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Petrology of plagiogranite from Sjenica, Dinaridic Ophiolite Belt (southwestern Serbia)

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Abstract: The Sjenica plagiogranite occurs in the southern part of the Dinaridic Ophiolite Belt, 5 km northwest of Sjenica. The main minerals are albite with strongly altered biotite (replaced with chlorite), with occasional amphibole (magnesio hornblende to tschermakite) and quartz. An enclave of fine-grained granitic rocks with garnet grains was noted too. Secondary minerals are calcite and chlorite (daphnite). Major, trace and REE geochemistry coupled with field observations support a model by which the Sjenica plagiogranite could be formed by fractional crystallization of mantle origin mafic magma in a supra-subduction zone setting. Occurrences of calcite and chlorite nests in the Sjenica plagiogranites revealed that these rocks underwent hydrothermal alteration due to intensive sea water circulation in a sub-sea-floor environment.

Key words: Serbia, Dinaridic Ophiolite Belt, geochemistry, petrology, ophiolite, plagiogranite.

Introduction

Occurrences of plagiogranites within ophiolitic complexes are of particular interest because of their extreme composition and controversial origin. Ophiolitic sequences are considered incomplete without plagiogranites.

In Serbia plagiogranites occur in the Dinaridic Ophiolite Belt and in the Vardar Zone (Karamata & Krstić 1996). In the Dinaridic Ophiolite Belt plagiogranites were noted at numerous localities (Karamata 1958; Pamić & Olujić 1969; Pamić & Tojerkauf 1970; Lugović et al. 1991; Majer & Garašić 2001), while in the Vardar Zone they are less abundant (Milovanović 1980; Jović 1984). Both, the Dinaridic Ophiolite Belt and the Vardar Zone, are parts of the Alpine-Mediterranean mountain belt which belongs to a main suture zone between Eurasia and Gondwanaland after their collision during the Late Jurassic/Early Cretaceous (Karamata 2006). These two differ in origin, structure and age and can be traced continually nearly 700 km, from the Southern Alps in the north to the Hellenides in the south. Different reconstructions of the Mesozoic ophiolite evolution in the Balkan Peninsula during the last few years have aroused the questions about the existence of one or more oceanic basins, their size, emplacement etc. One suggestion is that Tethys ophiolites were developed in two or more ocean basins, separated by rifted micro-continents (Pamić 1999; Karamata et al. 2000; Pamić et al. 2002; Robertson 2002; Stampfli & Borel 2002; Karamata 2004). During the Mesozoic, the Drina-Ivanjica-Pelagonide micro-continent separated the Vardar Ocean in the east from the Dinaridic Ocean in the west (Robertson & Karamata 1994). An alternative suggestion is that Tethys ophiolites were generated from a single ocean basin (e.g. Dercourt et al. 1986, 1993; Dal Piaz et al. 1995; Bortolotti et al. 2004).

The aim of this paper is to define petrographic and geochemical features of the Sjenica plagiogranites which occur in the southern part of the Dinaridic Ophiolite Belt. This part of the Eastern Mediterranean region has been investigated by numerous workers. The most important studies are those made by Karamata who has studied the Sjenica plagiogranites and initiated a new approach to interpretation of Mesozoic evolution in this region (1958, 2004).

Geological setting

The Sjenica plagiogranite occurs in the southern part of the Dinaridic Ophiolite Belt, which represents remnants of the Tethys and its marginal seas. The Sjenica plagiogranite occurs 5 km northwest of Sjenica (Coordinates: E 7146381, N 4793606; Fig. 1). The largest area is covered by ophiolite mélange ($J_{2,3}$) composed of chert, sandstone, claystone, limestone, diabase, gabbro, serpentinite and plagiogranite blocks (lenses) bonded with the sandy-silty matrix. Triassic rocks comprise widespread Middle Triassic limestone and dolomites with chert concretions and Upper Triassic banked to massive, highly karstified dolomitic limestone and dolomites, reaching in thickness up to 300 m. Lower Jurassic, Liassic limestone (J_1) is light reddish, oolitic in places. The youngest unit in this area is Miocene in age and corresponds to freshwater sediments with lignite layers and less abundant marly and dolomitic limestone (Fig. 2). Plagiogranites occur as lenses, about 50 m in length and 20 m in thickness, enclosed in the ophiolitic mélange, with irregular and jagged contacts. Field relations between plagiogranites and surrounding rocks could not be established due to intensive faulting. The present variably dismembered state is related to obduction and post-obduction tectonics.

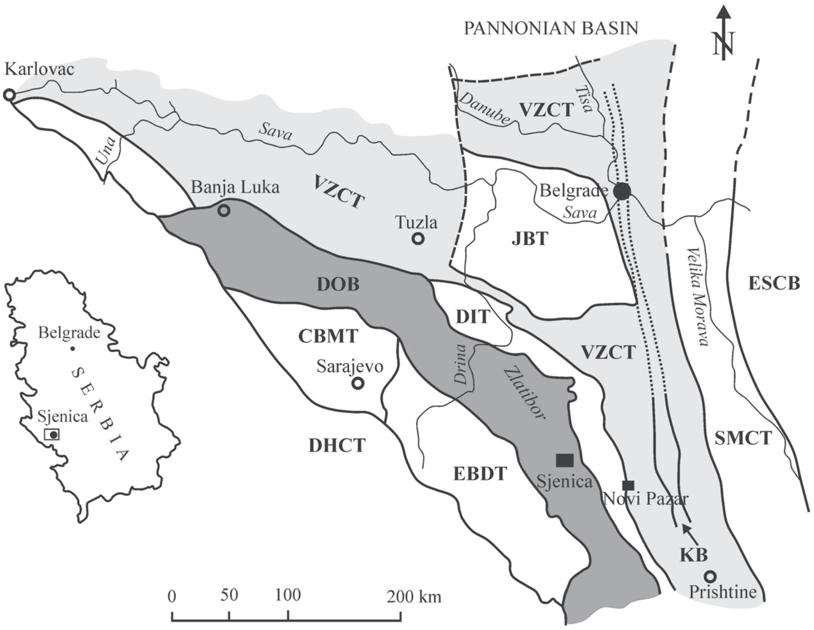

Fig. 1. The terranes in the central part of the Balkan Peninsula along with the position of the Sjenica plagiogranite: **ESCB** — The composite terrane of the Carpatho-Balkanides; **SMCT** — The Serbian-Macedonian Composite Terrane; **VZCT** — The Vardar Zone Composite Terrane; **KB** — The Kopaonik Block; **JBT** — Jadar Block Terrane; **DIT** — The Drina-Ivanjica Terrane; **DOB** — The Dinaridic Ophiolite Belt; **EBDT** — The East Bosnian-Durmitor Terrane; **CBMT** — The Central Bosnia Mts Terrane; **DHCT** — The Dalmatian-Herzegovinian Composite Terrane (after Karamata 2004).

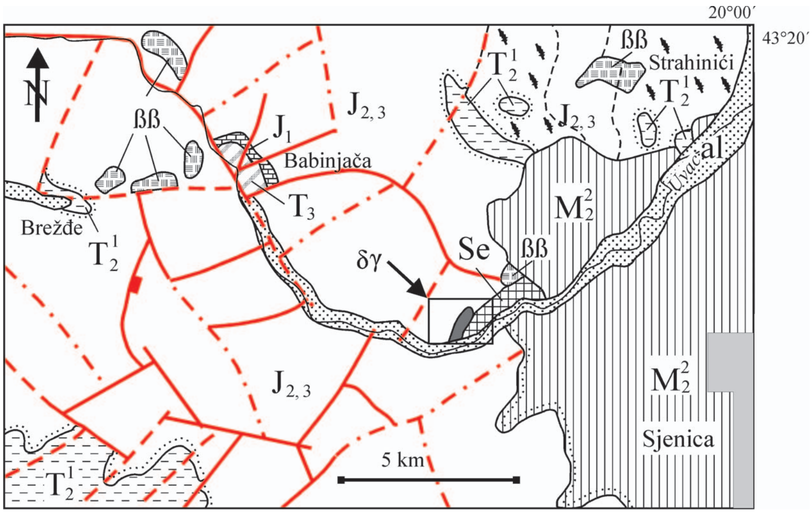

Fig. 2. Geological map of the Sjenica area with the occurrence of the plagiogranite (**black arrow**). Basic Geological Map, Sheet Bijelo Polje, 1:100,000 (Živaljević et al. 1982). Legend: $\mathbf{T_2^1}$ — Middle Triassic limestone with cherts; $\mathbf{T^3}$ — Upper Triassic limestone; $\mathbf{J_1}$ — Liassic reddish limestone; $\mathbf{J_{2,3}}$ — Ophiolitic mélange; **ββ** — Basaltic pillow lavas; **Se** — Serpentinite; $\mathbf{M_2}$ — Miocene clastic sediments; **δγ** — Plagiogranite (on the Basic Geological Map signed as granodiorite and quartzmonzonite).

Methods and techniques

On the basis of careful petrographic study of 30 samples, a representative suite of 5 samples was selected for geochemical analysis. The major element oxide, trace and REE element contents of these rock samples were analysed at the ACME analytical laboratory in Vancouver (Canada). The major and trace elements were determined from fused LiBO$_2$ discs by ICP-OES and ICP-MS, respectively, using 5 g of sample powder. Rare Earth elements were analysed by inductively coupled plasma-mass spectrometry (ICP-MS). The composition of minerals in selected samples was determined using a CAMECA SX 100 electron microprobe at the Department of Mineralogy and Petrography, University of Hamburg, Germany. Operating conditions were 20 kV accelerating voltage and 20 nA beam current with 20 s and 2 s counts for peak and background respectively.

Petrography and mineral chemistry

The Sjenica plagiogranite is holocrystalline, medium- to coarse-grained (average grain size 2 mm), homogeneous and unfoliated (Fig. 3). The overall texture is hypidiomorphic granular. These rocks show slight variations in the proportions of mafic and felsic minerals across the outcrop. Plagiogranites are mainly composed of plagioclase (albite) and quartz (Fig. 4). Vermicular quartz-plagioclase intergrowths that were interpreted as a primary magmatic feature by Coleman & Donato (1979), have been observed occasionally. Quartz comprises up to 30 % of the mode. In samples with amphibole the quantity of quartz decreases to about 20–25 %.

Albite is present as euhedral, twinned crystals, up to 5 mm in size, with minor sericitization. Plagiogranites contain 40 to 50 % modal albite. Twelve plagioclase grains were analysed. According to the obtained data, presented on Table 1 they correspond to almost pure albite ranging in composition between Ab (92.1–98.7 %).

Mafic minerals are chlorite, strongly altered biotite (?) and occasional amphibole. Chlorite occurs in veins, as irregular patches, interstitial accumulations (nests between albite and quartz grains) or as pseudomorphs after primary biotite. Chlorite is present in abundances from 5 % to 10 %. Microprobe analyses of chlorite were performed on twelve chlorite grains (Table 2). The obtained X_{Fe} values (Fe/Fe+Mg) range from 0.807 to 0.848. Chlorites are dominantly daphnite (Holland & Powell 1998).

Amphiboles occur locally in the eastern part of the outcrop. They are randomly oriented, typically exhibiting prismatic and acicular shapes. This mineral is partially altered

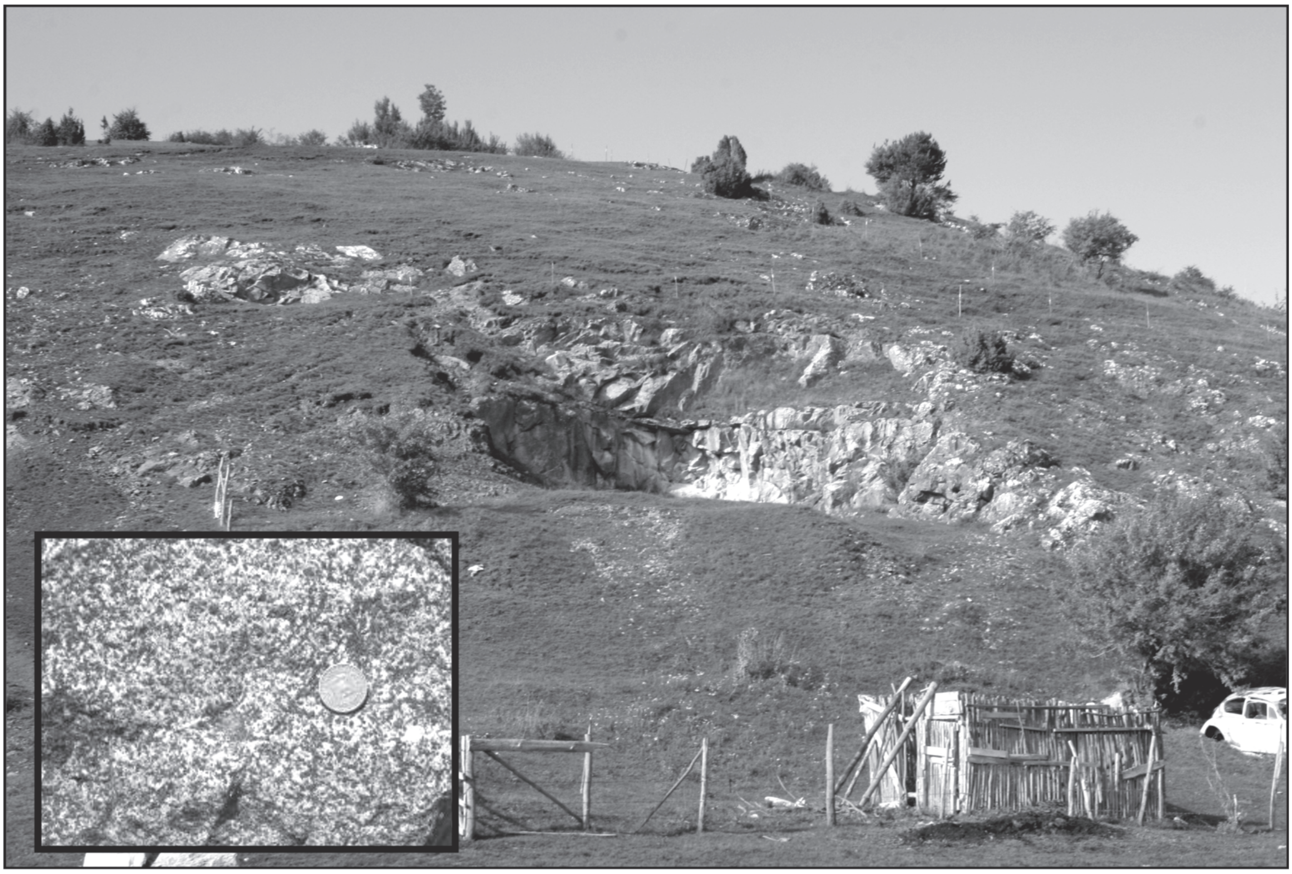

Fig. 3. The Sjenica plagiogranite outcrop, with detail of rock sample.

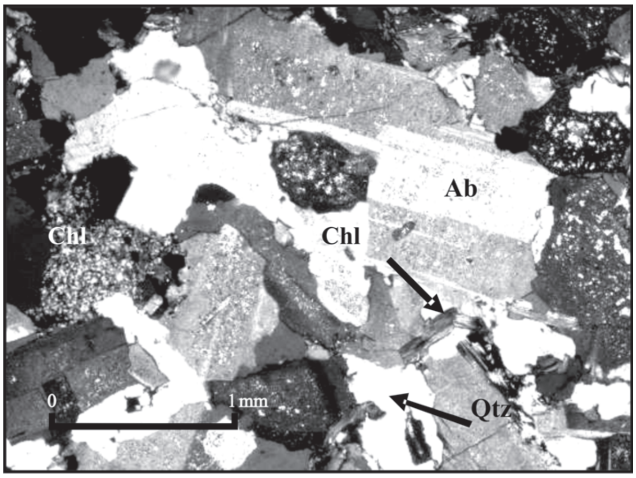

Fig. 4. Microphotograph of the Sjenica plagiogranite (N+). Abbreviations: **Ab** — albite, **Chl** — chlorite, **Q** — Quartz.

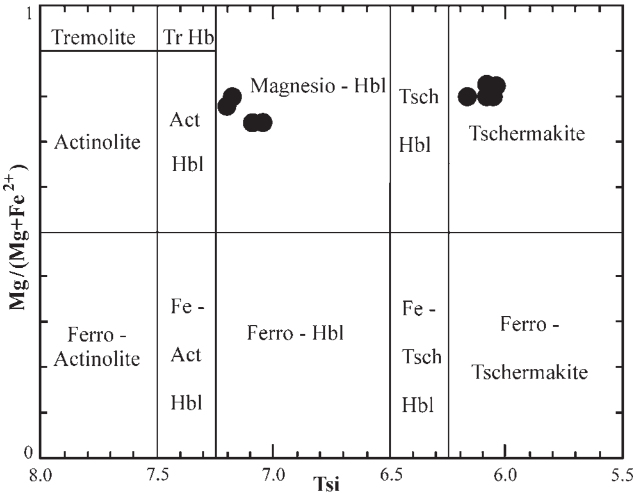

Fig. 5. Composition of amphiboles from the Sjenica plagiogranites plotted on the diagram of Leake (1997).

into chlorite and iron oxides. Pale green pleochroism has been observed. Amphibole grains correspond to Ca amphibole according to the nomenclature of Leake (1997), more precisely to magnesio hornblende or to tschermakite (Table 3, Fig. 5). The presence of two groups of amphiboles could be either a result of different conditions during crystallization or the result of their different alteration degree. The abundances of amphibole is below 10 %.

Secondary calcite occurs locally, building nests with chlorite, usually in intergranular spaces between albite and quartz grains. Calcite forms up to 3 % vol. of rock. Accessory minerals are apatite, zircon and magnetite.

In the eastern part of the outcrop (Fig. 6) we have found within the plagiogranite an enclave approximately 10 cm in diameter of fine-grained garnet-bearing granite (which also contains albite, chlorite and quartz).

Table 1: Chemical composition of albite.

Sample	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	66.95	66.83	66.96	66.81	67.32	67.48	66.42	67.21	66.78	66.86	66.03	66.32
Al_2O_3	20.61	20.97	20.42	20.92	20.77	19.97	21.09	20.32	20.87	20.91	22.11	20.78
CaO	0.35	0.11	0.12	0.41	0.12	0.16	0.21	0.21	0.35	0.43	0.16	0.26
Na_2O	10.95	10.94	10.99	10.87	11.22	11.35	10.87	11.23	10.99	10.95	10.31	10.98
K_2O	0.00	0.64	0.59	0.61	0.15	0.22	0.94	0.21	0.52	0.61	1.21	0.73
Total	**98.86**	**99.49**	**99.08**	**99.62**	**99.58**	**99.18**	**99.53**	**99.18**	**99.51**	**99.76**	**99.82**	**99.07**
Calculated on 32 O												
Si	11.81	11.76	11.83	11.75	11.81	11.89	11.71	11.84	11.75	11.74	11.60	11.74
Al	4.28	4.34	4.25	4.33	4.29	4.14	4.38	4.22	4.33	4.33	4.58	4.33
Ca	0.07	0.02	0.02	0.08	0.02	0.03	0.04	0.04	0.07	0.08	0.03	0.05
Na	3.75	3.73	3.76	3.71	3.81	3.88	3.72	3.84	3.75	3.73	3.51	3.77
K	0.00	0.14	0.13	0.14	0.03	0.05	0.21	0.05	0.12	0.14	0.27	0.17
An	1.8	0.6	0.5	2.0	0.6	0.8	1.0	1.0	1.8	2.0	0.8	1.2
Ab	98.2	95.9	96.2	94.4	98.7	98.0	93.7	97.7	95.2	94.4	92.1	94.5
Or	0.0	3.5	3.3	3.6	0.7	1.2	5.3	1.3	3.0	3.6	7.1	4.3

Table 2: Chemical composition of chlorite.

Sample	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	23.58	23.33	25.31	25.24	24.63	23.43	23.54	23.26	23.29	24.51	25.14	24.36
$Al2O_3$	20.29	20.91	19.09	19.98	19.20	19.86	20.02	20.83	20.31	19.70	18.98	19.08
FeO^{tot}	37.06	38.32	37.22	37.40	37.98	38.74	38.88	38.09	38.55	38.38	37.79	39.26
MnO	1.03	1.05	0.82	0.86	0.95	1.04	0.97	1.09	1.07	0.89	0.85	1.05
MgO	4.98	3.92	4.62	4.62	4.43	4.18	4.16	4.18	4.03	4.33	4.48	3.95
Total	**86.94**	**87.53**	**87.06**	**88.10**	**87.19**	**87.25**	**87.57**	**87.45**	**87.25**	**87.81**	**87.24**	**87.70**
Calculated on 28 O												
Si	5.39	5.34	5.76	5.67	5.61	5.39	5.40	5.32	5.36	5.57	5.71	5.59
Al	5.42	5.63	5.11	5.28	5.15	5.38	5.41	5.61	5.50	5.27	5.08	5.15
Fe	7.08	7.33	7.08	7.02	7.23	7.46	7.46	7.29	7.42	7.30	7.18	7.53
Mn	0.20	0.20	0.16	0.16	0.18	0.20	0.19	0.21	0.21	0.17	0.16	0.20
Mg	1.70	1.34	1.57	1.55	1.50	1.43	1.42	1.43	1.38	1.47	1.52	1.35

Table 3: Chemical composition of amphibole (■ — core of grains).

Sample	1■	2■	3■	4■	5■	6■	7■	8■	9■	10■
SiO_2	49.72	50.04	41.93	42.15	42.63	42.01	41.83	48.96	49.52	48.46
TiO_2	0.03	0.87	3.63	3.46	3.26	3.31	3.40	0.97	0.88	1.06
Al_2O_3	4.57	4.14	12.06	12.03	11.34	11.75	11.92	4.94	4.16	5.02
FeO^{tot}	18.69	17.63	13.63	13.51	13.41	13.71	13.46	17.72	17.45	17.80
Cr_2O_3	0.03	0.07	0.03	0.02	0.03	0.06	0.05	0.07	0.09	0.14
MnO	0.64	0.27	0.23	0.00	0.23	0.26	0.00	0.23	0.27	0.31
MgO	11.29	13.27	13.27	13.29	13.31	13.27	13.29	12.88	13.16	12.69
CaO	11.30	10.01	10.89	10.90	10.89	10.90	10.91	10.16	9.74	10.11
Na_2O	0.61	0.98	2.49	2.49	2.38	2.46	2.51	1.10	0.96	1.13
K_2O	0.20	0.20	0.11	0.13	0.10	0.11	0.11	0.29	0.19	0.28
Total	**97.08**	**97.48**	**98.27**	**97.98**	**97.58**	**97.84**	**97.48**	**97.32**	**96.42**	**97.00**
Calculated on 23 O (13-CNK)										
Si	7.332	7.198	6.039	6.085	6.177	6.078	6.074	7.090	7.185	7.051
Ti	0.003	0.094	0.393	0.376	0.355	0.360	0.371	0.106	0.096	0.116
Al	0.794	0.701	2.045	2.046	1.936	2.002	2.038	0.842	0.711	0.860
Cr	0.003	0.008	0.003	0.002	0.003	0.007	0.006	0.008	0.010	0.016
Fe^{3+}	0.748	1.312	1.010	0.937	0.927	1.025	0.945	1.244	1.382	1.267
Fe^{2+}	1.557	0.809	0.631	0.694	0.698	0.634	0.690	0.902	0.735	0.899
Mn	0.080	0.033	0.028	0.000	0.028	0.032	0.000	0.028	0.033	0.038
Mg	2.482	2.845	2.849	2.860	2.875	2.862	2.877	2.780	2.847	2.753
Ca	1.785	1.543	1.680	1.686	1.691	1.690	1.697	1.576	1.514	1.576
Na	0.174	0.273	0.696	0.697	0.668	0.690	0.707	0.309	0.270	0.319
K	0.038	0.037	0.020	0.024	0.018	0.020	0.020	0.054	0.035	0.052

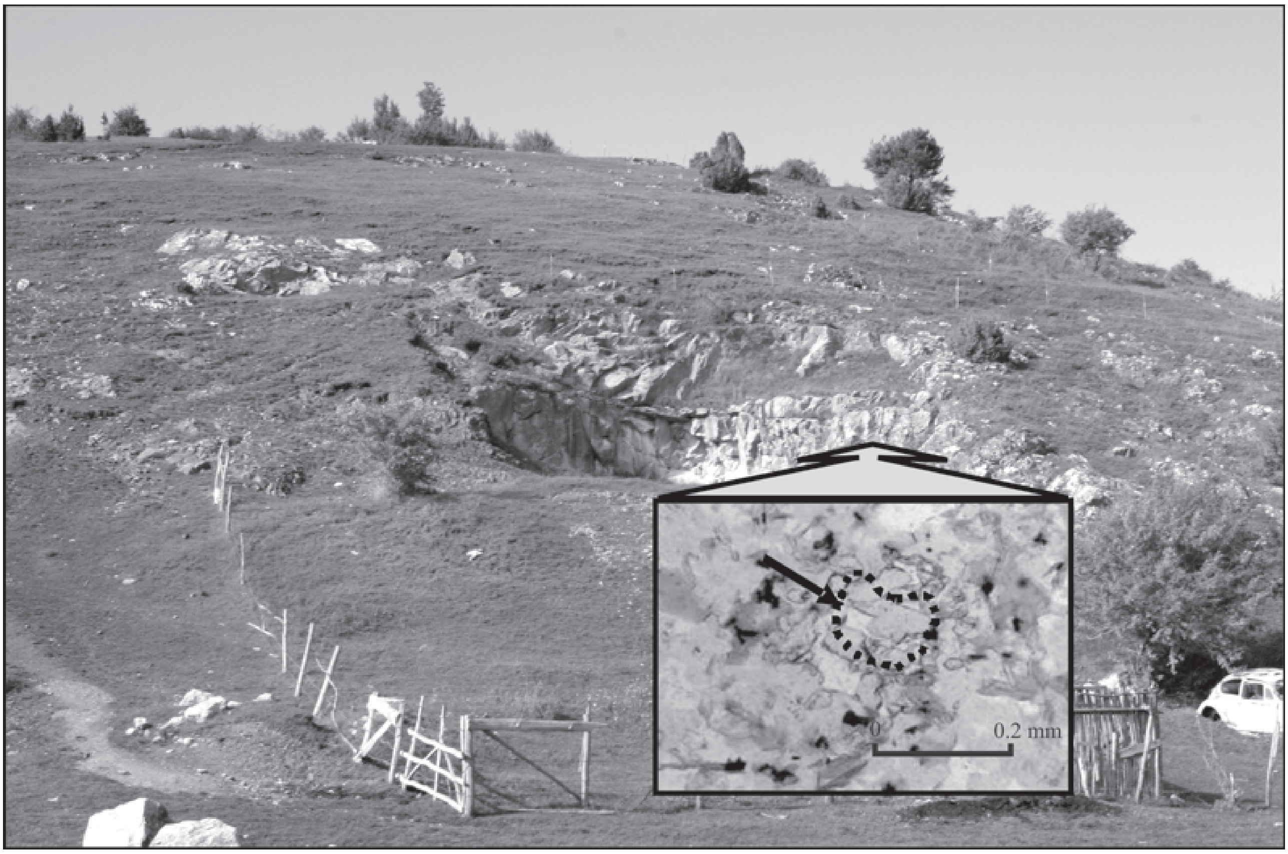

Fig. 6. Enclave of fine-grained plagiogranite with garnet porphyroblasts (?), black arrow. Microphotograph is N II.

The garnet is almandine rich, but it must be noted that the high amount of Fe^{3+} probably implies subsequent alteration processes (Table 4). Almandine component ranges from 67.2 to 68.5 %, pyrope from 17.8 to 19.5 %. Spessartine and andradite contents are about 6 %, whereas amounts of uvarovite and grossular components are insignificant. No compositional zoning was detected.

Classification and nomenclature

Coleman & Peterman (1975) proposed the term "oceanic plagiogranite" for rocks consisting of quartz and plagioclase (An10–60), typically characterized by a granophyric intergrowth with less than 10 % ferromagnesian minerals. This term encompasses rocks that range from diorite through trondhjemite to albite granite, which are all associated with ophiolites. On the basis of a wt. % K_2O vs. SiO_2 discrimination diagram (Coleman & Peterman 1975; Coleman & Donato 1979; Maniar & Piccoli 1989), the Sjenica plagiogranites can be considered as oceanic plagiogranites, except the sample with amphibole (Fig. 7). Plagiogranites from the Milatkoviće village near Novi Pazar which display similar geochemical features with the oceanic plagiogranites from the Troodos ophiolite massif were plotted on the same diagram (Milovanović 1980). For the purpose of geochemical characterization, CaO, Na_2O and K_2O have been plotted in the CNK ternary diagram of Glikson (1979) and the CIPW-normative

Table 4: Chemical compositions of garnets.

Sample	1	2	3	4	5	6
SiO_2	36.36	36.38	36.46	36.11	36.79	36.50
TiO_2	0.28	0.29	0.25	0.27	0.25	0.25
Al_2O_3	21.28	20.96	21.05	20.83	20.79	20.86
FeO^{tot}	34.48	34.20	34.80	34.37	34.13	34.25
Cr_2O_3	0.05	0.06	0.08	0.00	0.06	0.07
MnO	2.16	2.35	2.15	2.37	2.36	2.00
MgO	3.71	3.78	3.76	3.46	3.46	3.75
CaO	1.69	1.83	1.71	1.93	1.78	1.71
Total	**100.01**	**99.85**	**100.21**	**99.34**	**99.62**	**99.39**
Calculated on 12 O						
Si	2.925	2.925	2.921	2.923	2.969	2.947
Ti	0.017	0.075	0.015	0.016	0.015	0.015
Al	1.997	1.984	1.986	1.986	1.977	1.984
Cr	0.003	0.004	0.005	0.000	0.004	0.004
Fe	2.320	2.299	2.331	2.327	2.304	2.313
Mn	0.147	0.160	0.146	0.163	0.161	0.137
Mg	0.445	0.453	0.449	0.418	0.416	0.451
Ca	0.146	0.158	0.147	0.167	0.154	0.148
Almandine	68.500	67.183	68.208	68.174	67.780	68.216
Andradite	6.016	6.469	5.965	7.128	2.961	5.218
Grossulare	0.000	0.000	0.000	0.000	3.566	0.880
Pyrope	18.997	19.291	19.248	17.779	18.335	19.491
Spessartine	6.284	6.814	6.253	6.919	7.106	5.906
Uvarovite	0.204	0.244	0.326	0.000	0.253	0.289

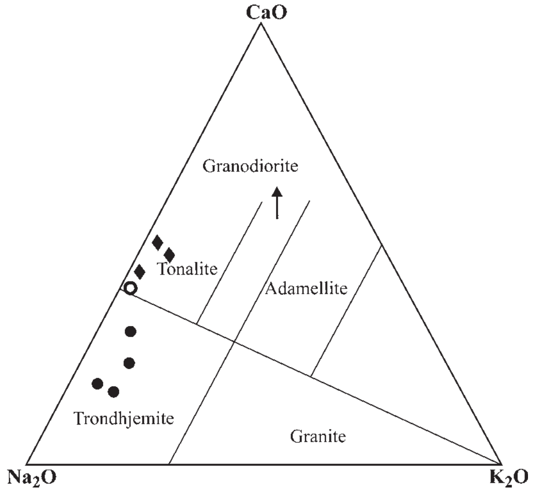

Fig. 7. Classification and nomenclature of the Sjenica plagiogranite according to CNK diagram (Glikson et al. 1979).

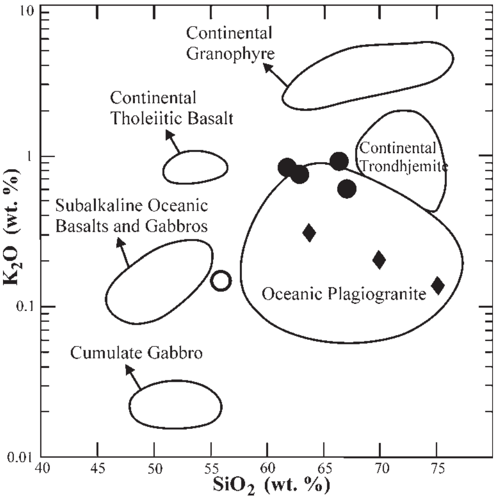

Fig. 8. Plot of the Sjenica plagiogranite (● — full symbols for plagiogranites with chlorite; ○— empty symbol for plagiogranite with amphibole) and Milatkovice plagiogranite (♦) on K_2O (%) vs. SiO_2 (%) binary diagram. Field boundaries are after Coleman & Peterman (1975).

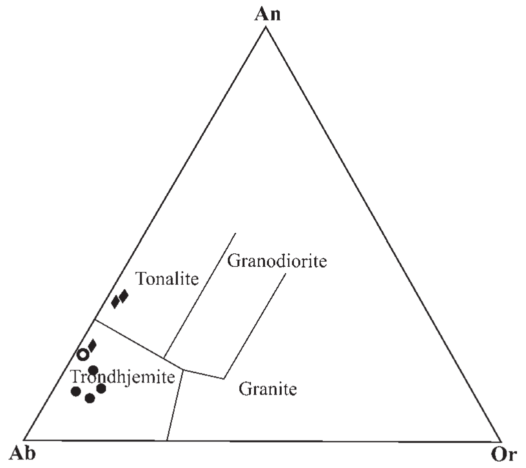

Fig. 9. Classification and nomenclature of the Sjenica plagiogranite according to the normative An-Ab-Or diagram (after Barker 1979).

An, Ab and Or ternary diagram of Barker (1979). In both diagrams, samples of the investigated rocks fall in the trondhjemite field (Figs. 8 and 9). The exception is the sample with amphibole, which is near the boundary of trondhjemite and tonalite fields on figure 8.

One rock (sample 5, with amphibole) within a representative suite of 5 selected samples has a bulk chemical composition that is intermediate between the plagiogranites and the enclosing gabbroic rocks. This sample has a relatively high MgO content (6.14 %) and a lower SiO_2 content (55.89 %) with respect to the plagiogranites. The other four samples of plagiogranites from Sjenica show low TiO_2, K_2O, P_2O_5, Rb and Ba and high Na_2O contents (Table 5).

Geochemistry

REE data (Table 5) and their distribution patterns show that the plagiogranites are enriched by twenty to one hundred times compared with the relative average chondrite value (Fig. 10). They all show similar patterns with a slight LREE enrichment and a small negative Eu anomaly. The latter indicates plagioclase involvement during either a fractionation or melting process (Floyd et al. 1998).

On a multi-element spider diagram normalized to primitive mantle the Sjenica plagiogranites show enrichments of Rb, Ba, K, Th, Sr, depletions of Eu, Ti, P and Sr and flat HREE patterns (Fig. 11). When taken together these data suggest that the plagiogranites may have been generated by low-pressure fractionation in which plagioclase and pyroxene were important differentiation phases and garnet and hornblende were not involved (Drummond & Defant 1990).

Discussion

Usually suggested models for plagiogranite genesis in ophiolite complexes are:

- fractional crystallization of a parental MORB melt at shallow depths in oceanic crust. This model has been supported by a number of authors on Alpine and Apennine ophiolites (e.g. Coleman & Peterman 1975; Engel & Fisher 1975; Coleman 1977; Saunders et al. 1979; Dixon & Rutherford 1979; Kontinen 1987; Borsi et al. 1996; Montanini et al. 2006);
- partial melting of gabbroic rocks under hydrous conditions in tectonically active areas of midocean ridge systems (Gerlach et al. 1981; Pedersen & Malpas 1984; Koepke et al. 2004, 2007). The role of water-rich fluid, either of magmatic origin (e.g. Maeda et al. 2002) or sea-water derived (e.g. Gregory & Taylor 1981), is suggested by the presence of amphibole in these leucocratic rocks;
- liquid immiscibility (Dixon & Rutherford 1979);
- special type of anatexis proceeding at the roof zone of axial magma chambers under fast spreading ridges (e.g. Michael & Schilling 1989).

Plagiogranites of Sjenica display similar values in the elemental abundances with respect to ORG (ocean ridge granites; Pearce et al. 1984). ORG-normalized patterns are character-

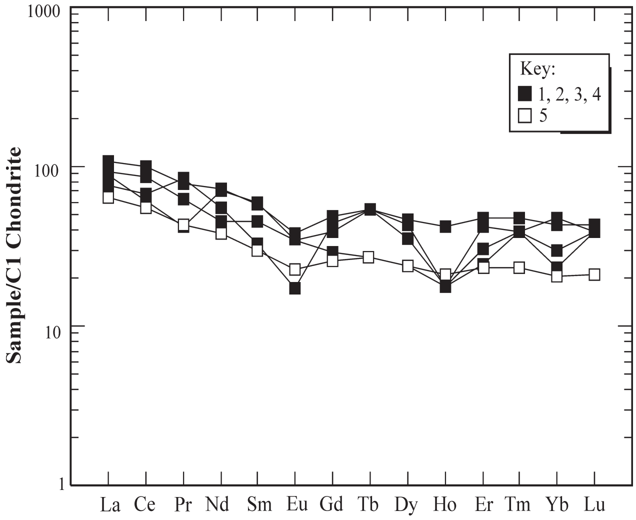

Fig. 10. REE patterns of plagiogranites (normalized values from Sun & McDonough 1989).

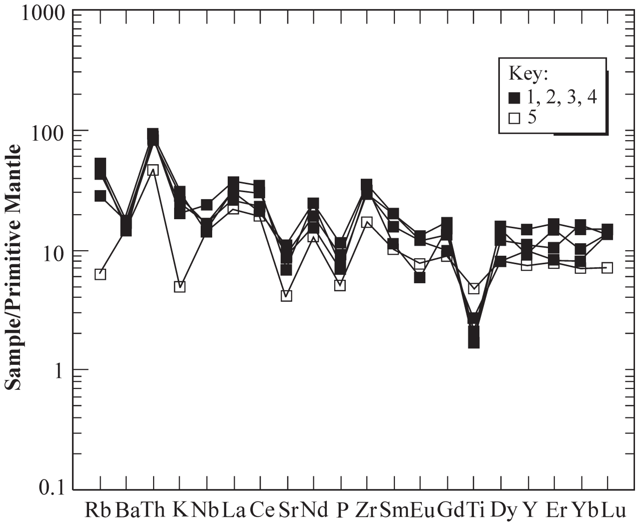

Fig. 11. Primitive mantle normalized multielement spider diagram of the Sjenica plagiogranite. Normalizing values from Sun & McDonough (1989).

Table 5: Chemical composition of the Sjenica plagiogranites (1–4 — plagiogranites with chlorite; plagiogranite with amphibole).

Sample	**1**	**2**	**3**	**4**	**5**
SiO_2	67.06	66.44	62.90	61.82	55.89
TiO_2	0.37	0.37	0.46	0.59	1.05
Al_2O_3	14.96	15.88	15.95	16.06	14.48
FeO^{tot}	5.17	5.75	6.13	8.71	8.76
MnO	0.13	0.16	0.17	0.23	0.20
MgO	0.53	0.71	0.73	1.23	6.14
CaO	1.52	1.38	3.08	2.02	3.84
Na_2O	6.41	6.15	6.46	5.73	5.61
K_2O	0.61	0.93	0.76	0.84	0.15
P_2O_5	0.16	0.15	0.20	0.25	0.11
LOI	2.38	2.09	3.26	2.71	3.31
Total	**99.30**	**100.01**	**100.10**	**100.19**	**99.54**
Trace elements (ppm)					
Ba	124	115	121	106	103
Rb	18	28	34	30	4
Sr	146	187	184	231	88
Ga	22	22	18	21	9
Ta	0.6	0.3	0.3	0.4	0.4
Nb	17	10	12	12	10
Hf	8.8	9	5	8	4.7
Zr	326	340	380	398	191
Y	68	51	42	45	34
Th	8	8	7	7	4
U	1.3	0	0	0	0.8
Cr	41	171	39	71	291
Ni	80	36	115	94	120
Co	22	25	27	29	32
Sc	22	20	23	21	34
V	29	52	84	125	209
Cu	25	28	37	82	85
Pb	12	11	12	12	2
Zn	89	92	93	115	124
REE elements (ppm)					
La	25.5	22	18	21	15.2
Ce	61.8	53	41	37	34.1
Pr	7.5	6	8	4	4.1
Nd	33.7	21	26	33	17.7
Sm	8.9	7	5	9	4.5
Eu	2.2	2	1	2	1.3
Gd	10.1	8	9	6	5.3
Tb	2	2	2	1	1
Dy	11.7	9	11	6	6
Ho	2.4	1	1	1	1.2
Er	7.9	5	7	4	3.8
Tm	1.2	1	1	1	0.6
Yb	7.4	8	5	4	3.5
Lu	1.1	1	1	1	0.53

ized by high content of LILE elements (K_2O, Rb, Ba and Th) and Ta negative anomalies (Fig. 12). Such geochemical features can be attributed to an arc or suprasubduction zone ophiolitic plagiogranites or variable mobilizations of the LILE elements during metamorphism, crustal involvement and/or hydrothermal alteration (ocean floor metamorphism).

On the N-MORB-normalized trace-element variation diagram the Sjenica plagiogranites are characterized by some large ion lithophile element (LILE) enrichments and relative depletion in HFSE (Fig. 13).

Amphibole-bearing plagiogranites, which are present in minor abundances, could form at fluid pressure of 200 MPa, and at depths greater than 6 km (Dixon & Rutherford 1979).

The enclave with garnet appears to have originated by low to moderate degree partial melting of hydrated basaltic/gabbroic rocks in oceanic crust. The essential conditions for the stability of garnet varies over a temperature range of 800–1000 °C and within a pressure range of 0.9–1.4 GPa (Vielzeuf & Schmidt 2001) which correspond to a depth < 30 km. The garnet could not be regarded as a major residual phase as no significant LREE/HREE fractionation was noted.

The major, trace and REE geochemistry and field relations indicate that plagiogranites were formed through a complex process of fractional crystallization of mantle origin mafic magma that derived under high degrees of partial melting in the presence of water introduced by subduction (?). The chemistry of the Sjenica plagiogranites cannot be explained without a subduction processes (Moores et al. 1984). The enrichment of Rb, Ba, Sr, Th and LREE values and the presence of Nb anomalies are consistent with variable mobilization of the LILE elements

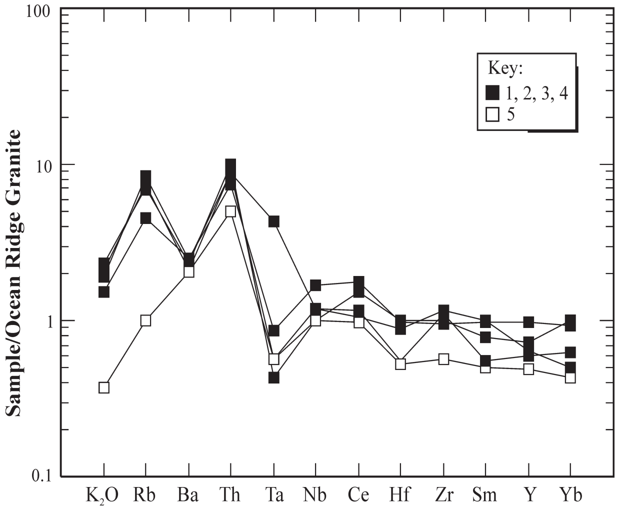

Fig. 12. Spider diagram for the Sjenica plagiogranites. Normalizing values from Pearce et al. (1984).

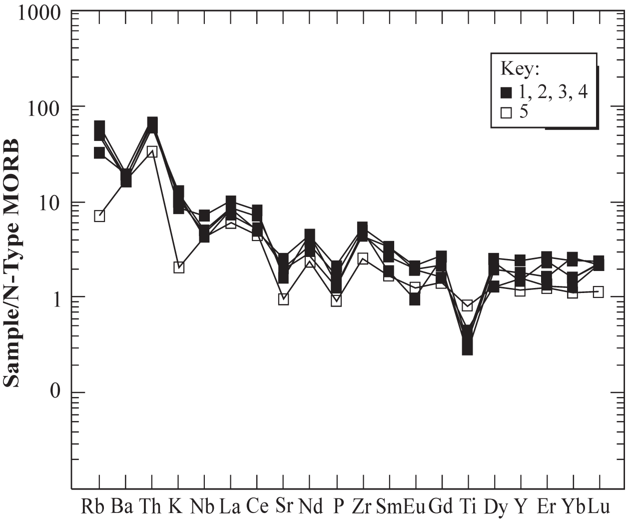

Fig. 13. N-MORB-normalized incompatible element diagram for the Sjenica Plagiogranites. Normalized values from Sun & McDonough (1989).

in an arc or supra-subduction zone (SSZ). It is increasingly accepted that many ophiolites have been formed by spreading above subduction zones, the so-called supra-subduction zone ophiolites (Pearce et al. 1984; Shervais 2001). Supra-subduction type ophiolites typically formed during short-lived periods (<5 Ma) of regional plate re-organization, in narrow rifted basins where melts were contaminated by partial melting of neighbouring lower crust (Hall 1984; Dilek et al. 1999).

Occurrences of calcite and chlorite nests in the Sjenica plagiogranites revealed that these rocks were affected by hydrothermal alteration due to intensive sea water circulation in a sub-sea-floor environment (Spooner & Fyfe 1973; Lecuyer et al. 1990). Hydrothermal alteration in the oceanic environment is known to often induce strong chemical mobilization in ophiolites and ocean ridge rocks (Alt 1995, 1999). The high Na_2O and low K_2O contents in plagiogranites are due to exchange with sea water that gained access to the magma chamber or to late magmatic vapour-phase transport and removal of K_2O (Coleman & Donato 1979; Sinton & Byerly 1980). The availability of Na during these processes was probably responsible for the enlargement of the stability field of albite. Sea water infiltration into the lower crust occurred along listric shear zones under low fluid/rock ratios during the initial stages of deformation and metamorphism. These relations clearly show that successive episodes of hydrothermal alteration of fossil oceanic crust in the Dinaridic Ophiolite Belt were entirely intra-oceanic in origin.

Conclusion

The Sjenica plagiogranites correspond to remnants of an oceanic basement evolved in the Dinaridic Ophiolite Belt, and so in an intra-oceanic environment. The absence of LT/HP metamorphism suggests that ocean basins in which the Dinaridic ophiolites have been formed were mainly bordered by passive margins.

The Sjenica plagiogranites, a part of the East Mediterranean ophiolites are fragments of the oceanic lithosphere probably related to a process of fractional crystallization of mantle origin mafic magma in the so-called supra-subduction zone. The SSZ type ORG affinity of the Sjenica plagiogranite is substantiated by a low content of HFSE relative to high abundance of LILE. The mineral composition and chemistry of plagiogranites were additionally changed due to interaction with sea water during sub-sea-floor metamorphism. However, a complete understanding of these ophiolite emplacements remains elusive including the occurrence of garnet that requires further investigation.

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