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ASSESSMENT OF BORAČ-KOTLENIK MAGMATIC MASSIF ROCK MASS TECHNICAL PROPERTIES AS POTENTIAL SOURCE FOR OPTIMAL DEVELOPMENT OF REGIONAL ROAD INFRASTRUCTURE BASED ON LOCAL STONE MATERIALS

OCENA TEHNIČKIH SVOJSTAVA STENSKE MASE BORAČKO-KOTLENIČKOG MAGMATSKOG KOMPLEKSA KAO PODLOGE ZA RAZVOJ REGIONALNE PUTNE INFRASTRUKTURE NA BAZI LOKALNIH KAMENIH MATERIJALA

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Keywords
- Morava corridor
- Borač-Kotlenik magmatic massif
- volcanic stone materials

Abstract

The Borač-Kotlenik magmatic massif in central Serbia is mainly made up of effusive and pyroclastic rocks, formed in three main phases of volcanic activity: 1. dacite and andesite, 2. quartz-latite and dacite, and 3. basaltoid rocks.

Rock mass samples from this magmatic massif have been examined and mined in numerous localities during the XX century for purposes of building and reconstruction works of local and regional road networks. The examination process continues today for purposes of 'Morava corridor' highway building and its demand for the local stone material of the specified quality.

The results of rock mass technical properties' tests have shown that its quality for road building purposes depends significantly on petrologic type, soundness, and hydrothermal alteration type. Oxidation alteration types can cause a significant decrease in compressive strength, an increase in porosity and water absorption, especially as oxidative chemical processes cause increased susceptibility to weathering, thus making the rock mass unusable in road construction profile layers above the embankment.

Testing results demonstrate that effusive volcanic rocks of the Borač-Kotlenik magmatic massif generally can be used in the road building process. For this purpose, it is necessary to select the conformable rock mass zones at each locality, where hydrothermal alteration and weathering products are absent in order to obtain the best available stone material of volcanic origin.

Ključne reči
- Moravski koridor
- Boračko-kotlenički magmatski kompleks
- kameni materijali vulkanitskog porekla

Izvod

Boračko-kotlenički magmatski masiv u centralnoj Srbiji pretežno čine efuzivne i piroklastične stene, formirane u tri glavne faze vulkanske aktivnosti: 1. daciti i andeziti, 2. kvarclatiti i daciti, i 3. bazaltoidne stene.

Uzorci stenske mase iz ovog magmatskog masiva ispitivani su i eksploatisani na brojnim lokalitetima tokom 20. veka za potrebe izgradnje i rekonstrukcije lokalne i regionalne putne mreže. Ispitivanje se nastavlja i danas za potrebe izgradnje autoputa 'Moravski koridor' i potražnje za lokalnim kamenim materijalom specificiranog kvaliteta.

Rezultati ispitivanja tehničkih svojstava stenske mase pokazali su da njen kvalitet za potrebe izgradnje puteva značajno zavisi od petrološkog tipa, čvrstoće i tipa hidrotermalnih promena. Alteracije oksidacionog tipa mogu da dovedu do značajnog smanjenja pritisne čvrstoće, povećanja poroznosti i upijanja vode posebno, jer oksidacioni hemijski procesi izazivaju povećanu osetljivost na atmosferske uticaje, čineći tako stensku masu neupotrebljivom u slojevima kolovoznog profila iznad nasipa.

Rezultati ispitivanja su pokazali da se efuzivne vulkanske stene Boračko-kotleničkog magmatskog kompleksa generalno mogu koristiti u procesu izgradnje puteva. U tu svrhu potrebno je odabrati pogodne zone u okviru stenske mase na svakom lokalitetu, gde nema hidrotermalnih promena i produkata raspadanja pod uticajem atmosferilija, kako bi se dobio najkvalitetniji dostupni kameni materijal vulkanskog porekla.

INTRODUCTION

The Morava corridor, or A5 motorway, the building of which has begun in 2019 and is planned to be finished in 2025 is a highway around 110 km long, connecting Kruševac (village Pojate) and Čačak (village Preljina) cities in central Serbia. It runs generally along the Zapadna Morava River, approximately 110 km south of Serbia's capital Belgrade. As this main traffic artery is finalised, the significant regional roads will continue to be built and reconstructed in wide extent in central Serbia, since the last regional reconstruction of the road network in this area has been performed around 50 years ago.

In the road-building process, it is common practice to use the local stone material with suitable technical (physical-mechanical) properties. These can be extracted from the riverbed or nearby stone pit localities. Most local stone materials are suitable for the lower layers of the road structure – the embankment, sub-base and lower base course. The surface wearing course stone materials must conform to more strict quality requirements.

The vast range of local stone materials used in the construction and reconstruction of the Kragujevac-Ljuljaci-Gornji Milanovac, Kragujevac-Bare-Knić-Toponica-Mrčajevci and Kragujevac-Topola roads were tested in 'The stone and aggregate laboratory' of the IMS Institute in Belgrade. This database can be very useful today as road building and reconstruction continues in the area.

The geologic composition of the terrain near Zapadna Morava River is such that the lower parts of terrain are covered by Neogene sediments, while the hilly and mountainous parts uncover magmatic rocks. Older sedimentary, namely Cretaceous and metamorphic rocks are also present in the wider Borač-Kotlenik area. However, their technical properties are less favourable in road construction compared to volcanic rocks.

Kotlenik and Borač Mts. (Fig. 1), situated north of Zapadna Morava River are entirely made up of magmatic, namely, volcanic rocks. Considering the vast amounts of available stone material necessary in road construction that these mountains provide and their vicinity to road construction site, the quality of various petrographic types has been examined for the purpose of determining their potential use in the 'Morava corridor' building process and lateral roads construction.

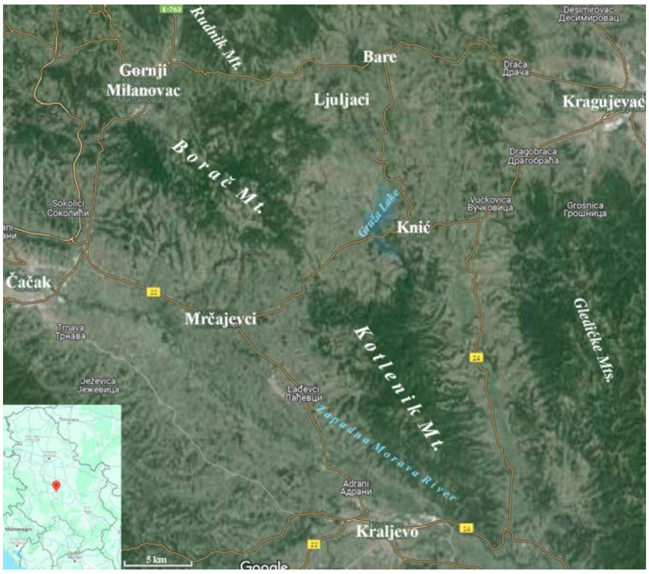

Figure 1. Geographic location of Borač and Kotlenik massifs (inset: the location within Serbia).

GEOLOGIC SETTING

Borač-Kotlenik magmatic massif is a continuation of the Rudnik magmatic massif towards the SE. A tectonic subsidence line within the area of *Bumbarevo brdo* has created a valley filled by a veneer of Neogene sediments, thus dividing the magmatic massif at the surface level into two morphologically distinct entities: Borač in the NW (extending between Gornji Milanovac and Knić, at around 95 km south of Belgrade), and Kotlenik in the SE (extending between Knić and Kraljevo). The magmatic massif is surrounded by tectonic valleys filled by tertiary sediments (Fig. 2). The magmatic rocks are of Egerian-Eggenburgian age, formed 23-20 Ma ago /1-3/.

The volcanic province Rudnik-Borač-Kotlenik is a part of Paleogene-Neogene volcanic formation of the central axis of the Balkan Peninsula, situated within the composite terrane of the Vardar zone, where the Jadar block is tectonically docked by the main Tethys ocean suture zone /4/. More recent studies suggest that some volcanic bodies, attributed to the so-called third phase of volcanic activity, such as trachyandesite, trachybasalt and similar volcanites, occurring as generally smaller volume magmatic pool derivative bodies typical of wider flanks of Borač Mt. may be related to a different magmatic belt /5, 6/. Nevertheless, it is evident that magmas that generated the magmatic rocks of Borač-Kotlenik massif had demonstrated a wide range of variations in silica, alkalis and fluid contents, thus birthing a wide range of volcanic rock facies and compositions.

The intersection of regional faults trending NNW-SSE and local faults trending west-east represent the main locations of magmatic activity, /7/. Based on the results of aeromagnetometric surveys, the magmatic massif in Borač-Kotlenik area is the upward extension of the hidden massive plutonic body extending through and beneath Gledići Mts.-Kotlenik-Borač-Takovo-Rudnik-Belanovica area, /8, 9/.

The Borač-Kotlenik massif is mostly made up of effusive magmatic and pyroclastic rocks, with rare outcrops of plutonic rocks, /11/. Volcanic rocks of Borač-Kotlenik massif are divided into products of three main phases of volcanic activity: 1. dacito-andesite; 2. quartz-latite and dacite; and 3. basaltoid, slightly alkaline rocks. Pyroclastic rocks have been formed along with effusive ones throughout all three phases /10, 12, 13/, Fig. 2.

Other authors had given a slightly different view of the genetic sequence: the first phase of volcanic activity in the Lower Miocene had created dacite lava flows; after a short break, in the second phase, riodacite to dacite and unwelded ignimbrite formed in explosive (Plinian to subPlinian) eruptions; following swiftly the next phase had generated quartz-latite lava flows, domes and volcanic necks along with pyroclastic facies, and then andesite, hyaloclastite and lamprophyre sills. The formation of andesitic lavas had marked the ending of volcanic activity in the area, /7/. However, since the basic geologic map (OGK 1:100000 K34-6 section Kraljevo /10/) has perfectly shown disposition of volcanic products of almost the entire Borač-Kotlenik magmatic massif, for the purpose of this study we stick to the perspective elaborated by Marković et al. /10/. Furthermore, the description of the main products of the three phases of volcanic activity follows the view of the said authors.

First phase volcanites - andesite and dacite (map markings $\alpha\alpha q$ and αq)

Andesite and dacite form a petrologic unity regarding the appearance, mutual relationship and mineral associations, thus are often named 'dacito-andesites' and depending on quartz content, they grade into each other continuously. Their texture is hypocrystalline porphyric. Main minerals are andesine, quartz, biotite, hornblende, ferroan enstatite and clinopyroxene. Plagioclase feldspars are rarely unaltered.

Continuous oxidation of mafic minerals leads to ultimate formation of hematite, giving the rock a red hue. Propylitisation is prevalent in subvolcanic facies and is giving rocks a green hue and sometimes significant pyrite content. Salic minerals mostly remain unaltered in this type of alteration.

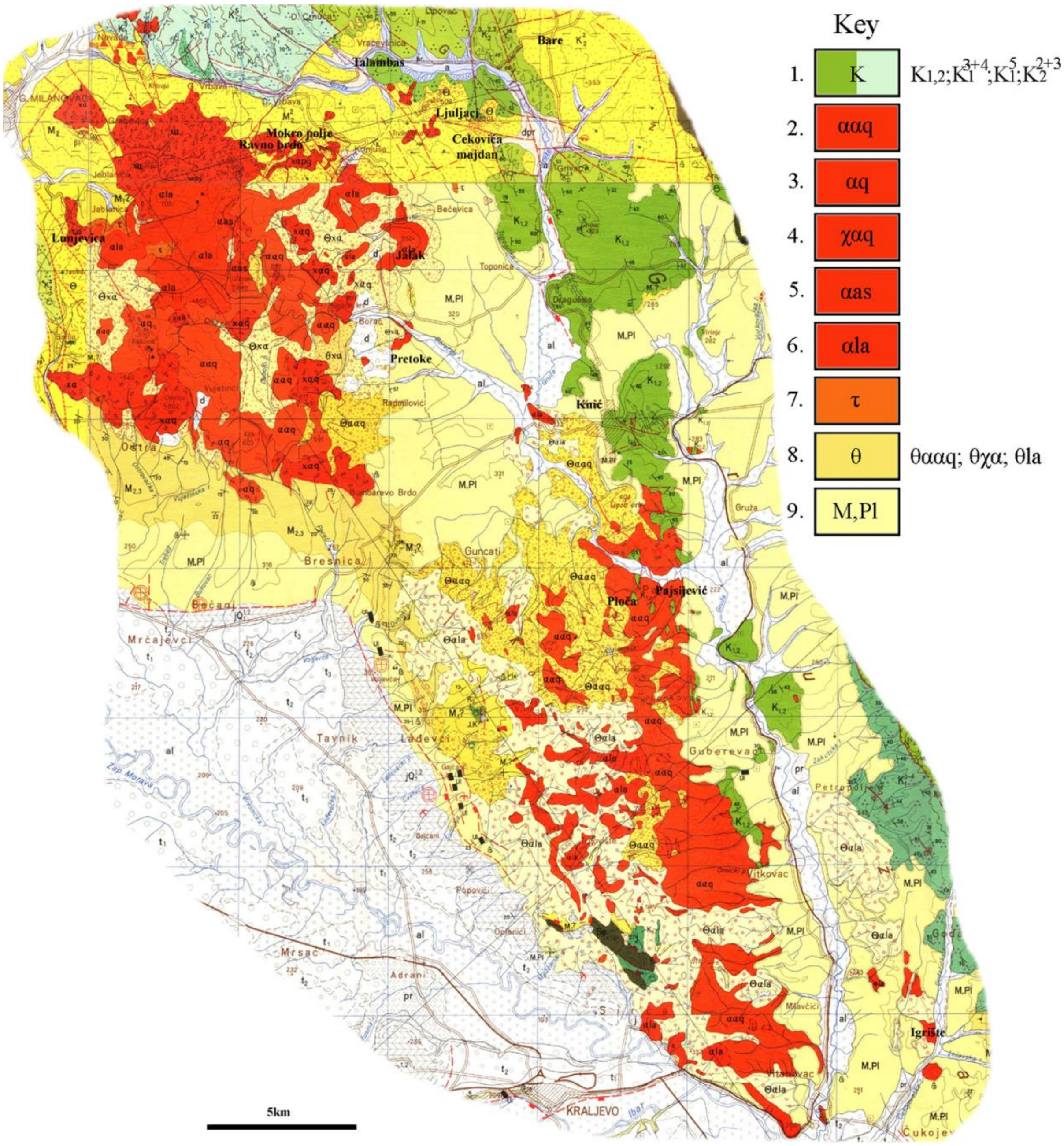

Figure 2. Geologic map of Borač-Kotlenik area (after /10/, modified) with locations of sampling areas. Key: 1. various Cretaceous sediments; 2. dacite-andesite (formed in the first phase of volcanic activity); 3. dacite (ibid.); 4. quartz-latite and dacite (formed in the second phase of volcanic activity); 5. andesine- and labradorite-andesite and hyaloandesite (formed in the third phase of volcanic activity); 6. labradorite-andesite (ibid.); 7. trachytoid rocks (ibid.); 8. pyroclastic products (of all three phases of volcanic activity); 9. Tertiary sediments.

Second phase volcanites - quartz-latite and dacite (map marking $\chi\alpha q$)

These rocks are easily discernable in the field as they usually contain large sanidine grains and make up morphologically conspicuous bodies such as volcanic necks, cliffs and also subvolcanic bodies consolidated within the older dacite-andesite rocks and pyroclastites. Their texture is hypocrystalline porphyric with hyalopillitic matrix. Main minerals: quartz, andesine, sanidine, hornblende, biotite and rarely monoclinic pyroxene. Sanidine content is variable. With its decrease, quartz-latite grades into dacite. Oxidation and zeolitisation are prevalent alteration types.

Third phase volcanites - basaltoid volcanites (map markings α_{as}, α_{la}, τ)

This phase had generated predominantly labradorite-andesite, more rarely hyaloandesite, trachytoid rocks (trachyandesite, trachybasalt), and rarely basalt. These types grade into each other. These rocks are most often found in the wider Borač area and at SW flanks of Kotlenik Mt., forming generally smaller dykes in dacite-andesite and Lower Miocene sediments, or concordant bodies formed contemporaneously with pyroclastic projections.

Labradorite-andesite has basaltoid appearance and has thus been named andesite-basalt by former authors. Its texture is hypocrystalline to holocrystalline porphyric with hyalopillitic to cryptocrystalline or fluidal matrix. Main minerals: andesine to bytownite plagioclase, ferroan enstatite, clinopyroxene, sometimes hornblende. Plagioclase is altered into zeolite and carbonate along the cracks and mafic minerals are partly altered into chlorite, carbonate and amphibole. Silification can be present in a varying degree.

Pyroclastic rocks (map markings $\Theta\alpha\alpha q$, $\Theta\chi\alpha q$, $\Theta\alpha la$)

These comprise agglomeratic volcanic breccias and tuffs, making up a major part of the massif's surface. In Kotlenik area, effusive to pyroclastic rocks ratio is 1:2. Due to lack of cohesion and high susceptibility to weathering, these are barely usable in the road embankment structure.

TECHNICAL PROPERTIES OF ROCK MASS TESTING RESULTS

Testing methods of the rock mass used for production of various final products used in road-building are stated in technical specifications, /14-17/. These specifications also state the allowed results' ranges for each testing method. As mentioned, these tests were performed on stone samples in *The stone and aggregate laboratory* of IMS Institute over the course of 75 years.

Data compiled from *The stone and aggregate Laboratory* of IMS Institute in Belgrade, Doctoral theses /18/ and /19/ are presented graphically for an easier overview.

DISCUSSION

In the road-building technical requirement specifications /14-17/, the requirements pertaining to stone materials stand for technical properties, such as minimal value of uniaxial compressive strength under various curing conditions, maximum compressive strength decrease after freeze-thaw cycles, water absorption or abrasion resistance (loss) of rock mass samples, for aggregate grading, etc. Unlike the technical requirement specifications for concrete production, in road-building technical requirement specifications, detrimental minerals which might be present within the stone material are not individually stipulated. However, they all /14-17/ emphasize that the presence of alterations within the rock mass is undesirable. Most alteration types, when present within the rock mass, can lead to rapid decrease in quality of built-in stone materials after their placement within the road structure and application of wear and tear, reducing their service-life quality and longevity. Also, certain types of alteration can lead to rapid decrease in maximal size of available rock mass blocks. This is the reason due attention must be given to alteration type present within the rock mass and its intensity degree. These are obtained by diligent field examinations in combination with in-lab petrographic analyses.

Dacito-andesite (so-called 1st phase volcanites)

When fresh, grey in colour, but more often than not - altered, gaining red, purplish, or green hue. Plagioclase phenocrysts can be fresh - colourless and translucent, or altered and off white to yellowish and matted. Mafic mineral grains can be altered to such an extent that it is impossible to determine the primary mineral. At outcrops, the rock is heavily fractured into pieces up to a few tens of centimetres. Where fresh or silicified, the rock cannot be broken by hammer.

Technical property values vary significantly, depending on alteration type and intensity. Above average water absorption and porosity values are noted, along with increased presence of pyrite formed in the propylitization process. In some localities (e.g., Desivojevića majdan, village Pretoke, Knić municipality; Cekovića majdan, village Ljuljaci, municipality Knić; quarry Ploča 2, village Pajsijević, municipality Gruža), the rock mass' technical properties meet the requirements of the technical specifications for use in building of bituminous lower base, sub-base and surface wearing courses. In others, they do not conform to the requirements for water absorption to be below 1 % or the decrease in uniaxial compressive strength value after freeze-thaw cycles to be under 20 %, compared to dry state measured values (Ravno brdo, village Donja Vrbava, municipality G. Milanovac; quarry Igrište, village Čukojevac, municipality Kraljevo; quarry Ploča 3, village Pajsijević, municipality Gruža).

Andesite from Cekovića majdan locality has been used for decades in the production of cubes, curbs, crushed stone, aggregate for road-building, and as such has been built into many roads in central Serbia (e.g., Kragujevac-Belgrade) and over time has proven to be of high quality, /19/.

Quartz-latite (so-called 2nd phase volcanites)

In more fresh state, the rock is grey in colour, gaining bluish or lavender to deep red hue when altered. At outcrops, the rock is heavily fractured into irregularly-shaped pieces up to few tens of centimetres in length. Limonite is present along the joints due to weathering. In spite of alteration, larger pieces of rock mass cannot be broken by hammer. In some localities (Boškovića majdan, village Knić, municipality Knić; quarry Ljuljaci, village Ljuljaci, municipality Knić), rock mass technical properties meet the requirements of the technical specifications for use in the building of bituminous lower base, sub-base and surface wearing courses. Also, it has been noted that large sanidine crystal grains, due the presence of natural cleavage plains, are prone to accelerated fallout of crystal grain pieces.

Products of this volcanic activity phase were examined and used less frequently than others, presumably due to their less frequent outcrops and their occurrence as smaller magmatic bodies in pyroclastic rocks.

Labradorite-andesite, trachyandesite, trachybasalt etc. (so-called 3rd phase volcanites)

They are usually grey, dark grey to black in colour. Alteration degree varies significantly, and so does the tectonisation degree. Mafic mineral grains are often completely altered. Feldspars tend to be fresher or altered along the rims. Silification intensity varies from one locality to the other, influencing the rock mass technical properties. In most localities (quarry Jalak, village Bečevica, municipality Knić; quarry Mirisavka, village Lunjevica, municipality G. Milanovac; quarry Talambas, village Vraćevšnica; quarry Ljuljaci, village Ljuljaci, municipality Knić), the rock mass technical properties meet the requirements of the technical specifications for use in building of bituminous lower base, sub-base and surface wearing courses.

Higher radioactivity levels of Borač volcanic rocks (quartz-latite: 7.8 ppm U and 29.7 ppm Th; andesite: 6.9 ppm U and 26.3 ppm Th; pyroclastite: 10.5 ppm U and 30.1 ppm Th) compared to Kotlenik volcanic rocks (andesite: 2.4 ppm U and 9.2 ppm Th; pyroclastite: 4.3 ppm U and 12.5 ppm Th) have been noted /20/, however, this should not influence the service life of the used stone materials. The most significant technical properties and their mutual relations are shown in Figs. 3-6.

The graph presenting the values of compressive strength obtained by lab testing, determined for three curing conditions (Fig. 3), provides an approximate picture of rock mass quality, considering it is based on only one technical property. The locality sequence is generally ordered by increasing compressive strength value determined in dry state from 1st phase andesite of Mokro polje (village Donja Vrbava) to the 3rd phase pyroxene andesite of Jalak deposit (village Bečevica). Aside from demonstrating a normal heterogeneity of natural stone material, other phenomena can be observed. Six of twenty samples (not all are shown in the graph to preserve the visibility of the majority of results, see Table 1) have higher compressive strength values determined in water-saturated state or after freeze-thaw cycles than in dry state. This phenomenon is often observed in natural stone materials of volcanic origin, especially from magmatic massifs of central and southern Serbia (Rudnik, Mekote, Bisina, Jošanica). Otherwise, lab test results for majority of homogenous natural stone materials (e.g., limestone, granite, marble, etc.) have compressive strength values in decreasing order from that obtained in dry state testing towards those obtained after freeze-thaw cycles. The cause of the reversed phenomenon in testing results obtained on volcanic rock samples from the complex magmatic massif such as Borač-Kotlenik can be a pronounced variability of alteration degree within the rock mass itself, as noted during field examinations, /14/. Especially oxidative alteration types tend to be most intense immediately around fault-joint-crack systems, decreasing in intensity further away from them toward the unfractured, and thus, less altered rock mass.

Table 1. Test results of physical-mechanical (technical) properties of rock mass samples from the Borač-Kotlenik magmatic massif.

Sampling locality (pit and village)	Apparent density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)	Water absorption (%)	Uniaxial compressive strength (MPa)			Abrasion resistance (cm^3/50 cm^2)	Resistance to frost or salt crystallisation (% or description)	Petrographic determination	Assumed formation in volcanic phase 1, 2 or 3
					dry state	water-saturated	after 25 freeze-thaw cycles				
Ravno brdo, D. Vrbava	2.525	2.670	5.40	1.71	145	120	102 (-30%)	16.65	0.17	dacite	1
Markova njiva, Bare	2.680	2.700	0.74	0.15	297	326	324	-	0.21	andesite	3
Jalak, Bečevica	2.620	2.650	1.13	0.39	323	284	287 (-11%)	-	-	pyroxene andesite	3
Mirisavka, Lunjevica	2.750	2.770	0.72	0.21	301	290	321	10.84	stable	trachyandesite to trachybasalt	3
Cekovića majdan, Ljuljaci	2.570	2.670	3.70	0.3	199	187	180 (9%)	9.6	stable	andesite	1
Mokro polje 1, D. Vrbava	2.460	2.630	6.46	1.75	171	140	135 (-21%)	-	stable	andesite	1
Ibid. 2	2.490	2.700	7.78	2.00	115	150	101 (-12%)	21.41	-	andesite	1
Ljuljaci 1, Ljuljaci	2.731	2.784	1.90	0.48	235	229	198 (-16%)	8.21	stable	basalt	3
Ibid. 2	2.630	2.650	0.75	0.46	270	251	285	20.27	stable	dacite with less quartz	2
Ibid. 3	2.590	2.650	2.26	0.35	188	199	250	8.89	stable	dacite with less quartz	2
Talambas 1, Vraćevšnica	2.658	2.707	1.81	0.73	195	171	162 (-17%)	14.81	stable	trachybasalt	3
Ibid. 2	2.672	2.695	0.85	0.17	209	161	171 (-18%)	15.11	stable	trachybasalt	3
Pretoke, Knić	2.584	2.631	1.79	0.46	166	150	133 (-20%)	12.35	0.01	andesite	1
Ploča 2, Pajsijević	2.560	2.670	4.12	0.72	191	140	178 (-7%)	12.20	stable	andesite	1
Ploča 3, Pajsijević	2.560	2.670	4.12	1.10	127	134	167	14.26	stable	andesite	1
Knić, Knić	2.600	2.730	4.76	1.01	209	194	168 (-20%)	11.72	stable	andesite	1
put Knić-Kragujevac 14 km	2.690	2.710	0.74	0.28	308	332	279 (-9%)	9.12	stable	andesite	2
Boškovića majdan, Knić	2.620	2.700	2.96	0.68	285	257	237 (-17%)	8.47	stable	andesite with some quartz	2
Čukojevac, Čukojevac	1.250	2.380	47.48	33.66	13	5	fallen apart	-	unstable	dacitic tuff	1
Igrište, Čukojevac	2.540	-	-	1.53	125	87	-	11.65	2.53	andesite	1

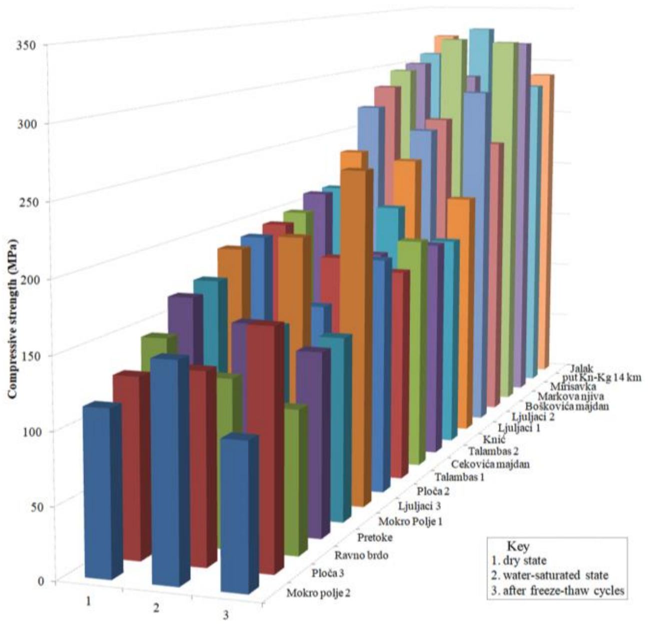

Figure 3. Compressive strength obtained in all three curing conditions.

In the graph presenting compressive strength obtained after freeze-thaw cycles versus water absorption values (Fig. 4), the localities are lined according to the increasing compressive strength value from 1st phase andesite of Mokro polje (village Donja Vrbava) to the 3rd phase andesite of Markova njiva (village Bare). As compressive strength increases, the water absorption values generally decrease, however, not continually. This is another common property of natural stone material. The first derivative has a positive value for the linear fitting function in compressive strength subset. On the opposite, the first derivative is negative in the subset of water absorption of the material.

In Fig. 4, above the sampling localities, the red, purple and black markings indicate the volcanic activity phase the rock has been formed in. Their order by increasing compressive strength values demonstrates that each next phase generally has better technical properties than the previous, inferred on compressive strength value. However, the layout in sequence of phases in the graph is not continuous (e.g., sample Talambas 1, a 3rd phase product, is among the 1st phase samples). Fieldwork examinations have shown that Talambas locality is characterised by varying degree of rock mass silification. Thus, the samples taken from less intensely silicified rock mass zones would have lower compressive strength values, matching those of the first phase products. It can be concluded that technical property values are influenced more by the degree of silification in each phase products than by the formation phase itself.

Rocks formed in the first phase of volcanic activity have generally the lowest values of compressive strength which is in agreement with the natural occurrence of hydrothermal alterations accompanying each phase of volcanic activity, making the first phase the one exposed to them for the longest period of time. This is readily observed in the field as oxidised reddish and propylitised greenish first phase rock masses.

The graph in Fig. 5 presents compressive strength values obtained in dry state where columns are coloured to illustrate the conformity with technical specification requirements for potential use of the rock mass in road building. As technical specification SRPS U.E9.028:1980 demands a minimal value of 100 MPa, it can be observed that all samples shown in Fig. 5 possess required quality for use in construction of bituminous lower base courses. A minimal dry compressive strength value of 120 MPa is demanded in ‘Roads of Serbia’ specifications /14/ and for surface wearing courses of road construction for very light- and light traffic; 140 MPa for moderate traffic; 160 MPa for heavy- and very heavy traffic and highway construction, /15/. Otherwise a very small percent of rock mass samples tested in The stone and aggregate laboratory of IMS Institute complies with the latter requirement; however, this graph demonstrates that most of the volcanic rock mass samples from Borač-Kotlenik massif comply with this requirement. Apart from dry compressive strength, other requirements must also be taken into consideration.

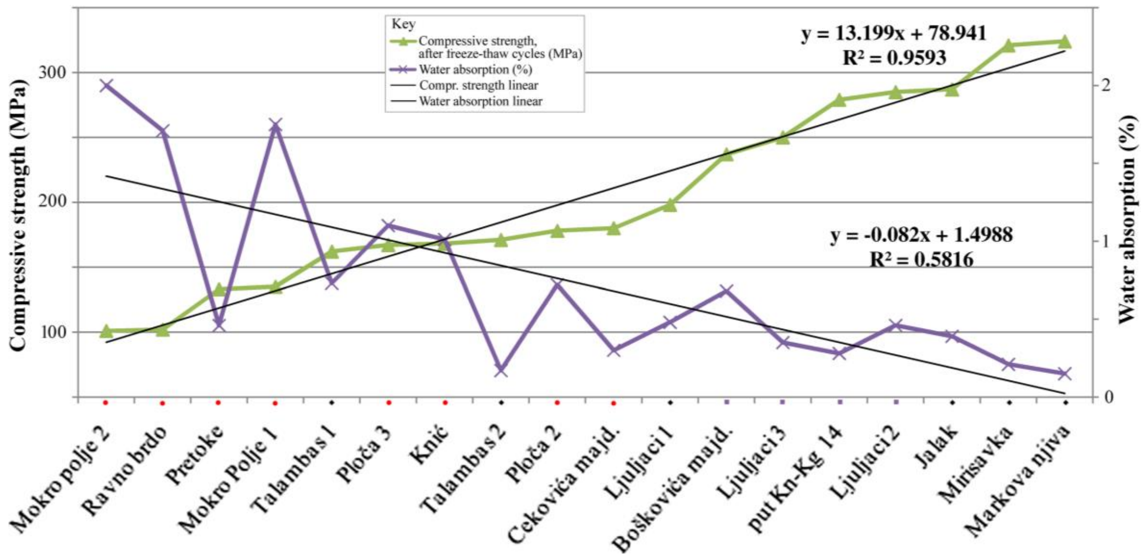

Figure 4. Compressive strength obtained after freeze-thaw cycles vs. water absorption diagram. For volcanic activity phase markings by each locality, see the Key in Fig. 6.

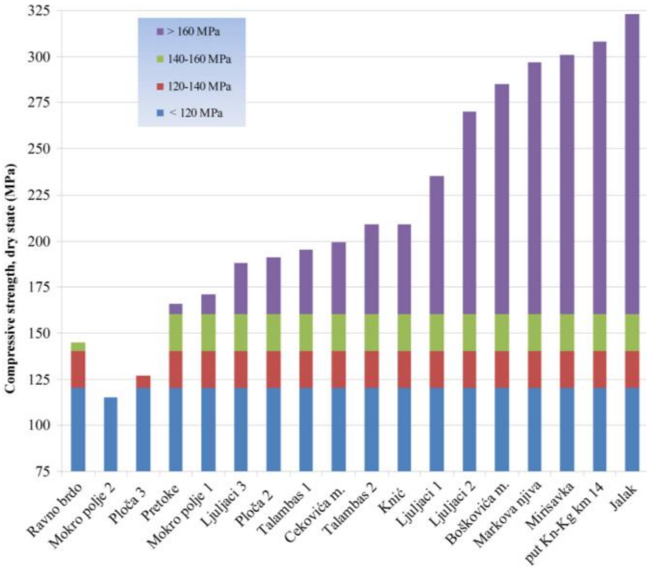

Figure 5. Dry state compressive strength stack-column diagram with technical specification requirements for minimal values /14, 15/.

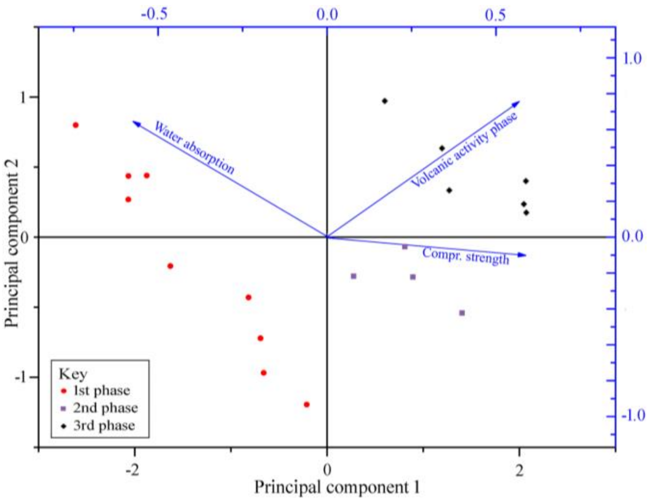

Figure 6. Multi-variation diagram based on dry compressive strength and water absorption values. Key contains markings of three different volcanic activity product tested samples.

Multi-variation analysis is based on data collected from dry compressive strength and water absorption values, as well as data from volcanic phases (Fig. 6). The bi-plot indicates reverse correlation between the two data subsets involved and also a clear genetic type segregation into three phases of volcanic activity products. The almost perfectly aligned dependence of compressive strength and water absorption values is a common, natural occurrence, since the same parameters influencing water absorption (e.g., porosity and alteration degree) in direct correlation also influence compressive strength in the reverse correlation.

First phase sample points (red circles) form an almost (~ 92 %) linear alignment, while 2nd (purple squares) and 3rd (black diamonds) phase product samples demonstrate less linear alignment, and all three alignments are mutually subparallel. From the genetic perspective, this points to the conclusion that, even though the magma chamber that had generated all three phases has most likely been the same, its evolution over time through magma hybridisation process is obvious. This occurrence is also natural and commonly observed in other areas with magmatic activity but has not been correlated with the technical properties of the formed rocks mass types before.

CONCLUSION

Within the Borač-Kotlenik magmatic massif in central Serbia there are several petrologic types of effusive and pyroclastic rocks, divided into products of three main phases of volcanic activity for practical purposes, as given in /10/.

Volcanic rocks formed in the first phase, dacite-andesites have technical properties favourable for use in road-building (sub-base, bituminous lower base and surface wearing courses) in some localities (Table 2). At other localities, increased values of water absorption, or insufficient compressive strength make them unconformable for road-building use. Volcanic rocks formed in the 2nd phase of volcanic activity, quartz-latites, have favourable properties and possibility of use in road-building like 1st phase products. Due to the presence of large crystal grains of sanidine which might lower their quality and durability, additional testing is recommended.

Table 2. Possibility of use of rock mass from various localities within the Borač-Kotlenik magmatic massif in road-building, based on technical specifications, /14-16/.

Volcanic phases	Petrologic rock type and locality of sampling	Possibility of rock mass use according to its conformity with technical requirements				
		1.*	2.			3.
			A	B	C	
1st phase volcanites	dacite, Ravno brdo, D. Vrbava (Borač)	-	-	-	-	+
	andesite, Cekovića majdan, Ljuljaci (Borač)	+	+	+	+	+
	andesite, Pretoke, Knić (Borač)	+	+	+	-	+
	andesite, Ploča 2, Pajsijević (Kotlenik)	+	+	+	-	+
	andesite, Ploča 3, Pajsijević (Kotlenik)	-	-	-	-	+
	andesite, Igrište, Čukojevac (Kotlenik)	-	-	-	-	+
2nd phase volcanites	dacite, Ljuljaci (Borač)	+	+	+	+	+
	andesite, Boškovića majdan, Knić (Kotlenik)	+	+	+	+	+
3rd phase volcanites	trachyandesite, Mirisavka and Talambas (Borač)	+	+	+	+	+
	basalt, Ljuljaci (Borač)	+	+	+	+	+
	trachybasalt, Talambas (Borač)	+	+	+	-	+

* 1. For building of unbound sub-base courses, /14/ (i.e., sub-base layer)
2. For building of bituminous surface wearing courses, /15/ (A - for light and very light traffic; B - for moderate traffic; C - for heavy, very heavy traffic and construction of highways)
3. For building of bound sub-base courses, /16/ (i.e., bituminous lower base courses)

Volcanic rocks formed in the 3rd phase of volcanic activity have excellent technical properties (Tables 1 and 2).

Entirely unaltered rock is a rarity within Borač-Kotlenik massif but is present in limited quantities. Rocks altered in varying degrees and types prevail. The type of hydrothermal alteration significantly influences the technical properties of the rock mass. Oxidative alteration types can cause a significant decrease in compressive strength, increase in porosity and water absorption, especially as oxidative chemical processes cause increased susceptibility to weathering, thus making the rock mass unusable in road construction profile layers above the embankment. On the other hand, where silification is present, the technical properties have values above or under average for the relevant petrologic type (increased compressive strength and abrasion resistance, i.e., lower values of loss on abrasion in testing) and conform to much stricter requirements, such as those for surface wearing courses.

Another technical specification in the area of road-building SRPS U.E9.021, /17/, contains requirements for stone materials used in bituminous upper road base course; however, no requirements are made for rock mass itself, but for crushed, graded stone and ungraded (all-in) mixed crushed stone produced from it. If the Los Angeles coefficient of the crushed stone and aggregate made of examined rock masses conforms to said requirements, it can be used also in bituminous upper road base construction.

Despite regular occurrence of rock mass alterations, typical for such complex magmatic massifs, its technical properties testing results have demonstrated that it generally can be used in the road building process. After the locality of extraction and a rock type with required technical properties are chosen, during the extraction process planning and organisation in each locality, caution is necessary due to the presence of several volcanic activity phases products or rock mass zones with different alteration degrees (e.g., Ploča 2 and Ploča 3) with differing technical properties. Some of these rocks can also be pyroclastic, which are unusable in road structure layers above embankment. It is necessary to select conformable rock mass zones in each locality, where hydrothermal alteration and weathering products are absent in order to obtain the best available stone material of volcanic origin.

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