogenetic districts	146	205
description of metallogenetic districts	districts according the former tectonic classification	revision of the metallogenetic districts according the new tectonic findings

CONCLUSION

With the most recent internet-version of the Interactive Raw Materials Information System IRIS Online NEW, Austria has one of the most significant and comprehensive mineral information systems worldwide. The synoptic display of several different basic information layers (e.g. geological, lithological and tectonic maps, streamsediment-geochemistry, aeromagnetics, isotopes a.s.o.), combinable with detail information of more than 5700 mineral deposits / occurrences IRIS Online NEW is an important tool for both the extractive industry and science as well. Contrary to the former information system, IRIS online NEW accesses the data bases directly („hot fusion").

It is not intended to describe the results (e.g. metallogenetic districts) in a comprehensive publication. However, it is planned to retrieve the characteristics of the metallogenetic districts - currently retrievable per HTML links – via the Thesaurus of the Geological Survey as well. The same is true for detailed information of the mineral deposits / occurrences. Each amendment or addition to the data base will be taken into account online, so that IRIS Online NEW provides the most actual information any time.

Thanks

The basis for the data base and the description of the metallogenetic districts have been carried out by the members of the „Mineral Deposits Expert Group" of the Austrian Mining Association (Dr. A. SCHEDL; Dr. I. CERNY; DI. C. REICHL, Mag. C. STRANZL, Univ. Prof. Dr. F. EBNER, Dr. G. DAXNER, DI Dr. H. MALI, Univ. Prof. Dr. J. RAITH; Mag. K. WEIDNER; Dr. M. HEINRICH; Dr. M. GÖTZINGER; Univ. Prof. Dr. W. PAAR; Prof. Dr. SACHSENHOFER; Hon. Prof. Dr. R. GÖD; Mag. R. TREIMER; DI T. SCHACHINGER; Dr. W. POSTL; Univ. Prof. Dr. W. PROCHASKA; Dr. W. MÖRTH; Univ. Prof. Dr. G. RANTITSCH; Univ. Prof. Dr. F. MELCHER; DI. Dr. W. BERNHARD; Dr. P. KOLLEGGER) under the scientific supervision of Univ. Prof. Dr. L. WEBER.

The compilation of the geological maps has been done by Dr. R. SCHUSTER. Programming and maintenance of the data base has been carried out by the staff of the Geological Survey of Austria (H. HEGER, BSc. MSc. A. KAIMBACHER, Mag. I. LIPIARSKA, Mag. P. LIPIARSKI, Mag. J. REISCHER, Dr. A. SCHEDL).

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Iris-Online NEW:

https://www.geologie.ac.at/services/webapplikationen/geofast/iris-interaktives-rohstoffinformationssystem/

IODINE, HYDROGEN SULFIDE, RADON AND METHANE – EXPRESS INDICATORS OF BURIED PORPHYRY COPPER MINERALIZATION

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25th World Mining Congress
ASTANA 2018 • KAZAKHSTAN

An important role of certain gas and vapor compounds as direct evidences of hydrothermal process was established in recent years. It has been demonstrated that high content of halogens, hydrogen sulfide, mercury, radioactive and other gases with high migration ability could trace buried and hidden ore mineralization (–Trofimov et al. 1988; Sudov et al. 1994; Diakonov et al. (2015) . Volatile components represent the most active part of geochemical haloes with penetrating ability to move over big distances, indicating ore bearing structures (Glukhov A.,Divakov V.,1996). They are superimposed on geochemical situation in a pattern related to the disposition of subsurface Post Hydrothermal Gases Leakage Fluxes (PHGLF) and can be interpreted in prognosis terms. PHGLF are regarded as inherited elements of hydrothermal fluid migration systems, usually situated- close to faults intersections. Dynamic analysis of certain gases behavior is of great importance, especially during early stages of exploration, significantly reducing cost and time for buried prospects appraisal. It has been successfully implied –in Kazakhstan, Russia and Uzbekistan for detecting copper and gold bearing structures overlapped by sediments up to 150m thick.

This paper summarizes several studies concerning volatile and ore elements subsurface distribution over buried porphyry copper deposit in Balkhash region. It touches upon soil gases behavior over productive hydrothermal structure: "ore hosting formation – near ore vadose water with dissolved gases - surface gas haloes". Certain post hydrothermal gases leakage regularities were used as indirect geochemical indicators, providing evidence of buried ore mineralization. The surface extend of these regularities have been shown to approximate productive limits of ore body in the subsurface. Special attention was given to the description of PHGLF of typical porphyry copper structure. For this type of deposits it consists of several steep telescopic zones of high permeability, situated in apical parts of granite intrusions, overlapped by effusive rocks. It is formed by multiple media inhomogeneities,– traced by concentric geochemical, gas, electromagnetic and other anomalies.

The aim of this study is comparative analysis of ore elements and gases distribution over buried porphyry copper productive structure. Metal and gases concentrations including Cu, Mo, Pb, Zn, Ag, Mn, Co, W, V and H_2S, CH_4, Rn were distinguished by ICP and soil gas analysis. Sampling was conducted within steppe area about 20 sq. km covered by sediments up to 25 m thick on the grid of orthogonal profiles with distance about 500 m. Sampling points were situated 60-100 m along profile lines. Portable emanometers and gas analyzers with detection limit 0,1-1ppm were used for in situ gases determination. Soil iodine measurements were made by analytical technique in the laboratory of University of Peoples Friendship, Moscow.

Surveyed -PHGLF is formed by enclosed concentric zones of high permeability, creating a steep cylinder-like structure. On the -surface these zones are grouped into elongated ellipse traced by numerous anomalies of iodine, hydrogen sulfide, radon, methane and hydrocarbon-containing gases. Its imaginary axis is situated inside intersection of profiles 3, 4 and 7, 8 steeply deeping to south-east. These anomalies create– well defined integrated halo anomaly, consisting of joined central and edge zones. Central zone is a large negative gases anomaly 1.5 x 2 km in diameter slightly overlapping ore body. It is characterized by low concentrations of all gases, except few most intensive small anomalies of radon, iodine and hydrogen sulfide over the central part of the ore body. This negative anomaly of measured gases could be associated with central zone of Cu-Mo-Au mineralization of typical porphyry copper structure (Sillitoe R., 2010).

Very well expressed edge zone is a concentric positive anomaly 2 x 3 km in diameter, formed by most intense upward leakage flow of all measured gases. High values of hydrogen sulfide, radon, methane and hydrocarbon-containing gases are grouped into numerous separate chains around central part of surveyed PHGLF with much more intense emanations on its eastern flank over hanging side of ore body.

The positive integrated gas anomaly coincides well with contours of polymetallic edging around the ore body. It is characterized by the highest soil concentrations of all metals, except Cu and Mo. Local anomalies of copper (< 500 g/t), molybdenum (< 5 g/t), tungsten (< 12 g/t), cobalt (< 40 g/t), manganese (< 20 g/t), zinc (< 140 g/t), lead (< 30 g/t) and silver (< 0.45 g/t) are scattered around central part of surveyed PHGLF. This positive halo anomaly of measured gases could be associated with polymetallic zone of Zn-Pb-Ag mineralization of porphyry copper structure (Sillitoe R., 2010).

Much information can be gained from a comparison analysis of main ore and volatile components behavior over surveyed productive structure. Maps of metals subsurface distribution show a variety of enclosed anomalies, randomly distributed around Cu-Mo ore body. Contours and centers of main “highs” do not fit for the majority of metals, except Cu, Mo and partly As, Ag, Cr. Only a few characteristic features with which might be associated ore bearing structure may be evident from these maps. An additional complication is that anomalies shape is influenced by active faults of SW-NE orientation. As a result linear anomalies of Sn, Sb and Ti are formed irrespectively of isometric ore-bearing structure. Much more informative is an integrated map of main metals soil distribution. Its contours are quite similar to those of volatiles with numerous closely spaced anomalies grouped around central part of surveyed- PHGLF. Geological interpretation of hydrogen sulfide, radon and methane distribution maps seems to be much easier regarding ore zoning.

Conclusions

- Soil gas dynamic analysis describes confidently buried porphyry copper structure. There was only one complex integrated halo anomaly of hydrogen sulfide, radon, methane and hydrocarbon-containing gases consisting of central negative (Cu-Mo ore body) and edge positive (Zn-Pb-Ag-Mn edge zone) values.
- Soil gas dynamic analysis results show clearly size and position of buried ore-bearing structure and can be interpreted in prognosis terms.
- Soil gas analysis can detect buried and deep porphyry copper targets too subtle for conventional geochem surveys.

The key factors that differentiate soil gases analysis from traditional geochem techniques are:
1. Time and costs saving approach towards prospects ranking. Standard field work, data interpretation and final reporting take less than one week for 1 sq.km of soil gas survey under normal conditions. Readings for some gases are obtained continuously, and recorded intervals can be less then one minute. This creates an ability to have huge data set for one target.
2. Possibility to map buried post hydrothermal gas fluxes’ configuration and media heterogeneities up to 1000m with the highest resolution among surface ordinary methods. Residual and second-derivatives maps to be plotted employing wavelength filters to separate shallow and deep anomalies.
3. Ability to characterize license potentials taking into account PHGLF size, its entropy regularities and gases flux rate as a function of total resources in place.
4. Ability to work with all types of terrains under any conditions including industrial sites, meeting the standard of “zero environmental impact”.

We pioneer new ways of imaging subsurface to ensure the best expense-to-gain ratio in mineral exploration. Our tested products for buried prospects evaluation include:

1. PHGLF Delineation. Field work is aimed at identification of geochemical signatures and gases leakage regularities as indirect indicators of ore mineralization. PHGLF' detection from the surface is made using preferred model of buoyancy-driven sub-vertical gases microseepage with limited lateral drift. High and constant certain gases leakage represents strong evidence of mineral charge. Only regenerated hydrothermal systems under combination of regional stress - local extension tectonic regimes are capable of accumulation of significant mineral resources. Gases temporal variations are used for calculating flow parameters above identified PHGLF (intensity, regularity, composition, constancy). These derived characteristics of multi-component anomalies are used for final prospects ranking.

2. Depth Geochemical Modeling. It is based on 3D extrapolation process analyzing time & depth-dependent variables derived from gases leakage monitoring. As a result of deciphering process halo' dynamics and composition variations are converted into deep geochem heterogeneities that can be traced below the sampling surface. At the end parameter of depth gases saturation is calculated on the basis of derived concentrations. It can provide information about migration channels and discharge plumes location showing the scale of mineralization process. The results can be presented as slice maps and pseudo-sections showing geochem anomalies related to fluxes and migration channels.

3. Subsurface Structural Modeling. Surface contents of volatile components are extrapolated to calculate depth-dependent variables of primary gases concentrations. Data interpretation is aimed at the description of site' tectonic framework and stress regimes. As a result pseudo layered block structure is defined. Main petrophysical horizons and their inclination to the horizontal are identified during the modeling. They could trace uplifts & depressions though their position may deviate from actual level of lithological boundaries in complicated geological settings. The technique ensures plotting of pseudo-sections and schematic structural maps within given depth intervals. It is quite acceptable for the search of big structures when seismic is absent or pour quality. However, as with many new methods, there are problems, both practical and theoretical.

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APPLICATION OF INNOVATIVE GEOPHYSICAL TECHNOLOGIES FOR REGIONAL RESEARCH

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SUMMARY

The great number of deep Magnetotellurics (MT) and Magnitovariational profiling (MVP) data accumulated since the 50s of the last century has been transformed into a new quality. It was found with a high degree of probability that large deep anomalies of electrical conductivity are associated with large ore deposits. These deposits connected with deep conductive anomaly by permeable channels which bring minerals close to the surface of the Earth. Based on these discoveries, a new hypothesis for the exploration of the new mineral provinces and large ore deposits was proposed by Australian geoscientists, which began the regular survey in scale 1: 5 000 0000 of the country's territory by broadband MT and MVP methods. The United States, Canada and Russia support this idea. Kazakhstan in a short time gain experience to use modern electromagnetic equipment and advanced technology and is quite capable of conducting such surveys as on its own territory as well as abroad.

KEYWORDS

Magnetotellurics (MT), Magnitovariational profiling (MVP), geotraverses, regional works, electromagnetic depth studies, project AusLAMP.

THE MAIN INNOVATIVE SOLUTIONS IN MT AND MVP METHODS

In the last decade Australian geoscientists have accomplished 16 projects (more than 3000 wide-range MTS and MVP sites). As result of this great investigation they have found a correlation between the location of anomalously conducting objects in the earth's crust and upper mantle and the position of large mineral deposits. The survey of the whole territory of the country on a scale of 1: 5,000,000 by broadband MT and MVP (the current AusLAMP project) is considered as the first stage of geophysical work for the discovery of new mineral provinces and large ore deposits. Same territory survey from 2006 provide USA and Canada start in this year. Russia collect same experience from early 80-s. The latest innovation in MT and MVP are:

- Ubiquitous transition to wide-range (at least 10,000 (30,000) Hz - 3,600 (10,000) sec.),
- 5-channel observations, providing simultaneous implementation of MTW and MVP methods.
- Work with a remote reference site.
- Complete failure in regional surveys from two channel data acquisition.
- The only 5 and 5+ generation equipment and wideband induction magnetic sensors application to have all advantages from now day's equipment.

Some peculiarities of the MTZ and MVP methods

Magnetotellurics (MT) (Berdichevsky & Dmitriev, 2009, Vanyan, 1997, Chave & Jones, 2012) and Magnetovariation profiling methods (MVP) (Rokityansky, 1981) is used as a source of energy natural alternating electromagnetic field of the Earth (NAEM).

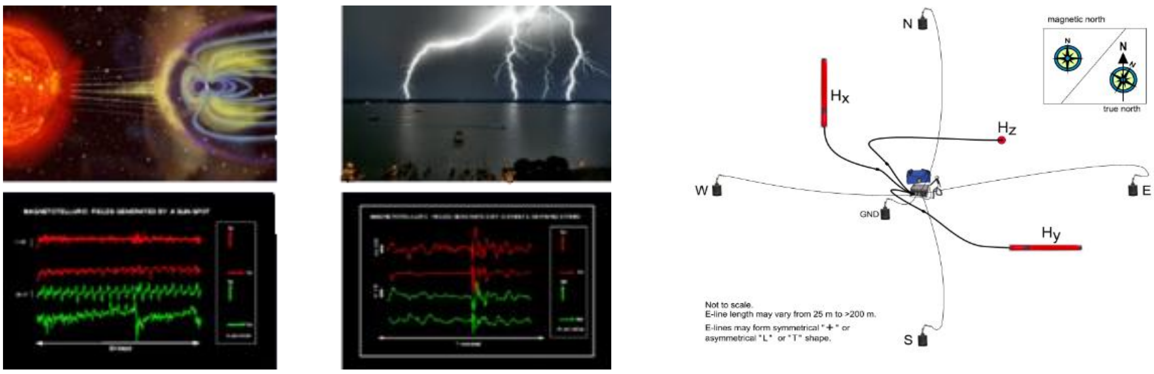

Figure 1 - Sources of EM energy for MTS and MVP methods and a scheme for field recording of a natural alternative electromagnetic (NAEM) field

These NAEM presented by - variations of the Earth's magnetic field under the influence of the solar wind (the flow of charged particles) and the energy of distant thunderstorms, which occur with a high frequency in the equatorial region of the Earth. Field data acquisition includes accurate recording of changes in time of the 5-component of the Earth's electromagnetic field (Figure 1), two horizontal electrical components (Ex and Ey), two horizontal magnetic components (Hx and Hy) and a vertical magnetic component (Hz) (Ingerov A., 2011, Ingerov I., 2014). The time series recorded by the field complex are diverted by Fourier transforms in the frequency characteristics of the medium response functions (Figure 2). Moreover, the presence of 5-component measurements makes it possible to calculate both Magnetotellurics and Magnetovariational response functions simultaneously (Figure 2).

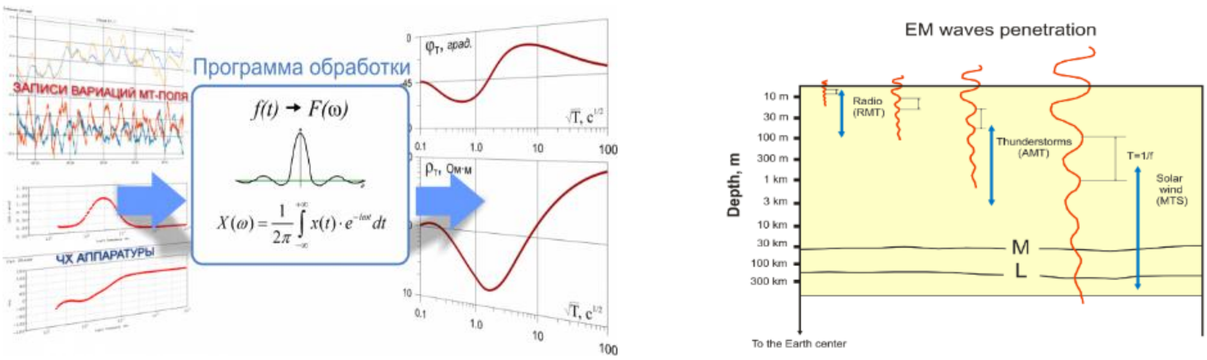

Figure 2 - The scheme of MT-MVP field records processing and the calculation of the environmental response functions and the dependence of the EM field penetration into the Earth as a function of the frequency of the EM field

The depth of penetration of the EM field into the Earth is determined by the phenomenon of the skin effect, it is proportional to the electrical resistivity of the rocks (ρ) and inversely proportional to the frequency of the electromagnetic field (Figure 2). Thus, using the wide frequency range of MT-MVP, we can study the structure of the Earth in the interval from the first meters to hundreds of kilometers. A significant difference in the electrical properties of rocks and minerals contributes to the successful use of electro-prospecting methods (Figure 3).

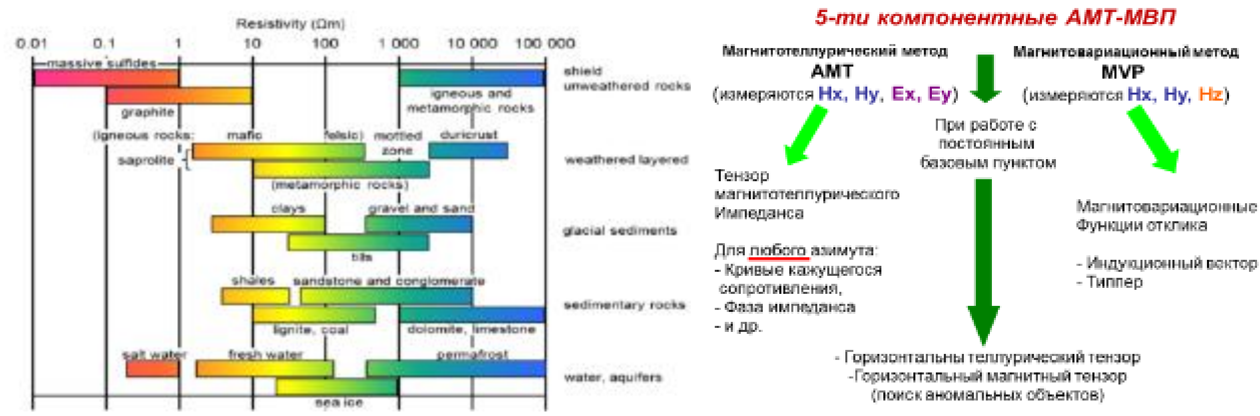

Figure 3 - Electrical properties of rocks and minerals (A). Implementation of MT and MVP methods for 5-component observations (B)

For consolidated rocks of the lithosphere, the resistivity is more affected by temperature, pressure, fracture and porosity of rocks, and also the degree of their filling with mineral solutions and molten rocks than by lithology (Parhomenko, E.J., 1989). As can be seen from the figure 3, with 5 components simultaneous measurements, two electro-prospecting methods are simultaneously realized: (MT) and (MVP). The first of them describes well the sub horizontal boundaries in the geoelectric section, as well as the second one has a unique sensitivity to the presence of horizontal inhomoginieties in the region of the observation profile (sites), that is, together they can restore a fairly accurate model of the Earth's structure in wide depth interval.

WHAT DOES THE DISCOVERY OF AUSTRALIAN SCIENTISES CONCLUDE?

According to: Dentith, M., Joly, A., Evans, S., Thiel, S., 2012; Robertson, K.E., Heinson, G.S. and Thiel, S., 2016
- Conductivity of the Earth's crust and upper mantle is closely related to the distribution of ore minerals;
- In the area of large deposits of gold and polymetals, conductive objects in the upper mantle and in the lower part of the earth's crust are observed, which may be a search sign for the discovery of new ore provinces;
- Conductive sleeves lead from deep conducting objects to the earth's surface, some of which end in large ore deposits, therefore, comparing the cost of magnetotellurics survey, as well as airborne survey (gravity, magnetic, spectrometry),

as well as their effectiveness for the deeper structure of the Earth, a decision was made, that an area survey of a scale of 1: 5,000,000 is the fastest and cheapest way of searching for new ore provinces and new large deposits in Australia. The project (Figure 4) was named AusLAMP and its implementation is promptly reflected on the WEB page of the Geological Survey of Australia;

The authors of the report believe that Australian geoscientists have missed yet another very important point: an operative assessment of the prospects of licensed areas, as it is enough to perform several dozens of 5-channel wide-range MTS sites on the area and it will be possible to answer the question: is it worth investing.

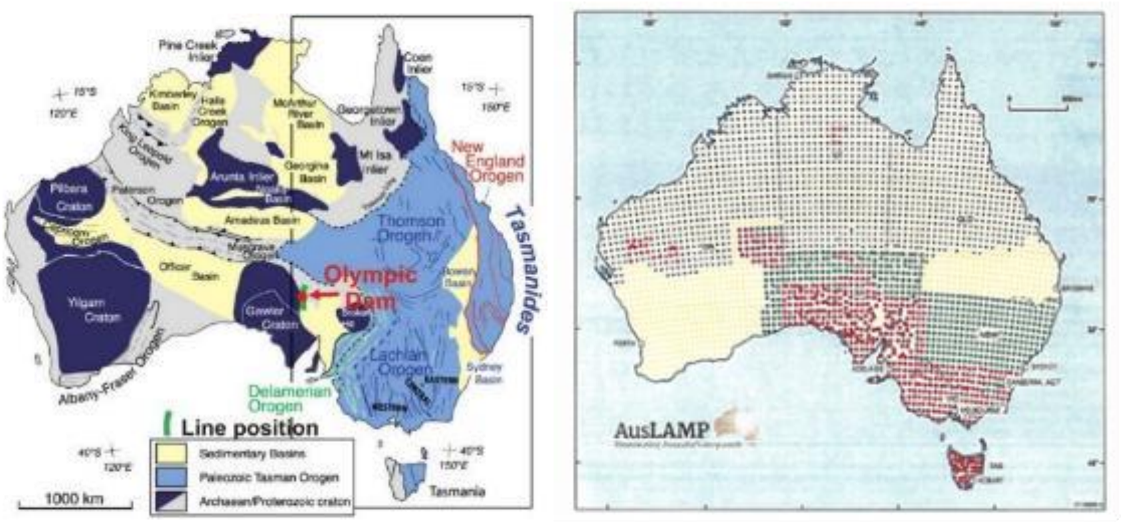

Figure 4 - AusLAMP project. Area coverage of the territory of Australia at a scale of 1: 5,000,000. In red shows the executed points, green - points in the process of execution to black - design points

As it shown in figure 5 there are several very interesting results from deep EM investigation in different parts of Australian territory.

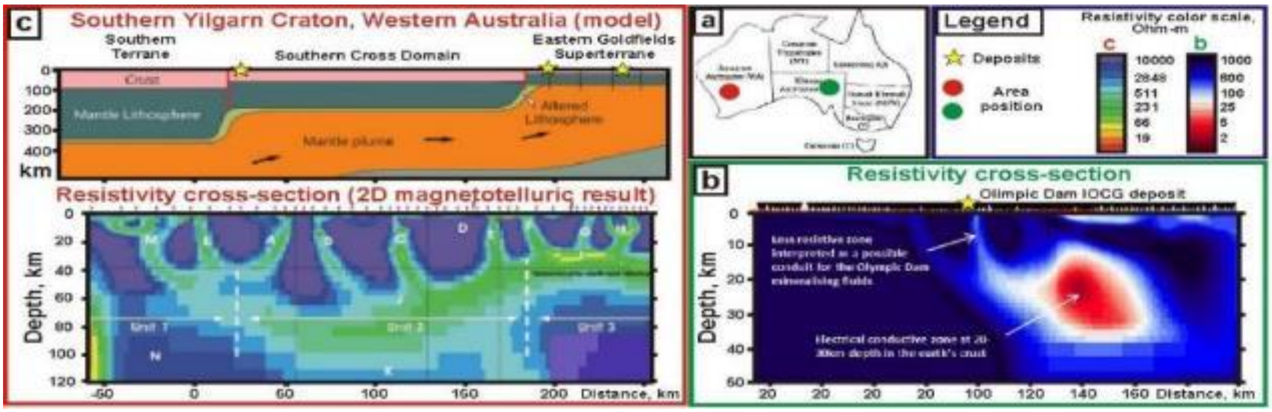

Figure 5 - Mantle plume and permeable channels for deep matter in Western Australia (A), Deep anomaly of conduction in the Earth's crust and in the upper mantle in the area of the Olympic Dam (B)

Olympic Dam (2012) Mineral Resources Status: Cu - 80 million ton, U_3O_8 - 2.4 million ton (300 g/t) - 2 500 ton (90 million oz). In the area of the deposit located in South Australia, there is a large deep anomaly of electrical conductivity (the crustal lower crust and upper mantle (the lower part of the earth's crust and upper mantle), the conductive anomaly is led to the deposit by a susceptible sleeve (Figure 5).

But what about other continents? Can Australia have a unique geological structure? A lot of deep MT-MVP experiments have been done all over the world since 80-s which bring very interesting information (Brasse, H. et al., 2006; Clowes, 2009, Jiracek, G. R., Gurtis, J. H. & Ramirez, J., 1989; Jones, A.G. & Ferguson, I. J., 2001; Jones, A. G., Ferguson, I. J., Chave, A. D., Evans, R. L. & McNeice, G. W., 2001; Pushkarev, P.Yu., 2002). It turns out that the US is performing an area survey of a scale of 1: 7,000,000 since 2006 (Figure 6). Canada this year (2018) provide 1000 broad band regional sounding integrated with reinterpretation old EM data at the survey area.

Figure 6 - Area survey of US territory by deep-seated MTW of scale 1: 7,000,000

But Russia provide regular net of deep MT – MVP profiles from early 70-s (Kozlovsky, E. A., 2008; Figure 7a). Till 2017 several long regional profiles have been finished (Figure 7b).

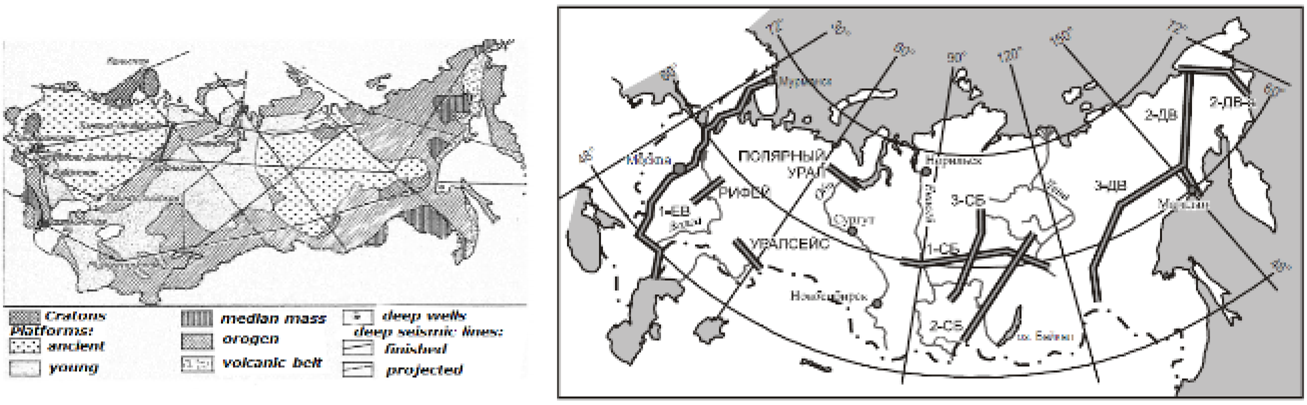

Figure 7 - Ultra-deep drilling program adopted in the 1980s on the initiative of the Minister of Geology Kozlovsky, E.A., 2008 (a). Realized deep geotraverses according to N. Palshin et al. in 2017 (b)

The results of these surveys are analysed in details in (Berdichevsky & Dmitriev, 2009) and latest ones in (Palshin, N. A., Aleksandrova, E. D., Yakovlev, A. G., Yakovlev, D. V. and Breves, V. R., 2017). We want attract the attention to the Far East results along profile 3 DV in Figure 8 (Okulov, S.A. & Yakovlev, 2016). There is some correlations between conductivity of the crust and position of known mineral deposits. So these data support Australian experience. Same result provided for several regional profiles in Siberian Platform (Alexanova, E. D., Bubnov, V. P., Kaplan, S. A., Livshits, V. V., Pospeev, V. V., Yakovlev, A. G., 2016). In Figure 9 two MT-AMT curves are shown. The curves are obtained near strategic gold deposit at Chukotka region (Ermolin, E., Savichev, A. & Ingerov, I., 2016). It clear seen from the figure that there is significant conductive anomaly in the crust with depth to the top 10 km. As can be seen from Figures 8 and 9 in the Far East region of the Russia there is a close relationship between the presence of conducting objects in the earth's crust and the location of mineral deposits.

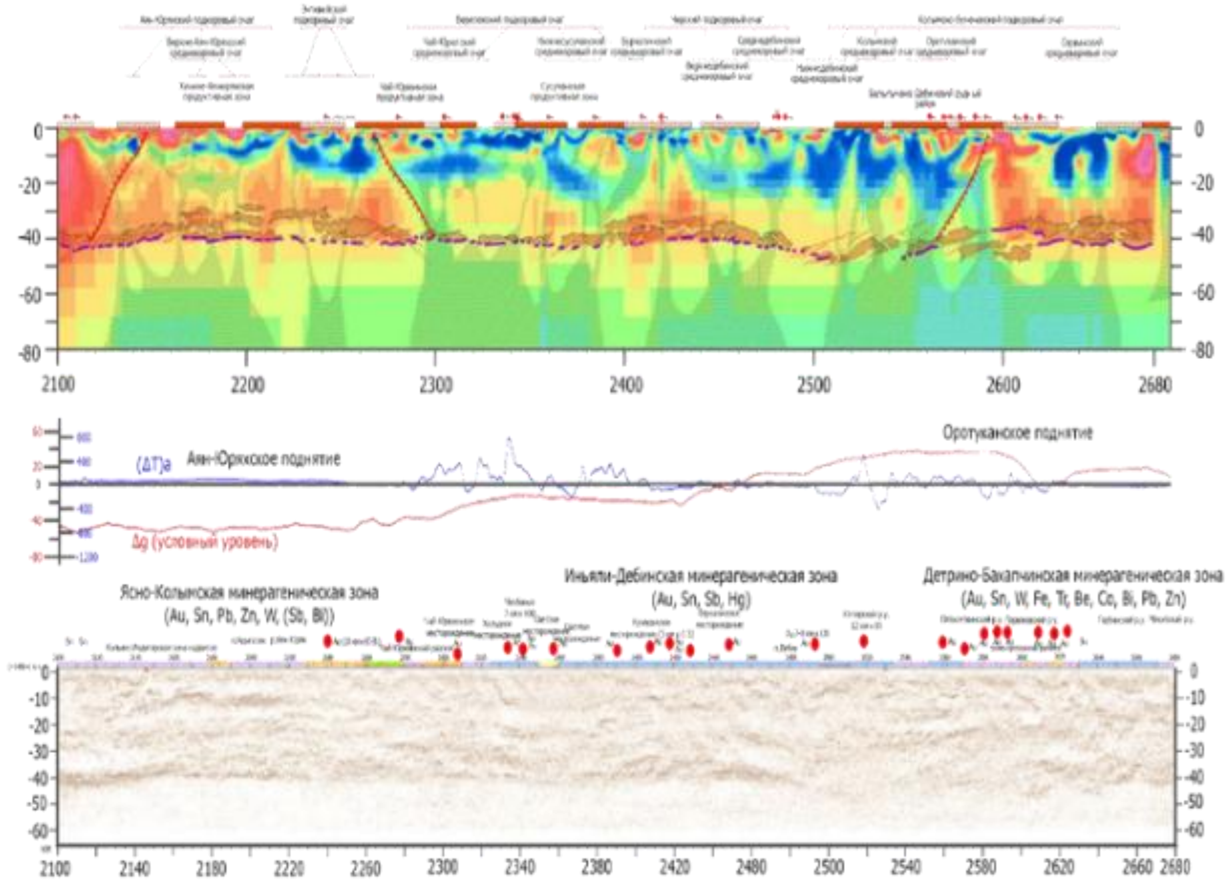

Figure 8 - Geophysical sections along the profile 3 DV (according to Okulov and D. Yakovlev)

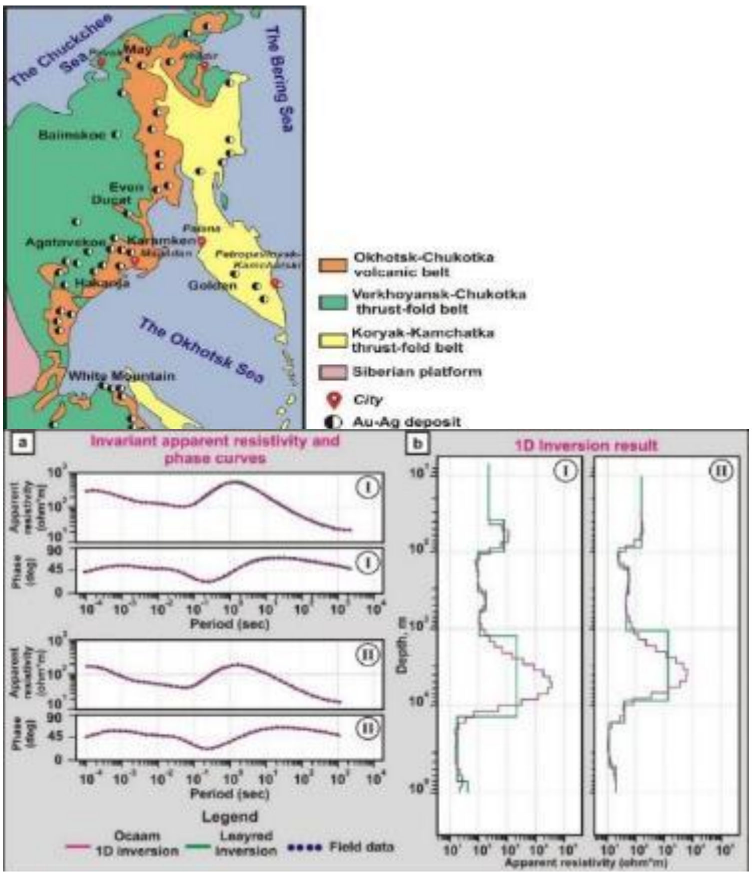

Figure 9 - Conductive anomaly in the Crust with 10 km depth to the top (in the location of strategic gold deposit in Chukotka), according to E. Ermolin

Oddly enough in the world there is a country (Ukraine), which completed a small-scale (1: 2 500 000) survey by deep MT-MVP methods in 1994 (Begin in 1981) and the results of this survey are of undoubted interest for the forecast of mineral deposits (Chekunov, A. V., 1993; Dyakonova, A. G., Ingerov, A. I., Rokityansky, I. I., 1986; Ingerov, A., 2004). Figure 10a shows a map of the total longitudinal conductivity of the Precambrian sediments, as well as the position of the broadband sites of the depth survey. Maps of apparent resistivity at a period of 150sec (B and C) reflect the total conductivity of the entire earth's crust. As can be seen from the comparison of these maps with the position of ore (B) and combustible (C) minerals, there is a definite relationship in the position of the mineral deposits relative to the position of the deep conducting zones (Ingerov, A. I. Rokityansky, I. I. & Tregubenko, V. I. 1999).

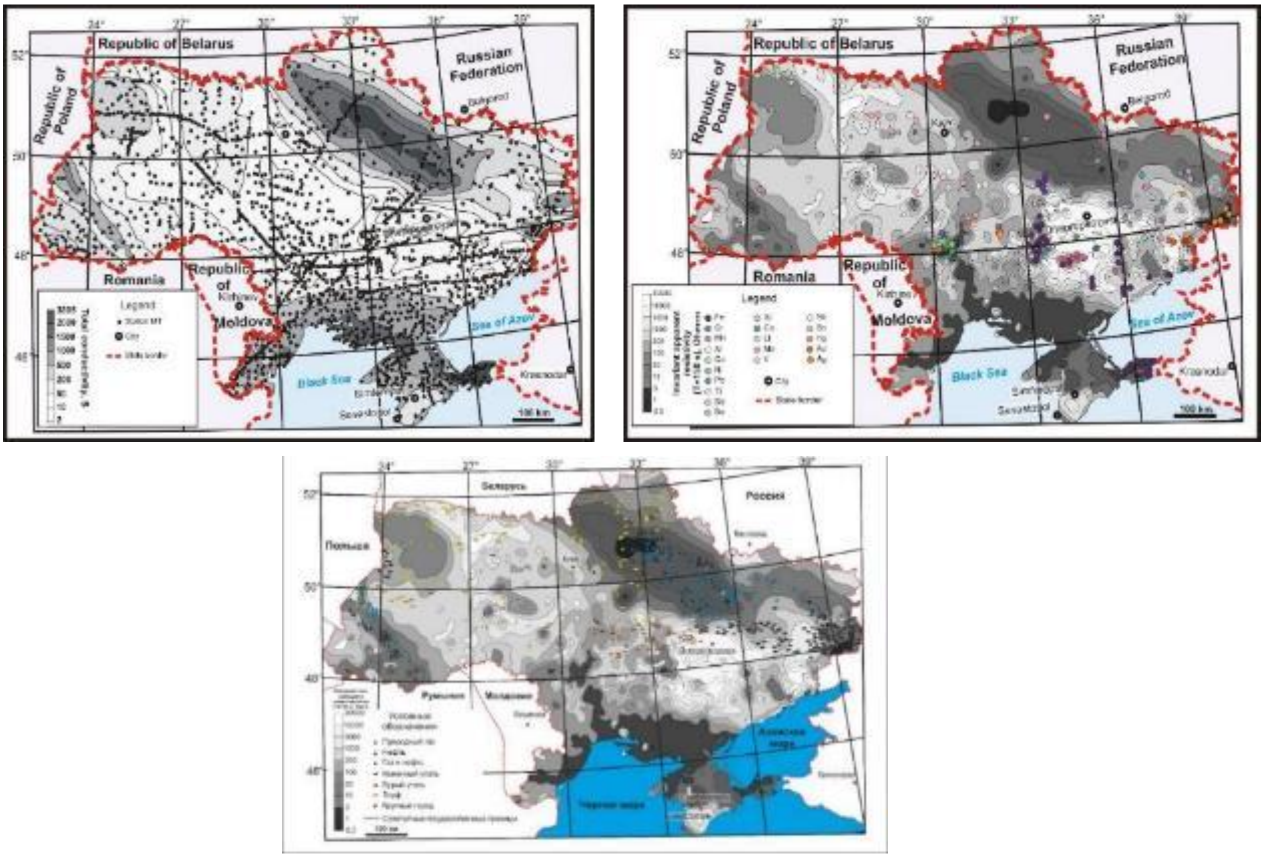

Figure 10 - Conductivity of the sedimentary cover and the consolidated Earth crust on the territory of Ukraine and the location of large mineral deposits

Kazakhstan start regular investigation of deep crust and mantle structure in 2015. The electroprospecting team quickly adopt innovative west equipment (mainly Canadian) and did first regional survey along 450 km long geotraverses with good quality of the data. The regional profile oriented in southeast – northwest direction and situated not far from Uzbekistan border (Figure 12). The spacing between MT-MVP sites is 1 km. The frequency range is 10 000 – 0.001 Hz. Regional profile crosses relatively shallow (1500 – 2000 m) sedimentary basin with total conductivity 100 – 300 Sm. Top of the basement represented by metamorphosed Paleozoic sedimentary rock. There is no significant geophysical sign of the border between Paleozoic and Precambrian rock. In geoelectric section along profile (Figure 13) unexpected big differentiation in resistivity of the Crust and upper Mantle rock is observed. Low resistivity bodies have very different forms. There are sub vertical roots which drives from the Mantle toward the surface as well as sub horizontal bodies. The border of the last ones is in good correlation with passive seismic borders. It is take attention the wide and deep low resistivity zone in the third quarter (from the left) of the profile). This part of the regional profile is shown in Figure 14 in bigger scale. So condition deep conductivity Lithosphere distribution in Kazakhstan can be effectively used for mineral exploration.

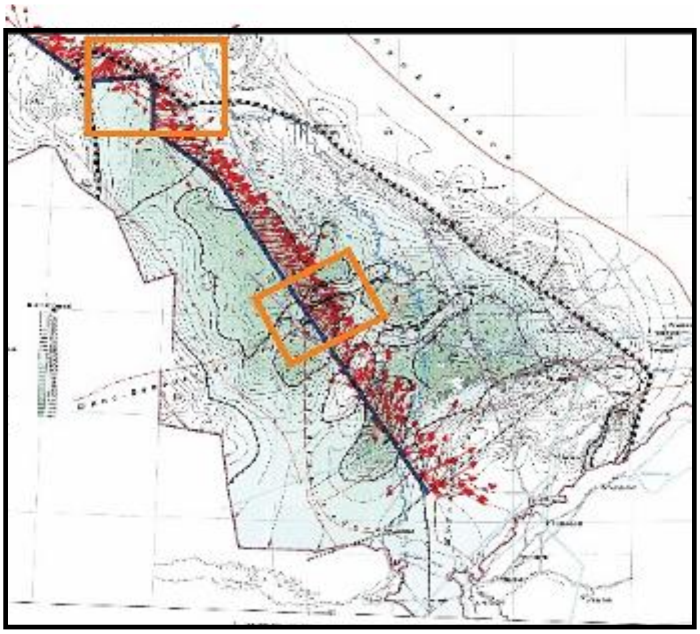

Figure 11 - The position of the geotraverses in the south part of Kazakhstan. The red arrows are real induction vectors in Parkinson convention

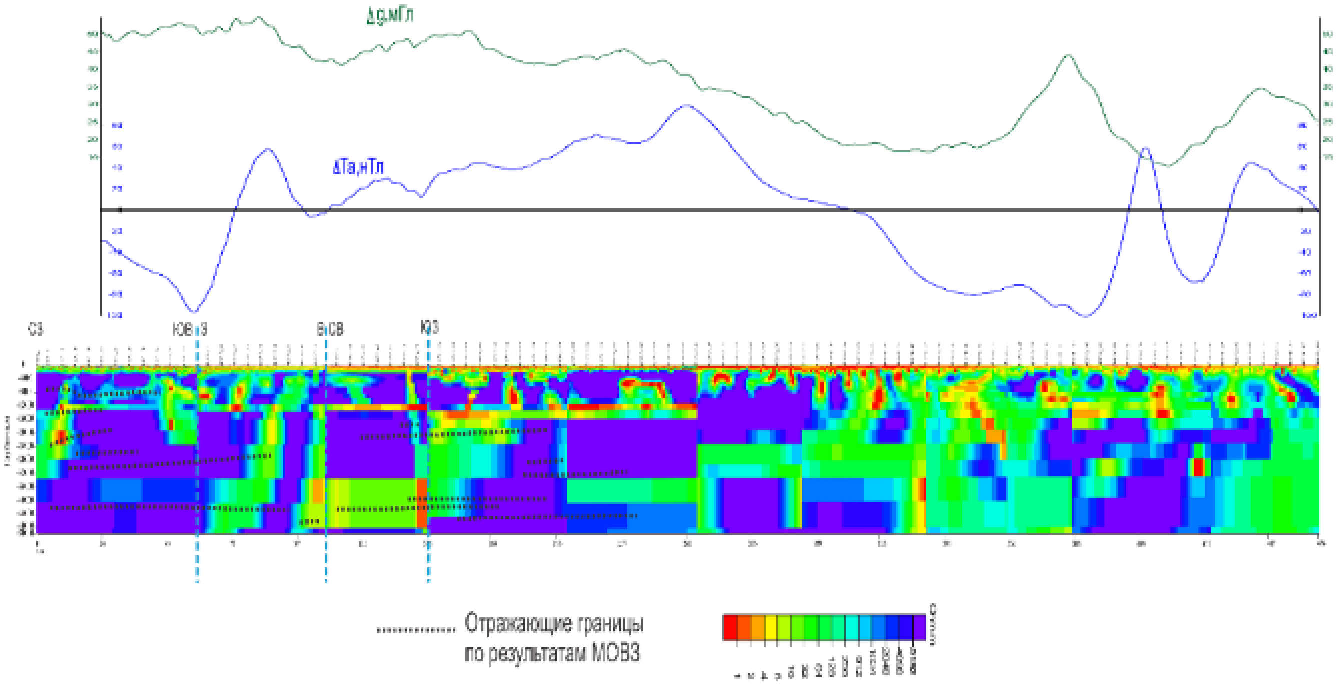

Figure 12 - The geoelectric section along Geotraverse in South Kazakhstan with passive seismic borders and gravity and magnetic fields

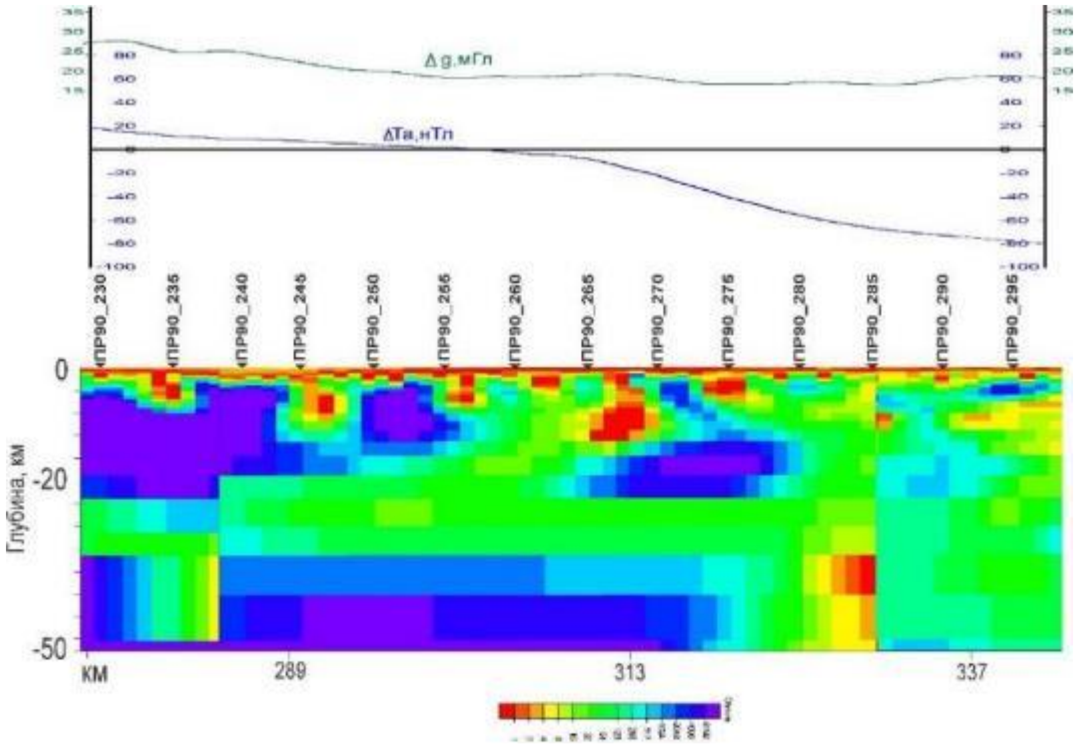

Figure 13 -The most conductive part of Geotraverse in detail

SOME REMARKS ON THE METHODOLOGY OF REGIONAL SURVEYS

It is expedient to integrate profile survey with spacing between MT-MVP sites equal 1-5 km with area survey of scale 1: 5,000,000 on both sides of the profile line (the width of the covered area 100 km). On the basis of the studies carried out, the authors recommend that the regional area MT-MVP works be carried out in the range 0.0001 - 3600 s (recording variations of 1-3 days). A network of long-period reference points is required in the range 0.0001 – 10000 s (recording variations of 7 days, each 10-20 regular sites). These points could be used as temporary remote reference sites. In areas where there are anomalies in the asthenosphere or there are big conductive anomalies in the lithosphere, it makes sense to conduct longer measurements with an extension of the frequency range to 100,000 s. All observations should be performed using technology with a remote reference sites (Gamble, T. D., Goubau, W. M. and Clarke, J., 1979). It is necessary to measure 5 components (2 electric and 3 orthogonal magnetic components) in order to be able to fully realize magnetotellurics and magneto variance methods. Equipment of 5-th ore 5-th+ generation have to be used only.
The easiest way to quickly assess the prospects of a license area is to cover it with a rare network of wide-range MT-MVP.

CONCLUSION

To date, it can be considered established fact that in the Earth's crust and upper mantle the big conducting zones, genetically connected with large mineral deposits. The identification of such conductive zones is one of the priorities of regional surveys. To date, the MT-MVP's regional survey have been prioritized in developed industrial countries as the most effective tool for studying the depth structure of the Earth to 150-200 km), geodynamic processes, and the search for new large deposits of minerals. Kazgeologia quickly mastered the advanced equipment and advanced world experience and performs such works at the modern level. Modern development in MT-MVP methods allows to distinguish three stages in the search for new deposits of minerals:
- reconnaissance in new promising provinces - regional studies on a rare network of separate intersecting profiles with a distance between research points of 5-50 km;
- exploration for mineral raw materials (including in-depth studies) in new areas (of deep conductive anomalies) or near existing mines (depth interval 200-2000 m);
- detailed exploration with a distance between sites in the profile 20-200m, depending on the structures studied.
The fastest and cheapest way to evaluate the prospective of the licensed area is a wide-range 5-channel survey of MT-MVP over a sparse net.

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