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Implementation of sustainable development approaches by creating the mining cluster: the case of MPP “Inguletskiy”

Y Hryhoriev¹, S Lutsenko¹, O Systierov², A Kuttybayev³ and A Kuttybayeva³

¹ Kryvyi Rih National University, 11 Vitalii Matusevych Str., Kryvyi Rih, 50027, Ukraine

² Ingulets iron ore enrichment works, 47 Rudna Str., Kryvyi Rih, 50027, Ukraine

³ Satbayev University, 22a Satpaeva Str., Almaty, 050013, The Republic of Kazakhstan

E-mail: yulian.hryhoriev@knu.edu.ua

Abstract. The article provides the basic foundations of the implementation of sustainable development approaches in the world society and their interpretation in mining activities. The study also analyzes the regulatory framework and organizational mechanisms for the implementation of these principles in the Ukrainian mining industry. An analysis of the current state of rational subsoil use and solid industrial waste management in Ukraine is given. The concept of a mining cluster and prospects for its formation in the region of the Kryvyi Rih iron ore basin are substantiated. An algorithm designed to optimize the schedule of mining operations in the mining cluster is described. The Ingulets iron ore deposit was analyzed from the standpoint of integrated development. The reserves of talc shale extracted from the open-pit and stored in a man-made deposit for further sale are separately allocated. The order of mining works for the development of man-made deposits is given.

1. Introduction

The 1992 United Nations Conference on Environment and Development in Rio de Janeiro, also known as the “Earth Summit”, announced a new paradigm for human development aimed at implementing sustainable development approaches. One of the results of the conference was the Declaration on Environment and Development, which is largely consistent with the principles of its predecessor – the Stockholm Conference of 1972, as well as its successor – the “Rio+20” Conference held in 2012 [1, 2].

The third principle of this Declaration emphasizes that the right to development must be exercised in such a way as to adequately meet the developmental and environmental needs of present and future generations [1, 2].

With regard to mineral resources, this principle directs society to solve the problem of providing them after the exhaustion of rich mineral deposits. In the context of the mining industry, this means that the slower new mineral deposits are brought into development, the more this principle will be fulfilled. And until humanity finds ways to industrially synthesize materials in sufficient volumes, comprehensive development of mineral deposits is the main direction of the implementation of the third principle of the UN Declaration on the Environment and Sustainable Development.



At the same time, the mineral and raw material base of Ukraine is quite significant on a global scale. Almost 20000 deposits and occurrences of 117 types of minerals have been discovered in the domestic subsoil, of which 8290 deposits and 1110 objects of accounting for 98 types of mineral raw materials are of industrial importance and are recorded in the state balance of mineral reserves, 3349 deposits are being developed [3–5].

The mineral and raw material complex of Ukraine provides a significant share of the gross national product. 48% of the country's industrial potential and up to 20% of its labor resources are associated with the mining industry and the subsequent use of minerals [6–8]. These indicators are quite comparable to the indicators of developed countries with a powerful mining industry. For example, the level of production waste utilization in the advanced countries of the world it reaches 80%. Such tendency of using of secondary resources has place in the Republic of South Africa, Japan, Canada, USA, Great Britain, France, Germany and other industrialized countries [9–11].

Today, in Ukraine numerous minerals are mined in Ukraine, such as coal (1.7% of total world production), commercial iron (4.5%) and manganese (9%) ores, uranium, titanium, zirconium, graphite (4%), kaolin (18%), bromine, ocher, non-ore metallurgical raw materials (quartzites, flux limestones and dolomites), chemical raw materials (native sulfur, rock and potassium salts), facing stone (granites, gabbros, labradorites), glass sand etc [12–14].

At the same time, the difficult economic situation does not allow geological exploration to be carried out sufficiently to reproduce the mineral and raw material base. Since 1994, the increase in explored reserves of most strategic types of minerals in Ukraine has not compensated for their extraction [3, 15].

There are a total of 54 iron ore deposits in Ukraine, of which 22 are in operation. Rich iron ores and iron quartzites are mined in the deposits of the Kryvorizka, Kremenchuk, and Belozirsk iron ore basins. Explored (confirmed) reserves amount to 28 billion tons, their share in the world's confirmed reserves (139 billion tons) is 20% [3, 16–18].

At the same time, the annual volume of waste in Ukraine only in the solid phase is 600 million m³. 25 billion tons (8,6 billion m³) of solid industrial waste accumulated to date are located on an area of more than 50000 hectares [19–21].

All this emphasizes the high relevance and paramount importance of the development of iron ore deposits of Kryvbas as a powerful mining complex of Ukraine.

2. Materials and methods

In order to determine how the provisions of the Declaration are implemented by mining enterprises of Ukraine, an analysis of the regulatory framework regulating their activities was performed.

Decree of the President of Ukraine dated July 23, 2021 No. 306/2021 implemented the decision of the National Security and Defense Council of Ukraine, which includes a list of metallic and non-metallic minerals that are of strategic importance for the sustainable development of the economy and the state's defense capability [14]. Iron ores are included in this list.

In the Law of Ukraine “On the approval of the State program for the development of the mineral and raw material base of Ukraine until 2030” [3], among the ways of solving existing economic problems, the “implementation of rational methods of development of complex deposits and extraction of associated components” is listed as one of the main steps to overcome crisis phenomena in the economy.

The Law of Ukraine “On Subsoil” [22], among the main principles of policy in the field of subsoil use, encourages users of subsoil to “rational, integrated use of subsoil ... to ensure the safety of the natural environment”.

The Code of Ukraine on the Subsoil, among other things, defines the concept of man-made mineral deposits as “places where the waste of extraction, enrichment and processing of

mineral raw materials has accumulated, the reserves of which are estimated and have industrial value" [22].

It is also noted that these deposits may arise as a result of losses during storage, transportation and use of mineral processing products. After the reserves of the man-made deposit have been assessed as industrial, it is included in the State Fund of Mineral Deposits, and all previously assessed mineral deposits are the reserve of this fund. In the same document, it is noted that the exercise of state control over the formation and use of man-made deposits and the processing of mineral raw materials is the responsibility of the Cabinet of Ministers of Ukraine. In turn, the procedure for state accounting of mineral deposits is regulated by the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for State Accounting of mineral deposits, reserves and occurrences": "...reserves of minerals are subject to accounting in the state balance sheet separately for each object (deposit, section of a deposit, mine field, etc.) according to the main industrial types, grades, brands, technological groups of minerals in accordance with current state standards, as well as according to the method of development, with allocation of reserves of raw materials suitable for extraction by underground, opencast, hydraulic and other methods" [23].

At the same time, it is obvious that in the long term, the development of man-made objects reduces the environmental load, but during the period of mining operations, the impact on the environment will be greater than from dumps in a re-cultivated state. And according to the law of Ukraine "On environmental impact assessment" "... it is prohibited to carry out economic activity... the use of man-made deposits of minerals, if the full observance of environmental conditions is not ensured" [24].

Carrying out an analysis of the legislator's base on how to develop man-made objects, showing the real imperfection that can be looked over. The above factors make it difficult to transfer man-made objects to the status of man-made deposits with their further development.

The measures laid down in the National Program provide for "...continuation of work on the formation of a database of man-made deposits of Ukraine" [3] and "...geological and economic evaluation of man-made deposits..." [3]. As a result of the implementation of the National Program for the Development of the Mineral and Raw Materials Base of Ukraine until 2030, it was planned to attract an additional 15 million tons of man-made raw materials from 2021 to 2030, that is very little on the scale of waste accumulated annually.

Solving the technological aspects of rational subsoil use begins with determining the schedule of mining operations, which would take into account all types of minerals that make up the deposit. For powerful operating enterprises, the question of choosing the main direction of development of mining works in most cases is already on the back burner, since there are restrictions on objects on the day surface, transport communications in the pit and the current situation of mining works [25–27]. However, the choice of the schedule of mining operations for subsidiary minerals, as well as the determination of the volumes of their extraction and storage in man-made deposits is still relevant. Moreover, variation of volumes and places of extraction is possible not only within the limits of separate mining enterprise, but of an entire mining cluster.

A cluster refers to a set of mining enterprises located in the same region and having stable technological, logistical, economic and financial connections among themselves. The identification of such clusters usually becomes possible when mining enterprises belong to the same owner. Then the market competition between such enterprises disappears and the connections outlined above strengthen. In turn, this strengthens the market positions of enterprises and significantly releases technological potential. The integration of enterprises in such clusters is initially appears in the simultaneous development of natural and man-made deposits with the management of a joint schedule of mining operations, and later – in the management of the schedule of mining operations and the productivity of the entire cluster of enterprises.

The Kryvyi Rih mining region is confidently moving towards the origination of such a cluster. This is confirmed by the purposeful formation of man-made deposits of subsidiary minerals, which takes place despite the difficult economic and technological conditions in the country.

3. Results

The Ingulets ferrous quartzite deposit, which is developed by the open-pit of MPP “Inguletskiy”, is complex, since, in addition to the main mineral – magnetite quartzites, it also includes deposits of oxidized ferrous quartzites, manganese ore, granites, talc shale, limestone, etc (figure 1).

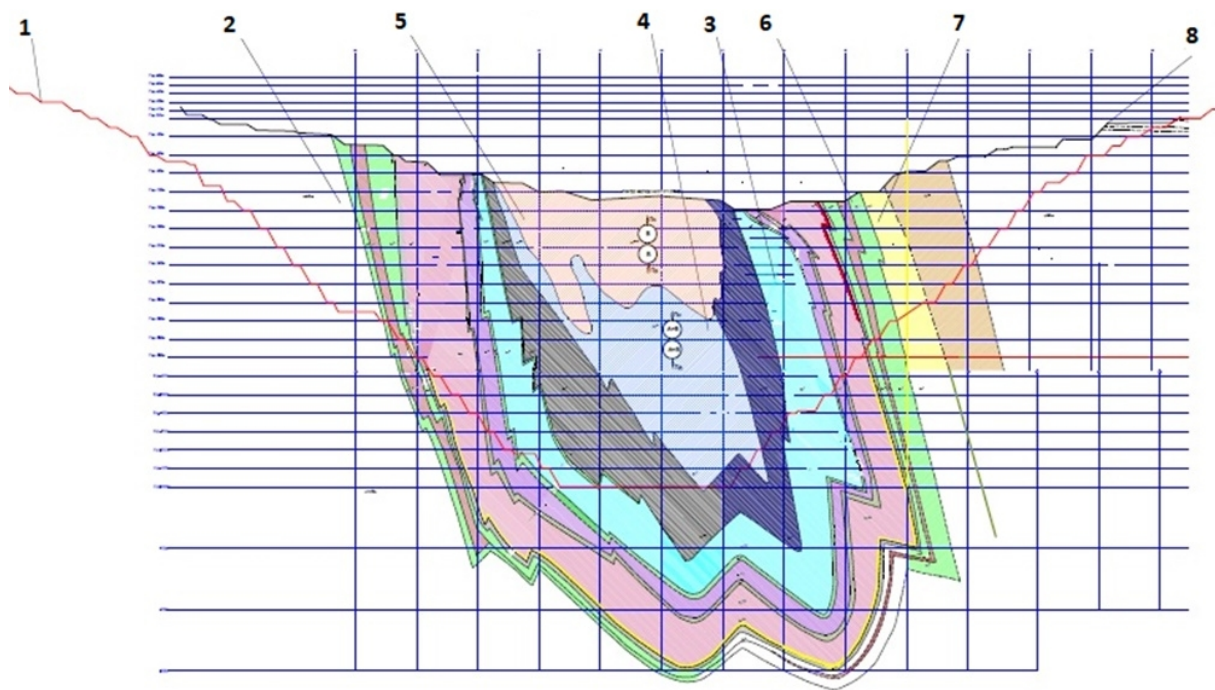


Figure 1. Geological section along surveying axis 70 of the pit of the MPP “Inguletskiy”: 1 – project outline of the pit; 2 – migmatite; 3 – magnetite, silicate-magnetite quartzites; 4 – hematite-martite quartzites; 5 – oxidized quartzites; 6 – amphibolite-biotite schists; 7 – talc shale; 8 – the actual position of mining operations.

In addition, magnetite quartzite, which is the main useful mineral, is represented by seven grades of ore with different indicators of the content of the useful component and enrichment. This further complicates the separation of cargo flows by subsidiary minerals.

Moreover, the full realization of subsidiary minerals currently extracted from the open-pit is impossible without temporary storage. This is explained by the variability of demand for minerals and the complexity of managing the schedule of mining operations for them. The figure 2 shows the dynamics of current mining of granites and talc shale from 2013 to 2021. Therefore, there is a need for temporary storage of subsidiary minerals with the formation of temporary warehouses and man-made deposits.

At the same time, the following technological difficulties arise during the exploitation of man-made deposits:

- Selective placement of each type of subsidiary minerals requires alienation of large land areas.

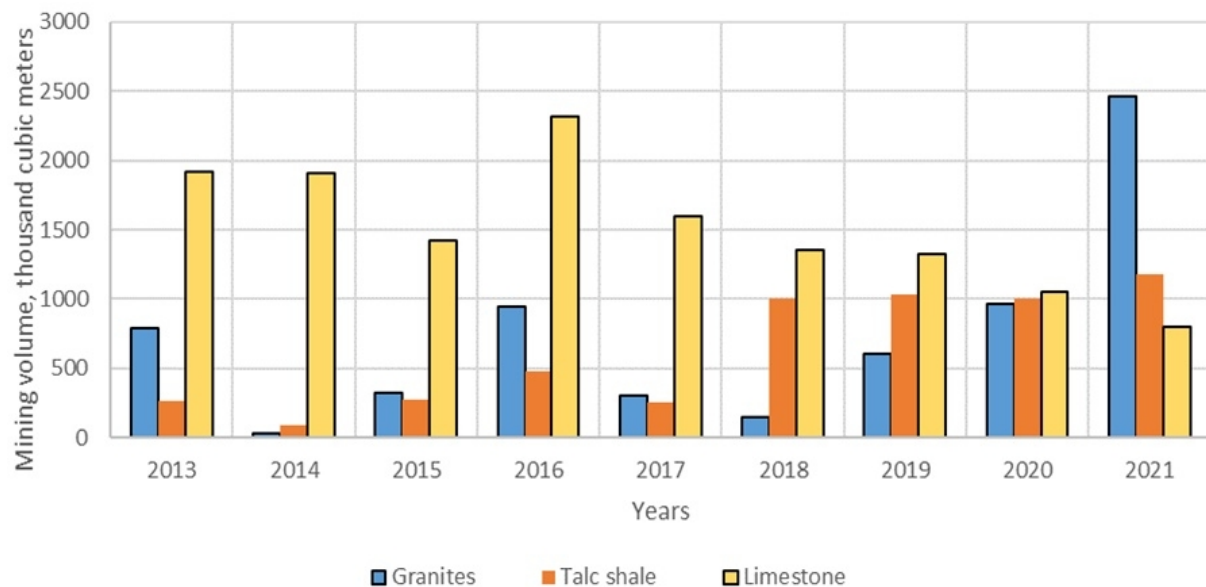


Figure 2. The dynamics of the production of transitory minerals in the open-pit of MPP “Inguletskiy”.

- In fact, in the process of waste rock dump creating or storage of man-made raw materials, the accounting of its quality characteristics is not carried out in most cases, and the spatial placement is recorded inaccurately.
- Quantitative and especially qualitative characteristics of man-made raw materials can change over time under the influence of meteorological factors of the external environment (precipitation, groundwater, physico-mechanical and physical properties of the base rocks) and the mutual influence of stored mineral substances.
- Based on the factors outlined above, the geological exploration of man-made deposits is also complicated, since it is quite problematic to take samples in the stratum of a bulk lumpy deposit, and the laws of distribution in space of quality characteristics are not always predicted.

Taking into account all the technological complexities of the development of man-made deposits, the percentage of waste should be reduced as much as possible at the stage of its extraction from the subsoil, and the creation of man-made deposits must be carried out in accordance with the principles of their purposeful formation, and not gross waste formation.

At the same time, it is recommended to realize right out of the open-pit of subsidiary minerals extracted, but here the question arises of determining the schedule of mining operations by subsidiary types. Combinatorial optimization problems can be used to control the mode of mining operations in the mining system as a search for the best element in some discrete set. For this purpose, an algorithm for finding the optimal sequence of extraction of geological blocks was developed.

The proposed algorithm is based on the improved method of determining the schedule of mining operations by Arsentiev [28] in accordance with the principles of reducing the current and boundary stripping ratios [29]. According to the proposed algorithm, the input data is loaded first. In the simplest case, the problem can have a set of flat solutions for each unit of the cluster, which consists of quarries, man-made deposits, storages. Therefore, at this stage, a set of transverse or longitudinal sections should be selected, given in the form of a database

of blocks, which contain information about their geometric coordinates, as well as the content of each mineral in each block. The next component of the input data is the forecast level of demand for each type of mineral, which must be satisfied by the regional mining cluster. It is usually projected based on long-term contracts and industry prospects.

Next, the main directions of movement of the bottom of the pits are chosen: behind both sides of the pit, along the hanging and lying sides of the deposit, and behind its center. According to the drawn lines of movement of the bottom of the pit, isolines of equal volumes of mining mass are constructed in automatic mode in accordance with the planned ones. Next, there are calculation blocks that intersect with this deepening line and the corresponding extraction cone is calculated, that is, the volume of rocks that must be removed to work this block. After all the cones for all the isolines are calculated, such cones are found that are characterized by minimal deviations of the actual volumes of extraction from the planned ones, and based on their set, the necessary version of the mining operation schedule is chosen.

Despite the organizational and economic difficulties in Ukraine, MPP “Inguletskiy” continues the policy of sustainable development and rational subsoil use. Thus, a large part of the granites extracted in the process of extracting ferruginous quartzites is used for the internal needs of the open-pit: for backfilling and ballasting of open-pit roads, as well as for the construction of the tailings dam.

Today, talc shale also belongs to the overburden rocks of the open-pit, but earlier they were part of the explored Inguletskiy deposit of brick raw material, which was located directly in the contour of the open-pit’s mining diversion. Within the boundaries of the Inguletskiy deposit, the layer of talc shale has a sloping bed with an eastern dip. The thickness of the layer in the south of the site is 18 m, in the northern part -64 m, the most characteristic thickness on average -40 m figure 3.

The talc shale occurs according to the rocks of the first shale horizon and belongs to the

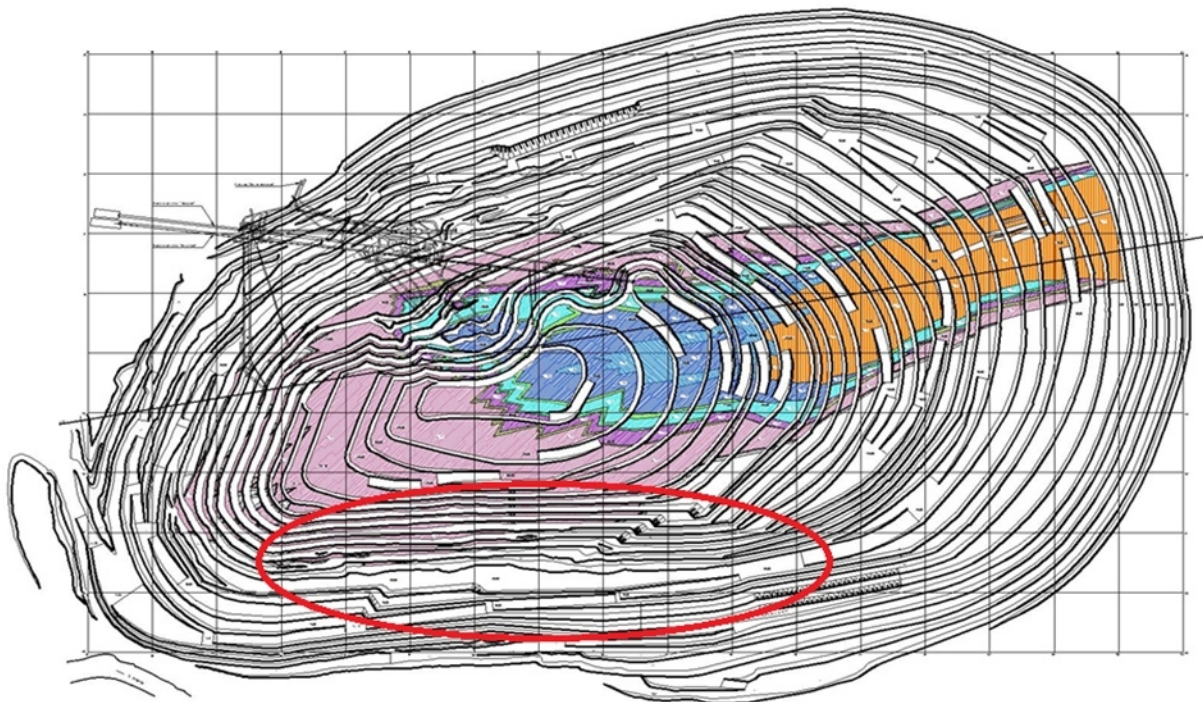


Figure 3. The state of the mining operations of the MPP “Inguletskiy” open-pit for 01.01.2022 with the marked zone of talc shale.

Skelevatska formation, which can be traced in the south of the deposit in the region of the closure of the fold behind the eastern and western wings. The chemical composition of talc shale is given in table 1.

Table 1. Chemical composition of talc shale according to the results of a detailed exploration.

No	Chemical composition	Contents, mass %
1	SiO ₂	31.94-48.28
2	Al ₂ O ₃	5.13-15.66
3	Fe ₂ O ₃	0.14-8.43
4	FeO	3.48-13.92
5	MgO	14.28-27.74
6	CaO	0-7.7
7	TiO ₂	0.321
8	SO ₃	0.11
9	Na ₂ O	0.1
10	K ₂ O	0.1
11	others	8.47

According to preliminary estimates of the trust “Ukrgeology”, the total reserves of talc shale in the Inguletsk deposit amount to 20-22 million tons with a volumetric weight of 2.6 t/m³ [30]. Of these, about 200 thousand tons are stored in three sections of a separate part of the waste rock dump, which is a man-made deposit. Areas of storage have a height of 3-3.5 m, the slope angle is 34-38°. The hydrogeological and mining technical conditions allow working out the man-made deposit in an open-pit way. Shales do not require enrichment or processing. Talc shale is planned to be sold in raw form to consumers in Ukraine. MPP “Inguletskiy” plans to conduct their development at the same time in three areas depending on the demand for raw materials.

Considering the low productivity of 20 thousand tons per year, the man-made deposit is expected to be developed in one shift during daylight hours in accordance with the current demand for raw materials. The isolated character of the deposition of man-made raw materials determines the absence of capital and excavation works. To carry out loading work, the use of a CAT-993K loader with a bucket capacity of 10 m³ or other similar equipment is envisaged. BELAZ-7540B dump trucks with a carrying capacity of 30 tons and BELAZ-7547 with a carrying capacity of 45 tons are accepted as rolling vehicles for internal transport, with further transshipment into railway vehicles.

Thus, the plant intends to ensure the rational use of natural resources, reduce the amount of overburden storage, freeing up space in dumps with an area of 2.68 hectares.

4. Conclusions

The Kryvyi Rih region has all the prerequisites for creating a mining cluster. For this, technological, logistical, economic and financial ties between the “Inguletskiy”, “Pivdenniy”, “Pivnichniy” and “Centralniy” mining and processing plants and their mineral bases should be strengthened. MPP “Inguletskiy” has significant success in this aspect and can become a driver of such transformations.

Further optimization of the schedule of mining operations within the system of “open-pit-technogenic deposits”, and in the future within the mining cluster, will contribute to more

complete extraction of subsidiary minerals due to the possibility of meeting demand in a timely manner. In turn, these measures ensure a more complete implementation of sustainable development approaches in the exploitation of mineral deposits by an open-cast method.

ORCID iDs

Y Hryhoriev <https://orcid.org/0000-0002-1780-5759>

S Lutsenko <https://orcid.org/0000-0002-5992-3622>

O Systierov <https://orcid.org/0009-0004-6850-0527>

A Kuttybayev <https://orcid.org/0000-0003-3997-8324>

A Kuttybayeva <https://orcid.org/0000-0001-7281-3690>

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