STUDY OF THE PHYSICO-MECHANICAL PROPERTIES OF THE ROCK MASSIF IN THE *SHUMACHEVSKI DOL* DEPOSIT, THE *ANDROW* SECTION

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ABSTRACT. In underground mining of vein deposits of minerals, it is necessary to know the physico-mechanical properties of the rock massif around the ore bodies. The lack of adequate knowledge of the state of the rock mass leads to deficiency in the bearing capacity or to over-reliability that result in the choice of support or lining structures, in the selection of design sections of the mine working grid, or in activities related to the management of such mining processes as host rock caving, back filling of stoped-out spaces, etc. The current work demonstrates a sequence of field and laboratory methods whose aim is to characterise the rock mass in terms of properties and condition.

Keywords: physico-mechanical properties, laboratory and field research, rock massif

ИЗСЛЕДВАНЕ НА ФИЗИКО МЕХАНИЧНИ СВОЙСТВА НА СКАЛНИЯ МАСИВ В НАХОДИЩЕ „ШУМАЧЕВСКИ ДОЛ", УЧАСТЪК „АНДРОУ" РУДНИК ЕРМА РЕКА

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РЕЗЮМЕ. При подземно разработване на жилни находища на полезни изкопаеми е необходимо да се познават физико-механичните свойства на скалния масив около рудните тела. Липсата на адекватни познания за състоянието на скалния масив води до дефицит на носеща способност или прекален запас на сигурност обуславящ се в избор на крепежни конструкции, избор на проектни сечения на мрежата минни изработки или мероприятия свързани с управлението на минните процеси като обрушаване на вместващите скали, запълване на иззетите пространства и др. Настоящата публикация цели да демонстрира една последователност от полеви и лабораторни методи с цел характеризация на скалния масив по свойства и състояние.

Ключови думи: механични свойства, лабораторни и полеви изследвания

Introduction

The *Androw* section of the *Shumachevski Dol* deposit is represented by vein hydrothermal lead and zinc mineralisation. The major mining operations are carried out along the following ore bodies: apophysis III/towards ore body 7/, ore body 7, ore body "Androw North", and ore body 5. The ore bodies are represented by quartz-carbonate sulphide veins with well-defined contacts. The specific conditions in the *Androw* section are the relatively great depth, the high temperature, the high moisture content, the approximation of the stopes to the piezometric level of hydrothermal pressure water with a temperature between two marble layers and manifestations of primary rock pressure as a result of the redistribution of the stresses in the massif during mining workings.

To determine the physico-mechanical properties of the host rocks in ore body 7 and ore body 5, a series of experimental works were performed near the ore bodies (apophysis and vein) along horizons 450 and 550 respectively.

Suitable locations were selected from these two main horizons for the deposit that best represent the geometrical position of the under host rocks, the hanging host rocks, and the enclosed ore body. For the purposes of characterising the massif, a pre-selection of platforms was made and platforms were determined and marked with the appropriate designations. The platforms were localised in sublevel workings, orts and cut-off entries.

Each of the platforms was specified in such a manner as to cover the three major lithological varieties (host rocks and ore body) as close as possible. Some of the platforms whereby cylindrical samples have been taken are presented in Figure 1.

Rock sampling was carried out by a *Hilti* mobile drill with a penetrating capacity of 50 cm in depth and a diameter (d) of 50 to 150 mm. The above activities were carried out on ten work platforms in order to cover most of the host rocks and ore bodies in the respective above-mentioned horizons (450 and 550). As a photographic application, Figure 2 shows the mobile drilling machine while operating and taking core samples.

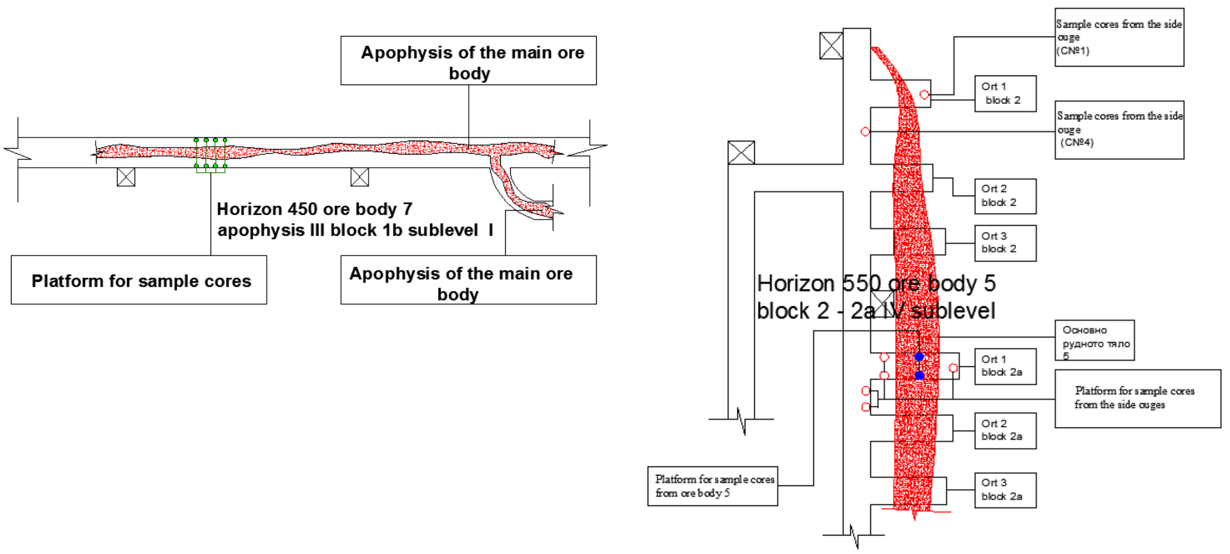


Fig. 1. Location of the working platforms along: a) level 450, ore body 7, apophysis III, stope 1b, sublevel 1; b) level 550, ore body 5, stope 2, sublevel 4

The core samples taken after drilling have a total length of 4.2 m and a diameter of d=50 mm, i.e. NX. The specimens have different lengths depending on the disturbance of the individual selected ore bodies as well as of the host massif. The angle of inclination and the orientation of the main cracks in the extracted rock specimens were also determined immediately after the sample was taken out of the borehole. All these studies and measurements are presented as a photographic application in Figure 2.

Fig. 2. Drilling core samples out of the host massif

In order to characterise the rock massif, the following necessary laboratory and field studies (ISRM, 1981; Dachev and Ivanov, 2016) concerning the density, strength and deformation parameters of the rocks are planned to be performed:

- Testing in laboratory conditions of the mechanical properties of specimens with a correct geometric shape in terms of strength and deformation;
- Preparation of cuts for determining the distribution of the main rock types in the production sections;
- Determining the orientation and location of structural disturbances (cracks, faults, etc.)

Laboratory research for determining the physico-mechanical properties of the host massif

As a result of the field experiments carried out, core samples (Fig. 3) were selected from the three lithological varieties of the rock massif. The core samples were tested in the accredited laboratory of *Eurotest-Control EAD* where their face surfaces were pre-formed. The individual sequences of rock specimens were grouped. Out of the test pieces with correct geometrical shape, 30 standard rock specimens were prepared in compliance with the recommendations of ISRM (ISRM, 1981; Dachev et al. 2018). Those were distributed in three sequences corresponding to the properties of the massif in one production section, i.e. hanging rock massif, ore body, under rock mass around the ore body.

Fig. 3. Grouping of a sets of rock specimens taken from the individual ore bodies in laboratory conditions

- **Strength tests**

The first series of laboratory samples has revealed that the samples taken from stope 1b, sublevel 1 are composed of varieties of hydrothermal alterations of two-mica gneisses with embedded quartz-sulphide mineralisation. The obtained results of the strength tests that were performed (ISRM, 1981) for the individual varieties of gneisses are given in Table 1 and Table 2.

The second series of laboratory samples has revealed that the samples taken from stope 2, sublevel 4 are composed of varieties of hydrothermal alterations of two-mica gneisses with embedded quartz-sulphide mineralisation.

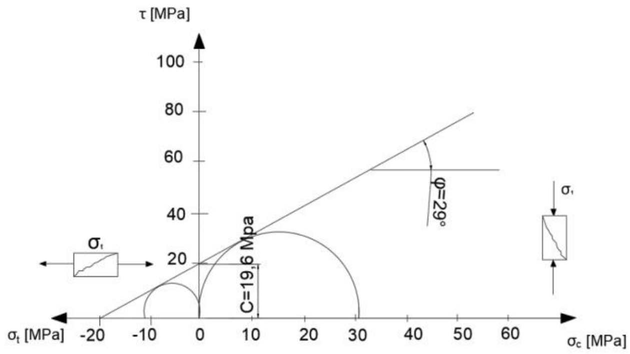
Table 1. *Laboratory data on the physico-mechanical properties of the host rocks and of ore body 7, apophysis III at block 1b of horizon/ 450*

Location / Parameters	Hanging ouge	Under ouge	Ore body
Volume density min/max, [MN/m^3]	0.0275 ±0.0002	0.0273±0.0002	0.0342/ 0.0469
Uniaxial pressure strength, σucs [MPa] min/max	46.2/51.6	63.9/70.3	45.5/ 60.2
Tensile strength, σt [MPa] min/max	12.5/17.2	18.1/20.4	15.3/19.5
Cohesion C [MPa]	15.4	10.4	11.2
Angle of internal friction,[°]	32	30	28.9
Elasticity modulus, E [MPa] min/max	23480/ 34515	40363	14817/ 17660
Poisson's ratio v [-]	0.10	0.09	0.08

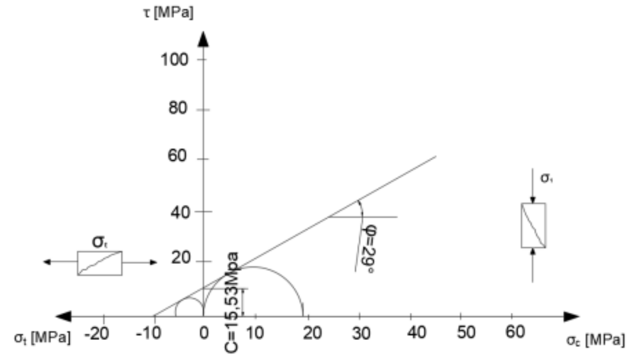
Table 2. *Laboratory data on the physico-mechanical properties of the host rocks and of ore body 5 in block 2 of horizon 550*

Location / Parameters	Hanging ouge	Under ouge	Ore body
Volume density min/max, [MN/m^3]	0.0255 ±0.0002	0.0257/ 0.0268	0.0291/ 0.0312
Uniaxial pressure strength, σucs [MPa] min/max	19.5/ 21.7	24.7/ 36.9	20.7/ 38.9
Tensile strength, σt [MPa] min/max	4.5/7.2	9.8/13.1	6.1/8.5
Cohesion C [MPa]	5.63	18.3	14.7
Angle of internal friction,[°]	34	34	33
Elasticity modulus E [MPa]	6820	12138	10450
Poisson's ratio v [-]	0.24	0.14	0.12

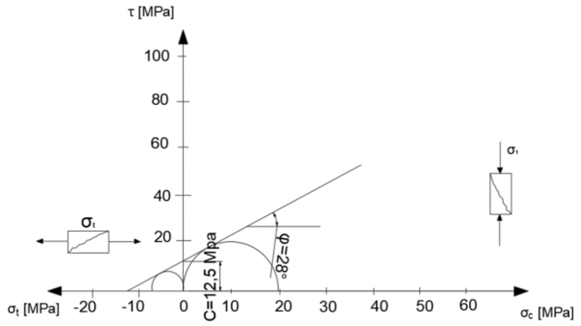
The test results presented in Tables 1 and 2 show that the rocks of the ore body are with the highest density, they have the lowest porosity. The strength parameters of the rocks from the hanging ouge are the lowest. The laboratory study has shown that during the test, the strength properties of the three characteristic groups of rock varieties have a range of variation from 20 to 30%. At the stage of each strength study, a strength layout for the particular type of rock variety needs to be designed. One of the most famous strength layouts is that of Mohr-Coulomb (Hoek, 2001; Brady and Brown, 2004). Using the Mohr-Coulomb criterion, the relationship between normal and tangential stress is given. Strength layouts were outlined in the studies performed. Part of the strength layouts based on laboratory test data is shown in Figure 4.



a) amphibole-biotite gneisses – lying host massif



b) hydrothermally altered amphibole-biotite gneisses – hanging host massif



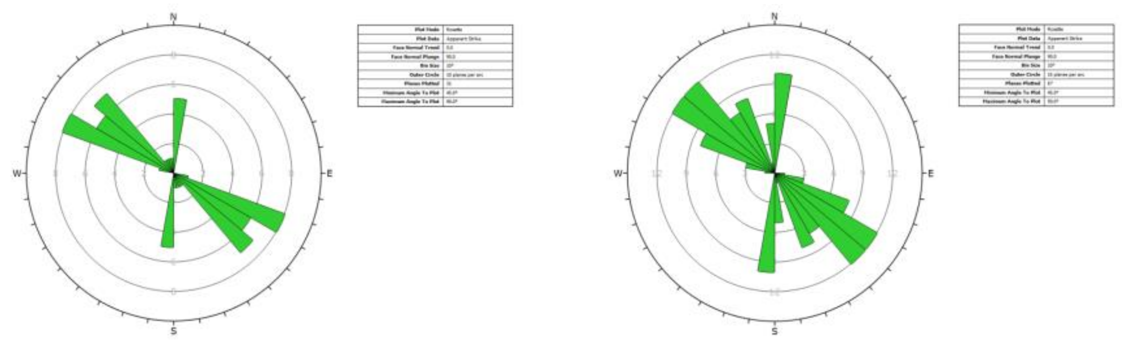
c) hydrothermally altered two-mica amphibole-biotite gneisses - ore body

Fig. 4. a, b, c - strength layouts of the rocks from the gneiss variants in the production section of horizon 550

Study of the structural disturbance of the rock mass

The structural disturbance of the massif provides the amount of information necessary to determine the state of the rock massif (Brady and Brown, 2004). The study of this information is a continuous process which begins with the stage of mineral survey and exploration and goes through all mining phases, thus resulting in a large amount of factual material amassed (Brady and Brown, 2004). The study of the structural disturbance of the massif in the *Androw* section is prompted by the need to determine the mechanical condition of the host massif around the ore bodies. The purpose is to provide stability in compliance with the applied development system in the individual ore bodies. The DIPS ver. 7.0 (Rocscience, 2018) software package was used to analyse the results related to the structural disturbance of the massif. Figure 5 shows the overall structural disturbance of the massif on horizon 450. Based on the results obtained, two groups of crack systems have been identified. The first crack system (which is the main one) is in the direction of 130°-310° and is embedded in the southeast-northwesterly direction; the second crack system is in the direction of 10°-190° and is embedded from the northeast to the southwest. Based on the measured cracks in terms of orientation and dip, the systems of cracks are determined (see Figure 5). One characteristic feature of the cracks on horizon 550 is that they are grouped into two or up to three main groups of systems: the first system is 125-305°, the second is 5-185°, and the third, which is pronging, is 160-340°.

The orientation of the crack in depth was determined after the extraction of the pieces of the oriented drill core.



A Б

Fig. 5. Results from the study of overall structural disruption/disturbance of the cracks - the three systems of cracks are displayed in the "rose-type diagram of cracks: A) on horizon 450; B) on horizon 550

Rock quality designation

Standard research on the rock quality designation (RQD) has not been carried out so far (Dachev and Ivanov, 2016). Determining the quality of the rock, i.e. RQD, is not performed by the classical method, but by one of the alternative methods (Brady and Brown, 2004), instead. The assessment of the rock quality is made in Fig. 6. The results of the structural disturbance of the massif are used and the parameters of average number of cracks per meter are determined (Brady and Brown, 2004).

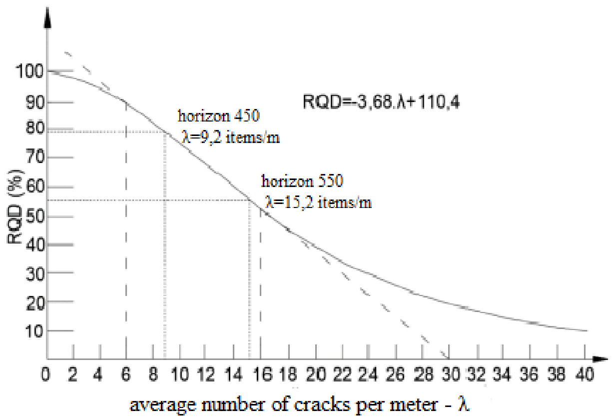


Fig. 6. Results of the quality of the massif RQD obtained through the method of Brady and Brown

For horizon 450

According to the results shown in Fig. 7, the RQD concerning the quality of the massif from the structural disruption/disturbance is 77% and ranges from 75% to 90%.

The results are shown by means of the bar chart in Fig. 7A); thus, it is possible to determine the average for the RQD, which is:

$$RQD_{cp.} = 77\% \rightarrow (75 \div 90) \Rightarrow R_{RQD} = 17$$

For level/horizon 550

As for the second region on level/horizon 550 studied, the results are also shown in Fig. 7. The RQD concerning the quality of the massif from the structural disruption/disturbance is 54.5% and ranges between 50% and 75%.

The results are shown by means of the bar chart in Fig. 7B); thus, it is possible to determine the average for the RQD, which is:

$$RQD_{cp.} = 54,5\% \rightarrow (50 \div 70) \Rightarrow R_{RQD} = 13$$

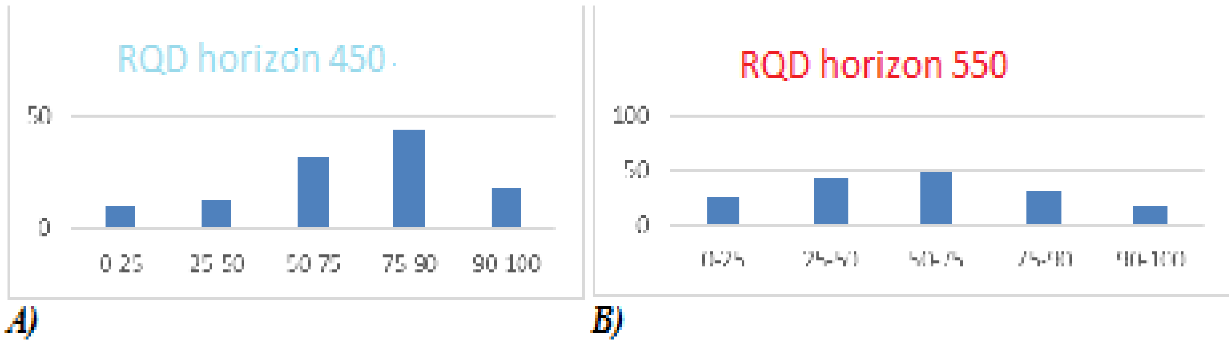


Fig. 7. Bar charts for the distribution of the RQD values for a geomechanical region on: A) horizon 450; B) horizon 450

The results for the RQD have been processed with the help of Table 3 offered by Deere.

Table 3. *Quality of the massif RQD, after Deere*

RQD %	***class/grade***	***Quality of the massif***	
0-25	***A***	***Very poor***	
25-50	***B***	***Poor***	
50-75	***C***	***Fair***	***The massif on horizon 550***
75-90	***D***	***Good***	***The massif on horizon 450***
90-100	***E***	***Excellent***	

Results of the research work

The obtained results concerning the mechanical condition of the massif are new for the *Androw* section. Based on them, several significant conclusions can be drawn:

- Complex laboratory tests have been carried out on samples of the rock varieties that make up the host massif. The strength and deformation characteristics of the various lithological varieties of rock that form the host massif in the experimental production section have been determined. Mohr-Coulomb strength layouts have been outlined for each lithological type of rock in the regions studied. New geomechanical software has been used to study the deformation behaviour and to determine the elastic constants.
- The structural disturbance (RQD) of the respective horizons has been studied and a geomechanical classification

of the massif has been offered. As a result of laboratory, field, and structural studies, a multidimensional database has been made for the purposes of the integrated characterisation of the massif.

Conclusion

Due to the extensive geomechanical research carried out, a database has been provided. Classification assessments have been made. Several significant conclusions can be drawn from the research applied. Those could serve as recommendations for the future development of the *Androw* section:

- Keeping a database of the physico-mechanical properties of the lithological varieties of host rocks around the ore bodies is imperative at the stage of the penetration in depth and the subsequent development and mining.
- The database should comprise information on the strength and deformation properties of the massif, data on the density properties, and mandatory data on the structural disturbance. This would lead to an adequate interpretation of the condition of the massif at each stage of the production or the construction of mining workings.

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