DOI: 10.25515/PMI.2017.6.641



UDC 622.338

# EXPERIENCE OF DEVELOPMENT OF PORPHYRY COPPER TYPE DEPOSITS IN THE URALS

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Russian copper company was the first in Russia to start developing porphyry copper deposits. In 2013 the Mikheevsky mining and processing plant with the annual production capacity of 18 mln t of ore was put into exploitation. The use of innovative approaches regarding choice of the technology, high-performance equipment and organization of construction allowed to bring the enterprise to a full capacity and to achieve expected results within three years. On the basis of the experience obtained during design, construction and exploitation of the Mikheevsky mining and processing plant in 2017 the company has started the construction of a new mining and processing plant in the Tominskoye deposit. The first stage anticipates the enterprise production capacity to be equal to 28 mln t with the possibility of its increase up to 56 mln t. The development of porphyry copper deposits in the Urals will allow to provide copper plants with the raw materials over the next 80-100 years.

***Key words*:** copper, gold, porphyry copper ores, open-pit, processing plant, grinding mill, conveyor, rock hardness, extraction, recovery efficiency, ecology

***How to cite this article*:** Altushkin I.A., Levin V.V., Sizikov A.V., Korol Yu.A. Experience of development of porphyry copper type deposits type in the Urals. Zapiski Gornogo instituta. 2017. Vol. 228, p. 641-648. DOI: 10.25515/PMI.2017.6.641

Porphyry copper type deposit belongs to a product of endogenous metallogeny and, as a rule, is a part of considerable ore-magmatic systems. These ores are not contrasting and fundamentally differ from traditional for the Urals copper-sulphide ores both regarding their physical and chemical properties and content of copper, gold, silver, plumb, zinc and other by-product metals. As early as 30-40 years ago porphyry copper metallization was not considered to be typical for the Urals and only geological exploration works of the latest decades allowed to «legalize» such type of deposits in this region. A necessity of exploration and development of new types of ores was driven by forecasted depletion of copper-sulphide ores deposits which are known to be basic raw material for copper industry branch of Russia [1, 5, 7]. Against prevailing all over the world copper production out of porphyry copper ores, realization of projects aiming to expand raw material base of metallurgic enterprises in the Urals will allow not only to load the capacities, conserve single-industry towns, provide tax revenues and perform social programs but also to considerably reduce negative influence on the environment of regions resulting from absence of harmful impurities or extremely negligible amount of them in this ore type.

In accordance with A.I.Krivtsov classification Ural porphyry copper province refers to basaltoid volcanic-plutonic belt (Fig.1) represented by perioceanic eugeosynclines (island-arc geostructures) [7, 3, 14]. One of distinctive features of such ores type is extremely negligible content of molybdenum and, consequently, high ratio of copper to this metal. Considering directly the Ural zone geologists highlight a range of the most prepared for development and currently exploring objects including the following: the Gumeshevskoye, the Voznesenskoye, the Tominskoye, the Tarutinskoye, the Mikheevskoye, the Benkalinskoye and the Salavatskoye deposits, the Verkhneuralskoye mineralization [3, 6]. All Ural porphyry copper ores, in addition to copper, contain negligible amounts of gold, silver, platinum and palladium. In addition, distribution of by-product metals among deposits is extremely uneven; for instance, content of platinum and palladium in the Tominskoye deposit is equal to 6.8-20 and 42-76 mg/t relatively; in the Mikheevskoye deposit content of platinum varies from 400 to 3200 mg/t and content of palladium alters from 600 to 2100 mg/t. Gold content in all objects is equal to 70-300 mg/t. Ores also contain significant amounts of rhenium [6, 9, 13]. According to A.I.Grabezhev the Urals may and should be considered not only like new industrial porphyry copper province but also like rhenium-bearing province [2].

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Fig.1. Copper-pyrite and copper-porphyry ores and metallizations within the Urals and the Central Asia

Authors of papers [4, 8] consider that besides perfectly explored and currently developing deposits in the Chelyabinsk region there are also prospective areas and porphyry copper ores metallization in the Middle Urals including Artemovo-Altinaysky ore-magmatic area in the Sverdlovsk region. Similar deposits and metallizations were indicated in the Orenburg region in Mednogorsk (the Utyagulovsko-Bliavinskaya), the Aschebutakskaya, the Dzgusinsko-Akdzharskaya, the Kiembayevskaya, the Kurmansayskaya, the Elenovsko-Kumakskaya and the Kidibayevskaya areas [8, 10-12, 15].

Low content of metals in porphyry copper ores results in necessity of construction of high-capacity mining and processing plants in order to provide the economic development of the deposits. In regions with traditional and customary copper development from porphyry copper ores all newly introduced ore mines exceed the capacity of 20 mln t; an ore mine Escondida in Chile which costs $ 1.8 billion has the production capacity of 45 mln t, an ore mine Grasberg in Indonesia which costs $ 2.2 billion processes 88 mln t of ore per year.

Necessity of transportation of huge volumes of ore resulted in introduction of changes to layout schemes of processing plants with the primary crushing stage location on a quarry bench or inside a quarry itself being a compulsory component of cyclic and continuous method of mining. Cone crushers (stationary or movable) are used as crushing equipment and are placed in the zone of mining with the production capacity varying from 1000 to 10000 t/hr.

Regarding second stage of crushing (fragmentation) the processes of ore semi-self-crushing (SSC) almost replaced traditional schemes of stage breaking. The use of semi-self-crushing mills of 12 m diameter allows to provide high specific production capacity of the equipment keeping maximal automatisation of production processes.

Considering the flotation stage world trends are directed to simplification of technological schemes and to the increase of the volumes of flotation machines. Types of processed porphyry copper ores and especially copper to molybdenum ratio impose some peculiarities on the processing technology and layout design of equipment for different deposits making them different from each other. Prevailing scheme is the flotation in the open cycle with reprocessing of the industrial product of rougher flotation in a separate flotation cycle with its preliminary regrinding. In the process of rougher flotation impeller flotation machines of minimal volume equal to100-300 $m^3$ are used. During operations of purifying, final concentration, rougher flotation both impeller flotation machines and column (pneumatic) flotation machines are widely spread.

Exploration and entering porphyry copper deposits on the balance sheet in Russia, especially in the Urals and also a prospective of the significant growth of reserves in the nearest future allowed to

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Fig.2. Mining machines at Mikheevsky MPP



Fig.3. Open-pit of Mikheevsy MPP

start their direct development. The very first experience of realization of a project of development and processing of such type deposits was obtained in 2013 by CJSC «Russian copper company» through construction and putting into operation of the Mikheevsky MPP [5].

Before now there was no experience of construction and exploitation of ore mines and processing plants for the development and processing of porphyry copper ores in Russia and especially if we consider enterprises with the production capacity exceeding 18 mln t. The production capacities of the largest-scale mining and processing plants built in the Soviet period in the field of development and processing of heavy non-ferrous metals do not usually exceed 6-9 mln t (MMC «Norilsk Nickel», Gaysky MPP). Peculiarities connected with the processing of ores of reinforced hardness and low copper content, absence of considerable amounts of by-product metals creating commercial value of the ore and also a necessity in the organization of large-scale production imposed certain constraints on determining the capacity of the Mikheevsky mining and processing plant. Phasing and priority of project realization depending on the experience acquired in deposit development was already foreseen at the stage of design and construction.

Before 2003 porphyry copper deposit in the Urals was at the stage of exploration and reserves calculation. After 2007 Russian copper company organized an extra geological exploration and investigation works regarding reserves update. On the basis of obtained results the volumes of saleable ore and copper significantly increased. With respect to the depletion of reserves as on 2016 the on-balance reserves of ore in the deposit were equal to 690 mln t including the reserves of copper exceeding 2.7 mln t, the reserves of gold – more than 75 t and the reserves of silver – up to 848 t.

In compliance with the approved project, the extraction of ore is led by means of open-pit mining using mining machines of big unit capacity: excavators KOMATSU PC4000-6D with the bucket capacity of 22 $m^3$; mining trucks KOMATSU 730E-AC with the load-carrying capacity of 186 t; drilling machines PV235 and PV271 (Fig.2). In August the length of a quarry was equal to 1900 m, its width – 1000 m and its depth – 180 m (Fig.3). The overall volume of the transported rock mass was equal to 59.49 mln $m^3$.

During the period of the deposit development 62.7 mln t of ore were extracted including 261 thsd. t of copper. The volumes of ore extraction and processing by year are represented in fig.4.

During realization of the project of porphyry ores extraction the following pioneer approaches and innovative solutions were used:

- design and construction of the ore mine of high capacity using mining machines and processing equipment of high specific production capacity;
- placing of crushing facilities in an open-pit;
- gathering and use of quarry and underspoil waters for the internal water consumption of the processing plant;

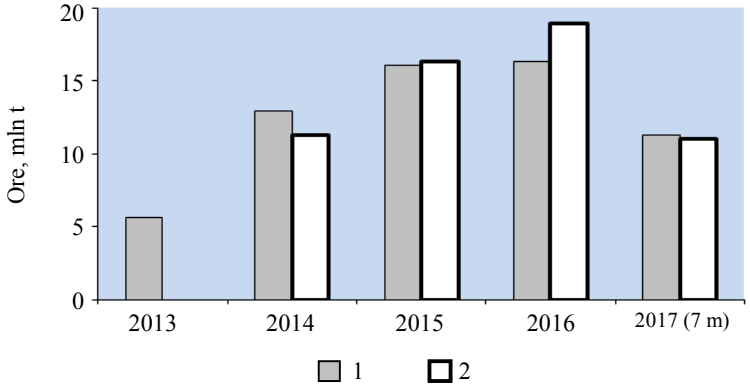



Fig.4. Volumes of ore extraction by years
1 and 2 – ore extraction and processing

DOI: 10.25515/PMI.2017.6.641



Fig.5. Mill SSC



Fig.6. Flotation machines of basic cycle



Fig.7. Flotation area

• the maximum automatization of mining operations with the organization of computer accounting of all production cycles both during their planning and practical realization.

During design and construction of the capacities for ore processing Russian copper company attracted world leading researches, designers and producers of the processing equipment including «Outotec», «Mehanobr-engineering», «AMMTEC», «Metso Minerals», «Warman», «Profstroy Company».

In the process of making a choice, purchasing and supply of main processing equipment the company was guided by the following basic aspects:

• highest technical and economic indicators of the equipment;

• maximal specific capacity and production capacity;

• convenience of assembling, repair works and servicing;

• provision of safety work conditions both for operational personnel and for the environment;

• compliance of the purchased equipment to the world latest achievements regarding technological parameters and version of machines and mechanisms [3].

Fig.5-7 presents the technological equipment in the milling and flotation areas.

In the processing cycle the following equipment was assembled: the gyratory crusher Superior 60-89 MK II of 600 kWt power, the cone crushers of 300 t/hr production capacity which work together with the double-deck screens, the mills SSC SAG 36'×20.7" of 11 m diameter and 17 MWt power with the production capacity of 1500 t/hr, the mill SSC SAG 22'×28.5' of 6.7 m diameter, the grinding mills 26'×44.6' of 7.9 m diameter and 17 MWt power, the flotation machines of basic flotation TC 300, the machines of the first cleaning and rougher flotation TC 100 and also TC 50 and TC 30. On the re-grinding stage a center-discharge mill of 5.5×8.4 m and Isamill M 10000 of 3000 kWt power were installed. Deliquefaction of the copper concentrate is carried out with the help of thickener Supaflo-17 with the production capacity of 51 t/hr and forcing filter press of the production capacity 26 t/hr and filtration area of 200 sq.m for production of the end-product with the humidity level of 10 %.

The use of high-performance equipment allowed to achieve high indicators of the complexity of natural resources use during processing of poor porphyry copper ores. The results of copper extraction by years and its content in the final tailings are represented in fig.8. Stable growth of the copper extraction up to the regulatory values of 85 % was predetermined by the decrease of oxygenized part ratio in the processing ores with the deposit development and strictly corresponds to the expected project indicators.

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During considered period there were produced 1083 thsd.t of copper concentrate containing 195 thsd.t of copper, 3.7 t of gold and 40.2 t of silver.

During short period of mining and processing plant performance more than 4 billion rubles were paid out to all level budgets; the obtained saleable output was equal to 49 billion rubles excluding VAT (Fig.9).

Currently more than 1081 people work at the enterprise; the average age of them is 37 years, the average salary level within mining and processing plant exceeds 47.5 thsd. rub. More than 700 people are involved in work of contracting organizations providing the ore mine with services.

Sustainable work of the Mikheevsky MPP provided compliance with the environmental protection legislation regarding waste dumping, spews into water objects and release of pollutants to the environment. Personnel of the plant is engaged in landscape gardening, provision of safety labor conditions on working places and in residential areas.

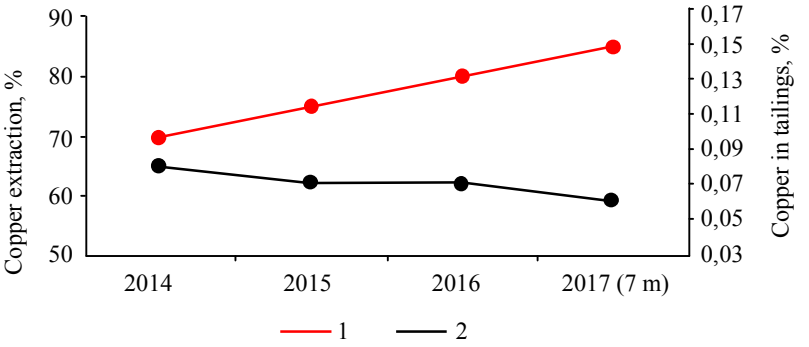



Fig.8. Qualitative technological parameters of processing
1 – copper extraction, %; 2 – copper in tailings, %

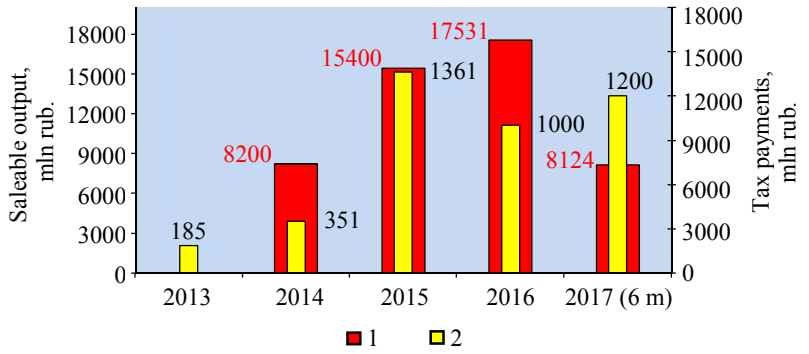



Fig.9. Revenues from sales, tax payments and cash outflow for the period 2013-2017
1 – saleable output; 2 – tax payments (paid in)

The experience obtained during the deposit development allowed Russian copper company to make a transfer to realization of the second stage of the project which consists in the following:

• the expansion of the ore mine production capacity as well as of the processing plant and further development of the infrastructure objects;

• the growth of technological indicators and quality of produced concentrate.

Precondition to the first direction consisting in the increase of production capacity of mining and processing plant was not only the world experience and global trends of projects progress in respect of porphyry copper deposits development but also a considerable increment in reserves as the result of geological exploration and corrections in the ore extraction project. The extracting reserves of all ore types were increased from 350 to 753 mln t. One of the essential factors of reserves increment refers to correction of the deposit opening project in respect of the growth of the quarry depth from 350 to 550 m. Correction of a project, in its turn, became possible on the basis of practical results of deposit development, use of high-performance mining machines, rather high level of world market prices for copper keeping reasonable costs for ore extraction.

The development of the second direction was provoked by the fact that though achieved results pertaining to the copper extraction are in compliance with the project performance figures, there is a certain reserve for their enhancement according to the MPP specialists' opinion. The analysis of technological parameters of the processing limit showed that the copper extraction may be increased by means of opening of the ore minerals on crushing stage to a greater extent. Herewith, in accordance to a project, fineness of crushing by class – 150 mkm must compose 80 %, in reality this parameter was exceeded being equal to 82-88 % (Fig.10).

During the development of the process regulation for ore processing at the Mikheevskoye deposit OJSC «Mehanobr Engineering» in 2008 recommended fineness of flotation machines feed $P_{80} = 130$ mkm that provided copper extraction of 79.9 % into the copper concentrate or copper extraction of 80 % to the collective copper-molybdenum concentrate. For the ores of higher hardness this parameter was more rigorously set by researchers as $P_{80} = 106$ mkm.

DOI: 10.25515/PMI.2017.6.641

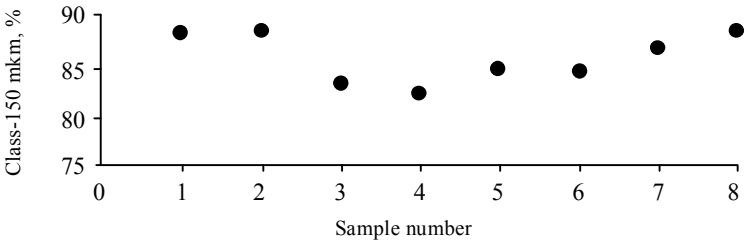



Fig.10. Proportion of a class with fineness lower then 150 mkm in feed pulp

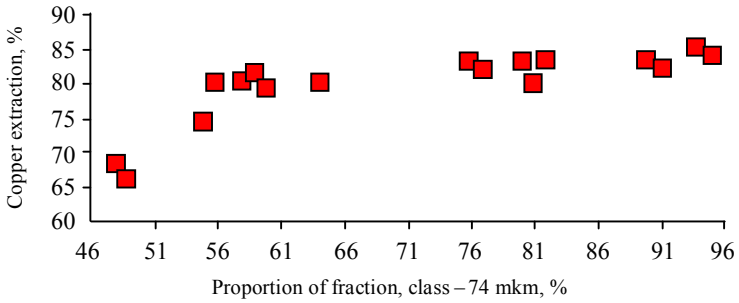



Fig.11. Proportion of a class of fineness less than 74 mkm in feed pulp

Using the existing equipment at the enterprise a project parameter of the copper extraction was achieved owing to more fine ore crushing on the basis of technological scheme reserves. Such a situation occurred due to the extremely high ore hardness as well as the adjacent rocks of the Mikheevskoye deposit. The hardness coefficient in accordance with Protodyakonov scale of hardness was equal to 19-20 which is much higher than was projected during the process regulation development on the basis of technological samples chosen by geologists. The research works performed under the conditions of existing production showed direct dependency of copper extraction from ore fragmentation (Fig.11).

In authors' opinion, an increment of copper extraction under the conditions of the increase of fineness degree for the conditions of ore processing in the Mikheevskoe deposit and regarding existing fleet of flotation machines and classification equipment, occurs owing to the decrease of proportion of 150 mkm fraction in a feed pulp from 15.3-18.6 to 0.6-2.9 %.

Within a framework of practical realization of the second stage of the project development at the Mikheevsky MPP industrial site a construction of the extra capacities for ore processing of annual volume of 9 mln t is under completion (Fig.12).

After putting into exploitation and achieving the project target values, the total capacity of the first, the second (Fig.13) and the third construction MPP stages will be equal to 27 mln t. For the purpose of provision of ore processing plants a correction of deposit opening project was made, the organizational measures aiming to provide mining production with extra machines, equipment, facilities and mechanisms were performed.

For the entire enlarged mining and processing complex the infrastructure was expanded including energy facilities, gas supply system, water supply and sewerage system, maintenance and exploitation services.

Regarding the development of the second stage a decision was made and a project is under realization; the project consists in construction of the third additional crushing stage using modular machines similar to the existing equipment considering the crushing process and classification and also a fleet of pumps.

After accomplishing the project and passing all relevant expert appraisals and public consultations with discussion and continuing the development of the direction considering the involvement of porphyry copper deposits to exploitation, Russian copper company proceeded to construction of a new MPP in the Tominskoye and the Kalinovskoye porphyry copper deposits in 2017; total ore reserves of these deposits are equal to 600 mln t with copper content of 0.41 % and gold content of 0.08 g/t.

On the basis of the obtained experience in the process of the Mikheevskoye deposit development the following project decisions were specified:

• mining and processing plant construction will be carried out in several steps;

• the first step includes two stages of construction with the annual capacity of 14 mln t of ore for each;

• the third stage includes the possibility of ore mine production capacity increase up to 56 mln t after geological exploration works accomplishment in this region and updating information about reserves;

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• use of mill tailings as backfilling material for lands restoration of the Korkinsky open pit coal mine situated on the distance of 18 km from the ore mine under construction is anticipated for the purpose of mill tailings disposal;

• aiming to preserve the environment for renewal of recycled water which is wasted during backfilling, the use of process water from wastewater treatment plants of Korkino, Kopeisk and Chelyabinsk city is provided;

• taking into account high hardness of adjacent strata the major part of the overburden rock will be used in the production of construction materials including crushed stone of high quality classes;



Fig.12. The first and the second operating stages of mine processing plant of 18 mln t capacity



Fig.13. Construction of the third stage of mining and processing plant of 9 mln t capacity

• experience of the Mikheevsky MPP regarding issues of ore crushing allowed to introduce clarifications to the project in respect of the use of more productive crushing and grinding equipment, in particular, the mills SSC were enlarged from 36 to 38 feet, an extra stage of grinding and classification is provided;

• on the basis of the experience of joint processing of oxidized, complex and primary ores in the Mikheevskoye deposit a decision to refuse from construction of a leach plant processing of oxidized ores by means of heap leaching and tank sulfuric acid leaching was made. A relevant decision was introduced to the project and to the approval documentation.

Special mention should be made of the joint collaboration of Russian copper company and Saint-Petersburg mining university. A cooperation considering the Mikheevsky MPP covers a preparation of the investment part of the project in order to include it in the list of major objects of the mineral resource management of Russia. A joint realization of innovative approaches in respect of the organization of modern mining production at the Tominsky MPP is leading at the moment. For the purpose of minimization of the environmental damage Russian copper company, having gained a scientific support of Saint-Petersburg mining university, developed a technology of mill tailings laying in the open goaf of the Korkinsky open pit coal mine. In Saint-Petersburg mining university research investigations dedicated to the possibility of use of the mill tailings as a backfill mixture were performed. Land rehabilitation of the biggest open pit coal mine in Europe which is led in parallel to development of porphyry copper deposits will allow to significantly reduce the negative impact of the open-cast mining consisting in the rock slides, fire accidents, displacements and cavings within Korkino town boundaries. The specialists from the Mining university control and provide the monitoring of operations of the land rehabilitation of the open pit coal mine to be in compliance with the project design documentation and carry out a scientific control of all mining and processing operations in terms of the Tominskoye porphyry copper deposit development.

**Conclusion.** Russian copper company for the first time ever in Russia proceeded to the porphyry copper deposits practice exploration in the Urals.

In 2013 the Mikheevsky MPP of annual production capacity of 18 mln t of ore was put into exploitation; the volume of attracting investments was equal to 28 billion rubles. Currently the construction of the third stage with the increase of the total capacity of MPP up to 27 mln t is almost completed. The enterprise is built in steppe from scratch with the simultaneous construction of all

DOI: 10.25515/PMI.2017.6.641

associated infrastructure facilities including a water-storage reservoir, a motorway and a railroad, a gas pipe-line, an electric generating station and a residential village.

Application of innovative approaches considering choice of technology, high-performance equipment and organization of construction process allowed to achieve full production capacity as well as all projected results over the three-year period of construction. At the moment this enterprise is the most productive in Russia considering copper ores processing and serves as a pattern for design and construction of the similar capacities. The practical effect of MPP operation validated a possibility of a high-performance development of the Ural porphyry copper deposits.

Based on experience acquired during design, construction and exploitation of the Mikheevsky MPP in 2017 Russian copper company proceeded to construction of a new mining and processing plant in the Tominskoye and the Kalinovskoye porphyry copper deposits of Chelyabinsk region. Production capacity of mining and processing plant at the first stage was projected to be equal to 28 mln t with the possible increase of it at the second stage up to 56 mln t. For the purpose of the impact reduction on the environment and decrease of the anthropogenic burden on the nature in the process of Tominsky MPP construction the following measures were projected: use of the mill tailings as backfill material for lands restoration of Korkinsky open pit coal mine and use of recycled waters, wastewater treatment effluent of Kopeisk, Korkino and Chelyabinsk city for the water balance recharge.

Development of the porphyry copper deposits in the Urals will allow to provide regional industry with the raw materials and, consequently, to expand the raw material base of copper and supply plant with the primary products over the next 80-100 years. A sustainable performance of the copper industry will allow to keep the stability and social tranquility in the single-industry towns of the copper branch of the Urals.

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*The paper was accepted for publication on 10 October, 2017.*