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INNOVATIVE STRATEGY TO MINE FLOODED FIELDS

Abstract. Currently, strategic mineral mining in Ukraine is restricted by various factors. One of them is the excessive water content of an open pit or its previous 'wet' temporary abandonment. Analysis of earlier studies has shown nonavailability of sufficiently grounded engineering decisions as for the development of such deposits consisting of hard rocks. Consequently, in the context of excessively watered of previously waterlogged deposits, it is quite actual to solve the problem of efficient quarry water control. The paper emphasizes the legal prohibition of the direct open pit water discharge into surface water bodies as well as onto a terrain.

The research purpose is to substantiate both strategy and engineering decisions concerning partial quarry reclamation for further resumption of commercial mining. It has been demonstrated that if there are no empty reservoirs with the capacity being sufficient to settle open pit water before its discharge, it is required to make new storage tanks for the deposit drainage. Pit edge water settlers are proposed for round quarries; if open pits are of the stretched shape, it is expedient to construct the dam from bottom dividing the bottom into a reservoir for quarry water settlement and a free area for future mining. Pit edge water settler needs doubling and tripling of benches to form a larger operational site. In this regard, the tanks should be enclosed to avoid water penetration into the rock formation. To make a reservoir at a quarry bottom under conditions of its flooding, it is required to calculate the required dam height, which would be expedient to build the structure using overburden rocks; the procedure should be performed within an area preventing from the mineral preservation. In this context, both the accumulated water and the current inflow must be taken into consideration.

The proposed strategy of the watered deposit was applied for Zavallia graphite field quarry which bottom is flooded. The suggested approaches will help extract up to 3.5 million cubic metres of graphite ore, i.e. almost 462 thousand cubic metres of graphite.

The innovative strategy will make it possible to substantiate engineering solutions for other flooded or watered deposits.

Keywords: quarry, watered deposits, mining schedules, dam, inflows.

1. Introduction

Open pit mining often involves a problem when mine workings are flooded by underground water since the quarry turns out to be submerged; in the future, it will complicate mineral mining or make it impossible.

Sometimes, while opening an aquifer, relying upon economic expediency at that time, decisions are made to submerge the quarry. However, if circumstances change and available reserves being under the water, the necessity arises to restart mining operations.

There are numerous engineering solutions concerning the development of such watered deposits if complete drainage is impossible. Unfortunately, none of them is versatile.

Selection of engineering solutions as for further mining depends upon following factors: occurrence depth of the mineral; inclination angle; thickness of the formation; hydrogeological conditions; rock characteristics; and economic expediency involving environmental aspects.



Analysis of publications. Mine working watering is the factor for surface and underground mining restricting development and affecting negatively the operational safety. Hence, the tendency involves numerous studies; the majority of them focus on problems of the predicted inflow modelling as well as rock mass drainage [1–10]; prevention from mine working flooding [11–17]; and watering influence on the stability of mine workings [18–21]. Many authors consider engineering solutions if complete drainage is impossible.

Paper [22] substantiates economically five basic mining schedules for the flooded deposits (titanium-zirconium fields are meant) including formation of dewatering wells; water-resistant walls; or use of hydromechanized mining system with an ore bed separation into enclosing rocks and heavy ore.

Paper [23] proposes a method of surface mining of the watered deposit; however, soft rocks are meant (in terms of Novo-Dmytrivka brown coal field). Opening as well as mining of each new level is proposed to be performed using bottom digging excavators with rock transportation by means of belt conveyors if trucking is impossible.

Paper [24] proposes early dewatering trenching helping shape a depression cone with further mining of the drained field.

Paper [12] suggests deposit draining through multilevel system of deep wells.

Paper [14] proposes to catch water beyond open-pit boundaries by means of well system and canalizing to avoid the quarry watering.

Authors of paper [11] consider waterproof barriers as the most efficient solution to prevent from an object flooding.

Paper [17] shows that the heaviest quarry watering takes place at the expense of rain water; consequently, catch water canal should be constructed along the open pit contour.

Paper [25] demonstrates efficient operation schedules to mine water-bearing placer deposits where the open rocks are of great thickness; the basic characteristic features of the flooded placer deposits; and relevant scientific principles to select adequate technological schemes. Paper [26] represents operation schedule for water-bearing placer deposits with the use of dredgers in terms of Motronivsky MPP. Authors of paper [27] propose a technique to mine water-bearing titanium deposits involving underwater extraction of ore sand, and its hydrotransportation to a floating preparation plant of rough concentrate.

Paper [28] proposes the developed method of underwater sand mining for river and marine conditions making it possible to mine deposits with complex structure while minimizing environmental harm, and decreasing the specific cost of mining operations.

Patent [29] illustrates a system of surface mining of water-bearing sedimentary deposits. The system includes the deposit separation into extraction blocks; overburden operations; the phased block-by-block mineral development with the help of a floating hydraulic dredger; slurry with mineral hydrotransportation to a preparation site; separation of various fractions of an end product, and its dewatering by means of mineral-processing equipment as well as depositing sites; loading and

delivery of the end product to consumers; and reclamation of a near-wall area of the quarry basin.

Patent [30] proposes a method for mining a deposit from the surface down to the groundwater level using excavators; below, dredgers are used delivering rock mass to the surface through a pressure line. The deposit drainage is performed simultaneously for further extraction.

The reviewed scientific sources reduce all alternatives to underwater mining; unfortunately, the abovementioned is possible only for soft rocks occurring at a depth of 15–20 m.

Hence, it is quite topical to substantiate engineering solutions as for water-bearing quarry mining where rocks occur.

Purpose of this research is to substantiate the strategy and technological solutions concerning partial drainage of an open pit for its further development.

2. Methods

In this study, both theoretical and empirical examination techniques were applied, namely analysis, synthesis, scientific data generalization, observation of the specific object, engineering solution modelling, and analytical models to substantiate the model.

3. Results and discussion

Surface mining is followed by opening of one or several aquifers. Hence, a design stage should involve both the efforts connected with water removal and the engineering solutions to collect and remove both underground and atmospheric water from the worked out quarry space.

Nevertheless, there are many flooded open pits with commercial reserves of minerals.

The quarries were flooded relying upon following reasons:

- operational shutdown of mining;
- opening of thick artesian aquifers;
- incorrect design of water removal;
- river water inrush into an open pit; and
- stoppage of mining operations as inexpedient for the certain time period, and ‘wet’ temporary abandonment.

However, after some time, the decision may be made to resume mineral mining through re-activation of the open pit.

Under these conditions, the problem arises of the quarry draining to enable mining. The issue is extremely topical if promising and valuable minerals are under the flooded bottom.

First, a quarry flooding can be removed through water pumping. However, according to Article 72 of the Water Code of Ukraine, mine and quarry water may be removed only to the specific tanks where mineralization of the liquid should be reduced using efficient engineering solutions. In accordance with Article 74 of the Water Code of Ukraine, water from settling reservoirs must be pumped out in terms

of the particular procedures agreed with the Regional Public Authorities on the Environmental Protection.

Generally, settlers for quarry water are designed for the specific liquid volume defined relying upon the predicted inflow; nevertheless, the excessive water ingress is ignored. Therefore, the problem arises to have empty reservoir for water pumping from the flooded open pit. The more water is accumulated in the quarry, the larger reservoir is required. Construction of such a surface vessel needs availability of spacious land plot as well as significant financial expenditures. Hence, it is proposed to use a quarry space for the water settler.

Since open pits vary in shape and mining systems, two different concept schemes are proposed to develop empty reservoirs for water:

- a round quarry with a small bottom area and dipping mining systems is suggested to have either one or several reservoirs within a pit wall above the flooding level (Fig.1); and
- a stretched open pit should have such reservoirs at a bottom through its division into two/three parts by means of a dam (Fig.2).

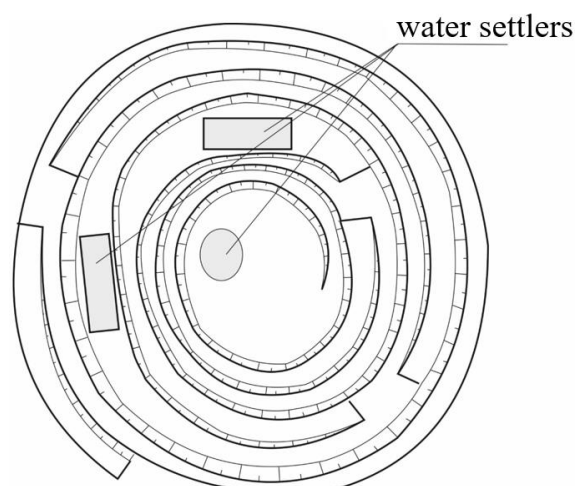


Figure 1 –Concept scheme to arrange water settlers in a quarry

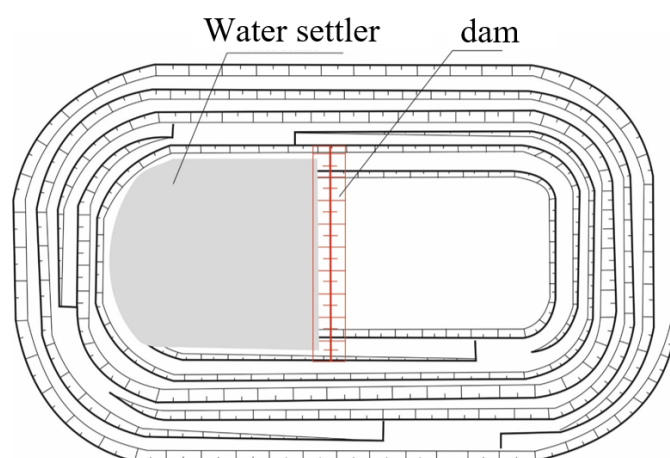


Figure 2– Concept scheme to divide a quarry into parts with the help of a dam

If a reservoir is at the quarry bottom, then it is necessary to identify a dam height h . If an open pit envelope is assumed as the truncated pyramid, then

$$h = \frac{3V_{res}}{S_1 + S_2 + \sqrt{S_1 \cdot S_2}}, \quad (2)$$

where S_1 and S_2 are areas of the bottom and water surface within the reservoir being formed.

Under a dam formation inside the tank, its useful amount will be decreased by a half of the dam volume V_{dam} . Accordingly, expression (1) will be expressed as

$$V_{res} = V - V_{av} + V_{cur} + 0,5V_{dam}. \quad (3)$$

Consequently, while computing the reservoir volume and a dam height being interdependent values, it is necessary to apply gradual approximations.

Zavallia graphite integrated works may be an example of such a flooded quarry where graphite being the strategic mineral is in its submerged part which amount can provide extraction for many years.

In accordance with geological survey, Zavallia field contains two ore zones – southern and northern [31, 32]. South-eastern site is mined. The rocks stretch north-westward. Inclination of ore bodies and barren ones is of subvertical type. Such conditions need the quarry deepening to mine commercial reserves inside.

However, due to numerous economic and process factors, up to the year of 2010, the quarry bottom turned out to be flooded by underground water down to -15.0 m (Fig.3); only upper layers were mined.

As of 2025, further graphite mining needs the open pit drying.

Geological and economic assessment identified eleven ore bodies within the quarry. The most promising ore bodies occur within western and eastern shares of the open pit (Fig. 4).

The open pit is of a stretch shape; its dimensions are 2000×600 m; and its depth is 170 m. Enclosing rocks are solid; hence, the ores are mined using drilling-and-blasting. Almost 2.2 million cubic meters of water are accumulated in the quarry.

Relying upon the abovementioned features, it is proposed to divide the open pit with the help of a dam (Fig. 5) using overburden rocks and the current techniques for dam strengthening. It is the most expedient idea to construct the dam almost centrally closer to east; the placement is defined by geological structure as well as occurrence of the promising ore bodies. Precisely such a dam location will help extract more graphite ore. It is also suggested to fill eastern part with water, and dry up the western one. In this regard, the key issue is a small volume of the available water settler being about 12 thousand cubic meters. In addition, almost 0.6 million cubic meters of water from the quarry can be transferred to a preparation plant and a tailing pond. Consequently, nearly 1.6 million cubic meters of water should be placed in the quarry.



a) as of July 2007



b) as of September 2025

Figure 3 – Zavallia graphite quarry location (the image was downloaded from Google Earth app)

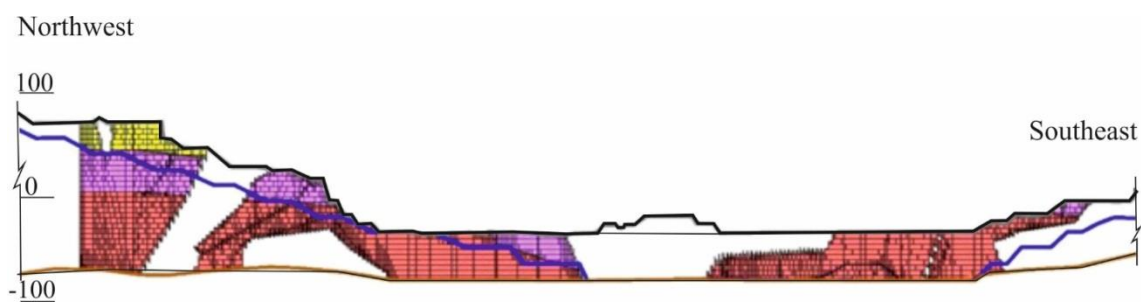


Figure 4– Occurrence of the ore bodies within the quarry (longitudinal profile) [32]

Calculations by expression (2) specified that 40-m dam height is quite sufficient. To prevent reliably from water inrush, it is proposed to construct a dam which width on a crest is 4 m; and foundation width is 120 m. Taking into consideration the fact that within the area of a dam construction, bottom topography has a 12.5-m ridge,

27.5 meters more should be dumped. Figures 5 and 6 illustrate graphically the proposed approach.

According to the offered solutions, it is possible to mine almost 3.5 million cubic meters of graphite ore or 462.0 thousand tons of graphite.

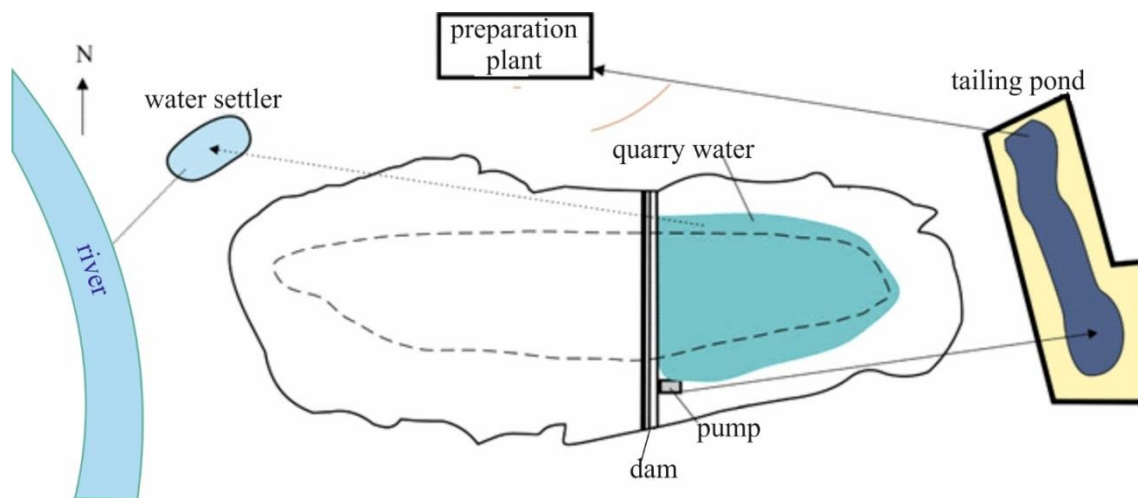


Figure 5–Illustration of the offered solutions for Zavallia graphite integrated works quarry

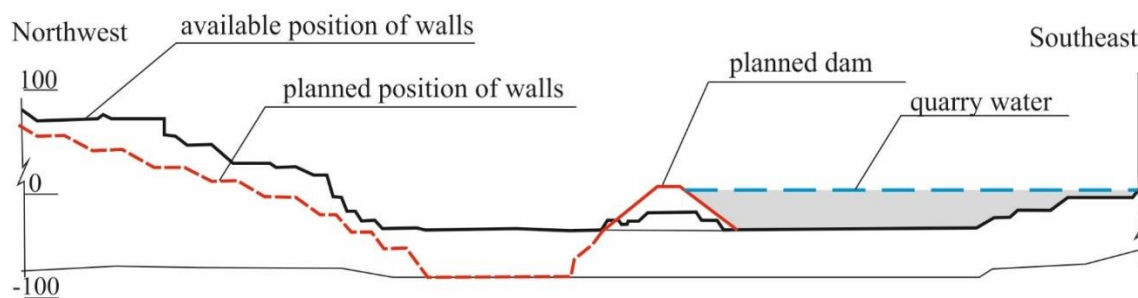


Figure 6– Illustration of the offered solutions for quarry of the Zavallia graphite integrated works in longitudinal section

4. Conclusions

Currently, surface mining of flooded deposits needs their partial or complete drainage for further extraction.

Taking into consideration the requirements of the actual environmental legislation, water should be transferred to the specific reservoirs according to the individual procedures to decrease water mineralization.

To solve the problem of water pumping from the submerged quarry without construction of a surface reservoir, which would take into consideration both predicted and excessive inflow, several alternatives are proposed to build a water settler inside an open pit; the abovementioned will make it possible to refuse from the involvement of additional space and reduce financial costs.

Depending upon the shape of a quarry, it is proposed for a round open pit to construct water settler within its walls; in turn, it is expedient for the stretched quarries to have a dam at its bottom to divide it into a tank for open pit water accumulating and settling and an area for mining operations.

The expressions are proposed to calculate the required tank capacity as well as a dam height.

While constructing water settlers within the quarry walls, it is suggested to double/triple benches for a larger field formation; in addition, the reservoirs should be shielded.

The tank formation at the flooded quarry bottom must involve calculation of a dam height (it will be constructed using overburden rocks). The dam has to be built within the area where the structure will not lead to the isolation of mineral reserves.

Implementation of the innovative strategy will help substantiate engineering solutions for various submerged and flooded deposits.

Process solutions are developed for Zavallia graphite deposit. They will help extract additionally up to 3.5 million cubic meters of graphite ore being almost 462 thousand cubic meters of graphite.

Conflict of interest

Authors state no conflict of interest.

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ІННОВАЦІЙНА СТРАТЕГІЯ ОСВОЄННЯ ОБВОДНЕНИХ ПОКЛАДІВ

Четверик М.С., Бабій К.В., Бубнова О.А., Левченко К.С., Рюміна Д.М.

Анотація. В умовах сьогодення виймання стратегічних корисних копалин в Україні обмежено різними факторами. Одним із таких факторів є надмірне обводнення кар'єру або його попередня «мокра» консервація. Аналіз попередніх досліджень показав відсутність достатньо обґрунтованих технологічних рішень щодо освоєння таких родовищ, складених міцними породами. Тому для родовищ, які надто обводнені або попередньо затоплені, актуальним є вирішення питання ефективного поводження з кар'єрною водою. У статті наголошується про законодавчу заборону прямого скидання кар'єрних вод у поверхневі водні об'єкти та на рельєф місцевості.

Метою роботи є обґрунтування стратегії та технологічних рішень щодо часткового осушення кар'єру для подальшого відновлення його промислової розробки. Показано, що за умови відсутності вільних ємностей достатньої ємності для відстоювання кар'єрних вод перед їх скиданням, для осушення родовища необхідно створювати нові ємності. Запропоновано для кар'єрів округлої форми формувати водовідстійники на бортах, а для витягнутих кар'єрів — на дні, шляхом спорудження дамби, що поділить дно на ємність для збору та відстоювання кар'єрних вод та вільну ділянку для подальшого розвитку гірничих робіт. Для створення

водовідстійників на бортах кар'єрів пропонується подвоювати або потроювати уступи з метою формування більшої робочої площадки, при цьому самі ємності необхідно екранувати для запобігання фільтрації води в масив гірських порід. Для створення ємності на дні кар'єру в умовах його затоплення запропоновано розрахувати необхідну висоту дамби, яку доцільно формувати з порід розкриття у місці, що не призводитиме до консервації запасів корисної копалини. При цьому необхідно враховувати не лише накопичені об'єми води, а й поточні водоприпливи.

За запропонованою стратегією освоєння обводнених родовищ розроблено технологічні рішення для умов кар'єру Заваллівського графітового родовища, дно якого затоплено. Запропоновані рішення дозволять додатково вилучити до 3,5 млн. м³ графітових руд, що становить близько 462 тис. м³ графіту.

За інноваційною стратегією можна обґрунтувати технологічні рішення для інших затоплених або обводнених родовищ.

Ключові слова: кар'єр, обводнені родовища, схеми розробки, дамба, водо припливи.