Acta Mineralogica-Petrographica, Szeged 2004, Vol. 45/1, pp. 93–100

ACTA
Mineralogica
Petrographica

GEOCHEMISTRY AND PETROLOGY OF SOME GRANITOIDS FROM PAPUK AND PSUNJ SLAVONIAN MOUNTAINS (CROATIA)

MARIJA HORVAT[1], GYÖRGY BUDA[2]

[1] Institute of Geology, Sachsova 2, 10000 Zagreb, P.O.Box. 268, Croatia
e-mail: mhorvat@igi.hr
[2] Department of Mineralogy, Eötvös Loránd University, H-1117 Budapest, Pázmány Péter sétány 1/C, Hungary
e-mail: buda@ludens.elte.hu

ABSTRACT

The investigated granitoids of Papuk and Psunj-Krndija Complexes in Slavonia (Croatia) are quartz diorite, granodiorite and monzogranite. Intermediate to highly ordered maximum microcline suggests a slow rate of cooling. The composition of plagioclase is andesine in the quartz diorite and oligoclase in the granodiorite and monzogranite. The granitoids contain primary muscovite and biotite showing peraluminous character in Papuk Complex, whereas the amphibole and lack of muscovite in granitoids of Psunj-Krndija Complex indicating a transitional met- and peraluminous characters. The majority of granitoids of the Papuk Complex are S-type but some I/S-type occur as well. The granitoids of the Psunj-Kradija Complex show mixed I/S-type character.

Key words: granitoids, peraluminous character, S-type, I/S-type, Slavonian Mountains, Croatia

INTRODUCTION

The Slavonian Mountains (Psunj, Papuk, Krndija, Požeška Gora and Dilj) are situated in the southernmost part of the Tisza Megaunit. The Psunj, Papuk and Krndija Mountains are built up dominantly from metamorphic and granitoid rocks.

Investigation of the Slavonian Mountains started almost one and half century ago. Tajder (1957) published the first report on the genesis of the granitoid. Raffaelli (1965) described a progressive metamorphic rock series at the southern slope of Papuk Mountain. Vragović (1965) dealt with the petrography of granitoid and metamorphic rocks of central and western part of Papuk Mountain, while Marci (1965, 1973) worked on granitoids of Psunj Mountain. Slovenec (1978) investigated biotite in granitoids. The first attempt at geothermometry, using the garnet-biotite and horblende-biotite pairs in granitoid and metamorphic rocks, was carried out by Slovenec (1982). Jamičić (1988) described the tectonic development of the area in his thesis. Jamičić and Brkić (1987) and Jamičić (1989) published the geological map (1:100000) of the Slavonian Mountains (Orahovica and Daruvar sheets).

Based on data of Jamičić (1988) a geological sketch map of the Papuk, Psunj and Krndija Mountains was compiled (Fig. 1).

Jamičić (1988) distinguished three lithostratigraphic complexes: Psunj-Krndija, Papuk and low-grade metamorphic Radlovac Complex (not studied in this paper). In Psunj-Krndija Complex the oldest metamorphic rock is garnet- and staurolite-bearing gneiss with rare kyanite and sillimanite. Gneisses are intercalated with different metabasic rocks (amphibolite, amphibole-schist and metagabbro). Marble is also common. Chlorite schists occur in the upper part of the Complex. The Papuk Complex is characterised by biotite-gneisses and migmatites with amphibolite and amphibole-schist intercalations, further on granitoids (pegmatites), chlorite-schists and serpentinites with relics of peridotite. This Complex thought to be formed during the Caledonian orogeny (Jamičić, 1988). Both Complexes were intruded by late-Variscan granitoids. Sedimentation began, again in the Uppermost Permian and continued in the Triassic, Jurassic and the lowermost part of the Cretaceous.

Based on K-Ar and Rb-Sr isotopic data most of metamorphic and igneous rocks from Psunj, Papuk and Krndija Mountains were formed during the Variscan orogeny (340–320 Ma) although, some data indicate older ages (658–421 Ma) (Pamić, 1988a; Pamić et al., 1988b, 1991, 1996).

Seven pre-Alpine terranes were distinguished between the Adriatic Sea and the Southern Pannonian Basin (Pamić et al., 1996–97). The Slavonian Mts. are grouped into the Moslavina-Slavonija terrane, which consists of: 1. Pre-Variscan and Variscan regionally metamorphosed sequences with migmatites and granitoids, 2. Variscan (?) weakly metamorphosed sequences with metabasites, 3. Triassic and Jurassic mostly carbonate sequences, 4. Upper Cretaceous-Paleogene (?) volcanic-sedimentary formation, 5. Neogene postorogenic sequences.

In this paper we deal with the geochemistry and petrology of the representative granitoids occurring in Papuk and Psunj-Krndija Complexes in order to get information about their genesis.

METHODS

Ten representative specimens were selected for geochemical analyses after macro- and microscopical observations (locations of the studied samples are shown in Fig. 1).

Major and minor element composition of the rock were determined by XRF and INAA methods in XRAL Laboratories,

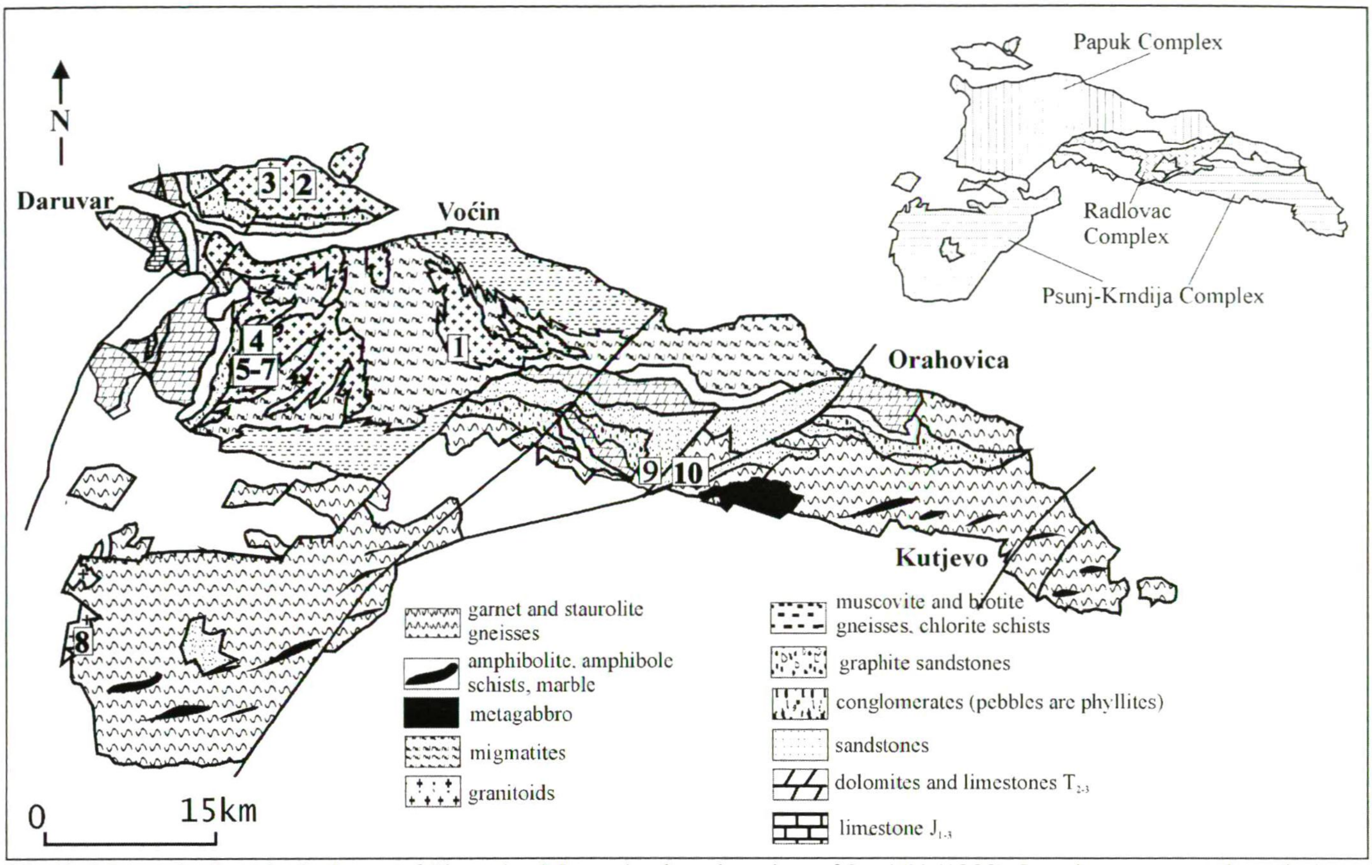

Fig. 1. Schematized geological map of Slavonian Mountains based on data of Jamičić (1988). Locality names and symbols are given in the Appendix. The symbols are the same in all figures.

Don Mills, Ontario, Canada (classical methods were used for FeO, H_2O and LOI). The REE data was normalized using the average of C1 chondrites data of Evensen et al. (1978). Trace element concentrations were normalized to MORB using normalizing data of Pearce (1982, 1983).

For the Goldsmith and Laves (1954) triclinicity calculation of feldspars XRD data were applied using Siemens D500 powder diffractometer (analogous register mode) at the Department of Mineralogy Eötvös Loránd University, Budapest.

Quantitative chemical analyses of minerals were carried out by AMRAY 1830 I/T6 type electronmicroscope equipped with EDAX PV9800 using the ZAF correction (measuring conditions were: 20kV, 1–2 nA) at the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest and by JEOL JCXA-733 electron microprobe equipped with 3WDS (15 kV, 36 nA) using the same correction method at the Laboratory for Geochemical Research, Hungarian Academy of Sciences, Budapest.

Legend for figures.

Locality and sample name	Locality name	Rock type	Symbol
1 (PPG-12)	Brzaja Creek (Papuk C.)	muscovite-biotite monzogranite	●
2 (2PPG-32)	Šandrovac Creek (Papuk C.)	muscovite-biotite monzogranite	□
3 (2PPG-33)	Rajčevica Creek (Papuk C.)	muscovite-biotite monzogranite	■
4 (PPG-31)	Sloboština Creek (Papuk C.)	granodiorite	◆
5 (PPG-18)	Pakra Creek (Papuk C.)	muscovite-biotite monzogranite	○
6 (PPG-24)	Pakra Creek (Papuk C.)	biotite granodiorite	⬓
7 (PPG-23)	Pakra Creek (Papuk C.)	muscovite-biotite granodiorite	▶
8 (PSG-1)	Omanovac quarry (Psunj-Krndija C.)	amphibole monzogranite	▼
9 (PSG-31)	Kišeljevac Creek (Psunj-Krndija C.)	biotite monzogranite	△
10 (PSG-38)	Bistra Creek (Psunj-Krndija C.)	quartz diorite	◨

Petrography

Three main rock types were distinguished: monzogranite, granodiorite and quartz diorite (IUGS, 1973), Fig. 2. The location of representative specimens can be found in Appendix and Fig. 1.

Monzogranite primary mineral phases are: quartz, microcline, plagioclase, biotite, muscovite and rarely amphibole. Accessory minerals are zircon, apatite, opaque minerals, allanite, titanite, garnet and rutile. Secondary minerals are chlorite, sericite, clay minerals, epidote and rare calcite. Texture is medium- or coarse-grained, equigranular.

Quartz is anhedral, sometimes fragmented and with undulatory extinction, containing biotite, opaque minerals, zircon and rutile inclusions. Two generations of quartz were recognized in the sample from Psunj Mt. (PSG-1). The first is coarse, anhedral, characterized by undulatory extinction and often contains fluid inclusions. The second one forms fine-grained aggregates.

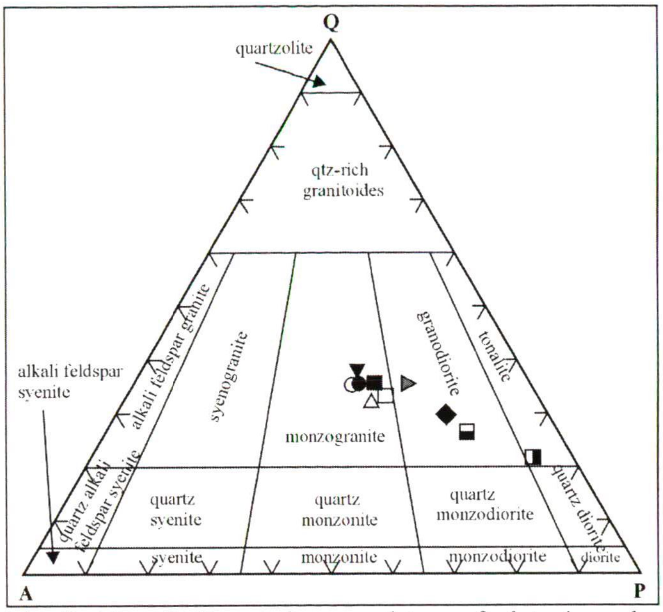

Fig. 2. Classification and nomenclature of plutonic rocks. (IUGS, 1973).

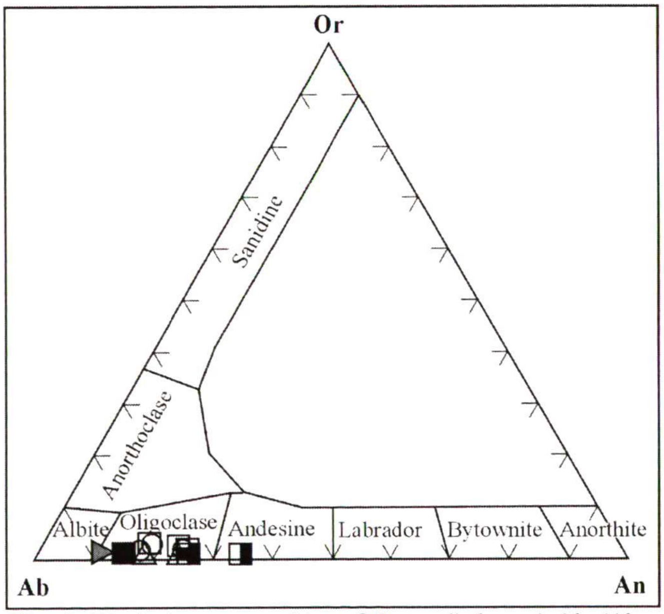

Fig. 3. Plagioclase composition of the studied granitoids (Ab = albite mol%, An = anorthite mol% and Or = orthoclase mol%).

Microcline is euhedral with crosshatched twins. Perthite is common. Large microcline grains contain sericitized plagioclase, quartz, chloritized biotite, zircon and acicular rutile inclusions.

Plagioclase is subhedral strongly altered to sericite and clay minerals. Zircon inclusions are common. The rim has albite composition. Myrmekite is also common.

Biotite is subhedral, tabular or lamellar and shows a strong pleochroism (yellowish-brown to dark brown or reddish-brown). Inclusions are opaque mineral, apatite, zircon with pleochroic halos and epidote. The majority of biotite is chloritized.

Muscovite is subordinate. It has various grain sizes. It often includes zircon.

Amphibole appears only in monzogranite from Psunj Mt. (PSG-1). It is anhedral, tabular with strong pleochroism (green to yellowish green). It is associated with opaque minerals and allanite.

Apatite and zircon are the most important accessory minerals. Titanite, rutile, allanite and opaque minerals also occur as accessories.

Granodiorite: major mineral components are quartz, plagioclase, biotite and small amount of microcline. Some samples contain muscovite. Accessories are apatite, zircon, garnet (PPG-31) and opaque minerals. Secondary minerals are chlorite, sericite, clay minerals and epidote. The texture is medium-grained, equigranular or porphyritic.

Quartz diorite: major minerals are plagioclase and quartz. Chlorite, sericite and clay minerals are products of alteration. The texture is medium-grained, equigranular.

Plagioclase is a predominant constituent. It is zoned or with polysynthetic albite twins. It is strongly altered to sericite and clay minerals.

Quartz very often is fragmented to small grains (probably some parts of the small grains are secondary in origin).

Chlorite is strongly pleochroic from light brown to greenish brown. The interference colour is grey-blue-purple to brown. It is associated with epidote grains and includes apatite and zircon crystals.

MINERAL CHEMISTRY

K-feldspars average composition is $Or_{89-97}Ab_{3-11}An_{0-0.3}$ in monzogranite and granodiorite. Goldsmith and Laves (1954) triclinicity ($\Delta = [d(131)-d(\bar{1}31)]*12.5$) reveals variation of Al/Si order/disorder relationship from intermediate to maximum microcline (Δ = 0.55–0.95). Among the microcline X-ray reflections low-albite peaks appears indicating perthite exsolution (Lovas et al., 1999).

Plagioclase is mostly oligoclase (An_{11-26}) in monzogranite and granodiorite. In the quartz diorite (PSG-38) the plagioclase is zoned with andesine core (An_{35}) and oligoclase rim (An_{26}) (Table 1 and Fig. 3).

Biotite composition plots in the central part of phlogopite-eastonite-siderophyllite-annite diagram (Table 2, Fig. 4). Most biotite has peraluminous character (Abdel-

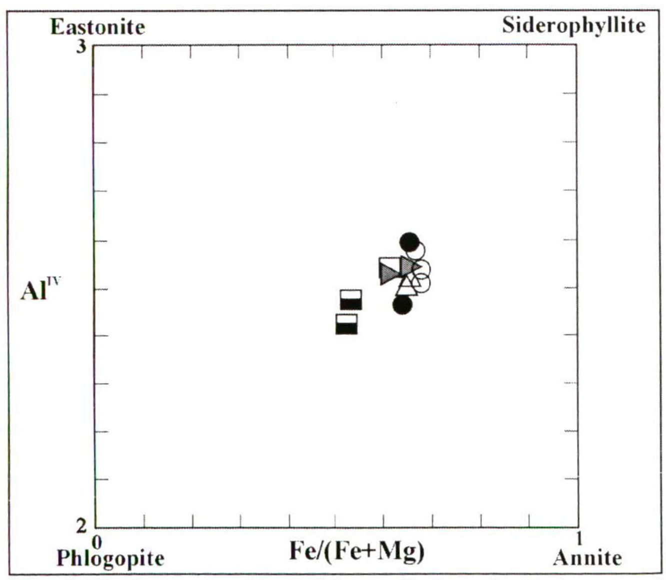

Fig. 4. Biotite composition of the studied granitoids (structural formulae are calculated on the basis of 22 oxygens).

Table 1. Representative plagioclase composition (wt%) of the granitoids.

Locality	1	1	2	2	3	5	6	7	9	9	10	10
Sample	PPG-12	PPG-12	2PPG-32	2PPG-32	2PPG-33	PPG-18	PPG-23	PPG-24	PSG-31	PSG-31	PSG-38 core	PSG-38 rim
SiO_2	63.88	61.87	62.74	61.61	64.61	62.73	65.63	61.60	63.39	61.58	58.98	60.41
Al_2O_3	22.36	23.87	22.76	23.65	22.08	21.89	21.28	23.89	22.91	23.61	26.26	24.63
CaO	3.53	5.12	3.89	4.94	3.10	3.91	2.32	5.47	3.78	4.87	7.14	5.47
Na_2O	9.36	8.45	9.18	8.60	9.75	9.11	10.16	8.48	9.22	8.50	7.41	8.38
K_2O	0.27	0.21	0.50	0.45	0.17	0.43	0.21	0.28	0.22	0.23	0.05	0.07
Σ	99.40	99.52	99.07	99.25	99.71	99.07	99.60	99.72	99.52	98.79	99.84	98.96
	Numbers of ions on the basis of 8 oxygens											
Si	2.834	2.753	2.802	2.754	2.853	2.800	2.895	2.742	2.811	2.760	2.632	2.709
Al	1.169	1.252	1.198	1.246	1.149	1.204	1.106	1.253	1.197	1.247	1.382	1.302
Ca	0.168	0.244	0.186	0.237	0.147	0.187	0.110	0.261	0.179	0.234	0.342	0.263
Na	0.805	0.729	0.795	0.745	0.835	0.788	0.869	0.732	0.793	0.739	0.641	0.728
K	0.015	0.012	0.028	0.026	0.009	0.024	0.012	0.016	0.012	0.013	0.003	0.004
cat#	4.991	4.991	5.010	5.008	4.994	5.004	4.992	5.005	4.993	4.992	4.998	5.006
Or	1.5	1.2	2.8	2.5	0.9	2.4	1.2	1.6	1.3	1.3	0.3	0.4
Ab	81.5	74.0	78.7	74.0	84.2	78.8	87.7	72.6	80.5	74.9	65.0	73.2
An	17	24.8	18.4	23.5	14.8	18.7	11.1	25.9	18.2	23.7	34.7	26.4

Rahman, 1994). The only exception is a slightly higher Mg-content biotite (mg#=47) occurring in granodiorite (PPG-24) that plots on the border line of calc-alkaline and peraluminous-type biotite (Fig. 5).

Amphibole occurs in monzogranite (PSG-1). It has low Mg-content: [Mg/(Mg+Fe)] = 0.1, Ca_B > 1.5 and [Na/(Na+K)] = 0.77. It is ferro-horblende according to the classification of IMA (Leake et al., 1997, Table 2, last column).

MAJOR ELEMENT COMPOSITION

Monzogranite and granodiorite occur in the Papuk and monzogranite and quartz diorite were identified in the Psunj-Krndija Complex (Table 3). Monzogranites have Na_2O/K_2O molar ratio approximetly equal with 1, while granodiorites and quartz diorite have this ratio higher than 1 with relatively constant Na-content.

Granitoids of both Complexes show a peraluminous character with [$Al_2O_3/(CaO+Na_2O+K_2O)$ = A/CNK] molar

Table 2. Representative biotite and average amphibole (last column) composition (wt%) of the granitoids.

Locality	1	1	2	5	5	5	6	6	7	7	9	9	Locality	8
Sample	PPG-12	PPG-12	2PPG-32	PPG-18	PPG-18	PPG-18	PPG-23	PPG-23	PPG-24	PPG-24	PSG-31	PSG-31	Sample	PSG-1
SiO_2	35.16	34.82	35.38	35.38	34.90	34.78	35.54	35.41	36.98	36.79	35.52	35.37	SiO_2	43.13
TiO_2	3.42	3.28	2.88	3.26	3.24	3.43	3.09	2.67	3.57	3.54	3.67	3.79	TiO_2	1.67
Al_2O_3	17.14	17.76	17.73	17.27	17.11	17.45	18.23	18.63	16.99	17.11	17.34	17.01	Al_2O_3	6.75
FeO	23.52	22.92	21.71	23.51	23.61	23.10	21.27	22.38	19.00	19.79	22.66	22.28	FeO	31.29
MnO	0.35	0.38	0.46	0.26	0.28	0.27	0.42	0.74	0.40	0.40	0.39	0.33	MnO	0.71
MgO	6.62	6.71	7.71	6.31	6.33	6.45	7.40	6.49	9.66	9.73	6.62	6.78	MgO	2.03
CaO	0.02	0.01	0.05	0.01	0.01	0.02	0	0	0	0	0.21	0.06	CaO	9.64
Na_2O	0.05	0.11	0.13	0.07	0.05	0.08	0	0	0	0	0.06	0.11	Na_2O	1.71
K_2O	9.11	9.45	9.11	9.59	9.55	9.63	8.93	9.23	9.24	9.33	9.38	9.29	K_2O	0.79
Σ	95.39	95.44	95.16	95.66	95.08	95.21	94.88	95.55	95.84	96.69	95.85	95.02	Σ	97.72
	Numbers of ions on the basis of 22 oxygens												oxy#	23
Si	5.467	5.410	5.464	5.494	5.465	5.428	5.474	5.460	5.577	5.250	5.479	5.494	Si	6.827
Al	2.533	2.590	2.536	2.506	2.535	2.572	2.526	2.540	2.423	2.475	2.521	2.506	Al	1.173
ΣT	8	8	8	8	8	8	8	8	8	8	8	8	ΣT	8
Al	0.609	0.661	0.690	0.654	0.623	0.637	0.784	0.846	0.596	0.553	0.631	0.608	Al	0.085
Ti	0.400	0.383	0.334	0.381	0.382	0.403	0.358	0.310	0.405	0.400	0.426	0.443	Ti	0.199
Mg	1.534	1.554	1.775	1.460	1.477	1.500	1.699	1.492	2.171	2.178	1.522	1.570	Fe^{3+}	0.736
Fe^{2+}	3.059	2.978	2.804	3.053	3.092	3.015	2.740	2.886	2.396	2.485	2.923	2.894	Mg	0.479
Mn	0.046	0.050	0.060	0.034	0.037	0.036	0.055	0.097	0.051	0.051	0.051	0.043	Fe^{2+}	3.405
ΣM	5.647	5.626	5.663	5.583	5.611	5.591	5.635	5.629	5.619	5.667	5.552	5.559	Mn	0.095
Ca	0.003	0.002	0.008	0.002	0.002	0.003	-	-	-	-	0.035	0.010	ΣC	5
Na	0.015	0.033	0.039	0.021	0.015	0.024	-	-	-	-	0.018	0.033	Ca	1.635
K	1.807	1.873	1.794	1.900	1.908	1.917	1.755	1.816	1.778	1.787	1.846	1.841	Na	0.365
ΣI	1.825	1.908	1.842	1.922	1.924	1.945	1.755	1.816	1.778	1.787	1.898	1.884	ΣB	2
													Na	0.16
mg#	33.41	34.28	38.76	32.35	32.33	33.23	38.27	34.07	47.54	46.70	34.24	35.15	K	0.16
ΣAl	3.141	3.252	3.227	3.161	3.158	3.210	3.309	3.386	3.020	3.028	3.152	3.114	ΣA	0.319
cat#	15.473	15.534	15.505	15.505	15.535	15.535	15.390	15.445	15.397	15.454	15.451	15.442	cat#	15.319

Table 3. Major element composition (wt%) and CIPW norms of the granitoids.

Locality	1	2	3	4	5	6	7	8	9	10
Sample	PPG-12	2PPG-32	2PPG-33	PPG-31	PPG-18	PPG-23	PPG-24	PSG-1	PSG-31	PSG-38
SiO_2	73.20	71.50	74.20	66.00	73.80	74.20	65.70	76.10	71.50	63.30
TiO_2	0.21	0.22	0.07	0.55	0.23	0.08	0.57	0.15	0.31	0.43
Al_2O_3	14.50	15.50	15.00	15.90	14.10	14.90	16.00	11.80	15.00	18.20
Fe_2O_3	0.70	0.65	0.48	1.25	1.05	0.50	1.11	0.82	0.69	1.64
FeO	0.70	1.20	0.30	2.40	0.60	0.30	2.50	0.90	1.20	1.70
MnO	0.04	0.04	0.01	0.06	0.00	0.01	0.08	0.01	0.03	0.07
MgO	0.41	0.58	0.50	1.73	0.47	0.22	1.55	0.00	0.58	1.99
CaO	0.89	1.27	0.62	2.02	1.12	0.75	2.93	0.21	2.01	3.94
Na_2O	3.59	3.92	4.04	4.24	3.39	4.64	4.38	3.97	3.36	4.87
K_2O	4.39	3.80	4.01	2.47	4.67	3.14	2.15	4.38	4.30	0.82
P_2O_5	0.12	0.16	0.08	0.27	0.09	0.10	0.24	0.02	0.16	0.10
H_2O^+	0.70	1.30	1.30	1.70	0.60	0.80	1.30	0.30	1.00	1.90
H_2O^-	0.10	0.10	0.10	0.30	0.10	0.20	0.20	0.10	0.10	0.20
LOI	0.75	1.10	0.90	1.95	0.60	0.95	1.25	0.30	0.75	1.90
Σ	99.55	100.24	100.71	98.89	99.17	99.84	98.71	98.76	100.24	99.16
					CIPW norms					
Q	33.55	30.73	33.72	25.30	33.51	33.93	23.38	36.13	30.48	20.78
Or	26.30	22.74	23.88	15.08	27.75	18.79	13.08	26.34	25.65	5.00
Ab	30.73	33.52	34.38	36.99	28.79	39.68	38.08	34.11	28.64	42.41
An	3.76	5.43	2.63	8.71	5.06	3.17	13.51	0.94	9.12	19.55
C	2.50	2.99	3.07	3.25	1.62	2.74	1.69	0.18	1.50	2.41
HyEn	1.04	1.47	1.26	4.46	1.18	0.56	3.99	0.00	1.46	5.13
HyFs	0.44	1.40	0.06	2.66	0.00	0.02	2.96	0.76	1.18	1.22
Mt	1.03	0.95	0.70	1.87	1.31	0.73	1.66	1.21	1.00	2.45
Il	0.40	0.42	0.14	1.08	0.44	0.15	1.11	0.29	0.60	0.84
Ap	0.27	0.35	0.18	0.61	0.20	0.22	0.54	0.04	0.35	0.22

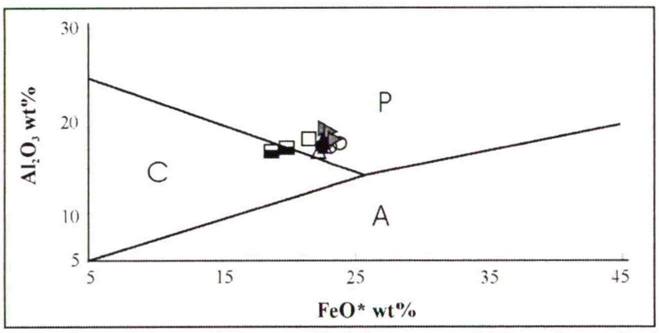

Fig. 5. Biotite Al_2O_3 v. FeO* composition of studied granitoids (Abdel-Rahman, 1994; A = alkaline; C = calc-alkaline and P = peraluminous biotite character).

ratio higher than 1 (Shand, 1947). The proposed I- and S-type subdivision (Chappell and White, 1974) with a limiting value for A/CNK = 1.1 shows that the majority of granitoids of Papuk Complex have A/CNK molar ratio higher than 1.1 while granitoids of Psunj-Krndija Complex have A/CNK ratio around or less than 1.1 (Fig. 6).

TRACE ELEMENT COMPOSITION

The majority of investigated granitoids are enriched in LREE ($(La/Lu)_{cn}$ =17–26) and have negative Eu anomalies (Table 4 and Fig. 7A, B). The amphibole-bearing monzogranite from Psunj Mt. (PSG-1) has the highest concentration of total REE with a strong negative anomaly (Fig. 7A). The monzogranite from Papuk Complex (2PPG-33) and monzogranite from Psunj-Krndija Complex (PSG-31) have exceptional REE pattern (Fig. 7A, B), being V-shaped (concave down), indicating enrichment in both, HREE and

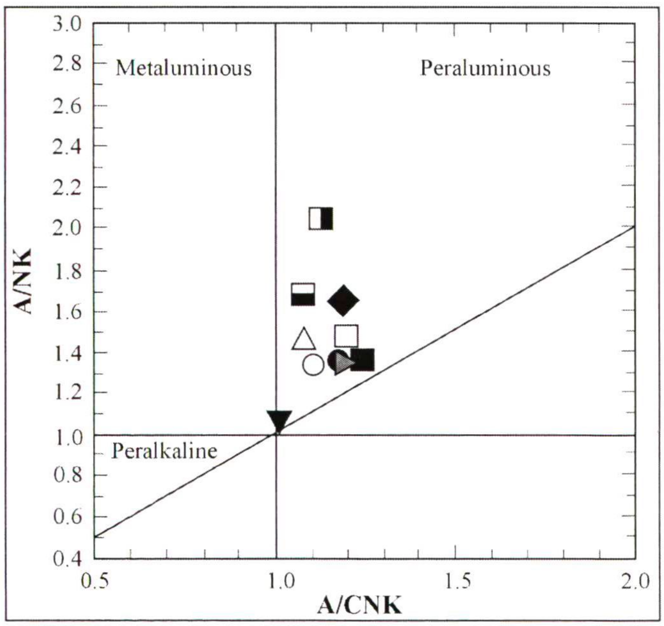

Fig. 6. Granitoid discrimination plots diagram after Maniar and Piccoli (1989); (A/CNK = molar ratios $Al_2O_3/(CaO+Na_2O+K_2O)$ and A/NK = molar ratios $Al_2O_3/(Na_2O+K_2O)$).

LREE. The enrichment in HREE is due to the higher amount of accessory minerals like zircon and garnet, while the enrichment in LREE (PSG-1) due to the presence of allanite (Buda and Nagy, 1995). The muscovite-biotite granodiorite from Papuk Complex (PPG-23) and quartz diorite from Psunj-Krndija Complex (PSG-38) have the lowest

Table 4. Trace element content (ppm) of the granitoids.

Locality	1	2	3	4	5	6	7	8	9	10
Sample	PPG-12	2PPG-32	2PPG-33	PPG-31	PPG-18	PPG-23	PPG-24	PSG-1	PSG-31	PSG-38
Ba	960	703	683	496	873	539	577	418	1750	218
Rb	105	112	113	109	137	146	104	63	98	38
Sr	233	179	153	420	157	254	535	37	203	701
Y	11	9	33	28	22	38	25	63	41	29
Nb	8	15	10	13	7	19	15	15	11	9
Zr	148	103	59	266	176	121	272	429	202	154
La	24.70	28.30	15.70	48.40	33.60	9.40	60.40	77.40	54.10	7.20
Ce	48.00	55.00	33.00	86.00	65.00	17.00	108.00	153.00	102.00	16.00
Nd	21.00	27.00	16.00	33.00	30.00	9.00	39.00	70.00	44.00	10.00
Sm	4.22	5.12	3.64	5.47	5.74	1.66	6.19	13.70	8.85	2.51
Eu	0.70	0.77	0.73	1.20	0.91	0.65	1.28	1.17	1.47	1.09
Tb	0.50	0.60	0.60	0.60	0.50	0.30	0.60	1.80	1.00	0.50
Dy	2.10	2.70	4.70	2.60	3.20	1.40	2.40	8.80	6.40	2.60
Yb	0.97	0.88	4.36	1.82	0.96	0.67	1.81	4.06	5.19	1.54
Lu	0.15	0.12	0.76	0.26	0.14	0.09	0.25	0.63	0.82	0.21
Σ REE	102.34	120.49	79.49	179.35	140.05	40.17	219.93	330.56	223.83	41.65
La/Lu_{cn}	17.66	25.30	2.21	19.94	25.73	11.20	25.90	13.17	7.07	3.67
Th	10.00	10.00	10.00	13.00	20.00	3.10	16.00	7.90	17.00	1.00
U	2.70	3.90	6.60	4.00	5.90	2.00	3.20	1.80	2.00	0.90
K	36443	31545	33288	20504	38767	26066	17848	36360	35696	6807
Ti	1265	1319	420	3291	1355	498	3447	917	1858	2572

concentrations of the LREE with low $(La/Lu)_{cn}$ ratios (11.2 and 3.7, respectively). Both samples have slight positive Eu anomalies. Their REE patterns show that they crystallized from plagioclase molecule-rich melt (Wilson, 1999). REE pattern of quartz diorite and monzogranites in Psunj-Krndija Complex indicate typical magmatic fractional crystallization with increasing ΣREE and negative Eu anomaly. The HREE concentration due to the presence of garnet (Fig. 7A). Similar trend was observed in Papuk Complex. Most granitoids enriched in ΣREE with negative Eu anomalies only one sample (PPG-23) has low ΣREE without negative Eu anomaly representing a plagioclase-rich part of the granitoid complex.

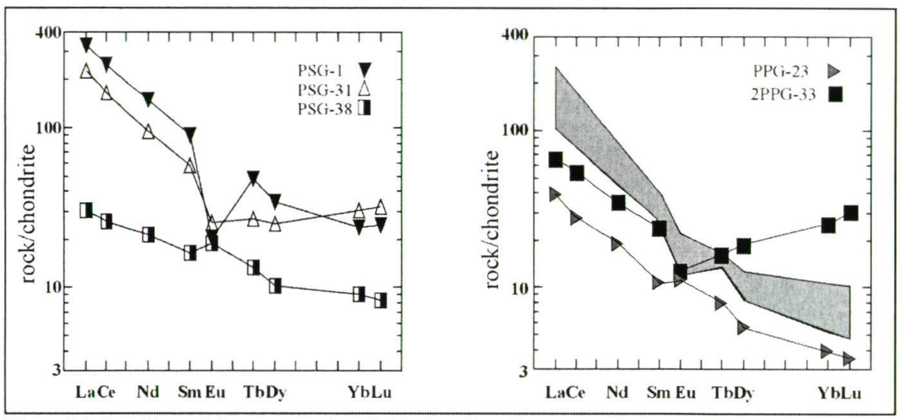

Fig. 7A,B. Chondrite normalized REE distribution of granitoids (normalizing values are from Evensen et al., 1978). Shaded area marks the average REE distribution of Papuk Complex granitoids.

MORB-normalized spider diagrams are shown in Fig. 8A, B. The majority of samples from Papuk and Psunj-Krndija Complexes show negative Nb, Sr and Ti anomalies. The negative Sr anomaly corresponds with a negative Eu anomaly. The negative Nb anomaly indicates crustal derived melts (Rollinson, 1993). Two samples (PPG-23 and PSG-38) also have a negative Ti anomaly but they have positive Nb and Sr anomalies (Fig. 8A, B) indicating a possible melt contribution from mantle.

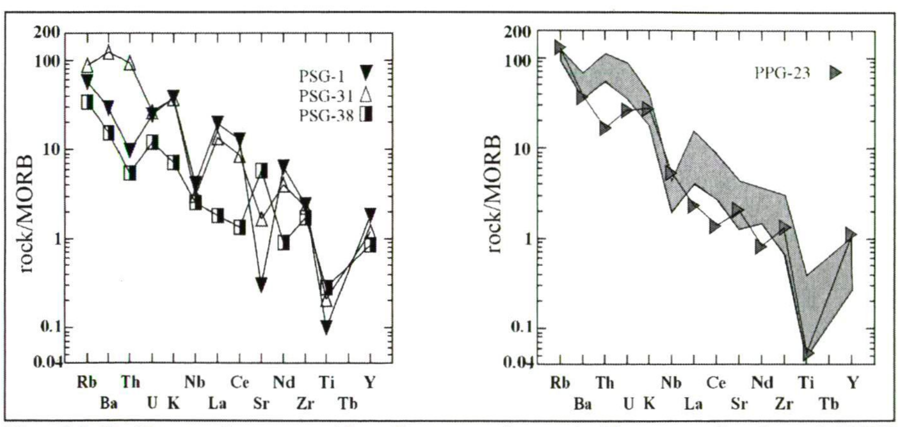

Fig. 8A,B. Trace element spider diagram of granitoids normalized to MORB (Pearce, 1982, 1983). Shaded area marks the average trace element distribution of Papuk Complex granitoids.

Discussion and conclusions

The microcline with intermediate to maximum triclinicities indicates a complex crystallization history and mostly a slow rate of cooling in both complexes. The biotite compositions depend largely upon the nature of magmas from which they have crystallized. The Fe- and Al-rich, peraluminous type biotite coexisting with muscovite most probably crystallized from a partially melted continental crust. The Mg-rich biotite shows a slight calc-alkaline character. In order to quantify the temperature of crystallization we used an empirical thermometer independent of pressure based on the amphibole stability in melt (Nabelek and Lindsley, 1985) and the Al content of ferro-hornblende. Temperature of crystallization (Hammarstrom and Zen, 1986) was between 740–770°C. This estimated crystallization temperature approximately corresponds with the eutectic composition of granite in the Ab-Or-Q ternary system.

Major element contents and CIPW norms of the investigated granitoids of two complexes reveal the following rock types: monzogranite, granodiorite and quartz diorite. According to the R_1-R_2 parameters (R_1 = 4Si–11*(Na+K)–2*(Fe+Ti); R_2 = 6Ca + 2Mg + Al, De la Roche et al., 1980) the majority of rocks plot in the field of syn-collision granitoids (Batchelor and Bowden 1985, Fig. 9). Two samples from the Papuk Complex plot in the field of post-colision and sample PSG-38 in the field of pre-plate collision granitoids.No significant differences can be observed between the granitoids of two complexes according to trace element content. The majority of granitoids (except quartz diorite from the Bistra Creek and muscovite-biotite granodiorite from the Pakra Creek) show enrichment in LREE with negative Eu anomaly.

We conclude from geochemical and petrological characteristics that the majority of granitoids of Papuk Complex are S-type and the granitoids of Psunj-Krndija Complex show magmatic fractional crystallization with mixed I/S-type characters.

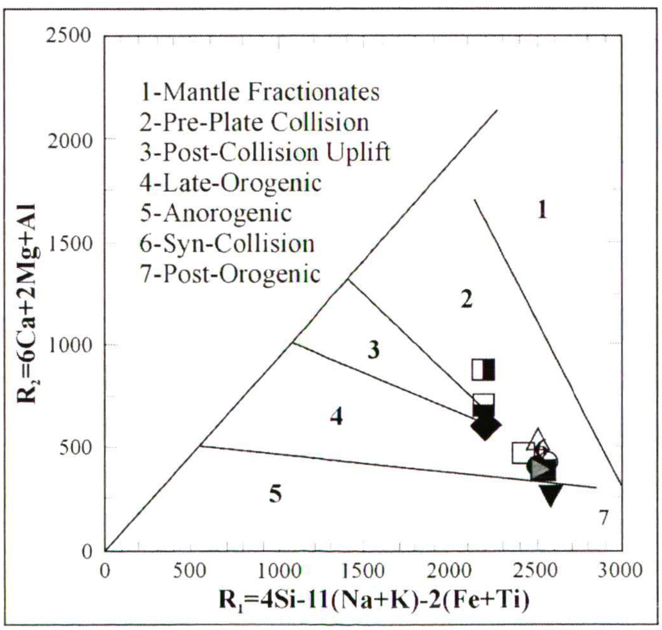

Fig. 9. Multicationic parameters R_1-R_2 of the studied granitoids showing tectonomagmatic position based on Batchelor and Bowden (1985).

Acknowledgements

The authors acknowledge Prof. T. Szederkényi (Hungary), M. Belak (Croatia) and an anonymous reviewer for revision of the manuscript and Prof. D. Watkinson (Canada) for the improvement of English. The study was financed by the Ministry of Education (PhD program) and supported by the Hungarian Science Foundation (OTKA No. 023762). Field trips were organized by the Institute of Geology (Zagreb, Croatia). Special thanks go to D. Jamičić (Croatia) who led the field investigations and gave a complete introduction to the geology of the studied area. The authors are indebted also to everybody who helped to improve this paper.

References

Abdel-Rahman, A. F. M. (1994): Nature of Biotites from Alkaline, Calc-alkaline and Peraluminous Magmas. Journal of Petrology, **35/II**, 525–541.

Batchelor R. A., Bowden P. (1985): Petrogenetic interpretation of granitoid rock series using multicationic parameters. Chemical Geology, **48**, 43–55.

Buda, Gy., Nagy, G. (1995): Some REE-bearing accessory minerals in two types of Variscan granitoids, Hungary. Geologica Carpathica, **46/2**, 67–78.

Chappell, B. W., White, A. J. R. (1974): Two contrasting granite types. Pacific Geology, **8**, 173–174.

De la Roche, H., Leterrier, J., Grandclaude, P., Marchal, M. (1980): A classification of volcanic and plutonic rocks using R_1R_2-diagram and major-element analyses-its relationships with current nomenclature. Chemical Geology Amsterdam, **29**, 183–210.

Evensen, N. M., Hamilton, P. J., O'Nions, R. K. (1978): Rare earth abundances in chondritic meteorites. Geochimica et Cosmochimica Acta, **42**, 1199–1212.

Goldsmith, J. R., Laves, F. (1954): Potassium feldspars structurally intermediate between microcline and sanidine. Geochimica et Cosmochimica Acta, **5**, 100–118.

Hammarstrom, M. J., Zen, E. (1986): Aluminium in Hornblende: an Empirical Igneous Geobarometer. American Mineralogist, **71**, 1297–1313.

IUGS Subcommission on the Systematics of Igneous Rocks (1973): Classification and Nomenclature of Plutonic Rocks. Recommendations. Neues Jahrbuch der Mineralogischen Abhandlungen Stuttgart, **H. 4**, 149–164.

Jamičić, D., Brkić, M. (1987): Basic geological map of SFRJ 1:100000 (Orahovica sheet), L 33-96. Geološki Zavod Zagreb.-Savezni Geološki Zavod Beograd, Beograd.

Jamičić, D. (1988): Structural Fabric of the Slavonian Mountains (northern Psunj, Papuk, and Krndija Mountain). Dissertation. Sveučilište u Zagrebu. Rudarsko-Geološko Naftni Fakultet, Zagreb, (in Croatian).

Jamičić, D. (1989): Basic geological map of SFRJ 1:100000 (Daruvar sheet), L 33-95. Geološki Zavod Zagreb.-Savezni Geološki Zavod Beograd, Beograd.

Leake, B. E., Woolley, A. R., Arps, C. E. S., Birch, W. D., Gilbert, M. C., Grice, J. D., Hawthorne, F. C., Kato, A., Kisch, H. J., Krivovichev, V. G., Linthout, K., Laird, J., Mandarino, J. A., Maresch, W. V., Nickel, E. H., Rock, N. M. S., Schumacher, J. C., Smith, D. C., Stephenson, N. C. N., Ungaretti, L., Whittaker, E. J. W., Youzhi, G. (1997): Nomenclature of amphiboles: report of the subcommittee on amphiboles of the IMA, commission on new minerals and mineral names. Mineralogical Magazine, **61**, 295–321.

Lovas, Gy., Horvat, M., Buda, Gy. (1999): K-feldspars of the Granitoids, Pegmatites and Migmatites from Papuk

Polymetamorphic Complex in East Slavonia, Croatia. Berichte der Deutschen Mineralogischen Gesellschaft, No.1., Beihefte zum European Journal of Mineralogy, **11**, Stuttgart, p. 149.

MANIAR, P. D., PICCOLI, P. M. (1989): Tectonic discrimination of granitoids. Geological Society of America Bulletin, **101**, 635–643.

MARCI, V. (1965): Petrography of the western part of Psunj Mountain. Acta Geologica Zagreb, **4**, 315–322, (in Croatian).

MARCI, V. (1973): Genesis of the granitic rocks of Psunj Mountain. Acta Geologica Zagreb, **7**, 195–231, (in Croatian).

NABELEK, C. R., LINDSLEY, D. H. (1985): Tetrahedral Al in amphibole: a potential thermometer for some mafic rocks. Geological Society of America Abstracts with Programs, **17**, page 673.

PAMIĆ, J. (1988a): Rocks of the Granite-Granodiorite Association from Mt. Krndija in Slavonia (Northern Croatia, Yugoslavia). Rad JAZU Zagreb, **441/23**, 97–114.

PAMIĆ, J., LANPHERE, M., MCKEE, E. (1988b): Radiometric Ages of Metamorphic and Associated Igneous Rocks of the Slavonian Mts. in the Southern Part of the Pannonian Basin, Yugoslavia. Acta Geologica Zagreb, **18/2**, 13–39.

PAMIĆ, J., LANPHERE, M. (1991): Hercynian Granites and Metamorphic Rocks from the Mts. Papuk, Psunj, Krndija and the Surrounding Basement of the Pannonian Basin in Slavonija (Northern Croatia, Yugoslavia). Geologija Ljubljana, **34**, 81–253.

PAMIĆ, J., LANPHERE, M., BELAK, M. (1996): Hercynian I-type and S-type granitoids from the Slavonian mountains (southern Pannonian Basin, northern Croatia). Neues Jahrbuch der Mineralogie, Abhandlungen, **171/2**, 155–186.

PAMIĆ, J., JELASKA, V., GUŠIĆ, I., ŠIKIĆ, K., BELAK, M., TOMIĆ, V. (1996-1997): Tectonostratigraphic units and terranes between the Adriatic Sea and the Southern Pannonian Basin. Annales Géologiques des Pays Helléniques, **37**, 401–427.

PEARCE, J. A. (1982): Trace element characteristics of lavas from destructive plate boundaries. In: Thorpe, R. S. (ed): Andesites.- Wiley, Chichester, 525–548.

PEARCE, J. A. (1983): Role of the sub-continental lithosphere in magma genesis at active continental margins. In: Hawkesworth, C. J., Norry, M. J. (ed): Continental basalts and mantle xenolites.- Shiva, Nautwitch, 230–249.

RAFFAELLI, P. (1965): Metamorphism of paleozoic pelitic schists of Ravna gora (Papuk Mountain, Croatia). Geološki Vjesnik Zagreb, **18/1** (1964), 61-111 (in Croatian).

ROLLINSON, H. (1993): Using Geochemical Data: evoluation, presentation, interpretation. Longman Scientific and Technical, London, 352 pp.

SHAND, S. J. (1947): Eruptive rocks. Their genesis, composition, classsification and their relations to ore-deposits. 3rd edition, Thomas Murby, London, 488 pp.

SLOVENEC, D. (1978): On the possible utilization of biotite as a genetic indicator in the Papuk granite-metamorphic rocks (north Croatia). Geološki Vjesnik Zagreb, **30/2**, 351–357, (in Croatian).

SLOVENEC, D. (1982): Chemical composition of biotites, garnets and amphiboles as an indicator of the formation temperature of granite-metamorphic rocks of the Papuk Mountain. Geološki Vjesnik Zagreb, **35**, 133–152, (in Croatian).

TAJDER, M. (1957): Petrographic investigation of the western part of the Papuk Mountain. Ljetopis JAZU Zagreb, **62**, 316–323, (in Croatian).

VRAGOVIĆ, M. (1965): Granites and gneisses of the Papuk Mountain. Dissertation. Sveučilište u Zagrebu, Prirodoslovno-matematički Fakultet, Zagreb, (in Croatian).

WILSON, M. (1989): Igneous Petrogenesis. HarperCollinsAcademic, London, 466 pp.