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DIFFERENT GEOCHEMICAL SIGNATURES DEVELOPED IN SOME BASIC MAGMATIC ROCKS OF MT. KALNIK (NORTH CROATIA)

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Key words: gabbro, basalt, diabase, metabasalt, REE patterns, spidergrams, Mt. Kalnik, mantle source, continental crust

Abstract

Basic magmatic rocks of Mt. Kalnik experienced hydrothermal alteration and low grade metamorphism. In such circumstances the most useful tracers of their magma sources and tectonic settings are REE patterns and other normalized trace element abundance plots. Gabbro, basalt, diabase and two samples of metabasalts were investigated in this preliminary study. Geochemical signature of gabbro points to the mantle source of magma and those of metabasalts indicates continental crust source. According to its features basalt could have been derived from the same magma as gabbro by process of magmatic differentiation. The magma giving diabase arised most probably from mantle wedge enriched by hydrothermal fluids ascending from the subducting slab.

Ključne riječi: gabro, bazalt, dijabaz, metabazalt, obrasci elemenata rijetkih zemalja, spidergrami, Kalnik, plaštni izvor, kontinentalna kora

Sažetak

Bazične magmatske stijene Kalnika su hidrotermalno alterirane i metamorfozirane do niskog stupnja. Za takve stijene najbolji pokazatelji izvora njihove magme i tektonskog položaja jesu obrasci elemenata rijetkih zemalja i drugi dijagrami normaliziranih elemenata u tragovima. U ovoj preliminarnoj studiji istraženi su gabro, bazalt, dijabaz i dva uzorka metabazalta. Geokemijske značajke gabra ukazuju na plaštni izvor magme, a one metabazalta ukazuju na kontinentalnu koru kao izvor. Prema svojim obilježjima bazalt je mogao nastati iz iste magme kao i gabro procesom magmatske diferencijacije. Magma iz koje je nastao dijabaz potječe najvjerojatnije iz omotačkog klina obogaćenoga hidrotermalnim fludima koji se dižu sa subducirajuće ploče.

Introduction

Highly dismembered fragments of basic magmatic rocks occurring either interlayered with sedimentary rocks or as isolated bodies of basalt, metabasalt, diabase and gabbro were found in tectonic mélange of Mt. Kalnik. More recently, fragments of harzburgite and amphibolite were found too (Pamić, 1997). Already one of the first investigator of Mt. Kalnik (Kišpatić, 1913) noticed the similarity of this association of rocks with those of ophiolitic rocks in Bosnia. Due to this fact the magmatic rocks of Mt. Kalnik are today interpretated by many authors as ophiolitic rocks (Halamić and Goričan, 1995; Pamić, 1997).

Geochemical studies of magmatic rocks of Mt. Kalnik are scarce. This is because of the sparsely exposed magmatic rocks on the one side and their high degree of hydrothermal alterations on the other side. Vrkljan (1989) and Pamić (1997) have published major and some trace element data of diabases and basalts. Their investigations have revealed that these rocks have chemical composition of tholeiitic basalts and according to Pamić (1997) characteristics of MORB. Halamić (1998) has studied basic effusive rocks, diabases, gabbros and ultramafic rocks. His basic effusive rocks show compositional features of alkalic but also of sub-alkalic series. Most of the rocks are tholeiites of N-MORB type (mid-oceanic ridge basalts), but some samples have signatures of WPB type (within plate basalts). Halamić (1998) has interpretated such samples as product of initial magmatism during the continental rifting. However, many important trace elements such as REE, U, Nd and others, which are very useful tracers of magmatic processes were not known. Therefore, in this preliminary study the more detailed geochemical characteristics of magmatic rocks of Mt. Kalnik were reported with discussion of their origin and implications for tectonic setting.

Geological setting

Mt. Kalnik is located in the SW part of Pannonian basin, in the structurally very heterogeneous area between Periadriatic-Balaton- and Zagreb-Zemplin Lineament system. According to Herak (1986) this terrain belongs to Supradinaric geodynamic unit or Inner Dinarides. Kovács et al. (1989) regarded it as extension of the Mid-

Transdanubian Range Unit. Haas et al. (2000) named this area the Sava Composite Unit in which South Alpine elements are overthrust onto Dinaridic ones along Tertiary (Oligocene-Miocene) thrust faults. After the same authors (2000) a Kalnik Unit being part of Sava composite Unit is regarded as a prolongation of the Vardar Zone.

Mt. Kalnik is comprised of Quaternary clastic rocks, Tertiary sedimentary rocks, Mesozoic magmatic-sedimentary complex and subordinate Middle and Upper Triassic limestones and dolomites (Vrkljan, 1989). Magmatic rocks occur in the form of a tectonic melánge, either interlayered with sandstone, shale, marl, radiolarites, limestone and tuff (Šimunić et al., 1993; Halamić and Goričan, 1995) or as isolated bodies of basalt, metabasalt, diabase or gabbro. In tectonic mélange Pamić (1997) found also fragments of harzburgite and amphibolite. The matrix of mélange is fine grained (Pamić, 1997). The magmatic-sedimentary complex borders Tertiary sediments and their contact is dominantly tectonic (Halamić and Goričan, 1995).

Crnković et al. (1974) found contact metamorphosed aureola around gabbro in clastic sediments, which were believed that they are of Cretaceous age. According this fact Crnković et al. (1974) concluded that gabbro is of Upper Cretaceous age. On the basis of the Middle Carnian to Norian radiolarians found in the radiolarites interbedded with pillow lavas Halamić and Goričan (1995) concluded that volcanics are also of Late Triassic age. The studying of contacts between magmatic and sedimentary rocks pointed to the synsedimentary and/ or postsedimentary repeated extrusions and shallow intrusions of basic lavas (Vrkljan et al., 2000). Recently, the apsolute age determinations were done using K-Ar method on the whole-rock samples of diabase and gabbro. Diabase cutting gabbro gave age of 189 ± 6.7 Ma and gabbro 185.0 ± 6 Ma (Pamić, 1997).

Simplified geological map showing the fragmented magmatic rocks of Kalnik (modified after Šimunić, 1992) is given in Fig. 1. Filled circles indicate the sampling locations of this study.

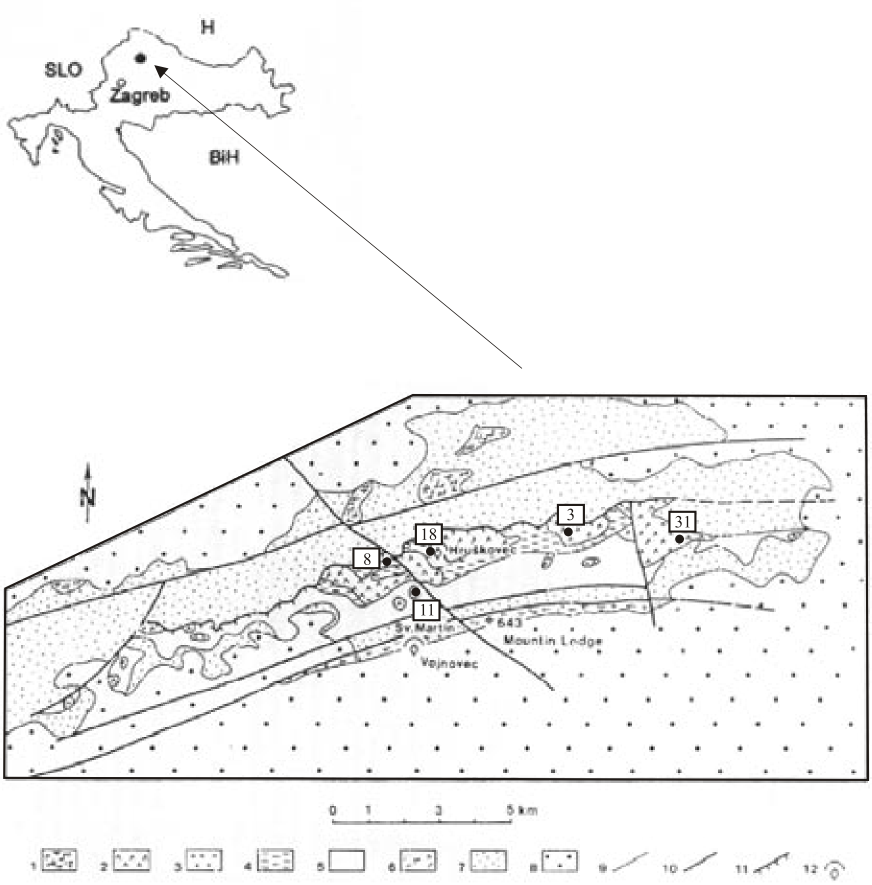

Figure 1. Simplified geological map showing the fragmented magmatic rocks of Mount Kalnik (modified after Simunic, 1992). Filled circles indicate the sampling locations of this study. Legend: 1 - Triassic dolomite and limestone; 2 - basalt; 3 - gabbro and diabase; 4 - Upper Triassic to Lower Cretaceous sedimentary rocks; 5 - Tectonized olistrostrome melange; 6 - post-Paleocene tectonic melange; 7 - Egerian-Eggenburgian sedimentary rocks; 8 - Badenian/Pontian sedimentary rocks; 9 - geological boundary; 10 - fault; 11 - reverse fault; 12 - quarry.

Slika 1. Pojednostavljena geoloska karta koja pokazuje fragmentirane magmatske stijene Kalnika. Legenda: 1 - trijaski dolomit i vapnenac; 2 - bazalt; 3 - gabro i dijabaz; 4 - gornjotrijaske do donjokredne sedimentne stijene; 5 - tektonizirani olistrostromski melanz; 6 - postpaleocenski tektonski melanz; 7 - egerijsko-egenburske sedimentne stijene; 8 - badensko-pontske sedimentne stijene; 9 - geoloska granica; 10 - rasjed; 11 - reversni rasjed; 12 - kamenolom.

Analytical methods

Major and trace element analyses (except REE and Sc) were carried out by X-ray fluorescence spectroscopy and REE compositions and Sc by ICP-MS at Federal Institute for Geosciences and Natural Resources (BFR) in Hannover.

Basic magmatic rocks of Mt. Kalnik experienced hydrothermal alteration and low-grade metamorphism, but for this study among 112 samples five were chosen displaying the minimal effects of this processes. The chosen samples occur as isolated bodies in tectonic mélange.

Petrography

On the basis of mineral compositions and structure four different kind of rocks can be distinguished: gabbro (sample 11), basalt (sample 8), diabase (sample 18) and metabasalt (samples 3 and 31).

Gabbro is characterized by hypidiomorphic to allotriomorphic structure. Its main minerals are Ti-augite and plagioclase (labradorite to bytownite). Accessory mineral is sphene with leucoxene. As alteration products of the plagioclase and to the less extent of Ti-augite occur chlorite, magnetite, zoisite-epidote, calcite and clay minerals.

Basalt displays a porphyritic structure. Scarce clinopyroxene phenochrysts being mostly alterated to chlorite are situated in ophitic-intergranular groundmass. Needle-shaped, fresh plagioclase (labradorite-bytownite) and clinopyroxene constitute the groundmass. In their interspaces occur chlorite, zoisite-epidote, magnetite, sphene and occasionally sericite as result of alteration processes.

Diabase has intergranular to ophitic structure. Te main minerals are fresh plagioclase (labradorite-bytownite) and augite to Ti-augite. Only rarely the alteration products such as chlorite, zoisite-epidote, clay minerals, magnetite and sericite are observed inside the grains, but in the mineral interspaces chlorite occurs often.

Metabasalts are characterized by porphyritic structure. As phenochrysts occurs clinopyroxene being almost completey converted to calcite or rarely to chlorite. Ophitic to intergranular groundmass comprises needle-shaped albite and fresh clinopyroxene. Albite may contain alteration products of primary plagioclase (zoisite-epidote, clay minerals, sericite). In mineral interspaces additionally occur chlorite, magnetite (being altered to hematite and limonite) and calcite. Sample 31 contains also calcite amygdules.

Rock chemistry

Rock nomenclature and magma series

The analyses were recalculated to 100% on an H_2O- and CO_2-free basis for the aim of chemical rock classification. In the diagram (Na_2O+K_2O) versus SiO_2 of Cox et al. (1979) all studied rocks plot in the basalt field (Fig. 2). Due to the amygdaloidal/vesicular character of some samples and hydrothermal alteration which influence the mobility of the major elements, we have used also $Zr/TiO_2*0.0001$ versus Nb/Y rock classification diagram of Winchester & Floyd (1977). There, basalt and diabase plot in the basalt field whereas gabbro and metabasalts plot in alkali basalt field (Fig. 3). These observations are very similiar to those of Halamić (1998).

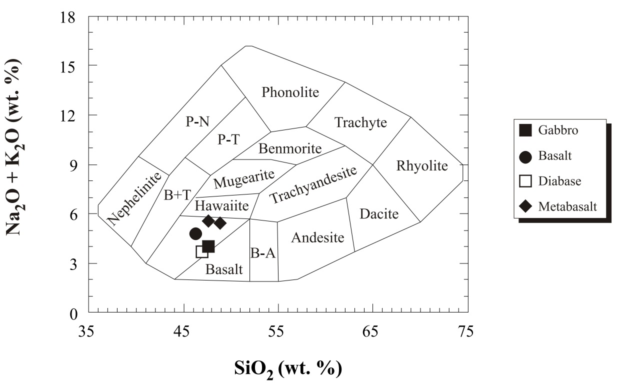

Figure 2. Diagram ($Na_2O + K_2O$) versus SiO_2 after Cox et al. (1979).

Slika 2. Dijagram ($Na_2O + K_2O$) - SiO_2 prema Cox i dr. (1979).

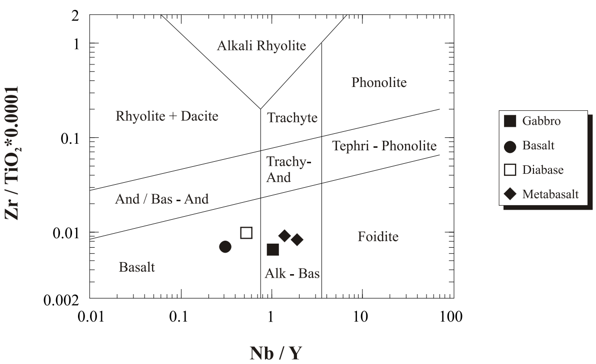

Figure 3. ($Zr / TiO_2*0.0001$) versus Nb / Y diagram after Winchester and Floyd (1977).

Slika 3. Dijagram ($Zr / TiO_2*0.0001$) - Nb / Y prema Winchester i Floyd (1977).

Regarding the magma series of studied rocks we have avoided to use classical AFM diagram and FeO*/MgO versus SiO_2 diagram of Miyashiro (1974) because of already mentioned possible mobility of the major element. Instead them we used Sr/Al_2O_3 versus SiO_2 diagram of Geisler and Vinx (1996). In this diagram all samples plot into tholeiitic field (Fig. 4).

This data are consistent with those of Vrkljan (1989), Pamić (1997) and partly of Halamić (1998).

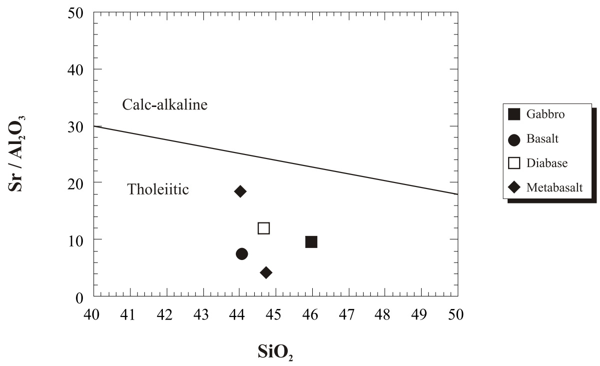

Figure 3. (Zr / TiO_2*0.0001) versus Nb / Y diagram after Winchester and Floyd (1977).

*Slika 3. Dijagram (Zr / TiO_2*0.0001) - Nb / Y prema Winchester i Floyd (1977).*

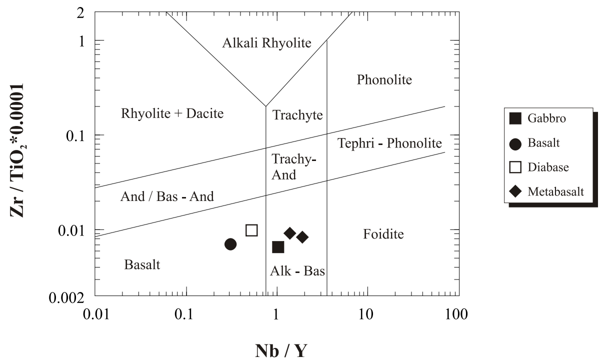

Figure 4. Sr / Al_2O_3 versus SiO_2 diagram after Geisler and Winx (1996).

Slika 4. Dijagram (Sr / Al_2O_3 - SiO_2) prema Geisler i Winx (1996).

Major elements, Cr and Ni

Representative analyses of major and trace elements are given in Table 1. Gabbro and basalt are characterized by high Mg values (0.69 and 0.63 respectively) compatible with melts in equilibrium with mantle sources. They also have high Cr- (870 and 670 ppm respectively) and high Ni-content (203 and 329 ppm respectively). Mg-values of diabase (0.57) and specially of metabasalts (0.45 and 0.54) are remarkably lower. Their Cr- (475 ppm for diabase, 242 and 180 ppm for metabasalts) and Ni-content (289 ppm for diabase and 159 and 161 ppm for metabasalts) are relative to gabbro and basalt lower too.

All rocks display extremely low K_2O content being in the range from 0 (gabbro and diabase) to 0.82 wt% (basalt, metabasalts). The TiO_2 content varies from 0.26 (gabbro) to 1.91 wt. % (metabasalt). Gabbro and basalt are characterized by significantly higher Al_2O_3 wt. % (21.30 and 19.11 wt. % respectively) relative to diabase (16.44 wt. %) and metabasalts (14.61 and 15.66 wt. %).

REE elements

Representative REE analyses are given in Table 2. A large variation in the REE patterns is observed between the samples. When plotted on C1-chondrite-normalized REE plots, the samples split into four types based on their slope.

C1-chondrite normalized REE pattern of gabbro displays an enrichment of approximately 3 to 9 times chondrite with significant positive Eu-anomaly (Fig. 5). The positive Eu-anomaly is usually interpreted as result of the early plagioclase accumulation in the magma chamber (Ottonello et al., 1984; Trubelja et al., 1995). This REE pattern resembles REE pattern of cumulate rocks of ophiolite suite in Bosnia (see Trubelja et al., 1995) if we ignore the occurrence of the negative Ce anomaly in Bosnia cumulate rocks. Such anomaly is usually attributed to the serpentinization in contact with sea water.

Relative to C1-chondrite values REE pattern of basalt is enriched between 9 to 17 times showing slightly but continual increase of enrichment from LREE to HREE (Fig. 5). Basalt REE pattern is enriched and slightly more differentiated relative to gabbro REE pattern. But generally both REE patterns are similar and display Gd-Tb anomaly (more pronounced in basalt REE pattern) whose meaning is not clear. Possibly, this two rocks could be connected by process of progressive magmatic differentiation.

Diabase shows completely different C1-chondrite normalized REE pattern. It is characterized by enriched (40 to 20 times relative to chondrite) but decreasing normalized LREE abundances from La to Gd and by enriched (approximately 20 times relative to chondrite) but nearly parallel HREE pattern (Fig. 5). Proposed explanations for such REE pattern include slightly enrichment of the mantle source by fluids ascending from a subducting slab, by a crustal contamination or by the mixture of a depleted and enriched mantle source (Condie, 1994).

Table 1: Chemical analyses of major and trace elements

Tablica 1: Kemijske analize glavnih elemenata i elemenata u tragovima

Sample *Uzorak*	3/104 KS	31/6 Gc	8/66 K	11/88 H	18/49 KA
	metabasalt *metabazalt*	metabasalt *metabazalt*	basalt *bazalt*	gabbro *gabro*	diabase *dijabaz*
SiO_2	44,02	44,72	44,04	45,96	44,67
TiO_2	1,91	1,68	1,03	0,26	1,63
Al_2O_3	15,66	14,61	19,11	21,3	16,44
Fe_2O_3	4,6	3,09	2,7	1,81	3,63
FeO	2,51	3,45	3,95	3,23	6,1
MnO	0,1	0,07	0,11	0,06	0,1
MgO	4,29	5,65	8,67	8,68	9,92
CaO	13,87	13,15	11,02	11,37	8,81
Na_2O	4,33	4,81	4,12	3,87	3,5
K_2O	0,82	0,15	0,45	0	0
P_2O_5	0,37	0,11	0	0,02	0,31
H_2O^+	4,53	2,41	2,7	3,28	3,37
H_2O^-	0,55	0,44	1,96	0,56	1,34
CO_2	2,87	5,65	0,45	0,42	0,86
Total Ukupno	**100,43**	**99,99**	**100,31**	**100,82**	**100,68**
Mg#	0,45	0,53	0,63	0,69	0,57
As	<7	<7	7	<7	<7
Ba	184	93	<50	188	<50
Bi	<10	<10	<10	<10	<10
Ce	38	43	<35	<35	<35
Co	40	45	62	42	53
Cr	242	180	670	870	475
Cu	55	54	95	14	70
Ga	21	27	21	23	24
Hf	<18	<18	<18	<18	<18
Mo	<4	<4	<4	<4	<4
Nb	30	26	<5	5	13
Ni	159	161	329	203	289
Pb	10	<10	<10	<10	<10
Rb	19	<5	<5	7	6
Sn	<30	43	66	<30	34
Sr	289	63	140	208	197
Ta	<10	<10	<10	<10	<10
Th	<10	<10	<10	<10	<10
U	9	<5	<5	6	9
V	237	205	211	111	262
W	<10	<10	<10	<10	<10
Y	16	19	16	<5	25
Zn	51	65	53	25	66
Zr	156	157	72	17	165
Sc	23	23	34	25	28
Ba/Rb	9,68			26,86	
Nb/U	3,33			0,83	1,44
Pb/Nd	0,50				

Table 2: Chemical analyses of REE

Tablica 2: Kemijske analize elemenata rijetkih zemalja

Sample *Uzorak*	3/104 KS	31/6 Gc	8/66 K	11/88 H	18/49 KA
	metabasalt *metabazalt*	metabasalt *metabazalt*	basalt *bazalt*	gabbro *gabro*	diabase *dijabaz*
La	23	19	2	0,7	8,5
Ce	45	41	7	2	22
Pr	4,9	4,7	1,2	0,3	3,3
Nd	20	19	7	2	16
Sm	4,6	4,5	2,4	0,7	4,6
Eu	1,5	1,3	0,95	0,5	1,5
Gd	4,7	4,5	2,2	0,6	4,3
Tb	0,63	0,65	0,44	0,12	0,68
Dy	4	4,3	3,9	1	4,9
Ho	0,77	0,79	0,74	0,17	0,88
Er	2,2	2,5	2,1	0,6	2,8
Tm	0,36	0,36	0,36	0,08	0,42
Yb	2,7	2,6	2,6	0,7	3,1
Lu	0,37	0,4	0,41	0,09	0,45
$(Nd/Yb)_N$	2,70	2,66	0,98	1,04	1,88

Relative to C1-chondrite values REE patterns of both metabasalts show extremely enriched (up to 100 times) and from La to Ho monotonically decreasing REE abundances (Fig. 6) with characteristic flattening from Ho to Lu. Comparing with REE pattern of diabases HREE abundances of metabasalts are slightly lower. Such REE pattern is typical for continental crust, but also for mantle source being intensively contaminated by crustal material.

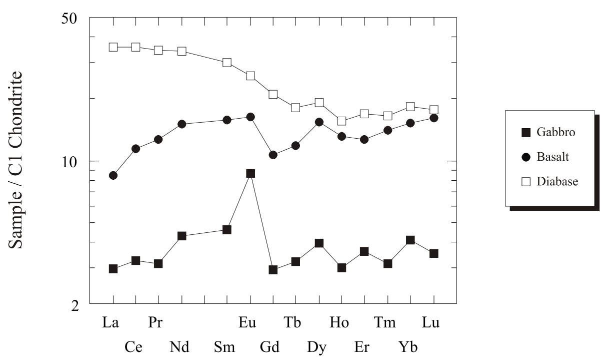

Figure 5. C1 Chondrite normalized REE pattern of gabbro, basalt and diabase. Normalization values are from Sun and McDonough (1989).

Slika 5. Obrasci elemenata rijetkih zemalja gabra, bazalta i dijabaza normalizirani na C1 hondrit. Normalizacijske vrijednosti su od Sun i McDonough (1989).

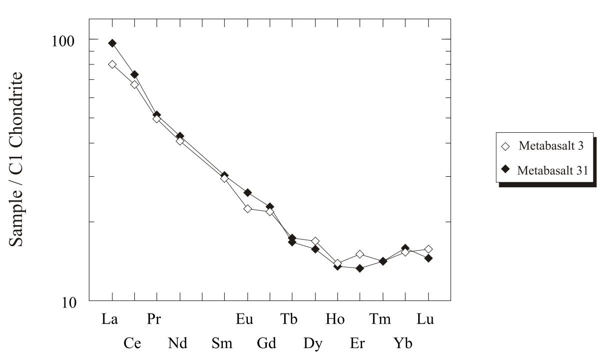

Figure 6. C1 Chondrite normalized REE patterns of metabasalts. Normalization values are from Sun and McDonough (1989).

Slika 6. Obrasci elemenata rijetkih zemalja metabazalta normalizirani na C1 hondrit. Normalizacijske vrijednosti su od Sun i McDonough (1989).

The Nd_N/Yb_N ratios of studied rocks offer additional insight to the nature of their magma source. For instance the study of Hofmann (1988) have revelead that typical Nd_N/Yb_N ratio for primitive mantle equals 0.998. The studied gabbro and basalts with Nd_N/Yb_N ratio of 1.04 and 0.98 respectively resemble very much primitive mantle. Diabase and metabasalts charachterized by remarkably higher Nd_N/Yb_N ratio (from 1.88 to 2.70) do not share this feature.

Neither diabase nor metabasalts display similarity with REE patterns of subvolcanic and volcanic rocks of ophiolite suite in Bosnia. Trubelja et al. (1995) showed that subvolcanic and volcanic rocks of ophiolite suite in Bosnia are characterized by depletion or weak enrichment of LREE relative to HREE. The strong enrichment of LREE relative to HREE typical for diabase and metabasalts of Mt. Kalnik indicate magma source being different from those of mentioned rocks of Bosnia.

Other trace elements

Spidergram of metabasalt 3, diabase and gabbro are given in Fig. 7 and 8. The spidergrams of other samples are not shown because of their unprecisely determinated Pb, U and Nb values.

Spidergram of metabasalt 3 (Fig. 7) is characterized by pronounced negative Nb and positive Pb spikes.These features are typical for continental materials or subduction related volcanic rocks (Hofmann, 2003).

Also other two spidergrams show negative Nb spike (Fig. 8) but unprecisely determinated positive Pb spike. Spidergram of diabase show the negative Sr spike indicating a plagioclase bearing magma source or it may have fractionally crystallized plagioclase. In contrast to it gabbro has positive Sr and Eu spike clearly pointing to the plagioclase accumulation.

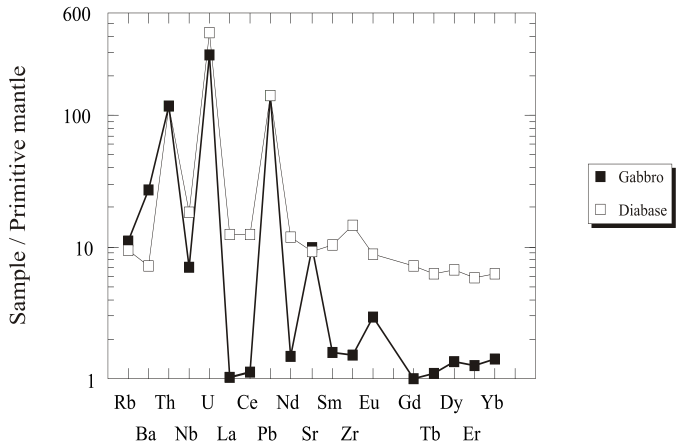

Figure 8. The spidergram of gabbro and diabase. The values of the normalizing constants are from Sun and McDonough (1989). The elements are arranged in the order of increasing compatibility (Hofmann, 1988).

Slika 8. Vrijednosti elemenata u tragovima u gabru i dijabazu normalizirane na primitivni plast. Vrijednosti normaliziranih konstanta su od Sun i McDonough (1989). Elementi su poredani u smjeru povecanja kompatibilnosti (Hofmann, 1988).

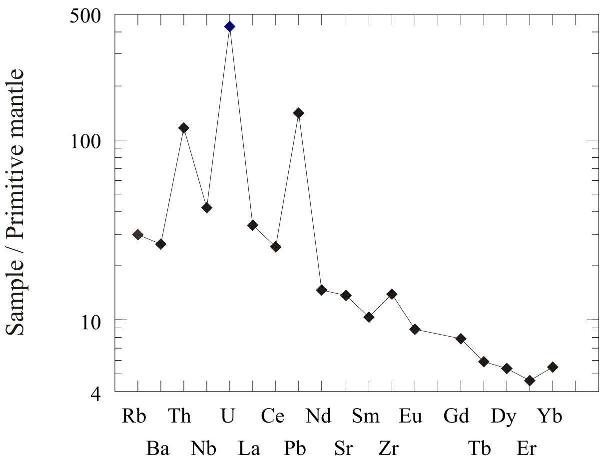

Figure 7. The spidergram of metabasalt 3. The values of the normalizing constants are from Sun and McDonough (1989). The elements are arranged in the order of increasing compatibility (Hofmann 1988).

Slika 7. Vrijednosti elemenata u tragovima u metabazaltu 3 normalizirane na primitivni plast. Vrijednosti normaliziranih konstanta su od Sun i McDonough (1989). Elementi su poredani u smjeru povecanja kompatibilnosti (Hofmann, 1988).

It is remarkable that all three spidergrams display pronounced positive U spike.

Very usefull tracers of magma source differences are trace element ratios of similarly incompatible pairs because of their small fractionation during the partial melting (Hofmann, 2003). For instance typical Nb/U ratio of MORB is 47±11, of OIB 52 ± 15 (Hofmann, 2003) and of continental crust 8 (Rudnick and Fountain, 1995). Due to the analytical limitations the Nb/U ratio in our samples was determined only in metabasalt 3 (3.33), gabbro (0.83) and diabase (1.44) and it is surprisingly low.

The average MORB value of Pb/Nd ratio is 0.04 and those of continents 0.63 (Hofmann, 2003). The Pb/Nd ratio determinated in metabasalt 3 equals 0.50 and points to the continental magma source.

Typical Ba/Rb ratio for crust is 6.7 (Rudnick and Fountain, 1995), whereas those of mantle equals 11 (Hofmann and White, 1983). Measured values of Ba/Rb ratio are in studied metabasalt 9.68 and in the gabbro 26.86.

It has to be stressed that Rb, Pb and U are mobile under low-temperature or hydrothermal processes.

Discussion

Our samples display effects of hydrothermal alteration and low-temperature metamorphism which may influence the mobility of the major elements. Because of this fact analyses of geochemical data are preferably based on the trace element.

The growth of the continental crust caused the depletion of highly incompatible trace elements in the mantle and their enrichment in the crust. Two mechanism control this process: the partial melting of the mantle and the ascending of hydrothermal fluid enriched in soluble elements from subduction slab into the overlying mantle (Hofmann, 2003). The degree of trace element enrichment in magma depends on source composition, the degree and mechanism of partial melting, subsequent fracional crystallization and assimilation. Due to the study of Johnson et al. (1990) it has been widely accepted that the trace element variations are primarily a function of the source differences (Hofmann, 2003).

Rare earth elements (REE) are typically immobile during metamorphism and hydrothermal alteration. The REE patterns of the basic magmatic rocks and ratios of selected rare earth elements show systematic chemical differences depending on a magma source or tectonic setting. Due to this fact they are useful in distinguishing among different tectonic settings.

Recently it was shown that MORB data are characterized by wide variations of trace element and isotopic compositions and that the practice to use their compositions as a normalization standard in trace element abundance plots should be avoided (Hofmann, 2003). Therefore, only C1-chondrite- and primitive mantle- normalized trace element plots were used for data presentation and discussion.

The REE pattern of gabbro being nearly parallel (except pronounced positive Eu anomaly) and 3 to 9 times enriched relative to chondrite indicate mantle source of gabbro magma. This is consistent with its Nd_N/Yb_N ratio, high Mg value, Cr and Ni. The positive Eu-anomaly points to the early plagioclase accumulation in the magma chamber. The REE pattern of basalt resembles those of gabbro but is slightly more enriched and differentiated. It may be genetically connected with gabbro by the process of magmatic differentiation. Its Nd_N/Yb_N ratio, Mg value, Cr and Ni support such model. The REE pattern od diabase being up to 40 time enriched relative to chondrite and showing the decrease of REE abundances from La to Gd suggests completely different magma source, most probably modified by crustal contamination processes. According to its Nd_N/Yb_N ratio, Mg value, Cr and Ni diabase magma still may have mantle origin, but partly enriched by continental material. Extremely enriched (up to 100 times relative to chondrite) and monotonically decreasing REE pattern of metabasalts point to the continental crust as magma source or mantle source being intensively contaminated by crustal material. Considering their low Mg values, Cr, Ni and high Nd_N/Yb_N ratio continental crust as their magma source is more prefered.

Additionally, all rocks show considerable negative Nb spike and positive Pb and U spike. Such features suggest modern-day subduction environments. But care should be taken interpeting this data, because negative Nb spike is observed relative to Th, which is in our samples not precisely determinated. The Pb and U spike should be also carefully treated, because of the mobility of this elements in hydrothermal conditions.

There are plenty of diagrams widely used for discriminations of rocks from different tectonic setting. But unfortunately many of them include elements which are controlled by crystal fractionation (Ti, Cr, V, P) or are redox-sensitive (Mn) or are mobile (Rb). Accordingly, they are not good tracer of magma source differences and have to be avoided to use them. On the other side there are very good discrimination diagrams including Th, Ta, Yb, Hf and Zr. An excellent tracer of magma source is Th/Yb versus Ta/Yb diagram (Pearce, 1983) due to the fact that magmas derived from the subduction settings display a characteristic Th enrichment. Unfortunately, because of unprecisely determinated Th, Ta and Hf concentrations they could not be used in this work.

Conclusion

Although the data base is small some preliminary conlusions may be drawn. Regarding the studied rocks geochemically most different are gabbro and metabasalts. Geochemical signature of gabbro points to the mantle source of magma, whereas those of metabasalts indicates continental crust source. According to its features basalt could have been derived from the same magma as gabbro by process of magmatic differentiation, whereas magma giving diabase could arise from mantle wedge enriched by hydrothermal fluids ascending from the subducting slab. Although more precise determinations of Th, Ta and Pb together with complete isotope data still have to be done in gaining a full interpretation of the origins of magmatic rocks of Mt. Kalnik, it seems that at least some of them have been formed in a subduction zone.

Combined with geochemical data geological relationships and age determinations support a model in which gabbro represents phase of magmatism being unrelated to metabasalts. The geological relationships show that gabbro cuts the sedimentary rocks pointing to its emplacement during the late stage of magmatism unrelated to the formation of volcanic rock being interlayered with sedimentary rocks. Determinated isotope ages of gabbro (185.0 ± 6 Ma according to Pamić, 1997) and proposed Late Triassic age of metabasalts (Halamić and Goričan, 1995) additionally support the model.

The presented preliminary REE- and other trace element investigations confirm the results of Halamić's work (1998) who pointed out that magmatic rocks of Mt.

Kalnik were formed in different tectonic settings and in different time.

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