One of the current trends of geotechnology modernization

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Abstract. The authors describe researches and their results on quality control in mineral wealth reproduction and preservation area. The need and capacity of drastic improvement of geotechnologies and geological support of mineral mining processes given optimization of representative sampling of mineral reserves is demonstrated.

1. Introduction

Natural conditions (physicogeographical and geological) extremely influence efficiency of any branch in the mineral mining industry. They condition the choice of a scheme to get access to a mineral, mining technology and equipment, methods of mineral processing as well as a mine capacity. A consequence of different natural conditions is that technical and economical performance (cost per unit product, labor productivity and other) of mining industry branches may differ by an order of magnitude and more.

The mineral mining depth is one of the key determinants of mining conditions and, thus, technical and economic performance of a mine since the deeper level mining entails elongation of underground openings and transportation networks, increased rate of hazardous events due to rock pressure, complication of ventilation and water drainage, etc. [1–4.

Development of geotechnologies aimed at resource reproduction and saving at all stages of mining is a single, permanent and almost inexhaustible source of enhanced efficiency of the mineral extraction industry.

At the same time, the most complete utilization of that source is impeded by the backwardness of the system of assaying, estimation of mineral quantity and quality and spatial distribution within a deposit [5–8]. This fact is clearly pointed at in the international technical literature, regulatory documents and instruction guidelines.

2. Research findings

Troitsky [5], on the strength of the ample hands-on experience and based on the comprehensive analyses of the specified issue within the latest decades, draws a few conclusions, among which of the interest are:

—actual gold recovery is always higher than the known reserves at placers (Figure 1);

—nobody ever made systematic assessment of the number of sites with proven reserves that were assumed uneconomic based on clearly “procedural” considerations;

—objections to the “uncertainty” of applied procedures are never considered and economic costs of geological exploration with a “negative result” are never repaid and are even neglected.

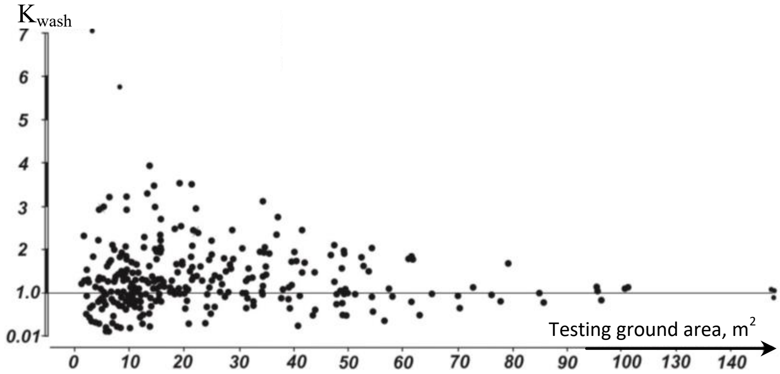

Figure 1. Cheka–Cheka placer mining results.

Jacqui Coombes [6] highlights that:

—two common disbenefits of models of mineral reserves are poor geological justification and insufficient data integrity;

—geostatistics makes a track toward studying and understanding regularities of geological assaying. Nonetheless, without a clear insight into geological evidence, geostatistics turns into the hermetic art in the mathematical wonderland "behind the mirrors;"

—the difficulty lies in combining the qualitative understanding of geological processes and the quantitative data of regularities in order to create reliable spatial prediction that, in the long run, assist mining engineers in efficient mine planning and mineral extraction.

An interesting publication by Ian Ewing in the Russian journal on gold mining [7] presents some recommendations that have been introduced in actual mining:

—special metal disks given a serial number and date are installed at oil stock piles. When a material enters a mill, a magnet elevates the disk, and the data on wherefrom and when the material comes are recorded. Thus, a specific operator who sent the material to a draw hole is identified;

—number of point samples is increased, and lodes are marked with special lines to orient miners and to ensure extraction of ore with the highest iron content;

—the period of sample tests is halved and tonnage of ore with low content is decreased: the next shift miners know where rich ore occurs and where barren rock lies in the beginning of the shift;

—the system of bonuses is changed: bonus is given for the ore product quality rather than for the production and processing output; bonus is given for the production of much gold rather than ore;

—management is learnt to find the golden mean between the cost minimization and labor productivity per miner.

These novations were on the whole discussed with favor and with some doubt about applicability of these recommendations in Russia. However, according to Jacqui Coombes [6], "the Quality Assurance/Quality Control procedures are meant to ensure reliable quality of data used to make decision on relevance of a project and on its progression. The quality of mining and project solutions totally relies on the quality of source data." Unfortunately, in the article and in the discussion, the addressed problem lags behind the state-of-the-art.

Within the late 20 years, the international and Russian science has developed new concepts and new theoretical basis for transition from exploratory constant and variable conditions to operational conditions that are space-differential and time-dynamic. In Russia such transition has been approved by the Ministry of Natural Resources in 1997.

This approach contains considerable resources for enhancing efficiency of mineral mining industry. To understand the scale of these resources, let us discuss operations involved in mineral mining and processing in the inverse order. A feature of processing stage is that ore feed at crushing stage always contains majority of oversizes (value of useful component in a fragment is less than the costs of crushing, milling and concentration to be incurred). For bodies of different minerals and different kinds of the same ore, percentage of oversize in the overall tonnage is different but on the average the mentioned tendency is obvious (see the table).

Percentage of oversized ore in feed of crushing stage.

Mineral deposit	Oversized ore percentage
Uranium	75–85
Tin ore	75–90
Antimony ore	65–85
Iron ore	40–75
Complex ore	30–70
Nonferrous metals	30–70
Rare metals	35–80
Gold ore	40–90
Diamond ore	75–95

Which features of geology and mining technology condition the ratio of quality and oversized ore in an overall output?

First, low thickness of ore lodes (bodies), high variability of thickness and contours, alternation of ore and barren rock layers etc. results in high dilution of ore with barren rocks, which varies in a wide range and most often is 15–50%.

Second, almost for all deposits, a cluster structure is typical, where quality blocks (clusters) make 20–40% of the total ore body and hold 70–90% of useful mineral reserves [8].

Third, the best quality cluster features greatly nonuniform mineralization and highly variable content of useful mineral per small unit area (e.g. 1 m^2), which results in production of much oversized ore (20–30%).

And, finally, fourth, for any ore texture uniformly distributed across an ore body, useful mineral of different dimension is scattered within the body, and any fragments, even of the same size, contain different amount of this mineral. Percentage of oversized ore in this case depends on average mineral composition, grain-size distribution of mineral–bearer of useful component and on the volume of fragments.

Naturally, for any deposit, the structure of mass balance of fragments in broken ore is different. For instance, for diamond deposits, of critical importance are low content and grain-size distribution of diamond crystals, and their rare dissemination in kimberlite. As a consequence, majority of kimberlite from quality clusters is barren. For example, at an African deposit, 50% of samples with a volume of 10 m^3 appear barren. For Yakutia deposits, with much higher content of diamonds, it is characteristics that samples that contain crystals not larger than 0.5 mm make 70% at the sample volume of 0.28 m^3 and 99% at the sample weight of 10 kg.

What is the economical loss of extraction, handling, crushing, milling and concentration of 70–90% of gangue?

It is known that even with the mean distances, ore handling to a processing plant (distance of the order of 15–20 km) costs much more than mining in Yakutia and North–East of Russia. The same holds true for processing. For this reason, an important resource to enhance efficiency of mining industry in these regions is elimination of oversized ore from all operations of extraction, transport and processing.

Implementation of this idea within a mine needs essential changes of basic and auxiliary production processes such as:

—improvement of advanced and concurrent operational and technological assaying in order to detect quality ore clusters within an ore body and to carry out mapping of the ore body and study its morphology;

—development of labeling system for ores of different quality and process properties in production and development stopes with a view to enhancing selectivity of separate extraction of such ores and their subsequent batch sorting;

—introduction of proper and efficient methods and means of geophysical and geological assaying of ore in the host rocks, in bins, flows and fragments and in beneficiation products;

—introduction of new drilling and blasting patterns to be adaptable to selective ore mining and processing;

—change of parameters of production benches (as a rule, reduction in bench height, e.g. to 4 or even to 2 in open pit gold mines) and re-design of underground mines for comfortable selective mining and processing using new process flow charts;

—separation of ore fragments with lower content of useful component at the stages of mining and pre-treatment and sending these fragment for heap leaching or to stock piles to be used later on;

—optimization of the list and parameters of mining machines to conform with the new conditions and requirements of mining, pre-treatment and processing.

The undertaken research has reveled high potential of the listed measures to increase production output per miner by many times at the considerable saving of cost per unit finished product. Conventional notions of loss and dilution are essentially transformed in this case [9].

The basic assaying results are always verified with the more reliable and representative assaying. The comparison of the basic and control assaying data make it possible to substantiate assumability of the basic assaying and to derive some correction factors that are required to be validated as per the regulatory documents.

It almost always happens that the comparison of data obtained in different volume assaying or in assaying using two different methods of different accuracy (representability) yields quantitatively similar conclusions: interval correction factors for the content of minimum size grade more than one (up to 3 or higher) gradually decrease in the higher grade sizes down to figure less than on in the maximum size grades. It was long ago called the “effect of blending” [10].

As regards the method of deriving correction factors: all samples of the basic assaying, properly approved, are grouped into classes of content, and average content $\overline{C}_{0i}$ (i = 1, 2, …, r, r—number of classes of content) is calculated per each class. The control sample belongs in the class where the proved sample of the basic assaying is. Based on the proven samples in an i-th class of content, the average contents $\overline{C}_{pi}$. are calculated, too. The correction factor K_{CF} for each class of content is defined by a ratio of the average contents $\overline{C}_{0i}$ and $\overline{C}_{pi}$.: $K_{CF} = \overline{C}_{pi} / \overline{C}_{oi}$.

Let us discuss typical situations that result in various regularities of change in CF with an increase in the number of interval of the basic assaying contents (Figure 2).

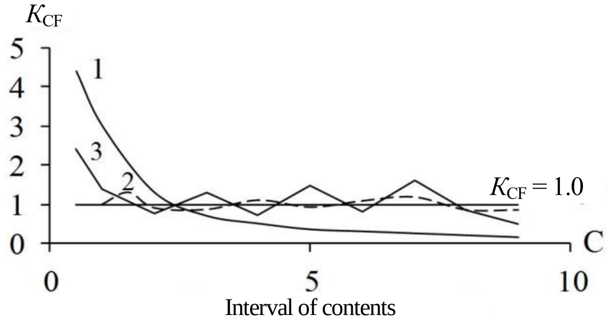

Figure 2. Curves of CF at different combinations of the basic and control assaying: 1—unrepresentative basic and representative control; 2–both basic and control assaying are representative; 3—both basic and control assaying are unrepresentative but the latter is more accurate.

It is known that in a larger sample (or a more representative sample), the interval of probable variation in the content is narrower. Considerably unrepresentative assaying underestimates content more often than not.

The underestimation per unit sample reaches 10 times, which is clearly observed in underground mines and placers of diamond and gold ore as large crystals of diamonds and particle of gold become out of a sample. This feature being typical and known for gold placers and all diamond mines has revealed itself in underground gold ore bodies only in the 21st century [11].

When reserves exploration includes only considerably unrepresentative assaying, out of hundreds and thousands of samples, up to 80% show considerably underestimated content. When we prove these samples using representative control assaying, the result is not underestimated content at lower random error. In accordance with the rule of determination of a correction factor, we put them in the class of the low content together with the proven sample of the basic unrepresentative assaying. As a consequence, CF in the first classes of contents is always much higher than one. It is important that many high values of contents are excluded from the data of the basic assaying.

The last classes of the basic assaying keep a thousandth path of the highest and “hurricane” values. Their average figure is naturally higher than the average of the associated samples, and CF appears less than 1 (Figure 2, curve 1).

Bekker et al [12] give correction factors for vertical margin, average content and thickness of gold sands based on the data of verification of basic assaying in cable drilling in placers in Russia’s North–East. The cable drilling was very representative (total 2376 holes). However, as follows from the experience of exploration, appraisal and development of placers of coarse and medium-coarse gold, cable drilling assaying is insufficiently representative.

Percentage of verified holes in the last class of contents as per basic assaying is feeble, 1–3% of the total number of holes. Some of them show actual content in the zone of high contents, and the majority is the abnormally high random values as a result of unrepresentative assaying. In the last intervals of contents, there are 5% of high values of vertical margin in accord with the control assaying.

It seems that at all deposits where the said borehole values have been verified, there are very few holes to show high actual reserves and, consequently, reserves with high vertical margin.

Accordingly, basic assaying shows no sites and areas with high vertical margins, and the correction factor in the classes of high contents (in the unrevealed areas and sites!!!) appears less than one. On the whole, $K_{CF} = 0.98$ per all holes. Nearly half of the basic assaying holes, being considerably unrepresentative show the lowest vertical margin. Here, $K_{CF} = 2.94$.

Correction factor per gold placer was recommended to apply to an entire deposit [13], which is unreflective of a true pattern of reserves distribution per blocks.

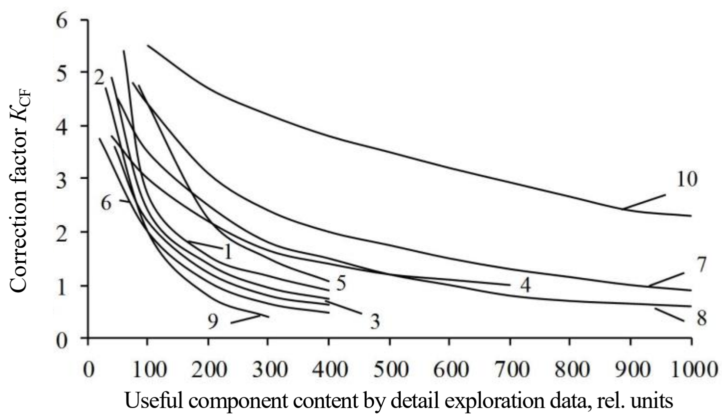

Figure 3. $K_{CF} = f(C_p)$ per placers: 1–3—Transbaikalia; 4, 5—Kransnoyarsk Territory; 6—West Siberia; 7—Lena River valley; 8—Republic of Tyva; 9—Ural; 10—Yakutia. 1–9 are gold placers; 10 is a diamond placer.

Based on the generalization of an immense amount of data on the control assaying of placers, Chemezov [13] offers plots of interval correction factors (Figure 3). CF K_{CF} is determined by the data of bulk assaying of sands per operating dredges, considering assumed loss of the useful component (placers 1–7 and 20) and based on data of the control holes (placers 8 and 9). The plots display the effect of sorting only in the first and third typical situations discussed above (refer to Figure 2) as the basic assaying during the detail exploration of the placers was not representative.

A cardinal difference of an error in the estimate of the useful mineral content of rocks (ores) based on assaying from an error of physical measurements due to geological features of a medium consists in that error of the content estimate can also occur when all direct and indirect measurements in all operation of sampling, processing and analysis are faultless. The error in this case is governed by the rate of representativity of the primary geological assaying. Unallowable random and systemic errors of that kind are possible to avoid only by using representative samples. Erroneous direct and indirect measurements in the course of assaying, preparation and analysis of the samples merely increase the overall mistake.

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