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Petrology and chronology of the Vučje gneiss, Serbo-Macedonian massif, Yugoslavia

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Abstract. The Vučje Gneiss consists of K-feldspar, plagioclase (oligoclase, andesine), biotite, muscovite and quartz. Mineral and chemical composition suggest that they were originally igneous rocks, i.e. peraluminous granites.

The gneisses of Vučje have a geochemical signature that is comparable with that of granitoids of within-plate tectonic setting, and of syn-collision granites.

The geochronological data suggest that three main periods of tectonism, metamorphism and/or igneous activities occurred: Caledonian , Hercynian and Alpine.

Key words: petrology, chronology, gneiss, Serbo-Macedonian massif

Introduction

The Vučje gneiss belongs to the Serbian-Macedonian Massif (Dimitrijevič, 1959), composed of two metamorphic complexes.

The Lower complex, pre-Cambrian in age, consists of different gneisses (locally migmatitized), micaschists, quartzites and marbles (in lower horizons). This complex also includes granitic rocks of two ages: the Vlajna pluton at the boundary between the lower and the upper complexes (450 Ma, Upper Ordovician, Vukanovič et al, 1973), and the Bujanovac granitic pluton (347 Ma, Lower Carboniferous, Dimitrijevič, 1958).

The Upper, or **Vlajna complex**, unconformably overlying the lower one, contains the paleofloral and faunal remains showing its Riphean-Cambrian to Ordovician (and probably even younger) age. It consists of greenschist facies metamorphosed rocks. The first outcrops of this complex are located about 15 km west of Leskovac.

The Vučje gneiss is situated south of the Leskovac Neogene depression, in the neighbourhood of Vučje township (Fig. 1). This concordant, strongly foliated body has a gradual transition toward the adjacent metamorphic rocks. General shape of the **Vučje gneiss** body is roughly elipsoidal, outcropping over an area of about 4x2 km. Northern part of the body is cut by a young fault toward the Neogene basin of the Veternica river. In the eastern direction it is flanked by the Vlajna granitic body, and by the Vlajna dome to the south, with conspicuous masses of migmatites. During previous investigations the Vučje gneiss has been regarded as a migmatite, together with the surrounding rocks, and mapped as an eyed-amygdaloidal embrechite. No special studies were formerly performed. New

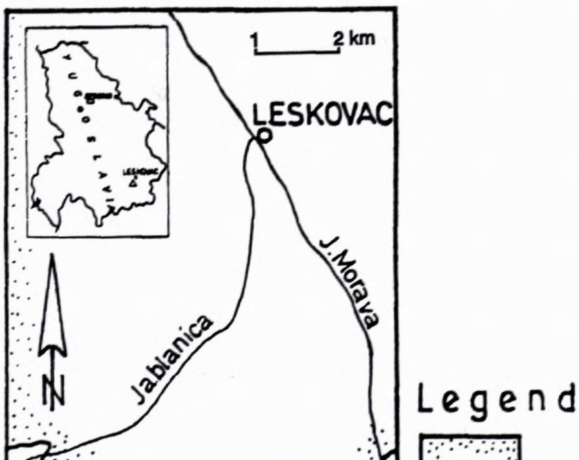

Fig. 1. Locations and simplified geology of the Vučje Gneiss (after Dimitrijevič et al. 1966/67). Legend: 1. Quaternary and Neogene; 2. Hercynian granitoid rocks; 3. Crystalline schists of Lower complex of Serbo-Macedonian massif; 4. Gneisses of Vučje.

investigations cover many aspects, including field relations, petrology, geochemistry and isotope geochemistry.

The purpose of this paper is to discuss the petrological and geochronological features of these rocks, basing on a substantial set of new analyses, and to present an idea of possible physical processes which controlled the thermal and structural evolution of this part of the Serbo-Macedonian Massif.

Petrography

The Vučje gneiss consists of K-feldspar, plagioclase, biotite, muscovite and quartz. The accessories include zircon, apatite and tourmaline.

The gneisses are medium to coarse grained. The rocks vary from augen-to rarely banded gneisses. This banding is believed to be of structural-metamorphic origin because the original texture has not been preserved and the presence of augen structure requires a deformation. The general consistency in the orientation of foliation in the banded and augen gneisses suggests that the rock fabric was controlled by the regional strains. Leucocratic material in the outcrop ranges from the millimeter-thick layers and lenses to larger bodies as much as10 cm thick.

K-feldspar is a dominant mineral and constitutes between 35-40% of the volume of in investigated rocks. It occurs both as poikiloblasts and as small granoblastic matrix grains. Globular porphyroblasts of K-feldspar, as much as 5 cm in size, form 'eyes' in hand specimens. The crenulation folding in places deformed these eyes to an elipsoidal shape. Apparently, the K-feldspar porphyroblasts developed due to pressure solution of the same mineral in the protolith, although the metamorphic reactions may have also contributed to its development. The K-feldspar shows the Carlsbad twining and some perthitic and myrmekitic intergrowths. Some grains of K-feldspar have undulatory extinction, forming a lobate to sutural texture, but are not recrystallised along the grain boundaries. Locally, the K-feldspar contains as inclusions randomly oriented flakes of sericite.

Plagioclase is relatively fresh and twinned with polygonal boundaries. The grains are 0.1 to 0.5 mm in diameter and show no chemical zonation or significant compositional variations. This mineral also occurs as small anhedral grains included in K-feldspar. The evidence of retrogression to sericite is rare. This mineral constitutes as much as 20% of the rock.

Biotite is pale to red-brown and, together with rare flakes of muscovite, it defines the foliation of the gneisses. This mineral constitutes as much 20% of the rock. It scarcely enwraps large K-feldspar grains. Large biotite flakes (as much as 3 mm in size) are pleochroic, ranging from pale to reddish-brown, locally show some chloritic alterations, with, or without Fe-oxides, and may associate with muscovite to form patches. Some biotite flakes have cuspate contacts with the surrounding quartz-feldspathic matrix suggesting textural disequilibrium. Deformations, without mechanical discontinuity, also occur in some places. Biotite crystals are at places surrounded by a fine aggregate of K-feldspar and ilmenite.

Muscovite is scarce or totally absent. The flakes of this mineral sporadically occur as randomly oriented grains within biotite.

The quartz grains are elongated and show the deformation bands and undulatory extinction. This mineral shows a variety of recovery and recrystallization features, such as ribbon texture, separate grain boundaries and the development of fine-grained polygonal mosaics.

Chemistry

Bulk rock chemistry

Main and trace elements were determined on 5 carefully selected samples of Vučje gneisses using the X-ray fluorescence. The REE were determined by means of inductivelly coupled plasma mass spectrometer (ICP-MS). The analytical precision was tested using the international standards and was shown to be better than 5% for ten main elements and the REE. Analyses were performed at the Federal Institute of Geosciences and Natural Resources, Hannover (Germany).

The main and trace element contents and CIPW norms of the analysed rock samples are shown in Table 1. Mineral and chemical data suggest an originally granitoid composition. These rock have excessive molar Al_2O_3/ ($Cao+Na_2O+K_2O$) ratios, giving as much as 1.44% normative corundum (i.e. peraluminious granitic group, Maniar & Piccoli, 1989). The Vučje gneisses also follow a calcareous trend (Peacock, 1931) and chemical and mineral compositions correspond to granodiorites (Le Maitre 1989, Fig 2.).

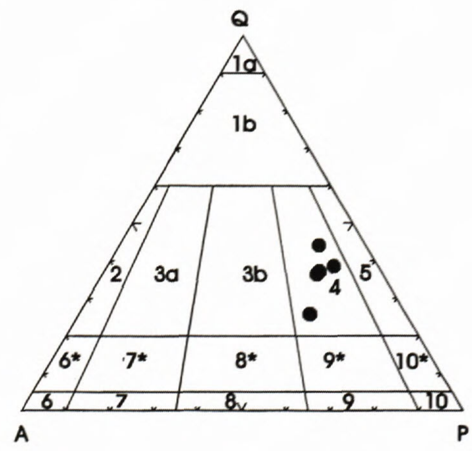

Fig. 2. Plot of Vučje gneiss data on the normative Q-A-P diagram (Le Maitre, 1989).
Fields: 1a-quartzolite; 1b-quartz-rich granitoids; 2-alkali feldspar granite; 3a- syeno-granite; 3b- monzo-granite; 4- granodiorite; 5-tonalite; 6- quartz alkali feldspar granite; 6-alkali feldspar syenite; 7*-quartz syenite; 7-syenite; 8*-quartz monzonite; 8-monzonite; 9-monzodiorite/monzogabbro; 10*- quartz diorite/quartz gabbro/quartz anorthosite; 10-diorite/gabbro/ anothosite.*

Mineral chemistry

The minerals were determined using the optical microscopy and electron microprobe. All minerals were analysed using the Cameca electron microprobe stationed at the University of Hamburg. Analytical conditions were as follows: 20 kV acceleration voltage, 10 nA sample current, 10 s counting time. Natural and synthetic oxide and minerals were used as standards. Representative mineral analyses are shown in Tables 2-4.

Table 1. Bulk rock chemistry of the Vučje gneisses

	1	2	3	4	5
SiO_2	68,68	73,55	71,56	70,82	70,03
TiO_2	0.35	0.33	0.39	0.31	0.34
Al_2O_3	16.15	12.92	14.54	14.39	15.13
Fe_2O_3	0.12	0.47	0.59	0.34	0.39
FeO	2.50	2.63	2.02	2.81	2.59
MnO	0.04	0.03	0.03	0.04	0.04
MgO	0.59	0.53	0.72	0.65	0.59
CaO	1.92	1.94	2.27	2.13	2.12
Na_2O	4.49	3.70	4.17	3.91	3.86
K_2O	4.09	2.36	2.21	2.91	3.01
P_2O_5	0.11	0.11	0.12	0.12	0.11
LOI	1.53	1.99	2.00	1.99	2.09
Total	100.57	100.56	100.62	100.42	100.30
CIPW-norm					
Q	20.41	36.56	32.05	29.73	29.15
C	1.11	1.01	1.45	1.22	1.93
or	24.17	13.31	13.06	17.20	17.79
ab	37.99	31.31	35.28	33.08	32.66
an	8.81	8.91	10.48	9.78	9.80
hy	5.46	5.27	4.43	6.06	5.42
mt	0.17	0.68	0.85	0.49	0.56
il	0.66	0.63	0.74	0.59	0.65
ap	0.25	0.25	0.28	0.28	0.25
norm Pl	18.81	22.14	22.89	22.82	23.07
Trace elements (ppm)					
Sc	6	5	6	5	6
Y	21.2	36.5	27.0	31.4	26.4
Ba	646	434	719	580	612
B	5.5	3.2	7.2	6.1	6.8
Cs	2.8	1.8	2.9	2.5	2
Hf	1.5	2.0	1.9	2	2
Li	18	13	20	16	18
Mo	1	1	1	1	1
Nb	24	21	22	22	21
Pb	19	17	13	18	17
Rb	119	66	88	90	92
Sr	248	271	333	311	298
Ta	2.3	2	2.2	2.1	2.2
Th	14.2	18.7	20.2	17.4	16.9
U	2.1	6.6	3.7	4.1	4.9
Zr	53	67	64	62	57
La	36	44	47	42	44
Ce	76	89	94	86	87
Pr	8	9	10	9	10
Nd	28	34	37	29	31
Sm	5.6	7.1	7.2	6.8	7.1
Eu	1	1	1	1	1
Gd	5	7	6	6	6
Tb	1	1	1	1	1
Dy	3.9	6.2	5.1	5.2	4.4
Ho	1.1	1.2	1.1	1.2	1.1
Er	8	3.4	2.5	3.1	2.8
Tm	1	1	1	1	1
Yb	1.7	3.1	2.1	1.9	2.5
Lu	1	1	1	1	1

Table 2. Representative analyses of potassium feldspars from the Vučje Gneisses

	1	2	3
SiO_2	64.99	64.52	64.74
Al_2O_3	19.00	19.20	19.12
CaO	0.04	0.42	0.00
Na_2O	0.88	1.67	0.68
K_2O	14.91	13.84	15.03
Total	99.82	99.65	99.57
Number of ions on the basis of 8 oxygens			
Si	3.0046	2.9735	3.0037
Al	1.0353	1.0429	1.0455
Ca	0.0020	0.0207	0.0000
Na	0.0789	0.1492	0.0612
K	0.8793	0.8136	0.8896
or	91.58	82.72	93.57
ab	8.21	15.17	6.43
an	0.21	2.11	0.00

Table 3. Representative analyses of plagioclase from the Vučje gneisses

	1	2	3	4	5
SiO_2	62.86	61.75	61.76	61.96	63.77
Al_2O_3	24.07	24.53	24.71	24.57	23.46
CaO	4.43	4.82	4.65	4.63	3.20
Na_2O	9.17	9.11	9.25	9.09	9.73
K_2O	0.24	0.12	0.17	0.14	0.27
Total	100.77	100.33	100.54	100.39	100.43
Number of ions on the basis of 8 oxygens					
Si	2.7556	2.7169	2.7084	2.7252	2.7955
Al	1.2436	1.2720	1.2771	1.2736	1.2121
Ca	0.2081	0.2272	0.2185	0.2182	0.1503
Na	0.7794	0.7771	0.7865	0.7752	0.8270
K	0.0134	0.0067	0.0095	0.0079	0.0151
ab	0.779	0.769	0.775	0.774	0.833
an	0.208	0.225	0.215	0.218	0.151
or	0.013	0.006	0.010	0.008	0.016

Table 4. Representative analyses of biotite from the Vučje Gneisses

	1	2	3	4	5
SiO_2	34.56	34.49	34.04	34.69	35.63
TiO_2	2.02	2.04	2.00	2.20	2.09
Al_2O_3	17.20	17.06	17.40	17.07	17.19
FeO	25.80	26.10	26.09	25.41	23.49
MnO	0.27	0.22	0.22	0.23	0.25
MgO	6.55	6.71	6.62	6.68	9.10
K_2O	9.09	9.26	9.05	9.33	9.49
Total	95.49	95.88	95.42	95.61	97.24
Number of ions on the basis of 22 oxygens					
Si	5.4335	5.4149	5.3686	5.4428	5.4335
Ti	0.2388	0.2408	0.2372	0.2596	0.2397
Al	3.1871	3.1567	3.2343	3.1565	3.0895
Fe^{2+}	3.3922	3.4268	3.4411	3.3341	2.9957
Mn	0.0360	0.0293	0.0294	0.0306	0.0323
Mg	1.5349	1.5702	1.5562	1.5622	2.0684
K	1.8230	1.8545	1.8207	1.8673	1.8461

The analyses are the averages of 3-5 measurements made on mineral grains in the same thin section. Analysis of approximately 50 K-feldspar grains have shown a stable composition (Table 2). Also the plagioclase, analysed on some 30 grains, have shown an almost identical composition at the oligoclase-andesine boundary (Table 3). Coarser plagioclase grains (1 mm in diameter) neither show the chemical zoning nor significant compositional variations.

The composition of biotite (approximately 30 grains analysed, Table 4) is siderophylitic. The combination with nominal 4% of H_2O content yielded a total average of only slightly more than 100%.

Geohronology

Geochronological data may be relevant to two fundamental questions: (1) when the granitoid protolith formed and (2) when it underwent the metamorphism and cooling.

Three samples have been selected for U-Pb dating (on zircon), and for K-Ar dating on plagioclase, alkali feldspar and biotite. The isotopic age of mentioned minerals was determined by Yu. Pushkarev (VSEGEI, Sankt Peterburg).

The results are: 500 (±1.4) Ma for zircon; 265 (±30) Ma for plagioclase; 150 (±5)Ma for biotite and 130 (±10) Ma for K-feldspar.

The age value of the zircon is interpreted as the age of the granitoid magmatic (Caledonian ?) intrusion. The age value of plagioclase reflects the age of the Hercynian metamorphism, rejuvenated by the Alpine reworking. Alpine rejuvenation metamorphism is unquestionable, considering the biotite and K-feldspar K-Ar age values.

Metamorphic conditions and evolution

The mineral assemblage in Vučje Gneiss does not allow to accurately determine the metamorphic pressures. Metamorphic temperature of in the mentioned rocks can only be obtained from the feldspar geothermometer of Whitney & Stormer (1977). On the basis of mentioned geothermometer (for a supposed pressure of 6 Kb) the metamorphic temperature for the investigated rocks falls within the range 450 to 530^0C. Mineral association in Vučje gneisses, Pl+Bt+Kfs+Ms+Qtz also indicates that temperature of metamorphism of the investigated rocks is compatible with the lower part of the amphibolite facies, close to the boundary with the greenschist facies (about 530-550^0C).

The metamorphic temperature of about 530-550^0C should be referred to the Hercynian metamorphism, because the post-tectonic, Hercynian Vlaina granitoid is not metamorphic (Fig. 1, symbol 2). Therephore, when this granitoid was intruded, the Vučje gneisses were already metamorphosed.

The Alpine effects were only minor, probably only producing an isotopic rejuvenation, but not new minerals. This conclusion is consistent with the fact that Hercynian granitoids do not show any mineral alteration, indicating an Alpine metamorphism.

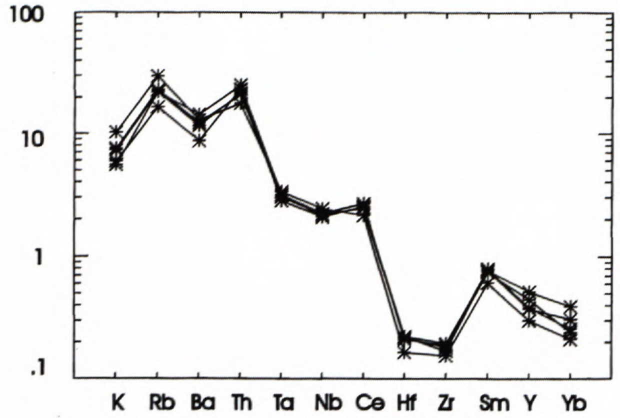

Fig. 3. Multi element diagram of some representative Vučje Gneiss analyses, normalised to ocean ridge granite. The order of the elements and values of the normalizing constants are from Pearce et al. (1984).

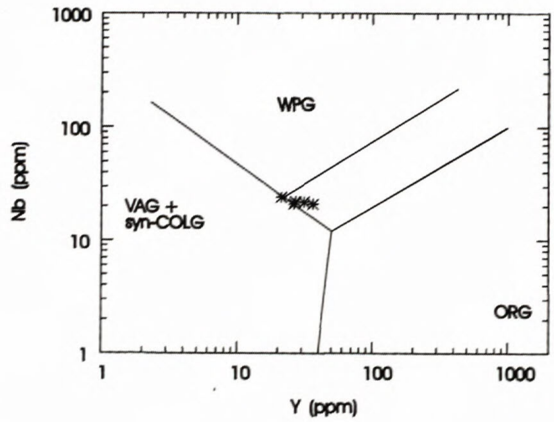

Fig. 4. Plot of the Vučje Gneiss analyses on the tectonomagmatic discrimination diagram for granitic rocks according to Pearce et al. 1984. WP: within plate granites; VAG+syn-COLG: volcanic arc granites and syncollision granites; ORG: ocean ridge granites

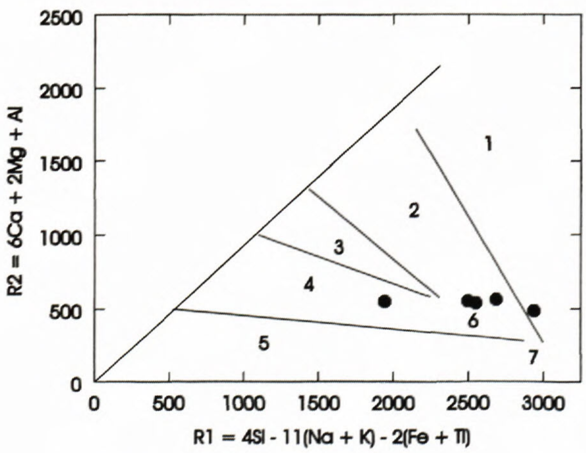

Fig. 5. Plot of the Vučje Gneiss using the multicationig parameters
(Batchelor & Bowden, 1985).
Legend: 1 Mantle fractionates; 2 Pre-plate collision; 3 Post-collision uplift; 4 Late-orogenic; 5 Anorogenic; 6 Syn-collision; 7 Post-orogenic

Conclusion

Mineralogical and chemical compositions of Vučje gneisses suggest that they were originally igneous rocks i.e. peraluminous granitoids. This type of granitic magma is commonly considered as generated directly from partial melting of crustal materials.

For the purpose of the tectonic setting granites have received less attention than basalts as tectonic indicators. However the geochemical studies of Vučje gneisses have an important bearing on the interpretation of tectonic setting.

The gneisses of Vučje are characterized by enrichments in K, Rb, Ba, Th, Nb and Ce relative to Hf, Zr, Sm, Y and Yb (Fig 3).

These rocks, when plotted on a discrimination trace element diagram (Fig 4.), have a geochemical signature that is comparable with the granitoids from within-plate tectonic setting (Pearce et al. 1984). Classification schemes based on the main components (Peacock, 1931, Chappel & White, 1974, White & Chappel, 1977, Collins et al, 1982 etc) do not give significant indications for the tectonic classifications.

The chemical data of Vučje gneisses fall in the field of syn-collisional melts (Fig . 5, Batchelor & Bowden, 1985)

Based on the geological and radiometric results, three main periods of tectonism, metamorphism and/or igneous activities can be recognised: Caledonian, Hercynian and Alpine.

Primary (?) crystallization of granitic magma (zircon age) happened 500 M/a ago. This has been considered as the age of plutonic emplacement of granitic magma.

The mineral assemblages of Vučje gneisses is therefore dominated by an amphibolite facies equilibrium assemblage, which shows only minor overprinting by the fine-grained recrystallization. The last phase of crystallization of minerals pertains to the lower part of amphibolite facies of metamorphism (recrystallization of plagioclase and formation of augen K-feldspar). The plagioclase age (265 m/a) can indicate a period of tectono-metamorphic activity, probably related to Hercynian orogenesis, or may be a result of an Alpine overprint.

The greenschist facies metamorphism (recrystallization of K-feldspar and the isotopic reseting of biotite) relates to Alpine metamorphism (K-feldspar and biotite age).

Acknowledgements

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