

ОБОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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Improving the technology of gold ore X-ray radiometric separation

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Abstract

Introduction. Gold ore pre-concentration is an urgent issue that can efficiently be solved by the technology of X-ray radiometric separation (XRS). Quarts and quarts-sulfide gold ore XRS is based on the methods of indirect sorting by gold accompanying chemical elements or genetic associate minerals laying the foundation for the creation of separation characteristics for these ores. Additional separation characteristics are required for efficient gold-quartz and gold-quartz-sulfide ore sorting; Irgiredmet Research Institute works on these characteristics search and development.

Research methodology. Optimal ore separation characteristics for each specific deposit are chosen after studying and analyzing the spectral information acquired at XRF separators when detecting secondary characteristic radiation from each specific deposit ore samples. The recent modernization of XRF separators significantly enhanced the technological capabilities of XRS concerning intensive search and study of new separation characteristics for gold ore. It has been established that most ores can be efficiently sorted by three characteristics.

Research results. A new method of gold ore XRS has been developed which consists of simultaneously applying three, two, or one decision criterion of a lump separation depending on the type, geological-mineralogical properties, and material composition of the processed ore.

Keywords: pre-concentration; gold ore; X-ray radiometric separation; separation characteristic; X-ray spectrum; decision criterion of lump separation.

Introduction. Both in Russia [1] and abroad [2–5], ore pre-concentration technology is becoming an increasingly urgent issue for mining enterprises. The implementation of this technology makes it possible to significantly improve the effectiveness of field development since the first task of the pre-concentration technology is to improve the quality of the ore that undergoes processing [6]. It fully applies to gold mining enterprises that develop an increasing number of gold ore deposits with low gold content in base ore, and there is no doubt that the need for pre-concentration grows [7].

Almost 40 years ago, in Irgiredmet an efficient technology of gold ore and rare metal ore pre-concentration was developed. The technology was based on lump sorting using the X-ray fluorescence method (XFM) and called the X-ray radiometric separation (XRS). Multiple studies, testing, and introduction carried out by the institute together with partners have shown that compared to other radiometric methods, the X-ray fluorescence method is more efficient for a diverse range of minerals when solving various process tasks [8–10]. The main equipment for XRS is an X-ray fluorescence separator of XRF type.

The applied quarts and quarts-sulfide gold ore XRS technology is based on indirect sorting methods by gold accompanying chemical elements or genetic associate

minerals. Most commonly, they are the elements within the included in sulfide minerals: Fe (pyrite), Cu (chalcopyrite), Zn (sphalerite), As (arsenopyrite), Pb (galenite), Bi (bismuthine), and Sb (antimonite) [11]. The use of XRS for such ore sorting is based on gold correlation with these elements, the content of which is identical to the separation characteristics. XRS is used to develop the analytical parameters of separation as well.

Commonly, gold is loosely correlated with informative elements of sulfide minerals (preventing from effective sorting), but at the same time, as a rule, it is bound to quartz. XRS method, based on “sulfide” separation characteristics only, associated with the content of sulfide minerals, doesn't make it possible to efficiently extract quartz from ore, especially if it is presented in the form of impregnation with thin veins, strings, and grains having a layered structure, or manifesting in other clots [12].

Improving the efficiency of gold-quarts and gold-quarts-sulfide ore XRS by searching and developing additional separation characteristics and efficiently implementing them in the X-ray fluorescence XRF separators metering system is a topical issue. It will enable a wider use of this method for such ore pre-concentration and allow involving poor and off-balance ore into processing in a lot of deposits.

Research methodology. Recently, due to modernization, technological capabilities of XRF separators were enhanced significantly [13]. First off all, the sensitivity and selectivity of chemical elements determination were improved because the separators were equipped with high-resolution semiconductor detectors making it possible to detect different elements in lumps under their content in ore making up to the thousands of one percent. Improved metering and control system of modern XRF separators allows applying up to three separation characteristics simultaneously when carrying out separation. All of the above mentioned significantly enhances the technological capabilities of XRS concerning intensive search and study of new separation characteristics for gold ore.

Having analyzed the results of the research and testing carried out in the past 7 years in the XRS technological center of Irgiredmet on numerous gold ores (in more than 70 deposits), it has been established that the majority of them may effectively be sorted according the three separation characteristics.

Sulfide and quartz-sulfide gold ore with any content of genetic associate minerals in the ore (informative elements of the sulfide minerals) are sorted using the approach developed earlier in Irgiredmet [14] according to a well-known criterion of processing, which is the ratio of the characteristic radiation (CR) (of K- or L-series) of the accompanying element (N_{Ae}) to the scattered radiation (N_S).

Gold-quartz and gold-quartz-sulfide ore can be sorted according to the separation characteristic of Fe, the minimum content of which corresponds to quartz lumps, which are gold enclosing medium, for the most part. There is a lot more Fe in rock, and quartz can separate from rock in relation to the fixed value of a decision-criterion of lump separation – the ratio of CR Fe (N_{Fe}) to the scattered radiation (N_S).

To extract gold-bearing quartz presented in the oxidized form (under a high concentration of Fe same and higher than in rock lumps), a new method was developed. The method applies the ratio between the CR intensity of Sr (N_{Sr}) included in the composition of goldless lumps and the intensity of the scattered radiation (N_S). There is a tiny content of strontium in ore quartz material as compared to its content in strontium-bearing goldless ore lumps (rock lumps).

If there are no explicit lumps of quartz material in ore, gold focuses in lumps with silification (impregnation, grains, veins, strings, and bands), which is often unobservable in case of using other ways of sorting gold ore. It has been determined that the presence of silification in lumps can also be detected through the content of Sr that is a lot higher

in rock lumps. In both instances, one and the same criterion of separation by strontium content is used.

Based on the research results and aimed at improving the efficiency of pre-concentration through the XRS method, Irgiredmet research institute developed a new method of XRS separation of gold ore with the use of three, two, and one criterion of concentration depending on the type, geological-mineralogical properties, and the material composition of the concentrated ore [15].

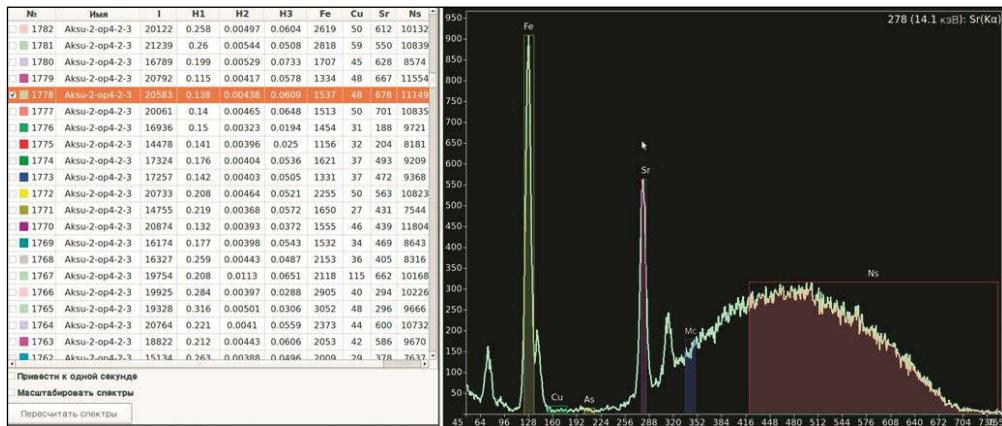


Fig. 1. Spectrum of rock sample by three separation characteristics
Рис. 1. Спектр породного образца по трем разделяльным признакам

If the study established a higher efficiency of simultaneous application of three criteria, gold-bearing lumps sorting is carried out according to the three-valued logic (<< OR >>):

$$C_1(Ae) = \frac{N_{Ae}}{N_S} > M_1(Ae);$$

<< OR >>

$$C_2(Fe) = \frac{N_{Fe}}{N_S} < M_2(Fe);$$

<< OR >>

$$C_3(Sr) = \frac{N_{Sr}}{N_S} < M_3(Sr),$$

where $C_1(Ae)$, $C_2(Fe)$, $C_3(Sr)$ are the decision-criteria of lump separation by accompanying element, iron, and strontium correspondingly; N_{Ae} , N_{Fe} , N_{Sr} is the CR intensity of the accompanying element, iron, and strontium correspondingly; N_S is the intensity of the scattered radiation; $M_1(Ae)$, $M_2(Fe)$, $M_3(Sr)$ is the margin of the decision criterion of lump separation (sorting threshold).

The (<< OR >>) logic for each decision-criterion of lump separation means the condition of selecting a lump rich in gold (concentrated):

<< OR >> higher than M_1 (contains sulfides);

<< OR >> lower than M_2 (quartz lump);

<< OR >> lower than M_3 (presence of silification in a lump).

The remaining lumps, where the numerical values of the decision-criterion do not comply with this logic, refer to rock lumps.

The three-valued logic << OR >> is general for the majority of the gold ores. However, depending on the particular ore, the simplified two-value or one-value logic can be used.

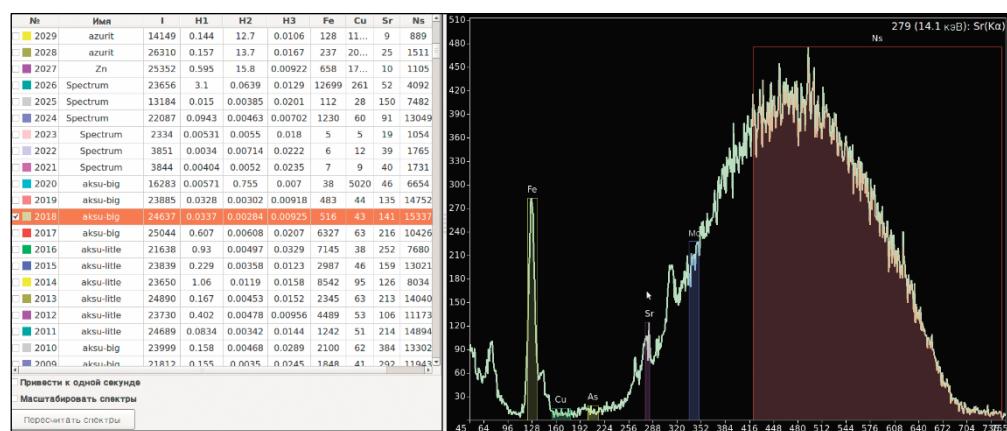


Fig. 2. Spectrum of ore sample by two separation characteristics
Рис. 2. Спектр рудного образца по двум разделительным признакам

The two-value logic is applied if two decision-criteria of lump separation are enough for efficient sorting:

$C_1 > M_1 \text{ << OR >> } C_2 < M_2 \text{ (no Sr);}$

$C_1 > M_1 \text{ << OR >> } C_3 < M_3 \text{ (no quartz);}$

$C_2 < M_2 \text{ << OR >> } C_3 < M_3 \text{ (no sulfides).}$

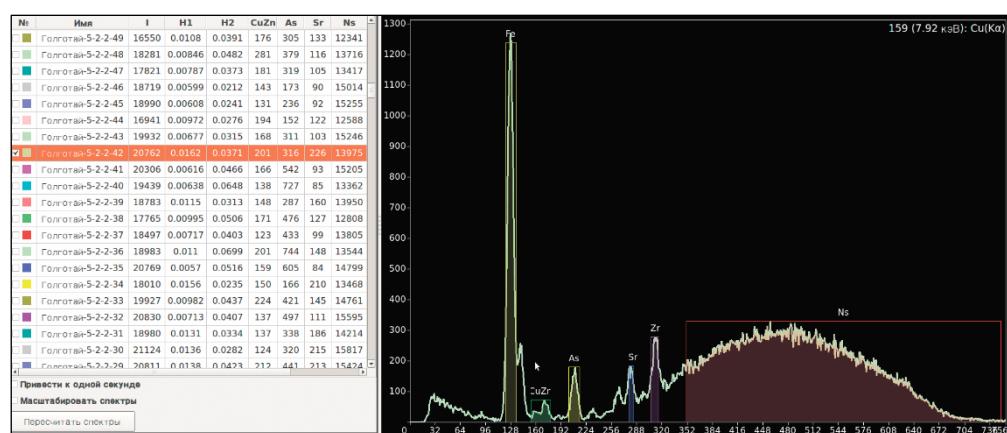


Fig. 3. Spectrum of ore sample by one sulfide separation characteristic of As
Рис. 3. Спектр рудного образца по одному сульфидному разделительному признаку – As

One decision-criterion of lump separation is enough for efficient sorting when using the one-value logic: $C_1 > M_1$ is sorting by the sulfide characteristic; $C_2 < M_2$ is sorting by the quartz characteristic of Fe; $C_3 < M_3$ is sorting by the quartz characteristic of Sr.

The optimal variant for the ore of a particular deposit is chosen after studying and analyzing the spectral information obtained at XRF separators when detecting secondary (characteristic) radiation from ore and rock samples collected in the deposit.

Examples of secondary radiation characteristic spectra of ore and rock samples of typical quartz-sulfide gold ore deposits are presented in fig. 1–4.

Fig. 1 shows the spectrum of a rock sample detected using the three-valued logic by three separation characteristics. A high Fe peak proves that the sample lacks quarts, a high Sr peak proves that there is no silification. Lack of peaks As, Cu, and other indication elements in sulfide minerals indicates that the sample lacks genetic associate minerals of gold.

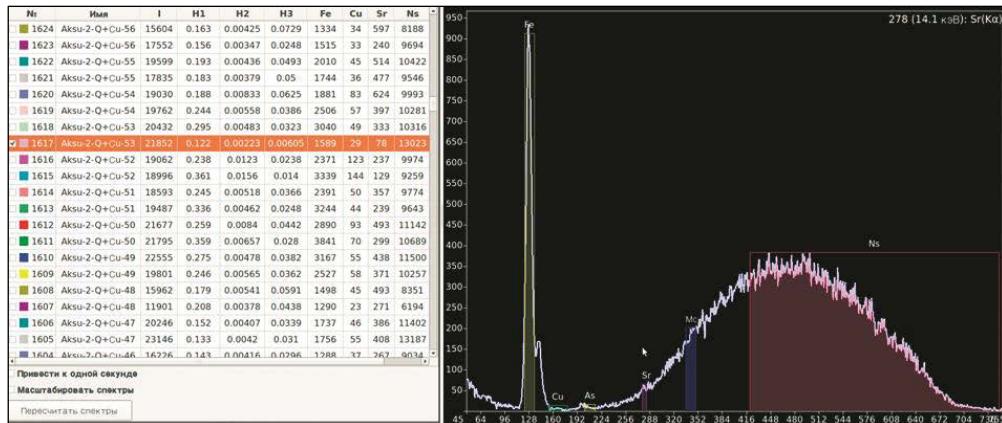


Fig. 4. Spectrum of ore sample by one quartz separation characteristic of Sr

Рис. 4. Спектр рудного образца по одному кварцевому разделительному признаку – Sr

Fig. 2 shows an example of spectrum for an ore sample, detected using the two-value logic with two quartz separation characteristics. Low peaks of Fe and Sr confirm that the sample contains quartz, which is an enclosing medium for gold in this deposit.

Table 1. XRS results of gold-bearing ore of –150+50 size class by the well-known and new method with the use of three criteria

Таблица 1. Результаты РРС золотосодержащей руды класса крупности –150+50 мм по известному и новому способу с использованием трех критерий

Product	Yield, %	Gold content, g/t	Gold recovery, %
<i>Separation only by an accompanying element As with one criterion</i>			
XRS concentrate	11.2	4.60	29.1
XRS middlings	51.0	1.71	49.2
XRS tailings	37.8	1.02	21.7
Primary	100.0	1.77	100.0
<i>Separation by three criteria and factors: an accompanying element As and quartz separation characteristics of Fe and Sr</i>			
XRS concentrate	11.3	8.57	64.7
XRS middlings	14.8	1.30	13.0
XRS tailings	73.9	0.45	22.3
Primary	100.0	1.49	100.0

Fig. 3 presents a spectrum for an ore sample, detected by one sulfide separation characteristic (by the accompanying element As in the arsenopyrite); Cu and Zn in this case are secondary.

Fig. 4 contains an example of spectrum for an ore sample by one quartz separation characteristic. High silification of the sample confirms the absence of Sr. In this instance, Fe cannot be used as a separation characteristic due to its high content.

In all spectra presented in the figures, the work of each separation characteristic is clearly observed individually and in total. Same X-ray spectra from ore and rock samples are typical for many gold fields of quartz-sulfide type.

Table 2. XRS results of gold-bearing ore of –150+20 size class by the well-known and new method with the use of two criteria

Таблица 2. Результаты PPC золотосодержащей руды класса крупности –150+20 мм по известному и новому способу с использованием двух критерии

Product	Yield, %	Gold content, g/t	Gold recovery, %
<i>Separation only by an accompanying element Cu with one criterion</i>			
XRS concentrate	14.2	2.80	68.6
XRS tailings	85.8	0.21	31.4
Primary	100.0	0.58	100.0
<i>Separation by two criteria and factors: an accompanying element Cu and quartz separation characteristics of Sr</i>			
XRS concentrate	30.2	1.47	77.0
XRS tailings	69.8	0.19	23.0
Primary	100.0	0.58	100.0

Research results. The developed method of XRS was verified at gold-bearing ore in different deposits, including quartz-sulfide ore of Aksu field and Srednii Golgotai deposit.

Table 3. XRS results of gold-bearing ore of –150+20 size class by the well-known and new method with the use of three criteria

Таблица 3. Результаты PPC золотосодержащей руды класса крупности –150+20 мм по известному и новому способу с использованием одного критерия

Product	Yield, %	Gold content, g/t	Gold recovery, %
<i>Separation only by an accompanying element Fe with one known criterion</i>			
XRS concentrate	19.2	1.10	31.1
XRS tailings	80.8	0.58	68.9
Primary	100.0	0.68	100.0
<i>Separation only by an accompanying element Cu with one known criterion</i>			
XRS concentrate	27.0	0.47	22.8
XRS tailings	73.0	0.59	77.2
Primary	100.0	0.56	100.0
<i>Separation only by quartz separation characteristic of Sr with one new criterion</i>			
XRS concentrate	24.5	1.12	54.7
XRS tailings	75.5	0.30	45.3
Primary	100.0	0.62	100.0

Table 1 presents the comparison of XRS of Srednii Golgotai ore according to the well-known method (by the accompanying element As with one criterion of concentration) and the new method using three decision-criteria of lump separation and

three separation characteristics (by the accompanying element As and quartz separation characteristics Fe and Sr). Results obtained with the three-value logic are significantly higher.

Table 2 presents the comparative characteristics of poor ore XRS in Aksu field using the well-known method (by the accompanying element Cu with one criterion of concentration) and the new method using two decision-criteria of lump separation and two separation characteristics (by the accompanying element Cu and quartz separation characteristics of Sr). When sorting using the two-value logic, higher extraction of gold into the XRS concentrate is acquired, therefore, XRS tail losses are lower.

A comparative example of XRS of Aksu gold ore using one decision-criterion of lump separation according to the well-known method (by the accompanying element Cu or Fe) or the new method (by the quartz separation characteristic of Sr) is presented in table 3. Sorting by one separation characteristic Sr is significantly more efficient, making it possible to obtain XRS tailings with the waste gold grade.

The obtained results show that the current level of XRS technology and equipment development is so high that efficient separation characteristics can be found almost for any ore, using its natural technological properties to the maximum.

Conclusions. The study and testing confirmed the possibility of the wide acceptance and universal character of the developed gold-quartz-sulfide ore XRS technology and method.

Technological indicators of gold ore XRS depend crucially on the selected separation characteristics; search for the characteristics, their development, and testing of new methods of separation are actively carried out both in the XRS technological center of Irgiredmet Research Institute and industrially using large-scale process samples.

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Совершенствование технологии рентгенорадиометрической сепарации золотосодержащих руд

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Реферат

Введение. Предварительное обогащение золотосодержащих руд является актуальной проблемой, эффективное решение которой возможно с применением технологии рентгенорадиометрической сепарации (PPC). В основу PPC сульфидных и кварц-сульфидных золотосодержащих руд заложены косвенные методы сортировки по сопутствующим золоту химическим элементам или генетическим спутникам, на основе которых для этих руд формируются разделительные признаки. Для эффективной сортировки золото-кварцевых и золото-кварц-сульфидных руд необходимы дополнительные разделительные признаки; исследования по их поиску и разработке активно ведет НИИ «Иргредмет».

Методология исследований. Выбор оптимальных разделительных признаков для руд каждого конкретного месторождения производится на основании изучения и анализа спектральной информации, полученной на сепараторах СРФ при детектировании вторичного характеристического рентгеновского излучения от образцов проб руды данного месторождения. Проведенная в последнее время модернизация сепараторов СРФ значительно расширила технологические возможности PPC для интенсивного поиска и изучения новых разделительных признаков для золотосодержащих руд. Установлено, что большинство из них могут эффективно сортироваться по трем признакам.

Результаты исследований. Разработан новый способ PPC золотосодержащих руд с использованием одновременно трех, двух или одного критерия принятия решения о выделении куска в зависимости от типа, геолого-минералогических свойств и вещественного состава обогащаемых руд.

Ключевые слова: предварительное обогащение; золотосодержащая руда; рентгенорадиометрическая сепарация; разделительный признак; рентгеновский спектр; критерий принятия решения о выделении куска.

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