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BASIC GEOTECHNICAL PARAMETERS OF METALLIC MINERAL DEPOSITS IN THE REPUBLIC OF MACEDONIA

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A b s t r a c t: This paper deals with the analysis of basic geotechnical properties of monolithic rock samples from several metallic mineral deposits in the Republic of Macedonia. Namely, results from geotechnical investigation on samples from the deposits of Ilovica, Borov Dol, Kazan Dol, Plavica, Kadiica and Bučim were subject of the work presented herein. Over 800 different geotechnical tests have been performed on samples from different depths and zones of these deposits. The most frequently performed basic tests during geotechnical investigation phases included: point load index tests, unconfined compression tests, unit and specific weight, porosity, shear strength along joints. All data is statistically analyzed and certain conclusions for different geotechnical parameters are achieved. Special attention is paid to the vertical distribution of the parameter's values, since this is of greatest interest for the mining planning and processes. Differences among certain deposits are discussed and certain conclusions and recommendations for further investigations are presented. We note that this is a first attempt to analyze such amount of geotechnical data from metallic mineral deposits in Macedonia, and the herein presented correlations are to be updated as new data is collected.

Key words: geotechnical properties; metallic mineral deposits; statistical analysis; vertical distribution

INTRODUCTION

Rock mechanics, or to be more exact, *Mining rock mechanics*, as a sub-discipline in geotechnics has had profound influence on the mining industry throughout history (Brady and Brown, 2006). In general, the knowledge of geotechnical properties of rock masses in metallic and nonmetallic mineral deposits is of high importance for the economy of the mining process, safety of works and environmental protection.

Many aspects of mining (during design process and during exploitation) depend on the geotechnical characterization of both the ore bearing as well as surrounding waste rock. To be more precise, geotechnical characterization is essential for successful fulfilling of the following design stages and phases of exploitation/mine life:

– Design of working and final slope angles at open pit mines.

– Design of support in underground mines.

– Design of tailing dams and civil engineering structures from waste rock.

– Determination and control of excavation, loading and transport conditions.

– Determination and control of rock durability with time in relation to environmental protection.

– Determination of the possibility to use waste rock for road or embankment construction.

– Determination of tailing dams stability and their monitoring.

– Foundation of structures in zone of mines.

– Stress and deformation analyses.

– Monitoring of the rock mass performance.

– Rock support and reinforcement design.

– Rock related risk management.

– Design of access and haul roads.

– Design of protective measures for workers.

As it can be noticed and also stated by McG Robertson and Caldwell (n.d.), mining process starts with geotechnical analyses and design, regardless of the type of mining. Moreover, it ends with geotechnics as it is needed to deal with the waste material and the safety of the mines throughout and after the exploitation phase. The importance and value of the geotechnical investigations and tests and their statistical analysis in general and not only for metallic mineral deposits are stressed by many authors. Geotechnical engineering in mining involves many tasks, as listed above, due to which there are numerous geotechnical guidelines specifically for mining, such as the ones given separately for open pit and underground mines recommended by the Government of Western Australia (Department of Minerals and Energy, 1999, and Department of Industry and Resources, 1997). On the other hand, Blight, Troncoso and Fourie (2000) analyze some of the geotechnical issues in mining.

Adamczyk (2012) points out that the material properties change with transportation, handling, compaction and weathering of the material. The same author presents changes in particle size distribution and moisture with time, which affects the geotechnical parameters. Even though that paper is dedicated to coal deposits it stresses the significance of geotechnical parameters' alteration with time. Regarding metallic mineral deposits, Yan et al. (2011) present results from testing of strength parameters of rocks from lead, zinc and gold mine. Also Bieniawski (1974) shows a practical approach for determination of the strength properties or rock materials and lists the influencing factors. The factors upon which the shear strength of rocks depends, weathering importance and stability are also described by McLemore et al. (2009). Furthermore, results from large in situ shear tests on rock piles from the surface layer of Questa Molybdenum Mine are presented by Boakye (2008).

Considering the size of a mine, there is usually a large amount of waste material to handle. Therefore, in many cases part of it is used to build the containing structure. However, the material should satisfy the requirements of aggregate for this kind of structure. This topic is analyzed in details by many authors among which Smith and Colhs (2001).

The geotechnical parameters of the rock masses have large variations from deposit to deposit, and in most cases, even within a particular deposit. This is the main goal of this paper, to show the variation of the geotechnical parameters in some metallic mineral deposits in the Republic of Macedonia. It should be noted that, except the active mine for the deeposit Bučim, all the other deposits are in phase of detailed geological investigations.

GENERAL GEOLOGICAL OVERVIEW OF ANALYZED METALLIC MINERAL DEPOSITS

In the past decade in the Republic of Macedonia there have been intensive geological investigations for new metallic as well as nonmetallic mineral deposits, where certain amount of geotechnical works has been done. Here belong the deposits: Ilovica–Štuka near town of Strumica, Borov Dol and Bučim near town of Radoviš, Kazan Dol near Valandovo, Plavica near Kratovo and Kadiica near Pehčevo (Figure 1).

The Plavica deposit is a part of the well known Kratovo–Zletovo ore area that in general is characterized with a complex composition of mainly Tertiary volcanic-sedimentary complex. It is imposed on the foundation of the Serbian-Macedonian massif, which represents constitutive part of the western Tethyan belt. K/Ar radiometric data (Karamata et. al., 1992; Serafimovski, 1990) yield an age of 32–16 Ma (late Oligocene to middle Miocene). In the geological setting of the Plavica deposit participate mainly volcanic and volcano-sedimentary rocks, which exact determination is complex due to intensive presence of hydrothermal alterations. However, with numerous lithostratigraphic and petrographic studies it was confirmed that in the geological setting of this deposit participate ignimbrite, stratified volcanic tuff and breccia, dacito-andesite and their pyroclasts as well as quartzlatites mostly occuring as breakthroughs. Definition of these rocks is hard because of intensive hydrothermal alterations such as: kaolinization, silification, alunization, seritization and other (Serafimovski, 1993; Serafimovski et al., 2014). The central part of Plavica is made of different kind of volcanic rocks, hydrothermally altered, pyritized, and mineralized with ore mineralization (Cu, Au, Ag, Pb, Zn). According to the research made on Plavica mainly based on boreholes data, the depth of the ore mineralization and intensive hydrothermal alteration exceedes 1000 m.

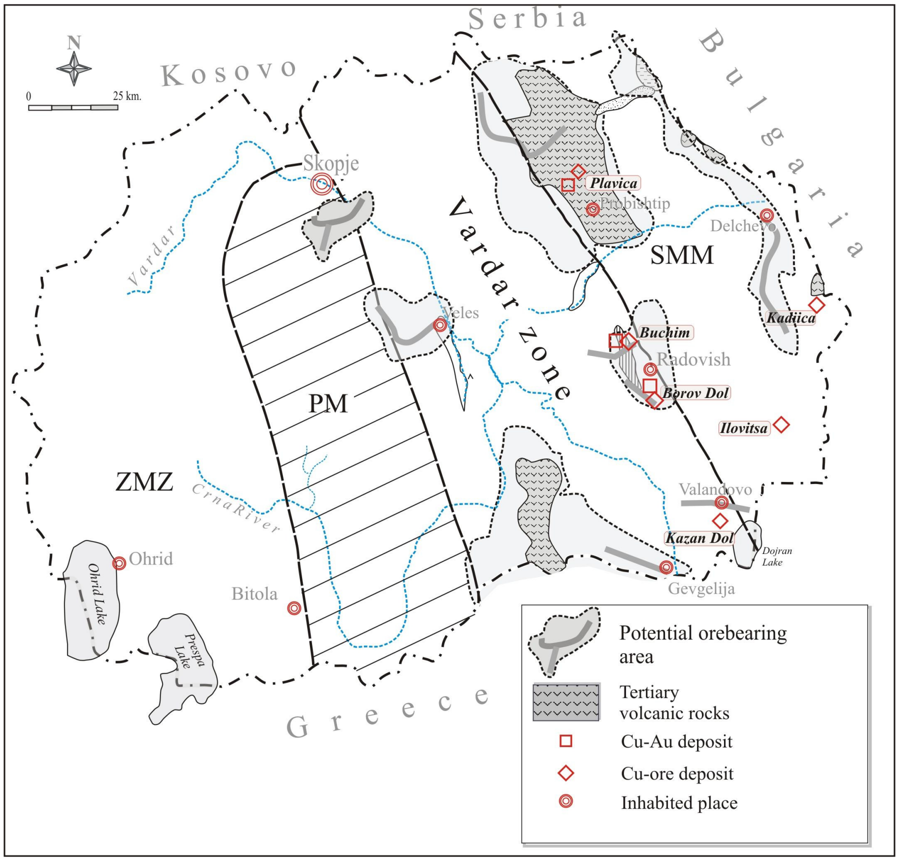

Fig. 1. Geographic position of the analyzed deposits

The silica ledges seen on Plavica represent the level of paleo-regional ground water table. Due to their silica content both areas have resisted erosion and formed prominent landforms through topographic inversion. Tertiary rocks are the dominant lithology at the Plavica area. Review of these numerous different types of rocks will be presented according to their geochronological order defined on the basis of found fauna superpozitional relations and absolute age of certain types of volcanic rocks (Serafimovski et al., 2014)

The geological setting of the immediate surroundings of the Bučim deposit includes the following end members: Precambrian metamorphic complex, Paleozoic magmatic rocks and Tertiary volcanic rocks.

In the Precambrian metamorphic complex gneisses are the most widespread rocks in both, broader and immediate areas around the deposit. According to the mineral composition, several intercalating facies can be distinguished: biotite gneisses, amphibole-biotite gneisses, muscovite gneisses, two-mica gneisses, and metasomatic (leucocratic) gneisses. Micaschists represent a normal lithological member of the crystalline schist in which they occur as an interstratified facies. Consequently, they are of the same metamorphic age. From the aspect of mineralization, they are unfavorable environment, compared to gneisses, being poorly permeable for hydrothermal solutions. Amphibolites occur in the crystalline schist in the form of lenses or strata and larger irregular masses. Generally, they are concordant to the crystalline schist and at places depart from their foliation. They are featured by dark green color and schistose structure (Serafimovski et al., 2016).

The Paleozoic magmatic rocks occur in the form of small lenses distributed along clearly pronounced ruptures. So far, the following ones have been recognized (Čulev, 1970): Amphibolites, fine-grained rocks of thin banded texture, which represent unfavorable environment for deposition of the Cu mineralization. They are composed of hornblende, plagioclase and partly, foliated biotite and chlorite aggregates (Ivanov, 1982; Čifliganec et al., 1993). Serpentinites occur north of the

Vršnik ore body. They have significant sizes and thickness (about 10 m), being distributed along the rupture zone.

The Tertiary volcanic rocks played an important role in the geological setting of the Bučim deposit (Majer, 1958; Karamata, 1983; Čifliganec, 1987, 1993; Denkovski et al., 1983; Denkovski and Bandilov, 1985; Serafimovski, 1990, 1993; Stojanov and Serafimovski, 1990; Stojanov and Boev, 1993; Boev and Yanev, 2001). They occur as minor intrusives within the Precambrian metamorphic complex. During the Neogene, tectonic and magmatic processes resulted in widespread magmatism. At the present erosion level it is represented by sub-volcanic and volcanic facies of latite and andesite in the form of dykes and necks. In the intrusive level the rocks correspond in composition from quartz-diorite to granodiorite. In terms of chemism, they belong to calk-alkaline and alkaline affinity. At later stages, they were enriched in potassium.

The ore deposition is genetically connected with the emplacement of Tertiary, Oligocene-Miocene subvolcanic latitic and latite-andesitic bodies within Precambrian metamorphic rocks – gneisses, micaschists and amphibolites (27.5–24.5 Ma, Serafimovski, 1993, or 24.5–24.0 Ma, Lehmann et al., 2013).

The Borov Dol deposit is related to the Tertiary volcanic-plutonic complex (27–37 Ma; Serafimovski, 1993). The ore-bearing volcanic rocks are metasomatically altered. The volcanic rocks belong to the high-K shoshonitic series and correspond to monzodiorite and monzonite in K_2O-SiO_2 discrimination. These are andesite, latite, trachyte and rhyolite, including transitional varieties (Serafimovski et al., 2010; Lehmann et al., 2013). It is worth mentioning that the rocks of shoshonitic series are typical for districts with porphyry Cu mineralization at continental margins, e.g. Bajo Alumbrera, Gunumba, Bingham, Ok-Tedi, Grasberg, Cadia, etc. (Müller & Groves, 2000; Blevin, 2002).

The wider area of Kazan Dol is built mainly of metamorphic rocks of Precambrian (finegrained biotite gneiss, muscovite-biotite gneiss and muscovite gneiss) and Lower Paleozoic age (sandstones and marble breccia), as well as Mesozoic products represented by so-called Furka granites, quartz and/or quartzless porphyries, serpentinites, diabase, gabbro etc. Cenozoic is represented by Tertiary and Quaternary products. The geological setting in the closest vicinity of the Kazan Dol deposit is built of Precambrian metamorphic rocks, yellow and compact porphyroblastic gneiss in westernmost parts of the terrain as well as two-mica cordierite gneiss present along the Jurt-Deresi, Armut-Tepesi, Kazan Dol village and Bogdanci direction. Paleozoic products are represented by grey-greenish sericitechlorite schist in southernmost parts of the area. Mesozoic has been represented by Furka granites (central and south-eastern parts of the area), quartz and quartzless porphyries (along tectonic lines of NNW-SSE direction), quartz keratophyre and keratophyre.

These granites have determined absolute age of 155±5 Ma by Rb/Sr method (Šoptrajanova, 1967) and 156 ± 6 Ma (Borsi et al., 1966). Interesting mineralizations of Cu, Fe, Zn of skarn type and especially Cu-vein type of the Kazan Dol type were related to these Jurassic granitoids (Ivanov, 1966; Ligovski, 2015).

From the geological and structural aspects, the Bukovik-Kadiica area belongs to the well-known Serbo-Macedonian mass. It is composed mainly of Riphean-Cambrian and Paleozoic metamorphic rocks represented by metadiabases and schists (diabase-phyllitoid complex, Vlasina complex) and diorites (Tasev, 2010). The Paleozoic rocks have experienced green schist facies metamorphism and display a well-developed schistosity. Near Berovo they directly cover gneisses of the amphibolite facies (Karamata, 1974; Kockel et al., 1975, Grubić, 1980; Dumurdžanov et al., 2005). The mineralizations are related to the Oligo-Miocene to Lower Pliocene, 25 to 14 Ma (Harkovska et al., 1989; Stojanov et al., 1995; Boev et al., 1997; Boev and Yanev, 2001) calc-alkaline complexes (rhyolite-quartzlatite-dacite/andesite), which occur in intervals along the fractured zones. The Tertiary volcanism in the Bukovik-Kadiica area is represented by the volcanic dome Bukovik (1722 m) and small subvolcanic bodies of dacites and rhyodacites at Belo Brdo and Kadiica (1932 m) at a surface of about 4 km^2. Small dacite bodies and dykes have been found also on Bulgarian territory within a zone of NW–SE direction as well as an extrusive dome with subvolcanic breccias at the intersection of faults with north-south and NE-SW strike (Harkovska, 1984). The Kadiica subvolcanic intrusive center is one of several Neogene dacitic plugs that have intruded a variety of metamorphic rocks of the Serbo-Macedonian massif (Tasev, 2010; Serafimovski et al., 2014 – Elaborate). Several of these intrusives are associated with quartz vein stockwork development and wide-spread hydrothermal alteration. The subvolcanic intrusive complex is poorly exposed on the Bukovik hill

(1722 m a.s.l.) and consists of flow banded dacite and massive fine crystalline aphyric dacite that have been intruded by a coarser equigranular dacite phase, a quartz-, biotite- and plagioclase-phyricdacite porphyry and a postulated second dacite porphyry at depth. Near-surface pyroclastics and dacitic autobreccias are exposed along the southwest side of the Bukovik hill.

Interesting mineralizations of Cu Fe, Zn of scarn type and especially Cu-vein type of the Kazan Dol type were related to these Jurassic granitoids. It is located on the territory of Republic of Macedonia, more precisely in its southeastern part, at about 17 km distance from Strumica city, in the immediate vicinity of the Ilovitza village.

Mineralogical-petrographic characteristics of the Ogražden massif indicate that it is quite heterogeneous and is basically represented by calcalcaline granites. These granites shall occupy the central parts of the mountain Ogražden, represented by: biotite coarse-grained granites, leucocrate coarse-grained granites, granitoporphyries, muscovite leucocrate granites, two mica medium-grained granites, biotite porphyry granites and granodiorite, leucocrate schist granites.

From mineralogical aspect, the Ogražden massif is represented by large crystals of feldspar, a large amount of biotite and quartz. From petrographic aspect, the same are characterized by alotriomorfic grain to porphyry texture with massive, and sometimes weaker schists structure.

Hydrothermal changes in the dacite–andesite caused almost completely destroyed primary structure and changes in the mineral composition. These changes are manifested in the form of silicification, sericitization, alunitization, kaolinitization and at some places opalitization and chloritization (Rogožareva, 2013). The zone of intensive silicification and sericitization space is expressed on the west side of the dacite–andesite disruption.

The zone of intensive silicification and alunitization space is expressed on the eastern part of the dacite-andesite disruption, in which the presence of alunite varies from 20 to 50%.

It is noticed that in the parts where alunite is present within the limits of 20–48%, sulphide mineralization is missing, similarly as in Plavica polymetallic systems (Stojanov, 1980) and Dudica (Ivanov and Ivanova, 1980). However, in the parts where intensive silicification and alunitization are registered as well as certain contents of gold (over 19 g/t), which mark one epithermal area, the mineral components are products of acidly sulfate solutions (Serafimovski and Aleksandrov, 1995).

MATERIALS AND METHODS

During the period between 2008 and 2016 within detailed geological investigations of the above described metallic mineral deposits, certain scope of geotechnical investigations and tests were performed. In most of the cases, separate programs for geotechnical investigations were prepared, which were later realized as planned. As part of these investigations, numerous other field work and tests were done in relation to define as more precisely as possible the engineering-geological, geophysical and hydrogeological properties of the deposits. These will be presented elsewhere and herein is only analyzed the geotechnical data obtained from laboratory tests. In particular, this paper deals with analysis of the following geotechnical parameters of rock samples taken from different zones of the mentioned deposits:

– Point load strength tests (Js_{50}) (PLT);

– Uniaxial compressive strength tests (UCS);

– Unit and specific weight measurements (UW and SW);

– Porosity (P);

– Shear strength along joints (SS).

It should be noted that all tests (over 800) have been performed according to the suggested methods of the International Society for Rock Mechanics and in the certified laboratory of the Chair for Geotechnics at the Faculty of Civil Engineering in Skopje, Republic of Macedonia. The whole process of testing is accordingly documented by taking photographs of tested samples (Figure 2), notation of failure modes, notation of samples showing unusual behavior (swelling, decomposing during preparation, etc.).

Point load strength tests were performed mostly on irregular rock lumps from the superficial layer of on rock core from investigation boreholes.

Uniaxial compressive strength tests were done on regular samples with height/diameter ration $H/D \geq 2$, and for shorter samples appropriate corrections of the obtained values were made. The load speed, usually 0.25 MPa/s, was controlled automatically by computer unit (Figure 2).

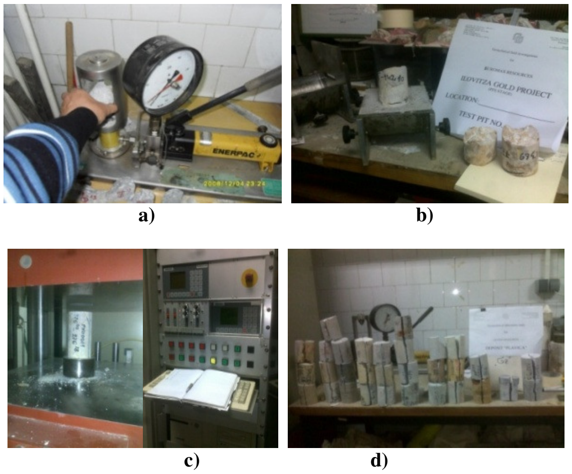

Fig. 2. Photograhs from laboratory tests: **a)** point load strength, **b)** shear strength along joints (samples in phase of preparation), **c)** uniaxial compression test (UCS) and control unit, **d)** look of samples after UCS test

The samples tested for definition of unit weight, specific weight and porosity were selected in order to cover as many zones as possible for each of the treated deposits, and to obtain more accurate information on the variation of these parameters.

Test for shear strength along joints were performed on natural joints, in some cases also with known dip elements and by known procedures for selection of vertical loads. Here we only discussed the friction angle and joint roughness.

It should be taken into consideration that the number of tested samples for particular property is not equal for each deposit, and for certain deposits some types of tests were not performed at all or the number of tests was rather small. This is result of the different geotechnical investigations programs which were developed for each separate deposit. As other limitations of this analysis can be considered: lack of samples from larger depth from some of the deposits; lack of samples from some of the particular "alteration" zones designated in respective deposits; discrepancy in relation to depth of taken samples for establishment of more precise correlation among parameters (for example, different depths of samples for unit weight and specific weight, different depth of samples tested on point load and uniaxial strength or similar); lack of UCS strain gauges tests to define the stress-deformation properties of the rock monoliths.

With future investigation stages at these deposits, and during exploitation period these shortcomings should be surpassed and more precise geotechnical profile of the deposits will be obtained. Therefore, in this paper, the geotechnical data collected to present date is discussed, and as new data is obtained in future, the shown correlations will be updated.

RESULTS AND DISCUSSION

In the following sub-chapters, diagrams and charts the statistical analysis of values of each particular geotechnical parameter is presented. Detailed data on statistical distribution of the results are shown in Tables 1 and 2.

Table 1

Statistical distribution of point load strength, uniaxial compressive strength and shear strength along joints for all deposits

Parameter												Deposit
Shear strength along joints Friction angle (°)				Uniaxial compressive strength (MPa)				Point load strenght $Js_{(50)}$ (MPa)				
SD	Max	Min	Av.	SD	Max	Min	Av.	SD	Max	Min	Av.	
6.55	51.27	17.00	32.08	30.55	139.50	2.00	34.96	1.65	7.60	0.32	2.68	Ilovica
				21.87	74.30	10.60	36.06	0.85	3.84	0.78	1.92	Kadiica
				18.18	113.71	2.33	26.69	1.80	9.54	0.54	2.85	Plavica
2.98	36.00	26.00	30.71	46.13	186.57	5.99	63.38	1.90	9.96	4.14	6.11	Bučim
				18.21	52.32	6.37	32.41	1.85	8.82	0.43	3.53	Kazan dol
6.57	37.00	14.00	29.75	29.66	101.21	5.45	47.84	2.88	12.63	0.54	4.41	Borov dol
6.34	51.27	14.00	31.63	30.57	186.57	2.00	36.60	2.04	12.63	0.32	3.12	All samples

T a b l e 2

Statistical distribution of unit weight, specific weight and porosity for all deposits

Porosity (%)				Specific weight (kN/m³)				Unit weight (kN/m³)				Deposit
SD	Max	Min	Av.	SD	Max	Min	Av.	SD	Max	Min	Av.	
6.10	27.12	0.22	6.96	1.02	30.35	26.02	27.52	2.07	27.19	17.22	23.95	Ilovica
								1.18	27.96	23.27	25.91	Kadiica
6.68	31.37	3.21	16.21	1.07	32.25	26.57	28.62	2.02	28.72	18.02	23.67	Plavica
								0.58	27.79	24.45	26.14	Bučim
2.56	8.57	0.93	5.10	0.65	28.83	26.00	27.55	0.63	27.84	24.58	26.12	Kazan dol
5.81	20.95	0.66	7.83	0.74	29.44	27.01	28.31	1.43	29.28	20.69	25.32	Borov dol
7.40	31.37	0.22	9.74	1.08	32.25	26.00	28.03	2.02	29.28	17.22	24.50	All samples

Point load strength tests

The point load strength results show that most of the tested samples belong to the medium range of strength. More precisely, according to the most usual strength classifications presented by Jovanovski et al. (2012), tested samples represent mostly strong, average (weak) and very strong rock classifications. (Figure 3).

In relation to the vertical distribution, it was found that for all deposits, PLT values vary to some extent. For example: for the deposits Plavica and Ilovica, Borov Dol and Kazan Dol values are usualy in range from 2.0 to 8.0 MPa; for the deposit Bučim (in particualar ore body Čukar) the values are in range from 4.0 to 8.0 MPa.

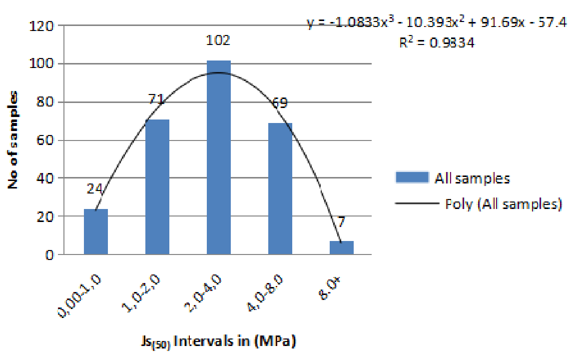

Fig. 3. Number of point load strangth Js_{50} samples divided in five strength classes

For the deposit Kadiica, the values are usualy in range from 1.0 to 4.0 MPa. If all data is taken into account, then certain trend toward lowering of the values to a range of 1.0 to 4.0 MPa as the depth increases can be noticed (Figure 4). However, there is small number of samples from larger depth for some of the deposits so in future this statement needs to be confirmed.

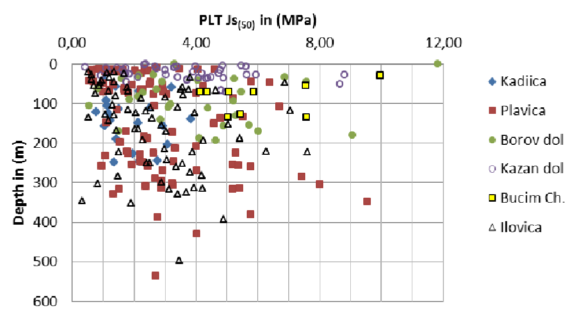

Fig. 4. Variation of point load strength Js_{50} with depth for all deposits

Uniaxial compressive strength tests (UCS)

In contrast to the point load strength results, the results from uniaxial compressive strength imply that most of the rocks belong to category of medium strong, then strong and very strong rock classifications according to ISRM (Figure 5).

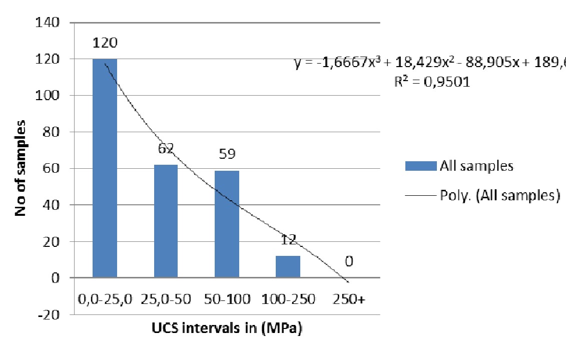

Fig. 5. Number of uniaxial compressive strength samples divided in five strength classes

In relation to values distribution in vertical direction, certain patterns are visible for particular deposits (Figure 6). If all data is considered, then there is trend to decreasing of the strength as the depth increases with the most frequent values of the strength in the range of 5.0–50.0 MPa. The samples from Bučim deposit have the highest strength, while the lowest strength values are noticed for deposit of Ilovica. Uniaxial compressive strength of samples from the Ilovica and Plavica deposits varies in wide range, however with noticeable decrease of strength as depth increases. Strength of samples from the deposits of Kadiica and Borov Dol show narrower range, but in this case the number of samples is very low. It is clearly noticeable that the highest values of the uniaxial strength are registered for samples taken from depths in the interval of 0.0–200.0 m.

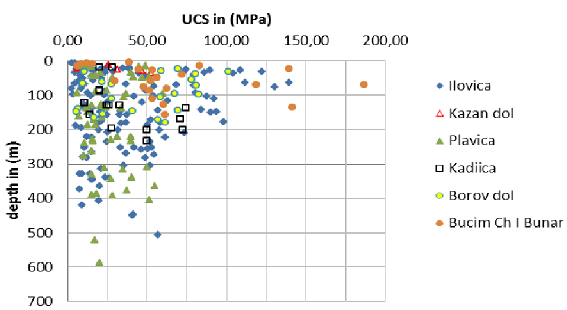

Fig. 6. Variation of uniaxial compressive strength with depth for all deposits

In the values of uniaxial compressive strength from all analyzed deposits are compared with the typical values of bare (without ore) igneous rocks, then it is clear that the alteration processes have lowered the strength of the rock to a very high extent. Just for example, average values for most igneous rocks in non-metallic deposits is over the value of 80.0 MPa, usually over 150.0 MPa, while in this case most of the deposits have average values in range of 35.0–60.0MPa. In the case of deposit Bučim, the highest average (63.38 MPa) and highest achieved uniaxial strength (186.57 MPa) as a result of the intense silicification of the rock mass were registered. On the other hand, in the deposit of Plavica average of 26.69 MPa was found, as well as the lowest achieved strength of 2.33 MPa which is clear result of the alterations.

If the values of uniaxial compressive strength are correlated with the point load strength results (Figure 7), then it is clear that the usual coefficient (22) in the well-known equation UCS (σp) = $Js_{50}\cdot 22$ is not applicable for general use when it comes to rock strength estimation for these metallic mineral deposits. In this relation more specific test programs should be performed in future.

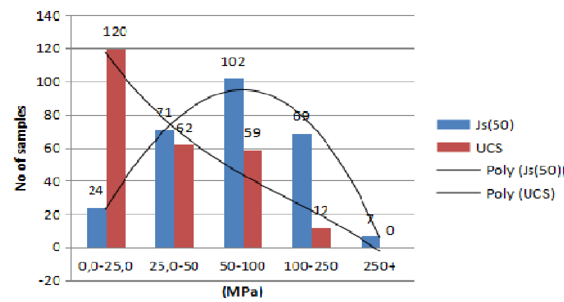

Fig. 7. Correlation of results from UCS and $Js_{(50)}$ tests

Shear strength along joints

The analysis of shear strength along joints is performed for very small number of samples in relation to other tests (Figures 8, 9, 10 and 11). The most frequent value of the obtained friction angle is in the range of 30–35° and the most usual value of the joint roughness coefficient is JRC = 4–10. In particular, for Ilovica deposit it can be noticed that the friction angle increases with depth, and that JRC tend to conform to a narrower range in relation to the ranges of shallower samples (Figure 11).

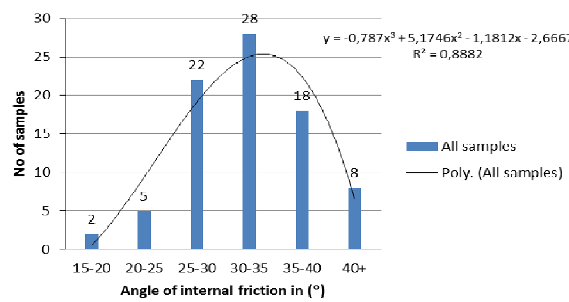

Fig. 8. Number of samples tested for shear strength along joints divided in six classes (angle of internal friction)

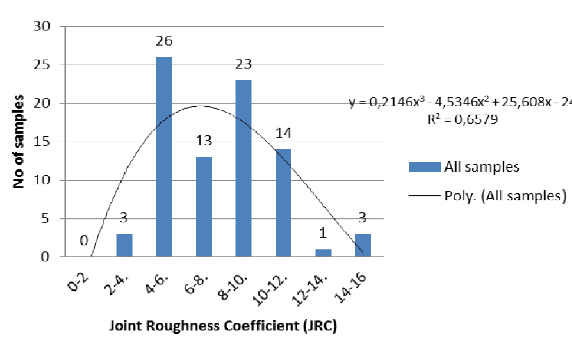

Fig. 9. Number of samples tested for shear strength along joints divided in six classes (joint roughness coefficient)

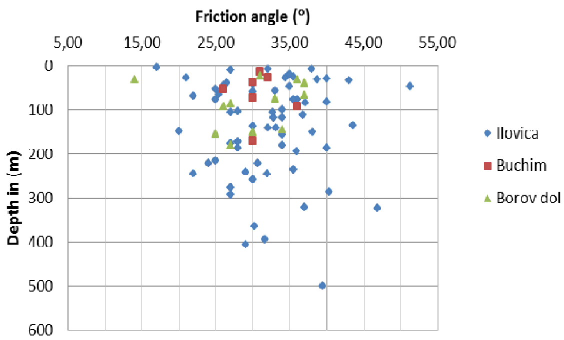

Fig. 10. Variation of friction angle along joints for all deposits

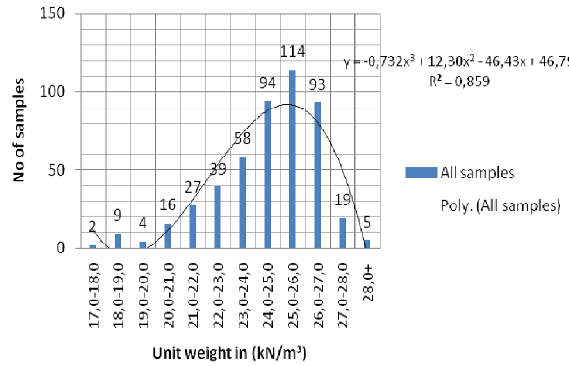

Fig. 12. Number of unit weight samples divided in 7 classes

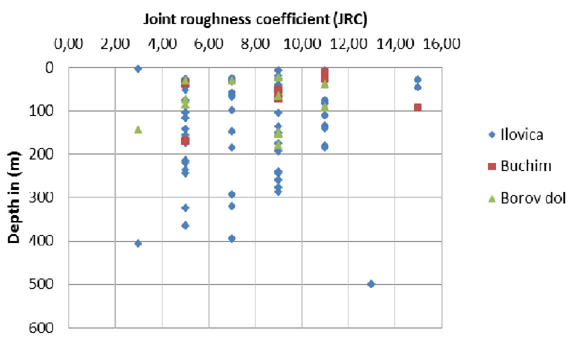

Fig. 11. Variation of joint roughness coefficient for all deposits

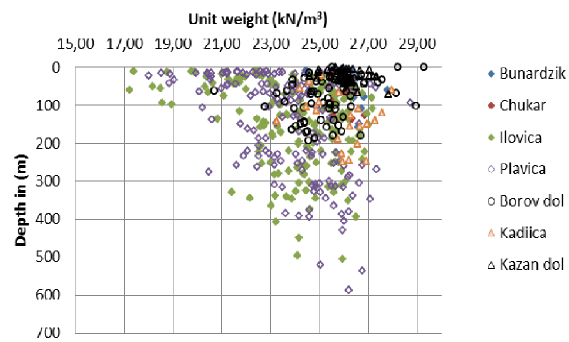

Fig. 13. Variation of unit weight with depth for all deposits

Since the shear strength along joints is from particular interest in the mining design of the working benches slope angles, as well as for the final pit shell slopes in open pit mines, it is very important to perform additional investigations for some of the deposits. Therefore, the results presented herein can be used to extrapolate some of the shear strength parameters only for certain zones of the Ilovica deposit, while for the other deposits it can be considered that there are not enough samples to perform any extrapolations in this sense.

Unit weight

If the results from all deposits are analyzed it is noticed that the unit weight of the rocks is in the interval between 17.0 and 29.0 kN/m^3 (Figure 12). Such large variations in the values are characteristic mostly for samples to the depth of 100.0 to 150.0 m (Figure 13). Samples from depth over 150.0 m show reducition of this variation, with tendency towards values between 24 and 27.0 kN/m^3. The largest variations are noticed for the deposits of Ilovica and Plavica, while the lowest for Bučim and Kazan Dol (Figure 13 and Table 2).

Specific weight

Specific weight tests were performed only on samples from three of the deposits. The obtained values are usually in the range of 27.0–29.0 kN/m^3 and with slightly but noticeable tendency towards larger values as the depth increases (Figures.14 and 15). However, because only three of the deposits are analyzed, no general conclusions are achieved.

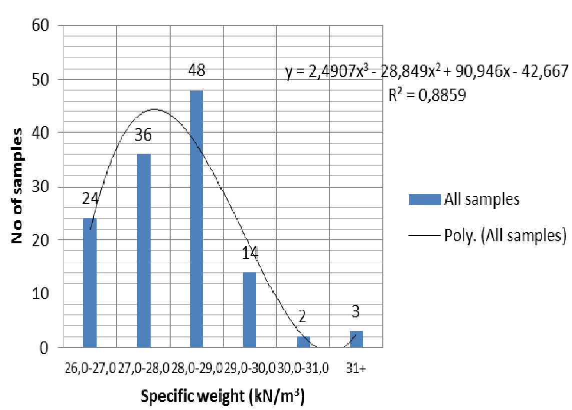

Fig. 14. Number of specific weight samples divided in six weight classes

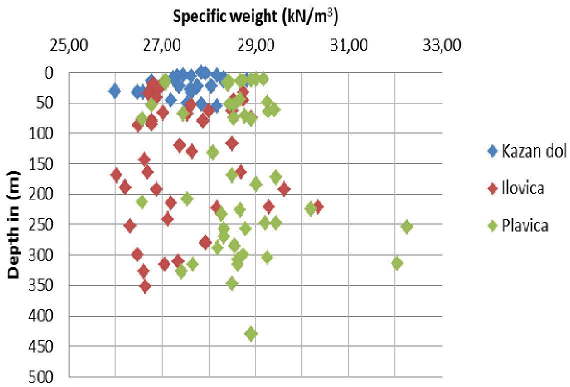

Fig. 15. Variation of specific weight with depth for deposits of Kazan Dol, Ilovica and Plavica

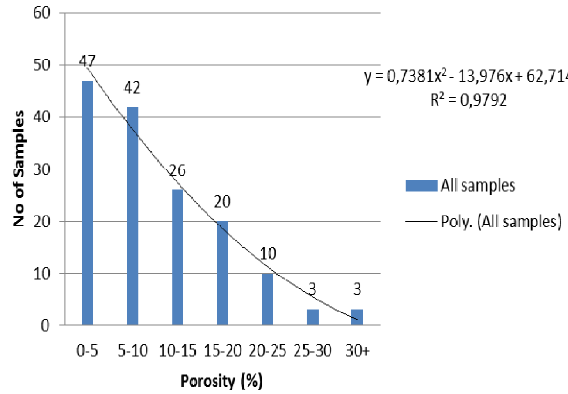

Fig 16. Number of samples tested for porosity divided in seven porosity classes

Porosity

The porosity ranges for all rocks from four of the deposits are presented in Figure 16. Most of the values classify the rock in group of low to medium porosity (n = 1–15%), while the rest can be classified as rock with high porosity (15–30%).

If these values are compared with porosity of bare igneous rocks (without ore) then the difference is significant. Standard values of igneous rocks porosity with some rare exceptions are in range of up to 2%). In relation to changes in vertical direction, it is clear that the porosity decreases with depth in all of the analyzed deposits (Figure 17).

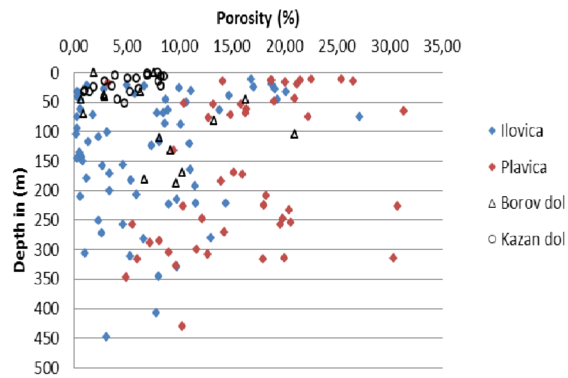

Fig. 17. Vaiation of porosity with depth for deposits of Kazan Dol, Ilovica, Plavica and Borov Dol

CONCLUSIONS

Metallic mineral deposits in the Republic of Macedonia have very variable values of the basic geotechnical properties. The most pronounced variability is related to the strength parameter or in particular the unconfined uniaxial strength of the rocks. In relation to the changes in vertical profile of the deposits, particular patterns are noticed almost for all properties and these relations are more or less pronounced from deposit to deposit. From the noticed trends in the vertical profiles of all deposits, it can be concluded that most geotechnical parameters tend to some stabilization-equalization as the depth increases.

However, one should be very precautious during performing certain extrapolations in the uninvestigated zones of the deposits, especially with taking into account the mentioned shortcomings and limitations of the analyses presented herein. It is suggested that further investigations and statistical analyses are performed in order to get more precise picture of the geotechnical values variations both in vertical and horizontal direction for each of the deposits.

In this context, possible investigations should be aimed at:

– establishing correlations between geotechnical parameters with certain rock types / hydrothermal alterations;

– establishing correlations between geotechnical parameters with distance from the center of the hydrothermal/porphyry system in horizontal and vertical direction;

– divide each deposit in particular geotechnical domains using geotechnical modeling softwares.

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Р е з и м е

ОСНОВНИ ГЕОТЕХНИЧКИ ПАРАМЕТРИ НА НАОЃАЛИШТА НА МЕТАЛИЧНИ МИНЕРАЛНИ СУРОВИНИ ВО РЕПУБЛИКА МАКЕДОНИЈА

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Клучни зборови: геотехнички параметри; наоѓалишта на метални минерални суровини; статистичка анализа; вертикална дистрибуција

Во трудот е презентирана анализа на основните геотехнички параметри на карпести примероци од поголем број наоѓалишта на метални минерани суровини во Република Македонија. Имено, прикажани се резултати од опсежни геотехнички истражувања изведени на наоѓалиштата Иловица, Боров Дол, Казан Дол, Плавица, Кадиица, Бучим. Изведени се повеќе од 800 различни геотехнички лабораториски опити на примероци од јадра земени од различни зони на овие наоѓалишта. Најчесто изведуваните тестови во рамките на геотехничките програми за истражувања на овие наоѓалишта вклучуваат: индекс на точкеста јакост, едноаксијална јакост на притисок, волуменска и специфична тежина, порозност, јакост на смолкнување надолж пукнатини. Сите податоци се статистички анализирани и дадени се одредени заклучоци кои се однесуваат на поедините геотехнички параметри. Особено внимание е посветено на вертикалната дистрибуција на вредностите на геотехничките параметри, имајќи ја предвид нивната важност за самиот процес на планирање ископи (особено димензионирање на отворени копови) и преработка на рудата. Дискутирани се разликите помеѓу одредени наоѓалишта и дадени се одредени заклучоци и препораки за идни истражувања. Се напомнува дека ова е прв обид да се анализраат олку голем број геотехнички податоци за наоѓалишта на метални минерални суровини во Република Македонија, но со прибирање нови податоци, можно е овде претставените корелации да претрпат промени.