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The development of numerical forecasting systems of primary sources of gold on the results of placer sampling in the example Vagran placer cluster (North Urals)

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Abstract. Based on the results of field research, as well as data from stock reports, two types of placer gold were identified within the Vagran placer cluster, which are indicators of primary mineralization. They are used as benchmarks for developing a digital system for predicting parameters and localizing primary sources of placer gold.

Formalized typomorphic characteristics of placer gold (size, roundness, fineness, sorting and content of trace elements), combined in multiplicative indicators, make it possible to forecast the composition and localization of the primary mineralization with greater confidence than ordinary parameters separately. The data required for such an assessment do not require additional field and highly qualified laboratory studies, they are contained in standard reports on the heavy minerals testing, and, in contrast to the characteristics of individual indicator types of placer gold, they give more stable results.

The study of the correlation system allowed to identify characteristic indicators for the primary mineralization of gold-sulfide-quartz and hypogenic-hypergenic types, and to give recommendations for conducting prospecting and exploration in order to identify the primary gold content of the cluster. The proposed method of creating forecast estimates allows to computerize the process of determining the prospects for primary mineralization of territories.

Keywords: placer deposits, strategic metals, modeling, forecast, multiplicative indicators

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During 200 years of exploitation of gold deposits of Urals main part of mining gold was produced from placer deposits, but at present, the main prospects for maintaining of the gold production in this region are associated with primary ore bodies. Available placers and its halos can be used as a search criterion for primary gold deposits. To assess the potential of long-term developing ore-placer clusters for endogenous mineralization, including new non-traditional types (Barannikov, 2009), it is necessary to carry out of material and spatial-genetic relationships in the series “primary gold source– intermediate host – placer”.

Despite almost a century of mining of gold placers on the territory of the Vagran cluster, some questions related to the primary sources of gold remain unresolved. It is believed that at the stage of Mesozoic peneplanation of the Ural folded belt, placer gold was released from the zones of ore mineralization of the gold-sulfide-quartz type, and then re-deposited in the formation of the Quaternary alluvial complex through the weathering crust systems and erosion-structural depressions (ESD) (Barannikov, 2009; Sazonov et al., 2001).

To find out the primary sources of placer gold, it is necessary to carry out specialized field work and laboratory research. The algorithm proposed by the authors based on formalizing standard typomorphic characteristics of placer gold and further combining them into multiplicative indicators makes it possible to automate, significantly simplify and optimize the process of forecasting of the ore mineralization.

Geology and primary metallogeny of Vagran cluster

The Vagran cluster, which we took as a model, is located within Sur’ya-Promyslovsky and Ashkinsky metallogeny zones of Northen Urals, the border between

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them runs along a regional meridionally oriented fault. In both ore zones, rocks of the black shale formation are developed: in the Ashkinsky – Upper Riphean and in the Sur'ya-Promyslovsky – mainly Ordovician ages. The size of the studied part of this cluster is 12.5 by 15 km.

The Riphean complex consists of metamorphosed terrigenous sediments, the lower part of which is dominated by coarser-grained varieties (chlorite-sericite shales, quartzite-sandstones, rarely quartzite conglomerates), the upper part – clay chlorite-quartz shales and phyllites) (Sazonov, Velikanov, 2010). The Ordovician complex is represented by gray and black carboniferous-quartzite and carboniferous-phyllite shales with subordinate layers of carbonate-containing varieties; in the upper part there are basic volcanics with corresponding layers of quartz porphyrites. The complex is intruded by a series of dolerite and gabbro-dolerite dikes. There are single dikes of metamorphosed granitoids, more common bodies of metadolerites (Fig. 1). According to geophysical data, a large buried granitoid massif is located within the cluster (Petrov et al., 2015).

Currently, single quartz veins with a sulfide content up to 0.5-2.0%, represented by pyrite, rarely chalcopyrite and tennantite, which show weak but widespread gold mineralization with a gold content of 0.2 ppm, rarely of 2-5 ppm, which have been identified within the Vagran cluster. In addition, weak gold content (of 0.5-1.0 ppm) accompanies linear zones of shale and pyritization, locations of crushing in metamorphic shales and

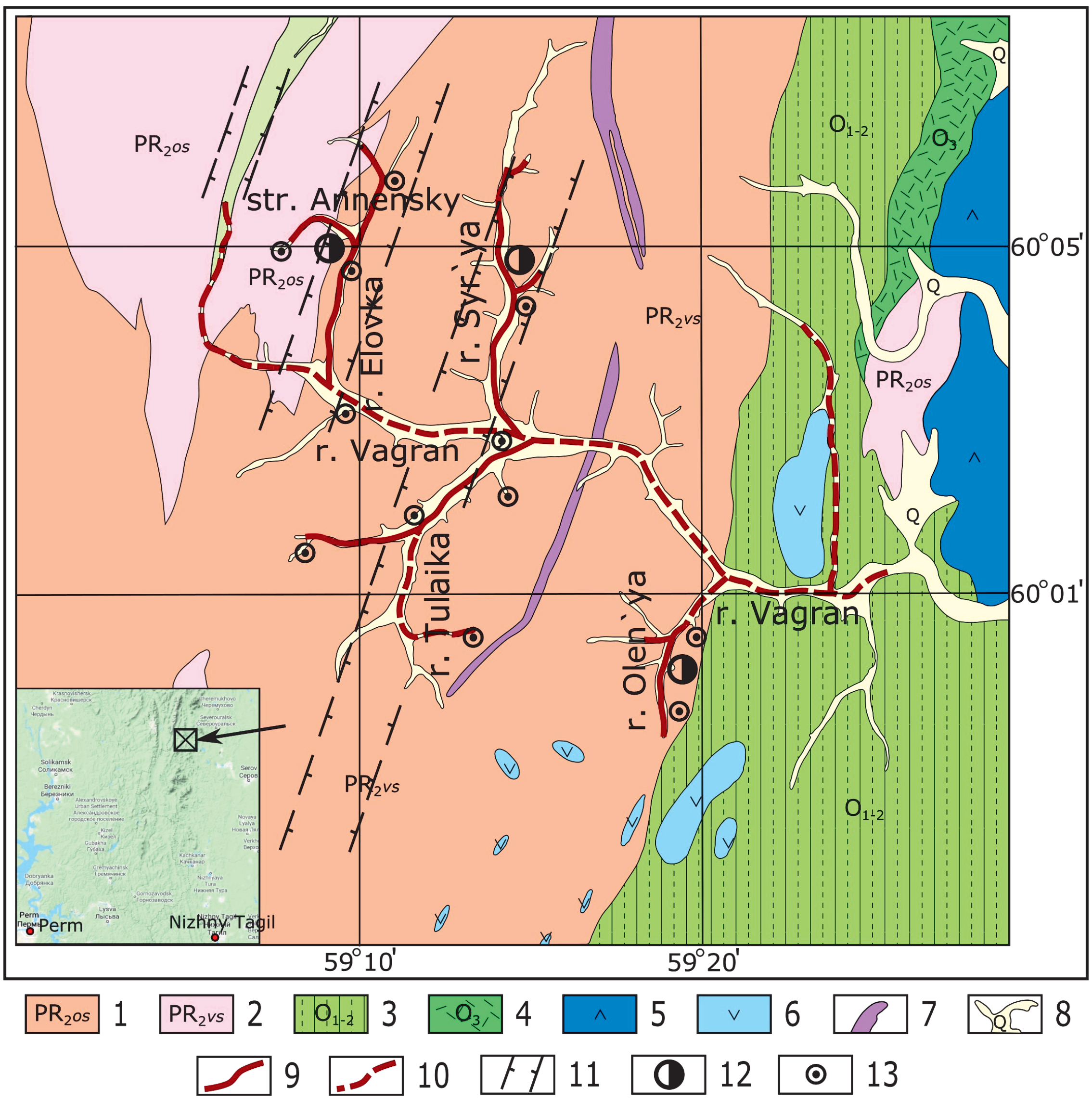

Fig. 1. Geological map of Vagran gold-bearing placer cluster base on a Report (Novitskiy et al., 1967). 1, 2 – metamorphosed clastic sediments of Upper Proterozoic (Riphean): 1 – quartzite, and sandstone of Oslyan Formation, 2 – carbonate-black shale strata with the basic volcanics of the Visim Formation; 3 – Lower-Middle Ordovician (black carbon-quartzite and carbonaceous-phyllite shales with subordinate layers of carbonate-containing varieties); 4 – Upper Ordovician (basic volcanics with under lying layers of quartz porphyry); 5 – gabbro-hornblende, biotite-hornblende amphibolites; 6 – altered gabbro; 7 – albite gneiss, gneissogranite and interstratified porphyry; 8 – Quaternary alluvial sediments; 9, 10 – gold placers: 9 – industrial importance, 10 – non-industrial; 11 – erosion-structural depressions; 12 – primary gold deposits; 13 – sample positions.

listvenite-like zones of hydrothermally altered rocks (Novitskiy et al., 1967).

The ore occurrence of gold-sulfide-quartz type has been identified in the headwater of Sur'ya Creek. It is represented by a zone of veined-disseminated mineralization of pyrite, chalcopyrite, sphalerite, gray copper ores and other sulfides, sulfoarsenides, tellurides with a gold content of 8 ppm and platinum of 3.7 ppm (Petrov et al., 2015). It is assumed that quartz-vein bodies with gold-sulfide-quartz mineralization, which served as sources of placers of Jurassic, Early Miocene and Quaternary age, were mostly eroded at similar ore occurrences at the level of the modern erosive section (Barannikov, Azovskova, 2017), and Sur'ya ore occurrence is the bottom parts of this gold mineralization.

In addition to gold-polysulfide-quartz orogenic mineralization, new non-traditional geological and industrial types for the Urals were established in the adjacent territory: gold-shale "Sukhoy log type", gold-argillisite and ore-bearing chemical weathering crusts (Lezhepekov, 2006; Petrov, 2014).

The mineralization of the hypogenic-hypergenic type, which singled out last time, is associated with the prospects of identifying new gold deposits in the Urals. The mineralization is associated with the stitch zones, disjunctive dislocations and strain zones. The hypogenic component is caused by the development of low-temperature hydrothermal metasomatites, while the hypergenic component is caused by the presence of chemical weathering crusts. Activation of low-depth low-temperature processes of gold ore genesis took place in several stages: Early Mesozoic (T-J_1), Late Mesozoic (J_2-K) and Cenozoic (Pg_3-Q), which generally coincided with the phases of post-collisional tectonic-magmatic activation of the region (Shub et al., 1993). A distinctive feature of this type of mineralization is the dominance of fine-grained and fine gold, as well as a wide range of probity and the absence of hypergenic changes (Gryaznov et al., 2007; Barannikov, Azovskova, 2017).

Placer metal content is localized in the headwaters of Vagran River and its tributaries within Quaternary watercourses of I-III orders. The productive layer of mainly alluvial genesis lies on fractured bedrocks, which is represented by metamorphosed shales, siltstones and sandstones, or on weathered eluvial deposits; in some cases, the layer lies on a false bottom at the base of the second (mid-Quaternary) cycle of alluvial system development. The gold distribution both in thickness and width, as well as strike of placers is uneven.

Sample collection and data of previous investigations

The material for the study based on data from sampling of alluvial, slope and eluvial sediments within the modern and mined quarriers and river-bedded material of natural streams, which were held on the territory of placer cluster over an area of approximately 400 km^2, and were taken from "Report on geological exploration at the Vagranskoe deposit of alluvial gold" (Novitskiy et al., 1967). At the field stage of research bulk samples of the river valley sediments each with an approximate weight of 20 kg were hand-panned to heavy mineral concentrate, from which the gold was extracted by separation in a heavy liquid in the laboratory of Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of the Russian Academy of Sciences (IGEM RAS). Within the Vagran cluster, a total of 20 points were tested (which were then combined and the total number of points was 10) and 372 grains of placer native gold were obtained (Lalomov et al., 2020).

Obtained gold grains were studied for morphology on binocular. Back-scattered-electron (BSE) images of the gold were taken for 94 original grains using a Scanning Electron Microscope (SEM) GSM 5610LV. 112 grains were later analyzed by electron microprobe at the Analytical Laboratory of IGEM RAS using JEOL JXA-8200 electron microbrobe (Japan) by analyst E. Kovalchuk. 7 grains with inclusions and pronounced rim-core zoning were studied in detail with SEM and energy dispersive spectrometer INCA-Energy 450 by analyst L.O. Magazina (IGEM RAS).

Data on the geological structure of the cluster, grain-size composition and fineness of gold was taken from the report (Novitskiy et al., 1967).

In previous works (Lalomov et al., 2020; Lalomov et al., 2017) the authors identified five types of gold, which differ in morphology, chemical composition and structure of gold particles (Fig. 2). The first type

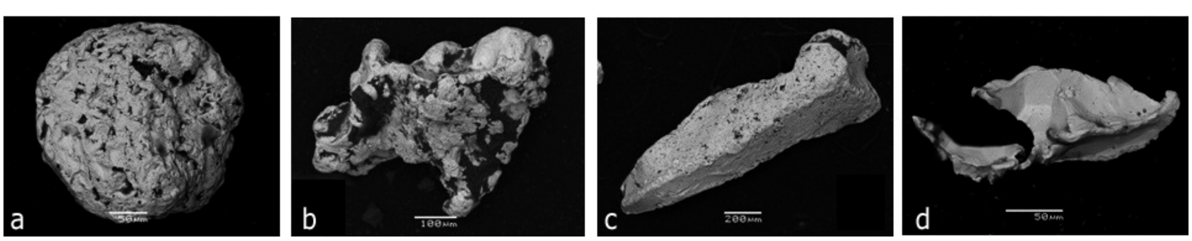

Fig. 2. Morphological types of concentrate gold of the Vagran cluster. a – medium to well-rounded with high fineness (type I); b – medium to subrounded with high fineness (type II); c – idiomorphic and interstitial with high fineness (type IV); d – irregular angular to sub-angular with medium and low fineness with high content of silver and mercury (type V).

(I) is classified as rounded and well-rounded particles of high fineness and absence of gold-rich rim zone, whereas second type (II) are characterized by rounded to sub-rounded gold grains of high gold fineness and absence of gold-rich rim zone. Morphologically third type (III) is identify to grains of types I and II, but it has high gold fineness rim zone of hypergenic origin. Gold of fourth type (IV) is idiomorphic and interstitial with high gold fineness without gold-rich rim zone, which is characterized mezothermal level of mineralization zone at first. Gold grains of fifth type (V) are sub-angular, medium to low gold fineness with an increased content of silver and mercury (Table 1).

The distribution of the selected types of gold within Vagran cluster is uneven: types I and II are found throughout the territory, while the periphery is dominated by more rounded gold of the type I. Gold of types III and IV tends to the ESD zones. V-type gold is poorly connected to the modern relief and driangle system and is controlled by the North-Western strike zone, which is diagonal to the structures of the Urals.

The similarity of composition of the first four types of gold indicates the similarity of their primary source, which is attributed to gold-sulfide-quartz formation, at the same time the differences can be explained by zoning of primary mineralization and history of transformation of native gold in hypergenesis. The least distant from the source (least rounded) is gold of type II.

The characteristics of V-type gold indicate a second primary source of gold, discovered at later stages of

	Types of gold				
	I	II	III	IV	V
Shape and surface	Gold grains are of a spherical shape with rough, rarely slightly smooth and pitted surface.	Grains are with rough slightly smooth. The shape of the gold is mainly dendritic, wire-like, leaf-like, and the internal structure is uniform.	Similar to grains of type I and II	Gold of idiomorphic and interstitial morphology with a rough surface.	Gold particles are presented angular monocrystalline secretions of idiomorphic and xenomorphic particles with smooth and conchoidal surface.
Roundness	Well-rounded and rounded	Rounded and sub-angular	Well, rounded and sub-angular	Moderate traces of roundness	sub-angular and angular
Fineness	933 (882- 970) *	931 (901- 957)	In core 932 (882- 970), in rim-zone - 986 (967- 997)	948 (923- 966)	828 (571- 901)
Trace elements (wt.%)	Ag 6.18 (2.03- 11.62); Cu 0.15 (0.06- 1.08); Hg (0.154- 0.268) - in single grains	Similar to type I	Ag 6.38; Cu 0.15.	Ag 4.76.; Cu 0.17.	Ag 15.8.; Hg of 1.15
% in placers	36.7	28.8	13.8	9.2	11.5 (0 - 76.5)
Internal structure	Mostly homogeneous, there is a lumpy, spongy and layered structure, formed when rolled into spherical aggregates of irregularly shaped gold particles during transportation.	Mostly homogeneous in individual grains inclusions of cobaltite.	High fineness rim-zone (10-40 microns)	Without rim zone. The internal structure is uniform, similar in composition to grains of type I and II.	The structure is uniform, with veinlets enriched with mercury. Thin (3-5 microns), highly enriched (fineness 923-967) rim zone in the individual grains.
Localities	They are distributed throughout the cluster, have signs of transfer and long-term stay in the zone of hypergenesis.		It tends to ESD zones.	It tends to Sos'vinskaya ESD zone.	There are signs of short-distance drift and a relatively short time spent in the hypergenesis zone.
	Well-rounded gold predominates on the flanks of the cluster.	Dendritic rounded gold predominates in the central part of the cluster and decreases on the flanks.			

*Table 1. Distinguished types of placer gold (Lalomov et al., 2020). * Average content (variations of values).*

formation of the cluster placers, at the same time weak roudness indicating its minimal displacement. The distribution of gold of this type over the area is poorly controlled by driangle system: the increased content is confined to a linear zone diagonally oriented in relation to the folded structures of the Urals. Presumably, the source of this gold is hypogenic-hypergenic mineralization (Lalomov et al., 2020).

Thus, gold halos of the types II and V have the greatest connection with primary mineralization and can serve as indicators of primary ore mineralization, which were used as a model for creating complex search indicators.

The development of forecasting multiplicative indicators

When prospecting of gold deposits applies a complex of methods, among which the most important is the heavy mineral concentrate sampling. At the same time, not only the total gold content in alluvium sediments is informative, but also its morphology, first of all, its roundness, which indicates the degree of its distance

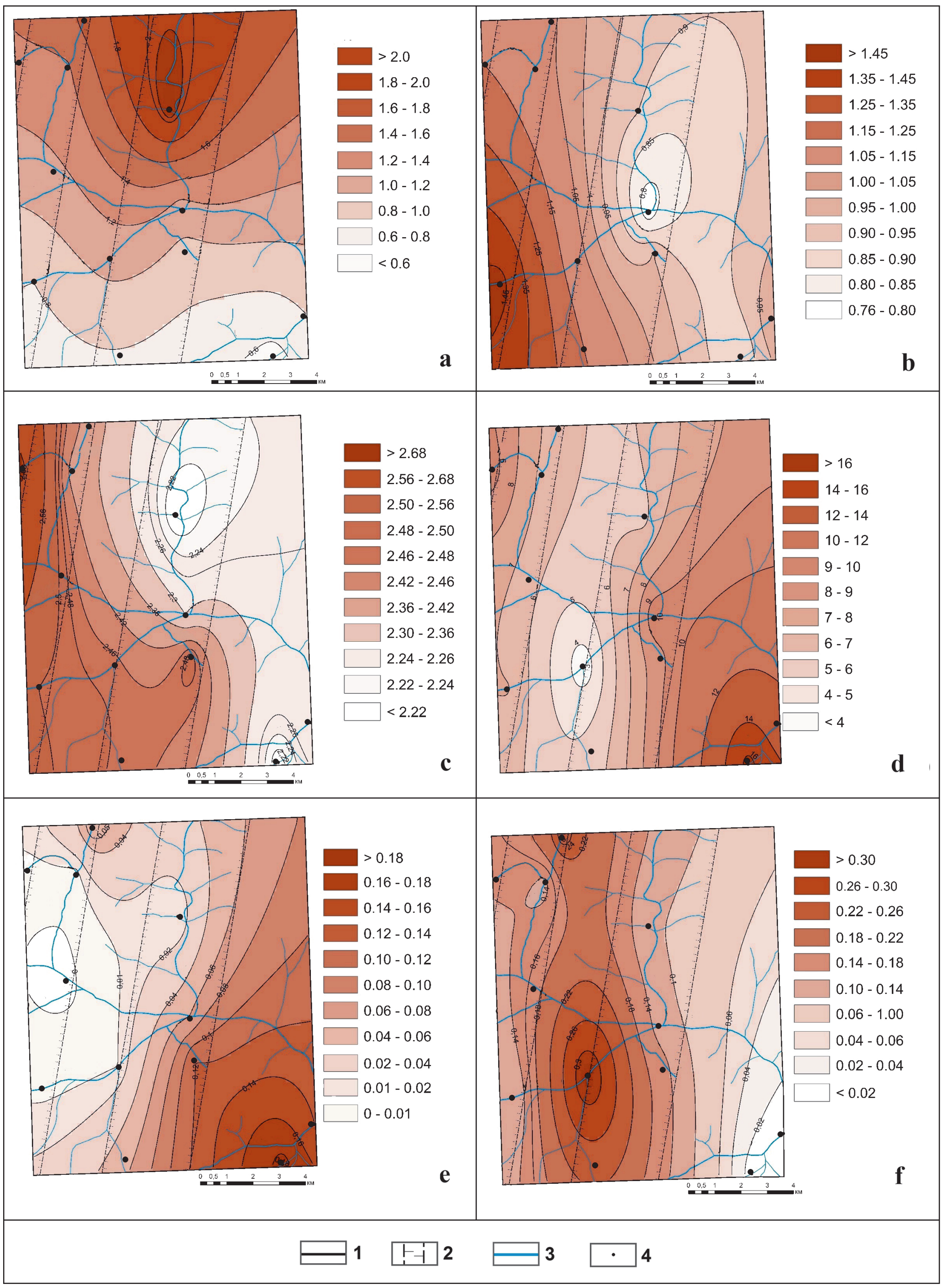

Fig. 3. The distribution of formalized indicator characteristics over the cluster area: a – size, b – sorting, c – roundness, d – content of Ag, e – content of Hg, f – content of Cu. 1 – cluster boundaries, 2 – erosion-structural depressions, 3 – watercourses, 4 – sampling points.

from the primary source. At the present stage, different types of concentrate gold are additionally distinguished, its composition, structure and nature of inclusions are studied, which allows us to establish the types of primary sources and the history of gold conversion in the hypergenesis zone.

Sometimes such data is sufficient to solve the problem of identifying the primary source of placers, but most often the level of features individually is not sufficiently informative, and methods are needed to obtain complex indicators that are more contrasting than individual factors. The various study of the Vagran cluster's gold concentrate allowed us to formulate and test methods for creating and applying such complex indicators on its example.

In order to create a computerized system for predicting primary mineralization, the following steps have been taken sequentially:

- the main indicator characteristics (IC) of placer native gold haloes are highlighted, the direction and degree of their connection with indices of basic mineralization are determined;
- formalized (quantitative assessment) of these IC has been done;
- within the framework of the GIS project of the Vagran cluster, the quantitatively evaluated IC received spatial reference;
- based on the correlation analysis, the primary IC are combined into multiplicative indicators constructed taking into account the directivity of the influence of the parameters on the overall predicted result.

The created computerized system allows to collect, store, process and visualize data at all stages of the process of creating forecast estimates.

To solve the problem, we used the following typomorphic IC of placer gold – weighted average size, sorting (formalized by the coefficient of variation of the size), roundness according to a 5-point scale from 0 (non-rounded) to 4 (very well rounded grains) for different types and for the sample as a whole, the fineness and content of trace elements: silver, copper and mercury (Fig. 3). All the obtained characteristics are spatially linked within the framework of the GIS project in the ArcGis package.

The formalization of sorting through the coefficient of variation is caused by a number of reasons: the distribution entropy according to S.I. Romanovsky requires a more detailed analysis of particle size distribution (Romanovsky, 1988); the classical sorting coefficient using trask quantiles (Trask, 1932) is not universal, it is suitable for the most rough estimation of granulometric composition (Logvinenko, Sergeeva, 1986). The magnitude of the standard deviation depends on the size of the particles being analyzed, therefore, the coefficient of variation (the dimensionless value of the standard deviation of the size divided by the weighted average particle size) is, in this case, the most representative indicator of the sorting of gold particles by size.

Ordinary indicators far from always can unambiguously characterize the forecast potential of the studied area for various types of mineralization, therefore, multiplicative indicators (MI) were used, similar to those used in geochemistry to increase the contrast of indicator features. MI is calculated according to the formula in which the numerator contains the products of the results of the analysis of elements (in our case, IC) of positive correlation with the desired type of mineralization, and the denominator contains the product of neutral or negative indicators of the desired parameter (Grigoryan et al., 1983).

Due to the directed amplification of correlated useful signals, the influence of fluctuations (background) is minimized, and therefore the multiplicative halos show a closer connection with the geological and structural features of ore bodies and deposits, which significantly increases the reliability of their interpretation. When m elements are multiplied, the anomaly amplitude increases m times, and the variance only $\sqrt{m}$ times. Accordingly, the contrast of the anomaly increases by a factor of $\sqrt{m}$. MI also gives a more stable result, reducing the influence of random deviations and errors (Voroshilov, 2011).

To create generalized predictive characteristics, a matrix of pair correlation coefficients between them and the gold content of types II and V, which are the reference indicators of primary mineralization, was constructed (Table 2). Based on these data, MI were formulated that characterize the zones most promising for searches for bedrock sources of gold.

The second type of gold ("C_{II}") has a positive correlation with the particle size and copper content, and negative correlation with the sorting, roundness and silver and mercury content. MI-1 characterizes (through the prevalence of type II gold) the bedrock sources of the gold-sulfide-quartz formation, discovered at the stage of peneplanation and passed through the intermediate hosts. It can be calculated by the formula:

$$MI\text{-}1 = (K \times Cu) / (S \times O \times Ag \times Hg) \quad (1)$$

The fifth type of gold ("C_V") has positive correlation with content of silver and mercury, and the negative correlation with particle size, sorting, particle roundness and copper content. MI-2 characterizes (through the prevalence of type V gold) the bedrock sources of the hypogenous-hypergenic type, discovered at the Quaternary stage. It can be calculated by the formula:

$$MI\text{-}2 = (Ag \times Hg) / (K \times S \times O \times Cu) \quad (2)$$

The data from Table 2 demonstrates that MI-2 has a real stable correlation with the type V gold content (R = 0.86), more significant than the correlation

	C_{II}	C_V	K	S	O	Ag	Hg	Cu	MI-1	MI-2
C_{II}		**-0.59**	0.44	-0.12	-0.31	-0.61	-0.34	0.31	**0.46**	-0.48
C_V			-0.54	-0.52	-0.45	0.80	0.80	-0.56	-0.53	**0.86**
K				-0.10	-0.05	-0.60	-0.60	0.36		
S					0.61	-0.37	-0.50	0.18		
O						-0.33	-0.46	0.43		
Ag							0.81	-0.79		
Hg								-0.54		
Cu										

Table 2. Matrix of pair correlation coefficients (R) between typomorphic indicator characteristics, the content of indicator gold types and obtained multiplicative indicators (MI). Notes: "C_{II}", "C_V" – gold content of indicator types II and V in the total placer gold; "K" – the average size of the placer gold (fineness); "S" – sorting, expressed in terms of the coefficient of variation of dimension; "O" – roundness on a 5-point scale; "Ag", "Hg", "Cu" – the content of silver, mercury and copper in gold; "MI-1", "MI-2" values of multiplicative indicators. The critical value is R = 0.55 with a sample size of N = 10 and a confidence probability of α = 0.90.

relationships of individual characteristics, which allows MI-2 to be used as a criterion for allocating areas for the search for hypogenous-hypergenic mineralization.

The multiplicative indicator MI-1 has a less obvious connection with the zone of the primary source characterized by type II gold. Although MI-1 has a more stable correlation with the main indicator of gold-sulfide-quartz mineralization than individual IC (with the exception of silver content), the overall correlation stability (R = 0.46) is less than the critical value R = 0.55 at a confidence level of α = 0.90. Obviously, this is due to the fact that gold entered the placers not directly from the zones of primary mineralization, but through a system of intermediate

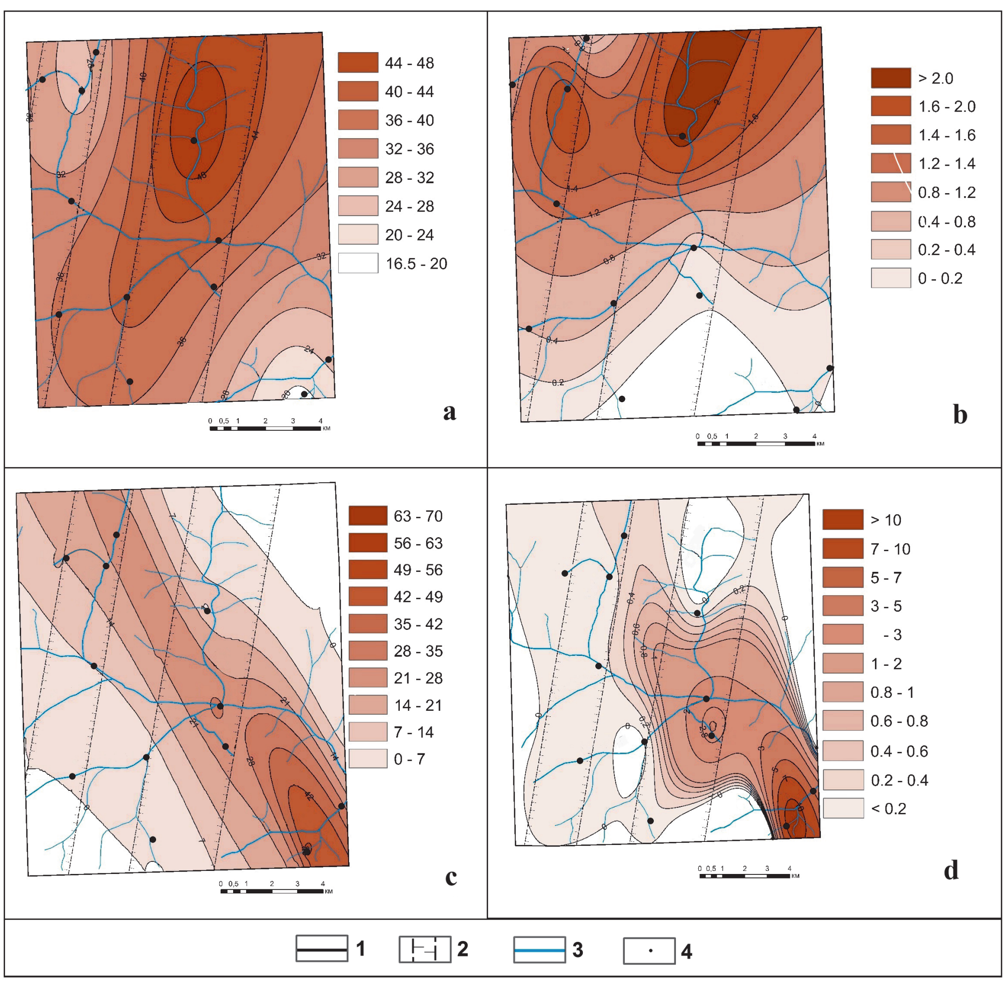

Fig. 4. Distribution of indicator types of bedrock gold and multiplicative indicators: a – gold of type II (%), b – MI-1, c – gold of type V (%), d – MI-2. 1 – boundaries of the site, 2 – erosion-structural depressions, 3 – watercourses, 4 – sampling points.

hosts, which introduced a distortion into the picture of the spatial-genetic relationships between the primary source and placer gold of Quaternary streams.

Although the silver content (which is equivalent to the fineness due to the low contents of other trace elements) is more contrasted in comparison with MI-1 (R = -0.61), separately use ID silver content may have an increased error and characterize the zonality of the variation in the fineness of a single source, rather than the presence of different formation sources. Therefore, the use of MI-1 gives a more stable and reasonable result.

A stable negative correlation between the contents of gold of types II and V (R = -0.59) confirms the assumption that these types of alluvial gold came from different sources.

The final results of data processing are presented in Fig. 4. Distributions of indicator types of gold II and V were adopted as reference indices of primary mineralization, and MI-1 and MI-2 were used as forecast criteria.

MI-1 has maximum value in the region of the middle and upper part of the valley of the Sur`ya River; the second, less pronounced maximum, is associated with the basin of the Elovka River (mouth of the Annensky creek). The values of MI-1 are reduced to the periphery of the cluster. This approximately coincides with the distribution of type II gold and confirms the assumption that the main primary source of alluvial gold of the cluster was localized in this zone.

The maximum values of MI-2 are concentrated in a linear zone extending from the middle course of the Olen`ya river through the site of confluence in the Vagran river Sur`ya, Tulaika rivers and Bazovy creek, to the upper part of the valley of river Elovka (above Annensky creek).

The available irregular sampling on the primary mineralization of the cluster is insufficient for the development of MI, therefore, in the proposed study, short transported placer gold was used as indicator sign of primary mineralization. Nevertheless, the identified prospective areas are confirmed by the available data on the bedrock gold mineralization. Revealed gold-sulfide-quartz mineralization in the upper river Sur'ya has gold contents up to 8 ppm (Petrov et al., 2015). It coincides with the maximum contents of type II gold and elevated values of MI-1. Unfortunately, available publications have not description of the typomorphic features of the bedrock gold, fineness is not indicated, therefore, the type of mineralization can be characterized only tentatively.

In the Olen`ya-Elovka zone, which corresponds to elevated gold contents of type V and MI-2, ore gold with a content of 2.0-6.9 ppm is presents in the selected bedrock samples. The silver content of 3.6-1.7 ppm and mercury 0.05-0.10 ppm indicates possible connection with type V placer gold. There is no doubt that the use of directly primary rock analyses as standards will increase the reliability of the method.

The prospective areas obtained from the multiplicative indicators can be used for setting up prospecting works for gold ore objects.

Thus, with respect to the forecast of the bedrock gold mineralization within the Vagran cluster, the most promising is the linear north-east – south-west strike zone, which controls the distribution in the placers of medium-grade mercury placer gold of low-temperature hypogenous-hypergenic type. It is assumed that it is determined by the linear zone of faults and/or deconsolidation of rocks established at the stage of postcolysis tectonic-magmatic activation. A weak manifestation of the relationship between the distribution of gold of the fifth type and elements of the hydrogrid indicates its late opening (Quaternary time), which suggests a small level of its erosion section and, accordingly, an increased ore potential.

The use of a computerized system for processing the data of heavy mineral concentrate sampling and the obtained multiplicative indicators can be used to predict the bedrock metal content. Although the distribution of indicator types of gold is more directly than the multiplicative indicators associated with bedrock mineralization, their direct application is complicated by a number of reasons:

- to highlight the indicator types of placer gold, indicating bedrock objects, it is necessary to test the entire investigated area and obtain placer gold samples for specialized studies;
- the bonds of placer gold with primary sources are manifested at the level of the internal structure of grains and their chemical composition, therefore, it is necessary to carry out specialized hardware analytical studies (electron microscopy, microprobe analysis in polished pieces);
- to distinguishing of the indicator types of the placer gold and for creation of forecast of primary mineralization, high qualification and extensive practical experience of the researcher in the study of primary mineralization and placer native gold are required. At present, the number of such specialists in Russia is not enough to conduct mass forecast estimates.

The proposed method allows to carry out a predictive assessment quickly, with less cost and in an automated mode:

- does not require special field and laboratory studies, uses standard data from geological reports on the study of placer gold deposits and aureoles;
- consists of standard operations within the framework of the developed algorithm and does not require high qualifications and extensive practical experience of the operator.

Currently, the method is under development and has a number of unresolved issues that will need to be investigated when continuing the work:

- IC were tested within a single gold-bearing cluster on two types of primary mineralization (gold-sulfide-quartz and hypogenous-hypergenic); the amount of used IC and the types of characterized primary mineralization types can be increased;

- at the current stage, placer gold with minimal signs of transfer, which has the maximum connection with primary mineralization, has been used as indicator types of primary sources; the application of this technique at sites with known ore mineralization will increase the reliability of the model;

- equations (1) and (2) solve the problem in a first approximation, based on the assumption of a linear nature of the relationship between IC and the ore potential of the territories. In the case of nonlinearity of these relationships, the calculation formulas of the MI can change, but the qualitative nature is likely to continue. The use of complex multiplicative indicators can reduce the influence of individual characteristics (even if they have a nonlinear correlation dependence) and strengthen the general regularities. This issue requires additional research in the subsequent stages of the development of the methodology.

Thus, in the current state, the proposed methodology is optimally applicable at the initial stages of forecasting and planning of the exploration, when the problem should be solved using available data and without additional research. In the case of confirmation of the forecast, it is recommended that more detailed work be undertaken on the prospective areas.

Conclusion

Based on the formalized (quantitatively estimated) indicator characteristics of placer gold, computer numerical modeling and GIS technologies using the example of the Vagran goldiferous cluster, a system for spatially calculating and positioning multiplicative indicators that evaluate the zone of the likely occurrence of primary metal bearing has been created.

The proposed methodology makes it possible at the initial stages of work to use the results of ordinary analyzes (including those contained in stock reports) for forecasting.

Obtained multiplicative indicators are oriented to forecasting of two types of mineralization (gold-sulfide-quartz and hypogenous-hypergenic); for other ore-bearing formations can be used other parameters, that will be the subject of further research.

Nevertheless, already in its present form, it can be used for planning geological exploration, and also serve as the basis for the further development of more detailed and accurate versions of the methodology, as well as expanding it to other geological and genetic types of mineralization.

Based on the conducted studies, a zone was identified within the Vagrans gold-bearing cluster that is promising for the identification of the primary bedrock mineralization of the hypogenous-hypergenic type.

Application of the developing method does not mean abandonment of existing methods for predicting of bedrock mineralization. It will not be able to completely replace the specialist, and therefore it will be used as a hybrid system operating in the "operator-computer" dialogue mode, which facilitates the decision-making process for the specialist. A similar approach is already used for the express assessment of gold ore occurrences in the Arctic zone of Russia (Chizhova et al., 2019).

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