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Tertiary plutonic rocks of southern Serbia Vardar Zone as dimension stone

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Abstract. Three granitoid plutons of south-Serbian part of the Vardar Zone, of Tertiary age were studied in order to establish their potential for utilization as dimension stone. These rocks vary in composition from quartzmonconite to quartzdiorite. Field study aimed at establishing the geological factors – presence of fractures, harmful minerals, alterations, jointing type and fabric homogeneity in order to determine the possibility of obtaining large size blocks of stone from the plutons. Laboratory examinations comprised petrological analyses and testing of technical properties. Stone from these plutons has shown favourable results in both field and laboratory examinations. Evaluation of the rock based on obtained laboratory testing results is performed according to technical requirements of the Serbian standard B.B3.200. It has shown that rocks from these plutons can be used as dimension stone for the production of slabs for the exterior and interior paving and cladding.

Key words: dimension stone, Vardar Zone, Tertiary granitoids, southern Serbia.

Апстракт. Истражена су три гранитоидна плутона терцијарне старости у јужносрбијанском делу Вардарске зоне, са циљем да се утврди њихова потенцијалност са аспекта архитектонског грађевинског камена. Састав стена у овим плутонима варира од кварцмонцонита до кварцдиорита. Циљ теренских истраживања је био да се утврде геолошки фактори – присуство раседа и пратећих пукотинско-прслинских система, штетних минерала, алтерација, типа лучења и хомогеност склопа стена, како би се установила могућност добијања стенских блокова комерцијалних димензија из плутона. Лабораторијска испитивања су обухватила минералошко-петролошке анализе стена и испитивање физичко-механичких својстава стенске масе. Стенска маса из ових плутона је показала задовољавајуће резултате теренских и лабораторијских испитивања. Оцена употребљивости стенске масе на основу лабораторијских испитивања је извршена према техничким захтевима Српског стандарда Б.Б3.200. Закључено је да се стенска маса из ових плутона може користити као архитектонски грађевински камен за добијање плоча за хоризонтално и вертикално облагање површина у екстеријеру и ентеријеру грађевинских објеката.

Кључне речи: архитектонски грађевински камен, Вардарска зона, терцијарни гранитоиди, јужна Србија.

Introduction

Until 1990, Serbia had a stone production that covered almost all the domestic needs. Over the last 23 years, it has turned into an importer of significant amounts of dimension stone (table 1). Efforts made at the state level to start the recovery of the national stone industry are founded on reassessment of the domestic resources of decorative stone raw materials basis. Kurešević (2013a) comprised various types of exploration methods of Tertiary magmatic complexes in the Vardar Zone of Serbia (Fig. 1) at the level of reconnaissance survey. The Tertiary volcanic complexes of the Vardar zone have proved to be more compliable for use as crushed stone (especially as aggregate in road-building), while plutonic complexes have significant potential as dimension stone. This paper presents the properties of three plutonic com-

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Table 1. Relationship between dimension stone commerce and production in 1990 and 2000 in Serbia (according to the National statistics institute data).

year	Commerce				Production		
	blocks		slabs and tiles		blocks	slabs	tiles
	import	export	import	export			
1990	209 t	0	1388 t	0	777 m^3 (2100 t)	29591 m^2	1613 m^2*
2000	40602 t	150 t	326 t	0	5 m^3 (13.5 t)	2018 m^2	467 m^2

*the missing data is replaced by the data from the first following year where it appears, 1992.

plexes situated in the southern part of the Vardar Zone in Serbia, Kremići, Drenje and Željin that are important for their evaluation as potential sources of dimension stone (Fig. 1, plutons within the rectangular frame). The Kopaonik pluton, which is also situated in this part of the Vardar Zone, is within the territory of the National park and is therefore excluded from any further exploration and mining plans. The properties of the Tertiary plutons of the northern and western Serbian part of the Vardar Zone (Cer, Boranja, Kosmaj, Brajkovac, Bukulja) are presented in KUREŠEVIĆ (2013b).

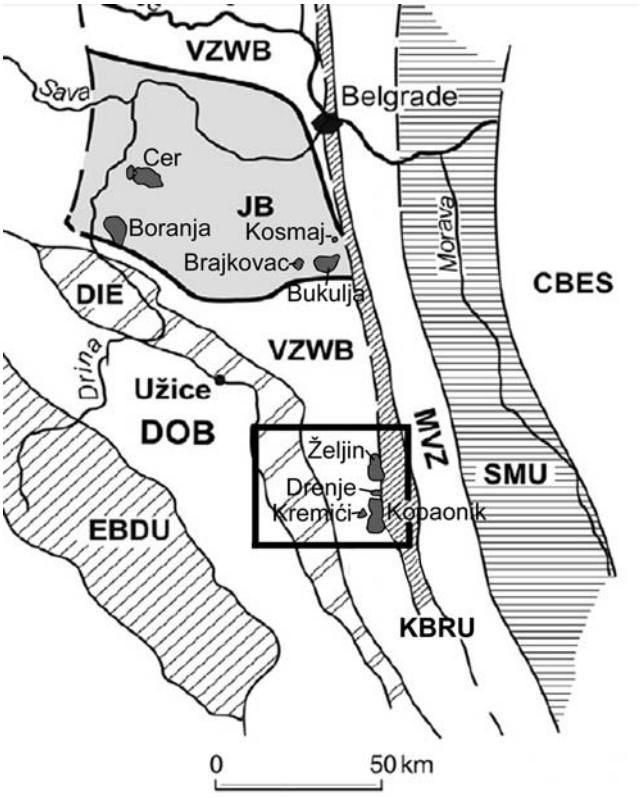

Fig. 1. Location of studied Tertiary plutons (within rectangular frame) in the Vardar Zone (tectonic units according to KARAMATA, 2006 and ROBERTSON *et al*., 2009); **CBES,** Carpato-Balcanides of Eastern Serbia; **SMU,** Serbian-Macedonian Unit; **MVZ,** Main Vardar Zone; **KBRU,** Kopaonik Block and Ridge Unit; **VZWB,** Vardar Zone Western Belt; **JB,** Jadar Block; **DIE,** Drina–Ivanjica Element; **DOB,** Dinaric Ophiolitic Belt; **EBDU,** Eastern Bosnian-Durmitor Unit).

The formation of Tertiary magmatic complexes of the Vardar Zone is connected with geotectonic evolution as a part of the Tethys ocean – the opening of oceanic subdomains, their closure, subduction and collision (SCHEFER *et al*. 2011). According to CVETKOVIĆ *et al*. (2000), the examined plutons belong to the Tertiary igneous formation of the Dinarides, Vardar Zone and adjacent regions, group of Late Paleogene-Early Neogene granitoid formation, subgroup Dinaridic granitoid suite. 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. Basic data on the examined plutons are summarised in Table 2.

Material and 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 to determine the possibility of obtaining large size blocks of stone from the plutons. Laboratory examinations comprised petrological analyses and testing of technical properties. Microscopic study was performed on polarizing microscope for transmitted light type Leica DMLSP with a digital camera. Laboratory testing of stone technical properties was 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.

Table 2. Summarised basic data on studied plutons (KUREŠEVIĆ 2013a), and their ages.

Pluton	Open surface (km^2)	Petrologic determination	Age (Ma)
Kremići	5	quartzdiorite-granodiorite, < quartzmonconite	31.9 (KARAMATA *et al*., 1992)
Drenje	4	granodiorite, < quartzdiorite	31.7–31.2 (SCHEFER *et al*., 2011)
Željin	56	granodiorite-quartzmonconite, < quartzdiorite	31.8–31.4 (SCHEFER *et al*., 2011)

Results

Kremići pluton

This pluton is situated around 180 km south of Serbia's capital, Belgrade. Its shape is an irregular dyke with an open surface of 5 km^2. It intrudes into Ibar ultramafic complex (UROŠEVIĆ *et al*. 1973a, b). The tectonic framework is presented mostly by faults striking NW–SE, NE–SW, E–W and N–S. Mineral composition (quartz, andesine, K-feldspar (orthoclase to microcline), hornblende, biotite; Fig. 2A), mostly corresponds to quartzdiorite and granodiorite (amphibole-biotite, rarely amphibole varieties). Quartzmonconite occurs in central parts of the pluton. The rock texture is hipidiomorphic granular. The major part of the pluton open by erosion is today covered with soil and thick woods. Therefore, only small marginal parts of the pluton are available for observation. Here, jointing is tabular, prismatic and irregular (Fig. 2B). Slight hydrothermal alterations are found along the NW pluton margins; otherwise the rock is fresh and sound.

As a dimension stone, this rock has both favourable properties (durability, soundness, favourable texture) and unfavourable (inhomogeneous appearance, xenoliths, sporadic occurrence of slight magmatic layering, unfavourable jointing types and small dimensions of natural blocks). However, only a small part of the pluton is open and available for examination and it is quite certain that deeper parts of the plutonic mass have more favourable properties from the aspect of dimension stone.

According to the laboratory testing of technical properties and evaluation of the rock by the Serbian standard B.B3.200, as dimension stone it can be used for the production of slabs for the interior and exterior paving and cladding with no restrictions.

Drenje pluton

This pluton is situated around 170 km south of Belgrade. Its open surface is 4 km^2. It intrudes into Triassic metamorphic complex of the Kopaonik Block and Ridge Unit (UROŠEVIĆ *et al*. 1973a). The tectonic framework comprises faults striking NW–SE and N–S. Mineral composition (andesine, quartz, K-feldspar (orthoclase to microcline), biotite, hornblende; Fig. 2C) mostly corresponds to granodiorite, and quartzdiorite along the pluton margins. Rock texture is hipidiomorphic granular. Magmatic layering is clearly displayed, especially along pluton margins. Jointing is tabular in peripheral parts of the magmatic body and prismatic to massive in central parts (Fig. 2D). Hydrothermal alterations have been observed along the SE margin of the pluton.

As a dimension stone, this rock has both favourable properties (durability, soundness, favourable jointing and possibility of obtaining large stone blocks) and unfavourable (inhomogeneous appearance due to magmatic layering). There are also pegmatite-aplite veins and xenoliths throughout the pluton.

According to the laboratory testing of technical properties, the stone can be used for the production of slabs for all the interior paving and cladding with no restrictions, but due to a somewhat lower compressive and flexural strengths for exterior cladding only up to 30 m in height and for the paving of surfaces with intensive and medium intensive pedestrian traffic.

Željin granitoid

This pluton is situated around 155 km south of Belgrade and has exposed open surface of 56 km^2. It intrudes into Triassic metamorphic complex of the Kopaonik Block and Ridge Unit. The tectonic framework is presented mostly by faults striking NNW–SSE and NE–SW to ENE–WSW. Mineral composition (quartz, andesine, K-feldspar (orthoclase to microcline), biotite, hornblende, epidote up to 10 %; Fig. 2E), mostly corresponds to granodiorite and quartzmonconite in central parts of the pluton and to quartzdiorite along its rims. Rock texture is hipidiomorphic granular. Magmatic layering is clearly displayed along pluton margins. Jointing is tabular in peripheral parts of the pluton and irregular to massive in its central parts (Fig. 2F). Hydrothermal alterations have not been observed.

As a dimension stone, this rock has both favourable properties (durability, soundness, favourable texture in central parts of magmatic body and possibility of obtaining stone blocks over 10 m in length) and unfavourable (inhomogeneous appearance due to magmatic layering, in addition to pegmatite veins in the marginal parts of the pluton; they are rarer in central parts of the pluton).

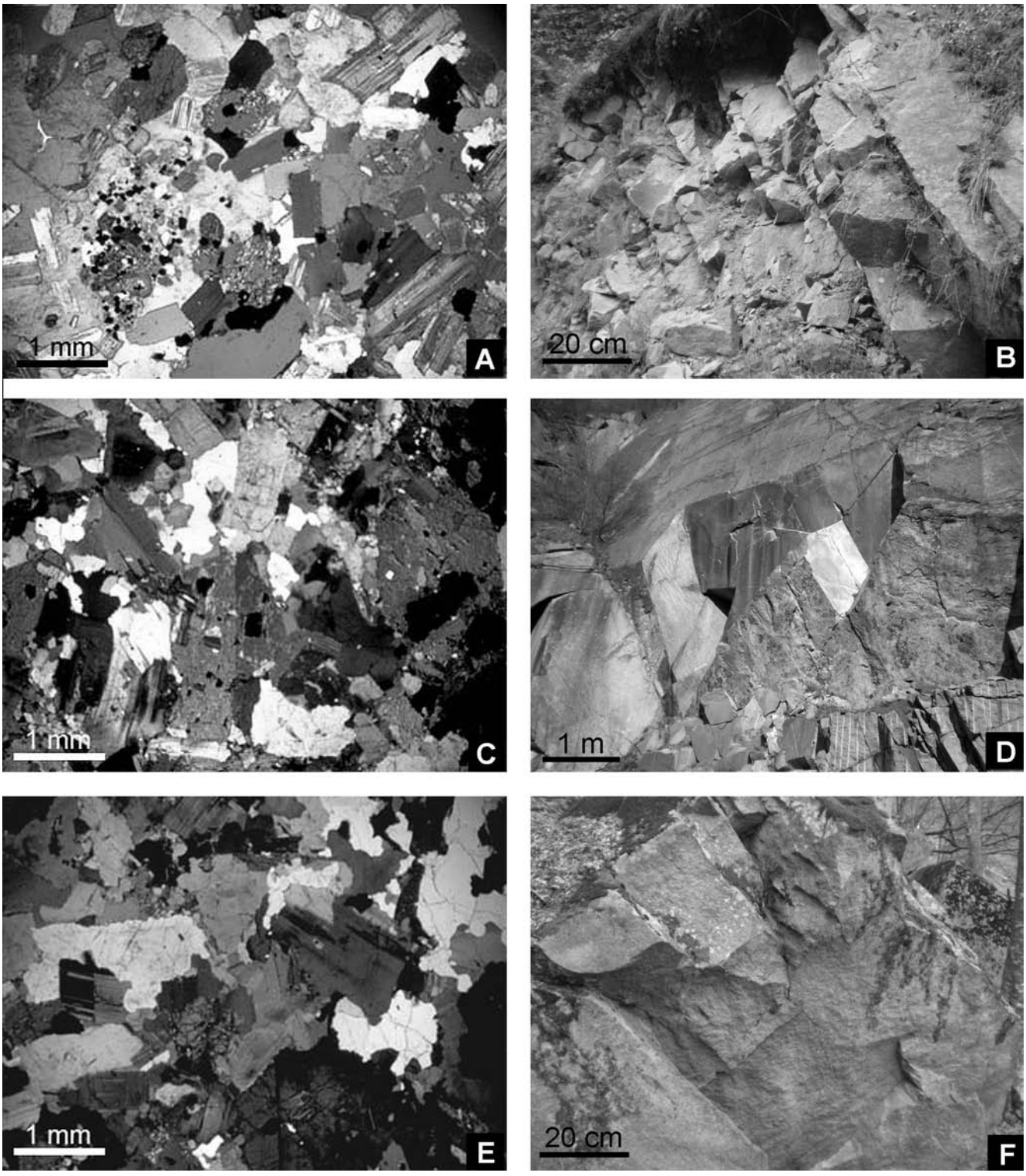

Fig. 2. **A**, Photomicrograph of the Kremići granodiorite thin section. Crossed polars; **B**, Field photograph showing the jointing in the Kremići pluton marginal parts; **C**, Photomicrograph of the Drenje granodiorite thin section. Crossed polars; **D**, Field photograph showing the jointing in central parts of the Drenje pluton; **E**, Photomicrograph of the Željin granodiorite thin section. Crossed polars; **F**, Field photograph showing the jointing in the Željin pluton.

Laboratory testing of technical properties has shown that the stone can be used for the production of slabs for all the interior paving and cladding with no restrictions, but due to a lower flexural strength, for exterior cladding only up to 30 m in height and for the paving of surfaces with intensive and medium intensive pedestrian traffic.

Common properties of examined plutons

Throughout the rock mass of each pluton, there is a moderately pronounced variation of mineral-petrological composition and technical properties, which is typical for a natural rock. The degree of jointing and fracturing is higher in plutons' marginal parts compared to their central parts. With the increasing depth, the intensity of fracturing and jointing is decreasing. Therefore, the dimensions of natural blocks of rock mass are increasing too, enabling the production of commercial size stone blocks.

Technical properties of the stone are favourable (Table 3). Samples for lab testing have been taken from the field surface, and the experience suggests that the samples from the fresh-open rock parts from greater depth would yield even better testing results. All samples are resistant to frost impact and crystallization of Na_2SO_4.

Decorative properties of stone from these plutons are average, as grey colour predominates, and textures are granular with small grain sizes (Fig. 3). In some parts of Željin pluton, increased incidence of epidote grains up to 3 mm in size has been observed. This property gives the stone from these parts of pluton a higher decorative value. The presence of harmful minerals has not been observed in the examined plutons.

Discussion

Examined plutons display differences in size and jointing type. Their other properties relevant for use as dimension stone – mineral composition, fabric, intensity of faulting, fracturing and alteration, decorative properties, technical properties and their variation throughout the rock are rather uniform. There is an increased incidence of pegmatite-aplite veins, xeno-

Table 3. Results of technical properties testing (Kurešević 2013a). 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.

Stone property	Units	Standard SRPS	Testing results, average value		
			Kremići	Drenje	Željin
Uniaxial compressive strength: - dry	Mpa	B.B8.012	169	158	189
- water-saturated			136	154	145
- after 25 freeze-thaw cycles			134	145	145
Abrasion resistance	$cm^3/50\ cm^2$	B.B8.015	10.01	9.79	11.00
Flexural strength	MPa	B.B8.017	31.97	17.67	15.62
Porosity	%	B.B8.032	0.9	1.0	1.7
Water absorption	%	B.B8.010	0.40	0.31	0.29
Apparent density	g/cm^3	B.B8.032	2.678	2.710	2.701
Particle density	g/cm^3	B.B8.032	2.703	2.737	2.752
Thermal expansion	mm/m	ISO 10545-8	0.499	0.656	0.620

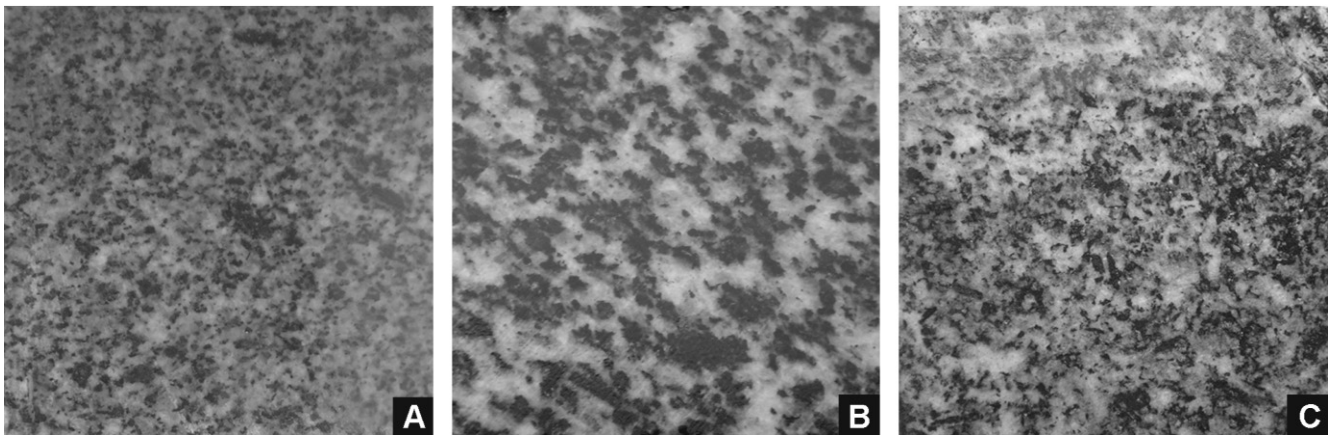

Fig. 3. Macroscopic appearance of the straight cut stone surface; **A**, Kremići; **B**, Drenje; **C**, Željin.

Table 4. Possible use of tested stone according to Serbian standard SRPS B.B3.200. **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; **UV** Interior walls cladding; **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.

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
Kremići	+	+	+	+	+	+	+	+	+	+
Drenje	+	+	+	+	–	+	+	–	+	+
Željin	+	+	+	+	–	+	+	–	+	+

liths, magmatic layering, unfavourable jointing and hydrothermal alterations presence in marginal parts compared to central parts of the magmatic body in each pluton.

All samples are taken from the existing outcrops, so the weathering degree is rather uniform for all and can be correlated and compared. The results of technical properties testing (Tables 3 and 4) show that the stone from the Kremići pluton can be used for the production of slabs for all the interior and exterior paving and cladding with no limitations, according to the technical requirements of Serbian standard SRPS B.B3.200. Stone from the other two plutons has unlimited possibility for use as dimension stone for production of slabs for the interior paving and cladding while the exterior paving span is limited to areas with intensive (SH-2) and moderate (SH-3) pedestrian traffic, and exterior cladding is limited to categories up to 30 m above ground level (SV-2 and SV-3).

Conclusion

All laboratory testing and field studies of the examined plutons have shown satisfactory results from the aspect of dimension stone. Željin, as a larger pluton, has higher potential because fault-free zones can be located more easily. All tested rock samples satisfy the requirements of the Serbian standard SRPS B.B3.200 and their use for the production of slabs for the exterior and interior paving and cladding is possible. It is reasonable to assume that samples taken from the fresh-open deeper parts of rock mass, which have not been subjected to long-lasting weathering, would have had even better testing results. However, even with the results obtained here, their use is possible. The dimensions of naturally jointed blocks of rock significantly increase with depth. All three examined plutons display rock fabric heterogeneity. Therefore, the stone from these plutons can not comply if there is a demand for large number of slabs of uniform appearance. As these investigations have been performed at the reconnaissance survey level, the results should be used in directing the further phases of the geological exploration process. In Željin pluton, central parts have the highest potential for dimension stone. The entire Drenje pluton has inhomogeneous fabric. Only a small part of the Kremići pluton is open and available for exploration and it is not possible to give a reliable assessment of its potential at this exploration stage.

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Резиме

Терцијарни плутони јужног дела Вардарске зоне Србије са аспекта архитектонског грађевинског камена

Истражена су три гранитоидна плутона терцијарне старости у јужном делу Вардарске зоне Србије, са циљем да се утврди њихова потенцијалност за коришћење као архитектонски грађевински камен: жељински, кремићки и дрењски. Теренска проучавања су имала за циљ утврђивање геолошких фактора оцене потенцијалности – присуство дисјунктивних структура, штетних минерала, алтерација, типа лучења и хомогености склопа, како би се утврдила могућност добијања крупних стенских блокова из плутона. Лабораторијска испитивања су обухватила минералошко-петролошке анализе стена и испитивање физичко-механичких карактеристика стенске масе.

Плутон Кремића се налази око 180 km јужно од Београда. Има облик неправилног дајка, отворене површине од око 5 km^2. Интрудован је у Ибарски ултрамафитски комплекс. Минералошки састав (кварц, андезин, калијски фелдспати (ортоклас до микроклин), хорнбленда, биотит), углавном одговара кварцдиориту до гранодиориту (амфиол-биотитски, ретко амфиболски варијетети). Кварцмонцонит је заступљен у централним деловима плутона. Структура стене је хипидиоморфно зрнаста. Највећи део ерозијом откривене површине плутона данас је покривен земљиштем и густом шумом. Теренском проучавању су доступни само мали, ободни делови плутона. У њима је лучење плочасто, призматично и неправилно. Утврђено је присуство слабих алтерација уз северозападни обод плутона. У осталим деловима плутона, стенска маса је свежа и чврста.

Као архитектонски грађевински камен, стенска маса из кремићког плутона има повољна својства (чврстоћу, једрину, повољну структуру), али и неповољна (нехомоген изглед, присуство ксенолита, местимична појава магматског литажа, неповољни типови лучења и мале димензије природно лучених блокова). Лабораторијска испитивања су показала да се стенска маса може користити за производњу плоча за хоризонтално и вертикално облагање у екстеријеру и ентеријеру без ограничења.

Плутон Дрења налази се око 170 km јужно од Београда. Његова ерозијом отворена површина је око 4 km^2. Интрудован је у метаморфни комплекс Копаоничког блока, тријаске старости. Минералошки састав (андезин, кварц, калијски фелдспати (ортоклас до микроклин), биотит, хорнбленда) углавном одговара гранодиориту, и кварцдиориту дуж обода плутона. Структура стене је хипидиоморфно зрнаста. Магматски литаж је јасно изражен, нарочито у ободним деловима плутона. Лучење је плочасто у ободним деловима плутона, и призматично до масивно у централним. Хидротермалне алтерације су примећене дуж југоисточног обода плутона.

Као архитектонски грађевински камен, стенска маса из дрењског плутона има повољна својства (чврстоћу, једрину, повољан тип лучења и могућност добијања крупних блокова стенске масе), али и неповољна (нехомоген изглед, присуство ксенолита и аплитско-пегматитских жица, местимична појава магматског литажа). Лабораторијска испитивања су показала да се може користити за производњу плоча за хоризонтално и вертикално облагање у ентеријеру без ограничења, а због нешто ниже притисне и савојне чврстоће у екстеријеру ограничено.

Жељински плутон се налази око 155 km јужно од Београда. Његова ерозијом отворена површина је око 56 km^2. Интрудован је у метаморфни комплекс Копаоничког блока, тријаске старости. Минералошки састав (кварц, андезин, калијски фелдспати (ортоклас до микроклин), биотит, хорнбленда, епидот) углавном одговара гранодиориту и кварцмонциониту у централним деловима плутона и кварцдиориту дуж обода плутона. Структура

стене је хипидиоморфно зрнаста. Магматски литаж је јасно изражен у ободним деловима плутона. Лучење је плочасто у ободним деловима плутона, и неправилно до масивно у централним. Хидротермалне алтерације нису констатоване.

Као архитектонски грађевински камен, стенска маса из жељинског плутона има повољна својства (чврстоћу, једрину, повољну структуру и тип лучења у централним деловима плутона, и могућност добијања крупних блокова стенске масе, дужине преко 10 m), али и неповољна (нехомоген изглед због магматског литажа, и присуство аплитско-пегматитских жица, нарочито у ободним деловима плутона). Лабораторијска испитивања су показала да се може користити за производњу плоча за хоризонтално и вертикално облагање у ентеријеру без ограничења, а због нешто ниже савојне чврстоће у екстеријеру ограничено.

Плутони показују нека заједничка својства. Склоп стена, као и изглед камена су хетерогени, услед присуства магматског литажа. Из овог разлога, стенска маса из ових плутона се не може користити у случајевима када се захтева камен униформног изгледа.

Димензије природно лучених блокова стена повећавају се са дубином. Жељински плутон због својих димензија има највећу потенцијалност због лакшег лоцирања зона без структурних деформација. Цео дрењски плутон има нехомоген склоп. На данашњем нивоу еродованости, само мали део плутона Кремића је отворен и доступан за истраживање, те стога није могуће дати поуздану оцену његове потенцијалности у овој фази истраживања.

Оцена могућности примене на основу добијених резултата лабораторијских испитивања врши се у складу са техничким захтевима Српског стандарда Б.Б3.200, и показала је да се камен из ових плутона може користити као архитектонски грађевински камен за вертикално и хоризонтално облагање грађевинских објеката у ентеријеру и екстеријеру. Можемо предпоставити да би узорци узети из свежих, дубљих делова стенске масе, који нису били изложени дуготрајном утицају атмосферилија, имали још боље резултате испитивања. Међутим, чак и са овим резултатима, оцена њихове употребљивости је позитивна.

Камен из ових плутона је показао повољне резултате теренских и лабораторијских испитивања. С обзиром да су ова истраживања спроведена на нивоу регионалне проспекције, њихове резултате треба користити као смернице у наредној фази процеса геолошког истраживања.