An estimate of the level of intersection of mineralization based on geochemical data using the method of pattern recognition

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Much attention has been paid to questions of studying the zonal distribution of orebody components and endogenic geochemical haloes of hydrothermal deposits, since the recognition of zonation enables us to estimate the prospects of mineralization at depth (Smirnov, 1976).

Such an estimate depends on the establishment of the level of erosion exposure of the mineralization. The best approach in this instance is that which is based on the group usage of geological-structural and mineralogical-geochemical zonation. However, the detail required in this study often does not allow us to use these methods of estimating mineralization in the early stages of exploration research. In addition, attention has been paid to methods of estimating mineralization at depth based on the application of geochemical data only (Solovov et al., 1970; Balasanov et al., 1963). In this case, only lithochemical-sampling data are necessary, which represent quite objective information and in addition may be obtained during a relatively minor geological study of a deposit.

In this report, we consider one way of estimating the prospects of mineralization continuation at depth from geochemical data as a basis for estimating the level of intersection of mineralization by methods of pattern recognition. The original information for the solution of the problem consisted of the amounts of a series of elements in samples collected from different ore intersections in a deposit.

At the present time, widespread publicity is given to methods of investigating zonation, based on linear, areal, or three-dimensional productivity of the element-indicators, and also the various ratios of pairs of groups of elements (additive and multiplicative). Thus, a method has been proposed in the works of Solovov et al. (1970, 1973), which takes account of the relationship between the generated amounts or the productivities of different orders, forming nonrandom monotonously decreasing functions based on the dip of the ore segregations. From the values of the monotonously decreasing indices, we obtain a probability estimate of the level of the intersection being studied.

In the work of Ovchinnikov and Grigoryan (1970) and in the methodological recommendations (Geochemical Methods ..., 1974), a method has been proposed for recognizing the elements of supra-ore and sub-ore primary haloes as a basis for calculating particular series of zonation and their comparison with an overall series of hydrothermal deposits. Such series are compared by tracing different characteristics of the zonation: the ratios of linear or areal productivities (indices of zonation and coefficients of contrast in zonation).

In the above and other works, many examples are cited of the successful application of methods developed during forecasting estimates of mineralization. However, the use of productivities is possible only under conditions of adequate investigation of the deposit, when there are data on a significant number of complete intersections of ore zones at different levels. During the early prospecting-assessment phase, there are, as a rule, only data available on isolated ore intersections; under these conditions, the most objective characteristics of the zonation may only be the amounts of element-indicators in the samples, which have also been used for solving the problem.

Treatment of the data on a computer has been conducted with the aid of the "Potentsial-2" algorithm of space perception (Savinskiy, 1974), employing a series of significant practical facilities with adequate effectiveness of recognition: the possibility of separating the objects of examination (amounts in samples) into K classes, and control of effectiveness of recognition on the same objects of instruction, which eliminates the necessity to expend part of the information on control samples; the recognition of informative combinations of elements with control of their effectiveness. All this has enabled us to set the most complex objective for estimating the prospects of mineralization at depth in a multistage mineralization with recognition of the best combination of element-indicators for its resolution.

An estimate of the level of intersection of mineralization by the method indicated has been

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Translated from Otsenka urovnya peresecheniya orudeneniya po geokhimicheskim dannym s pomoshch'yu metoda raspoznavaniya obrazov. Geologiya Rudnykh Mestorozhdeniy, 1977, v. 19, no. 4, p. 107-115. Co-authors with Kostikov are S. G. Rabinovich, R.I. Rossman, I.D. Savinskiy and G.I. Frolov.

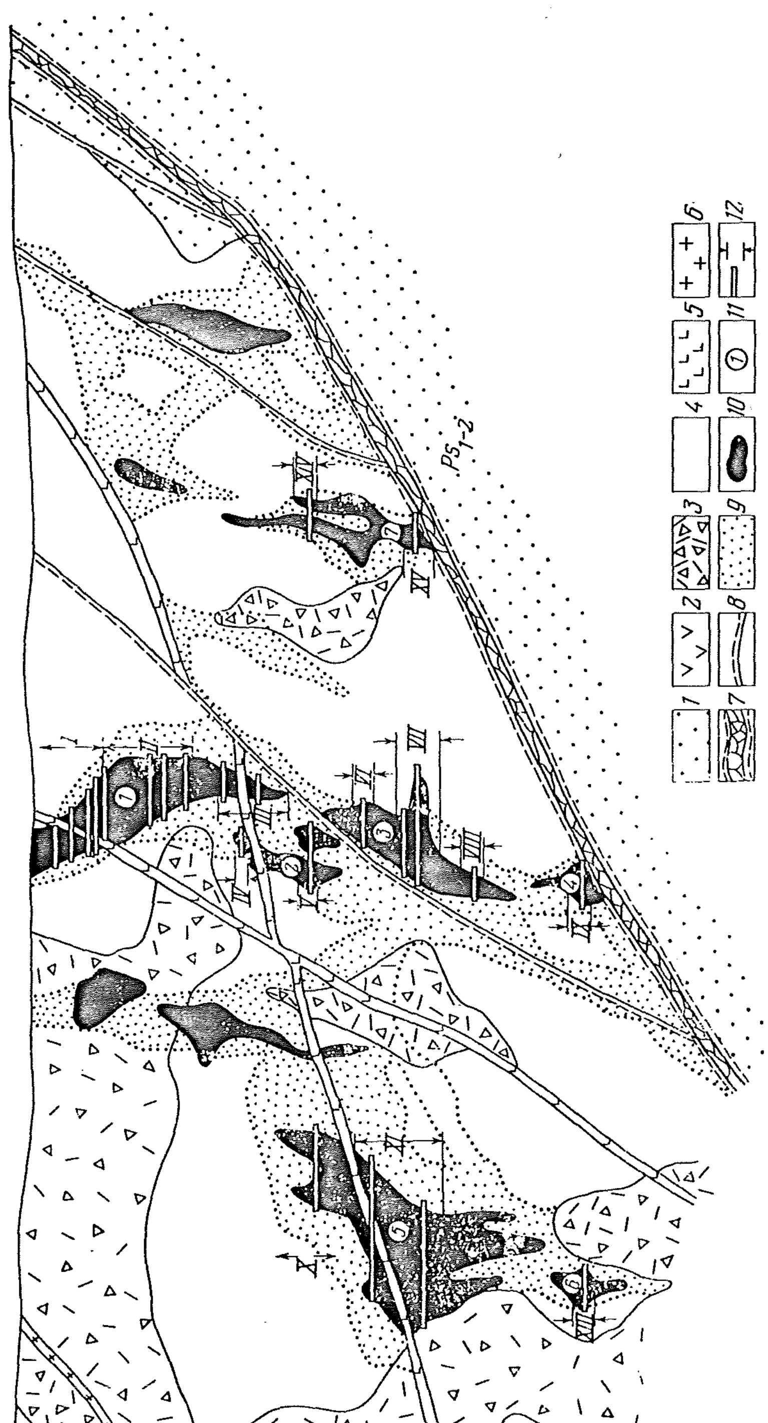

FIGURE 1. Longitudinal geological section of deposit:

1 - gray sandstones with seams of tuffs and conglomerates of mixed composition; 2 - andesite porphyrites; 3 - lava breccias of felsite porphyries; 4 - massive felsite porphyries; 5 - diorite porphyry dikes; 6 - granite porphyry dikes; 7 - main fault of 1st order; 8 - transverse faults of 2nd order; 9 - fields of hydrothermally altered (beresitized) felsite porphyries; 10 - contours of orebodies; 11 - orebodies; 12 - sections in orebodies (I-XV).

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carried out on one of the hydrothermal molybdenum — rare-earth deposits (fig. 1). The ore segregations in the deposit are localized in a near-fault, paleovolcanic pile of the central type, the position of which has been controlled by a fracture zone of deep-seated origin and lengthy development of the first order. The volcanic pile of large dimensions is characterized by a clearly defined linear shape, differentiation of composition of the rocks from dacites to rhyolite porphyries, and heterogeneity of internal construction, controlled by the presence of several phases of injection. The leading structural-morphological types of ore segregations are steeply dipping stockworks, localized at the nodes of intersection between a principal deep-seated fault and transverse, differently oriented fractures of second and higher orders. The stockworks replace one another en echelon along the dip, and in combination form ore columns extending for several hundreds of meters.

The overwhelming majority of the orebodies are inclined steeply toward the site of the principal ore-controlling fault, which restricts the development of mineralization at depth (fig. 1).

The rocks surrounding the mineralization have been subjected to various postmagmatic changes. Hydrothermal activity has been manifested in the deposit in two stages. The first stage includes hydrothermal metamorphism of the eruptives and their crater facies, associated with the emplacement of the volcanic rocks themselves. Changes of this type are widely developed and are of an areal nature.

Hydrothermal activity of the second stage, which led to the formation of the commercial mineralization, took place after injection of the youngest dikes of basic and intermediate composition. Four phases have been recognized in the hydrothermal postintrusive stage of mineral formation. During the course of the first two phases, veinlets, nests, and a segregation of quartz-tourmaline-biotite composition were formed, and also a wide zone of quartz-sericite-pyrite metasomatites. Ore mineralization, outside the contour of the metasomatic changes, is almost absent in the deposit. During the ore phase, molybdenite, galena, sphalerite, the main bulk of arsenopyrite, sericite, quartz, carbonate, chlorite, and certain other minerals were formed. The productive phase of the process has been associated with the principal influx of Mo, Pb, As, Zn, Zr, Bi, Sb, and Tl, and certain amounts of Sn, Y, Yb, W, Cu, U, etc. Most of these elements have also been deposited, although in significantly smaller concentrations, during the formation of the pre-ore metasomatites and post-ore quartz-carbonate veins and veinlets. The hydrothermal stage ends in the deposit with the formation of post-ore quartz-calcite veins with minor amounts of ankerite, barite, and fluorite, and also galena, sphalerite, chalcopyrite, and marcasite.

Up to the time of ore formation, the volcanic pile was overlain by a gently lying sequence of volcanogenic-sedimentary rocks. This situation, in company with lithological-structural factors, determined the duration of the ore-forming process under conditions of a "closed" system, which in turn controlled the intense peri-ore development of the ore-surrounding rocks, the formation of the vertically elongated ore segregations, and the predominant development of the metasomatic, finely segregated and veinlet-segregated ores.

It has been established that in hydrothermal deposits of different composition, formed in volcanic piles, a vertical zonation of the orebodies and the accompanying endogenic haloes is manifested (Gapontsev et al., 1969). And in the present deposit, the previously conducted work has shown that the head portions of the ore segregations, independently of their topographic level, have been enriched in sulfides of iron, lead, arsenic, and zinc.

The zonation of the ore columns, consisting of a series of en echelon segregations, has been less studied and is characterized by a more complicated picture.

In order to resolve the problem, samples have been collected at different levels in the standard deposit along a series of ore intersections (fig. 1, I-XV); the amounts of elements in the samples have been determined by the proximate-quantitative X-ray method (spill method). The analyses were carried out in one and the same laboratory. The samples were selected with an approximately equal length of 1.5 to 2 m, and the variations in length of the individual samples did not exceed a few tens of centimeters.

Histograms for a series of horizons in the main ore column, presented in Figure 2, give an idea of the variation in the amounts of elements with depth. The sub-intervals of amounts during the construction of the histograms were chosen so that they were based on not less than two adjacent points on the standard graph, used during the X-ray analysis.

The elements, which, allowing for the indicated requirements, seemed possible for constructing adequately representative histograms, are shown in Figure 2. On the basis of these histograms, the amounts of the 12 selected elements were encoded on a three-five graded system; during selection of the coding interval, several intervals on the histograms were grouped into one interval, so that, on the one hand, the vertical zonation was best

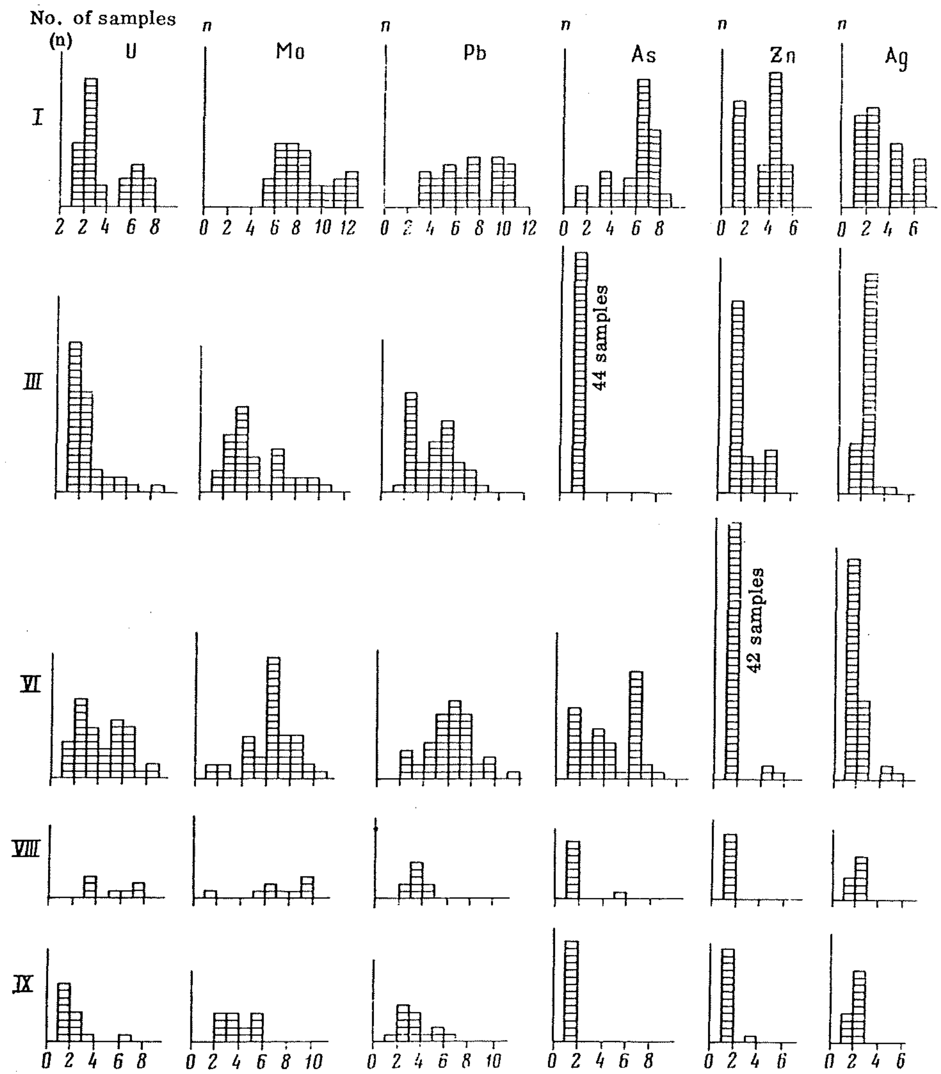

FIGURE 2. Histograms of distribution of amounts of elements in samples from a series of intersections of the main ore column.

emphasized, and on the other, the number of samples in the coding intervals were not markedly different.

For training purposes, the following selections were made for the intersections: I (45 samples), III (44 samples), VI (45 samples), VIII + IX (23 samples), which defined the main ore column on its various levels. The first stage in the solution of the problem was a check with the aid of the "Potentsial-2" algorithm of the effectiveness of assigning the samples to a particular level with a paired comparison of four recognized levels, and also in discerning the reduced "informative" combination of the elements during such a comparison.

The check of the effectiveness of the discrimination was carried out by means of alternate exclusion from the training selection of each of N samples and its examination with the use of the remaining N-1 samples (Savinskiy, 1974). As the measure of the effectiveness of the discrimination during the use of the complete combination of the original elements, we accepted a number of δ errors, obtained after carrying out all N examinations. The division of the samples between pairs of intersections within the same ore column has been carried out extremely effectively (thus, for example, during the separation of horizons I and III, we obtained $\delta = 5.7$ on 89 investigated samples, which amounts to 93.6 correct answers).

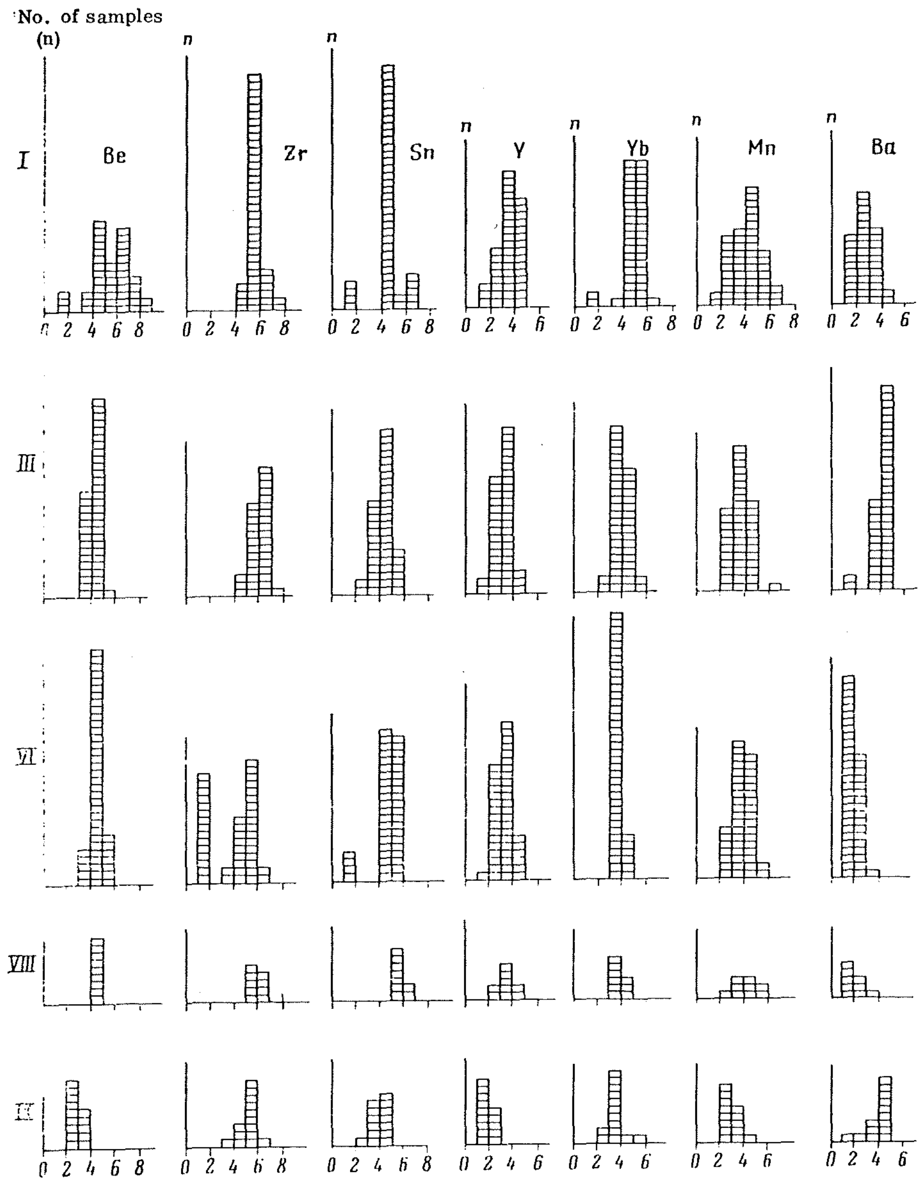

FIGURE 2 (cont.)

The recognition of the reduced informative combination of features was carried out by means of an alternate exclusion of individual elements and investigation of the δ errors.

During the first stage, we obtained informative combinations of elements during a paired comparison of different intersections (column levels). Since such a recognition of the informative combinations still does not provide the answer to the question as to the best combination during the classification of the samples simultaneously into four classes (levels), we formed a generalized combination (Mo, As, Zr, Yb) on their basis, which has also been used for solving the problem of the classification of the control intersections.

It has been established that all the elements of the informative combination have been recognized in significant numbers during the productive phase of the process, which suggests that the zonation, on which the solution of the problem is based, is to a significant degree a zonation of deposition.

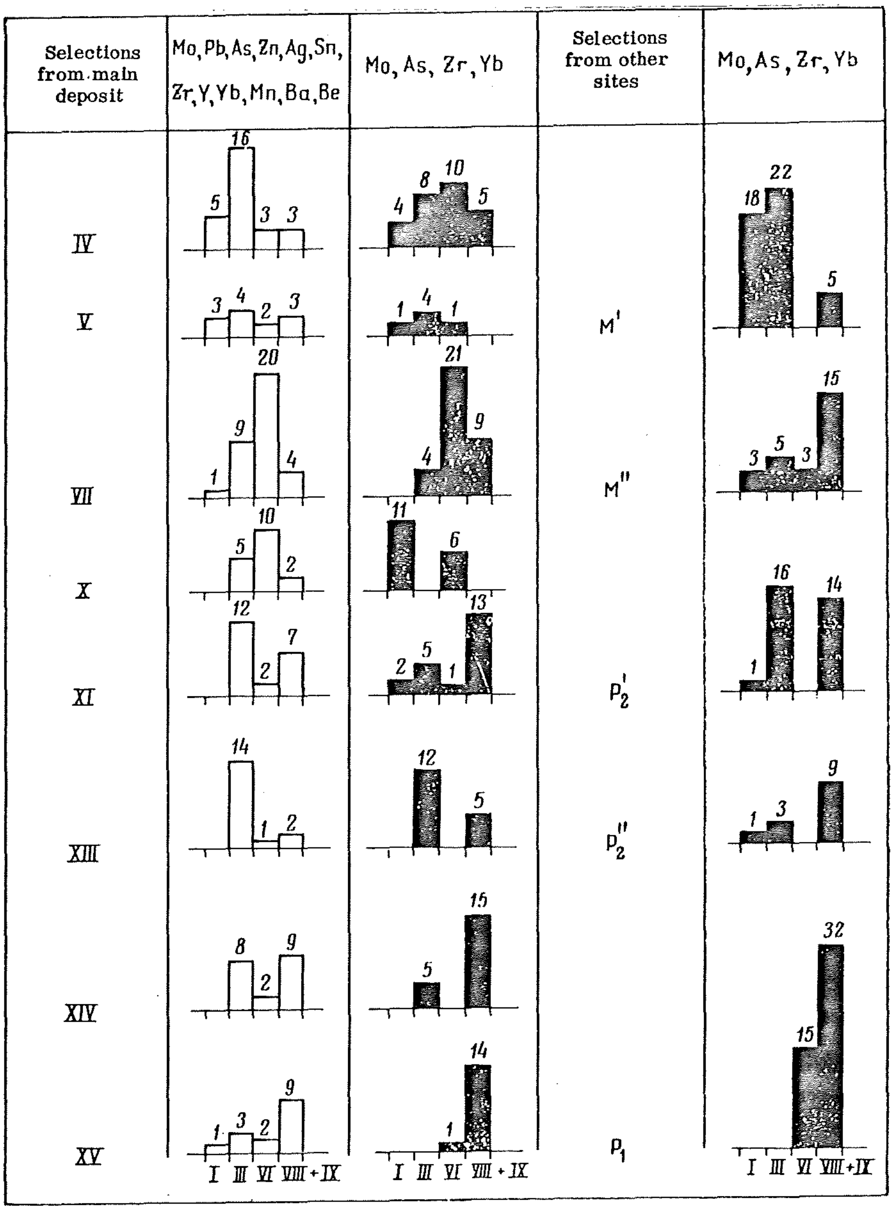

FIGURE 3. Results of classifying control selections. I, III, VI, VIII + IX) sections in standard ore column.

The results of the classification of the control intersections are presented in the form of histograms in Figure 3. The histograms show the number of samples, "heading" one or other of the four standard levels each by each of the intersections examined (the number of intersections is shown on the left-hand graphs). In the first place, we shall consider the results obtained, and we shall note that horizons XV, VIII + IX, and XIII, located near the Main ore-conducting fault (the relative distance of intersection XIII from the fault on Figure 1 still does not indicate its spatial distance owing to the extremely steep dip of the fault and the acute angle of incidence of the plane of this fault with the plane of the diagram), must be regarded as the root parts of the ore columns.

Intersections XV and XIV, located near the Main fault, have been clearly assigned on the basis of the combination of four elements to the near-root intersection of VIII + IX, that is, the prospects of mineralization at depth, based on the results of discrimination, must here be acknowledged as absent. Intersections X, VII, and IV, assigned mainly to intersections III and VI (the middle part of the ore column), on the basis of the results of the classification, must completely correctly be determined as having prospects at depth.

We may note as an example that intersection XIV, occurring approximately at one topographic level with intersections IV and X, have correctly been classified as belonging to the basal parts of the ore column, and the last two intersections have been determined as belonging to higher levels and consequently, they have prospects for the continuation of mineralization at depth. This example demonstrates that the use of discrimination methods in the present case enables us to provide a more correct forecast as compared with the hypothesis on the continuation of mineralization at depth based only on the deep levels of the ore intersections.

We should also note the errors assumed during the classification. Thus, an erroneous result was obtained during the classificiation of intersection IX, which had been assigned to the lower part of the ore column, and XIII, determined as its upper portion.

The errors during classification must be explained primarily by the presence of vertical zonation in the individual orebodies (as a consequence of assignment to the basal layers of the orebody, intersection XIII had been assigned to intersection III). The factor of local zonation of the orebodies undoubtedly significantly complicates the overall zonation of the column of mineralization and consequently, the solution of the problem under consideration. Nevertheless, the results obtained on the whole show that the inhibiting factor indicated does not prevent a satisfactory solution to the problem of determining the level of intersection relative to the column, and the method described may be used for a practical assessment of the prospects of mineralization at depth within the ore field of the standard deposit.

There is significant practical importance in clarifying the possibility of the wider application of the method in assessing ore shows, which occur at a substantial distance from the standard object.

With this in mind, we made an estimate of the prospects of mineralization at depth for two ore shows (denoted on fig. 3 by P_1 and P_2) and a single deposit (M), which occur outside the given ore field at varying distances (20-100 km) from the standard deposit.

Ore show (P_1) is located in the same structural-facies zone; in material composition and geological-structural conditions of localization, it is similar to the standard object. The ore mineralization has been distributed in a paleovolcanic pile of rhyolite-dacite porphyries of the covered type and consists of spatially separated nested accumulations and small lensoid bodies. The ore show has been drilled by a large number of wells. The mineralization has been traced from the surface only to a depth of a few hundred meters. Geological-exploration work carried out earlier (and repeatedly renewed) for prospecting the ore-show has turned out to give negative results.

In order to solve the problem by the discrimination method, samples were collected along the drill holes in the contour of mineralization from a depth of 80-100 m. Discrimination was carried out using the combination of Mo, As, Zr, and Yb. As is seen from Figure 3, the great majority of the samples have been assigned to the lower part of the mineralization of the standard deposit (intersections VIII + IX), that is, it has "headed" from the lower erosion profile in the ore show and consequently, in the absence of prospective mineralization.

Deposit (M) and ore show (P_2) occupy a similar geological position, located in paleovolcanic structures of the central type; mineralization has been traced in drill holes and mine workings to depths of 500 m from the present surface.

An estimate of these objects has been carried out based on two selections of samples, each of which characterized respectively the upper parts (down to depths of 250 m (P_2', M') and the root parts (P_2'', M'') of the mineralization.

As Figure 3 shows, the intersections from the upper parts of the objects being assessed are acknowledged as the upper and middle parts of the standard ore column and have been respectively determined as being prospective at depth. The samples from the lower parts have been unequivocally assigned to the root portions of the standard deposit.

Thus, the results of the estimate in the present case also conform with those of the exploration and research work.

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