Opening-up of mine reserves in combined development of marble deposit

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Abstract. The article describes the opening-up methods in the combined development of facing stone deposits. It describes the indicators affecting the application of a certain opening method and features of this process in the conditions of the mine “Doverie” with different ratios of production capacity for open and underground mining.

1. Introduction
To ensure the operation of stone-cutting, mining, transport and other types of equipment, in the process of mining of mineral deposits, it is necessary to ensure the mine opening stage or its part, i.e., stocks to be processed at this given period [1, 2].

The opening method should ensure safe working conditions and a required production capacity of the mine with a minimum size of opening workings, capital costs of field opening and mine construction [3].

During open pit mining, the opening is carried out by inclined permanent trenches, half-trenches, and trenchless techniques (opening by pits) [4-7].

In the underground mining method, the opening is carried out by vertical and inclined shafts, adits and their combinations [8-10].

In case of the mountainous terrain, they often use adits, which can be driven in minerals and rocks of the foot and side walls across and along the strike of the field.

When penetrating the adit across the strike, it is positioned so that the ore body is above its level [11, 12].

When using adits in the steep mine, if the adit is parallel to the strike of the field, it is mined depending on the strength and stability of the rocks, the conditions of further development in the foot and side walls.

In the development of facing stone deposits, the section of the mine opening is much smaller and is determined mainly by mining and transporting equipment - wheel loaders and excavators. At the same time, the physical-mechanical properties of the rocks ensure the stable condition of the roof without additional roof bolting support [13-15].

The opening method influences the economic efficiency of mining, determining the volumes of mine openings, the initial capital expenditures for mine construction, the period of construction, the efficiency of technological transport, the method of ventilation and labor safety [16-20].

The opening of oil shale deposit in the Leningrad Region was done using vertical shafts; they also extract by-product limestone blocks from the host rocks. In Italy, at the Cavomontive mine in the province of Lecce, the travertine deposit was opened by a vertical shaft (3 m in diameter and 40 m deep), as it approaches the production area is gradually shaped up to a square section with a side of 5 m.
Opening by inclined shafts is less common and is used when the production layer does not have access to the surface, but some parts occur close to it (the Okninskaya limestone mine in Moldova, etc.). During the extraction of Moselle shale at the Katzenberg mine (Rathscheck Schiefer und Dach-Systeme KG, Germany [21]), the blocks are delivered to the loading platform along an inclined spiral ramp with a 15° gradient.

The Lengefeld mine (Geomin Erzgebirgische Kalkwerke, Germany [21]) develops a dolomite marble deposit; the mine was opened with a vertical shaft and an inclined ramp for self-propelled machinery.

A significant number of the sawn and facing stone deposits are located on slopes with a difference in elevation of up to several tens of meters within site; the method of opening by horizontal adits was widely used as the simplest and most economical - it provided short construction time and small capital expenditures on opening workings. At the same time, underground and surface transportation used the same type of equipment.

If a part of the deposit is mined by a quarry, then it is rational to open the mine directly from the side of the pit using the shaft; in this case, there is no need to prepare special banks and access roads.

2. Materials and methods
When developing marble deposits, the following technical and economic indicators have a great influence on the efficiency of underground mining [1]: the cost of building transport communications, as well as creating the necessary dimensions of the working area of the mine; specific and total costs for mining operations; block output ratio; the cost of mining blocks.

According to Yu.I. Mikhailov [22] abroad they use the room method in underground mining of blocks, leaving support pillars, the chambers are 7–8 m wide and 3–4 m high. At the “Doverie” mine they also use a chamber development system with rib pillars, the width of the chamber is 10-15 m, and height is 4.5-6-18 m.

When designing the “Doverie” mine for the development of the second geological section of the Kibik-Kordonsky marble deposit, they adopted the opening scheme with three shafts with a central location of the main and flanking location of the ventilation shafts in the flank ventilation scheme. The opening of the reserves of the next levels will be carried out by adits, passed from the benches of the pit (Fig. 1).

![Figure 1. The layout of the first level of underground mining of “Doverie” mine](image)

1 - shaft, 2 – currently mined chamber, 3 – ribpillar, 4 – opening shaft, 5 – portal, 6 – ventilation shaft

The parameters of the shaft should provide continuous transportation flow between underground and surface structures; therefore, its width should be at least the width of a single-lane road, and the height should be at least the height of the bench. The transportation scheme is shown in Figure 2.
Figure 2. The marble blocks and crushed stone transportation scheme in the workings of “Doverie” mine.

The choice of the location of the mining and development workings is based on the geology of the marble deposit, as well as the fracturing of the marble rock mass, within which it is preferable to have these workings.

The mine uses a single and two-stage block mining technology. The single-stage technology is used in heading opening and development workings, and the two-stage technology is used for stopping of the chambers.

When opening from the pit wall, they initially make the first working with height from 2-3.5 to 5-6 m, followed by head-and-bench mining operations in the underground area. The excavation is carried out by bar cutters, wire saws or their combination.

The combined development method involves underground and open-pit mining in interdependent (IWA) and independent working areas (INWA) (Fig. 3).

Figure 3. Schemes of the combined development of a marble deposit with IWA (a) and INWA (b): 1 and 2 – current status of mining at the end of the development; 3 – temporary pillars in the mine for sliding ramps; 4 – a pillar for loading area; 5 – dip

The combined technology with IWA is widely used in the development of marble deposits in Italy, where the quarry resembles a shaft with a square section with sides of 50 m and more.

In the case of IWA during open and underground mining (Fig. 3, a) the reduction rates for different methods should be the same. Then the total volume of block production is limited to the least intensive method, the nature of the deposit separation by development methods and the mode of operation of the open-pit mine (year-round or seasonal).
In the case of INWA option (Fig. 3, b) and the seasonal work of the quarry, the cutting is carried out considering the full man and equipment loading during the year and the simultaneous development of the deposit by the open and underground methods. Obviously, in the latter case, greater production capacity will be achieved with less investment.

The inequality in the reduction of mining operations can be caused by the small spatial size of the mine relative to the quarry; it can also be due to increased productivity in large blocks of marble with palettes that are in demand in the stone market. An important role is played by the meteorological conditions of the area, because of which there can be downtime in the quarry, and consequently, a decrease in productivity.

The independence of the working areas is ensured by the establishment of a transfer area located on temporarily abandoned in the bench stocks of marble (Fig. 4). In this case, the independence of the working areas allows the mine to continue to work during the period of seasonal mine downtime, and, thanks to the advance opening of the lower mine levels, to place mining complexes from the pit.

![Diagram of the transfer area at the beginning of the deposit development](image)

**Figure 4.** Schematic diagram of the transfer area at the beginning of the deposit development: 1 - a platform for the installation of a derrick crane; 2 - opening semi-trench; 3 - opening adit; 4 - ventilation shaft; 5 – transfer area; 6 – quarry

While using the combined development method with independent working areas (IWA), it is necessary to preserve the mine opening from the pit walls by reloading blocks and crushed stone to the external wheel transport.

When developing a field with INWA the following pattern of opening and mining of the second and subsequent levels is possible.

Initially, they mine the shaft from the floor of the first level along the minefield till the marked floor of the second level. Then, from this position, horizontal workings pass through the minefield, providing the shortest access to the location of the next transfer area in the quarry. The working directly facing the transfer area is the opening one. Further, the mining front develops to the flanks of the minefield with the advancement of the faces near the boundary of the quarry field. This development allows in the shortest possible time to pass two more ventilation shafts on the flanks of the field and to carry out, if necessary, simultaneous work on two floors. Until the open mining reaches the level of workings passed from the minefield to the open pit, the rock mass is delivered from the mine by wheel loaders to the existing transfer area. After that, they can start removing pillars supporting the transfer area. Further, using a system of sliding ramps (Fig. 5), mining operations in one part of the minefield are intensively reduced to create the conditions necessary for the excavation of underground workings, which, by analogy with the above, ensure that the next floor is opened.
The implementation of the proposed technological scheme will provide approximately the same intensity of the reduction of mining operations in the open-pit and mine. It will already be justified at the stage of dividing the marble deposits into the working zones. At the same time, due to the seasonal work of the quarry and independent working zones, reducing the mining operations in the quarry does not limit the production capacity of the mine and allows you to fully utilize the equipment and personnel.

3. Conclusion
Analysis of mine opening techniques in the combined development of marble deposits, taking into account the nature of their relief, has shown that to ensure work in the mine and open-pit, it is advisable to open the mine reserves with adits from the pit walls, and it is necessary to develop measures to ensure the transport of bottom faces with points of discharge of rock mass on a surface. So, when developing with the INWA, a transfer area is formed in the quarry. Moreover, with IWA the “chess” layout is used for mining trenches (pits) from flank to flank when reducing mining in the quarry, the values of the reduction rate will be similar for underground and open mining operations.

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