Tertiary plutonic rocks of central and western Serbia Vardar zone as dimension stone

Lidja Kurešević[1]

Five Tertiary granitoid plutons of central and western Serbia Vardar zone are examined in order to establish their potentiality for use as dimension stone. Field studies aimed at establishing the geological factors – presence of fractures, harmful minerals, jointing, alterations, fabric homogeneity. Laboratory examinations comprised petrological analyses and testing of technical properties. Evaluation of results of technical properties laboratory testing is performed according to technical requirements of the Serbian standard B.B3.200 and it has shown that stone from these plutons can be used as dimension stone for production of slabs for exterior and interior paving and cladding.

***Key words**: dimension stone, granitoid, Vardar zone*

Introduction

From a country with flourishing building stone production, Serbia has, over the last 23 years, turned into an importer of various types of building stone. It is necessary to reassess the national building stone raw materials basis as the first step in recovery of the national stone industry. Magmatic rocks generally have high potential as a source of dimension stone, but in Serbia, this potentiality is reduced because of its position on the suture of Tethys mobile belt.

PhD dissertation titled "Potentiality of Tertiary magmatic complexes of the Vardar zone in Serbia from the aspect of dimension stone" (Kurešević, 2013) comprised various types of examinations of Tertiary magmatic complexes, all situated in the External Vardar subzone (Fig. 1) – eight plutonic and five volcanic complexes. The volcanic complexes have proved to be more compliable for use as crushed stone, while plutonic magmatic complexes have significant potential as dimension stone. This paper presents the examination results for plutons situated in the central and western Serbia (inside the rectangle in Fig. 1).

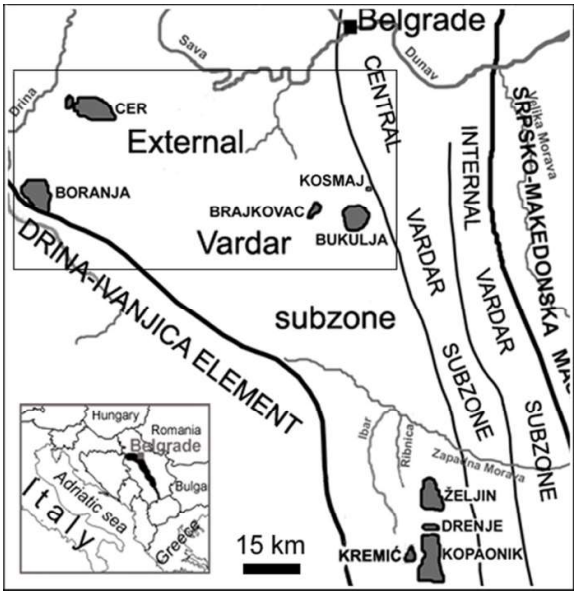

Fig. 1. Location of examined Tertiary plutons within the External Vardar subzone (lower left – its location in south-eastern Europe).

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Tertiary plutonic complexes of the central and western serbia

Geotectonic unit covering central and western Serbia, the Vardar zone, is a regional unit extending through the axis of the Balkan Peninsula. The formation of Tertiary magmatic complexes of the Vardar zone is the result of its evolution as a part of the Tethys belt – the opening of oceanic domains, their closure, subduction and collision (Schefer et al., 2011 and references therein). Examined plutons are all situated in the westernmost subunit of the Vardar zone – the External Vardar subzone (Dimitrijević, 1995). They are the part of the "Tertiary igneous formation of the Dinarides, Vardar zone and adjacent regions" (Cvetković et al. 2000) and belong to the group of Late Paleogene-Early Neogene granitoid formation, divided into two subgroups:

a, Dinaridic granitoid suite (Boranja, Brajkovac, Kosmaj) – these rocks are of calcalkaline I-type of magmatic arcs, formed from subcrustal melts generated by partial melting of the Upper mantle and significantly contaminated by crustal material. Magma is formed by melting of thickened continental crust which sank deep into the Upper mantle; and

b, Granitoids of the southern margin of the Panonian basin (Bukulja, Cer) – within these complexes there is an older I-type generation and a younger S-type generation of granitoids. The older generation is formed by similar processes as subgroup a), with a higher degree of crustal contamination. Younger generation granitoids are formed from the magma generated by partial melting or just mobilization of leucocratic material from the crust and they show the characteristics of syncollisional granitoids.

Their open areas, petrologic composition variations and isotope ages are shown in Tab. 1 and their properties that are most important for this subject are presented below.

Tab. 1. Summarized view of plutons' open surfaces, petrologic compositions and isotopic ages (Kurešević, 2013 and references therein).

Pluton	**Open surface** [km^2]	**Petrologic determination**	**Geologic age** [Ma]
Kosmaj	<< 1	granite	30-29
Boranja	70	granodiorite, < quartzmonconite and quartzdiorite	34-27
Brajkovac	8	granodiorite, < quartzmonconite, granite	31-18
Bukulja	40	ho-bi&bi granite	30-18
		two-mica granite	20-15
Cer	67	granodiorite	35-16
		granite	23-14

Examination methods

Field study has been performed as part of reconnaissance survey, aiming at establishing the geological factors – presence of fractures, harmful minerals, alterations, jointing type and fabric homogeneity in order todetermine the possibility of obtaining large size blocks of stone from the plutons. Laboratory examinations comprised petrological analyses and testing of technical properties. Microscopic examinations and photomicrograph capturing are performed on Petrology department of the Faculty of Mining and Geology in Belgrade, on polarizing microscope for transmitted light type Leica DMLSP with digital camera. Laboratory testing of stone technical properties is performed according to technical requirements of the Serbian standard B.B3.200, in the Stone and aggregate laboratory of the Institute for materials testing in Belgrade. Testing methods are stated in Table 2.

Examination results

Kosmaj pluton

This is the easternmost examined pluton. It is situated in central Serbia, 40 km south from Serbia's capital, Belgrade. Its open surface is very small. Several outcrops high up to 5 m and long up to 10 m occur along the Radovac stream on the western foothill of Kosmaj Mountain. The granitic magma intruded into the Upper Cretaceous flysch and has metamorphosed it into hornfels (Pavlović et al. 1980). Tectonic framework is presented mostly by faults striking NE-SW, NW-SE and NNW-SSE. Mineral composition (orthoclase, plagioclase, quartz, hornblende, biotite, Fig. 2) corresponds to granite. Texture is hipidiomorphic granular. Jointing is tabular along pluton rims and massive in the central parts (Fig. 3). Hydrothermal alterations have not been observed.

As dimension stone, this rock has favourable properties – durability, soundness, favourable texture, possibility of obtaining large stone blocks. However, the outcrop is too small to yield a reliable evaluation.

According to the laboratory testing of technical properties (Table 2), the stone can be used for production of slabs for interior paving and cladding with no restrictions. Due to somewhat lower compressive and flexural strengths, it can be used for exterior cladding only up to 30 m height and for the paving of surfaces with intensive and medium intensive pedestrian traffic. Note should be made that the sample for lab testing has been retrieved from the stream as it was impossible to break-off the samples from the fresh rock outcrop.

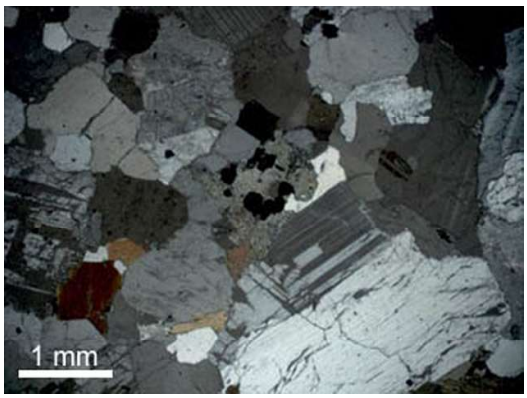

Fig. 2. Photomicrograph of Kosmaj granite thin section. Crossed polars.

Fig. 3. Jointing in Kosmaj pluton.

Boranja pluton

This is the westernmost examined pluton. It is situated in western Serbia, 115 km SW from Belgrade. Its open surface is 70 km^2. The magma intruded into Paleozoic-Mesozoic complex of Jadar block (Kubat, 1977; Mojsilović et al.; 1977). Tectonic framework is presented mostly by faults striking NW-SE and E-W. Predominant petrologic composition is that of granodiorite (amphibole-biotite, rarely biotite varieties) with occurrence of quartzmonconite and quartzdiorite in the southern parts of pluton. Mineral composition: quartz, plagioclase (andesine-oligoclase), K-feldspar (orthoclase, rarely microcline), biotite, hornblende (Fig. 4). Texture is hipidiomorphic granular. Jointing is tabular in peripheral parts of the pluton and prismatic to massive in its central parts (Fig. 5). Slight hydrothermal alterations are found along the eastern pluton margins, otherwise the rock-mass is fresh and sound.

As a dimension stone, this rock has favourable properties – durability, soundness, favourable texture, the possibility of obtaining large stone blocks; and unfavourable – slightly inhomogeneous appearance due to magmatic layering and abundant xenoliths and the presence of pyrite aggregates along pluton margins (these are not found in the central parts of the pluton).

According to the laboratory testing of technical properties (Tab. 2), the stone can be used for production of slabs for all interior and exterior paving and cladding with no exceptions.

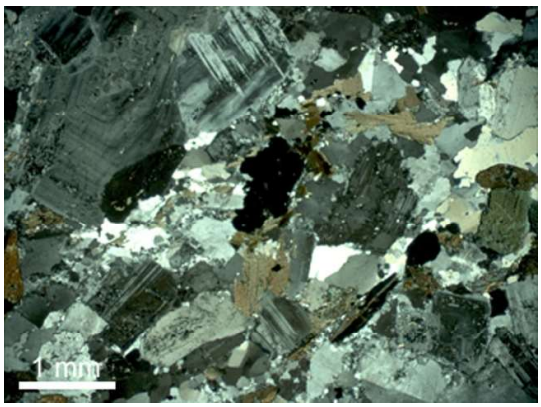

Fig. 4. Photomicrograph of Boranja granodiorite thin section. Crossed polars.

Fig. 5. Jointing in Boranja pluton.

Brajkovac pluton

It is situated in central Serbia, 60 km south from Belgrade. Its open surface is 8 km^2. The magma intruded into Paleozoic metamorphic complex of Jadar block (Filipović and Rodin, 1980; Filipović et al., 1978). The tectonic framework is presented by faults striking WNW-ESE, NE-SW, ENE-WSW and NW-SE. Predominant petrologic composition is granodiorite (biotite and amphibole-biotite varieties) with transitions to quartzmonconite and granite. Mineral composition: andesine, quartz, K-feldspar (orthoclase and microcline), biotite, hornblende (Fig. 6). Texture is hipidiomorphic granular. Jointing is tabular inperipheral parts of pluton and prismatic to massive in the central parts (Fig. 7). Slight hydrothermal alterations with pyrite occurrence are found occasionally along pluton margins, otherwise the rock-mass is fresh and sound.

As a dimension stone, this rock has favourable properties – durability, soundness, favourable texture, the possibility of obtaining large stone blocks; and unfavourable – presence of cracked quartz grains up to 2 cm, xenoliths, and pyrite disseminations along pluton margins.

According to the laboratory testing of technical properties (Tab. 2), the stone can be used for production of slabs for all interior and exterior paving and for interior cladding with no restrictions (except the marginal parts of pluton where pyrite is present). Due to a somewhat lower compressive strength, it can be used for exterior cladding only up to 30 m above ground level.

Fig. 6. Photomicrograph of Brajkovac granodiorite thin section. Crossed polars.

Fig. 7. Jointing in Brajkovac pluton.

Bukulja pluton

It is situated in central Serbia, 60 km south from Belgrade. Its open surface is 40 km^2. The magma intruded into Paleozoic metamorphic complex on the west and Upper Cretaceous sediments on the east (Brković et al. 1980, Pavlović et al. 1980, Filipović and Rodin 1980, Filipović et al. 1978). The tectonic framework is presented by faults striking WNW-ESE, NNE-SSW, N-S and WSW-ENE. Petrologic composition is complicated due to multiphase formation of the pluton. The older generation is represented by hornblende-biotite and biotite granite and the younger generation by two-mica granite. Hornblende-biotite and biotite granite is rarely found on the surface. Its mineral composition: quartz, K-feldspar, andesine, biotite, hornblende. Two-mica granite makes up about 95 % of the outcrops. Its mineral composition: quartz, K-feldspar, plagioclase (albite-oligoclase), biotite, muscovite, rarely hornblende (Fig. 8). Both generations have hipidiomorphic granular texture. There is also the occurrence of aplitic granite along pluton margins. Jointing is tabular along pluton rims and prismatic to massive in the central parts (Fig. 9). Southern parts of the pluton are heavily faulted, fractured and hydrothermally altered. Therefore only northern half of the pluton has potential as the source of the building stone.

As a dimension stone, this rock has favourable properties – durability, soundness, favourable texture, possibility of obtaining large stone blocks; and unfavourable – the occurrence of pegmatite-aplite veins along margins of the pluton.

According to the laboratory testing of technical properties (Tab. 2), the stone can be used for production of slabs for interior paving and cladding with no restrictions. Due to a somewhat lower flexural strength, it can be used for exterior cladding only up to 30 m above ground level and for the paving of surfaces with intensive and moderate pedestrian traffic.

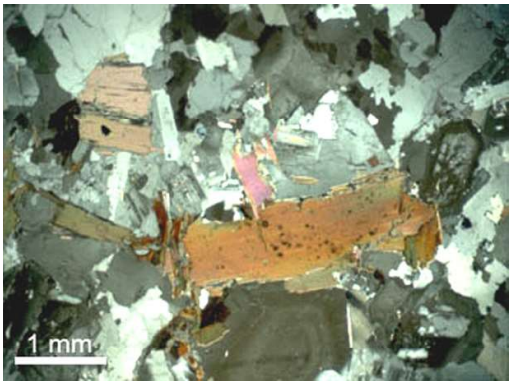

Fig. 8. Photomicrograph of Bukulja granite thin section. Crossed polars.

Fig. 9. Jointing in Bukulja pluton.

Cer pluton

This is the northernmost of the examined plutons. It is situated in western Serbia, 20 km SW from Šabac. Its open surface is 67 km^2. The magma it has formed from is intruded into Paleozoic metamorphic complex (Mojsilović et al., 1977; Filipović et al., 1973). The tectonic framework is presented by faults striking W-E, NE-SW, N-S and NNW-SSE. Petrologic composition is complicated due to multiphase formation of the pluton. The older generation is represented by hornblende-biotite and biotite granodiorite and the younger generation by two-mica granite. Both rock types are intimately intermixed in all observed locations and their selective mining is therefore not possible. There is also the occurrence of aplitic granite along pluton margins. Granodiorite mineral composition: quartz, andesine, orthoclase, biotite, hornblende (Fig. 10). Two-mica granite mineral composition: quartz, orthoclase, plagioclase, muscovite and biotite (Fig. 11). Their textures are hipidiomorphic granular. Jointing is prismatic to massive (Fig. 12).

As dimension stone, these rocks have the favourable property of soundness. Unfavourable properties predominate – inhomogeneous appearance due to intimate intermixing of two generations of rocks (with slightly different values of technical properties) which precludes obtaining large blocks of homogenic rock-mass. There is often the occurrence of intricate pegmatite and aplitic veins throughout the pluton, in addition to weathering, fracturing, the presence of xenoliths, significant mica content, and the occasional presence of pyrite.

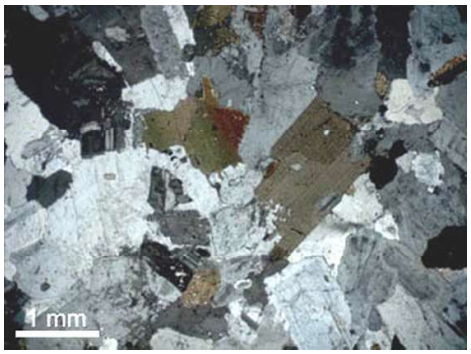

Fig. 10. Photomicrograph of Cer granodiorite thin section. Crossed polars.

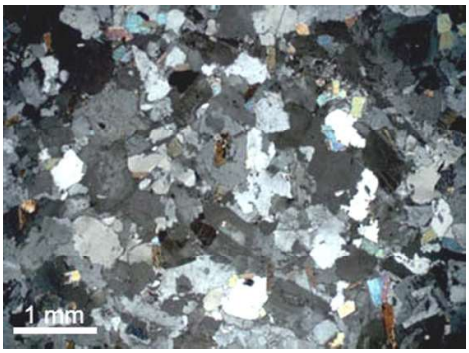

Fig. 11. Photomicrograph of Cer granite thin section. Crossed polars.

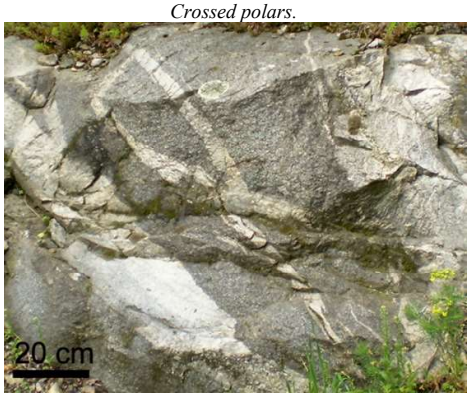

Fig. 12. Jointing in Cer pluton.

According to the laboratory testing of technical properties (Tab. 2), the stone can be used for the production of slabs for interior paving and cladding with no restrictions. Due to somewhat lower compressive and flexural strengths, it can be used for exterior cladding only up to 30 m above ground level and for the paving of surfaces with intensive and moderately intensive pedestrian traffic.

Tab. 2. Results of technical properties testing (Kurešević, 2013).

Stone property	Standard SRPS	Testing results, average value				
		Kosmaj	Boranja	Brajkovac	Bukulja	Cer
Compressive strength, [MPa] - dry	B.B8.012	147	227	154	170	147
- water-saturated		121	202	118	146	134
- after 25 freeze-thaw cycles		119	189	117	141	131
Abrasion resistance, [cm^3/50 cm^2]	B.B8.015	10.15	8.24	9.04	9.97	9.64
Flexural strength, [MPa]	B.B8.017	15.05	16.84	18.00	15.71	14.83
Porosity, [%]	B.B8.032	1.8	0.9	1.7	1.9	1.4
Water absorption, [%]	B.B8.010	0.46	0.31	0.53	0.43	0.44
Apparent density, [g/cm^3]	B.B8.032	2.670	2.691	2.639	2.630	2.628
Particle density, [g/cm^3]	B.B8.032	2.719	2.716	2.685	2.660	2.666
Thermal expansion, [mm/m]	ISO 10545-8	0.525	0.576	0.410	0.559	0.540

Note: reference values from the technical requirements of the Serbian standard SRPS B.B3.200 can be found on the web page www.lymak.com/bb3200.aspx.

Common properties of examined plutons

The degree of jointing and fracturing is significantly higher in marginal parts of magmatic bodies than in the central parts. Also, with the increasing depth, the degree of jointing and fracturing is decreasing. Therefore, the dimensions of natural blocks of rock-mass are increasing too, enabling the production of commercial stone blocks.

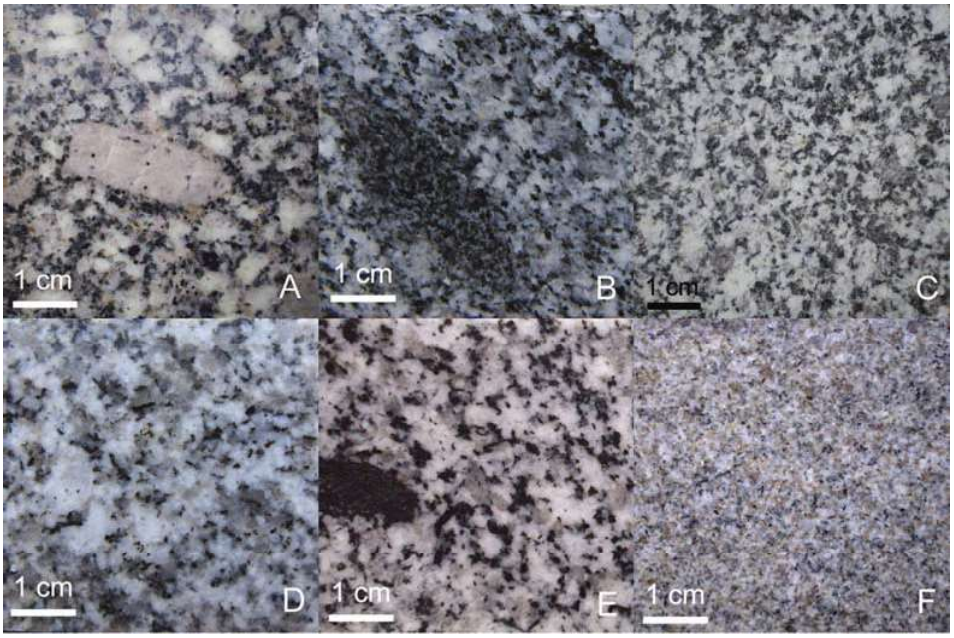

Fig. 13. Macroscopic appearance of the honed stone surface (A. Kosmaj, B. Boranja, C. Brajkovac, D. Bukulja, E. Cer granodiorite, F. Cer two-mica granite).

Most plutons' marginal parts show presence of pyrite disseminations which makes them susceptible to accelerated weathering. Stone from these parts of the rock-mass mustn't be used for external paving or cladding, or it should be avoided completely.

Technical properties of the stone are favourable (Tab. 2). Samples for lab testing have been taken from the field surface, and it is certain that the samples from the fresh-open rock-mass parts from greater depth would have given even better results. All samples are resistant to frost and crystallization of Na_2SO_4.

Throughout the rock-mass of each pluton, there is a moderately pronounced variation of petrological composition and technical characteristics' values, which is a natural property of rock.

Decorative properties of stone from these plutons are average, as grey colour predominates and textures are granular with small grain sizes. However, on honed stone surfaces, K-feldspar grains lilac in colour and up to 1.5 cm large start to become visible and this increases stones' decorative properties (Fig. 13). In the case of Kosmaj pluton, orthoclase grains can be over 5cm large and their decorative properties are significantly better (Fig. 13A).

Discussion

Examined plutons display differences in size, jointing type, intensity of faulting, fracturing and alteration. Their other properties relevant for use as dimension stone are rather uniform – mineral-petrologic composition, decorative properties, technical properties and their variation throughout the rock-mass. Also, there is an increased incidence of pegmatite-aplite veins, xenoliths, magmatic layering, unfavourable jointing, hydrothermal alterations and pyrite disseminations in marginal parts of the magmatic body in each pluton.

All samples are taken from the existing outcrops, so the level of weathering is rather uniform for all and can be correlated and compared. The results of technical properties testing (Tab. 2 and 3) show that the stone from the Boranja pluton can be used for production of slabs for all interior and exterior paving and cladding with no limitations according to the technical requirements of Serbian standard SRPS B.B3.200.

Rocks from other plutons have unlimited possibility for use as dimension stone for production of slabs for internal paving and cladding while exterior paving span is mostly limited to areas with intensive (SH-2) and moderate (SH-3) pedestrian traffic and exterior cladding is limited to categories up to 30m above ground level (SV-2 and SV-3).

Tab. 3. Possibility of use of tested stone according to Serbian standard SRPS B.B3.200.

Pluton	Interior				Exterior					
	paving			cladding	paving			cladding		
	UH-1	UH-2	UH-3	UV	SH-1	SH-2	SH-3	SV-1	SV-2	SV-3
Kosmaj	+	+	+	+	—	+	+	—	+	+
Boranja	+	+	+	+	+	+	+	+	+	+
Brajkovac	+	+	+	+	+	+	+	—	+	+
Bukulja	+	+	+	+	—	+	+	—	+	+
Cer	+	+	+	+	—	+	+	—	+	+

Key:

UH-1	Very intensive pedestrian traffic (hospitals, hotels, company buildings, industrial plants, theatres, cinemas etc.)
UH-2	Intensive pedestrian traffic (shops, residential buildings, museums, restaurants, schools etc.)
UH-3	Moderate pedestrian traffic (libraries, archives, book-shops, waiting-rooms etc.)
SH-1	Very intensive pedestrian, and sometimes even vehicle traffic (public squares, city pedestrian zones, streets, shopping molls)
SH-2	Intensive pedestrian traffic (parks, esplanades, less known city pedestrian zones etc.)
SH-3	Moderate pedestrian traffic
SV-1	Buildings high over 30 m above ground level
SV-2	Buildings high from 10 to 30 m above ground level
SV-3	Buildings high up to 10 m above ground level

Conclusion

Laboratory testing and field studies of the examined plutons have shown satisfactory results from the aspect of dimension stone. Larger plutons have more potential as they enable easier locating of fault-free zones. All tested stone samples satisfy the requirements of the Serbian standard SRPS B.B3.200. It is reasonable to assume that samples taken from the fresh-open deeper parts of rock-mass, which haven't been subjected to long-lasting impact of weathering, would have given even better testing results. Even with the obtained results, their use for production of slabs for exterior and interior paving and cladding is possible. The dimensions of naturally jointed blocks of rock-mass significantly increase with depth. Plutons display slight heterogeneity of fabric throughout the rock-mass and significant heterogeneity of fabric along the margins. A degree of caution is necessary regarding the mining for stone in the marginal parts of plutons because of the presence of harmful minerals. As these examinations have been performed on the level of reconnaissance survey, their best use is in directing the further geological exploration process. It is determined that the central parts of plutons bear the highest potentiality for dimension stone.

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