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MINERAL RELATIONSHIPS AND THEIR CHEMISTRY IN SOME BASIC MAGMATIC ROCKS OF BANIJA OPHIOLITE COMPLEX, CROATIA

VESNICA GARAŠIĆ, MAJA VRKLJAN, VLADIMIR MAJER

Faculty of Mining, Geology and Petroleum Engineering University of Zagreb
Pierottijeva 6, HR-10000 Zagreb, Croatia

E-mail: vgarasic@rgn.hr

Key words: metadiabase, spilite, ophiolite, mineral relationship, mineral chemistry, Banija, Dinaride

Abstract

Mineral relationships and their chemistry were studied in some basic magmatic rocks of Banija ophiolite complex. On the basis of mineral and structural characteristics three kind of rocks are distinguished: metadiabase I (being characterized by secondary amphibole), metadiabase II (being characterized by secondary albite) and spilite. Detailed chemistry of all mineral phases, specially of zoned clinopyroxenes and zoned amphiboles is given. The black opaque phases consist of different Fe-Ti-Mn oxides (ilmenite, Mn-ilmenite, magnetite, Ti-magnetite, ferropseudobrookite) being often at the rims replaced by Al- and Fe-rich titanite. All rocks are hydrothermally metamorphosed whereby amphibole replaced partly or completely clinopyroxene and plagioclase was altered in albite, prehnite, pumpellyite and/or sericite. Secondary chlorite occurs too. The whole rock chemistry of each studied rock corresponds to tholeiitic basalts.

Ključne riječi: metadijabaz, spilit, ofiolit, mineralni odnosi, mineralna kemija, Banija, Dinaridi

Sažetak

Međusobni odnosi minerala i njihova kemija proučavani su u nekim bazičnim magmatskim stijenama ofiolitnog kompleksa Banije. Na temelju mineralnih i stukturnih karakteristika razlikuju se tri vrste stijena: metadijabazi I (karakterizirani sekundarnim amfibolom), metadijabazi II (karakterizirani sekundarnim albitom) i spilit. Dana je detaljna kemija svih mineralnih faza, osobito zoniranih klinopiroksena i zoniranih amfibola. Crne opâke faze sastoje se od različitih Fe-Ti-Mn oksida (ilmenit, Mn-ilmenit, magnetit, Ti-magnetit, Fe-pseudobrukit) koje su često na rubovima potisnute Al- i Fe-bogatim titanitom. Sve su stijene hidrotermalno metamorfozirane pri čemu je amfibol djelomično ili potpuno potisnuo klinopiroksen, a plagioklas je izmijenjen u albit, prehnit, pumpeliit i/ili sericit. Pojavljuje se također i sekundarni klorit. Ukupna kemijska analiza svake proučavane stijene odgovara toleitskom bazaltu.

Introduction

Ophiolites of the Dinarides and their eastern margin – Vardar Zone constitute two different belts or provinces. The western ophiolite belt of the Central Dinaride (CDOB) or lherzolite province (LPD) is characterized by fertile spinel lherzolite of the subcontinental type. The eastern ophiolite belt of the Vardar Zone (VZOB) or harzburgite province (HPD) contains high depleted harzburgites and dunites (Fig. 1).

The ophiolite belt of the Central Dinaride (CDOB) consists of the separated ophiolite complexes (Banija, Kozara, Čelinac-Snjegotinja, Ljubić, Čavka, Borja-Mahnjača, Bosanski Ozren, Krivaja-Konjuh, Varda-Zlatibor and Sjenički Ozren) which extend in south-eastern direction from North-western Croatia through Bosnia to South-western Serbia. This complexes show differences in the dimensions and in the portion of the particular members of the ophiolite suite. In addition to the fertile spinel lherzolite and high-Al and high-Ti magmatic members of the ophiolite suites the special characteristic of this province are mantle garnet pyroxenites (”eclogites”), garnet amphibolites and amphibolites being cogenetic associated with lherzolite (Majer et al., 2003). The metamorphic rocks in the basis of the mantle peridotites correspond to the middle grade of Abukuma type metamorphism (Majer, 1993). The radiometric dating carried out on amphiboles of amphibolites underlying the peridotites gave an age between 160 and 174 m.y. (Lanphere et al., 1975; Majer et al., 1979), suggesting that the peridotites were exhumed in this time. In the time from the Upper Jurassic to the Upper Cretaceous and Paleocene compressive subduction and obduction tectonics caused the disintegration and the reduction of the ophiolite suite and created heterogeneous ophiolite mélange. It contains ophiolite blocks of the various dimensions, sediments (sandstones, shales,

Figure 1. Shematic position of the Central Dinaride ophiolite belt or lherzolitic province (CDOB/LP) and of the Vardar Zone ophiolite belt or harzburgite province (VZOB/HB), modified after Herak (1986).
Legend: A – Alps; B – Banija Region; CB – Carpatho-Balkan Arc; P – Pelagonian Basin, PB – Pannonian Basin; SP – Subpelagonian Zone; SMM – Serbian-Macedonian Mass; UD – Inner Dinarides; VD – Outer Dinarides.

Slika 1. Shematski položaj Centralno-dinaridskog ofiolitnog pojasa ili lercolitne provincije (CDOB/LP) i ofiolitnog pojasa Vardarske zone ili harcburgitne provincije (VZOB/HB), modificirano prema Heraku (1986).
Legenda: A – Alpe; B – područje Banije; CB – Karpatsko-balkanski luk; P – Pelagonski bazen; PB – Panonski bazen; SP – Subpelagonska zona; SMM – Srpsko-makedonska masa; UD – Unutarnji Dinaridi; VD – Vanjski Dinaridi.

radiolarian cherts) and metamorphic rocks (paraschists and orthometamorphites).

Over the past fifty years many researches investigated petrological or chemical characteristics of the rocks of CDOB (Majer, 1975; Lanphere et al., 1975; Pamić and Majer, 1977; Majer et al., 1979; Karamata et al., 1980; Popević, 1985; Maksimović and Jovanović, 1981). The first detailed geochemical study of CDOB magmatic rocks including also isotopic data was carried out by Lugović et al. (1991). It comprised peridotites, massive diabases (spilites) from mélange and doleritic dikes which intrude peridotites and underlying metamorphic rocks, but not occur in the mélange. Majer (1993) made comprehensive study of petrological and chemical characteristics of ophiolite suite rocks of the Banija and Pokuplje region in Croatia and Mt. Pastirevo in Northwestern Bosnia. Trubelja and Marchig (1995) studied the REE patterns of amphibolites and found that some of them have geochemical character of cumulate rocks developed in the lower crust, whereas other amphibolites originating in the upper crust show REE patterns typical for mid-oceanic ridge type basalts. The REE patterns and trace element discrimination diagrams of basalts and diabases show characteristics of mid-oceanic ridge type basalt too (Trubelja et al., 1995).

Recently, a good overview of geodynamic and petrogenetic evolution of ophiolite from the Central and North-western Dinarides was written by Pamić et al. (2002).

The aim of this work is to present a great diversity of mineral relationships in some basic magmatic rocks of Banija ophiolite complex and give their detailed mineral chemistry.

Geological setting

Banija ophiolite complex is located in the extreme northwestern part of the CDOB (Fig. 1). On its south-southwestern side it is bordered by Paleozoic and Triassic formations, whereas Upper Cretaceous and Neogene deposits are situated along its east-northeastern border. Banija ophiolite complex occurs in form of an ophiolite mélange composed of highly tectonically disintegrated ophiolite suite and slices and blocks of metamorphic and sedimentary rocks. The final formation of the mélange was in the Uppermost Cretaceous (Šparica et al., 1979). The age of the rocks of the ophiolite suite and its metamorphic basement based on isotopic K/Ar and Rb/Sr methods corresponds 160 to 170 m.y. (Majer et al., 1979). Disintegrated ophiolite suite consists dominantely of spilites and lherzolites being locally associated with dikes or layers of pyroxenites, garnet pyroxenites and upper mantle amphibolites. Other rocks are plagioclase wherlite, amphibole gabbro, gabbropegmatite, hornblendite, plagiogranite, keratophyres, different kind of dolerites (microgabbro) and diabases (Majer, 1993). In mélange occur also slices and blocks of sedimentary rocks (sandstones, shales, radiolarian cherts and limestones) and metamorphic rocks consisting of different kind of paraschists and metabasites (Majer, 1993). Geological map of studied area is given in Fig. 2.

Analytical techniques

Electron microprobe analyses were performed at Mineralogical Institute in Heidelberg on CAMECA SX51 five wavelength dispersive spectrometer instrument. Operating conditions were an accelerating voltage of 15 kV, a beam current of 20 nA and 10 s counting time for all elements. Electron microprobe diameter was ~1μm. The CAMECA PAP matrix correction program was applied to the raw data. Natural and synthetic silicate and oxide standards were used for calibration. The element concentration traverses through mineral grains were performed as a check for homogeneity. The major

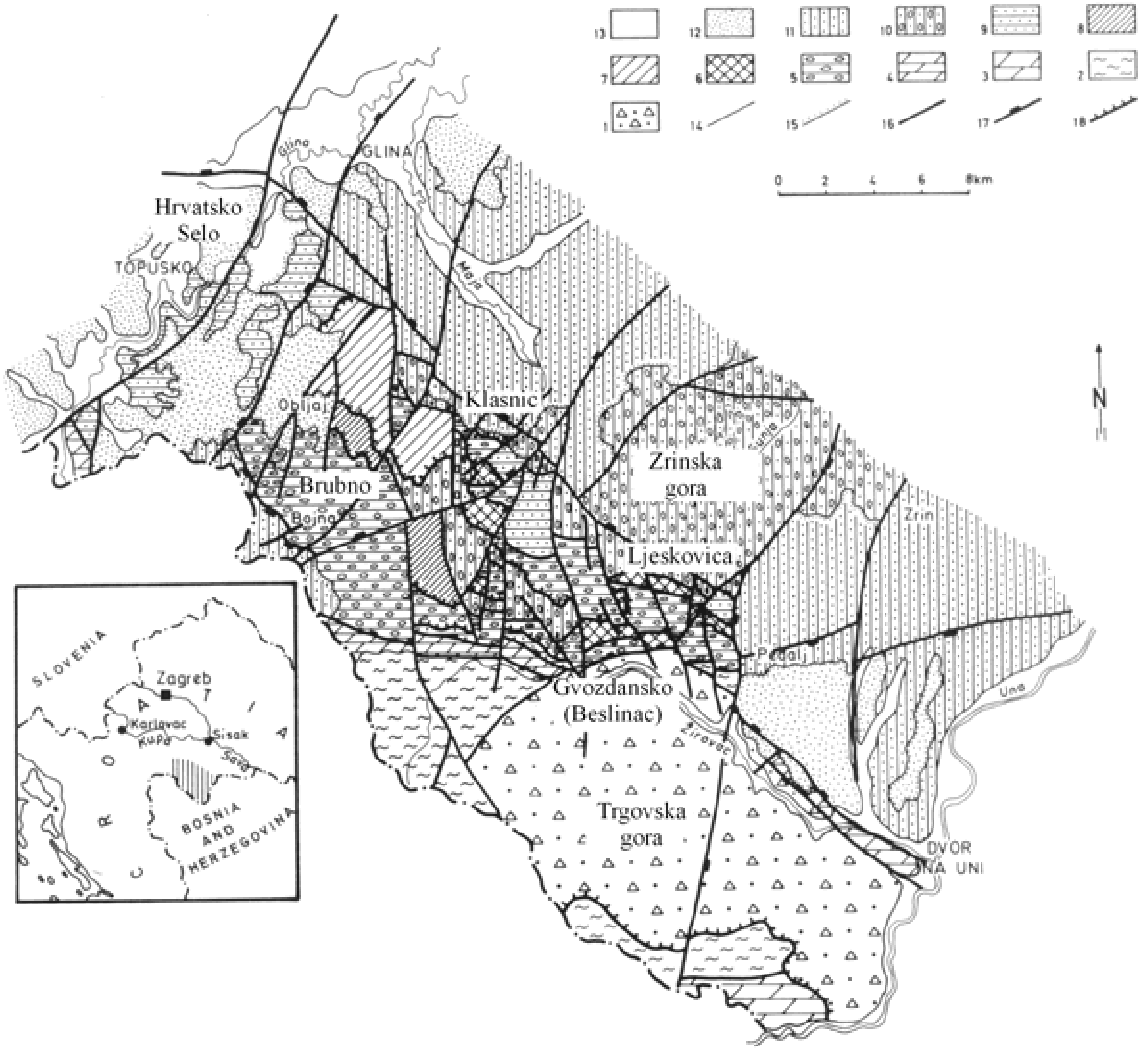

Figure 2. Geological map of the Zrinska and Trgovska Gora area modified after Šušnjar and Grimani (1986).
Legend: 1 - Pz (semimetamorphic clastic rocks); 2 - T_1 (sandstones, siltites, shales); 3 - T_2 (crystallinic dolomites and limestones), 4 - T_3J_1 (stromatolitic and crystallinic dolomites and limestones); 5 - J_3 (ophiolite); 6 - J_3 (serpentinites); 7 - $J_{2,3}$ (amphybolites); 8 - J_3 (phyllites, schists); 9 – $K_{1,2}$ (flysch beds and platy limestones with cherts - Scaglia beds); 10 - Pg (conglomerates, sandstones, marls, siltites); 11 - Ng (sandstones, marls, clays, sands); 12 - Pl, Q1 (gravels, sands, clays); 13 - al, Alluvium; 14 - geological boundary; 15 - transgressive geological boundary; 16 - fault; 17 - fault-subsided block; 18 - nappe.

Slika 2. Geološka karta područja Zrinske i Trgovske gore modificirana prema Šušnjar i Grimani (1986).
Legenda: 1 - Pz (semimetamorfne klastične stijene); 2 - T_1 (pješčenjaci, siltiti, šejlovi); 3 - T_2 (kristalinski dolomiti i vapnenci), 4 - T_3J_1 (stromatolitni i kristalinski dolomiti i vapnenci); 5 - J_3 (ofioliti); 6 - J_3 (serpentiniti); 7 - $J_{2,3}$ (amfiboliti); 8 - J_3 (filiti, škriljavci); 9 - $K_{1,2}$ (fliš i pločasti vapnenci s rožnjacima - Scaglia); 10 - Pg (konglomerati, pješčenjaci, lapori, siltiti); 11 - Ng (pješčenjaci, lapori, gline, pijesci); 12 - Pl, Q1 (šljunci, pijesci, gline); 13 - al, aluvij; 14 - geološka granica; 15 - transgresivna geološka granica; 16 – rasjed; 17 - rasjedni blok koji tone; 18 - navlaka.

and trace element of whole rocks were analysed by X-ray fluorescence (XRF) at Mineralogical Institute in Heidelberg.

Petrography

Thirteen samples from different localities of Banija ophiolite complex were collected for this study (Fig. 2). Most of this samples are different kind of diabase or dolerite rocks occurring either in the form of veins cutting peridotites, cumulate rocks, associated garnet pyroxenites and hornblendites or as small stocks having an extent of about 10 km^2. One sample (B9B) is spilite from mélange block. On the basis of mineral and structural characteristics six kind of rocks have been distinguished:

a) diabase (samples T4 and PS1B)
b) porphyritic diabase (sample HS1D)
c) metadolerite (sample B12B)
d) metadiabase I (samples Kl5, Lj11D, BR6A, DG4)
e) metadiabase II (samples L1, HS6A, B11, Lj1A)
f) spilite (sample B9B)

Microscopic investigations of thirteen samples showed that the mineral relationships and their chemistry should be carefully studied only in metadiabase and spilite rocks since diabase and dolerite kind of rocks was already described and investigated in details by Majer (1993). Samples from localities Klasnić (Kl5), Ljeskovica (Lj11D), Brubno (BR6A), Lasinja (L1), Hrvatsko Selo (HS6A) and Bešlinac (B9B) were choosen for detailed study.

Metadiabases I

Metadiabases I show subophitic to intergranular texture. Their essential minerals are plagioclase and amphibole which completely (sample Kl5), mostly (sample Lj11D) or partly (sample BR6A) replaces clinopyroxene (Fig. 3, 4 i 5). In the sample BR6A tiny relic orthopyroxene grains (visible only by microprobe) being replaced by amphibole were found too (Fig. 6). Al- and Fe-rich titanite usually form incrustations or borders around the original crystals of Fe-Ti-Mn oxide (ferropseudobrookite, Mn-ilmenite) which often have skeletal shape (Fig. 7, 8). Pale green chlorite is present in interstitial areas and in radial intergrowths with amphibole at the rims of ferromagnesian minerals. Additionally a small amount of quartz filling up little angular interspaces between plagioclases has been found in one sample (Lj11D). Accessory apatite may also be present. Plagioclases are clouded by formation of their low-temperature alteration products such as pumpellyite and sometimes prehnite and sericite (Fig. 9).

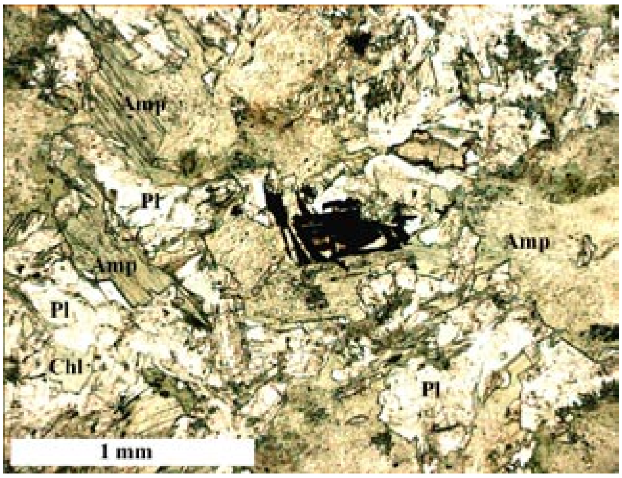

Figure 4. A photomicrograph of the amphibole bearing metadiabase I (sample Lj11D). It has subophitic structure and contains amphibole and plagioclase as main minerals. The black opaque phase is accessory.

Slika 4. Mikroskopska fotografija amfibolskog metadijabaza I (uzorak Lj11D). Iima subofitsku strukturu i sadrži amfibol i plagioklas kao glavne minerale. Crna opâka faza je akcesorna.

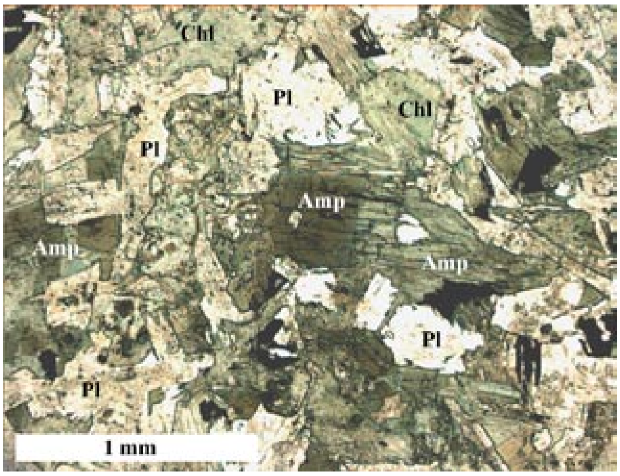

Figure 3. A photomicrograph of the amphibole bearing metadiabase I (sample Kl5). It is characterized by subophitic to intergranular structure. Plagioclase (Pl) and amphibole (Amp) occur as main minerals and black opaque phase is accessory.

Slika 3. Mikroskopska fotografija amfibolskog metadijabaza I (uzorak Kl5). Karakteriziran je subofitskom do intergranularnom strukturom. Plagioklas (Pl) i amfibol (Amp) su glavni minerali, a crna opâka faza je akcesorna.

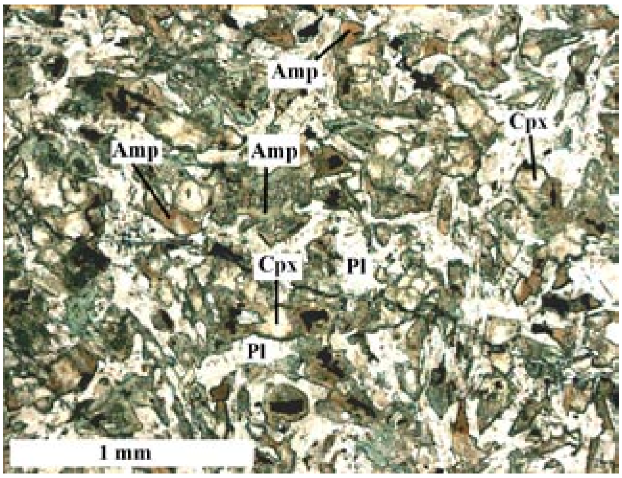

Figure 5. A photomicrograph of the amphibole bearing metadiabase I (sample BR6A). Two kind of amphibole are visible. Amphiboles clearly replace clinopyroxenes (Cpx) and envelope black magnetite minerals.

Slika 5. Mikroskopska fotografija amfibolskog metadijabaza I (uzorak BR6A). Vidljive su dvije vrste amfibola. Amfiboli jasno potiskuju klinopiroksene (Cpx) i obavijaju crna zrna magnetita.

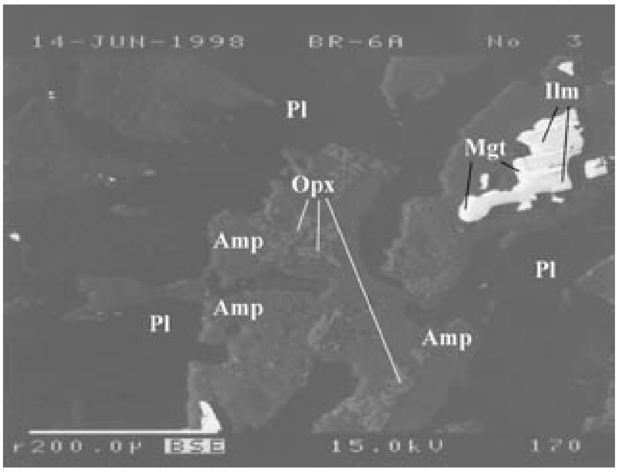

Figure 6. A microprobe BSE photo of the sample BR6A. Relic orthopyroxene (Opx) grains are replaced by amphibole. Ilmenite (Ilm) lamellae are recognizable in the magnetite (Mgt).

Slika 6. Mikrosondska BSE fotografija uzorka BR6A. Reliktna zrna ortopiroksena (Opx) su potisnuta amfibolom. Ilmenitne (Ilm) lamele su prepoznatljive u magnetitu (Mgt).

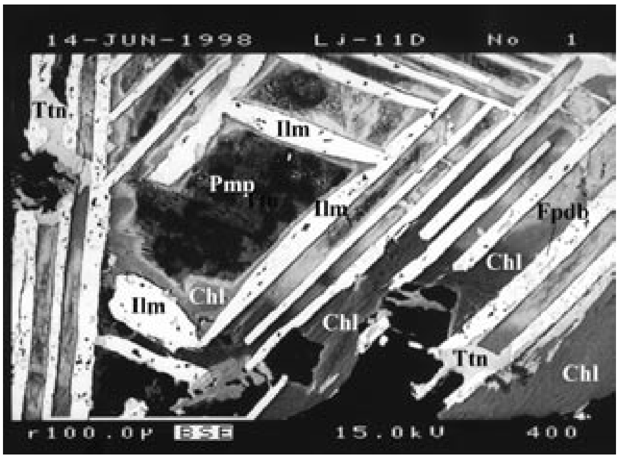

Figure 8. A microprobe BSE photo of the sample Lj11D. Al- and Fe-rich titanite replaces ilmenite lamellae. Secondary minerals such as chlorite (Chl) and pumpellyite (Pmp) are formed in the interspace of ilmenite lamellae.

Slika 8. Mikrosondska BSE fotografija uzorka LJ11D. Al- i Fe- bogati titanit potiskuje ilmenitne lamele. Sekundarni minerali kao što su klorit (Chl) i pumpeliit (Pmp) su formirani u međuprostoru ilmenitnih lamela.

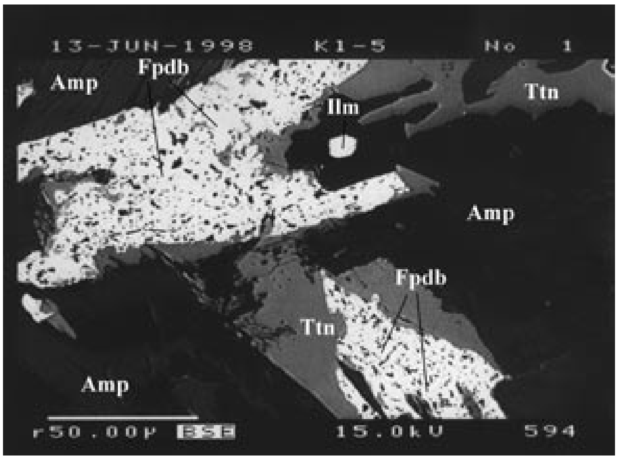

Figure 7. A microprobe BSE photo of the sample Kl5. Al- and Fe-rich titanite (Ttn) usually envelops ferropseudobrookite (Fpdb) pointing to the reaction between original Fe-Ti oxide and Ca-rich silicate.

Slika 7. Mikrosondska BSE fotografija uzorka Kl5. Al- i Fe-bogati titanit obično obavija feropseudobrukit (Fpdb) ukazujući na reakciju između orginalnog Fe-Ti oksida i Ca-bogatog silikata

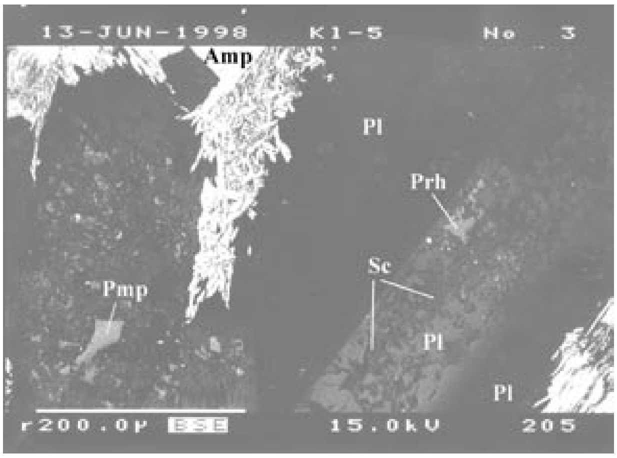

Figure 9. A microprobe BSE photo of the sample Kl5. Plagioclases are clouded by the formation of the low-temperature alteration products such as prehnite (Prh), sericite (Sc) and pumpellyite.

Slika 9. Mikrosondska BSE fotografija uzorka Kl5. Plagioklasi su zamućeni formiranjem produkata niskotemperaturne alteracije kao što su prehnit (Prh), sericit (Sc) i pumpeliit.

Metadiabases II

Metadiabases II are characterized by subophitic texture and consist mainly of shapeless fresh clinopyroxenes enclosing numerous albite laths (Fig. 10). Albite itself contains often chlorite or pumpellyite patches but also Al- and Fe-rich titanite or small complex inclusions consisting of clinopyroxene being enveloped by patchy pumpellyite (Fig. 11). Extremely fine and numerous Al- and Fe-rich titanite patches commonly occur in Ti-magnetite which is additionally in the sample HS6A characterized by exsolution of ilmenite lamellae. A significant amount of chlorite is present in mineral interspaces. Calcite veinlets cut some samples.

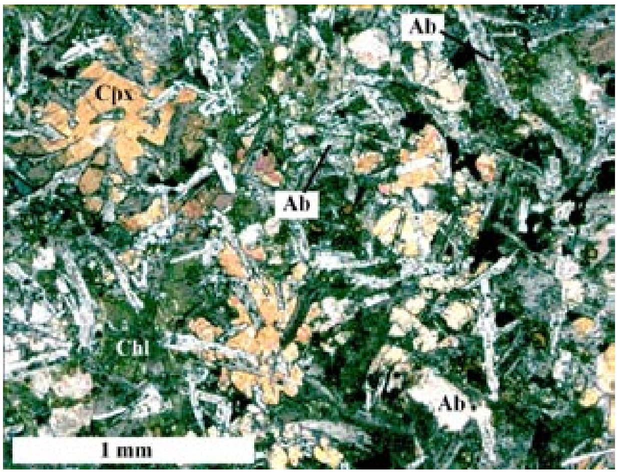

Figure 10. A photomicrograph of the metadiabase II (sample L1). Shapeless clinopyroxenes enclose numerous albite laths. Chlorite occurs in the mineral interspaces.

Slika 10. Mikroskopska fotografija metadijabaza II (uzorak L1). Alotriomorfni klinopirokseni uklapaju brojne albitne (Ab) prutiće. Klorit se pojavljuje u međuprostorima minerala.

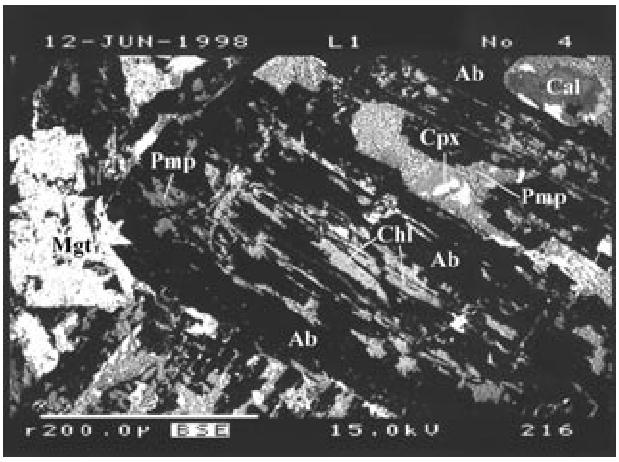

Figure 11. A microprobe BSE photo of the sample L1. Albite contains chlorite and pumpellyite patches and complex inclusions such as clinopyroxene enveloped by patchy pumpellyite.

Slika 11. Mikrosondska BSE fotografija uzorka L1. Albit sadrži kl

Spilite

Spilite contains amygdules which are filled with secondary calcite and chlorite. Calcite crystallizes mostly in the centre of amygdule and is enclosed by chlorite. The amygdules lie in the groundmass consisting of fresh purplish elongate clinopyroxene grains and plagioclase which is almost completely albitized (Fig. 12, 13). In mineral interspaces occur Ti-magnetite, Al- and Fe-rich titanite and chlorite as independent grains. Additonally chlorite and Al- and Fe-rich titanite can be found enclosed by albite and rarely by clinopyroxene.

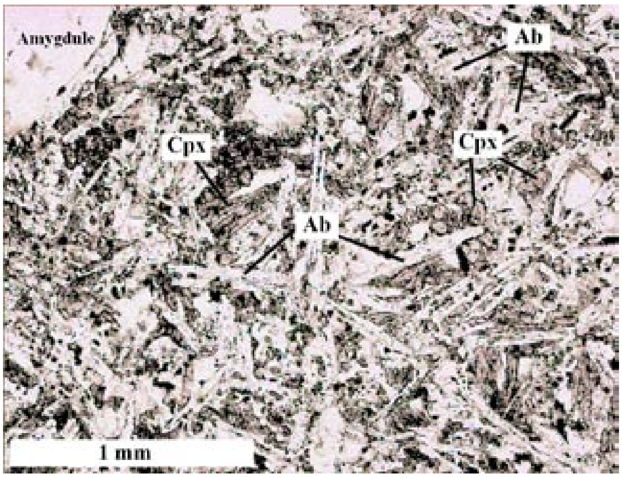

Figure 12. A photomicrograph of the spilite (sample B9B). It contains amygdules in the groundmass consisting of purplish elongated clinopyroxenes and almost completely albitized plagioclases.

Slika 12. Mikroskopska fotografija spilita (uzorak B9B). Sadrži mandule u osnovnoj masi koja se sastoji od blijedo crvenkastoplavih izduženih klinopiroksena i gotovo potpuno albitiziranih plagioklasa.

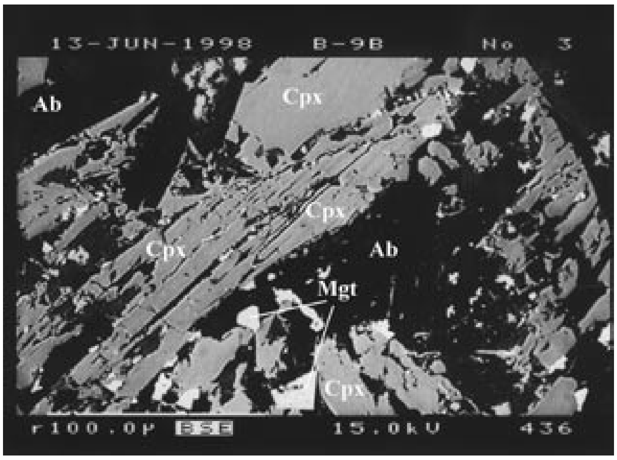

Figure 13. A microprobe BSE photo of the sample B9B. Elongated clinopyroxenes and albites are visible. The magnetite is characterized by nearly euhedral crystal forms indicating its primary origin.

Slika 13. Mikrosondska BSE fotografija uzorka B9B. Vidljivi su izduženi klinopirokseni i albiti. Magnetit je karakteriziran skoro idiomorfnim kristalnim formama što ukazuje na njegov primarni postanak.

Rock chemistry

Chemical analyses of whole rocks are given in Table 1. They were recalculated to 100% on an H_2O- and CO_2-free basis for the aim of chemical rock classification. The diagram of Cox et al. (1979) was used for the rock classification (Fig. 14). The studied rocks plot within the basalt field and basalt-andesite field. As metadiabases II and spilite display extensive albitization of plagioclase their spreading upwards to the basalt-hawaiite boundary is not surprise.

The tholeiite nature of all investigated rocks were determinated using the Sr/Al_2O_3-SiO_2 diagram of Geisler & Vinx (1996) (Fig. 15). This is additionally supported by plots of TiO_2 versus MgO (Fig. 16). The calc-alkaline suites display a characteristic Ti depletion with decreasing MgO value, the feature that was not shown by this plots. Tholeiite nature of diabases in Banija was also determinated by former study of Majer (1993).

Mg-values of metadiabases I range from 0,48 to 0,54, whereas those of metadiabases II and spilite are lower (0,26 to 0,29 and 0,40 respectively).

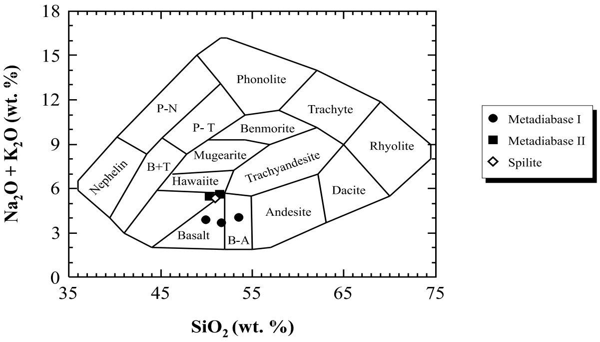

Figure 14. The total alkali versus silica classification diagram after Cox et al. (1979).

Slika 14. Klasifikacijski dijagram $Na_2O + K_2O$ (wt. %) - SiO_2 (wt. %) prema Cox et al. (1979)

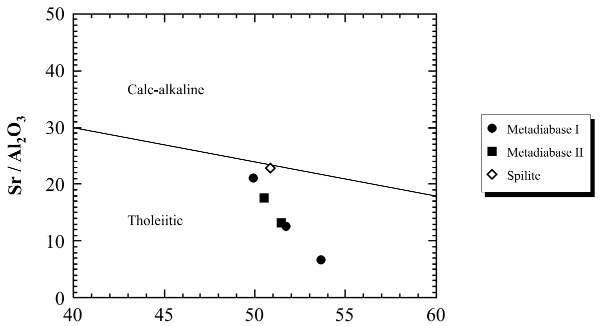

Figure 15. Sr / Al_2O_3 - SiO_2 diagram for the classification of tholeiitic and calc-alkaline rocks (after Geisler & Winx, 1996).

Slika 15. Sr / Al_2O_3 - SiO_2 dijagram za klasifikaciju toleiitskih i kalcijsko/alkalijskih stijena (prema Geisler & Winx, 1996).

The relatively high Cr contents (191 to 280 ppm for metadiabases I, 306 ppm for spilite) as also the Ni contents (78 to 91 ppm for metadiabases I and 163 ppm for spilite) indicate that their magmas were not strongly differentiated. Metadiabases II are characterized by remarkably lower Cr (9 to 10 ppm) and Ni contents (3 to 12 ppm).

All groups of rocks are characterized by high Al_2O_3 content (14.35 to 16.78 wt%).

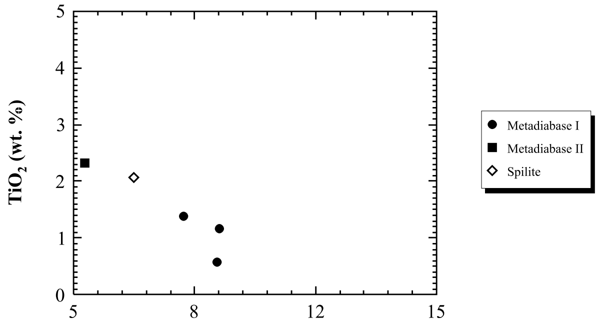

Figure 16. TiO_2 (wt. %) versus MgO (wt. %) diagram showing depletion of TiO_2 with increasing of MgO.

Slika 16. Dijagram TiO_2 (wt. %) - MgO (wt. %) koji pokazuje osiromasenje TiO_2 s povecanjem MgO.

Metadiabases I differ from metadiabases II and spilite in their lower contents of TiO_2 Na_2O and P_2O_5 (Table 1).

Compared with metadiabases I, metadiabases II and spilite are characterized by lower content of Ba and Rb, remarkably higher content of Nb and slightly higher content of Zr and Y.

Mineral chemistry

Pyroxenes

Selected microprobe analyses of pyroxenes are presented in Table 2. Relict clinopyroxene in metadiabases I is an augite $Wo_{34-47}En_{40-51}Fs_{12-20}$ (Fig. 17). It is always replaced by amphibole (Fig. 18). Clinopyroxenes in metadiabases II are generally similar in composition to augites in metadiabases I, but tend to have somewhat higher Ti- and Al-content ($Wo_{34-44}En_{31-52}Fs_{11-30}$). Spilite contains clinopyroxene which is compositionally diopside $Wo_{45-49}En_{27-32}Fs_{21-25}$ (Fig. 17). It also differs from augites of metadiabases I and II in its higher Ti-, Al-, Fe- and Na-content (Table 2) and lower En and higher Fs component.

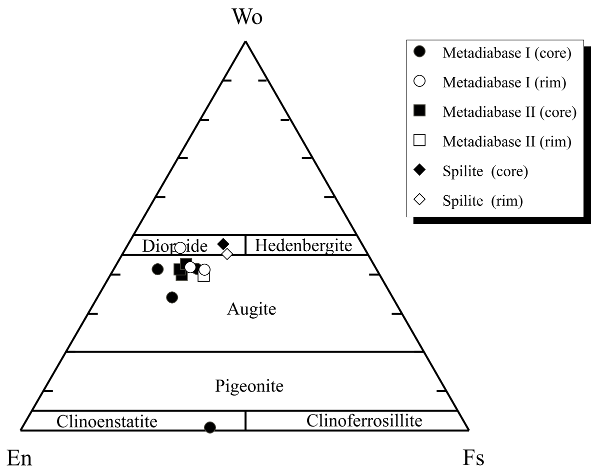

Figure 17. The nomenclature of the representative pyroxenes (Morimoto, 1989).

Slika 17. Nomenklatura reprezentativnih piroksena (Morimoto, 1989).

Table 1: Major and trace element analysis by XRF
Tablica 1: Glavni elementi i elementi u tragovima određeni XRF analizom

	Metadiabases I *Metadijabazi I*			Metadiabases II *Metadijabazi II*		Spilite *Spilit*
Sample *Uzorak*	Kl-5	Lj-11D	BR-6A	L1A	HS-6A	B-9B
SiO_2	50,08	51,82	48,71	48,75	50,36	48,50
TiO_2	1,13	0,55	1,33	2,23	2,60	1,97
Al_2O_3	15,61	16,78	16,46	15,46	14,35	14,61
Fe_2O_3	1,21	0,89	0,71	3,41	4,42	3,74
FeO	8,33	6,66	7,73	9,79	8,36	6,26
MnO	0,27	0,20	0,15	0,20	0,22	0,17
MgO	8,73	8,66	7,83	5,13	4,44	6,34
CaO	7,89	7,18	10,79	6,23	7,59	8,46
Na_2O	2,92	2,37	3,73	5,25	5,37	5,14
K_2O	0,67	1,52	0,19	0,04	0,10	0,02
P_2O_5	0,07	0,03	0,13	0,11	0,17	0,23
H_2O^+	3,11	3,45	2,05	3,71	2,34	3,46
CO_2	0,06	0,04	0,08	0,43	0,23	1,66
Total ***Ukupno***	**100,09**	**100,15**	**99,89**	**100,76**	**100,54**	**100,56**
Mg-value *Mg-vrijednost*	0,48	0,54	0,48	0,29	0,26	0,40
Ti	6754	3279	8001	13346	15550	11817
Cr	247	191	280	9	10	306
Ni	85	78	91	12	3	163
Co	59	36	48	90	65	66
Cu	32	19	77	16	11	24
Zn	78	57	70	85	85	88
V	263	194	181	346	394	221
Ba	141	506	149	97	102	54
Sr	201	117	357	278	190	348
Rb	20	38	7	1	2	1
Pb	3	3	2	3	4	3
Zr	63	28	112	109	128	178
Ga	17	15	17	18	21	16
Y	23	17	33	36	41	38
Nb	2	0	3	4	4	7

Clinopyroxenes in all rock types are zoned showing mostly decrease of Mg-, Al- and Ti-content from core to rim (Table 2, Fig. 18). Additionally, there are small compositional differences most prominently remarked on Ti- and Al-content between individual clinopyroxene grains within the same samples (samples L1 and BR6A, Table 2).

Relic orthopyroxene was found only in the sample BR6A. It is an enstatite (Fig.17) which occurs exclusively as micropatches within amphibole grains and is recognizable only by using a microprobe (Fig. 6).

Amphiboles

Amphiboles occur in metadiabases I. They are all calcic amphiboles (Table 3).

In sample Kl5 amphiboles are present as nearly euhedral brown grains (analyses 118 and 119, Table 3) showing often transitions to pale green amphibole at the rim. Shapeless grains of pale green amphibole occurs also in mineral interspaces (analyses 9 and 10, Table 3). Both, brown and pale green amphibole have the composition of magnesiohornblende (Fig. 19), but there are differences in

Ti-, Al- and Na-content which are significantly higher in brown amphibole. Additionally, intergrowths of actinolite and actinolite hornblende with chlorite occur at the rim of greater magnesiohornblende grains.

In the sample Lj11D amphibole grains are mostly actinolites being characterized by transitions to actinolite hornblende at the rims (Fig. 19). The rims of amphibole grains have higher Al- and Fe-contents than the cores (Table 3), what is nicely displayed on the microprobe BSE photo (Fig. 20).

In the sample BR6A amphiboles occur clearly as a breakdown product of clinopyroxene relict grains (Fig. 5, 18). There are considerable variation in amphibole compositions varying from pargasite hornblende or

Table 2: Representative pyroxene analyses
Tablica 2: Reprezentativne analize piroksena

	Metadiabases I *Metadijabazi I*						
Sample *Uzorak*	Lj11D-51	Lj11D-54	BR6A-11	BR6A-12	BR6A-85	BR6A-87	BR6A-77
	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	
SiO_2	50,67	51,22	51,86	52,47	50,82	50,16	52,00
TiO_2	0,48	0,50	0,46	0,28	0,78	0,72	0,09
Al_2O_3	2,45	2,10	2,42	1,82	4,76	4,07	0,60
FeO	10,81	12,27	9,96	7,35	6,05	9,85	25,80
Cr_2O_3	0,05	0,04	0,47	0,15	0,21	0,05	0,03
MnO	0,23	0,27	0,32	0,22	0,14	0,26	0,72
MgO	13,91	13,01	17,13	14,32	16,67	13,75	20,42
CaO	20,06	19,88	16,52	22,80	19,76	19,81	0,52
Na_2O	0,22	0,23	0,42	0,47	0,48	0,50	0,00
K_2O	0,00	0,01	0,00	0,02	0,02	0,01	0,00
Total ***Ukupno***	**98,88**	**99,53**	**99,56**	**99,90**	**99,69**	**99,18**	**100,18**
TSi	1,915	1,938	1,919	1,944	1,859	1,880	1,963
TAl	0,085	0,062	0,081	0,056	0,141	0,120	0,027
TFe^{3+}	0,000	0,000	0,000	0,000	0,000	0,000	0,011
M1Al	0,024	0,031	0,025	0,023	0,064	0,060	0,000
M1Ti	0,014	0,014	0,013	0,008	0,021	0,020	0,003
$M1Fe^{3+}$	0,048	0,019	0,046	0,048	0,062	0,054	0,031
$M1Fe^{2+}$	0,129	0,201	0,000	0,126	0,000	0,096	0,000
M1Cr	0,001	0,001	0,014	0,004	0,006	0,001	0,001
M1Mg	0,784	0,734	0,902	0,791	0,846	0,768	0,965
M2Mg	0,000	0,000	0,043	0,000	0,063	0,000	0,184
M2Fe2	0,164	0,168	0,262	0,054	0,123	0,159	0,772
M2Mn	0,007	0,009	0,010	0,007	0,004	0,008	0,023
M2Ca	0,812	0,806	0,655	0,905	0,775	0,796	0,021
M2Na	0,016	0,017	0,030	0,034	0,034	0,036	0,000
M2K	0,000	0,000	0,000	0,001	0,001	0,000	0,000
Cations ***Kationi***	**4,000**	**4,000**	**4,000**	**3,999**	**3,999**	**4,000**	**4,000**
WO	41,8	41,6	34,1	46,9	41,4	42,3	1,0
EN	40,3	37,9	49,3	41,0	48,5	40,8	57,2
FS	17,9	20,5	16,6	12,2	10,1	16,9	41,7

Cations are calculated on the basis of 6 O
Kationi su računani na bazi 6 kisika

Table 2: continued
Tablica 2: nastavlja se

	Metadiabases II *Metadijabazi II*						Spilite *Spilit*	
Sample *Uzorak*	L1-6	L1-7	L1-103	L1-104	HS6A-99	HS6A-100	B9B-70	B9B-69
	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*
SiO_2	49,23	49,51	51,20	52,49	50,33	51,26	43,96	46,40
TiO_2	1,45	1,44	0,83	0,48	1,08	0,81	4,20	3,30
Al_2O_3	4,00	3,21	3,15	1,96	3,00	2,08	6,20	4,16
FeO	9,33	12,36	7,36	6,54	9,22	9,23	11,93	13,31
Cr_2O_3	0,06	0,02	0,35	0,43	0,00	0,00	0,11	0,03
MnO	0,24	0,19	0,17	0,15	0,23	0,29	0,20	0,37
MgO	15,12	13,43	16,63	17,26	14,32	14,99	9,89	10,25
CaO	19,16	18,98	19,51	20,37	20,90	20,27	21,43	20,78
Na_2O	0,33	0,34	0,33	0,22	0,43	0,29	0,62	0,69
K_2O	0,00	0,01	0,00	0,01	0,01	0,01	0,01	0,00
Total ***Ukupno***	**98,92**	**99,49**	**99,53**	**99,91**	**99,52**	**99,23**	**98,55**	**99,29**
TSi	1,844	1,870	1,889	1,925	1,879	1,918	1,698	1,782
TAl	0,156	0,130	0,111	0,075	0,121	0,082	0,282	0,188
TFe^{3+}	0,000	0,000	0,000	0,000	0,000	0,000	0,020	0,029
M1Al	0,020	0,013	0,025	0,009	0,010	0,009	0,000	0,000
M1Ti	0,041	0,041	0,023	0,013	0,030	0,023	0,122	0,095
$M1Fe^{3+}$	0,076	0,060	0,053	0,043	0,082	0,049	0,101	0,077
$M1Fe^{2+}$	0,017	0,130	0,000	0,000	0,081	0,083	0,204	0,240
M1Cr	0,002	0,001	0,010	0,012	0,000	0,000	0,003	0,001
M1Mg	0,844	0,756	0,888	0,922	0,797	0,836	0,569	0,587
M2Mg	0,000	0,000	0,026	0,021	0,000	0,000	0,000	0,000
M2Fe2	0,200	0,201	0,174	0,158	0,125	0,157	0,060	0,081
M2Mn	0,008	0,006	0,005	0,005	0,007	0,009	0,007	0,012
M2Ca	0,769	0,768	0,771	0,800	0,836	0,812	0,887	0,855
M2Na	0,024	0,025	0,024	0,016	0,031	0,021	0,046	0,051
M2K	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Cations ***Kationi***	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**	**4,000**
WO	40,2	40,0	40,2	41,1	43,4	41,7	48,0	45,4
EN	44,1	39,4	47,7	48,4	41,3	43,0	30,8	31,2
FS	15,7	20,6	12,1	10,5	15,3	15,3	21,2	23,4

Cations are calculated on the basis of 6 O
Kationi su računani na bazi 6 kisika

ferroan pargasite hornblende in the core to edenite hornblende to the rim (Fig. 19). The amphibole rims are usually richer in Ti-, Al-, Fe- and Na-content but poorer in Si-content than cores (Table 3).

Plagioclase

Plagioclase crystals in metadiabases I are normally zoned, highly calcic in core An_{84-72} and mostly remain calcic to the outer rims An_{74-44} where occurs outermost narrow (5-20 µm) more sodic rim An_{25-2} (Table 4, Fig. 9) The core of plagioclase may contain large amount of minute (1-20 µm) sericite patches or coarser patches of prehnite and pumpellyite (Fig. 9).

Metadiabases II are characterized exclusively by albite plagioclase $An_{5.8-0.6}$. In spilite dominates also albite $An_{4.6-2.1}$, but some rare plagioclase grains with $An_{24.8-9.7}$ were found too.

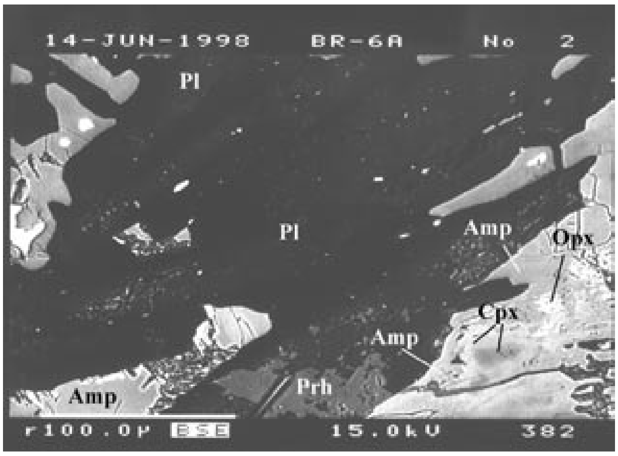

Figure 18. A microprobe BSE photo of the sample BR6A. Zoning of the clinopyroxene is clearly recognizable as also the fact that amphibole replaces both kind of pyroxenes.

Slika 18. Mikrosondska BSE fotografija uzorka BR6A. Jasno je prepoznatljivo zoniranje u klinopiroksenu kao i činjenica da amfibol potiskuje obje vrste piroksena.

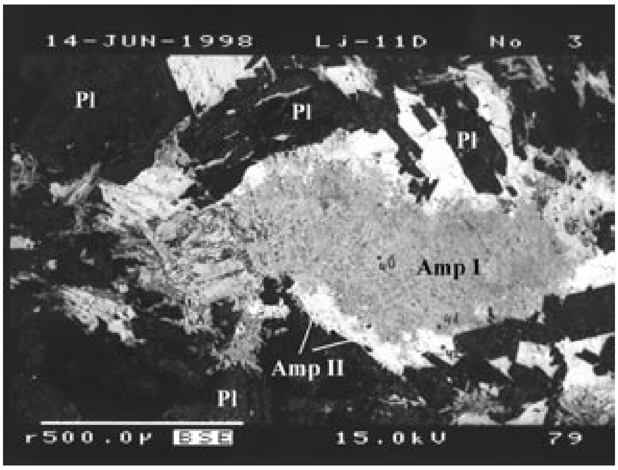

Figure 20. A microprobe BSE photo of the sample Lj11D. On the rims of older amphibole is usually developed new amphibole being richer in Al- and Fe-content.

Slika 20. Mikrosondska BSE fotografija uzorka Lj11D. Na rubovima starijeg amfibola obično je razvijen novi amfibol koji je bogatiji Al- i Fe-sadržajem.

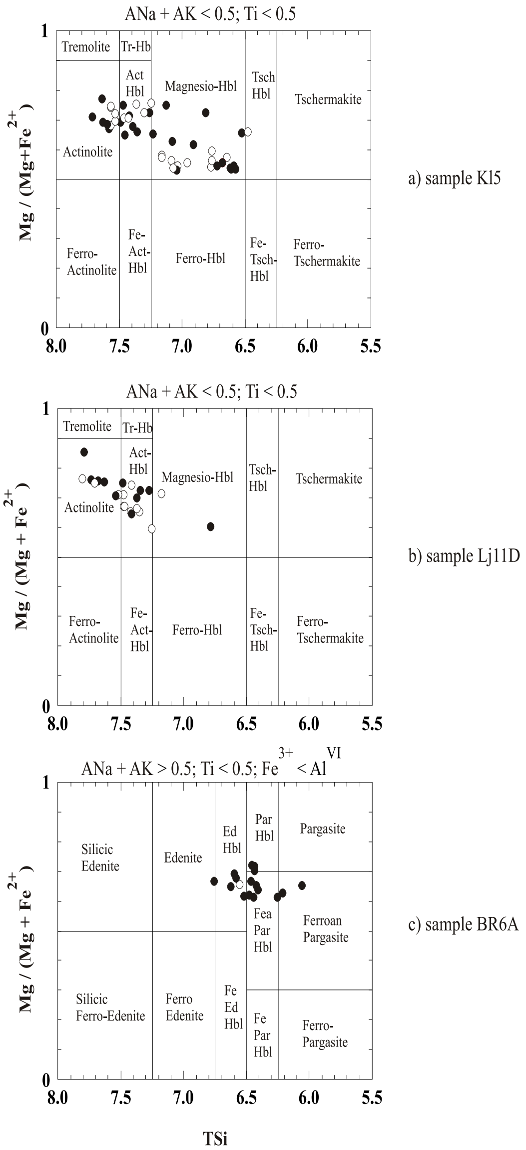

Figure 19. Classification of the amphiboles of metadiabases I after Hawthorne (1981).
Core compositions are represented by filled circles and those of rims by empty circles.

Slika 19. Klasifikacija amfibola metadijabaza I prema Hawthorne (1981). Sastavi jezgra su prikazani punim krugovima, a sastavi rubova praznim krugovima.

Al- and Fe-rich titanite

There is no significant chemical difference in the compositions of Al- and Fe-rich titanite in metadiabases I, metadiabases II and spilite (Table 5). But structural relationship indicates that Al- and Fe-rich titanite of the spilite could be accessory mineral whereas Al- and Fe-rich titanite in both kind of metadiabases are clearly reaction productes between primary Fe-Ti oxides and some Ca-rich silicate mineral (Fig. 7, 8).

Ilmenite

Ilmenite was not found in the spilite. Ilmenites of the samples Kl5 and Lj11D have remarkably higher Mn-content (up to 29.64 wt%) than those in metadiabases II (up to about 4.00 wt%). Representative analyses of ilmenites are shown in Table 6. Mn-rich ilmenites are very heterogeneous and inside them was locally analysed Fe-Ti oxide phase. Its chemical compositions matches at best mineral formula $FeTi_2O_5$ (ferropseudobrookite), Table 7. The relationship between this Fe-Ti phase and Mn-ilmenite is not clear since their colour differences on BSE photo are not recognizable.

Magnetite

Magnetite occurs only in the sample BR6A, whereas Ti-magnetite of variable Ti-content (Table 7) is typical for metadiabases II and spilite.

Table 3: Representative amphibole analyses
Tablica 3: Reprezentativne analize amfibola

	Metadiabases I *Metadijabazi I*							
Sample *Uzorak*	Kl5-9	Kl5-10	Kl5-43	Kl5-118	Kl5-119	Lj11D-40	Lj11D-41	Lj11D-42
	core *jezgra*	rim *rub*		core *jezgra*	rim *rub*	core *jezgra*	rim I *rub*	rim II *rub*
SiO_2	50,35	50,31	50,85	43,91	46,27	53,25	54,71	50,52
TiO_2	0,61	0,54	0,21	2,54	1,69	0,22	0,14	0,73
Al_2O_3	3,49	3,61	4,22	8,97	6,46	2,85	1,37	3,60
FeO	19,46	19,12	15,22	19,48	19,74	12,34	11,14	18,19
Cr_2O_3	0,00	0,00	0,01	0,00	0,01	0,20	0,11	0,05
MnO	0,56	0,55	0,27	0,28	0,30	0,34	0,22	0,36
MgO	14,53	14,12	14,03	9,77	10,54	16,08	17,12	13,09
CaO	6,99	7,60	12,02	10,01	10,05	11,52	12,30	10,19
Na_2O	0,56	0,46	0,61	1,64	1,23	0,38	0,19	0,33
K_2O	0,09	0,10	0,07	0,09	0,08	0,04	0,03	0,18
Total ***Ukupno***	**96,64**	**96,41**	**97,51**	**96,69**	**96,37**	**97,22**	**97,33**	**97,24**
TSi	7,252	7,286	7,390	6,616	6,959	7,628	7,803	7,374
TAl	0,541	0,549	0,610	1,384	1,038	0,372	0,196	0,564
TFe^{3+}	0,207	0,165	0,000	0,000	0,004	0,000	0,001	0,062
CAl	0,051	0,067	0,113	0,208	0,107	0,109	0,034	0,054
CCr	0,000	0,000	0,001	0,000	0,001	0,023	0,012	0,006
CFe^{3+}	0,972	1,005	0,402	0,567	0,597	0,353	0,194	0,708
CTi	0,066	0,059	0,023	0,288	0,191	0,024	0,015	0,080
CMg	3,120	3,049	3,040	2,195	2,363	3,434	3,640	2,848
CFe^{2+}	0,758	0,787	1,405	1,725	1,722	1,038	1,092	1,281
CMn	0,033	0,033	0,017	0,018	0,019	0,020	0,013	0,022
BFe^{2+}	0,408	0,358	0,043	0,163	0,160	0,088	0,043	0,169
BMn	0,035	0,035	0,017	0,018	0,019	0,021	0,013	0,023
BCa	1,079	1,179	1,872	1,616	1,619	1,768	1,880	1,594
BNa	0,076	0,063	0,068	0,203	0,177	0,052	0,026	0,046
ANa	0,081	0,066	0,103	0,276	0,182	0,053	0,026	0,047
AK	0,017	0,018	0,013	0,017	0,015	0,007	0,005	0,034
Cations ***Kationi***	**14,695**	**14,720**	**15,116**	**15,293**	**15,173**	**14,990**	**14,994**	**14,912**

Cations are calculated on the basis of 23 O
Kationi su računani na bazi 23 kisika

Table 3: continued
Tablica 3: nastavlja se

	Metadiabases I *Metadijabazi I*			
Sample *Uzorak*	BR6A-14	BR6A-15	BR6A-107	BR6A-106
	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*
SiO_2	45,40	44,22	49,73	44,60
TiO_2	2,27	1,90	0,58	0,86
Al_2O_3	8,74	10,24	6,05	10,11
FeO	13,86	13,71	13,07	14,51
Cr_2O_3	0,00	0,04	0,18	0,06
MnO	0,16	0,15	0,33	0,20
MgO	13,20	12,75	15,29	12,92
CaO	10,92	11,30	11,15	11,16
Na_2O	2,38	2,43	1,42	2,32
K_2O	0,32	0,35	0,12	0,26
Total ***Ukupno***	**97,25**	**97,09**	**97,92**	**97,00**
TSi	6,711	6,555	7,143	6,587
TAl	1,289	1,445	0,857	1,413
TFe^{3+}	0,000	0,000	0,000	0,000
CAl	0,232	0,343	0,166	0,345
CCr	0,000	0,005	0,020	0,007
CFe^{3+}	0,270	0,231	0,446	0,405
CTi	0,252	0,212	0,063	0,096
CMg	2,909	2,818	3,274	2,845
CFe^{2+}	1,326	1,382	1,011	1,290
CMn	0,010	0,009	0,020	0,012
BFe^{2+}	0,117	0,087	0,113	0,097
BMn	0,010	0,009	0,020	0,013
BCa	1,729	1,795	1,716	1,766
BNa	0,144	0,109	0,151	0,124
ANa	0,539	0,589	0,245	0,540
AK	0,060	0,066	0,022	0,049
Cations ***Kationi***	**15,599**	**15,656**	**15,267**	**15,589**

Cations are calculated on the basis of 23 O
Kationi su računani na bazi 23 kisika

Chlorites

Secondary chlorites show wide differences in the compositions. Representative analyses of chlorites are given in Table 8. Using the classification scheme of Deer et al. (1972) chlorites of metadiabases I plot along ripidiolite-brunsvigite and ripidiolite-pycnochlorite boundary except rare chlorites of the sample BR6A falling inside diabantite field. Chlorites of metadiabases II are predominantly brunsvigites, whereas chlorites of spilites are diabantites (Fig. 21).

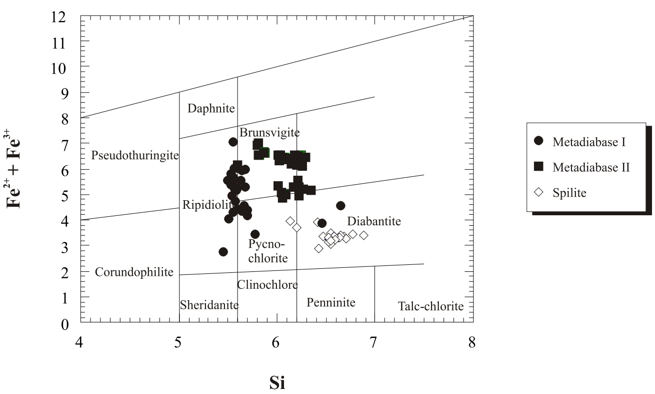

Figure 21. Chlorite classification after Deer et al. (1972).

Slika 21. Klasifikacija klorita prema Deer et al. (1972).

Table 4: Representative plagioclase analyses
Tablica 4: Reprezentativne analize plagioklasa

	Metadiabases I *Metadijabazi I*										Metadiabases II *Metadijabazi II*				Spilite *Spilit*
Sample *Uzorak*	Kl5-127	Kl5-128	Kl5-129	Lj11D-39	Lj11D-38	BR6A-56	BR6A-57	BR6A-55	BR6A-103	BR6A-102	L1-43	L1-44	HS6A-44	HS6A-43	B9B-37
	core *jezgra*	rim I *rub I*	rim II *rub II*	core *jezgra*	rim II *rub II*	core *jezgra*	rim I *rub I*	rim II *rub II*	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	core *jezgra*	rim *rub*	core *jezgra*
SiO_2	49,80	53,20	62,19	47,03	62,00	52,42	53,32	61,67	48,51	48,78	67,90	67,85	67,73	66,95	67,23
Al_2O_3	31,56	30,24	24,09	33,79	24,54	30,81	29,80	24,68	33,41	33,23	19,97	19,76	20,10	20,35	20,34
FeO	0,52	0,40	0,20	0,47	0,16	0,24	0,17	0,19	0,33	0,20	0,39	0,16	0,34	1,31	0,39
CaO	14,56	11,78	5,02	15,48	5,32	12,58	11,58	5,29	15,55	15,30	0,13	0,28	0,26	0,44	0,65
Na_2O	3,32	4,86	8,98	1,83	8,77	4,42	5,14	8,93	2,79	2,95	11,80	11,62	11,86	11,45	11,41
K_2O	0,06	0,12	0,08	0,59	0,14	0,07	0,05	0,12	0,04	0,01	0,05	0,01	0,06	0,14	0,06
Total ***Ukupno***	**99,82**	**100,60**	**100,56**	**99,19**	**100,93**	**100,54**	**100,06**	**100,88**	**100,63**	**100,47**	**100,24**	**99,68**	**100,35**	**100,64**	**100,08**
Si	9,122	9,585	10,978	8,702	10,912	9,459	9,645	10,870	8,832	8,882	11,870	11,907	11,837	11,730	11,785
Al	6,808	6,416	5,008	7,363	5,086	6,548	6,348	5,123	7,163	7,126	4,111	4,084	4,137	4,199	4,199
Fe^{2+}	0,080	0,060	0,030	0,073	0,024	0,036	0,026	0,028	0,050	0,030	0,057	0,023	0,050	0,192	0,057
Ca	2,857	2,274	0,949	3,069	1,003	2,432	2,244	0,999	3,033	2,985	0,024	0,053	0,049	0,083	0,122
Na	1,179	1,698	3,074	0,657	2,993	1,547	1,803	3,052	0,985	1,042	4,000	3,954	4,019	3,890	3,878
K	0,014	0,028	0,018	0,139	0,031	0,016	0,012	0,027	0,009	0,002	0,011	0,002	0,013	0,031	0,013
Cations ***Kationi***	**20,060**	**20,061**	**20,057**	**20,003**	**20,049**	**20,038**	**20,078**	**20,099**	**20,072**	**20,067**	**20,073**	**20,023**	**20,105**	**20,125**	**20,054**
Ab	29,1	42,5	76,1	17,0	74,3	38,7	44,4	74,8	24,5	25,9	99,1	98,6	98,5	97,2	96,6
An	70,5	56,9	23,5	79,4	24,9	60,9	55,3	24,5	75,3	74,1	0,6	1,3	1,2	2,1	3,0
Or	0,3	0,7	0,4	3,6	0,8	0,4	0,3	0,7	0,2	0,0	0,3	0,0	0,3	0,8	0,3

Cations are calculated on the basis of 32 O
Kationi su računani na bazi 32 kisika

Table 5: Representative analyses of Al- and Fe-rich titanite
Tablica 5. Reprezentativne analize Al- i Fe-bogatog titanita

	Metadiabases I *Metadijabazi I*		Metadiabases II *Metadijabazi II*		Spilite *Spilit*
Sample *Uzorak*	Kl5-25	Lj11D-2	L1-89	HS6A-30	B9B-65
SiO_2	30,37	30,70	30,83	30,63	30,84
TiO_2	34,26	34,11	31,65	33,51	32,86
Al_2O_3	3,15	3,04	4,35	3,18	3,70
Cr_2O_3	0,05	0,03	0,04	0,03	0,07
FeO	1,17	1,54	1,47	2,64	1,67
MnO	0,00	0,00	0,00	0,00	0,02
MgO	0,00	0,00	0,00	0,00	0,10
CaO	28,59	28,28	28,75	28,24	28,36
Na_2O	0,01	0,02	0,01	0,01	0,02
K_2O	0,00	0,03	0,00	0,02	0,00
Total ***Ukupno***	**97,60**	**97,75**	**97,10**	**98,26**	**97,64**
Si	4,062	4,100	4,137	4,089	4,120
Al	0,496	0,478	0,687	0,500	0,582
Ti	3,447	3,427	3,194	3,365	3,302
Cr	0,005	0,003	0,004	0,003	0,007
Fe^{3+}	0,000	0,000	0,000	0,000	0,000
Mg	0,000	0,000	0,000	0,000	0,020
Fe^{2+}	0,131	0,172	0,165	0,295	0,187
Mn	0,000	0,000	0,000	0,000	0,002
Na	0,003	0,005	0,003	0,003	0,005
Ca	4,097	4,047	4,133	4,039	4,059
K	0,000	0,005	0,000	0,003	0,000
Cations ***Kationi***	**12,241**	**12,237**	**12,323**	**12,297**	**12,284**

Cations are calculated on the basis of 20 O
Kationi su računani na bazi 20 kisika

Pumpellyite and prehnite

Low-temperature alteration processes caused the formation of hydrous Ca-rich minerals (pumpellyite and prehnite) and K-rich sericite in both kind of metadiabases, but not in spilite. The representative chemical analyses of pumellyite and prehnite are given in the Table 9. Pumpellyite of metadiabases II has higher Fe-content (up to 12.09 wt%) than those in metadiabases I (up to 4.77 wt%) indicating lower temperature and pressure conditions of its formation. Prehnite and sericite were found only in metadiabases I.

Discussion and conclusion

According to their chemical composition all studied rocks are basalts having tholeiitic nature.

The fact that **clinopyroxene** restite grains in metadiabases I and fresh clinopyroxene grains in metadiabases II have relatively similar composition may indicate that the both kind of rocks have formed in the similar magmatic environments, but have experienced different postcrystallization histories. On the other side the clinopyroxene of spilite is obviously formed in different magmatic environment, since it shows higher

Table 6: Representative analyses of ilmenites
Tablica 6: Reprezentativne analize ilmenita

	Metadiabases I *Metadijabazi I*				Metadiabase II *Metadijabaz II*
Sample *Uzorak*	Kl5-23	Lj11D-76	BR6A-32	BR6A-33	HS6A-82
			core jezgra	*rim rub*	
SiO_2	0,09	0,06	0,00	0,03	0,02
TiO_2	49,79	49,45	51,40	51,30	50,49
Al_2O_3	0,00	0,00	0,00	0,00	0,00
Cr_2O_3	0,04	0,02	0,03	0,00	0,01
FeO	29,49	41,21	46,06	45,85	43,97
MnO	18,92	7,46	0,74	0,82	3,93
MgO	0,04	0,04	1,19	1,10	0,04
CaO	0,27	0,61	0,04	0,12	0,02
Na_2O	0,02	0,03	0,02	0,00	0,00
K_2O	0,02	0,00	0,00	0,00	0,00
Total ***Ukupno***	**98,68**	**98,88**	**99,48**	**99,22**	**98,48**
Si	0,005	0,003	0,000	0,002	0,001
Al	0,000	0,000	0,000	0,000	0,000
Ti	1,934	1,923	1,960	1,961	1,961
Cr	0,002	0,001	0,001	0,000	0,000
Fe^{3+}	0,000	0,000	0,000	0,000	0,000
Mg	0,003	0,003	0,090	0,083	0,003
Fe^{2+}	1,273	1,782	1,953	1,949	1,899
Mn	0,827	0,327	0,032	0,035	0,172
Na	0,002	0,003	0,002	0,000	0,000
Ca	0,015	0,034	0,002	0,007	0,001
K	0,001	0,000	0,000	0,000	0,000
Cations ***Kationi***	**4,062**	**4,076**	**4,040**	**4,037**	**4,037**

Cations are calculated on the basis of 6 O
Kationi su računani na bazi 6 kisika

Ti-, Al- and Na-content and lower Mg-content. Such characteristics are typical for more evolved magmas.

The great variations of **amphibole** composition inside individual samples testify to the changeable prevailing p-T conditions. Textural relationship between amphiboles and clinopyroxenes points to the clear replacement of clinopyroxene by amphibole. Only the rare nearly euhedral brown magnesiohornblende in the sample Kl5 missing completely clinopyroxene may perhaps be primary magmatic amphibole.

Homogeneous primary **Ti-magnetite** occurs only in spilite. It is characterized by nearly euhedral crystal forms being partially resorbed.

Ti-magnetite in the sample BR6A was primary crystalline phase too, but in the course of time it converted into magnetite with exsolved **ilmenite** lamellae. Such Fe-Ti oxide is enveloped by secondary developed amphibole.

Completely different structural relationship characterizes Fe-Ti-Mn oxides and silicates in the samples Kl5 and Lj11D. There, black opaque oxides consisting of ferropseudobrookite and Mn-ilmenite are always found along the mineral boundaries at the contact with low temperature amphibole pointing to their late stage formation as result of the adjustment of amphibole composition to the temperature and pressure change.

Table 7: Representative analyses of ferropseudobrookite and magnetite
Tablica 7: Reprezentativne analize feropseudobrukita i magnetita

	Ferropseudobrookite *Feropseudobrukit*		Magnetite *Magnetit*			
	Metadiabases I *Metadijabazi I*		Metadiabase I *Metadijabaz I*	Metadiabases II *Metadijabazi II*		Spilite *Spilit*
Sample *Uzorak*	Kl5-32	Lj11D-3	BR6A-70	L1-92	HS6A-63	B9B-78
SiO_2	0,07	0,02	0,04	2,66	0,38	2,73
TiO_2	66,34	70,69	1,86	5,11	13,62	8,40
Al_2O_3	0,00	0,00	0,70	0,28	3,36	0,51
Cr_2O_3	0,01	0,01	0,22	0,03	0,08	0,00
FeO	24,65	22,29	89,80	79,03	74,41	75,73
MnO	0,65	0,13	0,03	0,72	0,17	0,72
MgO	0,10	0,07	0,03	0,03	0,00	0,03
CaO	0,42	0,17	0,06	0,91	0,41	0,94
Na_2O	0,04	0,00	0,02	0,08	0,02	0,23
K_2O	0,00	0,01	0,00	0,03	0,00	0,00
Total Ukupno	**92,28**	**93,39**	**92,76**	**88,88**	**92,45**	**89,27**
Si	0,003	0,001	0,013	0,857	0,117	0,876
Al	0,000	0,000	0,433	1,238	3,174	2,031
Ti	2,049	2,119	0,255	0,107	1,228	0,192
Cr	0,000	0,000	0,054	0,009	0,020	0,000
Fe^{3+}	0,000	0,000	14,799	11,696	8,169	9,994
Mg	0,006	0,004	0,012	0,012	0,000	0,016
Fe^{2+}	0,847	0,743	8,405	9,574	11,112	10,373
Mn	0,023	0,004	0,007	0,196	0,043	0,195
Na	0,003	0,000	0,000	0,000	0,000	0,000
Ca	0,018	0,007	0,021	0,313	0,136	0,324
K	0,000	0,001	0,000	0,000	0,000	0,000
Cations ***Kationi***	**2,949**	**2,879**	**24,000**	**24,000**	**24,000**	**24,000**
Fe/ Fe+Mg			0,999	0,999	1,000	0,999
Cr/ Cr+Al			0,175	0,075	0,016	0,000

Cations are calculated on the basis of 5 O (ferropseudobrookite) and 32 O (magnetite)
Kationi su računani na bazi 5 kisika (feropseudobrukit) i 32 kisika (magnetit)

Ti-magnetite containing numerous minute Al- and Fe-rich titanite patches occurs in metadiabases II. It may additionally have ilmenite lamellae and is usually developed in irregular form along the mineral boundaries. It often envelopes numerous part of silicate minerals pointing to the fact, that it was developed as the last one.

In both kind of metadiabases **Al- and Fe-rich titanite** was formed as result of reaction between primary Fe-Ti oxides and some Ca-rich silicate mineral, whereas Al- and Fe-rich titanite of spilites could be accessory mineral.

Hydrothermal metamorphism resulted in the formation of **chlorite** and patched secondary minerals such as **sericite, prehnite and pumpellyite.**

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Table 8: Representative analyses of chlorites
Tablica 8: Reprezentativne analize klorita

	Metadiabases I *Metadijabazi I*			Metadiabases II *Metadijabazi II*		Spilite *Spilit*
Sample *Uzorak*	Kl5-42	Lj11D-72	BR6A-50	L1-9	HS6A-87	B9B-29
SiO_2	25,82	26,07	31,26	28,12	26,16	32,67
TiO_2	0,07	0,51	0,06	0,00	0,00	0,00
Al_2O_3	19,29	18,16	14,55	16,02	16,44	14,54
Cr_2O_3	0,05	0,01	0,02	0,03	0,00	0,03
FeO	27,51	29,20	22,30	28,96	35,18	19,57
MnO	0,31	0,29	0,36	0,26	0,36	0,12
MgO	14,27	12,63	18,15	12,01	8,88	19,33
CaO	0,09	0,18	0,84	0,50	0,13	0,25
Na_2O	0,01	0,00	0,09	0,02	0,02	0,07
K_2O	0,00	0,00	0,11	0,27	0,17	0,39
H_2O	11,19	11,03	11,6	10,94	10,68	11,73
Total ***Ukupno***	**98,61**	**98,08**	**99,34**	**97,13**	**98,02**	**98,70**
Si	5,537	5,671	6,463	6,167	5,878	6,679
Al^{IV}	2,463	2,329	1,537	1,833	2,122	1,321
ΣT	8,000	8,000	8,000	8,000	8,000	8,000
Al^{VI}	2,409	2,323	2,006	2,305	2,228	2,180
Ti	0,011	0,083	0,009	0,000	0,000	0,000
Fe^{2+}	4,934	5,312	3,856	5,311	6,610	3,346
Cr	0,008	0,002	0,003	0,005	0,000	0,005
Mn	0,056	0,053	0,063	0,048	0,069	0,021
Mg	4,562	4,096	5,594	3,927	2,974	5,891
Ca	0,021	0,042	0,186	0,117	0,031	0,055
Na	0,004	0,000	0,036	0,009	0,009	0,028
K	0,000	0,000	0,029	0,076	0,049	0,102
Cations ***Kationi***	**20,005**	**19,911**	**19,782**	**19,798**	**19,970**	**19,628**
OH	16,000	16,000	0,000	16,000	16,000	16,000

Cations are calculated on the basis of 36 O
Kationi su računani na bazi 36 kisika

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Table 9: Representative analyses of pumpellyite and prehnite
Tablica 9: Reprezentativne analize pumpeliita i prehnita

	Pumpellyite *Pumpelit*				Prehnite *Prehnit*	
	Metadiabases I *Metadijabazi I*		Metadiabases II *Metadijabazi II*		Metadiabases I *Metadijabazi I*	
Sample	Kl5-76	Lj11D-11	L1-80	HS6A-73	Kl5-69	BR6A-59
SiO_2	37,50	37,35	36,03	35,91	43,27	43,15
TiO_2	0,06	0,12	0,09	0,03	0,03	0,00
Al_2O_3	26,19	25,20	21,11	21,71	24,53	23,94
Cr_2O_3	0,00	0,00	0,00	0,00	0,00	0,05
FeO	4,07	3,50	9,63	9,74	0,16	0,04
MnO	0,15	0,17	0,05	0,07	0,02	0,02
MgO	1,49	2,54	1,63	1,37	0,00	0,00
CaO	21,91	22,12	22,17	22,24	26,34	26,94
Na_2O	0,04	0,00	0,06	0,09	0,00	0,01
K_2O	0,00	0,01	0,02	0,00	0,01	0,01
Total **U*kupno***	**91,41**	**91,01**	**90,79**	**91,16**	**94,36**	**94,16**
Si	3,075	3,068	3,055	3,007	6,012	6,023
Al	2,529	2,437	2,108	2,141	4,014	3,935
Ti	0,004	0,007	0,006	0,002	0,003	0,000
Cr	0,000	0,000	0,000	0,000	0,000	0,006
Mg	0,182	0,311	0,206	0,171	0,000	0,000
Fe^{2+}	0,279	0,240	0,683	0,682	0,019	0,005
Mn	0,010	0,012	0,004	0,005	0,002	0,002
Na	0,006	0,000	0,010	0,015	0,000	0,003
Ca	1,925	1,947	2,014	1,995	3,921	4,029
K	0,000	0,001	0,002	0,000	0,002	0,002
Cations ***Kationi***	**8,010**	**8,023**	**8,088**	**8,018**	**13,973**	**14,005**

Cations of pumpellyite are calculated on the basis of 14 (O,OH) and those of prehnite on the basis of 24 (O,OH)
Kationi pumpeliita su računani na bazi 14 (O,OH), a oni prehnita na bazi 24 (O,OH)

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