Journal homepage: https://mining-journal.com.ua/en

MINING JOURNAL
of Kryvyi Rih National University

Vol. 58, No. 2, 2024

Received: 23.07.2024; Revised: 11.11.2024; Accepted: 24.12.2024

UDC 622.2

DOI: 10.31721/2306-5435-2024-2-40-49

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Analysis and problems of the world's practical experience in the extraction of minerals by the combined open-pit and underground method

Abstract. The purpose of this paper was to review and analyse the world practice of combined open-pit and underground mining with further justification of its application at mining enterprises in Kryvyi Rih. The following methods have been used: analysis of practical experience in mining by the combined open-pit and underground method of the world's most famous mines; generalisation of the shortcomings of technogenically destructive technologies of open-pit mining of iron ore raw materials and modern environmental problems of open-pit mining; calculations of the multifactorial structure of dependence in the operation of a mining enterprise on environmental losses; methods of analysis. It has been established that it is necessary to develop a comprehensive strategy for the transition from the existing open-pit mining technology to the technologies of open-pit and underground mining, taking into account the stress-strain state of the rock mass. The relationship between iron ore production at mining enterprises and environmental costs was established. The results of the calculations showed that 99.74% of the variability of environmental costs is explained by changes in the factors affecting the environment, which are calculated in the presented structure, and the remaining residuals are due to the effect of unaccounted factors. The paper investigated and developed transitional technologies with the formation of an underground mining complex on the side of a quarry. A review and analysis of the problems of transition from open-pit mining to the technology of combined open-pit and underground mining of iron ore raw materials was carried out. It was established that in the long-term planning of the development of mining enterprises for the future, preference should be given to the combined or underground mining method. Based on the practical experience of world mines with combined production, a comprehensive strategy for the transition from the existing open-pit mining technology to the technology of open-pit and underground mining has been developed, taking into account the stress-strain state of the rock mass. The practical significance is to develop the optimal technology in the future, taking into account the identified shortcomings and problems of the combined open-pit and underground method at world mines for the conditions of the Kryvyi Rih iron ore basin

Keywords: technology; research; working; mining; ore; scheme

Suggested Citation:
Shepel, O. (2024). Analysis and problems of the world's practical experience in the extraction of minerals by the combined open-pit and underground method. *Mining Journal of Kryvyi Rih National University*, 58(2), 40-49. doi: 10.31721/2306-5435-2024-2-40-49.

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Introduction

In 2022-2024 in Kryvyi Rih iron ore basin there was such situation, that actually there are no executed basic researches concerning definition and management of stresses and deformations at a transition period on mining operations opencast on a complex underground extraction of deposits. Also, not enough scientific researches on the combined mining operations which provide working of chambers of the second turn under an opencast bottom under protection of a pillar with hardening backfill and the further filling of a niche of opencast with the fulfilled barren rocks. Therefore, mining of the basic hypotheses of definition and management of the main stresses and deformations which arise under a bottom of working opencast with transition on underground an extraction of minerals, research, and also mining complex resource saving up technology thanks to which it is possible to provide the combined way of the further extraction of minerals, is the important practical problem.

Mining operations in the world has led to that practically in all developed mining countries deterioration mining and specifications is observed. There is a constant change of depth of mining operations, thickness of ore deposits decreases, power inputs increase by extraction 1 tonnes of minerals. To gradual fall of depth of mining of minerals there is a sharp increase in volumes of barren rocks and the cost price of the further opening of deposits considerably increases, that considerably worsens the general economic indicators at mining operations opencast. It would be expedient to apply a parallel deposit opening to maintenance of a solution of the given questions in the underground way together with working opencast which gradually stops the activity, on achievement of critical depth by it.

Authors S. Pysmennyi *et al.* (2023) noticed that necessity of application of the open-pit or underground excavation methods are defined taking into account geological conditions of burial of deposits and necessary productivity of the enterprise. At transition to the combined ways of working of ore deposits it is possible to allocate following most typical cases of association of the open-pit and underground mining operations in time: the combined working of reserves by the open-pit and underground way within one deposit; completion of reserves of a deposit by the open-underground way with gradual transition exclusively for an underground way of working and the termination of open-pit excavation method; working of reserves of perspective blocks of a deposit by open-pit way and completion of unpromising regions by open-underground and underground ways. For maintenance of safety of operations in developments at transition from open-pit mining operations to combined or an underground extraction the technique of definition of parameters which is put forward to the future underground workings is offered. Also, certain destructive processes which arise at underground mining operations are described.

Concerning a location of mine and opencast from mineral reserves it is possible to allocate the basic ways of conducting mining operations: with combination of model opencast-mine on axis Y where underground mining operations occur below coffin; with combination of model opencast-mine on axis X where underground mining operations occur in a pit wall; it is combined on axes Y and X. The design procedure of the general geometry of opencast according to the further mining of a deposit (Marchelli *et al.*, 2023). According to a problem of systematic transition from open-pit mining operations to underground mining operations, or to the combined working of mineral deposits the methodology of an establishment of the is intense-deformed condition of a massif (Stupnik *et al.*, 2024). Thanks to the resulted dependences of stresses and deformations which are established, it is possible to establish effective depth and parameters of the further mining of mineral deposits.

By authors R.M. Nisaa & N.I. Fawzi (2023) it is established that the coal mining considerable rates increases in the open-pit way, however it leads to deterioration and degradation of the earths which become unsuitable for their further use. Considerable influence of open-cast mining is confirmed in city Bontang in Indonesia which leads to air contamination in its suburbs. In such conditions problems with health can receive the majority of people. In article are specified requirement for the big necessity of recultivation of the earths at development of mining operations. It is one of harmful indicators on whom it is possible to assert, that transition to the combined or underground excavation method of minerals is safer for a surface.

Authors A. Salkynov *et al.* (2023) bring results of mathematical modelling with calculations of parameters of an actual mining. According to received data the basic dependences which describe a stress and deformations in a massif near a working excavation are revealed. On the basis of these results of the resulted calculations practical solutions for application directly on a deposit are recommended. Also, it is specified, that at the basic calculations it is necessary to consider the main influencing physic mechanical properties of rocks and ores. A. Driouch *et al.* (2023) specified that safe further mining by underground way needs application of a method of mining with application 2D or 3D geotechnical numerical modelling. For research of the is intense-deformed condition of a massif the finite element method which gives the chance to receive more exact results of research will be offered. By means of the software it is recommended to carry out calculations of the is intense-deformed condition of a massif of transitional technologies from open-cast mining to an underground extraction. The mathematical

approach to the description of stresses which arise in chambers under an opencast bottom at consecutive open-underground mining is offered.

By means of software H. Luo *et al.* (2024) recommend to carry out calculations of the is intense-deformed condition of a massif in tunnels which are exposed to a rock pressure. By such principle it is possible to apply the given approach at calculation of transitional technologies from open-pit mining to an underground extraction. The mathematical approach to the description of stresses which arise in a massif is offered agrees three key indexes. Scientist B. Rakishev (2023) notices that at mining of mineral deposits probably application resource saving up technologies which provide further a decrease of a contamination and losses of minerals. Thanks to technical solutions the considerable production efficiency is reached. Also, possibility of application of a variant of selective extraction of minerals which will improve mining quantity indicators is created. On the basis of such base terms as selective and resource saving up technologies of mining of deposits it will be developed effective practical solutions for working complex structural deposits.

The purpose of the study was to substantiate the use of the open-pit mining method in the Kryvyi Rih iron ore basin as the main method of deposit development, given that there is an urgent need for advance planning of deposit opening under existing mine pits.

Materials and Methods

Methods of research which were used in work: the analysis of practical experience on mining operations by the combined open-pit and underground methods of the famous world ore mines; generalisation of lacks of technogenic destructive technologies of open-pit mining iron of ore raw materials and modern environmental problems of open-pit mining of minerals; carrying out of calculations of the multifactorial form of dependence in work of the ore mining enterprise on ecological losses by means of settlement value of Student's coefficient; methods of analysis of the received data.

The analysis of practical experience on mining operations by the combined open-pit and underground methods of the famous world ore mines as problems which the world ore mining enterprises face will appear and in Kryvyi Rih iron ore basin was the basic method of research. At introduction in operation of extraction chambers which are under an opencast bottom, or in a pit wall, it is necessary to understand an overall picture of distribution of the main stresses and deformations which arise in a rock mass. Thus, it is possible to warn in advance extreme situations and to provide the future consequences at transition from the open-pit mining on combined technology.

Based on the practical experience of mining enterprises, the article summarises the disadvantages of technogenic and destructive technologies of open-pit mining of iron ore raw materials and modern environmental problems of open-pit mining. Understanding the main consequences for the ecology of the area caused by open-pit mining, it is possible to recommend effective resource-saving technologies for combined or separate underground mining. Based on the data from Official website of the Dnipropetrovsk Regional State Administration (n.d.), and also on the basis of the main problems and the reasons which arise, and consequences of application of open-pit mining of a deposit calculations of the multifactorial form of dependence in operation of the ore mining enterprise on ecological losses by means of settlement value of Student's coefficient are carried out. Indicators which directly or indirectly influence environment at open-pit mining of deposits were initial data for calculations.

For the purpose of revealing of the main dependences between indicators of interaction of mining iron ore mines on environment Kryvyi Rih iron ore basin and financing in nature protection functionality, had been applied the multifactorial form with one productive indicator Y and N causal indicators ($x_1, x_2, \ldots, x_n$). As causal indicators it is expedient to accept following key parameters of activity of factories: x_1 – the stored volume of overburdens (million m^3); x_2 – amount of the concentrated waste which remain on object (million tonnes); x_3 – amount atmospheric emissions (thousand tonnes); x_4 – the selected water (including water from storage reservoir) (million m^3); x_5 – downthrow or removal of recirculated waters (million m^3); x_6 – amount of the degraded daylight area (thousand tonnes); x_7 – the basic investments for protection of a surrounding habitat (million UAH). The analysis of the received results is carried out and the further effective of open-underground development of mining operations is offered.

Results

At carrying out of the analysis of practical experience on mining operations by the combined open-pit and underground way it is specified, that such ore mine as Ruttan Mine developed a copper deposit at first opencast, and then in the underground way. By underground operations in extraction chambers there was a backfill which warned displacement and daylight area destruction. Kamoto Mine in Katanga worked with long interruptions in operation, however since 2020 the mine again left on the planned volumes of a mining of copper and cobalt (Katanga Mining Limited..., 2019). The deposit most part is fulfilled by opencast. The basic underground reserves fulfil chamber systems with hardening backfill. Eight years were simultaneously conducted operations on extraction of a deposit by opencast and underground way. Hardening backfill requires additional expenses connected with its cost, preparation and transportation, however provides firmness day surface.

In Kazakhstan, an interesting example of the combined working of deposits is a Tishyn deposit ore. The

deposit looks like some parallel steeply dipping ore bodies with names "Osnovne" and "Paralelne". Deposits have big enough fluctuation of the sizes of thickness. Deposit reserves have started to fulfil opencast with gradual transition to the combined mining. Accordingly carrying out of the uncovering main and air shafts, and also inclined ramps (Fig. 1) in advance has begun. On an ore mine the thick high-efficiency equipment on transportation, both in opencast, and in underground workings (Dyachkov *et al.*, 2021). The deposit of ore mine Finsch (Fig. 2) is one more interesting example of the combined mining. Ore mine Finsch concerns one of world leaders on extraction of diamonds. In this region there is one more thick ore mine Venetia, that also extracts diamond.

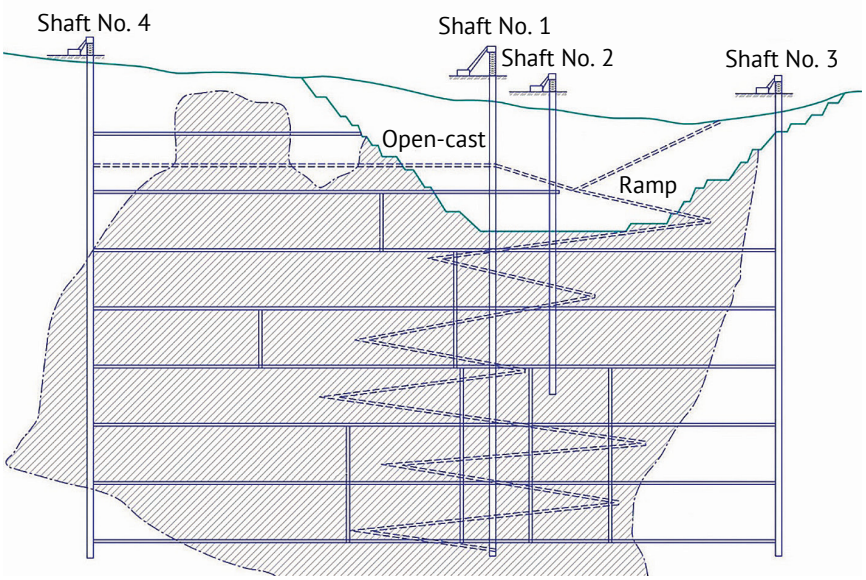

Figure 1. *Scheme of combined working of Tishyn ore reserves*

Source: *developed by the author*

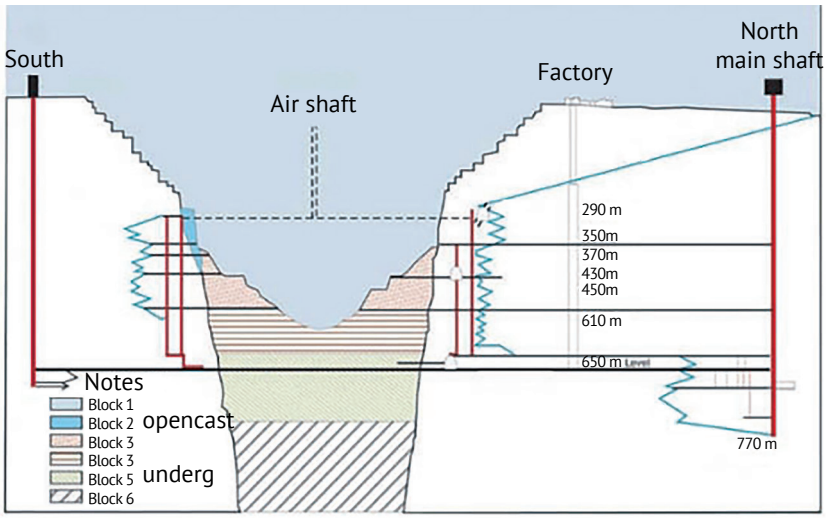

Figure 2. *Combined working of the deposit by the Finsch mine*

Source: *developed by the author*

In the beginning of a mining the deposit was fulfilled by opencast. Then consistently mining of a deposit was conducted by underground way under a coffin bowl. Opening of a block of underground mining operations is carried out from a surface by spiral ramps to level 680 m and shaft depth 763 m (Khati & Matabane, 2019). Operations are conducted by system of a floor induced caving on level of 630 m. On an ore mine apply highly heading equipment longwall sets of equipment, including – for drilling on complete section rising in diameter 2.9 m and more. On coal-face works for drilling of deep boreholes use a semi-automatic drilling complex "Tamrock" with dry drilling of boreholes (depth of boreholes more than 40 m).

One more classical technology combined open-underground mining deposits can be observed on ore mines Craigmont Mine in Canada (Fig. 3) and diamond mine Koffiefontein Mine (Fig. 4), located for 80 km from Kimberley in Southern Africa. Last is one of many mines Kimberley among which the most known neighbors are mine De Beers Consolidated Mine. By underground operations mining methods of a sublevel caving of ore and adjacent strata, in some cases of mining method with a caving of ore and strata are extended.

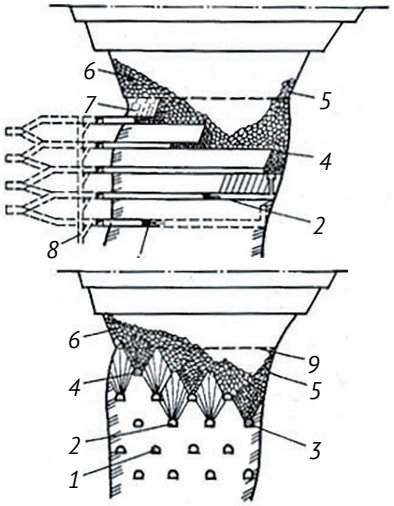

Figure 3. *Combined mining of deposits at the Craigmont Mine in Canada*
Notes: *1, 2 – blind gallery; 3 – drawing and loading of broken ore by self-propelled loading and transport machines; 4 – breaking; 5 – field boundaries; 6 – broken ore; 7 – boreholes; 8 – ore chute; 9 – contour of the lower border of the opencast*
Source: *developed by the author*

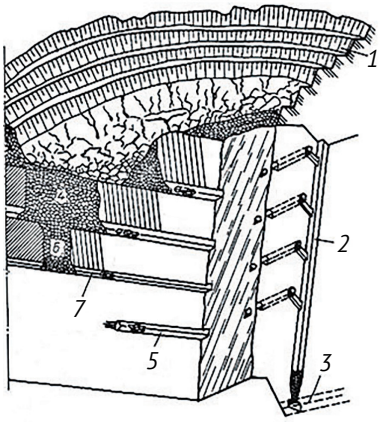

Figure 4. *Combined mining opencast-mine at mining of deposits at the diamond Koffiefontein Mine*
Notes: *1 – opencast bench; 2 – ore chute; 3 – haulage gate; 4 – broken ore of the second underground level; 5 – carrying out of loading and blind gallery; 6 – broken ore of the third underground level; 7 – drilling out of blastholes*
Source: *developed by the author*

One of high-efficiency mines with the combined mining operations is Kiruna mine. On an ore mine 30 million tonnes ore and accompanying raw materials is extracted annually almost. Until the 1960 mine produced ores opencast. Since 1961 mining of iron ores is carried out by underground way. The ore mine extracts rich magnetite ores. A development is conducted on level – 1,345 m. Deposit of iron ores on Kiruna mine is opened by the shafts driven on a lying side in barren rocks. From shaft on which ore to a deposit stands out crosscuts are spent. The mine field is divided into eight sections, everyone with own ore chute and ventilating system. Level reserves are allocated on sublevels in height of 28.5 m. From a surface to level which is fulfilled, there are driven spiral ramps for moving of the self-propelled equipment.

Ore mine Kidd Creek (Fig. 5) in Ontario, Canada is an example of conducting mining operations over 1,500 m. The ore mine develops complex ores. Along with copper and zinc here too extract indium, copper-nickel carbonate and other. A deposit has started to develop in 1966 in the open-pit way. Since 1968 the combined mining which occurred to gradual transition is applied. Carrying out of underground workings has begun for 100 m to final depth of opencast. Therefore, in advance all main workings before actual closing down in mining opencast have been spent. The transitional period lasted about ten years (Rankin *et al.*, 2024). The given ore mine is indicative in respect of performance of operations in some stages of opening. That is in parallel with opencast deposit working in the Stage 1 of opening has begun, depth to 1,400 m (Stage 2) gradually increased. Carrying out of underground workings to depth of level of the Stage 3 (level of 2,070 m) is gradually carried out.

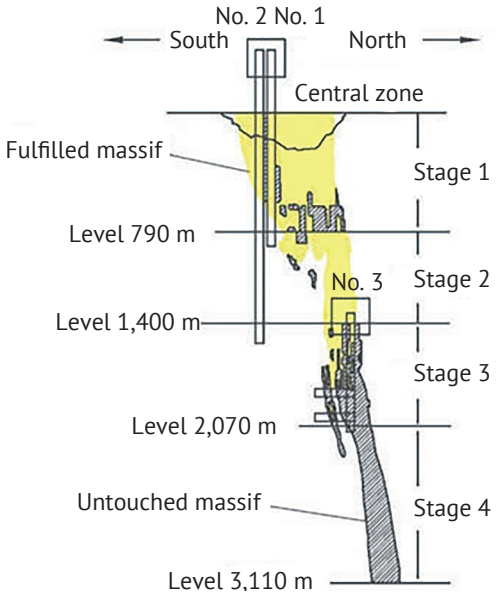

Figure 5. *Opening scheme of deposit Kidd Creek in the underground way*
Source: *developed by the author*

Also, the complex of capital ore chutes and two air raises (one is driven from opencast from depth 150 m) have been spent. In connection with considerable fluctuations of quality and irregularity of an ore mining in 2 times the capacity of sorting structure has been increased. In process of development of an underground mining capacity of opencast decreased, however the stable volume of an ore mining and constant load level of a preparation plant thus remained. The deposit is opened from a surface to level of 1,400 m. In carrying out there is a shaft No. 3, that working of reserves will provide the Stage 2 of opening to level of 2,070 m. In the long term is planned to depth of 3,100 m. The enterprise uses powerful drilling, loading, and transport equipment of the manufacturers "Ingersoll Rand", "Mission", "Cubex", "Tamrock" and others.

Analysis of the brought basic technologies gives the chance to tell, that at transition to the combined ways of working of mineral deposits under a bottom working, or the suspended opencast by the basic problem stabilisation of geodynamic processes in rock massif. Thus, there is a pressing question of transition on complex opencast-mine or underground working of deposits. Thus, there is a necessity of definition of parameters of technology of open-underground and underground mining operations, including with backfill of the fulfilled space, and regularities of the main stresses and deformations which define conditions of their application.

On the basis of the spent analysis it is established, that there is a necessity of carrying out of the review of the basic lacks of technogenic and destructive technologies of open-pit mining iron of ore raw materials and modern environmental problems of open-pit mining of minerals. The basic nature protection questions of mining regions are caused by the increased share of a contamination of environment. So, for example, the pivotal indicators which influence quality of air of the Kryvyi Rih, it is the caused industrial operations of mining ore mines and metallurgical plants, and also transport (Fig. 6).

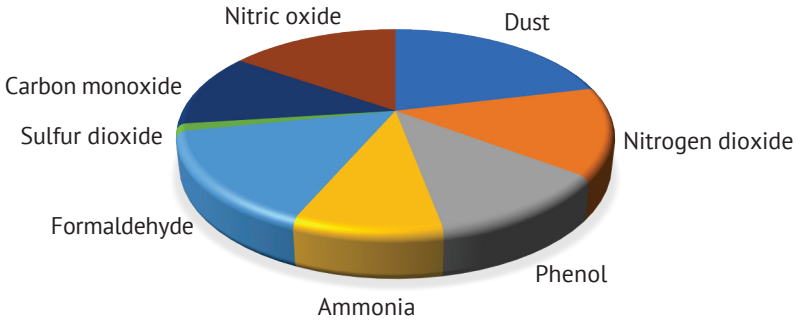

Figure 6. *Indicators of environmental contamination of territory Kryvyi Rih*
Source: *compiled by the author based on Ecological passport of Dnipropetrovsk region for 2023 (2024)*

For 2023, to atmosphere has got 16.3 million tonnes carbon dioxide which is the basic hotbed gas responsible for changes in a climate (Regional report..., 2024). The second dangerous environmental problem of mining regions are pollution of natural reservoirs. Pollution of water objects is carried out, as a rule, by downthrow of harmful impurities of mining objects and other. Removal of the polluted technical water in natural reservoirs for 2023 makes 515.964 million m^3 (the indicator has decreased for 4.7% in comparison with last year), consisting of: harmful – 106.637 million m^3; pure according to norms – 246.737 million m^3; cleaned – 162.59 million m^3 (Ecological passport..., 2024).

Working of deposits by open-pit way has considerable anthropogenic effect on surrounding habitat thus ecological position worsens. If to look the updated card Kryvyi Rih iron ore basin through Google maps with satellite display it is visually possible to see considerable breakages, downfalls, daylight area falls. The natural landscape which looks like huge breakages as after the bombardment, the forbidden zones with cavities and ledges because of direct action of open-pit mining, dumps, slime stores changes. Annual volumes of barren rocks which are transported to dumps, make 71 million m^3 which include of tailings and barren rock about 53 million tonnes, deformed the considerable area of a daylight area of 34,000 hectares, and from them annually recultivation only 100 hectares. Totally economic losses from described above factors for Kryvyi Rih iron ore basin can be estimated in some hundred million dollars.

Leaning against initial data it has been calculated plural to a determinant which has made size $R^2 = 0.9974$ and a multidimensional indicator of connection which is equaled accordingly $R = \sqrt{0.9974} = 0.995$. Calculations have shown that following results were approximately 99.74% variability of ecological expenses speaks change of factors which influence surrounding habitat which are calculated in the presented form and the rests – action of not considered factors. As $R > 0.9$, force of correlation is very strong. The calculated size of Student's coefficient above for tabular ($t_{tab} = 2.45$, attached to $n - m - 1 = 6$), hence a multidimensional indicator of connection R is the meaning. Other results calculations are brought in the Table 1.

Table 1. *Results of calculations of a multicomponent form of dependence in the work of a mining enterprise on environmental losses*

Index name		Calculated value	Indicator		Calculated value
Regression coefficients	y_0	-30,801.01	Reliability coefficients of regression coefficients (Student's coefficient value)	l_0	2.059
	y_1	1.59		l_1	3.83
	y_2	3.07		l_2	1.64
	y_3	0.26		l_3	2.83
	y_4	-0.53		l_4	0.48
	y_5	2.62		l_5	2.15
	y_6	4.07		l_6	1.17
	y_7	0.60		l_7	5.87
Errors of regression coefficients	S_0	14,959.787	Variance	v_1	7
	S_1	0.417		v_2	6
	S_2	1.874	Fisher adequacy criterion	f	167
	S_3	0.092	Table value of Student's coefficient	t	2.4469
	S_4	1.112			
	S_5	1.220			
	S_6	3.472	The tabular value of Fisher's test	f_{tab}	4.2150
	S_7	0.103			

Source: *developed by the author*

Thus, the executed researches allow to define an optimum direction of the further prospect of mining operations in region. The basic condition is necessity of gradual transition from the technogenic and destructive opencasts located on a daylight area, on modern ecologically safe technologies of the combined and underground mining operations (Veliyev, 2021). The basic advantages at working of mineral deposits by underground way or together with working opencast are following factors: reduction of losses of territories under formation of opencasts and waste heaps; improvement of an ecological condition of a daylight area of basin and cleanliness of air in areas of transition to complex technologies of mining operations; an intrusion of application of selective extraction at an ore mining; application, barren rocks from opening opencast, as accompanying material at manufacturing, for example the building goods; possibility of creation of reserved territories, recreational zones after achievement by opencasts of critical depth of mining.

So, results of the executed researches show, that in Kryvyi Rih iron ore basin, as well as in others iron extracted regions of Ukraine, underground excavation method not only does not concede opened for the basic technical and economic indicators, but also surpasses it for separately isolated factors, such as preservation of the environment. Therefore, at forward planning of development mines on the future it is necessary to prefer combined, or to underground excavation method. Technologies of mining of minerals are expedient for applying in cases when high efficiency of operation and considerable scales of manufacture get crucial importance in object view achievement. So, if mines of Ukraine with open-pit excavation method of iron ores do not take advantage of the nearest years of possibilities of halving of a complex mining in model opencast-mine next years they it is reached such cost price on which profitability of opencasts will come nearer to zero, and a number of opencasts become unprofitable.

Such conclusion is confirmed by calculations according to which combined open-underground, and in the future exclusively underground mining allows to reduce on the average on one opencast opening volume to 2.5-6.5 million m^3, considerably to reduce factor of opening with 3.0-3.5 to 0.1-0.2 m^3/tonnes, to lower a production cost on 35-55%, to increase by 20-35% profit. Except material advantages, improvement of an ecological condition of a daylight area of basin and cleanliness of air in areas of transition to complex technologies of mining operations is the core by environment preservation.

Discussion

S. Pysmennyi *et al.* (2022) notice that for reduction of the cost price of stripping at open-pit mining of mineral deposits it is expedient to form internal spoil heaps of barren rocks on boards of working opencasts. But there is actual enough problem of the further operation of opencasts in conditions when the significant number of barren rocks simply blocks in the volume access roads, the contamination of benches and other problems is created. Internal spoil heaps would be expedient for forming in opencasts provided that in them critical depth of mining is reached. That is, such conditions which opencasts without conducting underground mining operations do not allow to exploit further are created. Then it is possible to use not involved benches of opencasts under dumps of barren rocks. By researches in article it is proved, that it is necessary to use the complex approach of transition from open-pit mining operations to combined, or exclusively underground. The given approach will reduce

outbursts of harmful substances, will improve ecological position of region, and also will give the chance to utilise a significant number of barren rocks which usually remained in dump.

In spent researches M. Byle *et al*. (2024) it is offered to investigate long working supervision features of formation on a daylight area of caving zones and displacement zones at mining of mineral deposits in the conditions of a karst deposit. It is offered to observe of a part of a daylight area which directly contacts to a working excavation of the bottom level which is fulfilled in more details. Thus, it is recommended to pay especially attention to physical and mechanical properties above lying soils, such as fracturing, humidity and other. Also, it would be possible to recommend working of the top part of a deposit by open-pit way. Further with application of the same systems with a caving of ore and adjacent strata. If insufficient durability above lying soils, it would be more expedient to form a pillar from hardening backfill between a daylight area and a working excavation to warn a caving.

In scientific paper Y. Zhang & G. Sun (2020) it is specified, that open-pit mining operations in opencast on a coal mining have rather low complexity of operations and a production cost. However, in scientific paper it is specified nothing about considerable ecological influence on environment, considerable outbursts of harmful substances, considerable zones of alienation of a daylight area under opencasts. In the scientific paper in the open-pit way without consequences of such type of mining of minerals the problem of increase in efficiency of a coal mining dared at environment and ecological aspect as a whole. An effective coal mining in the open-pit way it would be expedient to spend taking into account results of researches of influence of harmful factors on nature protection indicators. For example, it is possible to create the plural form, model or structure to calculate plural to a determinant which will generate a direction of the further researches.

Authors Y. Zhang & G. Li (2020) methods of optimisation which are based on technologies of an artificial intellect of systems of decision-making at open-pit mining of mineral deposits are offered. In their article the basic lacks of open-pit mining of mineral deposits is described, but the ecology problem here too is not considered at conducting such way. It would be interesting to learn about application of an artificial intellect in the conditions of the combined mining when it is necessary to fulfil the deposit most part in the future in the underground way with application of an industrial plane of opencast in the industrial purposes. In the conditions of difficult environmental problems which arise at conducting open-pit excavation method of deposits, the intrusion of bases of an artificial intellect in settlement program complexes would be original idea at a solution of some problems. For example, calculations of technical and economic indicators of the basic processes of underground mining operations with artificial intellect application.

Scientists Y. Lu *et al*. (2024) research of stresses and deformations of benches and a massif is considered at deposit working by open-pit way. It is proved, that mining of a mineral deposit by opencast has considerable destroying actions on an earth daylight area. In research the complex approach for a regular estimation of shifts of pit walls is used. It is one of operations devoted to consideration of a problem of the increased inflow of water of opencast which influences directly the further mining of a deposit by underground way in the conditions of deep levels. However, in operation it would be possible to consider in the form of multifactorial model and other influencing indicators which are not considered in research.

At analysis of considerable territories of a daylight region at mining of deposits by the ore mining enterprises it has been analysed and compared geologic structure of surfaces for the purpose of analysis of degree of influence on the ecological factor. At an extraction of minerals there are destroyed fields of a daylight region which require recultivation and restoration of natural balance. To such questions though and on an example of the Lviv-Volyn coal basin, researches have been devoted K. Baraban *et al*. (2023).

So, at the general estimation of environment at transition from open-pit mining operations to the combined or underground excavation method of deposits it is possible to use pictures of satellites which give the evident image of a problem. Thus, it is possible to consider invisible from a daylight region to a human eye indicator. In general, the environment estimation at influence of activity of mining operations should be complex. All factors, such both physical and mechanical properties of ore and soils, and the main stresses and deformations in a massif that will give the chance to apply safely at mining of mineral deposits the combined way should be considered.

Conclusions

For the purpose of definition of the basic dependences between indicators of interaction of a mining iron ore mines on environment Kryvyi Rih iron ore basin and financing in nature protection functionality, had been applied the multifactorial form, as factorial signs key parameters of activity of factories have been accepted, including the stored volume of overburdens, volume of washery refuses and harmful impurities which gets to air, considerable failures of the earths, capital investments into ecology of extracting areas and other. It has been calculated plural a determinant which has made $R^2 = 0.9974$ and a multidimensional indicator of connection which is equaled accordingly $R = \sqrt{0.9974} = 0.995$. Calculations have shown that results were approximately 99.74% variability of ecological expenses speaks change of factors which

influence surrounding habitat, and the rests – action of not considered factors are calculated in the presented form. In the future transitional technologies with formation of an underground extracting complex in a pit wall and separately under a bottom of working opencast will be investigated and developed. It is confirmed, that combined open-underground, and in the future exclusively underground mining allows to reduce on the average on one opencast opening volume to 2.5-6.5 million m^3, considerably to reduce factor of opening with 3.0-3.5 to 0.1-0.2 m^3/tonnes, to lower a production cost on 35-55%, to increase by 20-35% profit. Except material advantages, improvement of an ecological condition of a daylight region of basin and cleanliness of air in areas of transition to complex technologies of mining operations. The further research will consist in definition of dependences of the main indicators of stresses and deformations in an opencast operative range at transition to an underground mining magnetite quartzites chamber mining methods with the combined backfill. Researches of the is intense-deformed condition of rock massif of an open-pit field will be carried out at mining operations by exclusively open-pit way.

Acknowledgements

None.

Conflict of Interest

None.

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Аналіз та проблеми світового практичного досвіду з видобутку корисних копалин комбінованим відкрито-підземним способом

Анотація. Метою даної роботи були розгляд та аналіз світової практики з видобутку корисних копалин комбінованим відкрито-підземним способом з подальшим обґрунтуванням його застосування на гірничих підприємствах Кривого Рогу. Використані наступні методи: аналіз практичного досвіду з видобутку корисних копалин комбінованим відкрито-підземним способом найвідоміших світових рудників; узагальнення недоліків техногенно-деструктивних технологій відкритого видобутку залізорудної сировини та сучасних екологічних проблем відкритої розробки корисних копалин; проведено розрахунки багатофакторної структури залежності в роботі гірничорудного підприємства на екологічні втрати; методи аналізу. Встановлено, що необхідна розробка комплексної стратегії переходу з існуючої відкритої технології видобутку сировини на технології відкрито-підземного та підземного видобутку корисних копалин з врахуванням напружено-деформованого стану гірського масиву. Встановлено залежність між показниками видобутку залізної руди на гірничорудних комбінатах та витратами в навколишнє середовище. Результати виконаних розрахунків свідчать, що 99,74 % варіативність екологічних витрат пояснюється зміною факторів, що впливають на навколишнє природне середовище, які розраховані в представленій структурі та інші залишки – дією неврахованих чинників. В роботі досліджено та розроблено перехідні технології з формуванням підземного видобувного комплексу в борту кар'єра. Виконано огляд та аналіз проблем переходу від видобутку корисних копалин відкритим способом на технології комбінованого відкрито-підземного й підземного видобутку залізорудної сировини. Встановлено, що при перспективному плануванні розвитку гірничодобувних підприємств на майбутнє слід віддавати перевагу комбінованому, або підземному способу розробки. На основі практичного досвіду світових рудників з комбінованим видобутком розроблено комплексну стратегію переходу з існуючої відкритої технології видобутку сировини на технології відкрито-підземного та підземного видобутку корисних копалин з врахуванням напружено-деформованого стану гірського масиву. Практична значимість полягає в розробленні оптимальної технології в майбутньому з врахуванням встановлених недоліків та проблем застосування комбінованого відкрито-підземного способу на світових рудниках для умов Криворізького залізорудного басейну

Ключові слова: технологія; дослідження; відпрацювання; розробка; руда; схема