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Improving the technology of field development at the Sadon ore cluster

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Abstract

Research objective *is to establish the particular changes of field development at the Sadon ore cluster in the historical context and assess the future technologies potential taking into account aspects of interaction with the environment.*

Methods of research *include generalization of reported data and literature on the technologies of the past; detailing the results of laboratory tests on metals extraction from ores by block, heap and activation leaching; giving recommendations on improving environmental management under the man-made impact.*

Research results and application. *A historical background of the field development at the Sadon ore cluster is given together with the mining methods indicators over the past 200 years. The details of the geologic setting and field characteristic are presented. The features and indicators of mining methods are summarized and mined ore quality parameters are described differentially for deposits. It was demonstrated that conventional technologies do not provide competitive indicators of mineral quality. The article systematizes information on the reagent leaching development originated in the 1970s. It has been confirmed that tailing storage facilities of processing plants pose a threat to the environment. A combination of conventional and innovative technologies is recommended as a way of minimizing the negative impact mining has on ecosystems.* ***The research results*** *on Sadon ore leaching in high-speed disintegrator mills are reported.*

Conclusions. *It is possible to reduce the negative environmental impact and qualitatively change mining operations through transition to combined metal mining technologies.*

Keywords: *field development; ore mining; development prospects; environment; leaching; disintegrator; Sadon ore cluster.*

Introduction. The Republic of North Ossetia–Alania has a centuries-old experience in the strategically important minerals extraction.

The Alans mined non-ferrous metals in the deposits of Ossetia in the 3rd–2nd centuries BC. A more intensive mining was driven by the Alans' relocation to the Caucasus mountains in the 13th century under the onslaught of the Tatar-Mongols [1, 2]. The Sadon deposit was systematically prospected in 1842; its commercial exploitation began in 1843. The year of 1853 marked the beginning of exploration by adits with the associated production of silver-lead ores [3], and by 1860 an ore resource base was created. Since 1892, sphalerite production has started improving the economic indicators of field development. The Kholstinsky and Ardonsky mines [4] started production in 1894, followed by the Stur-Izdinsky and Kurtatinsky mines. In 1926, Sadon's productivity recovered to the 1913 level. In 1927 Ossetia produced 100% of the country's zinc and 63% of lead. The development of the world's largest vein deposit of Zgidsky started in 1945; the Kholstinsky and Buronsky deposits have been in operation since 1953. The development of the Arkhonsky deposit began in 1960, the Levoberezhny deposit – in 1967, the the Kakadur-Khanikomsky deposit – in 1969. The Fasnalsky deposit was developed on and off in 1963–1964 and 1968.

Based on a comprehensive analysis of effective technologies for the natural-technical system sustainable development [5], green and resource-saving technologies were developed [6]. With the advent of new physical and chemical processes for metal extraction, the relevance of tailings utilization was increasing [7]. Algorithms for determining the efficiency of combining metal mining technologies were being developed [8]. Geoeconomic factors of the North Caucasus sustainable development received assessment and recommendations for practical implementation [9].

The problems of backfill optimization to improve the quality of the mined raw material [10], rational use of underground space [11], and the effect new technologies have on labor organization [12] in course of the new technologies assimilation [13] were explored in foreign researches. New solutions for rock mass state control in course of mining were presented in [14, 15]. The directions of metal-containing tailings utilization were analyzed in [16–18].

Methods of research include detailing the results of laboratory tests on metals extraction from ores by leaching.

The methodological basis of leaching is changing the properties of metal-containing raw materials by means of mechanical-chemical-physical impact. The extraction possibilities were studied on the Sadon ore processing tailings using disintegrator activators. The results of complex standard practice analytical and laboratory studies are to be considered when making recommendations.

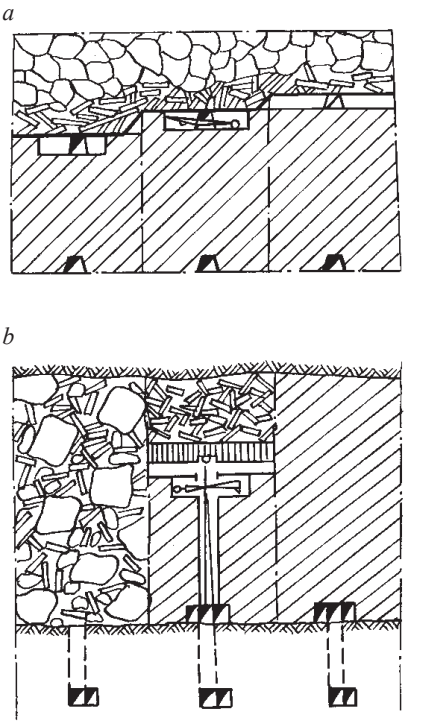

Figure 1. A top slicing mining method with flexible ceilings: *a* – cross section; *b* – plan

Рисунок 1. Слоевое обрушение под гибким перекрытием: *a* – разрез; *b* – план

Mining features. Quartz-polymetallic and pyrrhotite ore bodies of complex morphology with bending distortions, swells and ore pillars, broken by various tectonic faults and intensively dislocated occur at depths of up to 250 m. Ore bodies are 1–5 m thick on average. The ore body shapes are zones, veins, lenses, and veinlets. The deposits were developed with natural rock mass state control with dilution of 15–40% and losses of 5–6%.

The Sadon deposit is located at heights of 1200–2150 m above sea level. The strike of the deposit is up to 4.5–5.0 km, the pitch is up to 1.5 km. The vein thickness varies within 0.2–2.6 m, the vein extension is 20–50 m, sometimes more. The deposit is developed at more than 40 horizons to a depth of more than 1000 m.

During the commercial exploitation, deposit was mainly developed by the mining method of horizontal-layers and backfilling composed of ore sorting products.

In 1958, the development of reserves left in ground and metal-bearing backfill was started using caving methods. For the first time in world practice, a top slicing mining method with flexible ceilings was used (Figure 1).

Over the years of exploitation, ore reserves have been mined at an area of about 1 km in depth and more than 2 km along the strike. The features of the mining method applied depend on the ore quality requirements. Before zinc production technology was mastered, galena had been mined in Russia, while sphalerite and substandard galena were used to fill voids. The total content of lead and zinc in the backfill of that period reached 10–12%. In 1930–1950, the content of metal in the backfilling material was 2–3%. In the 1960s, the mined-out space accumulated ore with a metal content significantly exceeding the planned one. The amount of such backfill is estimated at

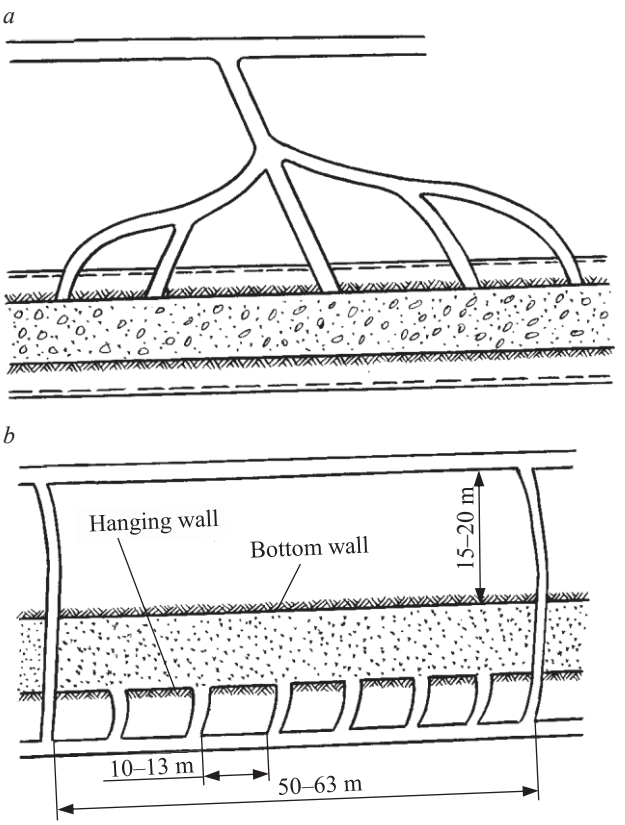

Figure 2. Metal-bearing backfill recovery: *a* – with one-sided opening; *b* – with two-sided opening

Рисунок 2. Выемка металлоносной закладки: *a* – с односторонним вскрытием; *b* – с двусторонним вскрытием

1 million tons. From 1958 to 1972, more than 600,000 tons of backfill were mined with the lead content of 1.4% and zinc content of 2.4%. From 1970 to 1990, more than 100,000 tons of backfill were mined, or 80–85% of total production per year. The process flow diagram of reworking with one-sided opening from the hanging wall or the bottom wall every 10–15 m are shown in Figure 2, *a*; with two-sided opening are shown in Figure 2, *b*: in a more stable hanging wall parallel to strike at a distance of 15–20 m a drift was driven with cross adits and loading cross drifts driven from it every 50–60 m.

The backfill extraction did not exceed 50%. In course of development, not only metal-bearing backfill but also rotted host rock was drawn, therefore, dilution exceeded 50%.

Zgidsky mine. Large faults of the Upper Zgidsky and Lower Zgidsky deposits intersect ore bodies and separate them into sections. The faults act as screens for mineralization.

Reserves are localized in the lode ore of the Upper Zgidsky and Lower Zgidsky deposits. The ore bodies 0.15–3.0 m thick are not continuous along the strike and pitch. The ore hardness coefficient according to M. M. Protodiakonov is 10–15, the bulk density is 3.0–3.2 t/m^3, the humidity is 5–7%. Ore minerals: galena, sphalerite, pyrite, chalcopyrite, magnetite, and tetrahedrite. Host rock, namely granites, granodiorite, quartz diorites and covering keratophyres are strong, weakly fractured and stable. The ore hardness coefficient according to M. M. Protodiakonov varies from 8 (keratophyres) to 18 (granodiorite). The bulk density of rock is 2.8 t/m^3. Exploitation began in 1945. The production capacity reached 200 thousand tons, 10–12 thousand of which being metal. In the upper part of the deposit, the lead content was 10–25%, zinc – 2–4%. Open stope mining methods with backfilling were used:

– shrinkage with backfill;
– shrinkage without backfill (about 10 options);
– horizontal layers with layer-by-layer cemented backfill;
– sublevel drifts (layer-by-layer shrinkage).

Arkhonsky mine. The quartz-polymetallic veins are 1–8 m thick. Granites and albitophyres make up host rock. Ore hardness coefficient is 10–12, rock hardness is from 6–8 to 10–15.

Mining methods:

– ore shrinkage with a scrapper level, under the vein thickness over 0.6 m and pitch over 55°;
– partial shrinkage in layers 4–6 m high broken by the longwall method from the bottom to the top;
– ore shrinkage and drawing to loading cross drifts with machine loading;
– ore shrinkage and breaking by boreholes from raise faces;
– ore shrinkage and drawing through hatches;
– sublevel caving.

Kholstinsky mine. The deposit is represented by steeply pitching ore veins 0.2–0.8 m thick. The veins thickness varies both along the strike and along the pitch at an angle of 60°–90°. The vein minerals are represented by galena, sphalerite, and pyrite. Granites and albitophyres make up host rock. Ore and host rock hardness according to M. M. Protodiakonov is 8–14.

Mining methods:

– ore shrinkage and drawing 30–35% of the broken ore; losses during ore drawing from chambers up to 50%, dilution 50–70%;
– selective mining and backfilling, where the block was divided into the "ore" and "rock" half-blocks by means of driving a haulage drift and block raise face; the maximum possible amount of broken host rock to be placed in one part of the block and the optimal length of ore haulage were taken into account (Figure 3);
– shrinkage and combined drawing of the stored ore onto the drift floor and machine loading;
– combined method with sublevel shrinkage that involves stoping the required sublevels under the ore of the overlying sub-level and onto the sub-console space created by hole firing.

Fiagdon mine. The Kakadur-Khanikomsky deposit is composed of a series of transverse zones 2–3 m thick. Ore minerals: pyrite, marcasite, sphalerite, and galena. The ore hardness coefficient is 3–10, rock hardness coefficient is 3–5. Ore bulk density is 2.7–2.9 t/m^3. Vein thickness is 0.3–6.0 m, pitch is 35°–90°.

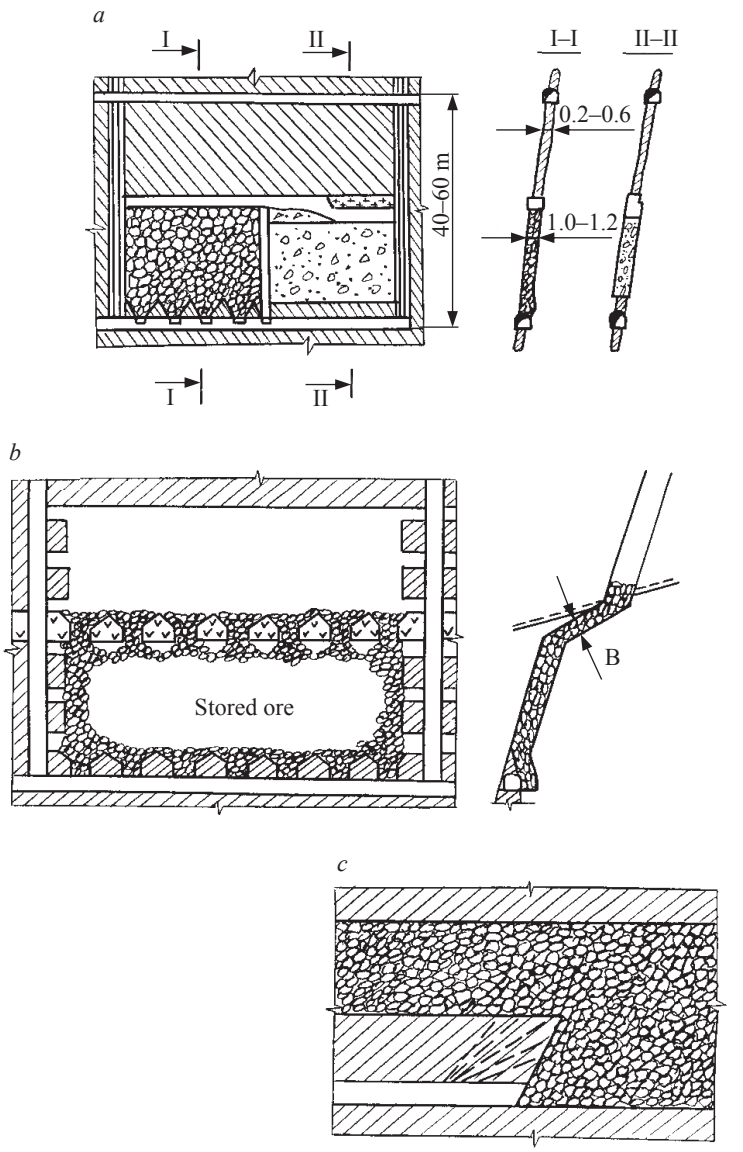

Figure 3. A mining method with shrinkage and machine loading: *a* – stored ore; *b* – cross section; *c* – block bottom; B – the thickness of the ore body
Рисунок 3. Система с магазинированием с машинной погрузкой: *a* – магазинирование руды; *b* – разрез; *c* – днище блока; B – толщина рудного тела

Mining methods:

– top slicing by stopes up the pitch and dividing into sublevels with an inclined height of 10–15 m and using an ascending method of breaking when mining the sublevels by the descending method;

– sublevel caving with ore breaking in horizontal layers, used for steeply pitching ore bodies 3–5 m thick;

– sublevel drifts and mass-breaking of ore into the mined-out space by a blasthole ring and drawing ore into the scraper drift;

– forced level caving with ore breaking in a clamp;

– sublevel caving (closed ring) with division into sublevels.

Geotechnological processes of the Sadon mines. Geotechnological processes developing in the Sadon mines goaf result in zinc and lead being removed by water. Losses are estimated at 2 million tons with a lead content of about 2.6% and zinc 3.6%. Mine waters contain up to 400 mg/l of zinc and up to 11 mg/l of lead.

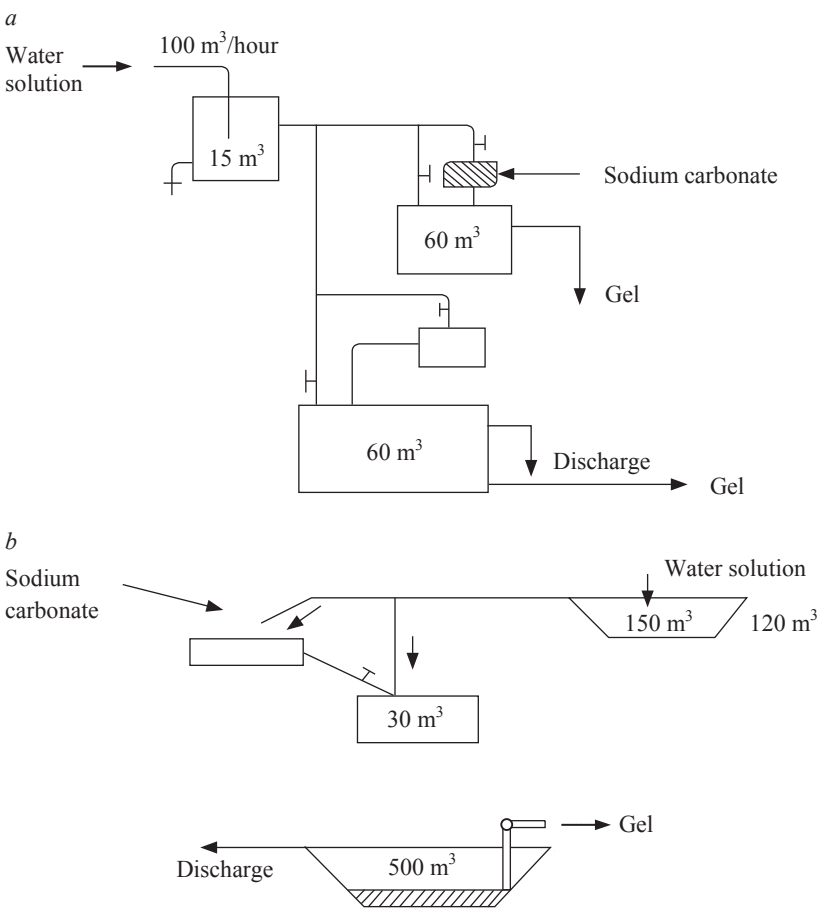

Figure 4. Plants for ore precipitation at mines: *a* – Arkhon; *b* – Fiagdon
Рисунок 4. Установки для осаждения металлов на рудниках: *a* – Архонский; *b* – Фиагдонский

Fiagdon mine. In spring, the zinc content in mine waters reached 0.71%. Salt and sulfuric acid are the reagents. Sodium carbonate and zinc dust are the precipitants. Product solutions of the first stage contained 210 g/m^3 zinc and 200 g/m^3 lead. Productivity – 150 m^3/hour.

Arkhon mine. Up to 150,000 tons of ore, up to 7,000 tons of zinc and up to 3,000 tons of lead were lost in the mine. In the discharge at the mouth of adit no. 22, the concentration of zinc is 60–70 mg/l and lead 6.5–7.0 mg/l under pH 5.5–6.0.

Over 51 working days, 40 tons of zinc were precipitated in gel at the precipitation plant with sodium carbonate as a precipitant. Under humidity of 65–78%, the gel contains zinc up to 25%, lead – 0.3–0.5%, copper – 0.15–0.28%, cadmium – 0.054%, cobalt – 0.08%, iron – 6.0%, nickel – 0.075%, and quartz – 4–20%.

Sadon mine. More than 1 million tons of metal-containing backfill with a content of 0.6–1.2% of metals is leached in the mined-out space of the Sadon mine. The zinc content in mine water reaches 308 g/m^3, lead – 10 g/m^3.

Metals were extracted from backfill with a zinc content of 0.55 % and lead of 0.15%. Size: 80% passability through a 15 mm screen. Chlorine water with a chlorine content of 0.8–1.2 g/l is a reagent. Extraction, %: zinc – 75, lead – over 21%. Content in solutions, mg/l: zinc – 40–460, lead – 4.5–6.0 (Figure 4).

Table 1. The results of metals extraction into solution
Таблица 1. Результаты извлечения металлов в раствор

Series number	Lead, %	Zinc, %
1	24.6	39.3
2	33.8	44.5
3	35.8	46.2
4	13.4	10.4
5	21.6	21.5
6	21.7	21.8

In the tailing storage facilities of the Sadon lead and zinc plant (Unalsky and Fiagdon tailing storage facilities), discharge is stored containing 0.08% of zinc, 0.16% of lead, 2% of sulfur, and 64% of silica. The area of the Unalsky tailing storage facility is 61 hectares, the amount of tailings is 2960 thousand tons. The area of the Fiagdon tailing storage facility is 56 hectares, the amount of tailings is 2313 thousand tons.

Metallurgical treatment of raw materials causes environmental degradation. The city waste dumps reach 2.7 million tons within an area of 16 hectares. They contain useful components that were not fully extracted (up to 1% of zinc, up to 0.7% of copper, up to 1.55 g/t of gold, up to 300 g/t of silver, etc.). The Sadon ore processing tailings were used to justify the phenomenon experimentally. The metals extraction into solution is shown in Table 1.

It was established by experiment that activation in a disintegrator and leaching outside the disintegrator increases extraction from the processing tailings (by 1.4 times for lead, by 1.1 times for zinc); approximately equal extraction is achieved 2 orders of magnitude faster.

When extracting metals in situ, in situ leaching tailings become analogues of hardening mixtures. Combining indicators are improved if a smaller part of ore is brought to the surface and the larger part is leached underground. The through extraction coefficient can be comparable to the extraction coefficient of a conventional technology (Figure 5).

At comparable costs, a greater amount of metal is extracted from explored, opened, developed and extracted raw materials. When leaching into a solution, almost all metals contained in the tailings are extracted. Under the selective extraction of metals from a colligative solution, it can increase the gross recoverable value.

North Ossetia–Alania is a pioneer in a number of technical innovations, including: high-speed mining; improvement of the method of ore caving under ceilings; block leaching of commercial ore; metals leaching in high-speed disintegrator mills, etc.

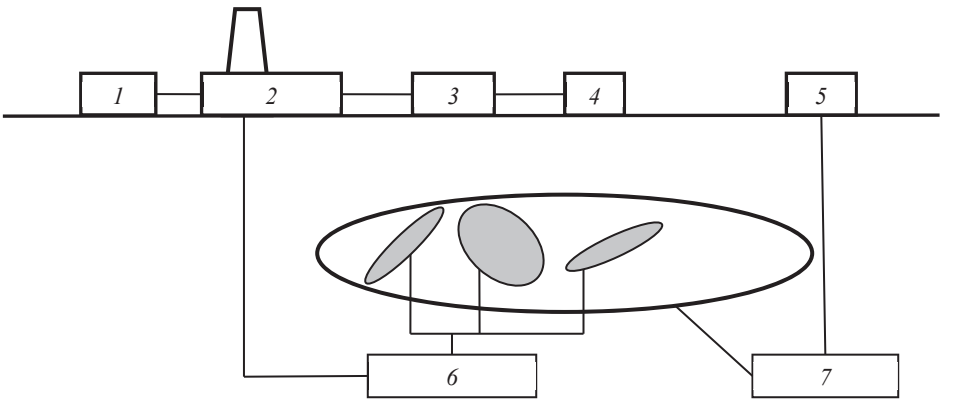

Figure 5. Combined development: *1* – leaching heap; *2* – ore quality control station; *3* – concentration station; *4* – stowage facility; *5* – reagent solutions preparation station; *6* – rich ore; *7* – low-grade ore;

Рисунок 5. Комбинированная разработка месторождения: *1* − куча выщелачивания; *2* – рудо-контрольная станция; *3* – обогатительная станция; *4* – закладочный комплекс; *5* – цех приготовления растворов реагентов; *6* – богатые руды; *7* – бедные руды;

Conclusion. Miners of Ossetia have a centuries-old experience which is a major contribution to the world's mining science. This experience should be used to restore the lost potential of an enterprise. It is recommended to combine metal mining technologies based on the criterion of complete development of various ore reserves and extraction of metals using leaching methods with mechanochemical activation.

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Совершенствование технологий разработки месторождения Садонского рудного узла

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Реферат

Цель исследования – *установление особенностей изменения технологий разработки месторождений Садонского рудного узла и оценка перспектив технологий будущего с учетом аспектов взаимодействия с окружающей природной средой.*

Методология. *Обобщение отчетных и литературных данных о технологиях прошлого. Детализация результатов лабораторных экспериментов по извлечению металлов из руд выщелачиванием в блоках, кучах и активаторах. Подготовка рекомендаций по совершенствованию управления состоянием окружающей природной среды при техногенном вмешательстве.*

Результаты работы и область их применения. *Дана историческая справка об освоении месторождений Садонской группы и показателей систем разработки за последние 200 лет. Детализированы геологическая позиция и характеристика месторождений. Обобщены особенности и показатели систем разработки с уточнением параметров качества добываемых руд, дифференцированно для разных месторождений. Показано, что традиционные технологии не обеспечивают конкурентоспособных показателей качества минерального сырья. Систематизированы сведения об освоении технологий добычи*

металлов реагентным выщелачиванием, которое было начато в 1970-х гг. в том числе, впервые в мировой практике. Подтверждено, что хвостохранилища обогатительных фабрик представляют угрозу окружающей среде. Рекомендовано комбинирование традиционных и новых технологий как способ минимизации негативного влияния горного производства на экосистемы. Приведены результаты исследований выщелачивания Садонских руд в скоростных мельницах – дезинтеграторах.

Выводы. *Реальное уменьшение негативного влияния на окружающую среду и качественное изменение горного производства возможно при переходе на комбинированные технологии добычи металлов.*

Ключевые слова: *разработка месторождений; добыча руды; перспективы освоения; окружающая среда; выщелачивание; дезинтегратор; Садонский рудный узел.*

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