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The first issue of the journal "Podzemni radovi" (Underground Mining Engineering) was published back in 1982. Its founders were: Business Association Rudis - Trbovlje and the Faculty of Mining and Geology Belgrade. After publishing only four issues, however, the publication of the journal ceased in the same year.

Ten years later, in 1992, on the initiative of the Chair for the Construction of Underground Roadways, the Faculty of mining and Geology as the publisher, has launched journal "Podzemni radovi". The initial concept of the journal was, primarily, to enable that experts in the field of underground works and disciplines directly connected with those activities get information and present their experiences and suggestions for solution of various problems in this scientific field.

Development of science and technique requires even larger multi-disciplinarity of underground works, but also of the entire mining as industrial sector as well. This has also determined the change in editorial policy of the journal. Today, papers in all fields of mining are published in the "Underground Mining Engineering", fields that are not so strictly in connection with underground works, such as: surface mining, mine surveying, mineral processing, mining machinery, environmental protection and safety at work, oil and gas engineering and many others.

Extended themes covered by this journal have resulted in higher quality of published papers, which have considerably added to the mining theory and practice in Serbia and which were very useful reading material for technical and scientific community.

A wish of editors is to extend themes being published in the "Underground Mining Engineering" even more and to include papers in the field of geology and other geo-sciences, but also in the field of other scientific and technical disciplines having direct or indirect application in mining.

The journal "Underground Mining Engineering" is published twice a year, in English language. Papers are subject to review.

This information represents the invitation for cooperation to all of those who have the need to publish their scientific, technical or research results in the field of mining, but also in the field of geology and other related scientific and technical disciplines having their application in mining.

Editors

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Original scientific paper

CHARACTERIZATION OF GROUND OSCILLATIONS INDUCED BY UNDERGROUND MINING

Srđan Kostić[1], Nebojša Vasović[2]

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Abstract: We examine ground acceleration during M1.5 and M2.0 seismic events induced by underground mining at Upper Silesian coal basin and Legnica Glogow copper mine, respectively, using methods of nonlinear time series analysis, in order to confirm its stochastic nature. Recorded time series are firstly embedded into the adequate phase space using the mutual information and box-assisted methods. After this, we performed stationarity test, by which we confirmed that the examined ground acceleration belongs to a group of stationary processes. Surrogate data testing is applied then, which resulted in following: (1) horizontal ground acceleration at Legnica Glogow copper mine represents stationary linear stochastic processes with Gaussian inputs, (2) ground acceleration at Upper Silesian coal basin originates from a stationary Gaussian linear process that has been distorted by a monotonic, instantaneous, time-independent non-linear function, (3) vertical ground acceleration at Legnica Glogow copper mine could not be ascribed to any of the examined processes, probably due to high level of instrumental or background noise. Low values of determinism coefficient ($\kappa \leq 0.7$), negative values of maximum Lyapunov exponent and quick saturation of neighboring points distance with the increase of embedding dimension indicate the absence of determinism in the observed ground acceleration time series

Keywords: underground mining, ground acceleration, time series analysis, stochasticity, determinism

1 INTRODUCTION

Analysis and characterization of recorded time series lies in the focus of both theoretical and applied science, since it enables verification and calibration of theoretical models, on one side, while it enables the possible prediction of the future development of the process under study, on the other side. The latter is of special concern, since catching the regularity of activity being monitored enables adequate design and planning of the further monitoring process, and engineering activities. In present paper, we analyze the recordings of the ground acceleration in order to confirm the existence of possible

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determinism or deterministic chaos, which could indicate the possibility of predicting the ground motion during some of the future seismic events.

The construction of underground chambers and the advancement of the ore mining process inevitably disturbs the primary stress state, with changes being larger and more complex if the geomechanical conditions before the construction of the underground chamber were complex, or if the excavation process has not been adjusted to the natural conditions prevailing in that part of the rock mass. This stress redistribution, in some cases, can lead to earthquakes, where earthquakes of the greatest magnitude ($M \geq 4$) are usually caused by the redistribution of tectonic stresses in the immediate vicinity of the excavation. Previous research (Smith, et al., 1974) indicates that mining activity in the Earth's crust, in the general case, leads to a reduction in the magnitude of lithostatic pressure, by relieving rock mass, while at the same time, the horizontal stresses have also changed, as a consequence of the unloading and the Poisson effect (Wong, 1985). In the compressive tectonic field, which predominates in the Earth's crust, the effect of mining activity will cause movements along existing mechanically weakened zones (faults) before the failure, by reducing the vertically oriented maximum principal stress and increasing shear stress along faults. As a result, a seismically active rupture may occur, depending on the friction along the joints, and their orientation relative to the direction of the maximum principal stress. Previous research has shown that earthquakes in mines caused by reactivation of movement along faults are one of the most common occurrences of mining-induced seismicity (Cui, et al. 2004; Donnelly, 2006;). Moreover, these earthquakes are mostly the biggest events with the most severe consequences. The strongest earthquakes often reach magnitude $M = 5$, in exceptional cases up to $M = 6$. Impacts of such magnitudes with a focal depth of 1-2 km can cause earthquakes of intensity VI-VIII degrees according to the Modified Mercalli Scale (Zembaty, 2011).

Mining-induced seismic events have been reported throughout the world extensively in the last 40 years (for review of mining induced seismic events, one should check the work of Kostić, 2013). For mining-generated earthquakes in Poland, Gibowicz (1984) identified focal mechanisms for four major earthquakes registered in three different mining areas in Poland. Two earthquakes, the first of magnitude $M_L = 4.5$, which occurred on June 24, 1977, between two copper mines in the Lubin area, and another, of magnitude $M_L = 4.3$, which occurred on September 30, 1980, at the Shombierki Coal Mine in the Upper Silesian Basin, were the result of a normal fault, with different extensions to the north and northwest. In the United States, the best documented cases of fault earthquakes have been reported in the lead, silver, and zinc mines in the Couer d'Alene area of northern Idaho, as well as in the coal mines in the Wasac and Beech Cliffs areas in central Utah (Zoback, Zoback, 1989), primarily due to the proximity of the tectonic plate boundary along the Pacific coast and the high degree of seismicity. In eastern Canada, in the Sadbury Basin, in the deep mines of metallic minerals, numerous mining earthquakes have been registered (Wetmiller, et al., 1990). Milev et al (1995) analyzed 2017 mine-induced seismic events with magnitudes in the range of $0.0 < M <$

3.1 at East Rand Proprietary Mines, in the period 1992-1993. McGarr and Fletcher (2005) developed ground-motion prediction equations relevant to shallow-mining induced seismicity in Rtial Mountain Area (USA), with magnitude up to 2.17. Fritschen (2010) analyzed mining-induced seismicity in Saarlan, Germany, considering the M4 seismic event induced by the coal extraction in the Primsmulde field. Lizurek et al. (2015) analyzed ML4.2 seismic event at the Legnica Glogow Copper district, which occurred in 2013 along an inactive fault. Emanov et al. (2021) examined M6.1 seismic event near the Bachat open-cast coal mine in Kuzbass (Russia) in 2013, which is currently considered as the world's largest man-made earthquake related to the extraction of solid minerals.

In present paper, we analyze ground oscillations induced by underground mining at two mine locations in Poland: Upper Silesian coal mine and Legnica Glogow copper mine. Recorded oscillations are examined by invoking methods of nonlinear time series analysis, in order to confirm the stochastic nature of the mining-induced ground oscillations. Methods of nonlinear time series analyzes for confirming determinism / stochasticity have been successfully applied before (Kodba et al., 2005; Kostić et al., 2013).

Paper is structured as follows. In Section 2 we describe the applied methodology, while the main results of the conducted research are given in Section 3. Discussion and conclusion are provided in the final section of the paper.

2 DATA ANALYZED AND APPLIED METHODS

We examine ground oscillations induced by underground mining at Upper Silesian coal basin (M1.5 seismic event) and at Legnica Glogow copper mine (M2.0 seismic event). Typical acceleration time series for these events is given in Figure 1.

In order to conduct this analysis, we had to embed the observed scalar series into the appropriate phase space: the optimal embedding delay is calculated using average mutual information method, while the minimum embedding dimension is examined by box-assisted method. With the observed series properly reconstructed in phase space, we were able to conduct a stationarity test, which is a necessary prerequisite for a random dataset. As a next step in our analysis, we conducted the surrogate data testing, by assuming that: (1) the observed data are independent random numbers drawn from some fixed but unknown distribution; (2) data originate from stationary linear stochastic process with Gaussian inputs; (3) recordings originate from a stationary Gaussian linear process that has been distorted by a monotonic, instantaneous, time-independent non-linear function (Perc et al., 2008). For this purpose, we generated 20 surrogates. Then, in order to compare the original data and generated surrogates, we calculated the zeroth-order prediction error ε. If this error for the original dataset (ε_0) is smaller in comparison to the calculated error for surrogate data (ε), then a null hypothesis can be rejected. On the other hand, if $\varepsilon 0 > \varepsilon$ at any instance of the test, the null hypothesis cannot be rejected.

Usually, more than one wrong result out of 20 is not considered acceptable. For testing the third null hypothesis, Since the function is unknown in this case, the procedure for forming surrogate time series (AAFT procedure - phase randomization procedure with adjusted amplitude) consists of the following. First, the data of the initial time series are scaled to match the Gaussian distribution (effect of an unknown nonlinear function). The phase randomization procedure described in the previous step is then applied. After applying the inverse Fourier transform, the obtained surrogate data is finally scaled again to match the distribution of the initial time series. This procedure is repeated for each surrogate time series, but each time with a different phase in the phase randomization procedure. However, since the inverse Fourier transform does not provide a completely reconstructed time series, primarily in terms of power spectrum (which is with more noise), the amplitude of Fourier transforms is adjusted as follows (IAAFT procedure - iterative phase procedure randomizations with adjusted amplitude). Let $|s_k|$ be the desired amplitudes of the Fourier transform of the initial time series. Let us perform the phase randomization procedure, when the obtained surrogate Fourier transform is further changed by comparing the amplitudes of the Fourier transform of the initial and surrogate time series: $s_k'' = s_k' |s_k| / |s_k'|$. This step is repeated until the amount of noise in the power spectrum is reduced to an acceptable level. After performing the inverse Fourier transform, the obtained surrogate time series is compared with the initial time series.

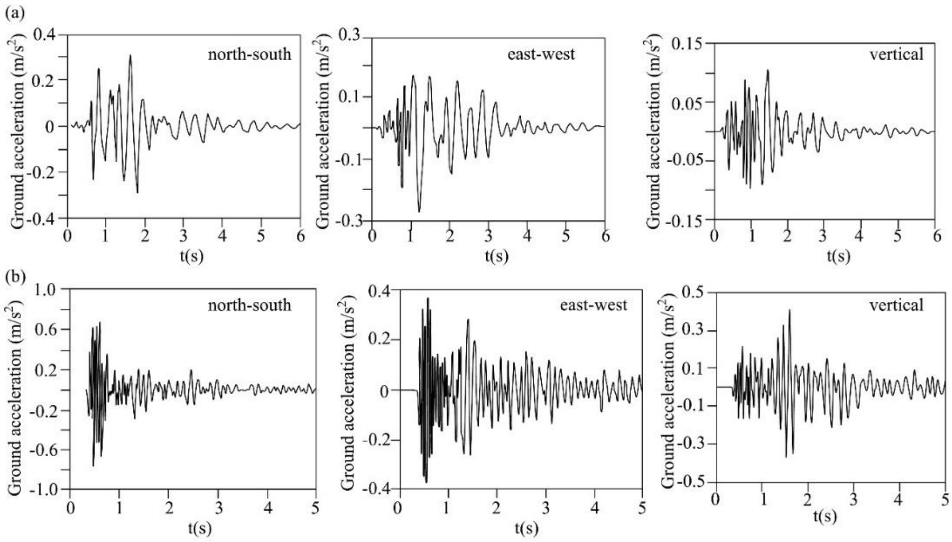

Figure 1 Typical ground acceleration time series, for M1.5 seismic event at Upper Silesian coal basin (a) and for M2.0 seismic event at Legnica Glogow copper mine (Dulinska and Fabijanska, 2011).

As a final step in the performed time series analysis, we applied a determinism test, which is based on the assumption that if a time series originates from a deterministic process, it can be described by a set of the first-order ordinary differential equations, whose vector field consist solely of vectors that have unit length. In other words, if the system is deterministic, the average length of all directional vectors κ will be 1, while for a completely random system, $\kappa \approx 0$.

3 RESULTS

Recorded time series are firstly embedded into the corresponding phase space, by calculating minimum embedding dimension and optimum embedding delay. For three directions of ground oscillations, results of calculation of optimum embedding delay are shown in Figure 2. As it could be seen, optimum embedding delays for north-south, east-west and vertical direction are τ=8, τ=10 and τ=12, respectively, at Upper Silesian coal basin, and τ=9, τ= 8 and τ=14, respectively at Legnica Glogow copper mine. Regarding the values of minimum embedding dimension, one commonly uses false nearest neighbor technique; however, it was shown by previous studies that results of FNN technique could lead to ambiguous results, especially in the case when relatively small dataset is analyzed. In present case, application of FNN technique results in the increase of embedding dimension with the rise of percentage of false nearest neighbors, so minimum embedding dimension could not be determined by using this method. Therefore, we invoke the box-assisted method proposed by Schreiber (1995). According to this method, minimum embedding dimension for the recorded ground acceleration in north-south, east-west and vertical direction is m=11, m=4 and m=4, respectively, for the location of Upper Silesian coal basin, while for the same directions is equal to m=3, m=5 and m=8, respectively, for the location of Legnica Glogow copper mine.

Having determined the minimum embedding dimension and the optimum embedding delay, we further conduct stationarity, in order to examine whether the recorded time series represent stationary process, i.e. to examine whether different non-overlapping segments of the time series have different dynamical properties, or the system parameters were constant during the process. It is clear form Figure 3 that most of pairs exhibit low to moderate cross-prediction error, confirming the stationarity of the examined time series. In particular, for recorded time series at Upper Silesian coal basin, for north-south direction 95.7% of pairs is with cross-prediction error $\varepsilon < 0.25$, for east-west direction 91.1% is with $\varepsilon < 0.16$, and for vertical direction 89.04% is with $\varepsilon < 0.08$. Similary, for ground acceleration time series recorded at Legnica Glogow copper mine, for north-south direction 94.02% of pairs is with cross-prediction error $\varepsilon < 0.6$, for east-west direction 94.96% is with $\varepsilon < 0.26$, and for vertical direction 94.09% is with $\varepsilon < 0.28$. Since all cross-prediction errors differ maximally by a factor of 2, we can clearly refute non-stationarity in the studied time series.

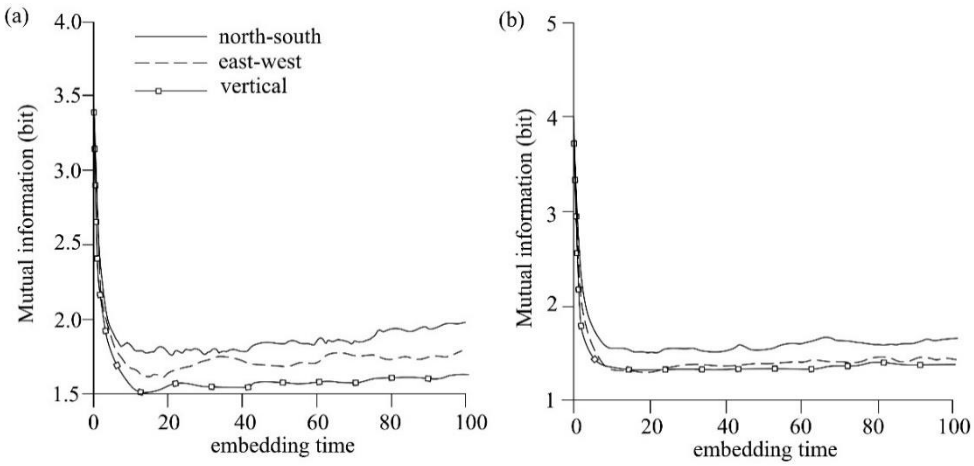

Figure 2 Results of mutual information method for ground oscillations at: (a) Upper Silesian coal basin, (b) Legnica Glogow copper mine.

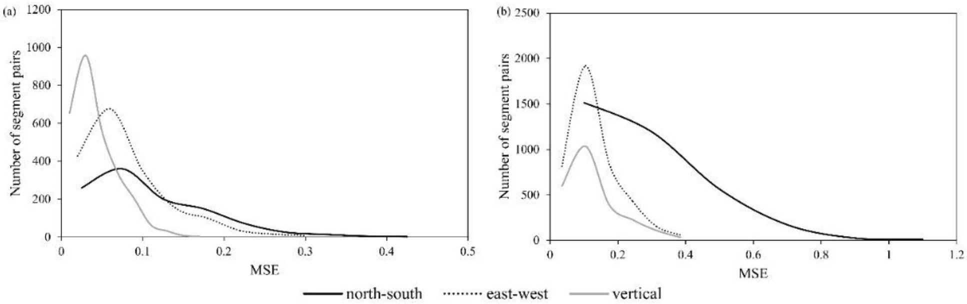

Figure 3 Histograms of cross-prediction errors for stationarity test: (a) Upper Silesian coal basin; (b) Legnica Glogow copper mine.

Surrogate data testing is further applied in order to classify the examined time series more closely. Results of testing the first null hypothesis are presented in Figure 4. As it is clear, hull hypothesis could be rejected for recordings made in the north-south direction at both examined locations, since $\varepsilon_0 < \varepsilon$ for each time step *n*. Qualitatively the same results are obtained for remaining two directions at both locations.

Regarding the results of testing the second null hypothesis, it is clear from Figure 5(a) that null hypothesis could be rejected for ground acceleration recorded at all three directions at Upper Silesian coal basin, since ε_0 is well within ε for each time step *n*. As for the results at Legnica Glogow copper mine, $\varepsilon_0 < \varepsilon$ for each time step n for the ground oscillation in horizontal plane (in both directions: north-south and east-west), while ε_0 is well within ε for each time step n for vertical oscillations (Figure 5b). Therefore, ground acceleration recorded in horizontal plane at Legnica Glogow copper mine could be characterized as stationary linear stochastic processes with Gaussian inputs.

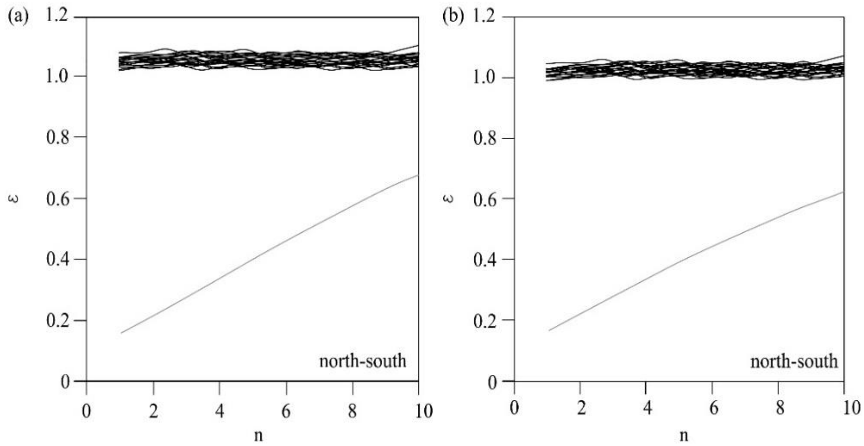

Figure 4 Surrogate data testing – I null hypothesis, for north-south direction at: (a) Upper Silesian coal basin, (b) Legnica Glogow copper mine. Qualitatively same results are obtained for other two directions. Gray line denotes the prediction error for the original time series (ε_0), while black lines denote error propagation for the surrogate time series (ε).

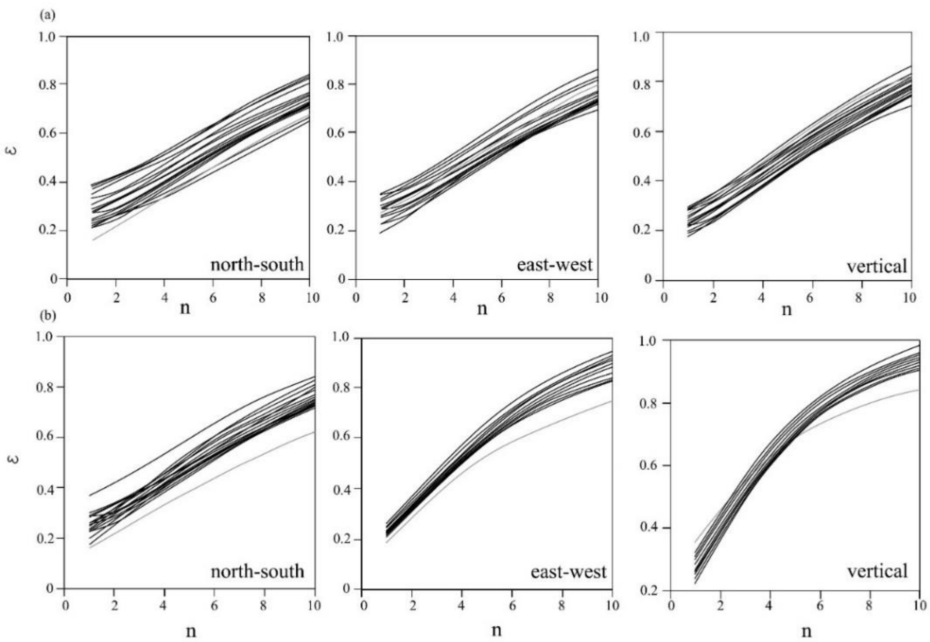

Figure 5 Surrogate data testing – II null hypothesis: (a) Upper Sileasian coal basin; (b) Legnica Glogow copper mine. Gray line denotes the prediction error for the original time series (ε_0), while black lines denote error propagation for the surrogate time series (ε).

Results of testing the third null hypothesis are shown in Figure 6. As it could be seen, third null hypothesis could not be rejected only for the recordings made in north-south direction at Upper Silesian coal basin. For all other recordings, ε_0 is well within ε for each time step *n*, so null hypothesis could be rejected. In case when IAAFT procedure is implemented than third null hypothesis for ground oscillations at Upper Silesian coal basin could not be rejected, while ε_0 is well within ε for each time step n for vertical oscillations at Legnica Glogow copper mine (Figure 7). This indicates that ground acceleration at Upper Sileasian cola basin could be characterized as originated from a stationary Gaussian linear process that has been distorted by a monotonic, instantaneous, time-independent non-linear function. Ground acceleration in vertical direction at Legnica Glogow copper mine could not be ascribed to any of the examined processes, probably indicating high level of instrumental or background noise. Moreover, results of surrogate data testing indicate the presence of colored noise, which is in such natural systems commonly expressed as additive noise.

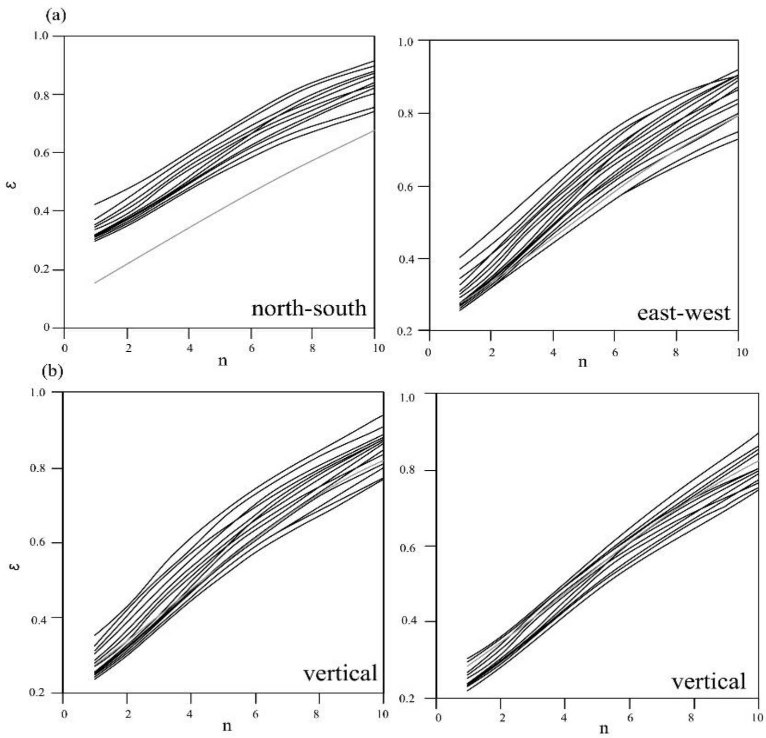

Figure 6 Surrogate data testing – III null hypothesis with AAFT procedure: (a) horizontal plane, location Upper Silesian coal basin; (b) vertical direction: Upper Sileasian coal basin (left) and Legnica Glogow copper mine (right). Gray line denotes the prediction error for the original time series (ε_0), while black lines denote error propagation for the surrogate time series (ε).

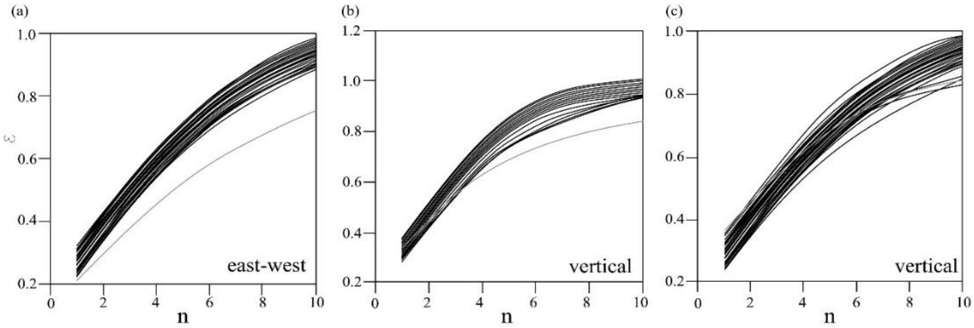

Figure 7 Surrogate data testing – III null hypothesis with iAAFT procedure: (a) east-west direction (Upper Silesian coal basin), (b) vertical direction (Upper Silesian coal basin); (c) vertical direction (Legnica Glogow copper mine). Gray line denotes the prediction error for the original time series (ε_0), while black lines denote error propagation for the surrogate time series (ε).

Determinism test, for the obtained embedding dimension and embedding delay, resulted in relatively low values of determinism factor κ=0.8, κ=0.6 and κ=0.76 for ground acceleration in NS, EW and V direction at Upper Silesian coal basin, respectively, and κ=0.6, κ=0.67 and κ=0.71, for the same directions at Legnica Glogow copper mine. As it could be seen, values of determinism coefficient are significantly smaller than 1, indicating relatively high level of stochasticity in the recorded ground acceleration time series.

Concerning the impact of variability of embedding dimension on determinism coefficient, additional analyzes confirmed that in the range of embedding dimension [2,11] determinism coefficient changes in the range [0.60-0.92], for Upper Silesia, and [0.67-0.92] for Legnica Glogow. Considering this, it is very important to determine the value of minimum embedding dimension in a proper way.

As a final step, we calculated largest Lyapunov exponent, using Wolf's method (1985) and Rosenstein method (1993). As it could be seen from Figure 8(a), largest Lyapunov exponent asymptotically approaches the negative value, indicating the absence of deterministic chaos in the system under study. In figure 8(b) according to Rosenstein method, curve S(Δn) shows sudden jump in the staring time t≈0 and it saturates very quickly with the increase of embedding dimension, indicating the stochastic nature of the analyzed ground acceleration time series. For this method to apply, we chose 1000 reference points, where each point is surrounded with minimum 10 points, while the distance between neighboring points is in interval ε=0.01-0.05.

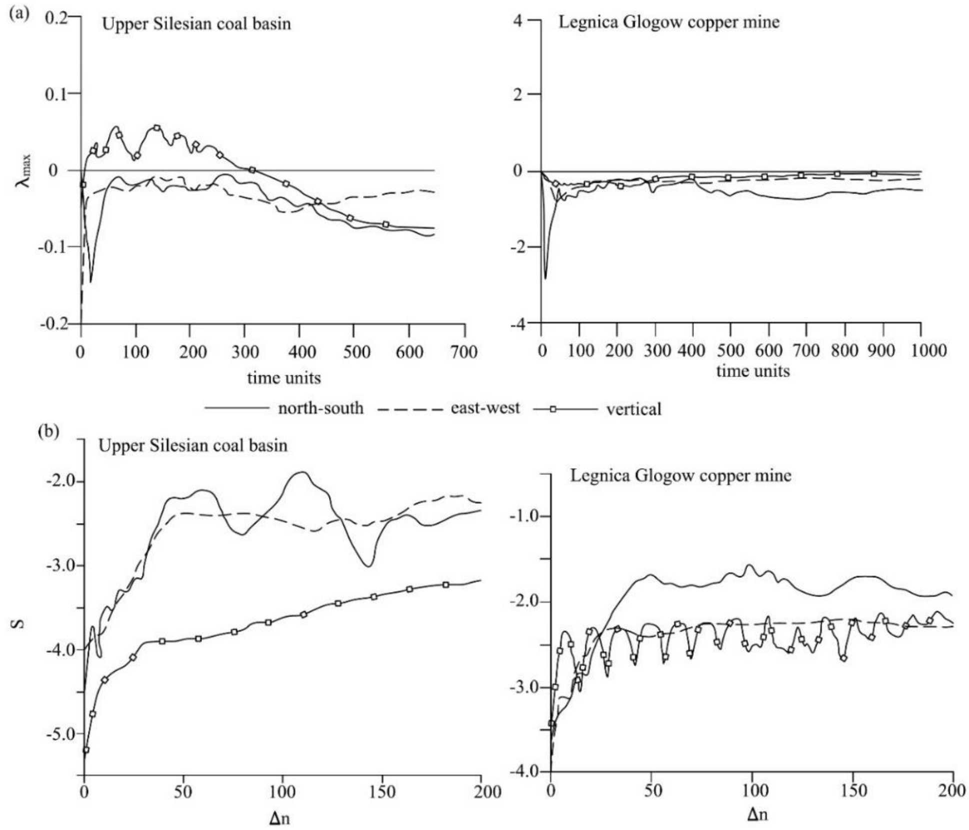

Figure 8 The largest Lyapunov exponent calculated according to Wolf's method (a) and Rosenstein method (b).

Based on the conducted research, one could derive general expression for estimation of mining-induced ground acceleration:

$$\dot{a} = Asin(\omega t) + Bcos(\omega t) - Ca(t) - a^3 + z(t)$$

$$dz(t) = -\frac{z}{\varepsilon}dt + \sqrt{\frac{2D}{\varepsilon}}dW \quad (1)$$

where A and B are Fourier coefficients, while parameter C controls the effect of autocorrelation properties on acceleration time history. Variable *a* stands for the mining-induced ground acceleration, while upper dot denotes the time derivative. Variable *z(t)* represents an Ornstein-Uhlenbeck process, and term $(2D/\varepsilon)^{1/2}dW$ represents stochastic increment of independent Wiener process. Colored noise generated by Ornstein-Uhlenbeck process with this parametrization is referred to as power-limited colored noise.

4 CONCLUSION

In present paper, we examined recorded ground acceleration induced by mining activities at two locations: Upper Silesian cola basin (M1.5) and Legnica Glogow copper mine (M2), both in Poland. Analysis was conducted for all three directions of acceleration: north-south, east-west and vertical. Aim of the analysis was to examine whether the recorded time series could be characterized as deterministic, stochastic, or they represent an example of deterministic chaos, to estimate the possibility of predicting the mining-induced oscillations. For this purpose, we applied a bundle of nonlinear time series analyzes, which resulted in following:

- we embedded the recorded time series into the appropriate phase space, by calculating the minimum embedding dimension and optimum embedding delay. Relatively high value of embedding dimension and the fact that the number of the nearest neighbors increase with the increase of embedding dimension could be treated as indications of strong stochasticity in the observed time series;
- none of the recorded ground series could be characterized as independent random numbers drawn from some fixed but unknown distribution;
- ground acceleration recorded in horizontal plane at Legnica Glogow copper mine could be characterized as stationary linear stochastic processes with Gaussian inputs
- ground acceleration recorded at Upper Silesian coal basin originates from a stationary Gaussian linear process that has been distorted by a monotonic, instantaneous, time-independent non-linear function
- ground acceleration in vertical direction recorded at Legnica Glogow copper mine could not be ascribed to any of the examined processes, probably due to high level of instrumental or background noise.
- All the examined time series are stationary (parameters of the system do not change in time), with all cross-prediction errors differing maximally by a factor of 2;
- Low determinism factor (0.7 and smaller) and negative maximum Lyapunov exponent, including the quick saturation of neighboring points distance with the increase of embedding dimension, indicate the absence of determinism in the recorded time series.

Results obtained indicate that ground acceleration time series induced by mining activities, for seismic events below M2, could not be reliably predicted. Instead, one needs to investigate the possibility of relating the peak ground acceleration and time series duration with the magnitude of seismic event. Also, it would be interesting to confirm the conclusions of this research for stronger seismic events (M>2).

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Original scientific paper

APPLICATION OF UBC METHODOLOGY FOR UNDERGROUND MINING METHOD SELECTION

Stojanče Mijalkovski[1], Zoran Despodov[1], Dejan Mirakovski[1], Vančo Adjiski[1], Nikolinka Doneva[1]

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Abstract: The total operating costs of each mine largely depend on the method of mining. Therefore, the appropriate choice of the method of mining excavation is very important and great attention is paid to this issue. There are several procedures for the selection of the mining method, among which the most important and most commonly used numerical method is the UBC methodology for the selection of the mining method. According to this methodology, the choice of the method of mining excavation is based on the mining-geological parameters of the ore and adjacent rocks. In this paper, the UBC methodology for the selection of the mining excavation method for a specific case will be applied. According to this methodology, it was obtained that Cut and Fill method is best ranked for specific conditions and the most appropriate way of mining.

Keywords: mining method, rational choice, UBC methodology, mining parameters, geological parameters

1 INTRODUCTION

When opening a new mine for underground exploitation or opening a new section in an already active underground mine, the correct choice of the method of mining excavation is of great importance. The correct choice of the method of mining excavation has the greatest direct impact on the total costs of exploitation of a given ore deposit, and thus affects the effect of the mine. The choice of the mining method depends on many parameters, and the more parameters are taken into account, the more adequate the choice of the mining method will be. The parameters that affect the choice of mining method can be divided into three groups (Bogdanovic et al., 2012):

- mining-geological parameters,

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- mining-technical parameters, and
- economic parameters.

Several authors have dealt with this issue, and it is widely believed that the procedure for choosing the method of mining excavation can be divided into rational and optimal choice of the method of mining excavation (Mijalkovski et al., 2021a).

In the rational choice of the method of mining excavation, the methods of mining excavation are distinguished according to the mining-geological parameters. The purpose of rational selection is to reduce the number of mining excavation methods, which will be considered later in the optimal choice. In the optimal choice of the method of mining excavation, the choice is made according to the mining - technical and economic parameters.

In practice, there are cases when mining-geological factors allow the application of a certain mining method of excavation, but its application is not economically justified. There are also cases that a certain way of mining excavation allows the use of certain mechanization, but this is not allowed by mining and technical factors (Bogdanovic et al., 2012). All this indicates complex and responsible work in choosing the method of mining excavation.

2 METHODOLOGY

Methodologies for the selection of the mining method (MMS) can be divided into three groups: qualitative methods, numerical methods and decision-making methods (Nourali et al., 2012). A comprehensive survey of literature on the first two groups can be found in Namin et al. (Namin et al., 2009).

The classification system proposed by Boshkov and Wright (1973), was one of the first qualitative classification schemes attempted for underground mining method selection. It uses general descriptions of the ore thickness, ore dip, strength of the ore, and strength of the walls to identify common methods that have been applied in similar conditions. Later, Morrison (1976), Laubscher (1981), Hamrin (1982, 1998), Hartman (1992), etc have suggested a series of approaches for mining method selection.

The first numerical approach for mining method selection was suggested by Nicholas (1981, 1992). This methodology numerically ranks deposit characteristics of ore geometry and rock mechanic characteristics of the ore zone, footwall and hanging wall. The rankings are then summed together whit the higher rankings being the more favorable or likely mining methods. In 1992 Nicholas made some modification to his selection procedure by introducing a weighting factor. The UBC (University of British Columbia) mining method selection algorithm developed by Miller, Pakalnis and Poulin (1995) is a modification to the Nicholas approach, which places more emphasis on stoping methods, thus better representing typical Canadian mining design practices (Miller et al., 1995).

Qualitative and numerical methods for selection of mining excavation method, selection of mining excavation method according to mining - geological parameters.

The most important mining-geological parameters that are taken into account when choosing a method of mining excavation are the following (Bogdanovic et al., 2012):

- geometry of deposit (general shape, ore thickness, dip, plunge, depth below the surface),
- rock quality (ore zone, hangingwall and footwall, i.e. rock substance strength, fracture spacing, fracture shear strength, rock quality designation, structures, strength, stress, stability),
- ore variability (ore boundaries, ore uniformity, continuity, grade distribution),
- quality of resource, etc.

In this paper, the UBC methodology will be applied to the selection of the most favorable method of mining excavation according to mining-geological parameters, ie the rational selection of a group of favorable methods for the exploitation of a certain ore deposit.

Ghazdali et al. In 2021, used the UBC to select the optimal mining method for shallow-dip vein deposits hosted in poor-quality rock (Ghazdali et al., 2021). Namin et al. In 2003, used the UBC for Mining Method Selection in Third Anomaly of Gol-E-Gohar Iron Ore Deposit (Namin et al., 2003). Ali and Kim in 2021, used the selection mining methods via multiple criteria decision analysis using TOPSIS and modification of the UBC method (Ali and Kim, 2021).

3 UBC METHODOLOGY

The UBC methodology for the selection of mining methods is a modified version of the Nicholas approach (Miller et al., 1995). This methodology was proposed by the University of British Columbia - Canada. The UBC methodology is primarily used for deep ore deposits to eliminate or limit the use of surface mining methods. Surface digging methods are quite diverse methods of excavation, which are seemingly always applicable excavation methods when the depth of ore deposits is not large.

The choice of mining methods according to the UBC methodology is a numerical ranking, to determine the method of mining or a group of excavation methods that are suitable for excavation of a given ore deposit. The choice of excavation method is based on:

- parameters for deposit geometry,

- grade distribution and
- mechanical characteristics of rock mass.

The adoption of parameters for the geometry of the ore body and grade distribution is done on the basis of the data shown in Table 1.

Table 1 Definition of Deposit Geometry and Grade Distribution (Miller et al., 1995)

General shape / width	equi-dimensional	all dimensions are on the same order of magnitude
	platy-tabular	two dimensions are many times the thickness, which does not usually exceed 35 m
	irregular	dimensions vary over short distances
Ore thickness	very narrow	< 3 m
	narrow	3 ÷ 10 m
	intermediate	10 ÷ 30 m
	thick	30 ÷ 100 m
	very thick	> 100 m
Plunge	flat	< 20º
	intermediate	20 ÷ 55º
	steep	> 55º
Depth below surface	shallow	0 ÷ 100m
	intermediate	100 ÷ 600 m
	deep	> 600 m
Grade distribution	uniform	the grade at any point in the deposit does not vary significantly from the mean grade for that deposit
	gradational	grade values have zonal characteristics, and the grades change gradually from one to another
	erratic	grade values change radically over short distances and do not exhibit any discernible pattern in their changes

The adoption of parameters for mechanical characteristics of ore, hanging wall and footwall is done on the basis of data shown in Table 2.

Table 2 Rock Mechanics Characteristics (Miller et al., 1995)

Rock Mass Rating (RMR)	very weak	0 ÷ 20
	weak	20 ÷ 40
	moderate	40 ÷ 60
	strong	60 ÷ 80
	very strong	80 ÷ 100
Rock Substance Strength (RSS)	very weak	< 5
	weak	5 ÷ 10
	moderate	10 ÷ 15
	strong	> 15

The UBC methodology for mining method selection classifies rock mechanics into two parameters, namely: Rock Mass Rating (RMR) and Rock Substance Strength (RSS). The Rock Mass Rating (RMR) consists of the Bieniawski's Rock Mass Rating (CSIR-1973).

This classification or ranking uses six input parameters that can be obtained from the research holes, and they are: strength of intact rock material, Rock Quality Designation (RQD), intermediate spacing of joints, condition of joints, ground water conditions and discontinuity orientation.

The Rock Substance Strength can be determined based on the value of the uniaxial compressive strength of the rock mass (σ_c, MPa).

The Fracture Spacing is defined by the number of fractures per meter and the RQD classification (Rock Quality Designation). Qualitative description of the rock mass fracture was obtained by defining the number of fractures per meter.

The Fracture Shear Strength is determined by observing existing fracture systems.

For a given ore body, it is necessary to adopt parameters for deposit geometry and grade distribution, and rock mechanic characteristics (ore, hanging wall and footwall) according to the divisions shown in Table 1 and Table 2.

Based on the previously mentioned parameters for the ore body, the following excavation methods are selected:

- Block Caving;
- Sublevel Stoping;
- Sublevel Caving;
- Room and Pillar Mining;
- Shrinkage Stoping;

- Cut and fill Stoping;
- Top Slicing;
- Square Set Stoping;
- Longwall Mining;
- Open pit Mining.

The choice of excavation methods is made in such a way that for each method of excavation special point values are adopted, the sum of which gives the point value which is entered in a special table and on the basis of those point values the mining method selection. It should be noted that this methodology does not choose the mining method for excavation, ie it does not favor any of the mining methods used in the excavation of a given ore body. The purpose of this selection is to single out all the favorable methods of mining excavation which, based on the characteristics of the ore body shown in Table 1 and Table 2, stand out as the most efficient. The efficiency of a certain method of mining excavation, according to the mentioned methodology, is defined by the total point value. The highest total value of points indicates the most efficient method of excavation. According to this principle, the methods of mining excavation are ranked and the results are shown in the table.

In case any method of excavation has a negative total point value, it should be eliminated as an unacceptable method of excavation of a given ore body.

The method of excavation, which has a total point value of zero (0), is not excluded, but its use for excavation of a given ore body is not recommended.

The group of possible excavation methods consists of excavation methods with total point values higher than the stated ones (conditionally less than 23)**.**

The group of favorable excavation methods consists of excavation methods with total point values greater than 23 and which do not differ significantly from each other.

Excavation methods differ based on the cost of excavation, with some excavation methods low and some high (Balt and Goosen, 2020). The comparison of the relative cost of excavation, for individual excavation methods, is based on the fact that each of the excavation methods is applied in conditions that suit it. For this purpose, it is necessary to take into account the mining-technical and economic factors, ie to make the optimal choice of the method of mining excavation (Mijalkovski et al., 2021a).

4 CASE STUDY

This paper examines the active underground mine of lead and zinc, where a new part is opened and it is necessary to choose the appropriate method of excavation (Mijalkovski et al., 2021a; Mijalkovski et al., 2021b). The input data for the ore deposit are given below.

Geological factors

- The platy-tabular lead-zinc ore body;
- The surrounding rocks: footwall – slate and hanging wall – slate;
- The average thickness of the ore body is 15 m (thickness ranges from a few meters to 30 meters);
- The average plunge is 37° (from 25 to 49°);
- The depth below surface is 500 meters;
- The grade distribution is erratic.

Rock mechanics characteristics

Mechanical characteristics of the ore

- Volume mass of ore is 3,5 tons per meter cubic;
- The average compressive strength of the ore is 93 MPa (the compressive strength ranges from 46 to 140 MPa);
- The average number of fractures per meter is 4 (the number of fractures per meter ranges from 3 to 5);
- The average value of the RQD index is 67% (the value of the RQD index ranges from 64 to 70%);
- The average value of the RMR index is 74%;
- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength

Mechanical characteristics of the hanging wall

- Volume mass of hanging wall (slate) is 2,7 tons per meter cubic;
- The average compressive strength of the hanging wall is 78 MPa (the compressive strength ranges from 31 to 125 MPa);
- The average number of fractures per meter is 9 (the number of fractures per meter ranges from 8 to 10);
- The average value of the RQD index is 58% (the value of the RQD index ranges from 56 to 60%);

- The average value of the RMR index is 75%;

- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength.

Mechanical characteristics of the footwall

- Volume mass of footwall (slate) is 2,7 tons per meter cubic;

- The average compressive strength of the footwall is 79 MPa (the compressive strength ranges from 33 to 125 MPa);

- The average number of fractures per meter is 8 (the number of fractures per meter ranges from 6 to 10);

- The average value of the RQD index is 59% (the value of the RQD index ranges from 58 to 60%);

- The average value of the RMR index is 76%;

- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength.

Based on the given input data on the deposit geometry and grade distribution, and rock mechanical characteristics of the ore and adjacent rocks (hanging wall and footwall), Table 3 is completed.

Table 3 Input data for mining method selection according to UBC methodology

Parameters for the deposit geometry and grade distribution	
General shape	platy-tabular
Ore thickness	intermediate
Plunge	intermediate
Depth below surface	intermediate
Grade distribution	erratic
Rock mechanical characteristics	
Ore	
Rock Mass Rating (RMR)	strong
Rock Substance Strength (RSS)	moderate
Hanging wall	
Rock Mass Rating (RMR)	moderate
Rock Substance Strength (RSS)	moderate
Footwall	
Rock Mass Rating (RMR)	moderate
Rock Substance Strength (RSS)	moderate

As it is an underground lead and zinc mine, i.e. underground exploitation of metal mineral raw materials, the mining methods of excavation is not taken into account: Longwall Mining and Open pit Mining.

After the calculation according to this methodology, the following order was obtained for the methods of mining excavation (Table 4):

Table 4 Ranking of mining methods according to UBC methodology

Serial number	Mining method	Total value points	Rank
1	Block Caving	20	6
2	Sublevel Stoping	35	2
3	Sublevel Caving	23	4
4	Room and Pillar Mining	21	5
5	Shrinkage Stoping	25	3
6	Cut and Fill Stoping	36	1
7	Top Slicing	14	7
8	Square Set Stoping	13	8

Table 4 shows that the Cut and Fill Stoping method has the highest value (Figure 1), which is the most efficient method of excavation.

The first four best ranked methods of mining excavation can be singled out as favorable methods of mining excavation for application in this case. The group of favorable mining methods includes the following mining methods:

1. Cut and Fill Stoping,
2. Sublevel Stoping,
3. Shrinkage Stoping
4. Sublevel Caving.

These methods of mining excavation can be taken into account in the optimal choice of mining methods based on mining-technical and economic factors, which will be the subject of research in the next study.

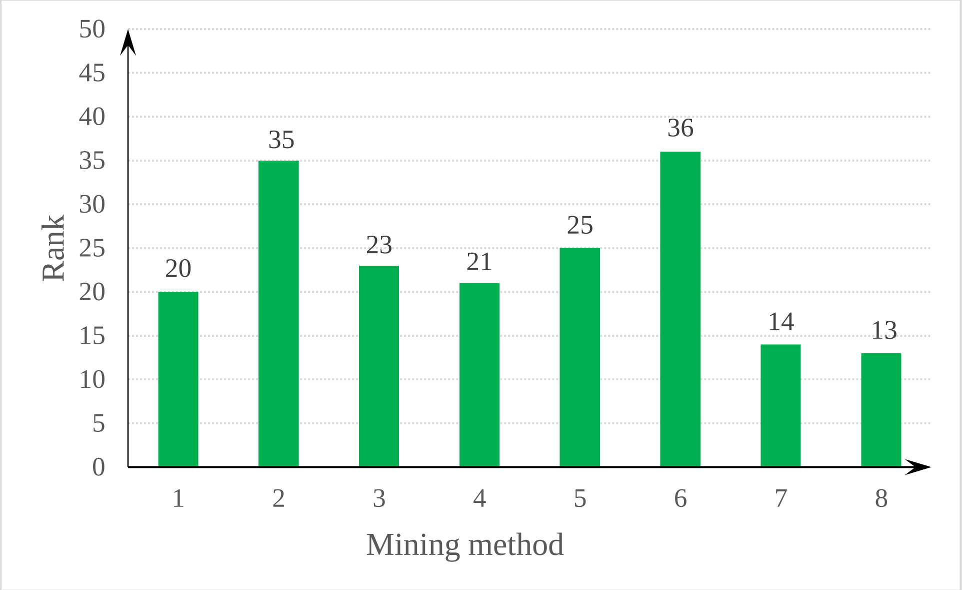

Figure 1 Ranking of mining methods

5 CONCLUSION

The financial effects that are achieved during the operation of each underground mine, largely depend on the applied method of mining, therefore it is of great importance for the correct choice of the method of mining. A number of authors have dealt with this issue, and the common opinion of most authors is that the choice of the mining method consists of two phases: rational and optimal choice of the mining method.

There are several procedures for the rational choice of mining methods, i.e. the choice of mining methods according to mining and geological factors, such as: procedure according to Boshkov and Wright, Morrison, Nicholas, Laubscher, Hartman, UBC etc.

This paper uses the UBC methodology of rational choice of the mining method, which represents the numerical ranking of mining methods and determining the most efficient method of excavation, as well as a group of favorable methods for excavation of a given ore body.

We have singled out the four best ranked mining methods as favorable mining methods for application in this case and can be used for the optimal choice of the mining method, which will take into account mining-technical and economic factors. Multi-criteria optimization methods can be used for optimal selection of the mining excavation method.

Multi-criteria optimization methods enable the choice of the method of mining excavation, taking into account a number of influencing factors, and thus enable the selection of the most appropriate method of mining excavation for a specific case, which will be the subject of research in the next study.

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EXAMINATION OF INFLUENCE SINTERING TEMPERATURE ON MINERAL COMPOUNDS

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Abstract: Mineral materials, such as corundum, quartz and periclase are very often used in technological processes. Due to its characteristics, and chemical reaction in solid state, these minerals form very interesting and useful material, cordierite. The mineral ratio in this compound (MgO : Al_2O_3 : SiO_2) is 2:2:5. They form cordierite, electronic ceramic, which can be sintered in a narrow temperature range, at about 1375 °C. Composition of this electronic ceramics material is is 2MgO-$2Al_2O_3$-$5SiO_2$ (MAS) and in this research 20% mass Bi_2O_3 was added in the aim of decrease the sintering temperature. The effects of sintering, the composition and morphology were followed by x-ray diffraction, scanning electron microscopy and EDS analysis, as a function of sintering temperature. MAS ceramics were sintered at 1000ºC, 1100ºC and 1200ºC.

Keywords: Ceramics, cordierite, x-ray diffraction, SEM, EDS

1 INTRODUCTION

Cordierite ($Mg_2Al_2Si_50_{18}$) is a very rare mineral in nature and where it occurs, it is found in small quantities. According to the systematization, based on the chemical composition, it belongs to the group of silicates. It is characterized by a low coefficient of thermal expansion, low electrical conductivity, high resistance to thermal shocks and high fire resistance (Babič, 2003). One of the applications of cordierite is the production of cordierite ceramics obtained from natural minerals such as talc, quartz, corundum, minerals of high-refractory clays, magnesium carbonate (Aćimović Pavlović et al., 2007). Due to its good properties, the application of cordierite has been constantly growing, so it was necessary to synthesize it in industrial conditions from oxides.

Magnesium oxide, MgO, occurs in nature in the form of periclase minerals. It is part of contact metamorphic rocks. It can be obtained from magnesite, $MgCO_3$, or dolomite

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CaMg $(CO_3)_2$. It is characterized by a high melting point of 2800 °C. That is why it is one of the components of refractory bricks (Babič, 2003). Al_2O_3 alumina is dehydrated alumina. They were obtained by the basic Bayer process, which consists of leaching bauxite with NaOH solution and subsequent separation of leached alumina. Alumina has a high melting point of 2072°C, so it is used as an insulator in blast furnaces (Vračar and Živković, 1993).

Quartz sand, SiO_2, is an unbound, loose rock, which basically consists of quartz grains. The use and quality of quartz sand are defined by its size, ie granulometric composition, then physical properties, as well as mineral and chemical composition. Quartz sand has a very large and wide application in various industries. Most of the produced quartz sand of different quality is used in construction (90-95% of world production). The remaining 5-10% is used in the industry of glass, ceramics, refractory bricks, then in certain metallurgical processes for obtaining metals and non-metals, in foundry, in the abrasive industry, chemical industry, etc. (Pavlica and Draškić, 1997).

Bi_2O_3 is added in order to lower the sintering temperature of cordierite ceramics. Bi_2O_3 is bismuth, one of the forms of bismuth in the Earth's crust, in addition to bismuth Bi_2S_3. Bismuth can also be formed as a by-product of extraction from ores of other metals such as ores of lead, copper, tin, molybdenum and tungsten. Bismuth oxide is used not only as an aid in sintering in technical ceramics, but also for the production of optical glasses and glass (Ojebuoboh, 1992; Klinikova et al, 2007).

Cordierite is material based on corundum, quartz and periclase. Sintered on high temperature (above 1350 °C) they make a chemical compound which have unique properties, such as low dielectric constants (~5) and low thermal expansion (20·10-7/ºC) (Moftah El-Buaishi et al., 2012). These properties make them suitable for a wide range of high-temperature applications. Due to remarkably properties, the uses are wide: catalytic converters, thermal insulation, components of portable electronic devices, kiln furniture. These properties make them suitable for a wide range of high-temperature applications (Obradović et al., 2012; Obradović et al., 2016) and semiconductors (Wadsworth and Stevens, 1992; Obradović et al., 2015; Obradović et al., 2016).

Cordierite is difficult to sinter because of the very narrow sintering temperature range (Obradović et al., 2012; Tumala, 1991) (1300-1400ºC). Because a low temperature process is desirable, it is necessary to found a functional adds which can allow easier process of sintering at lower temperature. The melting temperature of this aid should be lower than that of the precursors. In addition, the cationic radius should be much larger than the radius of the metals in MAS to avoid the substitution into cordierite sites. Different components have been used as sintering aid: Cr_2O_3, ZrO_2, K_2O, B_2O_3, TiO_2, Bi_2O_3 etc. (Knickerbocker et al., 1993; Djordjević et al., 2012). Bi_2O_3 has necessary criteria to form a liquid phase and support cordierite sintering, such as large radius and low melting temperature (825ºC). Bismuth oxide forms eutectics with magnesium, aluminum and silica.

2 EXPERIMENTAL PROCEDURE

During this research following components were used: MgO (Euro Hemija, Belgrade), Al_2O_3 (Aluminijumski kombinat, Podgorica), SiO_2 (Bela Reka) and Bi_2O_3, p.a. (Reahim, Rusia). Chemical composition of starting compounds is given in Table 1. Three-component system MgO-Al_2O_3-SiO_2 has 2-2-5 compositions, and the amount of 20% Bi_2O_3 was added to the MAS system.

Table 1 Chemical composition of the raw materials

	incineration loss %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %
Al_2O_3	0,18	0,17	99,19	0,089	0,07	0,049	0,236	0,012
MgO	-	-	-	-	1,40	98,60	-	-
SiO_2	2,22	96,10	0,14	0,243	0,112	-	0,047	1,16

In the aim of homogenization of the powders, each mixture has been melted in the laboratory cylindrical mill with ceramic balls, model 13x10,5”, producer by VEB, during 5 minutes. Sintering samples were prepared in the tablet shape, with radius 8 mm and height 4 mm, pressuring under the pressure of 1t/cm^2. Sintering temperatures of the system were 1000 ºC, 1100 ºC and 1200 ºC.

X-ray powder diffraction (XRPD) technique was used for identification and definition of the unit-cell parameters. XRPD analysis was performed using the Philips PW1710 diffractometer; with Cu Kα radiation (40kV, 30mA), step scan 0.25s, 0.02° 2θ, *d* range from 5° to 85°2θ.

The microstructures of the sintered samples were observed using scanning electron micrograph (SEM) “Joel” with microsonde (increasing range 500, 1000, 2000, 10.000 and 20.000x). SEM and energodispersion elementary analyses were done on the sintered sample fracture.

3 RESULTS AND DISCUSSION

$MgO \cdot Al_2O_3 \cdot SiO_2/Bi_2O_3$, sintering temperature: 1000 ºC and 1100 ºC

X-ray diffraction analyses of the system $MgO \cdot Al_2O_3 \cdot SiO_2$ with 10% Bi_2O_3 sintered at 1000ºC did not show the presence of cordierite (Fig 1). Based on the analysis and the obtained results, it is concluded based on the presence of $MgSiO_3$ (enstatite) that the sintering process started (according to the formation of this interphase compound), but that not enough temperature was reached for the formation of cordierite.

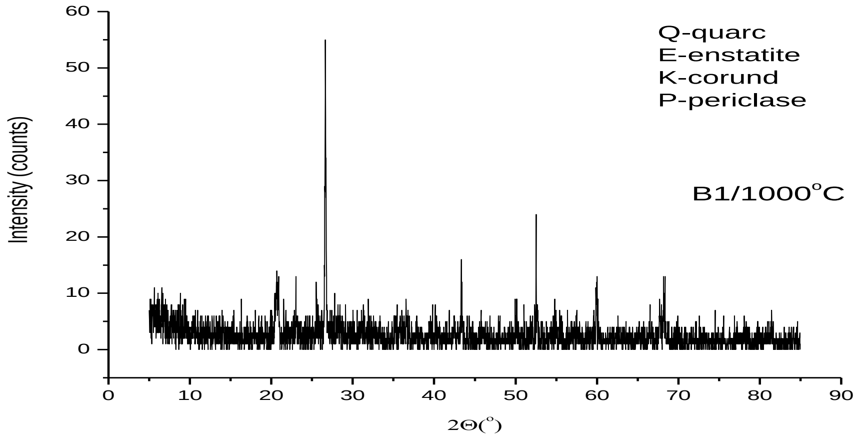

Figure 1 X-ray diffractograme of MAS/Bi2O3 sintered at 1000ºC

The X-ray diffraction analyses of the system sintered at 1100ºC (MAS/ Bi_2O_3) showed the reflections of low intensity characteristics for cordierite (in the Figure 2. the picks marked with star). The microphotographs of the sample MAS/Bi_2O_3 sintered at 1100ºC showed continual structure with hollows (Figure 2.). The present lonely grains are probably untreated components from the starting mixture. SEM showed that at the sintering temperature the homogenous structures in morphological sense were produced, EDS analyses proved the same (Fig. 4. and 5. shows the intensity of the elements present based on EDS analysis, as well as mass % and atomic %).

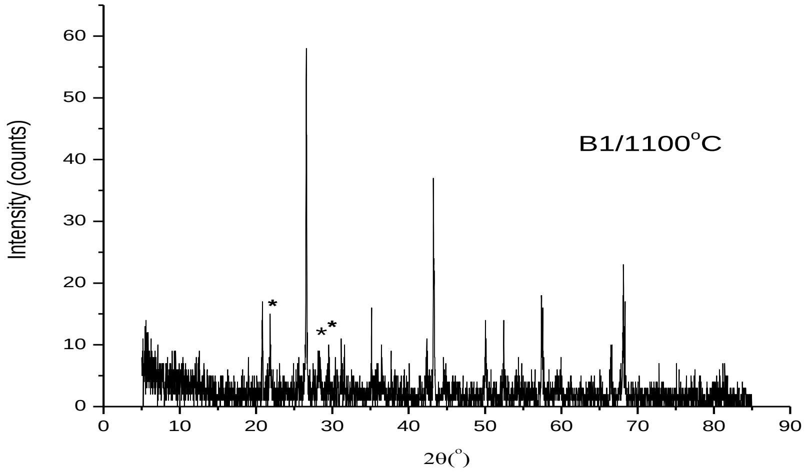

Figure 2 X-ray diffractogram of MAS/Bi_2O_3 sintered at 1100ºC

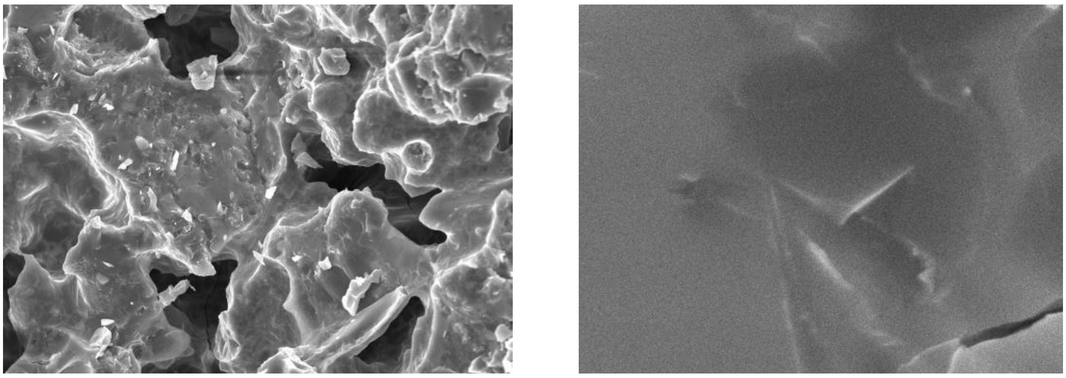

Figure 3 SEM microphotographs of the sample MAS/Bi_2O_3 sintered at 1100ºC (1000x and 20000X)

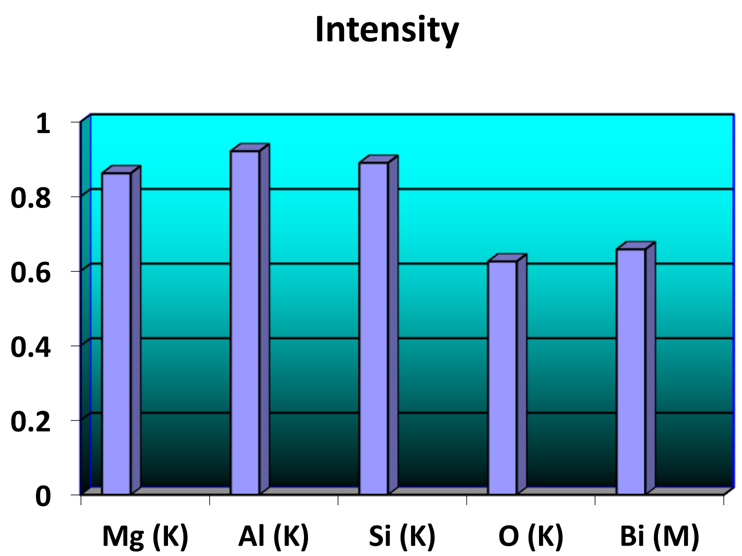

Figure 4 EDS MAS/Bi_2O_3 at 1100ºC, Intensity

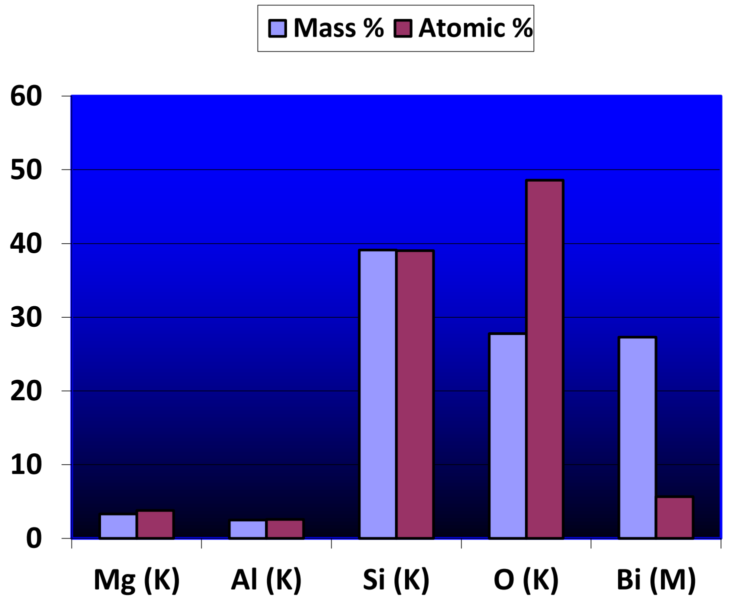

Figure 5 EDS MAS/Bi_2O_3 at 1100ºC, Mass % and Atomic %

$MgO \cdot Al_2O_3 \cdot SiO_2/Bi_2O_3$, sintering temperature: 1200ºC

After the sintering process of MAS/Bi_2O_3 system, at 1200 ºC, X-ray diffraction analyses showed the presence of indialite, which is the hexagonal form of cordierite.

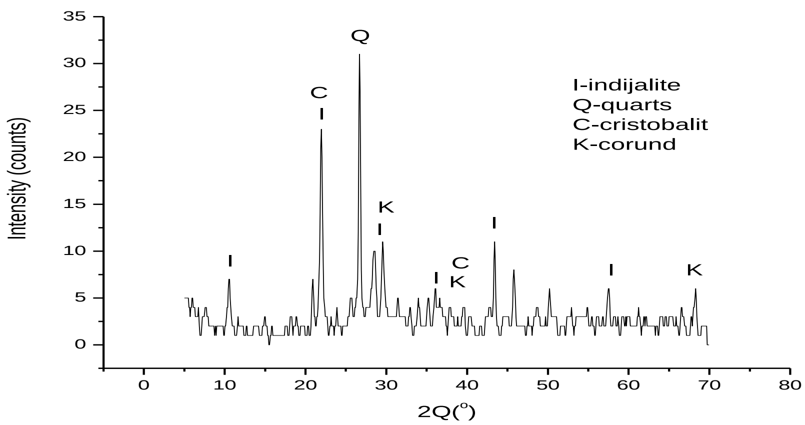

Figure 6 X-ray diffractogram of MAS/Bi_2O_3 sintered at 1200ºC

Beside the indialite, the presented phases in the sample were quarts, cristobalite and corund. The results of analysis indicate that the presence of Bi_2O_3 has enabled chemical reaction between the components. Although a temperature of 1375 ºC is required to obtain the final product, thanks to the presence of a liquid phase (bismuth oxide melts at 820 ºC) which enabled contact between the components that form cordierite, the form of the final product (indiate) was obtained.

The presented X-ray diffraction analyses of the MAS sample with 10% Bi_2O_3 sintered at 1000ºC, 1100ºC and 1200ºC did not show the presence of unstable compounds that were found by analysis of the samples MgO/Bi_2O_3 and Al_2O_3/Bi_2O_3. Bi_2O_3 is primary added as functional component to provide flux phase in the sintering system. In the more-component system, Bi_2O_3 obviously makes intermediary compounds and transports the ions (Mg^{2+} and Al^{3+}) to SiO_2. At this way, Bi_2O_3 can make influence on the mechanism of the reaction in the complex system.

4 CONCLUSION

In the aim of researching the reactions of cordierite synthesis, MgO, Al_2O_3, SiO_2/Bi_2O_3, sintered at 1000ºC, 1100ºC and 1200ºC. The results showed existing of the liquid phase at 820ºC (the melting temperature of Bi_2O_3). The unstable compounds defended through the liquid phase, which allowed (from the two aspects) the acceleration of the reaction in the more-component system.

Sintered MAS system with Bi_2O_3, the presence of cordierite was detected. The lowest temperature on which indialite was detected (the hexagonal form of cordierite) was 1100ºC. At 1200ºC indialite was the most presented component. With this research it was shown that presence of Bi_2O_3 in the starting MAS mixture decrease the sintering temperature for ~170ºC, comparing the temperature of forming cordierite ceramics from the mixture without functional adds.

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Review paper

REDUCING ENVIRONMENTAL IMPACT CAUSED BY MINING ACTIVITIES IN LIMESTONE MINES

Radmila Gaćina[1], Bojan Dimitrijević[1],

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Abstract: Mining and its related activities have always resulted in changes in the environment and these changes can vary from one area to another. As a result of mining, several types of changes can be distinguished: destruction of land and existing vegetation, changes in terrain topography, modification in air quality, changes in surface and groundwater quality, as well as change geotechnical conditions of the rock. Environmental impact of mining has been a public concern. There is widespread global interest in mining and its sustainability, and it is focused on the need to shift mining industry to a more sustainable framework. This article describes the possibilities of how to reduce the environmental impact of limestone excavation. Successful closure must consider medium to long term post mining land use and land capability, as well as minimizing environmental impact.

Keywords: environmental impact, mining, degraded surface, sustainability, recultivation

1 INTRODUCTION

Over the last two centuries, the Earth's surface has changed significantly due to the human activities. Several factors such as ecological crises, governmental decisions, and local authorities, affect land use changes. Land use/land-cover changes might have positive or negative effects on natural resources at local and global scale (Mialhe et al., 2015; Mousivan and Arsanjani, 2019).

One of the most important and basic foundations of any country's economy is its mineral resources (Sekerin et al., 2019). The role of mines in economic growth is very serious and strategic, and the exploitation of the country's mines is an undeniable necessity in economic development (Firozjaei, et al., 2021). Many people are working in this big industry, and it can be recognized that the mining industry in every country has a significant impact on social welfare. The adverse effects of mining on our environment are not hidden from anyone. However, to balance these three sectors, economic growth,

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social welfare and reducing environmental disorders, we are required to enter sustainable development in this industry.

Mining activity is such that it has externality effects (Papagiannis et al., 2014). These effects will arise when a company or individual engages in an activity that directly affects others, positively or negatively, but does not pay or receive money for it. This means that the individual or company creating the externality effect does not include the costs or benefits of doing so in its cost benefit calculations.

The mining industry uses many natural resources, such as water, soil and minerals. While it is a vital industry which contributes to the economy of many countries, it can be damaging to the environment. The first step in solving this challenge is to identify the adverse effects of mining activities on environmental conditions in surroundings and the social planner should try to make the level of activity of the company at the optimal level of society.

In some studies, satellite images have been employed to monitor and assess the effects of anthropogenic activities on surface biophysical characteristics state (Estoque and Murayama, 2017; Moghaddam et al., 2018). Satellite data offer several advantages, such as being multi-temporal and multi-spectral, and cover extensive areas, that make them suitable to study and explore dynamic phenomena. With the advent of Geographical Information System (GIS), many mining activities (from exploration to stope development, and production to mine recultivation and rehabilitation) instead of old paper drawing now can create layers and composite images.

GIS replaced old map-analysis processes, traditional drawing tools, and drafting and database technologies.

Soil destruction and deforestation are two most crucial environmental impacts of open pit mining activities. Surface mining speeds up erosion and sedimentation and short duration, high intensity storms can be a violent force moving thousands of tons of soil. Physical characteristics of the overburden, degree and length of slope, climate, amount and rate of rainfall, type and percentage of vegetative ground cover affect the vulnerability (Goldan et al. 2020).

The environmental problems facing mankind in the 21st century are global climate change, natural resources depletion and also ecosystem degradation (Kittipongvises and Polprasert, 2016).

Despite the growing importance of mineral extraction and mining production, there has been an increasing concern over environmental impacts associated with the exploration, extraction and use of mineral product (Norgate and Haque, 2012; Liu et al 2015; Morrow et al 2014). This makes environmental sustainability in the mining decisive (i.e. economic, environmental and social dimensions).

2 A BRIEF OWERVIEW OF CLOSURE PRACTISE

Serbian legislation governing mine closure, Act of Mining and Geology "Official Gazette RS", 101/2015, 95/2018 and 40/2021 requires mitigation of both biophysical and socio-economic impacts.

„The holder of exploitation is obliged to recultivate the land in the course of and after the completion of works on exploitation, and no later than one year from the day of completion of works on the areas where mining works have been completed, according to the technical project of technical and biological reclamation“.

Act of Land Protection (112/15), „Land reclamation is carried out on polluted and degraded surfaces for re-formation of the soil layer and establishment plant communities on the areas where the exploitation took place mineral resources, failed afforestation, as in the case of elemental disasters, fires and other anthropogenic influences“.

Post-mining regeneration priorities in Serbia include:

• restoration of land surface of sufficient quality to support pre-mining land use potential,

• restoration of the ecological function of mined land and in the case of previously degraded land, the ecological function must be improved,

• efficient alternative use of mine infrastructure should be encouraged where this can be economically justified; where no economic alternative uses exist, mine infrastructure must be removed and the site rehabilitated to pre-mining condition,

• Minimization of current and potential future impacts on water quality and supply,

• development projects to enable equitable participation in post mining economies by all members of the community, especially marginalized groups,

• enhancement of leadership capacity within the community and local government.

As the process of environmental degradation approaches a critical point, it is necessary to increase the efficiency and quality of work on the protection, restoration, and improvement of the environment.

3 IMPACT IDENTIFICATION

Identification of possible impacts of the limestone exploitation project is an analysis of the relationship between surface mining - environment and is based on knowledge of the characteristics of the selected technology of surface exploitation of mineral resources and knowledge of the basic ecological potentials of the analyzed area (Figure 1.)

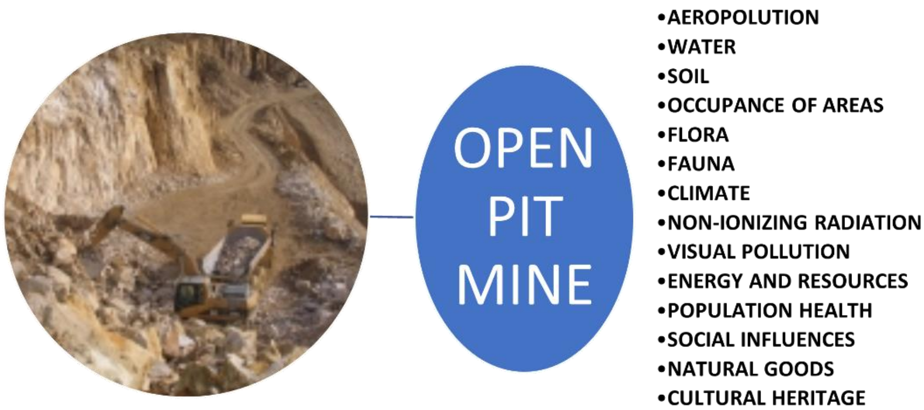

Figure 1 Relationship between the open pit and the environment

3.1 The Matrix of environmental impacts in the pilot site

Programs that address the reduction and control of environmental impacts in small scale mines generally rely on the experience and expertise of a project manager in order to identify the most important variables to be controlled and set objectives.

This Matrix method of evaluation as selecting objectives and goals, and giving relevance for different environmental impacts, improving reducing the level of subjectivity, and through the promotion of local stakeholder participation.

Table 1 Mining environment categories and impact factors

	Limestone Mining Environment	Impact factors
1	Health of humans	Land dispossession and potential funds
2	Social quality of life	Exposure, visibility of open pit
3	Air pollution	Atmospheric release of gas and dust
4	Water pollution	Above and underground water pollution
5	Soil Erosion	Increase in vehicular traffic
6	Loss of Biodiversity	The livelihood of the local workers
7	Aesthetic degradation	Vibration of ground
8	Noise pollution	Level of Noise
9	Economy	GDP Contribution

Every activity needs to be classified according to parameters with the summation indicating its significance for the environment. Variables with higher likelihood to cause environmental impact thus were given a higher priority. Every variable (mining activity) carries a potential environmental impact. To compose the matrix, a flowchart of the mining process in the area needs to be evaluated step by step. A summary of the variables is given in Table 2.

Table 2 List of mining activities with potential impacts on environment

#	Activities	#	Activities(continuation)
1	Surveying of deposit	9	Preparation refilled pit for revegetation
2	Removal of vegetation	10	Drainage of the mine
3	Transportation of equipment	11	Waste disposal
4	Installation of generator and motors	12	Revegetation
5	Excavation	13	Fertilization of vegetation
6	Drilling and Blasting	14	Fighting against pests and diseases
7	Preparation of limestone	15	Infrastructure objects (roads)
8	Backfilling old pits	16	Motors and pumps maintenance

4 LAND REMEDIATION

Land use must be decision to be made by society. Society can decide to change the land use on a rehabilitated area to housing or industrial estates, but mines have an obligation to ensure that no net loss in land capability occurs. This is primary objective in rehabilitating exploited land. Society is deprived of choice where land capability is not preserved, degraded lands can potentially support less land uses.

Agreements with communities regarding land use can be made prior to rehabilitation whereby a lower quality of rehabilitation is acceptable. For example, if the pre-mining land capability is tillable land, but the community is satisfied with grazing as a post-mining land capability. Such decisions do not promote sustainability even when are based on community preferences. Ground formation takes thousands of years and restoring a fraction of the original land capability, future generations are left of no choices that are available to this generation.

Remediation does not necessarily mean restoring the area to its original conditions. Rather is aimed at redeveloping the area to make it available for public use (naturalistic, sports purposes, educational or even scientific) or for other uses, yet with the focus always on sustainable development. Extraction operations in limestone open pit mines are the means to promote industrial activities for which social progress is an indispensable necessity.

5 CONCLUSION

In general, exploitation of limestone can cause serious damage to the environment near a mine area. Therefore, activities such as research, planning, design, and exploitation of surface mines are of exceptional importance from the aspect of preservation and protection of the environment.

Effects of mining on the environment are usually noticed after some years. Many environmental challenges such as land degradation soil erosion, noise, dust, toxic gases, and pollution water are created as result of the exploitation of the mine. Open pits affect local biodiversity, changing topography and vegetation. Drilling and blasting operations as well as application of heavy vehicles are very important to environmental effects because these operations generate noise, vibration, and dust.

Depending on the technology used and the mining methods adopted, mining activities can have significant consequences on environmental degradation and industrial pollution. Mining dumps of overburden are frequently the principal source of solid waste and can cause the contamination of ground and surface waters with toxic chemicals.

Workings performed for extracting limestone in open pits are small-scale developments but can lead to significant degradation of the surrounding terrain and waste dumps resulting from this activity.

Our research indicates a significant and negative impact of the mine activities up to the present time and how it will be continued in future. In last ten years, significant parts of natural areas were converted to mine lands and mining activities that reduced vegetation cover and increased land surface temperature. Combination of information obtained from satellite images increases the accuracy of modeling the soil characteristics and the impact of mining activities on the surface biophysical characteristics. In the other hand, predicting the effects of mining activities can significantly affect alter the surface biophysical characteristics. The application of predictive models has insights about the future changes in the ecosystem and taking protective measure against the unplanned and undesirable situations.

To lessen their impact on the environment, mining companies should look into using sustainable equipment and waste disposal procedures, implementing pollution control measures. They should also consider replenishing the local environment as often as possible, which will make the surrounding area habitable and able to return to a natural state once the mine has closed. Reducing both input and output of the mining process can also help to reduce the negative impact that mines have on the environment and local neighboring community.

There is need to furtherance environmental awareness and/or education in mining ambience and ensuring sustainable use of the environment in the face of on-going mining activities. This will create certain balance between development/economic growth and environmental requisites for community livelihoods.

The most important thing is to understand the system requirements and specifications and to address human interface issues to improve component and system reliabilities and minimize the occurrence of environmental negative impacts.

The above recommendations will help reducing and prevent the environmental impacts that disturbs the sustainability of the mining and environmental policies towards achieving environmental sustainability in Serbia.

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Review paper

SUSTAINABLE DEVELOPMENT AND NATURAL RESOURCES EXPLOITATION - BRIEF REVIEW

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Abstract: Natural resources are limited and uncontrolled exploitation can have negative effects on the environment. It is necessary to find approach of their sustainable use. Sustainable development is the framework for defining strategies of continuous state and social progress, without harm to the environment and natural resources essential for human activities in the future. Model that regulates sustainable use considers strategies and legal regulations for exploitation of natural resources and energy. Goal is to ensure the sustainable use of natural resources at national and global level. Sustainable use of natural resources is directly related to environmental protection. Also, the preservation of the working and living environment is related to the degree of economic development and the level of education of the population about the importance of a healthy environment and the way of its preservation. Accelerated technological development leads to an improvement in the quality of life in all spheres of human activity, but in parallel, it creates the possibility of greater environmental degradation. Therefore, it is necessary, within the goals of the development policy of the society, to include the correct criteria that will contribute to sustainable development. Thus, we contribute to preserving the environment and balance of natural ecosystems.

Keywords: natural resources, sustainable development, environmental protection

1 INTRODUCTION

The sustainable development concept was created with the aim of preserving the environment so that all partial measures and separate politics have united and thus give a better result. How complex is sustainable development concept and what are its based pillars is shown graphically in the figure 1 (Mihajlovic et al., 2018; https://mrbgeography.com; Mensah, 2019).

In 1980, the International Association for the Environment and Natural Resources Protection developed an environmental strategy with primary aim of achieving sustainable development through natural resources protection. Later, The World

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Commission on Environment and Development, known as Brundtland Commission, (Strbac et al., 2012), has taken over this concept. In 1987, the Brundtland Commission prepared a report called Our Common Future. Emphasis was placed on politically more acceptable idea of sustainable development than those ideas promoted in the 1972 in "Limits to Growth", (Milenovic, 1996). However, "Limits to Growth" idea which was based on resource wasting and possible limits to growth, drew attention to a wide range of global, scientific and political public. The concept sustainability strategies define the problem of goods and natural resources exploitation by species, spatial distribution, diversity, scope and quality. Besides, the balance categories are determined and condition changes, valuation method and conditions of sustainable use are predicted, (Pesic, 2002; Ilic, Mihajlovic and Omanovic, 2016). Definitions of natural resource sustainability and sustainable development can be classified into six groups, (Boskovic, 2015; Perman et al., 1999): 1. The natural resources sustainability is a condition in which the usefulness (or consumption) of resources does not decrease over time; 2. The natural resources sustainability implies resource management in such a way that their production capabilities are not diminished over time; 3. The natural resources sustainability means that there is no resource reserves decrease over time; 4. The natural resources sustainability means managing them in such a way to maintain a sustainable yield, ie. the effect of their use; 5. Sustainability implies providing a minimum of ecosystem stability conditions over time and 6. Sustainable use of resources and sustainable development are the capacity for achieving wide consensus.

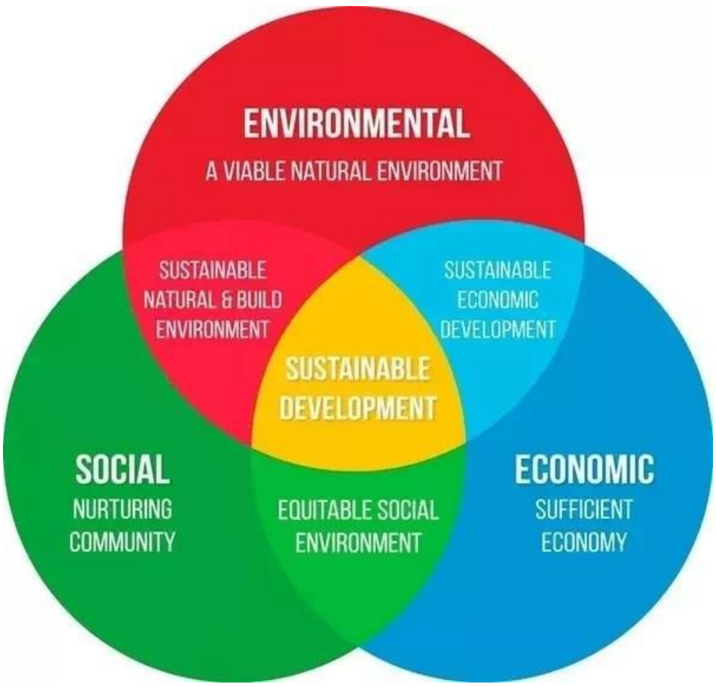

Figure 1 Pillars of sustainable development

In order to natural resources, as key elements of the environment, have sustainable use, it is necessary to fulfill certain conditions, (Boskovic, 2015; Goodstein, 2003; Milenkovic, 2006): 1. Development and preservation of all environmental elements and a complete turn in changing trends in their exploitation; 2. Greater efficiency of economic and ecological processing of environmental elements and always considers them as the basic wealth of humanity; 3 Quick but careful acceptance of technical and technological developments in the collection and quality environmental information processing and 4. Eliminate inappropriate activities of people in the environment as soon as possible, which could reduce the socio-economic efficiency of that environment in the future.

Environmental protection and sustainability of natural resources are common and priority goals of modern society at the global level. This is complex problem, and it is necessary to engage experts from all scientific fields to reach acceptable solutions. The Paris Agreement, which was adopted by the consensus of 196 countries on December 12, 2015, (signed in 2016.), also made a great contribution to the solution. Congress participants signed an agreement within the United Nations on climate change, climate change mitigation, adaptation and finance. The signatories to the agreement have pledged to report regularly on their contribution to mitigating global warming (United Nations, 2015).

To better protect nature and its resources and to implement the provisions of the Paris Agreement as efficiently as possible, the Green Agenda: Sustainability Planning in 2021 (European Commission, 2020) was adopted. It was pointed out that a key decade for the future of our planet will begin in 2021. It is necessary to apply multidisciplinary approach and a collective effort to bring climate change under control are needed.

Sustainability of natural resources and development are directly related to human activities and their aspiration to use natural resources. Term-ecological footprint is used as an indicator of sustainable development as a measure of that utilization.

Ecological footprint is an ecological deficit that determines the level of resource consumption and waste generation by an economy or population that exceeds sustainable natural production and the power of assimilation in the spatial sense (Veljković, 2021). This term describes the difference between the ecological footprint of a given economy and population of sertain geographical area. Calculating the ecological footprint, it was found that humanity in 21.st century does not live within the carrying capacity of the planet Earth. The ecological footprint showed that, for example, in 2008, 2.7 global hectares per person (gha/pers) were needed, which is 30% more than the natural biological capacity of 2.1 gha/pers. This environmental deficit at the global level is met from unsustainable extra sources, and they are obtained by: 1. inclusion in the services of world trade in raw materials and finished products; 2. taking from the past (e.g. fossil fuels), or 3. borrowing from the future on principles contrary to the concept of sustainable development (e.g. over-exploitation of forests and fish stocks) (Veljković, 2021; McManus and Haughton, 2006).

2 NATURAL RESOURCES

Natural resources encompass everything that comes from nature and have general wealth and use value. Mineral resources, water, forests, land, solar and wind energy have a direct use value, but climate and relief have indirect use value, as they represent conditions for the development of some other economic activities, (Milanovic, 2009; Kattumuri, 2018). A broader term for natural wealth is natural potential that encompasses all natural resources and conditions. They signify all material goods used by man: ores, coal, forests, biodiversity, climate and relief. When one begins to use these goods, they become a resource (Fr. ressoirece-source) that has its economic value, (http://vssp.edu.rs). Natural resources are divided according to the duration in (Milanovic et al., 2008): Non-renewable resources (raw material or mineral resources); 2. Renewable resources (land, water, air, flora and fauna) and 3. Sustainable resources (solar energy, wind, tides, running water).

2.1 Management of non-renewable natural resources

The management of non-renewable natural resources, including mineral resources, is very complex, because their available stocks continuously decreasing during exploitation. Mineral resource management must be strategic in order to achieve a high level of efficiency and effectiveness during the exploitation process. The basis of applied strategy is rationality in their use, which is based on the rule of maximizing the use of natural resources, (Ilic, Mihajlovic and Omanovic, 2016). Strategic management of mineral resources starts with economic evaluation at local, national and regional level. Management objectives at the local level are based on resource availability, quality and structure, capital investment amount, environmental aspects and interests of the population. National strategic management objectives are based on exploration and determination of available stocks, resource depletion, availability of resources for mineral exploitation (means of labor), human resources security, state of investment funding, implementation of measures and activities envisaged by strategic planning. The basic regional objectives of mineral resources strategic management are the reconciliation of primary production and processing (Ilic, Mihajlovic and Omanovic, 2016; Milenkovic, 2000). The precondition for the sustainable development is a balance between the exploitation of natural resources and preservation of biodiversity is (Mihajlovic et al., 2018; Maksimovic, Urosevic and Ivkovic, 2015; Magdalinovic and Magdalinovic Kalinovic, 2012; Mihajlovic and Blagojev, 2019). During the mineral exploitation process, both underground and surface excavation, the negative impact on the environment can be divided into three groups: 1. Depletion of reserves, 2. Destruction of the environment, and 3. Pollution of the environment. In areas with underground mines the environmental degradation is less than in the areas of surface mining.

Generally, all forms of exploitation and mining can have a negative impact on the environment. In this sense, the obligation to have a strong link between mining and environmental protection is also promoted by legislation (Ivkovic, Dramlic and Dragosavljevic, 2015).

2.2 Management of renewable natural resources

Renewable natural resources are characterized by the processes of constant renewal and regeneration, at the same time with the process of their consumption. The management of these resources is based on the harmonized relationship between consumption and renewal, i.e. regeneration. In order to conserve natural resources, some measures are taken by the state; legal measures, quantitative restrictions and economic measures, (Pesic, 2002; Lindkvist, Ekeberg and Norberg, 2017). Legal measures regulate property rights over resources and prevent free access and uncontrolled use. Quantitative restrictions refer to the resource utilization quantities (extent of exploitation, extent of collection of flora and fauna, etc.) Some analysis of activities contributing to the management of renewable natural resources indicates that the best results are achieved by application of economic measures. The introduction of the system of taxes and subsidies, as well as fiscal measures contributed to the protection and conservation of renewable resources. The most important part of renewable resources is flora and fauna. Special attention was paid to the use and trade of wild flora and fauna. This issue is regulated by a special decree of the Government of the Republic of Serbia (Regulation “Official Gazette of the RS, No. 31/05), which clearly specifies under what conditions and to what level protected species from natural habitats can be collected, used and placed in traffic, (Ilic, Mihajlovic and Omanovic, 2016).

3 CONCLUSION

A prerequisite for sustainable development is a balance between the exploitation of natural resources and the biodiversity conservation. The Sustainable development mission succeeds only if there is balance between economics and ecology. The main link in all activities on this topic is man and his awareness of the importance of preserving the environment and its existence within the natural laws. By raising the population awareness from the local level to the global level, we are getting closer to the concept of sustainability. Namely, it is a condition where man uses natural resources, but controlled with constant care and striving for their restoration. On the other hand, non-renewable resources require the formation of strategy of their rational use and exploitation.

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