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*Perspective*

# Access to Deposits as a Stage of Mining Works

**Krzysztof Skrzypkowski [1,*], Krzysztof Zagórski [2], Anna Zagórska [3] and Fhatuwani Sengani [4]**

1 Faculty of Civil Engineering and Resource Management, AGH University of Science and Technology, Mickiewicza 30 Av., 30-059 Kraków, Poland
2 Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology, Mickiewicza 30 Av., 30-059 Kraków, Poland
3 Research Centre in Kraków, Institute of Geological Sciences, Polish Academy of Science, Senacka 1, 31-002 Kraków, Poland
4 Department of Civil Engineering and Geomatics, Faculty of Engineering and the Built Environment, Durban University of Technology, P.O. Box 1334, Durban 4000, South Africa
* Correspondence: skrzypko@agh.edu.pl

**Abstract:** An extremely important role in the underground method of mining deposits is the type of access, which is the initial stage of the mining operations. The main feature of mineral deposits is their exhaustiveness and the inability to restore resources. This necessitates the rational management of deposit resources, especially the minimization of resource losses during exploitation. This article presents information on the mining area and methods of access the deposits. In particular, attention was paid to the advantages and disadvantages of access by means of an adit, decline, and a vertical and inclined shaft. Given the relationships among the various stages of mining works, it was found that the number of active levels depends on the volume of production and the adopted mining methods. In addition, attention was drawn to the fact that the access to deposits at increasing depth is related to the intensification of natural hazards that affect the access structure.

**Keywords:** mining area; access excavation; mining level; shaft; inclined shaft; decline; adit

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## 1. Introduction

Mining engineering is a field of science that includes work related to the exploration and recognition of a deposit and its access, preparation, exploitation and processing. More and more often, underground workings are used as hydrocarbon stores and for waste storage. The methods of obtaining raw materials can be divided into: underground; opencast; borehole; from the seabed [1]; from anthropogenic deposits [2]. It is worth mentioning that more and more raw materials (metals) are obtained from urban mining [3,4] and that a new field of science related to the exploitation of deposits in space is developing [5]. Among the methods mentioned, most of the workings are carried out in underground mining, and this trend will continue because shallow deposits, after reaching the maximum level of the floor, are transferred to underground mining [6,7]. An extremely important aspect when making a decision to continue exploitation is the model of the deposit [8] along with the estimation of the amount of resources that will be extracted to the ground surface by means of access workings. Hou et al. [9] stated that access layout optimalization can be treated as a network flow and should consider shortening the length of excavation and reducing the transportation distance. Musingwini [10] found that mine planning takes into account three phases: development layouts, production scheduling and equipment selection. Bołoz [11] noticed that improving the efficiency of the access workings execution is possible through the use of automation and robotization. Afum [12] determined that in order to make the deposit available, it is worth using computer-aided design, with the help of which it is possible to select the place of the deposit opening. Sirinanda et al. [13] pointed to the optimal access point, taking into account net present value.

*Mining Area*

The first step in setting up a mine in a place where there is a deposit that has been examined and considered suitable for favorable exploitation is to open access to the deposit, i.e., to make it available. Access to the deposit or part of it is understood to mean the performance of the main workings connecting the deposit with the ground surface. For each mine, a mining area is established, i.e., a space within which the entrepreneur is authorized to search for, identify and extract useful minerals covered by the concession. With small deposits, the mining area covers the entire deposit. The boundaries of the mining area are the lines on the surface and the vertical planes passing through them, reaching the depth of the deposit, taking into account its shape. The boundaries of mining areas are being adapted to the existing areas, taking into account adjustments according to natural conditions. In the case of deposits located over a large area, the mine field is sometimes defined by natural boundaries (for example: faults, outcrops, deposit deformations, protective pillars). The size of the area is determined so that the mine's useful life allows for the amortization of the costs incurred in its operation. Depending on the size of the deposit, one or more areas are allocated to individual mines for development. For horizontal deposits, the mining area has its width and length, while inclined deposits are characterized by width by extension and height: vertical and inclined. The size of the mining area is influenced by: the method of making the deposit available; number of beds and distance between them; deposit form, thickness, inclination, resources, tectonics, waterlogging, landform; the designed height of the level; projected extraction of minerals; service life; investment outlays and the period of mine construction. Increasing the mining area allows to reduce the depreciation per one ton of excavated material. Exceeding the optimal size of the mining area leads to an increase in transport and ventilation costs. When selecting the optimal size of the mining area, the sum of investment outlays and operating costs per one ton of extraction for which the value will be the lowest is taken into account.

The size of the mining area of a seam-type deposit can be determined by an analytical method [14]. According to the projected extraction and the method of access, with the size of the extraction level and the length of the mining area, the sum of capital expenditure and operating costs per one ton of extraction ($\sum R$) can be determined as a function of the number of levels or fields (n) and the length of the mining area (L) according to Equation (1):

$$\sum R = f(L, n) \tag{1}$$

where

L—length of the mining area;
n—number of levels.

In order to determine the extraction, the deposit utilization factor (η) according to Equation (2) and the dilution factor (ρ) according to Equation (3) should be taken into account:

$$\eta = (1 - 0.01a) \tag{2}$$

where

a—operational losses;

$$\rho = 0.001b \tag{3}$$

where

b—output dilution.

By inserting n = 1–3 and L = 100–1500 into Equations (4) and (5), respectively:

$$\frac{d\sum R}{dL} = 0 \tag{4}$$

$$\frac{d\sum R}{dn} = 0 \tag{5}$$

The number of mining levels corresponds to the current situation in underground hard coal and ore mining for Polish conditions. The length of the mining area was adopted due to the early stage of access works, where the deposit located very close to the shafts is cut.

For inclined and steep deposits, the length of the mining area is assumed with the number of mining levels corresponding to the depth of deposit exploitation (Figure 1).

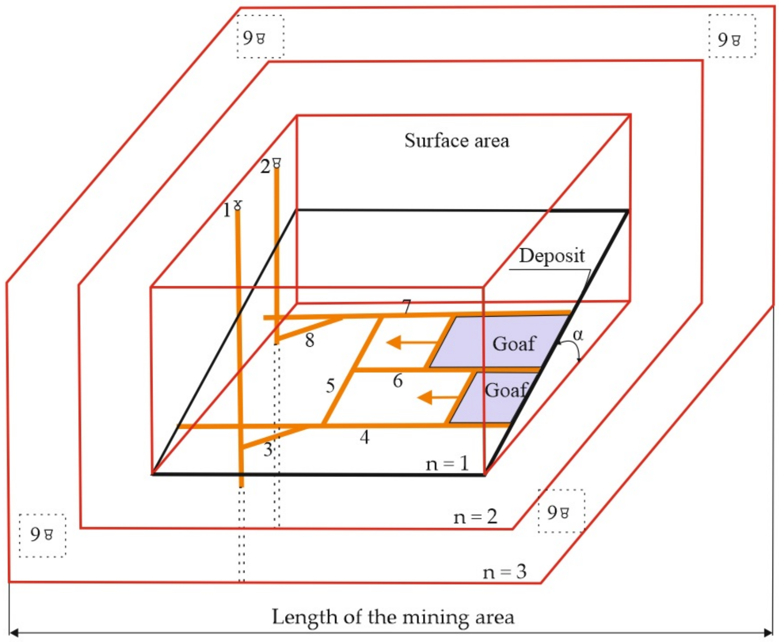



**Figure 1.** Dimensions of the mining area by the following method: n—number of operating mining levels; 1—output shaft; 2—ventilation shaft; 3—crosscut; 4—transportation gateroad; 5—inclined drift; 6—intermine gateroad; 7—ventilation gateroad; 8—ventilation crosscut; 9—ventilation shafts for expanding mining levels; α—inclination.

Individual mining areas are mined in parallel or in series, depending on: the degree of deposit recognition; the demand for a given raw material; the volume of extraction; the amount of capital expenditure and the period of mine construction. Deposits that are incompletely identified with very variable elements (veins) of deposition are made available in series. The areas of precious and rare metals are also exploited in series. With large-scale mining, mining areas can be operated in parallel. The areas of deposits that are insufficiently explored, with low resources and located at shallow depths, are exploited in series. The construction of the mine does not take long then, and the exploitation proceeds quickly. As the deposits are identified during exploitation in one area, the adjacent ones are opened. Inclined deposits running from the outcrop towards the fall are available in series. This direction enables gradual recognition of the deposit.

## 2. Ways of Access of Excavations

In underground mining, unit mines can be distinguished, serviced by two sets of shafts: mining-downhill and ventilation-material. A much more advanced organizational form is a combined mine consisting of several unit mines with independent movements but with a complex of mining shafts and a processing complex common to all mines. Combined mines are built when the mining areas are too large and hence the ventilation and transport roads are too long. Examples of combined mines are Mining Plants: Polkowice-Sieroszowice, Lubin and Rudna located in the Legnica-Głogów Copper District in Poland [15]. Each mine must have at least two connections to the ground surface [16]. One enters the mine with fresh air while the other one discharges exhausted air. The deposit can be accessed by: an adit; decline; vertical shaft; inclined shaft. The choice of the appropriate method of making the deposit available depends on: the topography; the shape of the bed; the thickness and angle of the bed; the size of the deposit and its depth; the nature of the rocks in which the deposit is located, especially the roof rocks (from the top to the surface); and the condition of the groundwater in the place where the deposit is to be made available. In underground mining, two basic access structures can be distinguished: deposit (Figure 1) and rock (Figure 2). In practical solutions, depending on the geological and mining situation, intermediate solutions are also used, with elements of both structures. In the case of low values of the strength parameters of the deposit and rocks directly surrounding the deposit or the occurrence of threats due to uplift of the floor, endogenous fires or rock bursts, it is advisable to limit the duration of the roadway workings in the deposit. In such cases, a rock structure is used, especially in hard rock mining conditions. The rock structure is characterized by a large number of excavations in the rock mass. However, this makes it possible to make the deposit available horizontally in many places and to separate independent exploitation areas (separate ventilation, crew movement, transport of excavated material, delivery of materials, supply of backfilling). In case of spontaneous combustion or roof falls, horizontal mining can be carried out with less disturbance than in the case of the deposit structure.

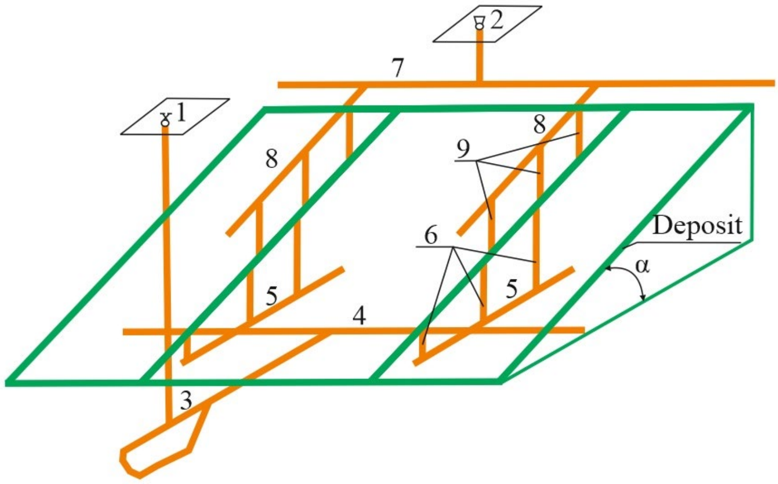
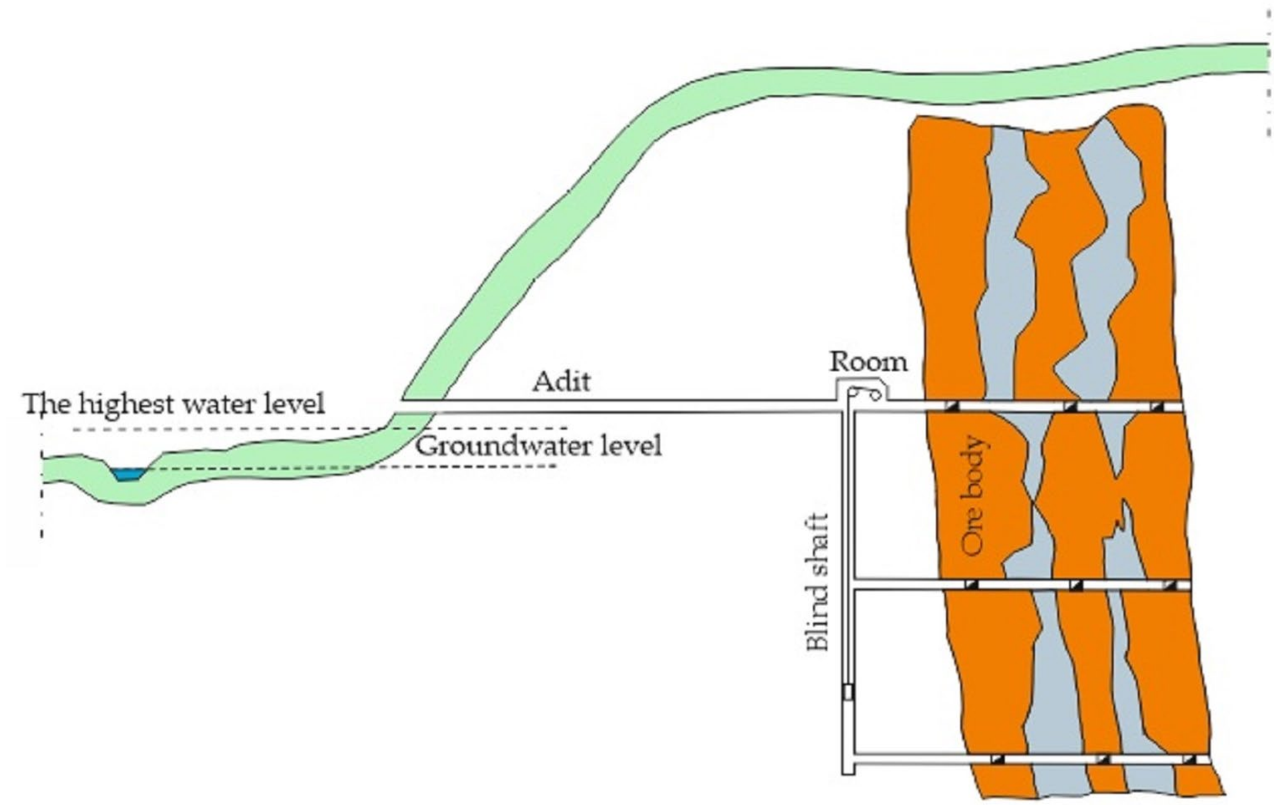


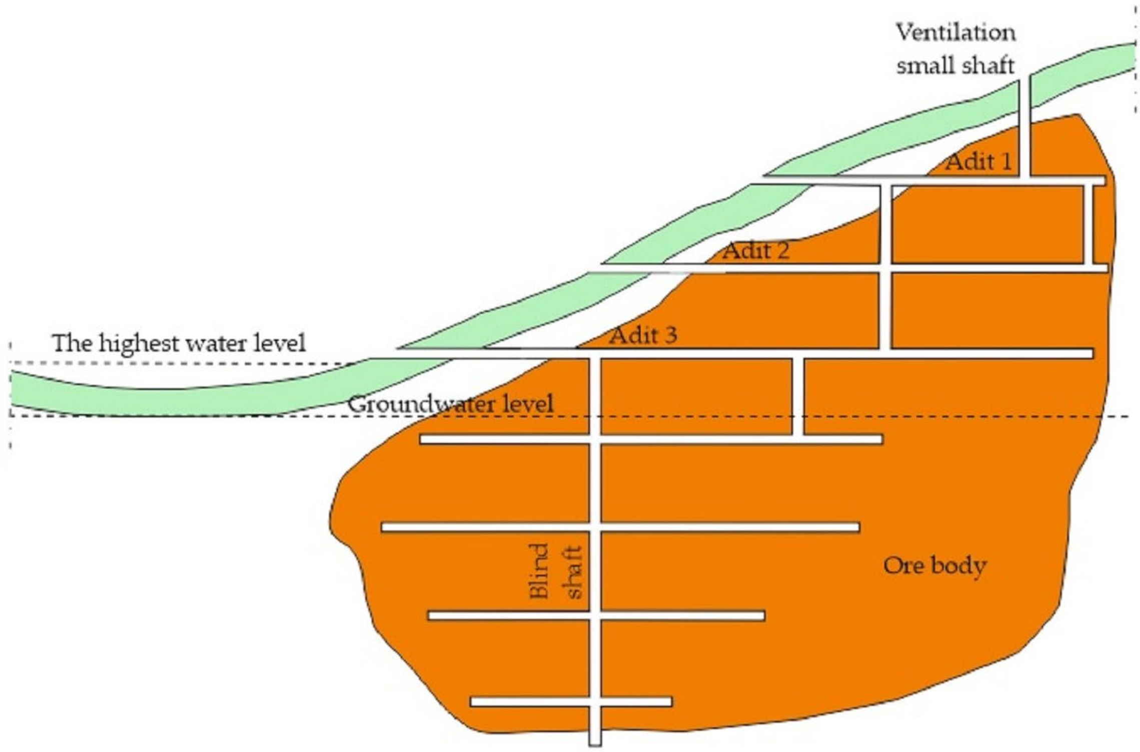

**Figure 2.** Rock access structure: 1—output shaft; 2—ventilation shaft; 3—transportation crosscut; 4—directional rock drift; 5—field rock drift; 6—output (mining) small shafts; 7—ventilation directional rock drift; 8—ventilation inclined drift; 9—ventilation small shafts.

### *2.1. Access by Means of Adit*

The deposit is usually accessed by adits in mountainous or hilly areas. The adit usually opens access to the upper part of the deposit [17] (Figure 3a). The lower the adit on the slope of the hill is located, the greater part of the deposit is available. If the height of the hill is high, several adits can be made [18], (Figure 3b). The mouth of the adit should be above the highest possible water level in the valley during the period of spring thaws, heavy rain or prolonged rains [19]. Failure to do so may lead to the adit flooding. The adit site should be selected so that it is possible to build the necessary mining equipment on the surface, such as a processing plant, baths, warehouses and a convenient rail connection between the mine and the rail network. Depending on the arrangement of the layers and the deposit as well as the topography, the adits can be led perpendicularly to the direction of the deposit's extension or in the deposit along its length. Sometimes, the adits are carried out from the open pit (Figure 3c) to provide access to a part of the deposit lying under a thick overburden, the open pit mining of which is unprofitable, or to make separate deposits available.

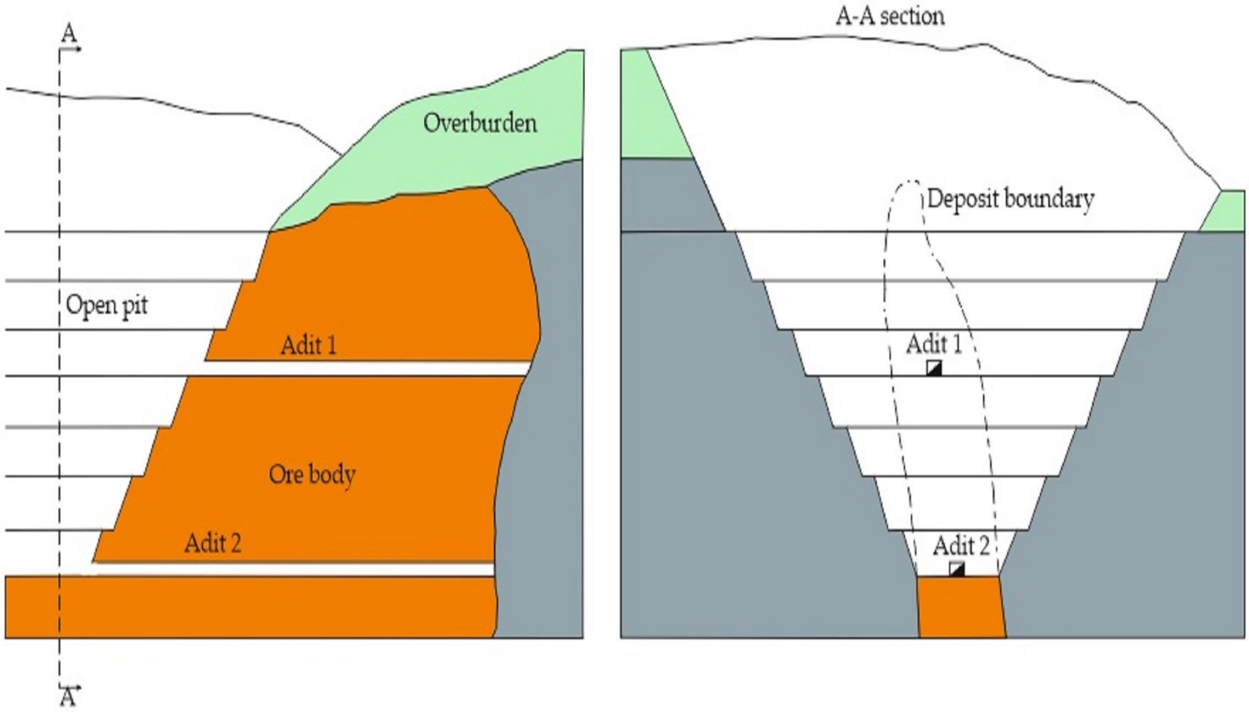



(**a**)




(**b**)

**Figure 3.** *Cont.*



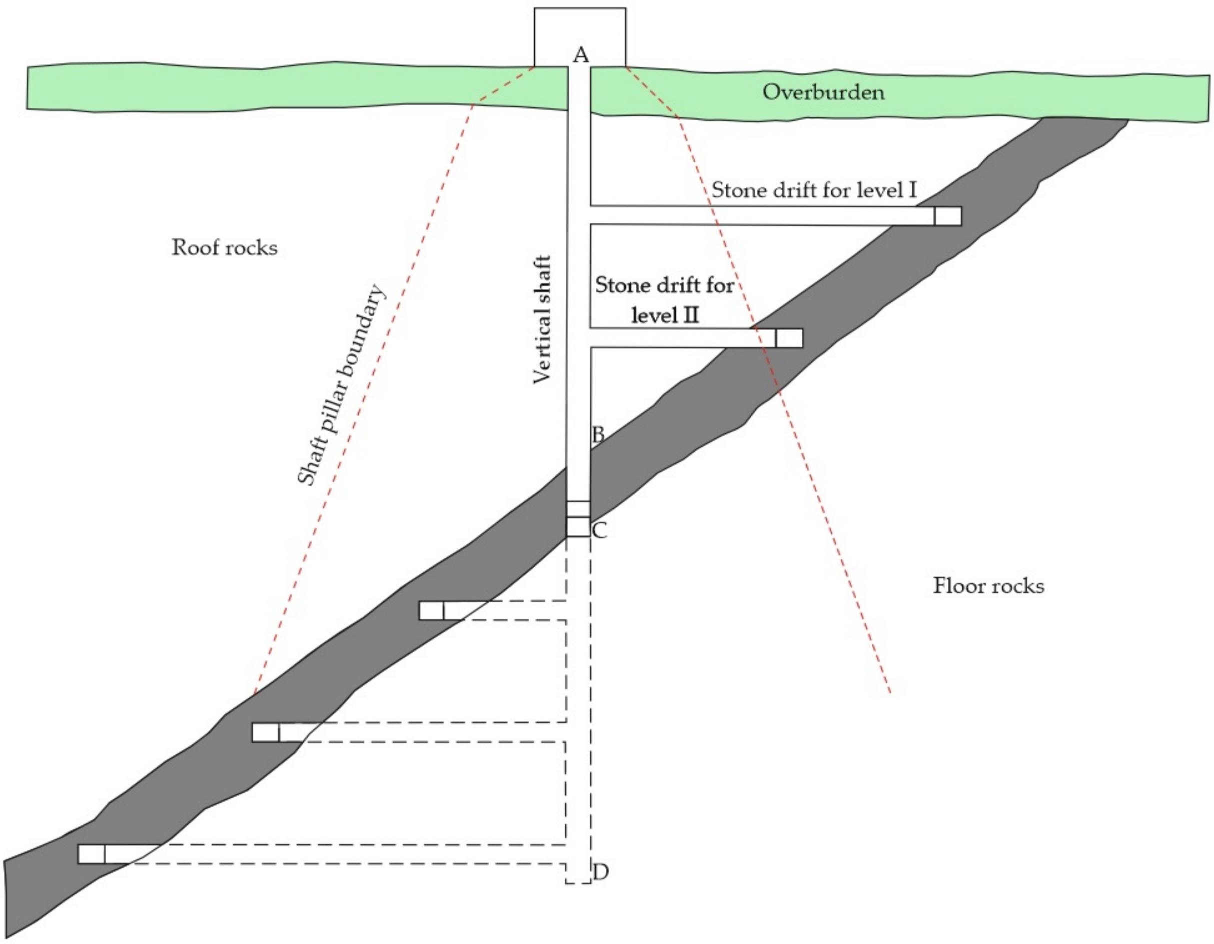

(**c**)

**Figure 3.** Access by means of adit: (**a**) Perpendicular to the strike; (**b**) Several adits; (**c**) From open pit mine.

The part of the deposit below the adit can be accessed with a blind shaft or a vertical shaft hollowed out from the ground surface. A blind shaft is used when the amount of the deposit below the adit is small. Then, the R room is constructed on the drift horizontal, in which the hoisting device is placed. The output is hoisted to the adit, and from there it is transported to the surface. When the resources of the deposit below the adit are significant, and therefore the daily output of the mine is sufficiently large, it is necessary to make larger rooms in order to place the hoisting device at the adit level. Then it may turn out to be more advantageous to hollow the shaft from the surface and install the hoist outside the mine. This solution also has the advantage that the machines on the surface do not wear as fast as underground, especially due to moisture. The output of the adit can be hoisted through the shaft or directly to the surface depending on the terrain conditions. If it is more convenient to locate the mine buildings at the mouth of the adit, the excavated material is hoisted to the adit, and from there it is transported to the surface. Then, usually above the adit, a container for the excavated material is made into which the material taken from the lower levels is poured. The adit becomes particularly important when the water flows into the mine, which saves the energy needed to transport it vertically to the surface. In addition, as a result of the construction of the adit, a part of the deposit lying above the adit is drained, which is a favorable phenomenon for mining.

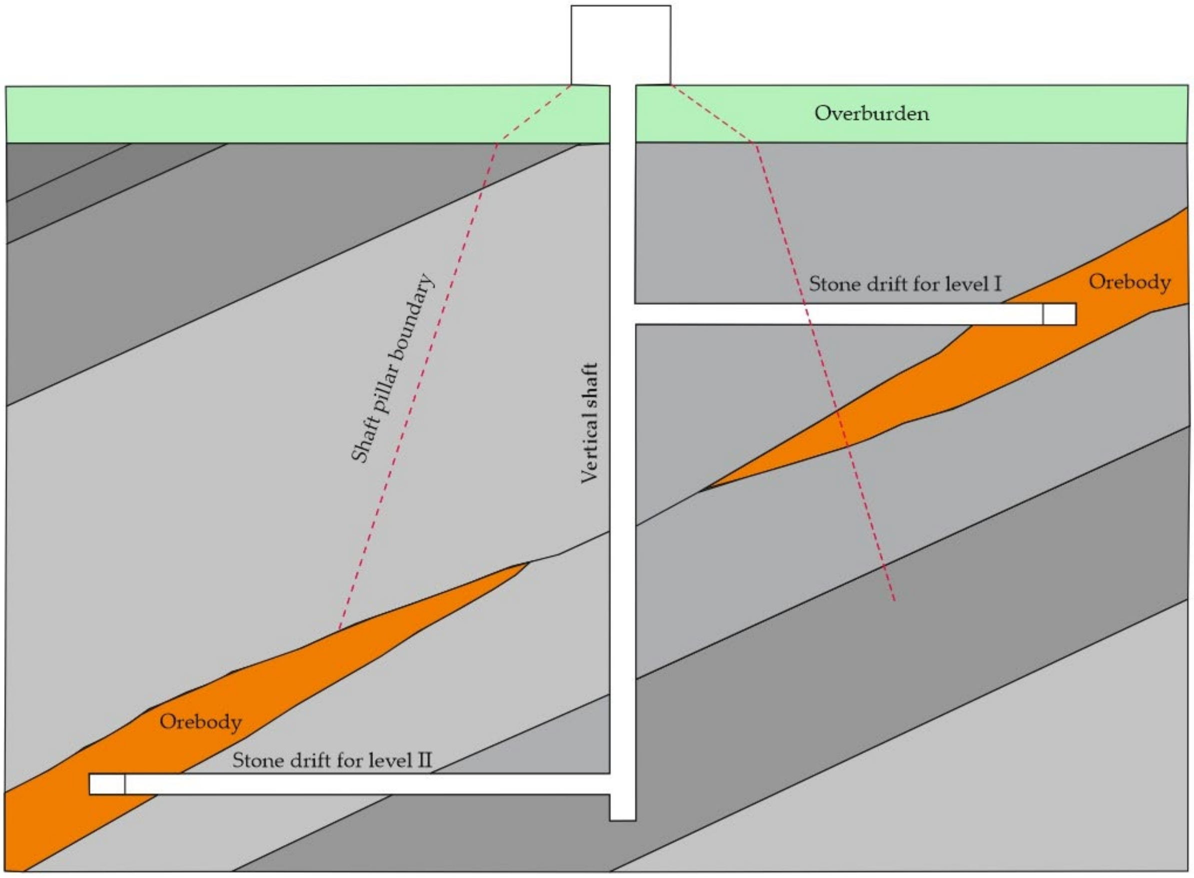
### *2.2. Access by Means of Vertical Shaft*

The most frequently used method of making deposits available is vertical shaft. The place where the shaft is established depends on the shape of the deposit, its size and angle of inclination as well as the topography [20]. It is not recommended to set up shafts in valleys near rivers and water reservoirs that would pose a risk of flooding the shaft. The shaft should be placed rather on a hill, from where it is easy to make rail and road connections with the main communication lines. Horizontal or low-slope on-board beds are accessible only through the vertical shaft, while incline beds require the excavation of stone drift from shaft to bed. If the inclined deck remains over a considerable space, a shaft is installed more or less in the center of the mine field (Figure 4a). Then the shaft passes through the roof rocks (part of the shaft marked with letters A–B), then through the deposit (part of the shaft marked with letters B–C) and then through the floor rocks (part of the shaft marked with letters C–D). The total length of all stone drifts in this case is the shortest. In order to protect the shaft and equipment on the surface, it is necessary to leave a part of the deposit around the shaft that cannot be exploited; this is the shaft's protective pillar. The thicker the bed and the greater the content of, for example, metals in the ore, the greater the losses due to leaving the protective pillar. Therefore, in order to reduce losses, shafts are sometimes located in places of irregularities in the deposit, such as of deformation, thinning or depletion. If the bed falls steeply, then it is more advantageous to locate the shaft outside the bed into roof or floor rocks (Figure 4b). With equally strong rocks in the floor and roof of the deposit, it is better to install a shaft in the floor rocks because it is easier to maintain. The pressure of the breaking rocks on the shaft lining due to the excavation of the deposit is lower in the floor than in the roof. In addition, the operation can be started earlier because the cross-sections of the upper levels are shorter. In order to avoid its destruction as a result of rock movement after selecting the deposit, if the shaft is located in the roof rocks, its distance from the deposit should be greater. The length of the stone drifts is then greater, so later it can start selecting the upper levels, and moreover, the costs of stone works increase significantly. Regardless of this, the movements of the rock mass can cause the stone drifts to collapse, or at least make them difficult to maintain. Therefore, the shaft is sinking out in the roof rocks only when it is impossible to locate it elsewhere, for example, if the floor of the deposit is covered with rocks that are not strong enough and water-bearing.




(**a**)

**Figure 4.** *Cont.*




(**b**)

**Figure 4.** Access by means of vertical shaft: (**a**) With stone drifts; (**b**) Located in the place of thinning out; A,B,C,D—points in the rock mass from which the sections for the roof, deposit and floor are marked.

A vertical shaft with stone drifts is the most appropriate and most frequently used method of making available several decks or steeply lying veins, as well as nest beds consisting of one or more sockets [21]. If the nests are located at different depths, it is necessary to drive shafts from stone drifts. The small shafts should be driven from the lower level to the higher nest, so that the output can be transported. Transporting the output to a higher level is associated with higher costs and then the transport capacity of the small shaft is lower. Therefore, the output is only hoisted when the nest lies below the deepest mining level of the mine. To avoid or reduce losses in the protective pillar, the shafts should be located between the sockets or on the side of the deposit. The advantages of vertical shafts include:

- Keeping the shaft vertical is easier than inclined, as the rock mass pressure on the lining is less;
- The vertical shaft, which accesses the deposit at the same depth as the inclined shaft, has a shorter length;
- The permissible speed of hoisting of output in vertical shafts is higher than in inclined shafts, and therefore the transport capacity of the vertical shaft is higher;
- The rope wear in vertical shafts is smaller than in inclined shafts, where the rope wears very quickly due to friction between the rope and the pulleys;
- The cost of water drainage from the mine through a vertical shaft is lower (shorter pipeline length).

### 2.3. Access by Means of Inclined Shaft

Inclined shafts have an inclination of several to several dozen degrees [22–24]. They are sinking in a deposit (Figure 5a) or waste rocks, most often in floor rocks (Figure 4b). If the rock strength is high and the inclination is solid, then the shaft can be sunk out in the bed. With this method of driving a shaft, the operating costs are reduced, since the output is immediately obtained. Simultaneously with sinking the shaft, it is possible to start preparing the upper parts of the deposit for exploitation. On both sides of the shaft, there is a retaining pillar several dozen meters wide, depending on the strength of the rocks and the length of the shaft. It is associated with significant formation losses, especially in thick deposits. If the bed consists of several decks or veins, it is most advantageous to locate the shaft in the deepest and possibly thinnest deck or vein, since the losses in the protective pillars are then the lowest. With a variable inclination of the deposit, low rock strength or high thickness, it is more appropriate to locate the shaft in the floor rocks. Short stone drifts are driven from the shaft to the deposit (Figure 5b), usually alternately to the left and right of the shaft. This is to increase the vertical distance between the stone drifts. The length of the stone drifts on each level is therefore the same. The transport of the output in the shaft can be carried out in wagons or skips moving on the tracks. In order to prevent the output from falling out of the wagons, especially with a steep inclination of the shaft, cages with a horizontal platform can be used. The disadvantage of this solution is the requirement of a sufficiently large shaft height, which makes it much more advantageous to use a skip that has smaller dimensions for the same capacity.

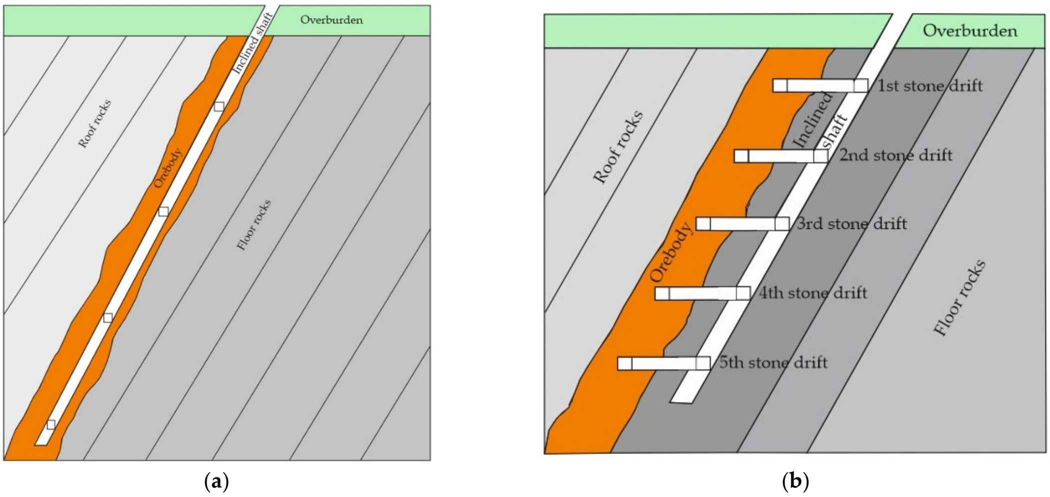



**Figure 5.** Access by Means of Inclined Shaft: (**a**) In the deposit; (**b**) In the floor rocks.

The advantages of inclined shafts include:

- If the shaft is sinking in the deposit, the excavated material is obtained when the deposit is made available, and there is no need to drive stone drifts, which reduces the costs of stone works.
- In the case of driving a shaft in floor rocks, it avoids leaving a supporting pillar along the shaft, and the length of the stone drifts is shorter than in the case of a vertical shaft.
- Faster preparation of the deposit for exploitation.

The disadvantages of inclined shafts are in particular:

- The need to leave support pillars along the shaft, which are usually larger than the protective pillars at vertical shafts. If the deposit consists of several seams or veins, and the inclined shaft is sunk in one of the upper seams, it is necessary to leave a protective pillar in the lower seams (or veins), which significantly increases the loss of useful mineral.
- When sinking a shaft in a deposit with a variable inclination, either take back rock or change the direction of the shaft according to the inclination of the deposit. The

transport of the output in a shaft with a variable inclination encounters considerable difficulties and reduces its extraction capacity.

*2.4. Access by Means of Decline*

A characteristic feature of the decline is the direction of driving from top to bottom, while the transport of the output is carried out from the opposite direction (Figure 6a). Very often, ore mines use this type of access, because self-propelled machines can drive directly to the mine from the surface, eliminating the process associated with their time-consuming assembly and disassembly. In the deposits located at greater depths, spiral ramps are also driven (Figure 6b) [25]. The inclination of the decline when self-propelled machines are used is up to 8° [26]. Moreover, the use of self-propelled haulage trucks is adequate with the maximum daily production volume of the mine at the level of 3000 tons [27]. Belt conveyors are used for larger production capacities of the mining plant. It is also worth noting that a belt conveyor may be installed in the decline; then the maximum angle of inclination of the excavation may be in the range from 15° to 25° depending on the natural repose angle of the transported material [27]. This applies to a situation where the entire cross-section of the decline is intended only for transporting the excavated material by a belt conveyor. In the case of mixed transport, when mining machines on a tire chassis move next to the belt conveyor in the decline, then the angle of inclination is about 12°.

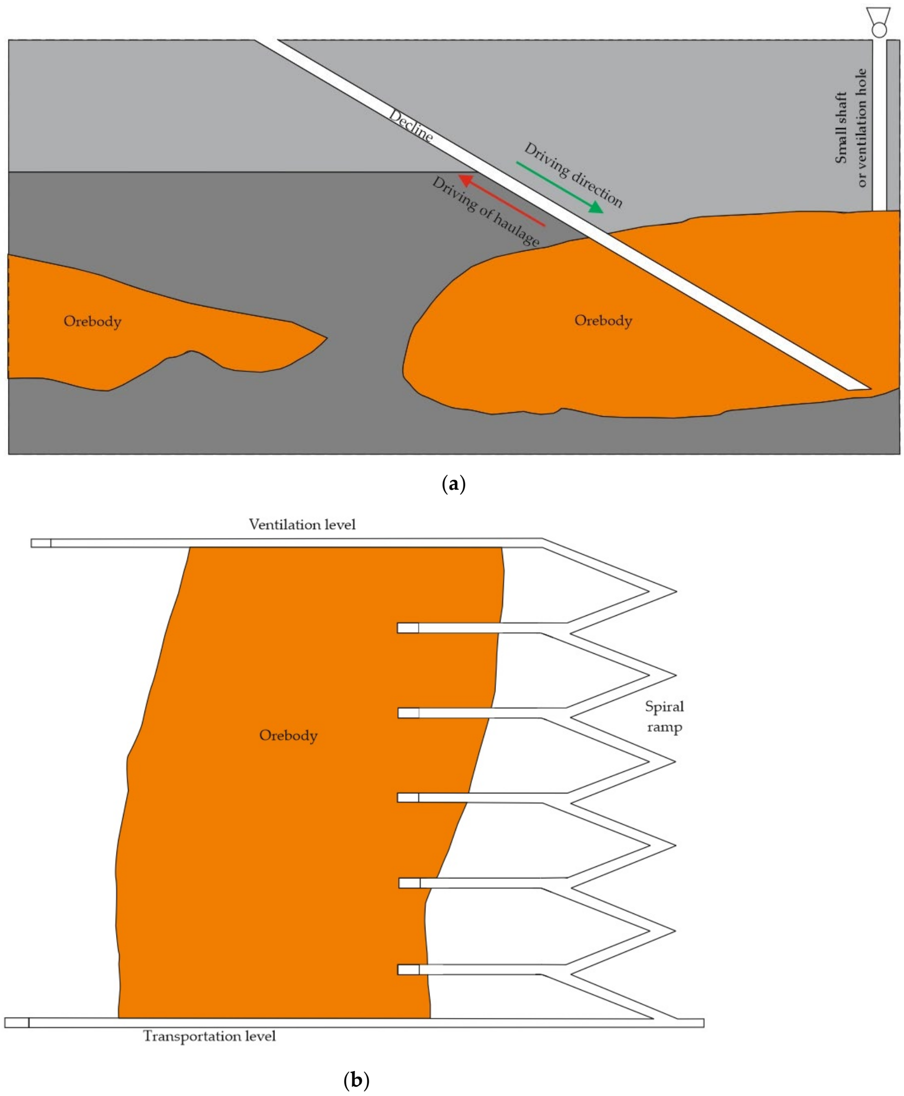



**Figure 6.** Access by means of decline: (**a**) With constant inclination; (**b**) Spiral ramp.

The advantages of inclined shafts include:

- The possibility of driving the excavation with the use of full-section machines (TBM) [28];
- Direct inspection of the excavation and equipment during the opening and operational works (for the vertical shaft, time should be allocated for its inspection);
- Easier movement of the mining crew between the levels (without the use of a hoisting machine);
- In the case of using a belt conveyor in a decline, high efficiency can be obtained (for a conveyor with a belt width of 1400 mm, up to 38.000 t/day can be obtained) [29].

The disadvantages of inclined shafts are in particular:

- The length of the decline providing access to a specific level and is several times greater than that of a vertical shaft;
- More resources are trapped in the decline protection pillar;
- In the case of transporting people and materials by suspended monorails installed in the decline, their efficiency is much lower compared with vertical transport in the shaft;
- Because the materials of the conveyor belt are flame retardant, it means that they can only be installed in the exhaust air stream. In addition, the greater length of the decline and, as a rule, a smaller cross-section in relation to the shafts, means several times greater ventilation resistance. Since the relative speed of the flowing air and the moving belt should be a maximum of 5 m/s, which allows to avoid excessive dust lifting, it means that the transporting decline cannot be used as the main ventilation excavation at the same time [30].

## 3. Relationship the Various Stages of Mining Works

The main stages of mining works: access, preparatory and exploitation of the deposit should be related to each other in time so that the previous stage overtakes the next one. Usually access overlaps with preparation in the same way that preparation overlaps with exploitation. The most appropriate ratio of the different stages is one where the upper mining level is exploited to the right extent, the lower mining level is carrying out preparatory work and the third mining level is made available. Often, depending on the geological and mining conditions, exploitation is carried out on several mining levels in order to obtain proper extraction. The advance notice for preparatory works should be determined taking into account: the recognition of the conditions and variable parameters of the deposit and the introduction of efficient mining methods. The advance in time of making the deposit available and preparing it for exploitation can be determined by the Equation (6):

$$t_o = \frac{t_e}{t_{a+d}} \tag{6}$$

where

$t_o$—time advance indicator;
$t_e$—horizontal exploitation time, (days);
$t_{a+d}$—time to access and prepare the level, (days).

Therefore, if the mining is carried out on the first level, the preparatory works on the second level, and the access works on the third level, then $t_{a+d}$ is equal to the sum of the preparation time for the second level and the access of the third level. For the proper functioning of the mine, the value of the index $t_o > 1$, therefore $t_e > t_{a+d}$. The access of deposits and the division into levels is related to the performance of two characteristic workings. The lower boundary of the level is a drift made along the length of the deposit, also known as the main transporting drift, which connects to the mining shaft. The upper drift, called the ventilation drift, connects to the ventilation shaft. In fact, the level is a part of the resource bounded by two horizontal planes: The lower plane is the transport and drainage level, and the upper plane is the ventilation and material level. The basic drift of the transporting level is connected to the drift of the ventilation level by a transporting inclined gallery, which is used to transport the excavated material and, at the same time, to close the air circulation of the extraction and ventilation shaft. The boundaries of the level on the strike side are the boundaries of the deposit area. The number of active levels depends on the volume of production and the adopted mining methods. When dividing the deposit into horizontal lines, it is possible to use a depth chart of resources with the depth of the deposit on the vertical axis and the size of the resources on the horizontal axis. By projecting the amount of resources horizontally onto the vertical axis, the vertical height of the level is obtained. The height of the level is determined by the following factors: the degree of recognition of the deposit, with less-explored and complex deposits having a lower height; the physical and mechanical properties of rocks, specifically, in rocks of low strength the height is lower; the angle of inclination, that is, the smaller the angle of inclination, the smaller the height of the level; the amount of investment outlays per one ton of excavated material; and the period needed to access and prepare the deposit for exploitation. With the height of the level, the resources of the deposit increase, and the expenditure on the preparation of preparatory excavations per one ton of excavated material decreases. On the other hand, the costs of ventilation and support maintenance are rising. The cost of delivering materials for mining excavations is also increasing. The time of accessing and preparing longer workings is extended. Additionally, the costs of haulage and dewatering increase slightly with an increase in the height of the level. Lower heights are beneficial in thin seams and veins and in irregular and tectonically disturbed deposits. The height of $H_l$ [31] according to the production capacity of the shaft and the intensity of exploitation works can be determined according to the Equation (7):

$$H_l = \frac{P \cdot \sin\alpha \cdot (1-\rho)}{n \cdot L \cdot m \cdot \gamma \cdot \eta}, \ (m) \tag{7}$$

where:

P—annual mining capacity of the shaft, (tons);
$\alpha$—the angle of the deck, (°);
$\rho$—output dilution coefficient;
n—number of operating wings (parts);
L—annual progress of exploitation works along strike, (m);
m—deck thickness, (m);
$\gamma$—volume weight of the output, (t/m$^3$);
$\eta$—deposit utilization factor.

According to the minimum expenditure per one ton of extraction, the height of the $H_l$ level can be determined analytically [31] according to the Equation (8):

$$H_l = \sqrt{\frac{(V \cdot K_0 + L_k \cdot K_k + L_e \cdot R_e) \cdot (1-\rho)}{0.5 \cdot (e + b + \Delta) \cdot S \cdot \eta \cdot \gamma}}, \ (m) \tag{8}$$

where:

V—volume of workings around shaft, (m$^3$);
$K_o$—cost of making 1 m$^3$ of a rock excavation;
$L_k$—length of the preparatory excavation of the level, (m);
$K_k$—unit cost of 1 m of the drift;
S—horizontal projection of the deposit, (m$^2$);
e—haulage cost of 1 ton of excavated material;
b—cost of dewatering per 1 ton of extraction;
$\Delta$—increase in operating costs per 1 ton of excavated material (output) with an increase in the height of the level by 1 m.

Assuming that at the lower level, access and preparatory works are carried out in advance of the operational works at the higher level, then according to the time of making available and preparing the $H_l$ level, Equation (9) can be used:

$$H_l > \frac{P \cdot w \cdot t \cdot (1 - \rho)}{S \cdot \gamma \cdot \eta}, \ (m) \tag{9}$$

where:

w—advance factor according to Equation (10):

$$w > \frac{t_o}{t}, \ (m) \tag{10}$$

where:

$t_o$—time of exploitation;
t—time for access and preparatory the lower mining level.

The access of deposits with increasing depth is complex because with increasing depth, a number of natural factors that hinder underground work are more intense. The manifestations of the negative impact of depth on the conditions and results for access have different severity, and therefore the related problems occur in different frequencies. These problems, although some of them overlap very strongly, could be divided into four main groups, some of which are major in terms of solving them, and the other are secondary. The first group includes problems related to the determination of the size and nature of the stresses on the perimeter of the excavations and the pressure phenomena occurring during the excavation of the deposit in the protective pillars. Primary pressure in the rock mass increases proportionally to the depth [32], affecting the size and nature of stresses around mining excavations, as well as the structure of the mine and mining technology. This group includes: the selection of appropriately strength rocks in which it is most advantageous to drive excavations; the selection of the appropriate cross section and the method of supporting the workings as well as the selection of the appropriate structure of the mine and mining methods in terms of monitoring the symptoms of rock mass pressure and natural hazards. The second group of issues includes securing proper climatic working conditions. The primary temperature of rocks increases with depth [33]. The increase in the temperature of the mine air with increasing depth is caused not only by the more intense absorption of rock mass but also by air compression in the deep inlet shafts. Both these factors, along with the increased oxidation of, for example, coal dust suspended in the air, act to worsen the climatic conditions for mining crews. The importance of proper climatic working conditions in deep mines is especially important when the primary rock temperature is higher than the air temperature permitted by mining regulations. Profitability of mechanization of mining works requires replacement of compressed air favorable for physiological working conditions with electricity. The electrification of a mine increases the temperature of the mine air as a result of the change from electrical energy to thermal energy. The improvement of climatic conditions is realized by concentration of mining works and simultaneous application of intensive ventilation. In order to obtain intensive ventilation, ensuring proper climatic working conditions, it is necessary to: determine the correct location of the inlet and outlet shafts in relation to the exploitation fields; proper location of fresh air inflow and used air discharge roads in the mine as well as transport and ventilation roads in the exploitation field itself; determining the appropriate cross-sections and the type of excavation support; determination of air speed and cooling intensity as well as selection of appropriate parameters of the main fans. The third group includes problems related to the greater gas capacity of coal seams lying at great depths. As the depth increases, the gas content in the coal seams and in the surrounding rocks increases [34], which makes access and exploitation difficult and complicated. Excessive amount of methane emitted into mining excavations is a factor that inhibits the progress of works in both access, preparatory and operational excavations, and therefore has a decisive influence on the method and intensity of ventilation. The intensity of gas evolution can reach such an extent that it can manifest itself in the form of outbursts of gases and rocks [35,36]. The fourth group of problems is related to the negative impact of depth on the broadly understood transport of output, people, materials and water: dewatering. This group is relatively the easiest in terms of their technical solution. The advantages of modern vertical transport solutions to a large extent compensate for the negative effects of the increased depth and are relatively well understood from a technical and economic point of view.

## 4. Conclusions

The deposit structure, including access, preparatory and exploitation excavations is characterized by a small number of driven workings in the rocks, low costs and a short time to access individual parts of the deposit. The mining process (transport, ventilation), however, requires a long period of keeping the gateroads in the deposit. In the case of shallow deposits, the most popular method of access will still be declines. The use of haul trucks in the decline offers flexibility in terms of variable geometric parameters of excavations and complex mine spatial plans. However, in the case of the transport of the output with haulage trucks in the decline, there is a threshold above which the introduction of additional self-propelled machines will result in excessive traffic congestion and planning difficulties. A certain solution is the use of a belt conveyor in the decline, which is mainly characterized by small, occupied spaces as well as a small amount of service and the possibility of central control and automation. Of course, it should be remembered that often the output should be pre-crushed in order to obtain the appropriate granulation and to avoid spilling it out during transport. The choice of the place where a deposit is made available depends on the distribution of resources in the deposit. As the costs of transporting the excavated material depend on the length of the excavations, the transport roads should be shortened, especially for those parts of the deposit where the resources are the highest. Each underground mine must have at least two serviceable connections of the underground workings with the ground surface, one for fresh air supply (intake shaft) and one for exhaust air discharge (exhaust shaft). Accessibility should ensure access to the lowest part of the deposit intended for exploitation due to drainage and gravity transport. Due to the time of accessing and maintaining workings, effort should be made to shorten their length while taking into account the physical and mechanical parameters of the rocks in which their construction is planned. The selection of the access method and the justification of their parameters usually are based on comparison of different rational variants of access. Such a comparison is based on economic analyses (cost effectiveness analyses) which takes into account cash flows over that time—net present value (NPV). It's worth noting that the timing of cash flows has a significant importance for the present value of an investment and economical effectiveness of the method of access. As a result a choice of an variant of access cannot base only on operating costs per 1 ton.

The coexistence of natural hazards and the multitude of geological and mining factors contribute to the search for more effective methods of mining and haulage of the output. Taking into account the increasing temperature of the rock mass and the intensification of dynamic hazards, future mining works should focus on the full automation of driving and support for workings with a reduction in the number of miners in particularly hazardous zones. Future access works should be based on the more effective use of computer-aided design of mining excavations, both on the plane of the highest deposit utilization factor and taking into account the time of excavation work.

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