Closed Mine Modeling and Assessment of Expected Environmental Impact

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Abstract: ***The negative impacts of closed mines are today a worrying problem not only for the environment but also for the people and their hopes for a better life. Increased impacted areas from mining subsidence, creation of new subsidence on abandoned mining works which are often unforeseen streams of contaminated water from mining galleries and gaseous emissions from abandoned mines are today very worrying problems. Measures to control and minimize this negative impact should be initiated by digitizing the measurement documentation for each closed mine. Based on this documentation, mine modeling and geological environment, accompanied with a full description of the phenomenon of rock massive movements should be realized. The assessment of this documentation by specialists in mining subsidence engineering will lead to the designation of areas with increased potential risk for expected environmental impacts of closed mines.***

Keywords: Mine subsidence engineering, Rock massive movements, Continuous subsidence and subsidence with ground fractures.

1. Introduction

Nowadays the opening of a new mining activity is accompanied by the environmental project, as an integral part of the mining project. This project assesses the environmental impact of mining activities, provides static and dynamic measures for minimizing the environmental damage expected during mining activities and details the work program for the full recovery of the damages brought to it.

We need to difference the closure of the mines after successful exploitation of the mineral reserves of a deposit, with the closure of mines for various economic, social or environmental reasons, as a termination of a mining activity without completing the assignment. In the first case, in the mine project, the mine closure phase is envisaged, that’s why the necessary funds and work processes will be developed for the regeneration of the damaged environment. In the second case, a mining project is interrupted because of an unforeseen obstacle in the mine project. Such an outage of mining activity has negative consequences not only for the employees of the mining project, but also for the environment.

Such interruptions to mining activities occurred during the 1990s in Albania. Many mines were abandoned, causing problems in the country's mining economy and miners. This was followed by the failure to prepare the complete mining and mining documentation that should accompany a closed mine. The lack of mine surveying documentation, with the latest state of the mining works, will be a worrying problem for many years, both for the control of environmental issues in areas near abandoned mines and in the preparation of mining projects for the reopening of closed mining.

The most recent monitoring carried out, shows that most closed mines continuously cause a negative impact on the environment. Depending on the opening scheme, the type of mineral, the utilization systems used the spatial position of the mining works and the methods used for their closure, the impacts on the environment are unavoidable but varying in size. In general, the forms of environmental impact from closed mines are:

- Continued surface subsidence due to the recapture of demolished rock massive in the subsidence area, creating landslides and slides. Most apparent this phenomenon is in mines where we have the presence of groundwater.
- The risk of creating new fun shape subsidence over the mining strata in small depths, where block caving or room and pillar mining method are used.
- Risk of demolition from mining works opened in small depths and the continuation of this collapse to the surface. Such occurrences are characteristic for mining works at depths of less than 40 meters.
- Discharge of contaminated water from mining entrances to the nearest water flow or river. These waters affect the damage of flora and fauna in the area they flow.
- Gas emission from mining works (mainly from shafts), which are often very disturbing to the community and polluting the atmosphere.
- Environmental impact from mining waste deposits. The impact of such deposits not only ruins the environmental image around them, but often these deposits are burned by emission harmful gases to the community or are a source of pollution of the waters flowing over these deposits, especially in periods of drift.

Before the environmental impact assessment of closed mines, it is required to be prepared a complete mine surveying documentation, where all the mining areas with increased potential for the occurrence of the above mentioned occurrences are evidenced. For this purpose, all plans, maps and logging kept in closed mines should be processed, combining these and the data obtained from the most recent measurements carried out in some mines. Based on the new documentation, studies should be conducted and mining areas with increased potential for adverse impacts on the environment should be identified.

1.1 Preparation of Graphic and Description Documentation for Closed Mines.

Like all other engineering disciplines, mining engineering is also based on surveying, evaluation and mapping of all mining works and processes. It is impossible for mining activities to work independently from mining surveying cartography. The Practical Code of Mining Surveying is an important place for the quality of the mining works plan preparation and the information that should be included in this documentation.

Even the closure of a mine should be accompanied by the preparation of plans for all mining levels, with the latest state of the mining works. The information provided by this documentation is essential in assessing the technical and economic indicators of mining activity, providing the necessary spatial information for reopening closed mines, assessing the environmental impacts of the mines closed, and carrying out a work safe in mines or other engineering projects that are expected to be developed near a closed mine.

The graphic and description documentation kept for the mines is very varied, detailed and distinguished for a high precision. [5] In general, the graphic documentation of the measurements in mines is manually prepared, in hard copy format and is well maintained. The logistic and geological documentation in our mines is mainly prepared on base-based paper, while the main plans were passed on in aluminum-based paper. Today it has become necessary that the information contained in this documentation, assembled by a generation of engineers, be transferred to the electronic surface of today's technology, as very important information for the new generation that will deal with the extractive industry and processing of minerals.

The information contained in the mining plans allows the definition of coordinates (*X, Y, Z*) for each object we are interested in, such as gallery positions, work positions connected different mines horizons, ore body positions given by geological documentation and mining, the positions of the mining and prepared production units, and many other information. Along with spatial information, mining documentation provides data on the timely development of mining processes and other phenomena monitored during mining activities. Of interest are information on ore reserves provided by the geological and mining report, data on the status of the mining reserves left unused as a result of discontinuance of the mining activity, and data on the behavior of stratum movements over the mining units and the phenomenon of underdeveloped rock mass movements.

Processing of geomatics documentation starts with scanning plans and cross sections and preserving scanned documentation (*raster images*). Scanned raster images are then used in CAD or GIS software, georeferenced, digitized and stored in special folders according to level and mining. All the data than will be converted into a 3D model with geological structures and all other data that can be extracted from the scanned images and descriptive documentation. [1]

Based on this documentation already prepared in digital format, different query is created which gives the descriptive data for each work or production units. The information provided in the generated query lists the blocks size, usage time of the blocks or the manufacturing units, the way of running the ceiling, the behavior of the ceiling and the massif of the rock, the dimensions of the mineral columns left over mining time, the status of the columns during the withdrawal of the exploitation works, massive mineral losses and other information collected by mining surveying services related to the mining engineer.

All 3D maps created for mining works are related to the surface map, geological drilling and space axial positions given by geological reports. We have thus created a complete digital information on the activities of each closed mine (*Figure 1*).

All mining documentation processed in digital format should be carefully guarded by the Mining Sector at the National Agency of Natural Resources, as the most important organ in the mining field. It is the duty of this institution to set up working groups with competent engineers for evaluating this documentation [6] and publishing it for every interested person, not only in the field of mineral exploitation but also in the construction of other engineering works that are positioned above or near surfaces, where we expect impacts of closed mines.

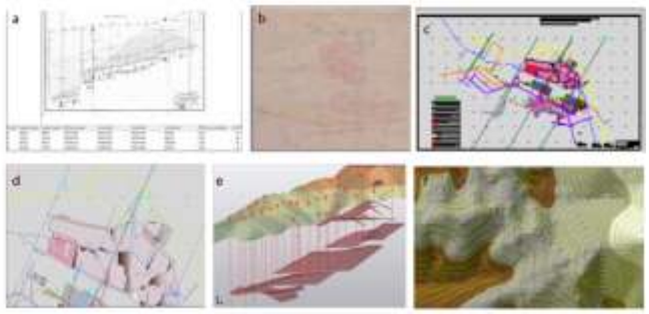

Figure 1: Preparation of mining documentation, a) Geological section, b) Scanning plane maps of mining works. c) Plane maps prepared in A-Cad. d) Plane maps of mining areas and mineral pillars. e) 3D presentation of mining works, ore bodies, and drillings. f) Surface map in 3D

2. Engineering evaluation of mining documentation, definition of areas with increased environmental risk.

Digitized mining documentation should be studied by competent persons in the field of mine surveying, minerals and geology. The study of this material concludes with the preparation of a database based on the fields of interest where are mentioned:

- The reopening of a closed mine or part of it to extract the remaining mining reserves without being exploited.
- Assessing the negative physical changes that are expected on surfaces that lie within the boundaries of the closed mining impact, and the measures that can be taken to minimize this impact on the environment.
- Investment plan for various engineering projects in the field of construction located near closed mines
- Use of graphic and descriptive documentation in the interest of scientific works and publications,
- Other needs for use of mining facilities.

All the above fields are important, and work should be carefully provided by the competent persons for the assessment of any interest expressed above. In this article we will discuss the study of this documentation and the preparation of a data base for assessing the negative environmental impacts at closed mines.

2.1 Mining Subsidence Engineering

Terrain subsidence and the collapse of the natural ecosystem of the underground water network are almost inevitable, accompanying the extraction of minerals with underground works. They may occupy small surfaces but may extend to relatively large surfaces. Numerous studies of surface subsidence from the mining influence have developed some theoretical concepts which, together, have created the discipline of mining subsidence engineering. These studies, based on the science of engineering geology, mining survey and mining engineering, have provided accurate conclusions regarding the movements of geological structures under exploitation and the transmission of this movement to the physical, vertical and horizontal changes of the rock massive and the surface of the earth.

Environmental impact assessment of a mining activity, as a result of the physical alteration of geological structures, from under extraction strata to surface layouts, has required that in addition to the concepts given in mining engineering, be completed with property studies mining, construction procedures, agricultural science, urban planning and social and economic considerations. Today, environmental assessments of a mining activity are given in detail in the environmental project that is being prepared with the start of mining activity, is completed during this activity, and continues even after the mining activity is closed.

The negative impact of closed mines is mainly related to the physical field changes that continue even after the mine closure, or the emergence of new structures and surface movements years after a mining activity has ended. These delayed movements relate mainly to (a) the continuation of terrain movements inside the mulda of subsidence (continual subsidence) or create of fun shape collapse during mining activity (b) delayed subsidence over voids created from mineral extraction using rooms and pillars mining methods and (c) the demolition of mining works open to small depths.

3. Continuation of surface movements in area affected by mining activity

Roof of cavities created by coal extraction or hard rock mining, collapsed, shreds and filled with materials brought to fruition, consolidate and create a balance that cannot be associated with large movements of geological strata overlying the voids. Based on mining subsidence engineering [4] it is estimated when the movement of geological structures will continue and when this movement reaches the surface. So, not in all cases, the subsidence of geological strata overlying the collapsed voids continue to the surface, but it is not excluded the possibility of activating the movements at a later stage. Under such conditions, some coal mines in our country have been closed, which should be investigated and determine whether these mines will have a negative impact on the surface, and if so, define these areas as unsuitable areas for engineering construction.

In cases where the movement of geological structures results in physical changes reaching to the surface, in the form of continued subsidence or sinkhole, the closure of the mining activity is accompanied by an environmental project supplement for continuous monitoring of the terrain movements. In many of our closed mines, lack of funds for mining closures, or the use of limited funds, has led to a negative impact on the environment. A negative example is the closure without a Mining and Environmental Project of the Copper Mine in Rehovë. The negative environmental impacts in this mine are present and continue to expand the areas of influence. Only the collapse of the surface in the form of a large sinkholes in the "Ciflig" mine, or the demolition of the quarry slopes at the "Dushku i Trashë" mine, have led to the continuous expansion of the damaged areas with ravines or mountain pastures (*Figure 2*).

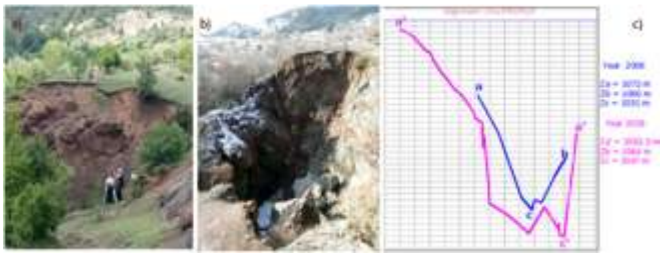

Figure 2: Environmental damage at Rehova copper mine. (a) Survey of a sinkhole. (b) Image from the sinkhole. (c) Presentation of the size of the funnel in a cross section, the sinkhole size in 2006 (blue line) and in 2018 (magenta line)

4. Delayed surface subsidence on closed mines

Not in all cases, the voids created by the extraction of coal or metal minerals are associated with the movement of geological structures, which can be reached up to surface layouts. A series of geologic and mining parameters determine the extent of this movement. According to SME, 1986 here are included the thickness of extracted ore body, mining depth, the angle of the fall of the ore bodies and the rock formations, the competence and nature of ore bodies and surrounding rocks, the fracture of the geological medium, the methods of exploitation, the rate of extraction minerals, topography of the ground, presence of groundwater, and other geotechnical and mineral factors. These factors should not only be well known, but also adapted to the concrete conditions in which they work.

Based on the above-mentioned factors, the graphical and descriptive documentation of each closed mine in our country, as well as some studies conducted in this, we point out that the problems of late demolitions in closed mines should be expected mainly in the metal mines, where rooms and pillars methods are used.

Room and pillar mining method have been successfully used in some nickel iron deposits, such as in mines like "Skroskë", "Bitinckë", "Bushtricë" and partly in "Guri Kuq". In this system, some parts of the ore body are extracted from the block, while some parts are left in the form of columns, to support the overlying strata, and to prevent the overlying strata from immediately caving or falling in while the mine is in operation. When mining of rooms finished, usually part of the ore in pillars removed as long term support is no longer necessary. Over the years the increased pressures on these columns cause their destruction and the movement of the overlying strata begins in the direction of the caves created from the extracted mineral. It is not possible to determine the exact time when the protective columns can be destroyed, and the overlying strata start moving, but it is expected that over the years this move will happen. If this move will reach the surface layouts, causing it to fall in sinkhole shape will depends on the presented factors. Based on the digitized documentation prepared for each mine, the analysis of the mining subsidence for each concrete case should be made.

Let us briefly summarize the above factor analysis, based on the graphical and descriptive documentation prepared for the Iron-Nickel mine in Skroska. [2] This iron nickel mine is part of the Nickel Iron Mining Complex in the Librazhd Basin and is distinguished as one of the mines with very good technical and economic indicators. The conveying system with chambers and columns in this mine was favored by the high solubility of limestone placed on the iron nickel rod, allowing the creation of rooms with relatively large surfaces.

Based on the calculated risk index value (Hazard index ≈ 0.78), this mine is categorized as mines with a very low risk of collapsing underground working spaces. During the years of work in this mine, there have been no problems with the collapse of the work spaces. But the high value of the risk index should be combined with the ratio of the dimensions of the rooms, columns and thickness of the iron nickel body.

During the mining operations at the +845 horizon of this mine, a considerable portion, more than 65%, of the minerals from pillars was removed. This created a new situation in the ratio of mining area with area of pillars. With new situation this ratio changes from 4 to 1, to 7 to 1. As seen in Figure 3, the distances between pillars are more than 150 meters. An increase in the width like this, increase the span to be bridged and create more chance for roof to be destroyed. This will bring the appearance of physical change on the surface, as the depth of the mining is not too great. Areas where sinkholes are expected should be determined by geomatics measurements and then marked with visible signs. The maps of these areas, through municipal employees, have to be known from residents that live there and explaining the risks they pose.

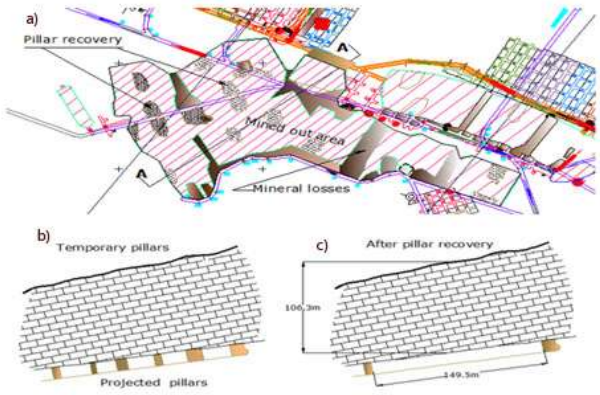

Figure 3: Skroska Mine Exploitation a) Plan of mining area and pillars. b) Cross section of room and pillars. (c) Cross section after partial mining of some pillars

5. The Demolition of Abandoned Mining Works Opened in Small Depths

Another worrying issue for the environment and the community living near closed mines is the impact to surface the demolition of mining works open to the deepest depth. Most often, these works are crumbling, filled with material brought to destruction, consolidated and create a balance that cannot cause problems in the overhead. There are few work breakdown cases which continues for a long time and may appear on the surface causing serious problems for surface construction

In Mining subsidence Engineering literature, it is noted that the presence of abandoned mining works in the deepest depths of the surface is a constant, untreated risk for the development of surface roughness. Break down deformations do not occur on any mining work placed at a low depth. Time and place when they occur is difficult to predict. Such developments have occurred in our mines as during the mining works and after several years.

The state of surface deformations depends on the development of destructive processes that develop near the surface. Depending on the ground properties, related to the thicknesses of loose ground in overburden and thickness of solid layer over voids, destructive process may cause characteristic deformation on the surface. Dangerous depths of mining works are considered depths less than 40 meters, where they encounter more cases of surface collapse. [3]

The activation of deformations on the rock mass, placed over abandoned mining works, mainly comes from the following factors:

- Loss of support load bearing capacity of old shallow workings
- The presence of water infiltration into the loosen overburden and rock mass

- Degradation of rock formation by water infiltration from the surface. When these waters communicate with mining works create new carvings and reduce their sustainability.
- Increasing the static load of land with different constructions, from the deposition of embankments material, landfills, etc., over the mining works.
- Changes in dynamic loading of the rock mass due to surface transport vibrations, explosive work in the area near them, seismic movements, etc.
- Methods used for mining closed process.

Based on the graphical documentation of the Mezes coal mine and the studies carried out on the delayed surface movements from the impact of the mining works of this mine, we note that the dynamics of the rock massive movements and the creation of new sinkholes in this mine is still present. This movement has become more problematic as a result of new construction developments in recent years.

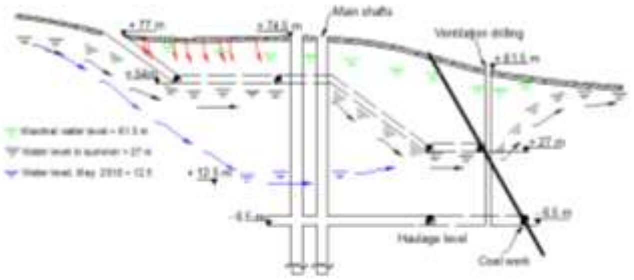

Figure 4: Changes in water levels in mining works

The surface subsidence over the first mining working level, in the form of deep holes, has been continuously occurring in this mine. In the first months of this year, the phenomenon of sinkhole creation has been present, as a result of the change in the level of groundwater in this mine. The average water level in the mine lies in the quota + 61.5 meters, as far as the quota of the mouth of a ventilation shaft that connect underground mining works with surface. In the warmer days of this summer, the water level in the ventilation shaft fell to + 27 meters, which is lower than the quota, + 54 meters, for the first level of this mine (*see Figure 4*).

Water extraction from the main shaft of this mine, at the beginning of this year, for community needs has led to a rapid reduction of the groundwater level in this mine to the level of + 12.5 meters. This action has been accompanied by the movement of water through the mining works and the removal of a small amount of collapsed material, favoring the collapse of other formations on mining works. The phenomenon of water infiltration into the rock mass may be reason for formation of a void situated much higher than the level of mining works. The combination of the above factors has led to the creation of some new sinkhole and creating numerous problems for new construction in this area. By continuous measurements in this mine are marked (*see figure 4*) some new sinkholes created this year (*point a, b, c and d*), along with several others encountered in years (*points 1, 2, 3, 4 and 5*).

Figure 5: Different areas with discontinues subsidence over the mining works in Mëzes coal mine. The collapse of the surface in years is market with point 1, 2, 3 and 4. Points a, b, c and d show new sinkholes create during this year.

6. Conclusions

- Most problems related to discontinuous subsidence of the surface are created by shallow exploitation carried out with leaving improperly backfilling post mining workings or improperly closed mining works. Shallow exploitation in the area of coal mine in Mezes has changed the structure of natural bedrock. The voids created in the shallow depth create a real threat of discontinuous deformations occurrence in a difficult to specify future.
- Closure of mines should be accompanied by the preparation of graphical and descriptive materials with the latest situation of mining works. This documentation is mainly prepared by mine surveying and geological service, should be submitted to the mining archives, according to the requirements enshrined in mining law. The closed mines documentation should be completed with studies conducted by mining specialists, giving information about the environmental impacts of mining activity, the expected impact on the environment, regeneration opportunities for mining damages, monitoring of the areas affected by closed mines, categorization the mining areas and their advertising for other uses.
- The extraction of minerals from hard-rock mines by underground mining can create environmental problems and safety hazards. Underground mining affect geologic structures overlying the mining areas resulting in surface impacts on the natural geomorphology and land use. In some cases, surface subsidence may appear many years after the mine is closed. Such a phenomenon is mainly related to the use of room and pillar mining method.
- The first level of mining works in the coal mine Mezes are very close to the surface. Creating sinkholes over these mining works is a constant concern for the people of this area. With the geophysical measurement should be determined accurately position of caves created by the demolition of mining works and take measures for their filling.

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