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Petrographic Characteristics of Extrusive Rocks from Hruškovec, Mt. Kalnik, NW Croatia

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Key words: Upper Cretaceous volcanism, Spilite, Spilitization, Greenschist facies, Ophiolites, Mt. Kalnik, NW Croatia

Abstract

Spilites, altered diabases and meta-basalts from Hruškovec quarry on Mt. Kalnik form part of a complex sequence of extrusive rocks. They are the result of several successive extrusions of basaltic lava within Upper Cretaceous sediments of heterogeneous petrographic composition. The mineral composition and the numerous textural variations are the results of different cooling histories. Intense spilitization was caused by descendent (sea water) and ascendent (juvenile) solutions. Products of the hydrothermal alteration are the result of very low to low-grade metamorphism. The contacts of the extrusives with surrounding sediments suggest an Upper Cretaceous age for the volcanism. The rocks resemble the extrusives found in other parts of Mt. Kalnik, as well as the extrusives from the wider area of NW Croatia and the rocks found in ophiolitic complexes of the Internal Dinarides.

1. INTRODUCTION

The Hruškovec quarry is situated on the north-western slopes of Mt. Kalnik about 8 km east of Novi Marof (Fig. 1). Exploitation of the extrusive rocks began in 1959 and has continued more or less continuously to the present.

Outcrop samples from the quarry were analysed both microscopically and chemically. The results were compared with bore-hole samples from the quarry and the surrounding area (CRNKOVIĆ, 1983, unpub. data).

The presence of diabase rocks in the region of the quarry was noted by WOLF (1861-62). KIŠPATIĆ (1913) quoted findings of very altered diabase. POLJAK (1914) regarded the area between Hruškovec and Glogovnica Creek as being completely composed of extrusives. In 1942 he reported the finding of primary diabase in the Hruškovec Creek (POLJAK, 1942). In the area of Hruškovec ŠIMUNIĆ & ŠIMUNIĆ (1979a) and ŠIMUNIĆ et al. (1981) described Cretaceous chaotic sediments with extrusives, predominantly diabases and spilites. The results of detailed sample analysis of extrusive rocks from the Hruškovec quarry and its surrounding area were presented by VRKLJAN (1989) and CRNKOVIĆ et al. (1974).

2. GEOLOGICAL SETTING

According to ŠIMUNIĆ & ŠIMUNIĆ (1979a) and ŠIMUNIĆ (1983) Upper Cretaceous chaotic sediments of heterogeneous petrographic composition with extrusive rocks are exposed in the valley of Hruškovec Creek. The chaotic sediments are predominantly sandstone and shale, with lesser amounts of fine-grained limestone with radiolaria, altered vitric tuff and radiolarian chert. They include olistoliths of dolomite, limestone and sandstone of Triassic, Jurrasic and Cretaceous age. The youngest limestone olistolith is of Albian-Upper Cretaceous age.

Figure 2 shows a geological map of the quarry area (from 1983, courtesy of CRNKOVIĆ & TOMAŠIĆ, unpublished).

Some parts of the extrusive sequence are massive, while others are composed of volcanic agglomerates. Pillow structures appear only sporadically. Strong and repetitive postgenetic Middle Miocene and Upper Pliocene tectonic movements had important effects on the visible fabric of the extrusive sequence (ŠIMUNIĆ, 1983; ŠIMUNIĆ & HEĆIMOVIĆ, 1979; ŠIMUNIĆ et al., 1981) as they disturbed the primary setting. In this volcanic-sedimentary formation it was not possible to determine the shapes and dimensions of extrusive bodies, because they are broken due to intense tectonism (as shown by the presence of numerous fissures, faults, tectonic breccias and slickensides).

Geomorphologically the quarry can be divided into three zones: the northern (NC), southern (SC) and western (WC) crests. The Northern and Southern crests are separated by the E-W valley of a tributary of Hruškovec Creek, and bounded to the west by the valley of the creek itself. The Western crest is located on the west side of Hruškovec Creek.

3. SAMPLING AND ANALYTICAL TECHNIQUES

Approximately 50 samples were collected at outcrop. Twelve have been analysed both microscopically and chemically. Silicate chemical analysis was done to quantitatively determine the major elements (6 samples from NC, 2 from SC and 4 from WC). In and around the quarry 34 samples from bore-holes (down to a depth

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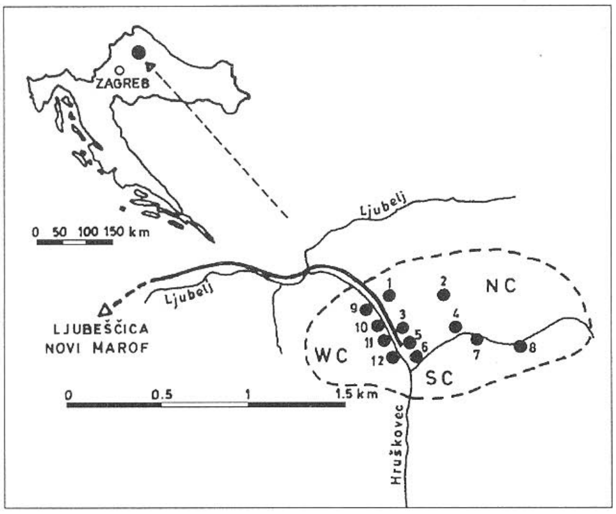

Fig. 1. Geographical position of the Hruškovec quarry and approximative sampling locations. Legend: NC - northern crest; SC - southern crest; WC - western crest; ---- - quarry area.

of 90 m) were also analysed microscopically and chemically (CRNKOVIĆ, 1983, unpubl. data). Results from both sets of samples are compared.

3.1. PETROGRAPHY

The rocks are predominantly gray and greenish in colour, sometimes with green or red-violet spots. Strata exhibiting homogeneous and amygdaloidal structures are equally represented. The numerous structural and textural variations of bore-hole samples are compared to those exhibited in surface samples. Porphyritic or glomerophyric and aphyric rocks are present in equal amount. The primary minerals and volcanic glass are partly or completely replaced by secondary minerals and devitrification products. Relict ophitic, intergranular, intersertal, hyalophitic, pilotaxitic and arborescent textures have been found (Pl. I, Figs. 1-3).

Mineral composition is similar in all investigated rocks suggesting a common genesis. All samples contain plagioclase (labradorite-bytownite) or albite, clinopyroxene, chlorite and the minerals of the zoisite-epidote group. Calcite, magnetite, titanite and sericite (illite?) are also present in the majority of the samples, while minerals such as uralite, pumpellyite, zeolite, prehnite, clay minerals, quartz, rutile, ilmenite, haematite and limonite occur only in a few samples.

Plagioclase (labradorite-bytownite) with 67-77 mol% an-component (samples 4, 5 and 12) was determined by means of theodolitic microscope measurements. Subhedral twins of the albite law with dimensions up to 2.82x0.81 mm occurr and they are cracked and sometimes zoned.

Albite is rarely present as a phenocryst. The grains are usually subhedral, lath-shaped or acicular, mainly simple or polysynthetic twins, sometimes bent with uneven margins and showing irregular extinction. Their sizes vary considerably. Variable amounts of the other alteration products of volcanic glass and primary plagioclase such as chlorite, the minerals of the zoisite-epidote group, sericite (illite?), prehnite and calcite accompany albite.

Clinopyroxene is present as a phenocryst (up to 1.2x0.5 mm) and as a groundmass constituent, or as a main constituent of the aphyric rocks (up to 2.7x2.4 mm). This mineral is frequently fractured, colourless to pale pink, or light brown to red-brown with very weak pleochroism. Some samples contain skeletal clinopy-

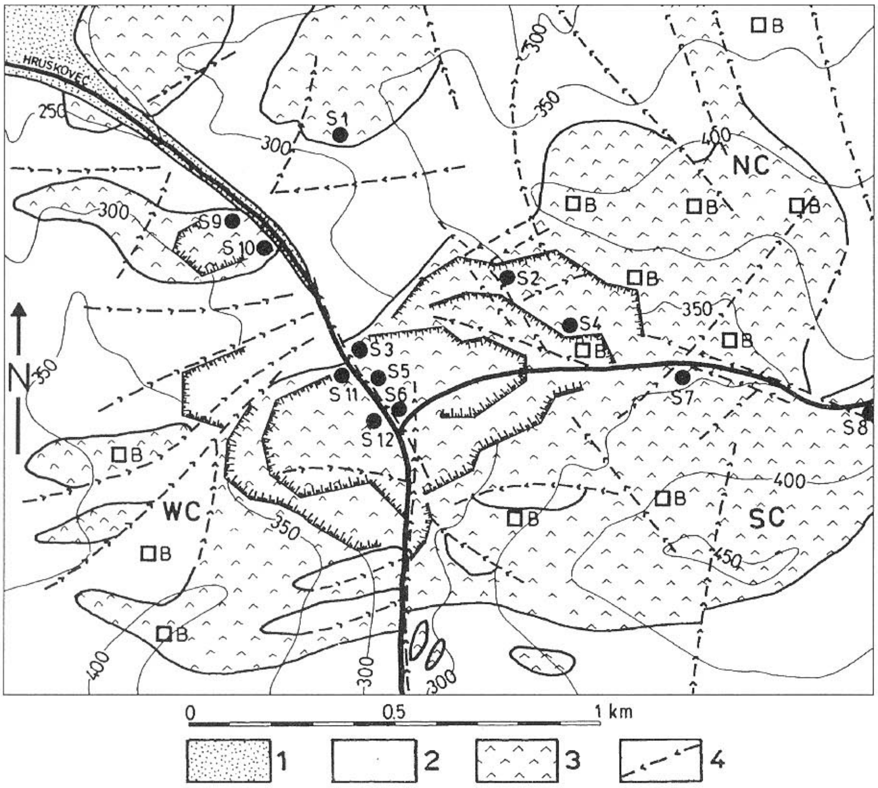

Fig. 2. Geological sketch-map of the quarry area (after CRNKOVIĆ & TOMAŠIĆ, 1983, unpublished). Legend: S - sampling location; B - bore-hole location; 1 - Quaternary; 2 - Upper Cretaceous clastic sediments; 3 - diabase and spilite; 4 - fault and tectonic zone.

roxene with shapes that are reminiscent of spinifex texture (Pl. I, Fig. 4). Some grains are partially altered, while in some samples only their outlines are preserved containing secondary minerals. The alteration products are calcite, epidote-zoisite, chlorite, titanite, pumpellyite, uralite and iron oxides. Clinopyroxene is optically determined as augite-titanaugite.

Chlorite is an alteration product of primary clinopyroxene and volcanic glass. The predominant leptochlorite aggregates, together with other alteration products, replace primary minerals. They are very abundant in the interstices of primary minerals, where sometimes they have replaced all the rock constituents. One sample contains renal-shaped chlorite aggregates which resemble recrystallized colloidal products.

The fine-grained aggregates of the **zoisite-epidote** group of minerals are the alteration products of plagioclase and clinopyroxene. They are also abundant together with other constituents in the interstices of albite and pyroxene grains. Precise mineralogical determination has not been possible, but the colourless to greenish, fine-grained aggregates, with high refraction indices and low to bright interference colours probably belong to this group of minerals.

Calcite is also an abundant alteration product. It sporadically completely replaces the primary minerals. **Magnetite** occurs as subhedral or anhedral grains in the interstices of plagioclase and clinopyroxene grains, less often as clusters. A few samples contain magnetite as the constituent of the opaque portions of clinopyroxene. Magnetite is often altered to haematite and limonite. **Titanite** is also a product of the alteration of clinopyroxene. It is present as a fine-grained aggregate and usually altered to leucoxene. Microscopic alteration products of plagioclase cannot be determined exactly but they resemble **sericite** and **illite**. **Uralite** occurs as lath-shaped aggregates. It is an alteration product of primary clinopyroxene (Pl. I, Fig. 5). **Pumpellyite** is present as lath-shaped or needle-shaped green pleochroic aggregates. Together with chlorite it replaces the original clinopyroxene. **Zeolite** and **prehnite** occur only sporadically as secondary constituents in the interstices of primary minerals. **Clay minerals**, **quartz** and **ilmenite** occur rarely. **Haematite** and **limonite** are present as alteration products of magnetite and other ferromagnesian minerals.

In almost all samples (especially samples 1, 6, 9, 10 and 11) devitrification products of volcanic glass were observed as cryptocrystalline arborescent aggregates.

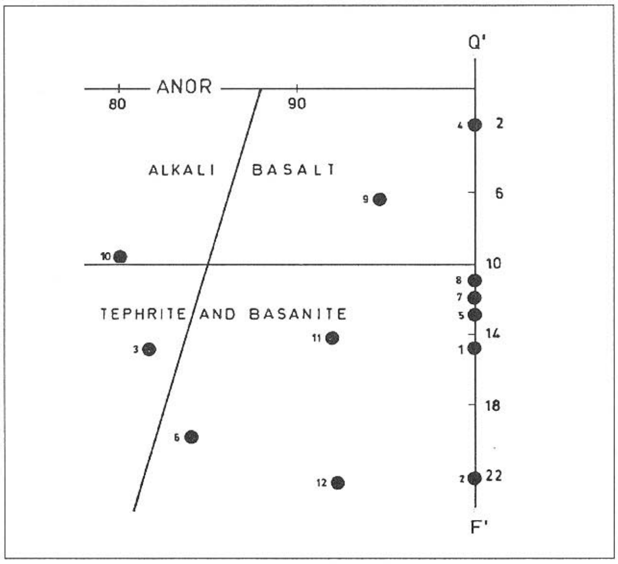

Fig. 3. Q'(F')-ANOR diagram after STRECKEISEN & LE MAITRE (1979).

Some samples contain amygdales of various size and composition, usually containing calcite and chlorite. Sometimes they are zoned, with calcite largely filling the central part, and chlorite filling the remaining part of the amygdale (Pl. I, Fig. 6). Some amygdales contain only chlorite (Pl. I, Fig. 7). The walls of the amygdales are occasionally surrounded by an opaque rim, containing leucoxene, iron oxides and fine vesicles filled with calcite, chlorite and haematite (Pl. I, Fig. 8). Calcite and chlorite fill veinlets of various thickness (≤0.8 mm), with marginal titanite and leucoxene. A few veinlets contain prehnite, epidote and quartz.

3.2. GEOCHEMISTRY

The bulk chemical composition of 12 surface rock samples is presented in Table 1.

The average chemical composition (Table 1) demonstrates that there are almost no differences in relation to the average mid-ocean ridge basalt - MORB (WEDEPOHL, 1988) with respect to Ti, Fe, Mn, Mg, K and P. There is a small variation in Al. Increased Na and H_2O together with decreased Si and Ca are interpreted as the result of abundantly formed secondary chlorite and albite during the spilitization process. A greater number of samples could confirm this interpretation.

Due to numerous micro- and cryptocrystalline alteration and devitrification products, the mineral composition of the majority of samples could not be completely determined. Therefore, norm data were calculated using the Niggli-Barth system (BARTH, 1962) despite the samples being altered. The data are presented in Table 1 and were plotted on a Q'(F')-ANOR diagram (STRECKEISEN & LE MAITRE, 1979). The points fall predominantly in the basanite fields, but also in the alkali basalt fields (Fig. 3). The SiO_2 wt% vs. normative colour index (following Niggli-Barth system; STRECKEISEN, 1978) termed the investigated rocks as leucobasalts and basalts. The rocks are also classified by means of a TAS diagram (LE BAS et al., 1986). The plotted points fall into the fields of basalt (especially the least altered rocks), trachy-basalt, basaltic trachyandesite and tephrite/basanite (Fig. 4). This diagram seems to be appropriate for the interpretation of the investigated rocks. Alternatively, a K/Si diagram could have been applied, but negligible K concentrations indicated that this would be unsuitable in this case.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	Average	Average
	SP	SP	SP	AD	AD	SP	SP	SP	SP	SP	SP	MB		MORB
SiO_2	41.84	42.60	43.66	44.67	43.16	43.92	41.31	39.97	48.55	48.90	48.49	44.04	44.26	49.10±1.50
TiO_2	1.55	1.75	1.70	1.63	1.54	0.90	1.23	1.32	1.74	1.63	1.45	1.03	1.46	1.17±0.50
Al_2O_3	17.42	15.98	18.60	16.44	18.10	20.09	18.35	16.70	17.64	17.98	15.46	19.11	17.66	15.60±1.60
Fe_2O_3	5.61	3.23	2.24	3.63	1.12	1.23	2.43	2.51	1.82	3.16	3.01	2.70	2.72	2.60±1.40
FeO	2.41	5.29	6.12	6.10	5.74	5.82	7.63	8.64	5.71	2.80	6.17	3.95	5.53	6.70±1.70
MnO	0.14	0.09	0.12	0.10	0.13	0.20	0.23	0.24	0.16	0.10	0.14	0.11	0.15	0.16±0.03
MgO	5.18	8.33	9.70	9.92	10.82	10.10	11.53	13.89	7.49	4.38	7.46	8.67	8.96	8.20±2.30
CaO	11.97	12.35	7.87	8.81	9.34	7.60	7.70	5.89	6.75	10.77	7.49	11.02	8.96	11.80±1.40
Na_2O	4.56	3.73	3.84	3.50	3.59	4.25	3.41	3.30	5.35	5.38	5.80	4.12	4.24	2.40±0.50
K_2O	tr	tr	1.16	tr	tr	1.06	tr	tr	0.24	0.95	0.24	0.45	0.25	0.20±0.19
P_2O_5	0.37	0.26	0.32	0.31	0.21	0.12	0.17	0.22	0.32	0.44	0.19	tr	0.25	0.12±0.05
H_2O^+	2.74	3.05	3.39	3.37	3.12	3.85	5.87	5.38	2.78	2.43	3.18	2.70	3.49	0.75±0.39
H_2O^-	0.48	1.24	0.82	1.34	2.37	0.61	0.59	0.80	0.65	0.47	0.56	1.96		
CO_2	4.83	2.66	1.29	0.86	1.13	0.88	0.28	1.28	1.04	1.26	0.78	0.45		
Σ	99.10	100.56	100.83	100.68	100.37	100.63	100.73	100.14	100.24	100.65	100.42	100.31		
C	-	-	-	-	-	-	-	1.25	-	-	-	-		
or	-	-	6.90	-	-	6.20	-	-	1.35	5.60	1.35	2.70		
ab	27.75	14.76	18.65	30.20	19.90	15.70	19.20	20.60	41.30	37.50	37.80	13.85		
an	29.40	28.20	30.78	30.15	34.35	32.95	36.00	28.95	23.80	22.53	15.75	32.83		
ne	9.96	12.24	9.90	1.32	8.04	13.62	7.44	6.15	4.53	7.02	9.15	14.31		
wo	12.86	-	-	-	-	-	-	-	-	11.54	-	-		
di	-	27.44	5.48	10.36	9.60	3.52	1.80	-	6.56	-	16.52	18.28		
fo	11.61	-	-	-	-	-	-	-	-	9.24	-	-		
ol	-	10.63	22.76	21.03	24.25	25.23	30.79	37.86	17.34	-	13.74	13.67		
mt	2.97	3.57	2.40	3.96	1.20	1.28	2.66	2.75	1.95	3.30	3.20	2.87		
hm	2.26	-	-	-	-	-	-	-	-	0.02	-	-		
il	2.30	2.60	2.44	2.32	2.20	1.26	1.76	1.96	2.52	2.28	2.08	1.48		
ap	0.91	0.56	0.69	0.67	0.45	0.24	0.37	0.48	0.67	0.96	0.43	-		
c.i.	32.91	44.80	33.77	38.34	37.70	31.53	37.38	43.05	29.04	27.34	35.97	36.30		
Q'	0	0	0	0	0	0	0	0	0	0	0	0		
F'	14.84	22.17	14.95	2.14	12.91	19.89	11.88	11.04	6.38	9.66	14.29	22.47		
ANOR	100	100	81.69	100	100	84.16	100	100	94.63	80.09	92.11	92.40		

Table 1. Chemical analyses (in weight %) and Niggli-Barth norms. Legend: SP - spilite; AD - alterated diabase; MB - meta-basalt; MORB - mid-ocean ridge basalt (WEDEPOHL, 1988).

In accordance with the mineral constituents, their relationships, structures, textures, and chemical composition, spilites prevail among the investigated rocks while altered diabases (samples 4 and 5) and meta-basalts (sample 12) containing labradorite-bytownite are minor components. According to STRECKEISEN (1978) a spilite is a basaltic rock with eruptive features and the albite-chlorite mineral assemblage typical of metasomatic or metamorphic processes. Altered diabase is hypabyssal rock, usually medium grained, of gabbroic composition, commonly with ophitic, subophitic or intergranular texture, which occurs in minor intrusions or in the interior of thick lava flows. Metabasalt is a slightly metamorphosed volcanic rock in which the igneous texture is still preserved allowing the original rock type to be deduced.

4. PETROGENESIS

All extrusive rocks from the Hruškovec quarry are more or less altered by postmagmatic hydrothermal processes, but the character of the primary magma cannot be strictly determined. Due to a high content of Na, normative nepheline appears in all the samples. Although in the Q'(F')-ANOR and TAS diagrams the points lie predominantly in the alkali fields, low TiO_2 as well as low K and P indicate that they probably belong to nonalkali rocks (HYNDMAN, 1985). Measurement of immobile HFS would yield more precise information about the character of the primary magma.

The rock textures are predominantly relict diabase or microdiabase. The diabase textures indicate slow cooling. However the arborescent texture, and presence of skeletal pyroxene reminiscent of spinifex texture (WIMMENAUER, 1985) suggest rapid crystallization. The altered diabases containing labradorite-bytownite (samples 4 and 5) originated from slow cooling in the interior of thick lava flows or shallow intrusions. Alteration processes have had little effect on these rocks and the basic plagioclases are not albitized. In the vicinity of the quarry CRNKOVIĆ et al. (1974) found and described graded structural alteration ranging from granular texture in the middle, to ophitic and porphyritic, pilotaxitic and microophitic in the outer parts of the magmatic body (where the plagioclase is less basic).

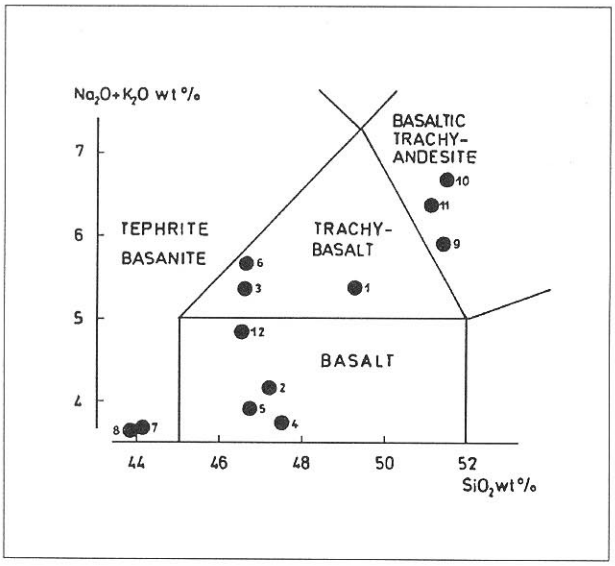

Fig. 4. TAS diagram after LE BAS et al. (1968).

According to experimental data (WINKLER, 1979), albite and less basic plagioclase originates from anorthite at lower temperatures than those required for basic plagioclases. Apparently, the percent of the an-component is directly related to the temperature of formation.

The abrupt, irregular changes of colour, structure and texture among the investigated rocks suggest several successive extrusions and different rates of cooling inside the magmatic body. The fluid lava has flowed into the adjacent sediments or into parts of previously partly or completely cooled extrusives.

The investigated rocks are of similar mineral composition, which differ in the percentages of a given constituent with varying intensity of alteration. Spilitization is the most common form of hydrothermal alteration. Appreciable amounts of calcite originated at temperatures ranging from 130 - 250°C (ECKHARDT, 1971) from the unstable anorthite component of plagioclase and from pyroxene. Calcite was precipitated in parts of the host minerals as well as in the intergranular spaces, fissures and cavities. The rare, visible pillow structures suggest a marine environment. Seawater would have been a good source of Na, while CO_2 probably had a juvenile origin. During extrusion into sea water or intrusion into unconsolidated marine sediments, abruptly cooled margins prevented the further issue of magmatic fluids. Thus, the juvenile solutions intensely affected the extrusives and altered them. Pumpellyite and prehnite are stable at temperatures up to 350°C and at pressures below 3 kbar. Uralite is stable up to 500°C (WINKLER, 1979). Up to 15 % titanite can occur in meta-basalt of very low to low-grade metamorphism at very low pressure. The appearance of zoisite/clinozoisite (also epidote if sufficient Fe^{3+} is available) defines the commencement of low-grade metamorphism (temperature about 350°C). Chlorite could be formed over a wide range of pressure and temperature conditions (diagenesis to low-grade metamorphism). It was proven experimentally (MUELLER & SAXENA, 1977) that leptochlorite was more stable at lower temperature than orthochlorite.

The observed mineral assemblage is typical of lower greenschist facies and is interpreted as being the result of the effects of descending reheated sea water and ascending juvenile hydrothermal solutions.

The rocks are strongly fractured due to postgenetic tectonic movements (Middle Miocene and Upper Pliocene). The cracks allowed the surface waters to penetrate to depth and also facilitated alteration and intense weathering of the extrusive body.

In the bore-holes the extrusive rocks are found to depths of about 90 m, and are similar in character to those on the surface - analogous mineral composition, the same alteration products, variable texture, tectonic dislocations and even weathering. The varying intensity of spilitization is attributed to changeable rates of inflow of the hydrothermal solutions in different parts of rock mass, due to the arrangement of the fissure system. In the middle course of Hruškovec Creek (about 1 km southwards from the quarry) outcrops of altered gabbro have been observed. Between this gabbro and altered diabase, spilitic rocks have been investigated (VRKLJAN, 1989). Altered diabase probably cooled in the interior of a thick lava flow or as shallow intrusion. Meta-basalt is formed due to a weak inflow of hydrothermal solutions.

The volcanic agglomerates were formed due to explosive extrusion or flow of lava enclosing fragments of previously formed extrusive rocks or surrounding sedimentary rocks.

The contacts of the extrusives with the surrounding sediments can be observed at several places. On the western crest the extrusive rocks are in tectonic contact with reddish, schistose, crumbly shale, which is strongly crushed, silicified and haematitized. At the contact, extrusive breccias and greenish, crushed, dusty extrusives with haematite impregnated fragments and ubiquitous renal-shaped chlorite aggregates (which resemble recrystallized colloidal products) occurr. This contact was also observed on the northern crest (Pl. II, Fig. 1). The clastic sediments are Upper Cretaceous in age (CRNKOVIĆ et al., 1974; ŠIMUNIĆ & ŠIMUNIĆ, 1979a).

Within the dark grey extrusives from northern crest, there are small to large fragments of pink limestone (Pl. II, Fig. 2). At the contact, the limestone is recrystallized and partly dolomitized due to alteration by postmagmatic hydrothermal solutions. The intensity of hydrothermal dolomitization decreases with distance from the contact (Pl. II, Fig. 3). Several millimetres to one centimetre from the contact the dolomitization process has disappeared completely. The cracks in the limestone resulted from the extrusion of the lava and they are filled with chlorite and epidote. Hydrothermal solutions of variable composition have successively flowed into the rock. Microcrystalline quartz (which replaces carbonates), is present in some veinlets. The youngest veinlets contain calcite and cross the contact between the extrusive and the limestone. The differences in the mineral composition of veinlets are due to the different pH conditions of the hydrothermal solutions.

The slow extrusion of lava into the tectonically crushed Turonian-Senonian micritic limestones was also observed on the northern crest (Pl. II, Fig. 4). The haematitized crystalline limestone has a granoblastic texture probably due to contact metamorphism. Along the contact of the lava with the recrystallized limestone a thin zone of haematite was observed. Calcite is also strained with haematite (Pl. II, Fig. 5).

The above-mentioned contacts of the extrusive rocks with different sedimentary rocks suggest an Upper Cretaceous age for the extrusions.

The investigated rocks are analogous to extrusive rocks from other parts of Mt. Kalnik (VRKLJAN, 1988, 1992; VRKLJAN & VRAGOVIĆ, 1991). Consequently, the petrogenic processes of the whole area were uniform.

In other parts of North-western Croatia (Mts. Ivanščica, Medvednica and Samoborska Gora) spilites of similar mineral composition and textures have been found and described. A Cretaceous for sandstones associated with ophiolite containing spilite on Mt. Ivanščica, was proposed by HERAK (1960). GOLUB & VRAGOVIĆ (1960) cited earlier authors who proposed a Triassic or Cretaceous age, for spilite from Gotalovac on Mt. Ivanščica. BABIĆ & GUŠIĆ (1978) investigated the age of a clastic complex associated with ophiolites on Mt. Ivanščica and, according to the fossils from interbedded limestones, assigned the strata to the Hauterivian-Albian and possibly Cenomanian. According to BABIĆ et al. (1979), spilitic rocks of Mt. Ivanščica form an integral part of the Repno formation. The Repno clastic formation was formed along an active continental slope from the Albian to the Turonian. ŠIMUNIĆ & ŠIMUNIĆ (1979b) cited Triassic (Anisian) spilites of Mt. Ivanščica. The albitized andesites in the area of Šumi Creek on Mt. Ivanščica, are also of Triassic age (MARCI et al., 1982, 1984). Their mineral paragenesis implies low-grade metamorphism. Within discussion of numerous different extrusive rocks of Cretaceous age on Mt. Medvednica, CRNKOVIĆ (1963), cited the spilites that originated due to sodium metasomatism of consolidated rocks. Spilitic rocks from Samoborska Gora were dated as Upper Cretaceous by HERAK (1956). They are commonly associated with Upper Cretaceous sandstones, which record alteration processes possibly caused by eruption. According to the analogous projection position of rock composition on a QLM diagram, BRAJDIĆ & BUKOVEC (1989) interpreted spilites from Samoborska Gora as being a continuum of an ophiolitic zone traced from Northern Bosnia. These spilites were interpreted as being low temperature alteration products of basaltic rocks and their mineral composition as a response to lower greenschist facies metamorphism.

Many observations of spilites from NW Croatia, claimed by different authors, highlighted the important role of magmatic activity in the Upper Cretaceous which consequently resulted in the appearance of the rocks which may be well compared to those found in ophiolites.

Spilite rocks derived from basaltic and basalt-andesitic magma, which intruded into saturated marine sediments or flowed directly into sea water, were investigated in the Upper Cretaceous Flysch complex of Northern Bosnia (PAMIĆ, 1977). Triassic or Jurassic (Malm) spilites of similar composition were found on the Dalmatian islands Brusnik, Jabuka and Vis (GOLUB & VRAGOVIĆ, 1975). Numerous other occurrences of similar rocks have been found in the Dinarides (TRUBELJA, 1984) as well as globally (ECKHARDT, 1971; HENTSCHELL, 1961; HERRMAN & WEDEPOHL, 1970; KALSBEEK & JEPSEN, 1984; MERRIMAN et al., 1986, and others).

Consequently, spilitization is the result of widespread low-grade metamorphism. It occurred in the presence of CO_2 regardless of the geological age and character of the primary magma, if hydrothermal solutions enriched in Na affected the basaltic rocks.

In NW Croatia spilites appear as part of the ophiolite complex (HERAK, 1960; BRAJDIĆ & BUKOVEC, 1989). However, in the Hruškovec quarry occurences of mantle peridotites have not been observed either on the surface, or in the bore-holes. Serpentinites occured on Mt. Kalnik only as deformed parts of olistoliths which owe their present position to tectonic movements (ŠIMUNIĆ et al., 1981). Gabbro has not as yet been discovered in the quarry. The rare occurences of gabbro on Mt. Kalnik (CRNKOVIĆ et al., 1974) very probably represent the slowly cooled interior of the extrusion or shallow intrusion (VRKLJAN, 1989). This Upper Cretaceous volcanic-sedimentary complex can be compared to similar formations in other parts of North-western Croatia (which are also of Upper Cretaceous age), as well as to Jurassic volcanic-sedimentary complexes of Internal Dinarides. On Mt. Kalnik some members of the Upper Cretaceous ophiolitic complex are missing completely or occur only sporadically.

The exact geotectonic setting for the Hruškovec quarry extrusive rocks could not been inferred from the current geochemical data, because all the rocks have been altered to a greater or lesser extent and more analytical data are required.

5. CONCLUSIONS

The complex fabric of the extrusive rocks in the Hruškovec quarry could be interpreted as the result of several successive extrusions, and shallow intrusions, of basaltic lava into Upper Cretaceous sediments of heterogeneous petrographic composition. This is inferred from the abrupt, irregular changes of colour, structure and texture observed among several rock types which are in contact. Intense postgenetic tectonics resulted in the presence of numerous fissures, faults, tectonic breccias and slickensides. The tectonic movements disturbed the primary relations of the rock mass. The mineral composition is similar in all examined samples, but the differences appear in different mineral percentages due to the variable intensity of spilitization. All the samples contain plagioclase (labradorite-bytownite) or albite, clinopyroxene (augite-titanaugite), chlorite and minerals of the zoisite-epidote group. Calcite, magnetite, titanite, sericite (illite?), uralite, pumpellyite, zeolite, prehnite, clay-minerals, quartz, rutile, haematite, limonite and ilmenite are the constituents of only a few samples.

The numerous textural variations, among which relict diabase and microdiabase textures prevail, suggest different cooling histories with regard to velocity and location of cooling.

Spilites predominate among the 12 microscopically and chemically examined samples. Two samples of altered diabase and one sample of meta-basalt contain labradorite-bytownite and they represent the slowly cooled, and weakly altered interior of the extrusion or shallow intrusion. The rocks were variably spilitized by the action of descending reheated sea water and ascending juvenile solutions. Alteration also occured by other hydrothermal processes. The observed mineral assemblage is typical of lower greenschist facies metamorphism. The weathering of rocks was also revealed.

The bore-hole samples of extrusive rocks at depths below 90 m are analogous to those from the surface according to texture, mineral composition and alteration. Due to intense tectonics, the eventual regular changes in intensity of spilitization with depth could not be established.

The contacts of the extrusives with crushed, silicified and haematitized shales of Upper Cretaceous age, and with recrystallized and dolomitized or haematitized micritic limestone of Turonian-Senonian age suggest an Upper Cretaceous age for the extrusions.

The extrusive rocks of the Hruškovec quarry are similar to those from the other parts of Mt. Kalnik and also from elsewhere in North-western Croatia. Magmatic activity in the Upper Cretaceous resulted in the formation of extrusive rocks (recent spilites) which, together with their associated sedimentary rocks, may be compared to those found in the ophiolitic complexes of the Central Dinaric Ophiolite Belt. They very probably represent dismembered ophiolites.

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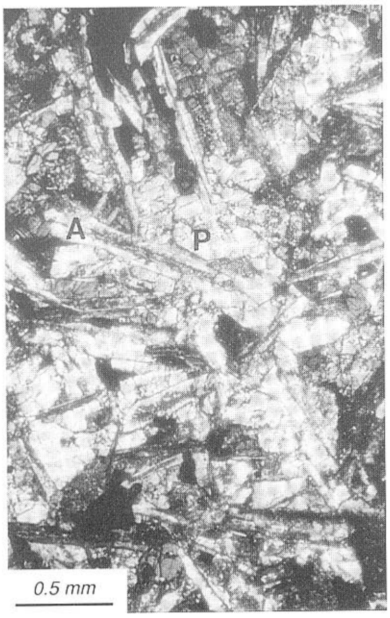
PLATE I

1. Relict ophitic to intergranular texture. Albite (A) and clinopyroxene (P), N+ (sample 3).
2. Relict pilotaxitic texture, N (sample 12).
3. The arborescent groundmass and the albite phenocryst (A), N+.
4. Sceletal clinopyroxene (P) with reminiscent spinifex texture, N (sample 6).
5. Uralite (U) replacing clinopyroxene (P), N (sample 8).
6. Amygdale with calcite (Cc) and chlorite (Ch), N+ (sample 6).
7. Amygdale with chlorite, N+ (sample 11).
8. Amygdale with calcite. Opaque amygdale boundary contains small amygdales with calcite (Cc), chlorite (Ch) and haematite (H), N+ (sample from the northern crest).

PLATE II

1. The tectonic contact between the spilite (E) and schistose shales (S). Northern crest of the Hruškovec quarry.
2. The enclaves of limestone (L) in the extrusive (E), northern crest.
3. Recrystallization and partial dolomitization (D) of the limestone (L) at the contact with the extrusive (E), N+ (detail from Fig. 2, in frame).
4. The contact of extrusive (E) and limestone (L), northern crest.
5. The contact of extrusive (E) and limestone (L). Amygdale of calcite (A), N+ (detail from Fig. 4, in frame).

PLATE I



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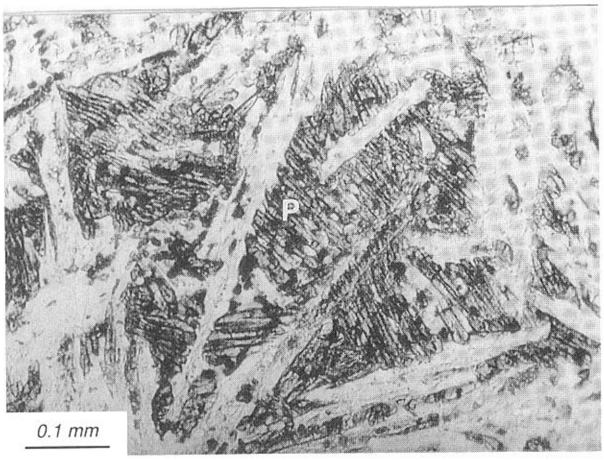

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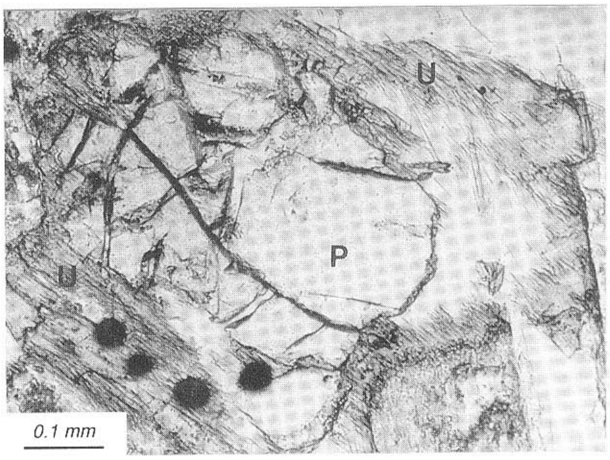

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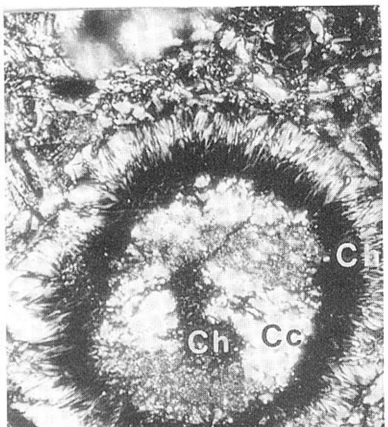

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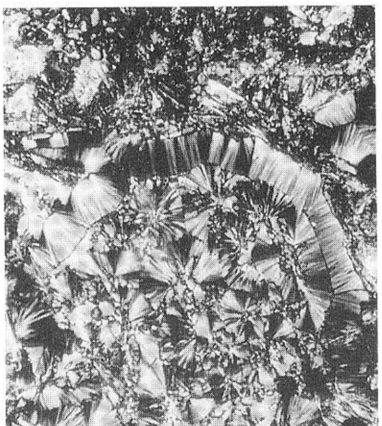

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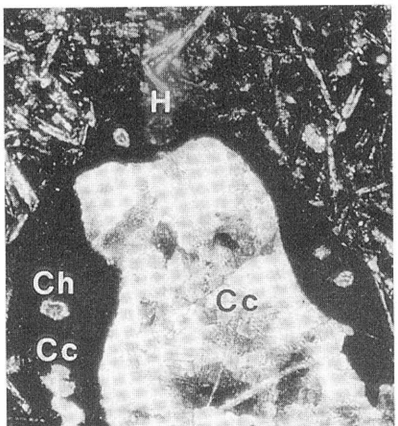

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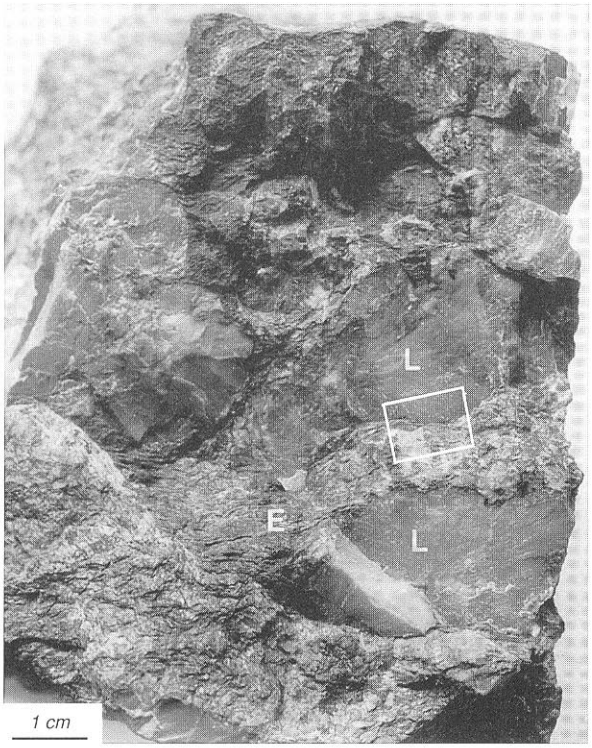

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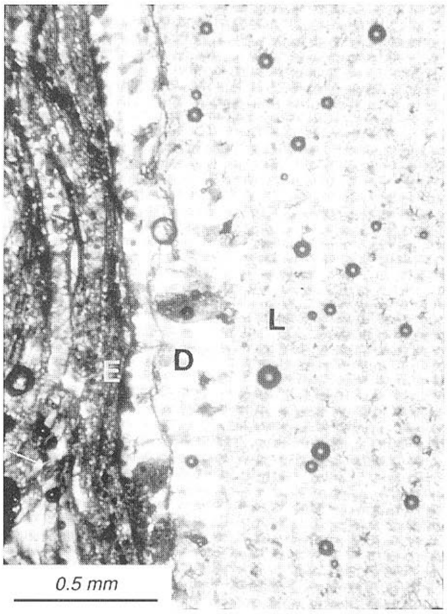

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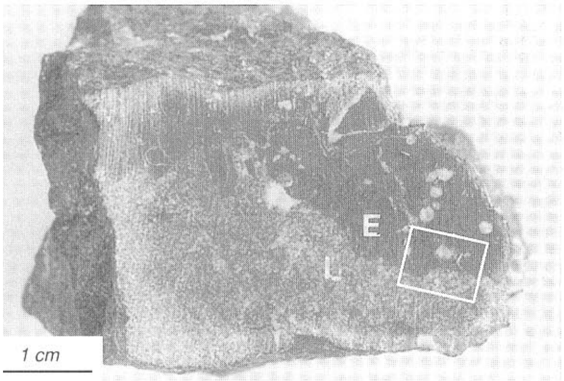

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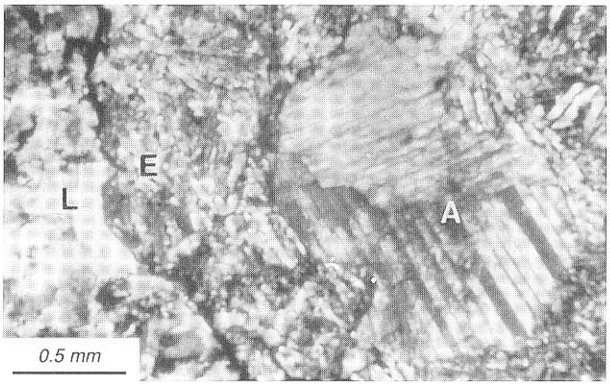

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