Provisions for higher mining efficiency with regard to cluster arrangement of mineral deposits

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Abstract. Cluster (discrete) arrangement of minerals and their aggregates in different vectors in space is typical of most placers and deposits. Large and small pockets of valuable components in mineral bodies have different shapes, sizes, formation conditions and other geological characteristics. Cluster arrangement exists on all scales: an ore province in a region; an ore zone in an ore province; a deposit in an ore zone; an ore body in a deposit; an ore pillar in an ore body; pay zones in an ore pillar, nest, etc. By analogy with taxonomy and image identification, for differentiation of mineral resources by their processing properties or commercial value, space-detached accumulations of points representing some mineral objects are assumed as clusters with increased or lowered content of useful components. Structural order and clustering are the common features of many mineral deposits. Accurate geometrization of placers with regard to useful component content, inclusion of spatially variable quality conditions of useful components and proper management of mining favors reduction in volume of rock mass to be extracted, hauled and processed by 2 times at the same recovery factor of useful component; make it possible to increase cutoff grade by 2 times, and enables increment in production of useful component within the same production areas and at the same production capacities.

1. Introduction
Naturally nonuniform distribution of minerals heavily affects performance of mineral exploration, production and processing. By analogy with clusters in taxonomy and in image identification toward differentiation of mineral resources based on their processing behavior or commercial attractiveness, spatially separated sets of points representing some valuable, barren or harmful objects can be assumed as clusters of minerals with higher or lower content. Introduced in [1] and evolved in [2, 3], the notion of a clustering structure of a mineral substance as some nested partitions with pronounced concentration (or bareness) of valuable components agrees well and is interlinked with the morphology, texture and structure of different rock masses.

As a consequence of the discrete arrangement, 80–85% of gold reserves in placers is contained in 20–30% of volume of conventionally developed sand [1]. From generalization of gold exploration and production data, proven reserves occupy merely 25% of total ore volume, and diseconomy of production and processing because of poor extent of exploration exceeds exploration expenditures by tens times. Up to this date, neither geology nor mining science provides reliable information on actual mineral resources and on their distributions by shape, size, density, etc. Available data are fragmentary, conflicting and, according to the analyzed accuracies of estimated contents of valuable components using conventional assaying methods, are extremely inaccurate and sometimes erroneous.
The current system of mineral exploration and appraisal disables accurate detailing of deposits. For this reason and considering clustering structure and discrete arrangement of valuable minerals, mining always needs improved in-situ assaying.

2. Cluster structure of mineral deposit

It is insufficient to characterize a cluster only by the content of mineral components. Most mineral deposits feature spatial nonuniformity and some other technological properties.

Nonuniformity of distribution of a useful component in placers is included in placer classifications by this attribute: placers of nested, banded, striated, etc. structure; very consistent, consistent, average consistency, inconsistent placers [1]. There are many typical geological formations which can facilitate initiation of different concentration zones of useful components in placers, for instance, gold: in front of protrusions in bedrocks and in zones of faulting and folding of the bottom; in front of other barriers on the way of the prevailing stream; in erosion baths of waterfalls; in the bottom dents in faults; in fractures or in fractured zones; in various indentations of plicative or erosion (not disjunctive) nature; at points of sharp change of the bottom slope in the valley cross-section; within different-age sequences, etc. [4–6].

Gold placers feature the same variety and complexity as ore bodies, which is not always taken into account in gold exploration, appraisal and production. In conventional appraisal of mineral resources, elements of placers are united in cross-section and delineated in plan based mostly on the formal criteria of vertical and horizontal limitedness, and of maximal reliability of straight-line outline. Instructions on taking into account geological peculiarities of placers are often violated because of lack of sufficiently complete typical characterization. Placer mining is often carried out within approved boundaries of extraction blocks without careful in-situ assaying. As a result, volumes of barren rocks often change, pay zones are mined-out insufficiently, and ineffective processing flow sheets bring higher losses of gold. Generally, these disbenefits are observed at large placers in vast valleys of extremely complex structure owing to formation specificity.

The reports prepared by the Institute of Mining of the North using the field data on placer mining in Neryungri, Yakutia show that performance of sluicing and, thus, gold recovery are largely influenced by content of heavy minerals having density higher than 7–8 g/cm³ in initial sand. Such heavy minerals make the basic mass in primary concentrates produced by sluices. The higher content of heavy minerals results in higher loss of gold, especially fine gold, and vice versa. Considering discrete and clustering nature of occurrence of heavy minerals in rocks, it is clear that content of other minerals in rocks is of the same important as the content of basic useful components.

Improved adapting of a mining technology to clustering arrangement of a mineral deposit, all other things being equal, can provide an increase in the average gold content of dredge sand by 1.5–2.5 times, enhance final product per employee by 2 times and to cut down gold production cost by 10–25% [1, 2].

High variability of gold content is intrinsic to one of the Russian Far East’s largest Kuranakh placer in South Yakutia. Coefficient of variation in gold content in conditionally delineated areas, calculated from the large bulk of primary data on geology and surveying, vary from 56.0–64.5% (exploration lines 196–218 and 170–192) to 112.7–137.9% (exploration lines 30–77 and 118–136). All areas belong to the most complex group in terms of nonuniformity [7].

Exploration and mining of complex placers is efficient to perform using the general provisions of the assaying theory [1], with regard to genetic structural peculiarities of elementary components, and, then, using factors of grade, conditions, etc. An obligatory element, even for small mines, should the application of geological information systems as they enable real-time modeling of processes included in exploration in mining with regard to time-changeable conditions and operating environment.

The latter statement is illustrated by the digital block models of an arbitrary area in Kuranakh placer, constructed using the tools of GIS Micromine (see Figure 1). As minimal cutoff grade of gold changes from 0.16 to 0.3 g/m³, outlines of barren and rich zones change dramatically.
More reliable delineation of placers with clear outlining of concentration zones of useful components improves further mine planning and operation, including selective extraction of typical sand in terms of processability and/or gold (diamond) content. Classification of rocks extracted from the subsoil by the criterion of useful component content, preliminary treatment of sand with reduction of barren rock and continuous removal of low-grade mineral material per blocks, portions and lumps, subsequent separate processing using alternative technologies, with regard to current or forecast prices of minerals favors efficient utilization of natural potential of mineral deposits.

Figure 1. Change in pay zone outlines in placer in case of different gold contents: (a) minimal commercial cutoff grade of 0.16 g/m³; (a) minimal production cutoff grade of 0.3 g/m³.

In case of efficient technology and with accounting for clustering structure of placers, it is possible to raise average gold cutoff grade in terms of extracted and processible sand by 2–3 times, to reduce cost per unit, the other conditions being equal, by 2 times and to enhance accordingly labor productivity in terms of final product [2], as well as to start mining placer resources currently assumed as unprofitable but enclosing local rich pay pockets [3].

The relevant activities to be undertaken include: improvement of the assaying theory using available general provisions [1] for optimization of exploration networking and assaying parameters; modeling and more reliable mapping of mineral resources using geological information systems and time-changeable conditions; preliminary thawing–freezing pre-treatment of difficult fin gold-bearing sand with high content of clay [8]; long-term planning and real-time management in mining with regard to differentiation of resources by processing types; use of flexible modular process lines in pretreatment and beneficiation, including dry concentration [9].
3. Conclusions

1. Geometrical parameters of clusters (standard quality areas) of ore and sand, and content of useful components in most complex-structure placers and ore bodies vary within wide ranges (from fractions to tens meters and from zero to outstanding). Isolated or united clusters detectable based on increased concentration of useful component are as a rule separated by barren rocks, sand and low-grade ore. High-grade ore and sand areas make 10–30% of volume of reserve estimation blocks while they contain major mineral reserves to be extracted from the subsoil.

2. At the proper mining technology, taking into account the cluster structure of mineral deposit allows, owing to removal of barren or poor components from extracted and stage-wise processed productive rock mass, increment in the average content of useful component, for instance, gold, at reduction in total cost in mineral mining and processing.

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