EVALUATION OF GRANITE WEATHERING IN THE JERONÝM MINE USING NON-DESTRUCTIVE METHODS

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ABSTRACT
The paper presents the results of experimental examination of the weathering grade of granite rock mass in the medieval Jeroným Mine (Czech Republic). This mine is declared as a cultural heritage site of the Czech Republic therefore, non-destructive methods for determination of the Schmidt hammer rebound value and the ultrasonic pulse velocity were used to minimize negative impact on the historical workings during in situ exploration. Weathering grade of selected parts of the rock mass in underground spaces was classified visually according to the assumed classification (Hencher and Martin, 1982 in Vahed et al., 2009) and the above mentioned measurements were performed in these parts. Results show that the rebound value and the ultrasonic pulse velocity are decreasing with increasing weathering grade for all investigated parts. Therefore this result is possible to use as a supplementary method for evaluation of weathering grade of rock massif in this mine.

KEYWORDS: weathering, granite, mine, ultrasonic pulse velocity, Schmidt hammer

INTRODUCTION

Examination of the properties of rocks subjected to weathering processes is an integral part of both rock environment exploration in situ and exploration of stones used in civil engineering and arts. Mostly in historical buildings built of natural stone, not only decorative stone elements and superficial layers on the facades are deteriorated (Lehrberger and Gillhuber, 2007), but also total devastation of structures or their parts due to the loss of stability of the supporting elements of stone occurs. A lot of non-destructive test methods proved practical for examination of the properties of these materials, the advantage of which is primarily obtaining information about the materials without coming to their visual damage. As presented by Svahn (2006), in the area of conservation and restoration of building stone, geophysical (e.g. ultrasonic pulse velocity measurement, hammer methods, acoustic emission methods, radar methods), spectroscopic and chemical methods (e.g. absorption spectroscopy, diffusion spectroscopy, radio chemical methods) and imaging techniques (laser scanning, thermography, radiography, computer tomography, photogrammetry) are used. Many methods are used both in field survey and in laboratory conditions for testing specimens. Based on the results, it is then possible to deduce the properties of the rock material and to search the correct approach to reconstruction or redevelopment, or perhaps, to support the stability. We encounter problems of gradual degradation and subsequent destruction of the rock material not only in monuments and artworks, but we may also encounter them in specific structures situated in the rock mass, such as geotechnical structures or mine workings.

This paper deals with the evaluation of degradation of rock material in a historical tin ore mine. Jeroným Mine is situated in the west part of the Czech Republic in the area with rich mining history and it is a valuable example of preserved historical mining operations dating back to the 16 century, such as extraction using a picker and miner's hammer, fire setting, underhand stoping or overhand stoping, chamber mining, etc. Nowadays, this mine is declared as a national heritage site and its opening for the public in the form of a mining museum is expected in the future. The stability of the mine, the parts of which are more than 400 years old, is the priority both in light of preservation of the unique spaces for the generations to come and in light of safety of people attending the mine. The evaluation of stability and the most critical places from the viewpoint of geomechanics can be found in several papers, e.g. Kaláb et al. (2008) or Kukutsch et al. (2011). This paper describes the problem of surface layers weathering of the rock mass in mine workings. For evaluation of the weathering grade, apart from its visual evaluation, also non-destructive test methods were used – measurement of the Schmidt hammer rebound values and ultrasonic pulse velocity (UPV) measurement. Their first results are presented in this paper.

LOCALITY DESCRIPTION

Jeroným Mine is found on the territory of the former Čistá municipality, Sokolov district. The more detailed description of this locality along with results of a long-term geomechanical monitoring can be found in many papers (e.g. Žůrek et al., 2008; Kaláb et al., 2008; Kaláb et al., 2006; Knejzlík et al., 2011). Within the framework of the grant projects 105/06/0068 (terminated in 2008) and 105/09/0089, the possibility of using this historical mine working as a natural experimental laboratory in this locality is presented as well. The distributed measurement network for seismological monitoring and continuous geomechanical measurement of selected parameters, e.g. the movements along fractures, fluctuation of mine water levels, atmosphere and water temperatures, pH and water resistivity, stress tensor variations in boreholes using the conical probe, is implemented in the mine working (Knejzlík and Rambouský, 2008; Lednická et al., 2011a). Results of these measurements are important not only for stability assessment, but they are used also for the fractal analysis of time dynamics of the measured parameters (Kaláb et al., 2010b; Telesca et al., 2011). A series of geophysical surveys, such as resistivity profiling, electrical resistance tomography, shallow refraction seismic method, microgravimetry and dipole electromagnetic profiling were carried out on the Jeroným Mine locality. The results of measurements performed can be found, e.g. in papers by Hoffrichterová et al. (2005) and Beneš (2011). One of the methods of visual observation used in the rock mass of Jeroným Mine, especially flaking-off phenomena, is the method of time-lapse recording (Kukutsch et al., 2010).

The territory, where the Jeroným Mine deposit is found, consists of metamorphised rocks of the Slavkov mantle crystalline complex (primarily the biotite paragneisses that are migmatitized in various intensities and granitized upon intrusion of granites) and of Variscian granites of the Ore Mountain pluton. The Jeroným deposit came into existence by the action of mineralizing solutions in the already solidified rock of the Krudum massif. The Sn-W mineralization is bound to two types of formation, either the quartz vein with cassiterite and wolframite or the impregnation of cassiterite and wolframite in altered granites. It is apparent from the structural-tectonic measurements executed within the scope of geological exploration that the fissure tectonics is represented by these directions: ENE – WSW and in the direction perpendicular to this direction NNW – SSE. Both directions are characterized by high values of inclination, ranging from 70 to 90 degrees. The third type is represented by the fissures oriented roughly horizontally with a slight inclination of 5 – 35 degrees. In relation to Cloose fissures of separation, the discontinuities in the direction NNW – SSE correspond with the "Q" type of fissures, the direction ENE – WSW with "S" type of fissures and the horizontally positioned areas correspond with "L" type of fissures. This natural fissure tectonics plays an important role in stability evaluation of the mine working. The fissure tectonics showing on the residual pillars was also studied. It is probably recent tectonics induced by anthropogenic factors. These, probably, tension cracks trace roughly the directions of natural tectonics. In contrast with it, they are predominantly uneven to pinnated with a substantially higher frequency (3-5/m); some are considerably open (1-5 cm) and fresh, without any clay coating (according to Žůrek et al., 2008).

Nowadays, Jeroným Mine represents a complex structure of galleries, shafts and chambers on at least three horizontal levels whereas the lowest level is permanently flooded and its scope is unknown for the time being (Fig. 1). For many years, when the complex of mine workings was inaccessible, the underground spaces were subjected to devastation. For instance, by failure of timbering, it collapsed and subsequent breaks occurred, which resulted in restricted ventilation and dewatering. The long-lasting action of ventilated or unventilated mine atmosphere as well as running water or backwater in underground spaces resulted in weathering of the exposed rocks. The rock mass is also exposed to other factors in terms of stability of underground spaces, such as more frequent traffic above the mine these days (Kaláb et al., 2010a), or the vibrations caused by earthquakes from the nearby area of Nový Kostel (Kaláb et al., 2011; Kaláb and Lednická, 2011). The vibrations are induced also by man-made sources such as usage of blasting operations during reconstruction of drainage gallery (Kaláb and Lednická, 2006). Other factors that are not specified here contribute also to the genesis of new critical locations or to development of the existing ones. We can see the critical locations not only in the underground itself, but also on the surface in the form of above ground formations (Kukutsch et al., 2011).

The knowledge of rock mass properties is important for the stability assessment and for other studies related to safety of workings. Detailed exploration of the properties of rocks in Jeroným Mine is limited due to protection of historical workings. It is not possible to carry out any destructive tests in the historically valuable parts. This eliminates the systematic sampling of rock massive for detailed laboratory measurements. Collecting samples for laboratory testing is disallowed also by the character of the rock mass which is considerably weathered in some parts of the working. Another problem results from spatial situation of some underground parts, due to complicated access to them. Within the framework of construction of the distributed measuring network in the underground spaces of the mine and installation of conical probes for measuring the variations in stress tensor in the massif, two boreholes were allowed to have been drilled in one of the biggest chambers in 2007. On two

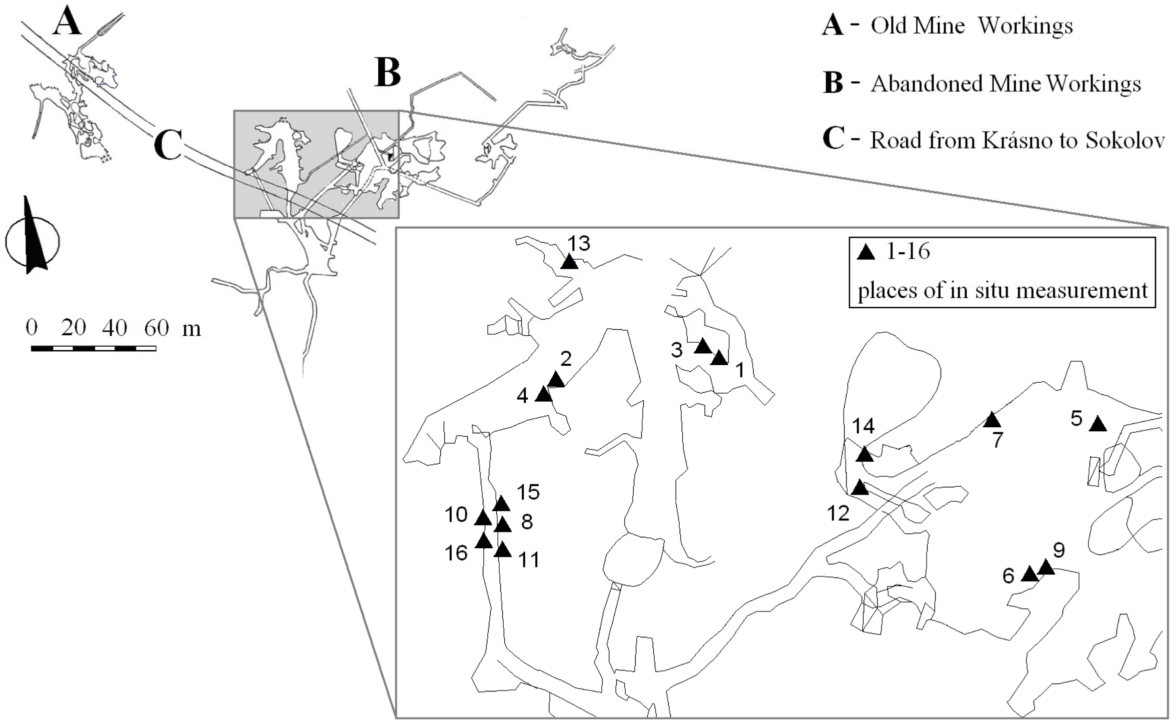

Fig. 1 Sketch of Jeronýi Mine underground spaces with identification of measurement locations (see below).

Table 1 Physical parameters of rock samples from drill cores (Lednická et al., 2011b) – symbols: ρ_0 - density, σ_D - compressive strength, E - Young modulus, μ - Poisson ratio, UPV_{DRY} - ultrasonic pulse velocity measured in longitudinal direction on dry specimen .

	Specimen number	ρ_0 (kg/m^3)	σ_D (MPa)	E (MPa)	μ (-)	UPV_{DRY} (m/s)
drill core I	11807/1	2618	57	15400	0.26	3439
	11807/2	2610	52	12700	0.19	3476
	11807/3	2600	61	16500	0.12	3632
	11807/4	2593	57	14800	0.14	3452
	11807/5	2602	66	15500	0.2	3489
drill core II	12070/1	2621	76	10400	0.22	3230
	12071/1	2631	83	11400	0.12	3448
	12071/2	2592	73	8600	0.11	3179
	12072/1	2617	72	12200	0.17	3520
	12073/1	2661	86	12400	0.11	3626
	12073/2	2642	80	11800	0.14	3483

approx. three-metre long drill cores, collected from two different parts of the chamber at depths of 25 and 30 m beneath the surface, laboratory measurements and determination of selected parameters of the rock were carried out. The summary of density, compressive strength, Young modulus, Poisson ratio and ultrasonic pulse velocity (UPV) is presented in Table 1 (Lednická et al., 2011b). Both drill cores show weathering grade II-III according visual evaluation (Table 2). Gradual change of weathering grade along drill cores was not observed, only in proximity of discontinuities. Based on laboratory measurements, it turned out that the drill cores under examination have different deformation characteristics. The determined properties of rocks can be used, e.g. for creation of mathematical models (Hrubešová et al., 2010; Hrubešová, 2011). In light of the entire mine complex, the properties determined from the boreholes represent only point information, which is quite insufficient in light of examination of stability of the mine working as a whole and the stability of its most critical parts. One of the possible approaches to determination of parameters of rocks is the non-destructive testing in the mine workings but it usually provides only the information about the near-surface rock mass strata.

WEATHERING PROCESSES IN JERONÝM MINE AND THEIR CAUSES

According Bell (2000), rock material tends to deteriorate in quality as a result of weathering and/or alteration. Weathering refers to those destructive processes, brought about by atmospheric agents at or near the Earth's surface. Alteration refers to those changes which occur in the chemical or mineralogical composition of a rock brought about by permeating hydrothermal fluids or by pneumatolytic action. Granite may weather away by chemical decomposition or by physical disintegration; however, these processes act together in most cases. During chemical decomposition of granites, the feldspars are decomposed to various clay minerals. Mechanically, the rock disintegrates by opening the fissures and forming new discontinuities. The intensity and scale of discontinuities often grows with the extent of weathering. The type and grade of weathering are dependent on climatic conditions, namely on temperature and precipitation (Bell, 2004). Chemical weathering processes mostly prevail over physical disintegration in wet environments. The presence of water accelerates the weathering process not only because water itself is an efficient weathering agent but in addition, it may contain dissolved substances that react with component minerals of rock. Chemical weathering processes may be further accelerated by mechanical breakdown that leads to the enlargement of mineral surfaces.

Weathering in Jeroným Mine takes its course by both physical disintegration and chemical decomposition. Specific climatic conditions, such as a relatively constant temperature of 4-8 Celsius´ degrees, almost a hundred per cent humidity and minimum air movement (only in certain spaces due to ventilation), prevail. Moreover, some parts of the workings have been flooded with underground water for a long time whereas the water level may vary from centimetres to metres. Outbursts of water from walls, breaks and inaccessible workings can be observed in several places in the mine, and the amount of outgoing water varies, depending on hydrogeological conditions of the surroundings and climatic changes on the surface.

In these specific conditions of the underground spaces, it is possible to eliminate some types of the physical weathering processes, such as mechanical weathering owing to frost wedging or thermal expansion, and owing to changes of temperatures in the daytime and at night. Conversely, the anthropogenic activity connected predominantly with mining caused mechanical breakdown of the massif, i.e. opening up the existing fissures or forming new ones.

Rock mass cracking during mining is realized to obtain better workability of the rocks. In the oldest stage of mining in the Jeroným mine, which began in the 16th century, the picker and miner's hammer were used for crumbling away the rock. Using this mining method, the rock cracked only in the contact zone of the hammer and the rock; the formation of cracks was negligible. The principle of rock ruptures in the contact zone of the hammer with the surface of rock material during manual work is presented in Figure 2. The surfaces formed by this work are preserved up to now in the majority of historic parts of Jeroným Mine and these belong to the most valuable ones from the historical point of view. Another method used in the oldest stage of mining in the deposit, the so-called fire setting, consisted in heating the rock using wood piles (Beran et al., 1996). During temperature changes, various minerals are subjected to volume changes at various speeds, resulting in development of stress at the boundaries among individual minerals. As a result, the surface layer of the rock cracked and it was easier to cleave it using the picker or hack-iron and miner's hammer. The area of the surface cracked in this way depended probably on the size of wood piles set on fire. The depth action radius of the cracked zone was greater compared with the extraction carried out using the picker and miner's hammer.

Drilling and blasting operations used in the deposit probably from the 19th century had the greatest impact on the impairment of the surface layers of the rock. The depth of the impaired zone (cracked zone, Fig. 3) depends on a number of parameters, e.g. the quasi-static pressure on hole wall, tensile strength of rock, hole radius, detonator charge radius, detonation velocity, rock density (Li et al., 2009). In addition to rock cracking and disintegration effects in the place of blast, vibrations are generated and disseminated, and these are characterized by high frequencies of 40 – 80 Hz, sometimes even by higher ones (e.g. Pandula and Kondela, 2010). This seismic

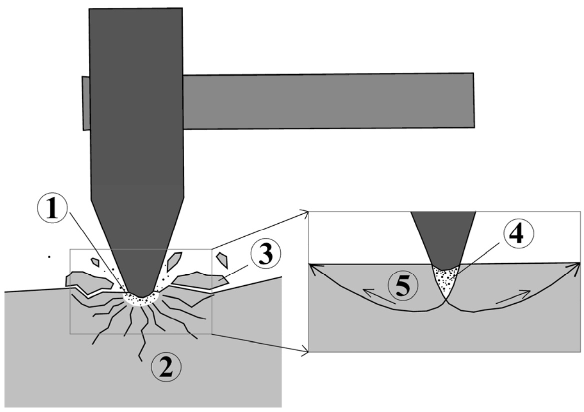

Fig. 2 Principle of rock ruptures after hammer blow; 1 - crushed zone, 2 - cracked zone (radial cracks), 3 – abruption of fragments, 4 - compression forces, 5 - shear forces (according Lehrberger and Gillhuber, 2007).

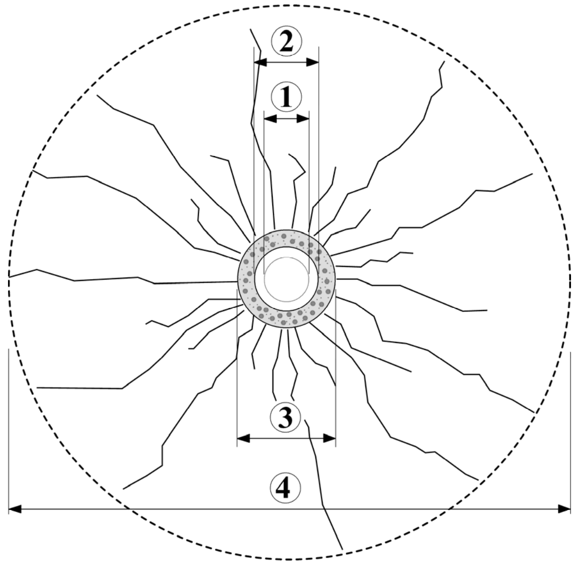

Fig. 3 Principle of rock ruptures around a blasthole; 1 - borehole, 2 - bulge, 3 - crushed zone, 4 - cracked zone (according Li et al., 2009).

loading acting on the workings might lead to the development of fissures in weakened spots of the massif (e.g. in residual pillars), or to development of the existing fissures. The purpose of blasting was to expand the original old confined profiles of galleries or extraction in spatial mining workings – chambers and making new galleries. Blasting operations were also used in the 20th century during the Second World War and probably during exploration in 1960s. Unfortunately, the exact localization of operations carried out is not described in historical documents. The last stage of utilization of blasting operations took its course from 2003 to 2006 during reconstruction of the Jeroným drainage gallery. The effect of this driving was monitored by a seismic station situated right in the mine working. This enabled to determine parameters of blasting operations in such a way so that the vibration velocity limit value at the reference site were not exceeded (Kaláb and Lednická, 2006).

During chemical weathering in humid climatic conditions in mine, hydrolysis, i.e. decomposition of feldspathic minerals to clay minerals, takes its course. The process of chemical weathering can be accelerated directly in the parts affected by mining where the cracked surface layers of the massif come up with leaking water.

It is not possible to leave out biological weathering in the underground spaces of Jeroným Mine localized very close to the surface (distances about ten metres below the surface). These are the chambers with sinking ceilings into which the caved material from the surface lead. It is possible to observe roots of trees penetrating into the caved material and into the cracks in the ceilings.

DETERMINATION OF WEATHERING GRADE

Determination of the weathering grade in selected parts of the rock mass in this mine was carried out visually. It means that colour changes of the rock mass, presence of cracks visible on the surface, friability and visual assessment of weathering state of feldspars were evaluated.

Table 2 Weathering classification system for granite and volcanic rocks (Hencher and Martin, 1982 in Vahed et al., 2009).

Grade	Description	Typical Distinctive Characteristic
VI	Residual soil	A soil formed by weathering in place but with original texture of rock completely destroyed
V	Completely weathered rock	Rock wholly weathered but rock texture preserved No rebound from N Schmidt hammer Slake readily in water Geological pick easily indents surface when pushed
IV	Highly weathered rock	Rock weakened so that large pieces can be broken by hand Positive N Schmidt rebound value up to 25 Does not slake readily in water Geological pick cannot be pushed into surface Hand penetrometer strength index greater than 250 kPa Individual grain may be plucked from surface
III	Moderately weathered rock	Completely discolored Considerably weathered but possessing strength such that pieces 55 mm diameter cannot be broken by hand N Schmidt rebound value of 25 to 45 Rock material not friable
II	Slightly weathered rock	Discolored along discontinuities Strength approaches that of fresh rock N Schmidt rebound value greater than 45 More than one blow of geological hammer to break specimen
I	Fresh rock	No visible signs of weathering or discolored

Table 3 Weathering classification of selected parts in Jeroným Mine according to classification in Table 2; results from field measurement of N Schmidt rebound value and ultrasonic pulse velocity are also included (for detail see text below).

In situ meas. number	Weathering grade	Description	N Schmidt rebound value	UPV (km/s)	Comment, description of locality
1	II	discolored along the discontinuities	34 - 50		northeastern wall of small chamber
2	II	discolored along the discontinuities	27 - 50		southeastern wall of large chamber
3	II	discolored along the discontinuities	33 - 49		northeastern wall of small chamber
4	II	discolored along the discontinuities	30 - 48		southeastern wall of large chamber
5	II-III	discolored along the discontinuities	28 - 46	3.2 – 4.2	eastern wall of large chamber, plane of discontinuity
6	II-III	discolored along the discontinuities	28 - 44		southern wall of large chamber, plane of discontinuity
7	III	color changes in rock material, rock material not friable	22 - 31	2.7 – 3.6	northern wall of large chamber, visible traces of drilling activity
8	III	color changes in material, rock material not friable	20 - 31		eastern wall of the gallery, gallery partially flooded, driven probably during the second world war by using drilling or blasting
9	III	color changes in rock material, rock material not friable, cracked at the surface	20 - 30	2.4 – 3.7	southern wall of large chamber, UPV parallel to cracks direction
10	III	color changes in rock material, rock material not friable, large pieces can be broken by hand	18 - 29	2.8 – 3.6	western wall of the gallery, gallery partially flooded, driven probably during the second world war by using drilling or blasting
11	IV	discolored rock material, individual grain may be plucked from surface	16 - 26		southern wall of small chamber, traces of hand mining,
12	IV	discolored rock material, large pieces of rock can be broken by hand, individual grain may be plucked from surface, crushable by hand	11 - 26		eastern wall of the gallery, gallery partially flooded, driven probably during the second world war by using drilling or blasting
13	IV	discolored rock material, individual grain may be plucked from surface	13 - 23		northern wall of small chamber, traces of hand mining
14	IV	discolored rock material, individual grain may be plucked from surface	14 - 20		wall of the pillar, traces of hand mining
15	IV	discolored rock material, large pieces of rock can be broken by hand, rock material friable	10 - 20	2.4 – 3.1	eastern wall of the gallery, gallery partially flooded, driven probably during the second world war by using drilling or blasting
16	V	discolored rock material, no rebound from N Schmidt hammer, rock wholly weathered but rock texture preserved,	-	2.5 – 2.7	western wall of the gallery, gallery partially flooded, driven probably during the second world war by using drilling or blasting

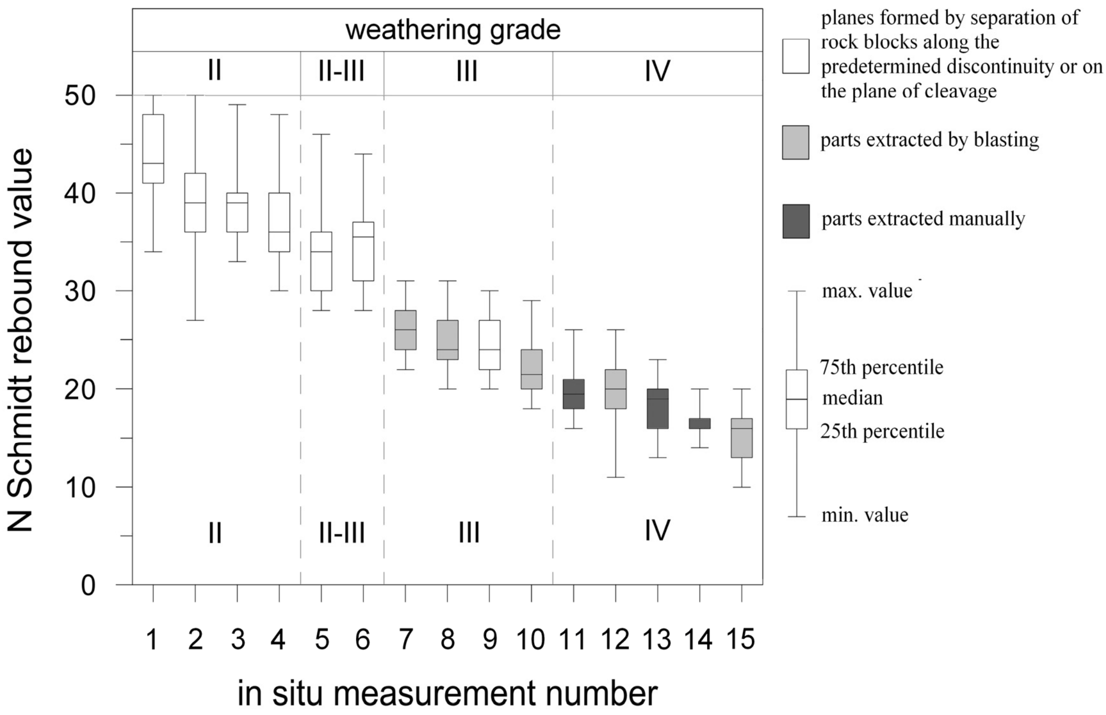

Fig. 4 Measured N Schmidt hammer rebound values (see the text, Table 2, Table 3 and Fig. 1).

In order to determine the grade of weathering, the classification of granites presented by Hencher and Martin (1982 in Vahed et al., 2009) was selected. This classification makes it possible to classify weathering grade according to visual assessment and the individual grades of weathering in this classification are also characterized with a range of rebound values of the N-type Schmidt hammer. The resulting classification of selected parts in Jeroným Mine according to classification in Table 2 is summarized in Table 3. Last mentioned table presents also results from field measurement of N Schmidt rebound value and ultrasonic pulse velocity. Description and interpretation of these field measurements are presented in next chapters.

MEASUREMENT OF SCHMIDT HAMMER REBOUND VALUES

The Schmidt hammer is used for approximate determination of surface hardness of concrete and rocks. The surface hardness is evaluated according to the height of rebound of a piston indicated on the rebound hammer scale. There are several types of Schmidt hammer; they differ in impact energy values of the spring. The N-type Schmidt hammer with the impact energy of the spring conformable to 2.207 Nm was used in our measurements. The surface hardness is converted from the measured rebound value pursuant to graphs given by the manufacturer for the appropriate type of hammer. The conversion must include also the correction for the position of the hammer, i.e. the deviation of the hammer axis during impact from the horizontal axis.

In situ measurements using the Schmidt hammer in Jeroným Mine were performed in 16 selected parts, see Figure 1. The parts were selected pursuant to visual assessment in such a way that the rock mass shows the same grade of weathering across the measured plane. The size of measured planes varied from 20 x 20 to 30 x 30 cm. The measurements were carried out in 30 points uniformly distributed across the measured plane. Only one measurement was carried out in each of the points. To determine the weathering grade, it is possible to use also a different test procedure when more measurements are performed in one point. This procedure has not been applied to the evaluated locality so far. As stated by Aydin and Basu (2005), or Basu et al. (2009), during two consequent measurements in one point, there are differences in the measured rebound value due to destruction of the surface layer by the impact of the piston. The second of the measured values shows usually a growth of rebound value whereas the difference between the first and the second measured values increases with the grade of weathering. Apart from surface hardness, the rebound value of the Schmidt hammer depends on the relative strength of coarse grains versus matrix, moisture content, anisotropy, etc. These effects were proved by a number of authors, e.g. Aydin (2009). During the field measurements in the Jeroným Mine, these effects were not proved in more detail. The dependence of the measured rebound values on visually determined weathering grade in selected parts is shown in graph in Figure 4. Box - whisker plots were used for presentation of the measured rebound values. Box –

whisker plot shows median, 25th and 75th percentiles, and the extreme values of the distribution. Generally, it is possible to state that the planes, which were formed by separation of rock blocks along the predetermined (natural) discontinuity or on the cleavage plane, show a lower weathering grade (II-III). Conversely, the parts extracted by blasting or manually by the picker and miner's hammer are subjected to the higher weathering grade (III-V).

ULTRASONIC PULSE VELOCITY MEASUREMENTS

Laboratory UPV measurements of granites with various weathering grades was implemented by a number of authors, e.g. Vasconcelos et al. (2007), Vasconcelos et al. (2008), Olona et al. (2010) and Gupta and Seshagiri Rao (1998). In laboratory conditions, it is possible to perform precise UPV measurements on specimens under defined conditions. The UPV can be correlated with a number of rock parameters, such as density, porosity, humidity, strength, Young modulus, etc. However, it is not possible to implement such exact ultrasonic measurements in field conditions of the mine. The geometry of workings allows using only indirect measurement on the wall and ceiling of the workings. It is possible to use direct measurements through thin pillars only sporadically. We encounter the same problem, for example, in the area of stone conservation. Svahn (2006) discussed that there are differences between the indirect and the direct measurements. The indirect measurements have slightly lower UPV with differences up to 0.8 km/s on the sandstone.

The determination of precise UPV values was not the objective of our research, but we were to check especially the application of this measurement to differentiate various weathering grades of surface layers of the rock mass in the mine working.

The Pundit Plus ultrasonic apparatus was used in field measurements. This allows measuring the travel time between the transmitting and receiving probes. Only 54 kHz probes were available for this apparatus. Some recommendations resulted from test measurements performed in the Jeroným Mine. The plasticine was the only acoustic couplant that made the measurement possible. It was necessary to reduce the contact surface of the 50 mm diameter probes to provide a better contact of the probes with the rock. Conical metal extensions for measuring probes, the contact area of which is 15 mm in diameter, were used for this purpose. During the UPV measurement of the cracked and weathered rock mass, the representation of waveform records of the ultrasonic signal is necessary. It is possible to determine the correct travel time only from these records. There is a considerable attenuation of the ultrasonic signal in the weathered rock mass and the apparatus is unable to recognize the arrival of the first wave and than to determine the correct travel time from it. As turned out during the measurements, with weathering grades IV and V the signal was attenuated so much that the measurement of travel time could be evaluated only at the distance of probes 0.1 m. For the weathering grade III, the measurement with probes´ distance up to 0.4 m was successful. In these measurements, there was an imperceptible growth of UPV with probes´ distance increasing. It is known that for a greater probes´ distance, the UPV measurement has a greater depth range and the signal passes through the less weathered part of the rock deeper under the surface. This is manifested by the increase in the velocity. For the 0.4 m probes´ distance, we suppose the depth range of approx. 0.1 m. Using Pundit Plus apparatus in our field conditions it was not possible to evaluate changes of rock mass weathering depending on depth in more detail. For measurements at small probes´ distance, it is more suitable to use the probes with higher frequencies (with regard to the wavelength of oscillation and the character of the measured rock); however, these probes were not available. Comparing the UPV acquired by measurement using the precise laboratory EMA2 apparatus and the portable Pundit Plus apparatus on the drill cores showed that the data measured with the field apparatus are useable for the given purpose (Lednická et al., 2011b).

For evaluation of the UPV for the measured parts in the workings, the UPV from measurements with the 0.1 m probes´ distance were selected due to a possibility of mutual comparison of these results. Figure 5 shows the results for six selected areas representing various weathering grades. These grades increase from left to right, beginning from II to V. It can be seen that both the UPV and the Schmidt hammer rebound values are decreasing in the same sense. In the area with the V grade of weathering, the UPV was determined, but the Schmidt hammer rebound values were not interpretable, which correspond to the presented classification according Hencher and Martin (Table 2). The transition of UPV among individual weathering grades is not sharp and the measured data are mutually overlapped in part. Among others, this is the consequence of non-homogeneity of the rock mass, its state of weathering and also by smooth transition of the weathering grades.

CONCLUSIONS

The paper presents the results of evaluation of the rock mass weathering grade of granite massif. In the example of medieval Jeroným Mine, in which only non-destructive testing methods can be used without the possibility of rock sample collection, the methods for determination of the Schmidt hammer rebound value and the ultrasonic pulse velocity were used. The selected parts of the rock mass in underground spaces were visually classified according to the assumed classification (Hencher and Martin, 1982 in Vahed et al., 2009) and the above mentioned measurements were performed in these parts.

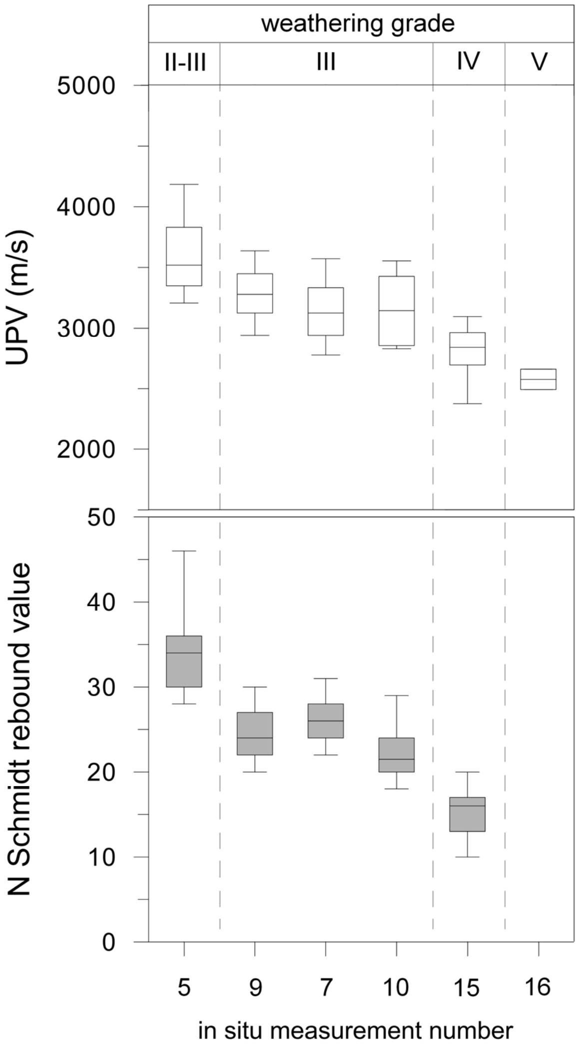

Fig. 5 Measured UPV and Schmidt hammer rebound values on six selected parts (see Table 2, Table 3 and Fig. 1).

Generally, it is possible to state that the planes, which were formed by separation of rock blocks along the predetermined (natural) discontinuity or on the plane of cleavage, show a lower weathering grade (II-III). Conversely, the parts extracted by blasting or manually by the picker and miner's hammer are subjected to the highest weathering grade (III-V). The non-destructive testing results show the dependence of rebound value and the ultrasonic pulse velocity on the determined weathering grade of rock; both measured values are decreasing with increasing weathering grade. These results are therefore usable as a supplementary method for evaluation of weathering grade of rock massif in this mine.

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