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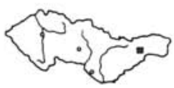
# PETROLOGY AND GEOCHEMISTRY OF METABASALTS FROM RAKOVEC (PALEOZOIC OF GEMERIC UNIT, INNER WESTERN CARPATHIANS)

*(Figs. 24, Tabs. 6)*

*We dedicate the work to the memory of our friend RNDr. Š. B a j a n í k, CSc. who had devoted all his life to the investigation of the Rakovec group.*



A b s t r a c t: Metabasalts from Rakovec are the most frequent rocks of the complex of metemorphosed volcanites, volcaniclasts and pelitic sediments included in Paleozoic. They are occurring in aphyric and porphyric types (clinopyroxene phenocrysts, and/or albitized plagioclase) with massive and amygdaloidal varieties, form lava flows several meters thick, sometimes showing pillow structure. The study of clinopyroxene composition as well as distribution of REE and other elements (Hf, Ta, Th, Y, Zr) considered immobile during metamorphism has shown their affinity to E-MORB, and/or OIT types. If they are compared to the data from the other Paleozoic groups of the Gemeric unit and the data from recent island arcs they having been generated in the environment of destructive lithospheric boundaries cannot be, however, discounted. The basalts underwent poly-phase metamorphism. The origin of Na-Ca amphibole in its PT-conditions corresponds to the interval between greenschist and blueschist facies and the origin of actinolitic hornblende to greenschist facies. Metamorphism is probable to have originally reached blueschist facies.

Р е з ю м е: Метабазальты района Раковец являются самым распространенными породами комплекса метаморфических вулканитов, вулканокластических и пелитовых осадков палеозоя. Они встречаются в афировых и порфировых типах (клинопироксеновые фенокристаллы и/или альбитизированные плагиоклазы) с массивными и миндалекаменными разновидностями. Они образуют лавовые потоки толщиной несколько метров, иногда проявляющие

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подушечную структуру. Изучение состава клинопироксена и распределения р. з. э. и других элементов ((Hf, Ta, Th, V, Zr), считаемых неподвижными во время метаморфизма, показало их сходство с E-MORB и/или типами OIT. Но если их сравнить с данными других палеозойских серий гемеридной единицы и современных островных дуг, их образование в среде разрушительных литосферических границ нельзя исключить. Базальты претерпели полифазовый метаморфизм. Образование Na-Ca амфибола в его PT условиях отвечает интервалу с фации зеленых сланцев по фацию голубих сланцев и образование актинолитовой роговой обманки отвечает фации зеленых сланцев. Предполагается, что метаморфизм первоначально достиг фации голубих сланцев.

## *Introduction*

The Western Carpathians are divided into outer, central and inner zones with the Gemeric unit representing the northernmost unit of the inner Western Carpathians. It shows Paleozoic and Mesozoic levels. Metabasalts from Rakovec are a component of the Rakovec group — one of the lithostratigraphic groups of the Gemeric unit Paleozoic. They have been investigated by several authors, but their petrogenetic model and lithostratigraphic classification have not been settled on yet. Chemical compositions of their rock-forming minerals have not been studied either. The aim of this paper is to give at least partial answers to these unsolved questions on the basis of our own data as well as re-evaluation of earlier data.

## *Geology*

The region where metabasalt bodies show rich occurrences S from the village of Rakovec (NE from Dobšiná) is the type locality of the Rakovec group (B a j a n í k, 1976) which has been defined as a volcanic-sedimentary complex of uncertain Paleozoic age that underwent a low degree of metamorphism. Volcanism showed mostly basic character. The Rakovec group forms a narrow belt (on the surface its maximum thickness reaches 2 km) tectonically limited. Its direction is conform with the general direction of the Paleozoic groups. The position of the Rakovec group with regard to the other Paleozoic units of the Gemeric unit as well as its lithostratigraphic characteristics are given in the scheme of Tab. 1.

The scheme in Tab. 1 represents a modified variation of the earlier conception of the Gemeric unit Paleozoic which originally had supposed its autochthonous, and/or subautochthonous position and lithological boundaries among lithostratigraphical groups (B a j a n í k et al., 1983). In recent years also a different conception has been published (G r e c u l a, 1982) saying that the complexes of the Gelnica and the Rakovec groups in original sense represent the unified Volovec group. This is divided into three lithostratigraphic sequences with characteristic volcanic complexes in lower and upper sequences. The mentioned author (l.c.) supposed nappe structure (8 partial nappes, each with complete development of the Volovec group). Following this conception the metabasalts under study are a component of highly developed upper sequence of the Volovec group (in this region the northernmost) nappe.

Table 1

The scheme of lithostratigraphic classification of Paleozoic in the region of the northern part of the inner Western Carpathians

| lithostratigraphic group | age | volcanic rocks | sedimentary rocks |
|---|---|---|---|
| the Krompachy group | Permian | metamorphosed rhyolites and their volcanoclasts, andesite volcanoclasts, rarely basalts | metamorphosed conglomerates, breccias and sandstones, violet schists, gypsums, rarely carbonates |
| the Dobšiná group | Upper Carboniferous | metamorphosed basalt volcanoclasts, less basalts | metamorphosed polymict conglomerates, sandstones, carbonates, black shales |
| the Klátov group | Lower Paleozoic (?) | amphiboles, serpentinites, metagabbros, metahyaloclastites | gneisses (metapsammites), carbonates |
| the Rakovec group the Sykavka sequence | Lower Paleozoic (?) | metamorphosed basalts to basaltoid andesites and their pyroclasts, rarely also dacites and rhyolites | sericitic, sericitic--chloritic and quartzose--sericitic phyllites |
| the Smrečina sequence | | rare metamorphosed basalts, their pyroclasts and rhyolites | metamorphosed sandstones, quartzose phyllites, quartzose-sericitic phyllites |
| the Gelnica group | Cambrian to Devonian | acid metavolcanoclasts, metamorphosed rhyolites, less basalts, rarely andesites | metamorphosed psammites (sandstones, graywackes, quartzites), graphitic, sericitic, chloritic-sericitic, quartzose phyllites |

The metabasalts under study are a part of the sequence which B a j a n í k et al. (1983) denoted as the volcanogenic sequence (Sykavka sequence) of the Rakovec group. In the lower part (more to the south) it is formed mostly of metabasalts and their volcaniclasts with sporadic intercalations of pelitic metasediments (sericitic phyllites, hematite phyllites to quartzites). There have been detected infrequent occurrences of metapyroclasts of acid effusives, probably dacites (B a j a n í k, 1969). To the north, the portion of pelitic metasediments increases. Near the northern margin the Rakovec group is formed mostly of metapelites (namely chloritic-sericitic phyllites) with rare occurrences of metabasalts, and/or metapyroclasts.

Most studied samples of metabasalts come from the southern part of the volcanigenic sequence, from the region S from the village of Rakovec between the Martinka and Ostrá peaks. In these places, metabasalts form lava flows of several meters separated by metapyroclasts, less frequently metapelites as well (B a j a n í k, 1976). Thicker flows can show differentiated textures with

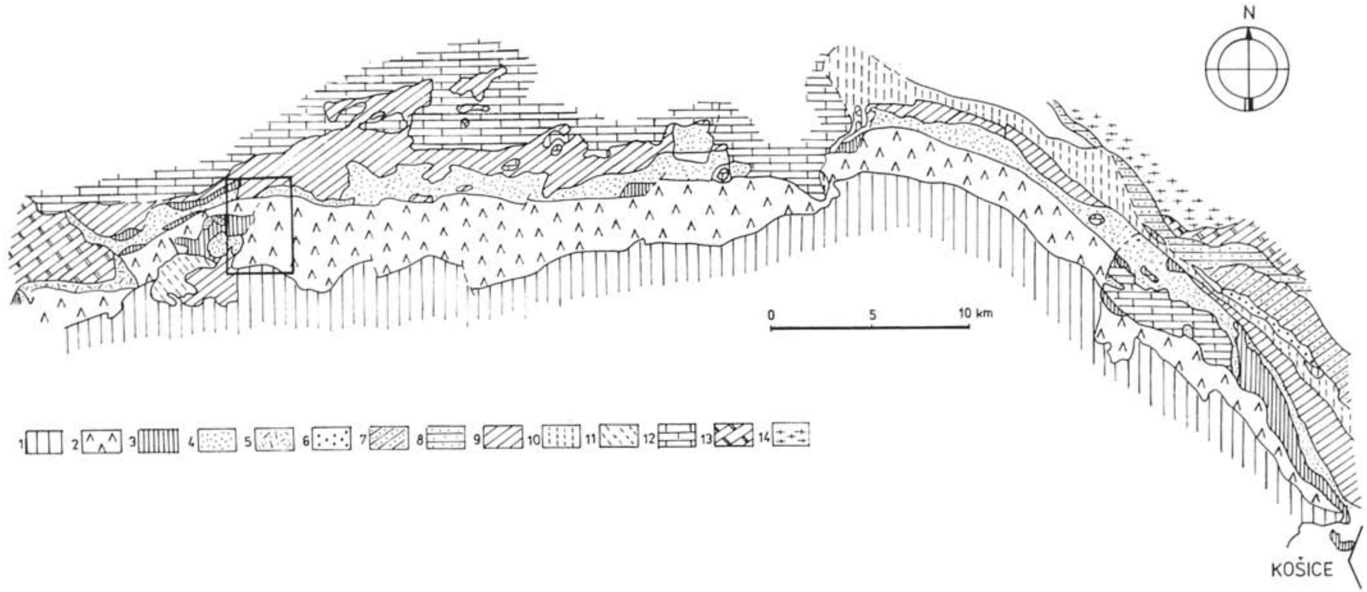


Fig. 1A. Simplified geological-tectonic sketch-map of the northern part of the inner Western Carpathians.
*Explanations:* 1 — Gelnica group; 2 — Rakovec group; 3 — Klátov group (1—3 Early Paleozoic); 4—6 Dobšiná group (Upper Carboniferous); 7 — Črmeľ group (Carboniferous); 8 — Carboniferous of envelope unit of the Čierna hora Mts. zone; 9 — Krompachy group (Permian); 10—12 — Mesozoic units of the inner Western Carpathians; 13–14 – units of the central Western Carpathians.

prevailing amygdaloidal types of structure in the upper parts of flows and ophitic, and/or porphyric structures in the centres of flows. Pillow structures (B a j a n í k, 1975) as well were found on the eastern slope of Ostrá. Few lava flows were forming in metapelite environment. Detailed study of paleovolcanic and lithostratigraphic study is rather limited due to superposed metamorphic processes and so far undistinguished tectonic pattern of a broader area.

### *Petrography*

Metabasalts from Rakovec show textures variable due to spatial positions in the body, and/or particular pillow. Aphyric and porphyric types can be distinguished. Porphyric clinopyroxene and plagioclases reach 5 mm, sometimes 10 mm in sizes. In several places their glomerophyric cluster can be seen. The both phases are characteristic for magmatic corrosion occurrences (Fig. 2). The matrix shows ophitic, and/or subophitic texture. The same texture can be seen also in aphyric types except those which had originally represented vitreous, and/or aphanitic varieties.

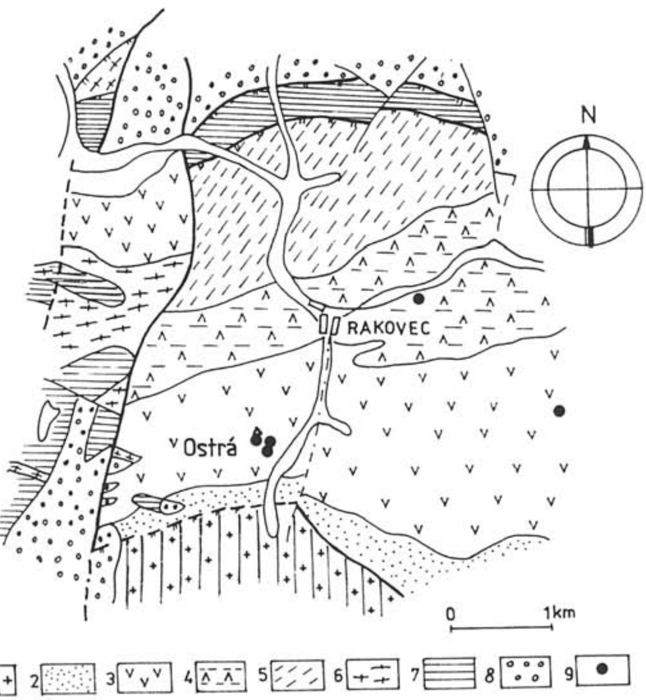


Fig. 1B. Geological sketch-map of the Rakovec surroundings (B a j a n í k et al., 1983 — adapted).

*Explanations:* 1 — Gelnica group; 2 — Rakovec group; Smrečina formation; 3—5 — Rakovec group, Sykavka formation, 3 — mostly metamorphosed basalts and their volcaniclasts, 4 — phyllites with intrusions of metamorphosed basalt, volcaniclasts, 5 — quartzose-sericitic, less chloritic-sericitic phyllites with few metabasalts and metavolcaniclasts; 6 — Klátov group; 7 — Dobšiná group; 8 — Krompachy group; 9 — places of metabasalt sampling.

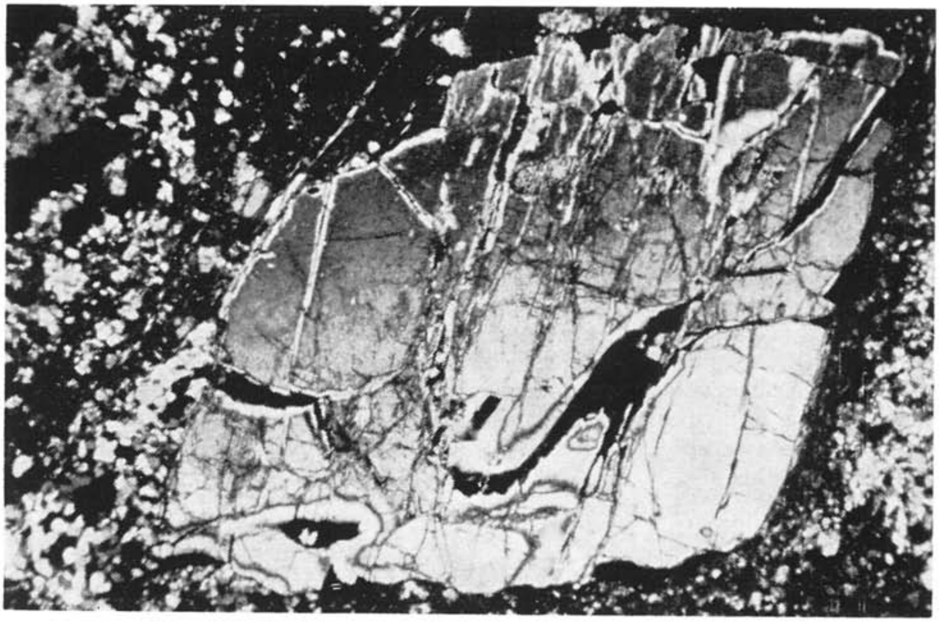

Fig. 2. Porphyric clinopyroxene in metabasalt from Rakovec with phenomena of magmatic corrosion. Magn. 30x, X polars.

Varietes of textural types are observable especially within particular pillows (Fig. 3). Their central parts were formed of plagioclase and clinopyroxenephyric basalt with massive structure. Towards upper margin of pillow the size and abundance of phenocrysts lower. Pillow margins (5—30 mm thick) show aphyric structures. Porphyric phases towards the basal part of pillow raise in number and simultaneously their sizes grow up to the maximum 10 mm (Figs. 4, 5). The above mentioned suggests that within particular pillows after being separated (formation of close systems) the process of gravitational differentiations took place to a lesser extent.

Except the types with massive structure there are rather frequent occurrences of amygdaloidal basalts with amygdales containing chlorite, albite and carbonates (Fig. 6). Amygdale sizes are under 6 mm. It is often possible to find porphyric-amygdaloidal basalts.

In several aphanitic types of basalts near the peak Ostrá, occurrences of enclosures, and/or breccias of basalts with different granular and structural developments can be found (Fig. 7). Enclosure sizes reach 3 mm, they are oval-shaped and in detail are not sharply limited in the environment. They are probably xenoliths – fragments from cooled volcanic bodies incorporated into moving lava.

All the mentioned marks of original volcanite textures as well as mineral associations of primary (magmatic) origin have been preserved in the area under study only partially. They were to various extents overlapped by meta-

Fig. 3. Pillow structure of basalt lava flow on the eastern slope of the Ostrá peak near Rakovec.

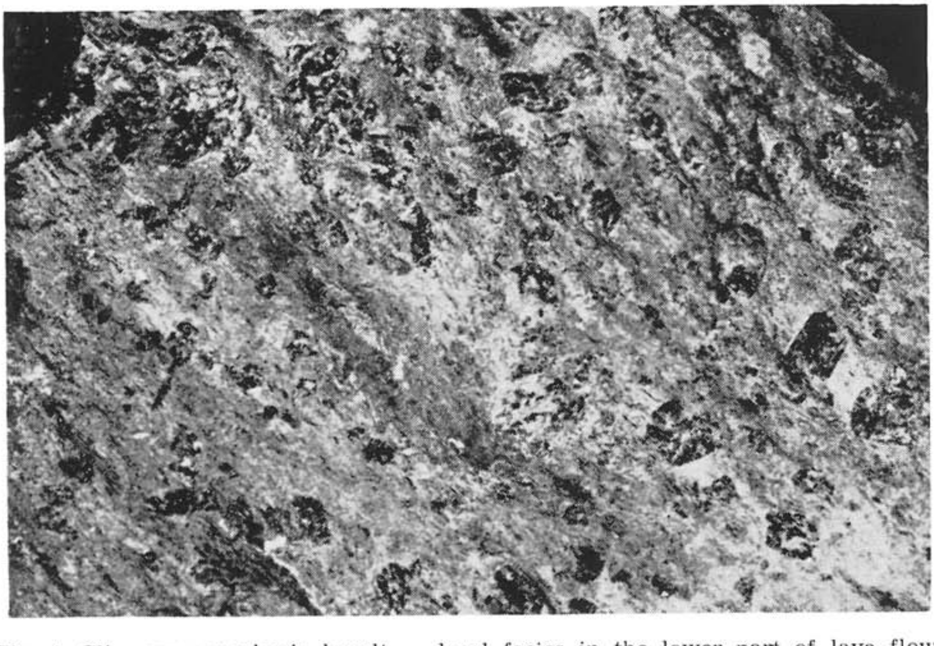

Fig. 4. Clinopyroxenephyric basalt — local facies in the lower part of lava flow; Rakovec, natural size.

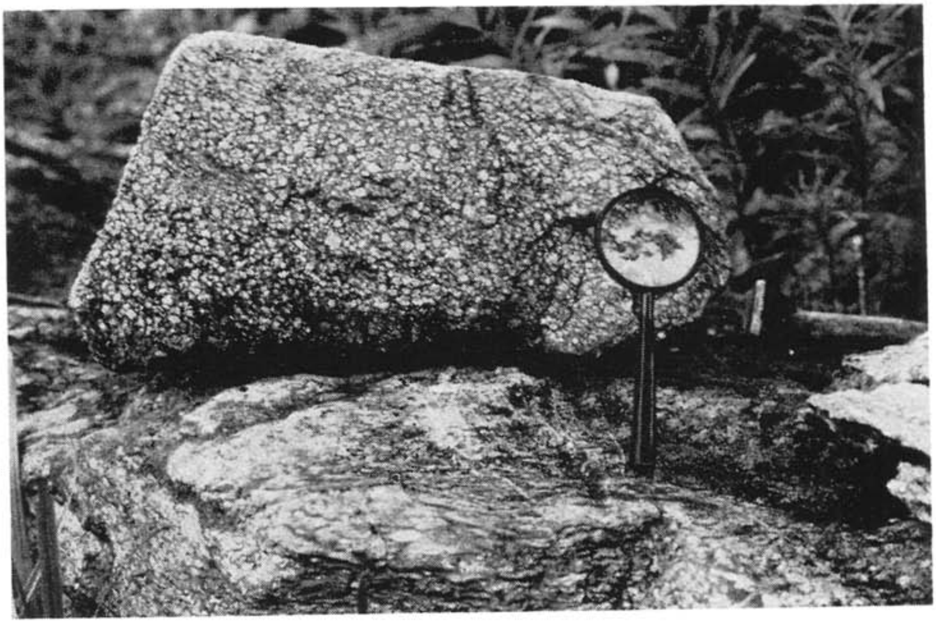

Fig. 5. The surface of plagioclasephyric basalt — local facies of lawa flow; Rakovec, 1/2 of size.

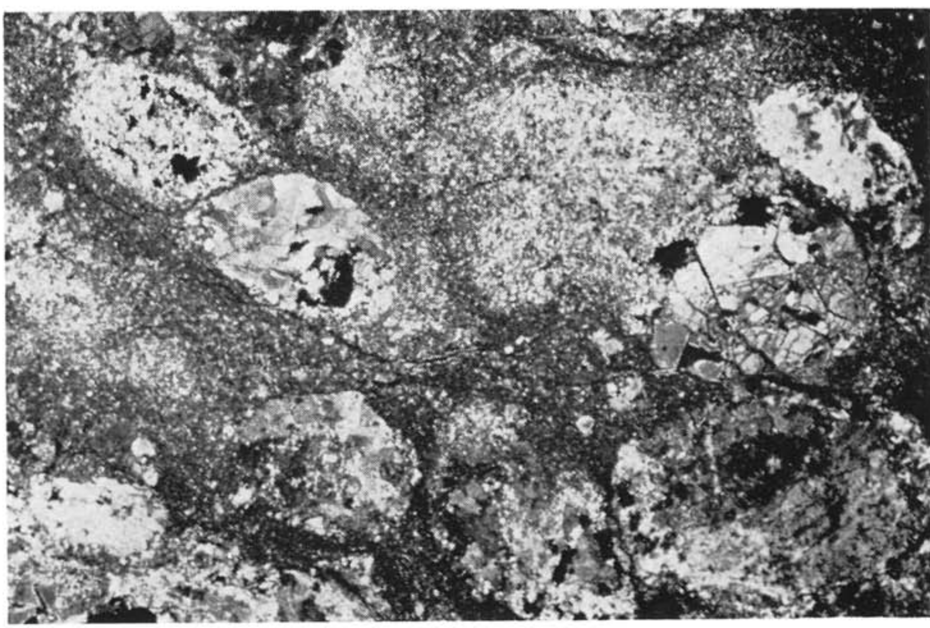

Fig. 6. Clinopyroxenephyric amygdaloidal metabasalt; Rakovec. Magn. 10x, X polars.

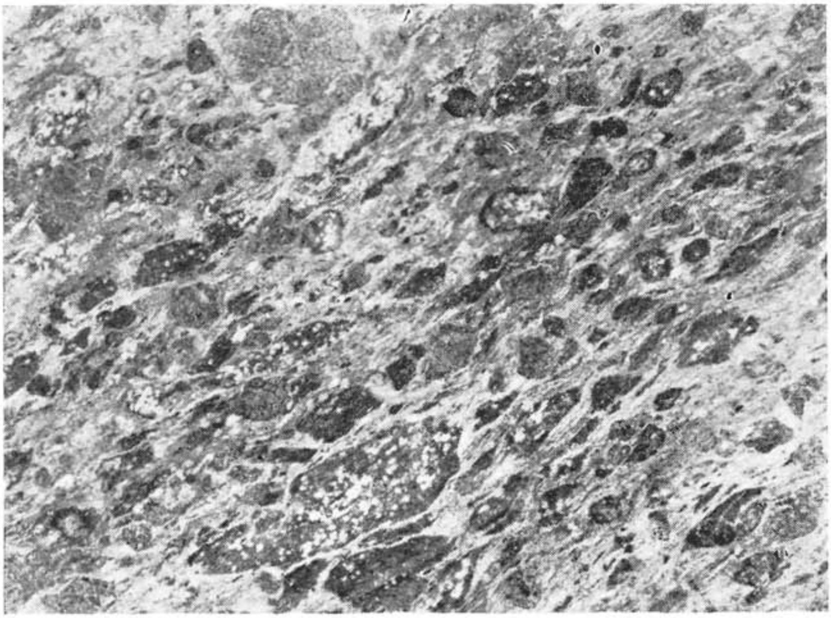

Fig. 7. Intersectional area of clinopyroxenephyric metabasalt with metamorphic foliation. Present xenolith of basalt (central lower part of the figure) with fine amygdaloidal structure. The eastern slope of the Ostrá peak near Rakovec; natural size.

Fig. 8. Blue amphiboles (1st generation amphiboles) in metabasalt. Magn. 95x; Rakovec.

Table 2

Chemical composition of clinopyroxenes

| | BRA — 2X | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2r | 2c | 3 | 4 | 5 |
| $SiO_2$ | 51.53 | 51.97 | 52.97 | 53.04 | 52.50 | 53.51 |
| $TiO_2$ | 1.59 | 1.34 | 1.42 | 1.72 | 1.32 | 1.46 |
| $Al_2O_3$ | 4.01 | 3.48 | 3.29 | 3.90 | 2.92 | 3.68 |
| $FeO^+$ | 7.79 | 7.21 | 7.17 | 7.81 | 7.93 | 8.18 |
| MnO | 0.10 | 0.11 | 0.13 | 0.14 | 0.11 | 0.20 |
| MgO | 14.78 | 15.24 | 15.19 | 14.26 | 14.52 | 13.09 |
| CaO | 19.55 | 10.08 | 19.77 | 18.26 | 19.31 | 18.57 |
| $Na_2O$ | 0.26 | 0.34 | 0.23 | 0.25 | 0.37 | 0.59 |
| $K_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 99.61 | 98.77 | 100.17 | 99.38 | 98.98 | 99.28 |
| Formula calculated to 6 (0) | | | | | | |
| Si | 1.90 | 1.93 | 1.94 | 1.95 | 1.95 | 1.97 |
| $Al^{IV}$ | 0.10 | 0.07 | 0.06 | 0.05 | 0.05 | 0.03 |
| $Al^{VI}$ | 0.07 | 0.08 | 0.08 | 0.12 | 0.08 | 0.09 |
| Ti | 0.04 | 0.04 | 0.04 | 0.05 | 0.04 | 0.04 |
| Fe | 0.24 | 0.22 | 0.22 | 0.24 | 0.25 | 0.25 |
| Mn | — | — | — | — | — | 0.01 |
| Mg | 0.81 | 0.84 | 0.03 | 0.78 | 0.80 | 0.72 |
| Ca | 0.77 | 0.76 | 0.77 | 0.72 | 0.77 | 0.73 |
| Na | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 |
| K | — | — | — | — | — | — |
| Fe | 13.2 | 12.1 | 12.1 | 13.8 | 13.7 | 14.7 |
| Mg | 44.5 | 46.2 | 45.6 | 44.8 | 44.0 | 42.4 |
| Ca | 42.3 | 41.8 | 42.3 | 41.4 | 42.3 | 42.9 |

morphic recrystallization having taken place in at least two stages which is supported by a complicated development of metamorphism in this area.

The first stage of metamorphic recrystallization which can be well proved is considered the origin of metamorphic mineral association with blue (after gama direction) sodic-calcic amphibole accompanied by albite, less frequently garnet, carbonate and titanite. The rock matrix is formed of fine-grained albite-titanite aggregate. Sodic-calcic amphibole forms prismatic and spicular shapes, seldom also oriented nest-like aggregates which enables origin of foliation planes. Garnet usually occurs mostly in oval shapes together with carbonate, less with albite which show pronounced blastic character, dilatate albite-amphibole--titanite aggregate. Smaller amounts of minerals epidote-clinozoisite together with chlorite and lepidomelane are occurring in veins conform with foliation. Phenocrysts of clinopyroxene (which have been mentioned already in paper Rozložník, 1965) and plagioclase are often penetrated by sodic-calcic amphibole spicules. Most extended amphibole development in the rock obscures the original texture of the matrix. Thus a rock type called prasinite is being formed (Eskola, 1939).

The second stage of metamorphic recrystallization can be seen through the replacement of blue Na-Ca amphibole by light-green actinolitic hornblende and

Table 2 continued

| | BRA — 1 | | | | | | BRA — 6 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1r | 1r-c | 1c | 2 | 3 | 4 | 1 | 2 | 3 |
| $SiO_2$ | 50.96 | 53.49 | 52.67 | 50.47 | 51.65 | 51.55 | 50.80 | 51.14 | 50.47 |
| $TiO_2$ | 0.96 | 0.92 | 1.04 | 1.11 | 1.10 | 1.11 | 1.15 | 1.05 | 1.06 |
| $Al_2O_3$ | 4.74 | 4.77 | 4.42 | 4.47 | 4.40 | 4.51 | 4.04 | 3.80 | 3.83 |
| $FeO^+$ | 6.45 | 5.68 | 5.65 | 5.38 | 5.64 | 5.40 | 6.43 | 6.64 | 6.36 |
| MnO | 0.14 | 0.13 | 0.10 | 0.07 | 0.13 | 0.09 | 0.14 | 0.13 | 0.07 |
| MgO | 15.37 | 15.32 | 15.30 | 16.17 | 15.45 | 15.60 | 19.37 | 18.54 | 19.11 |
| CaO | 19.73 | 19.05 | 20.63 | 21.40 | 21.41 | 21.54 | 18.97 | 18.92 | 19.08 |
| $Na_2O$ | 0.54 | 0.56 | 0.29 | 0.19 | 0.23 | 0.18 | 0.20 | 0.28 | 0.20 |
| $K_2O$ | 0.02 | 0.09 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.00 |
| Total | 98.91 | 100.01 | 100.10 | 99.26 | 100.01 | 100.00 | 101.12 | 100.50 | 100.18 |
| Formula calculated to 6 (0) | | | | | | | | | |
| Si | 1.89 | 1.94 | 1.91 | 1.86 | 1.89 | 1.89 | 1.84 | 1.87 | 1.85 |
| $Al^{IV}$ | 0.11 | 0.06 | 0.09 | 0.14 | 0.11 | 0.11 | 0.16 | 0.13 | 0.15 |
| $Al^{VI}$ | 0.10 | 0.15 | 0.14 | 0.10 | 0.08 | 0.08 | 0.01 | 0.03 | 0.02 |
| Ti | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Fe | 0.20 | 0.17 | 0.17 | 0.13 | 0.17 | 0.17 | 0.20 | 0.20 | 0.20 |
| Mn | 0.01 | — | — | — | — | — | — | — | — |
| Mg | 0.85 | 0.83 | 0.83 | 0.89 | 0.84 | 0.85 | 1.05 | 1.01 | 1.04 |
| Ca | 0.78 | 0.74 | 0.81 | 0.85 | 0.84 | 0.85 | 0.74 | 0.74 | 0.75 |
| Na | 0.04 | 0.04 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 |
| K | — | — | — | — | — | — | — | — | — |
| Fe | 10.9 | 9.80 | 9.4 | 7.0 | 9.2 | 9.1 | 10.1 | 10.3 | 10.1 |
| Mg | 46.4 | 47.7 | 44.8 | 47.6 | 45.4 | 45.5 | 52.8 | 51.8 | 52.3 |
| Ca | 42.6 | 42.5 | 45.9 | 45.5 | 45.4 | 45.5 | 37.2 | 37.9 | 37.6 |

the originating of epidote and chlorite. Actinolitic hornblende occurs in two forms — (1) as margins of blue amphibole (can be observed only with greater sizes of grains) and (2) as spicular aggregates morphologically equal with blue amphibole aggregates (which they displace). Epidote and Fe-Mg chlorite together with actinolitic hornblende and albite represented substantial components of the rock.

Metabasalts showing albite, chlorite, epidote and titanite in their compositions and often occurring in the region under study are supposed to represent the last stage of their metamorphism.

## *Mineralogy*

Metabasalts from Rakovec have been studied for the chemical composition of the following minerals phases: clinopyroxene, amphibole, epidote, albite and garnet. Attention has been paid to pyroxene which as a relict magmatic phase can offer information on pre-metamorphic character of basalts (e.g. Leterrier et al., 1982) and amphibole as a possible indicator of the conditions of metamorphic recrystallization.

Clinopyroxene

Relict magmatic clinopyroxene in metabasalts from Rakovec occurs in the form of phenocrysts as well as preserved fine (0.x mm) grains in matrix. We have investigated the chemical compositions of clinopyroxenes in phenocrysts. The results are summed up in Tab. 2. With several phenocrysts the results are from analyses of core and rim as well. The compositions, however, show only slight differences. According to the classification scheme by Poldervaart and Hess (1951) the clinopyroxenes of metabasalts from Rakovec fall mostly within augite field (Fig. 9).

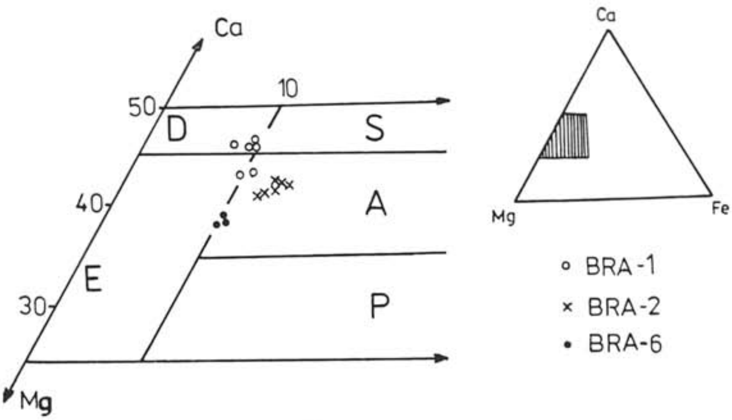


Fig. 9. Projection points of analyzed clinopyroxenes in metabasalts in projection diagram (Poldervaart—Hess, 1951); E — endiopside, D — diopside, S — salite, A — augite, P — pigeonite-augite.

Parent magma dependence of clinopyroxenes is considered in $SiO_2/Al_2O_3$ diagram (Le Bas, 1692; Fig. 10). The analyzed clinopyroxenes belong to the rocks of subalkaline sequence. Certain number of projection points, however, lie out of the field that is characteristic of oceanic basalt clinopyroxenes. Equal results are suggested by $SiO_2/TiO_2$ diagram (Le Bas, 1962; Fig. 11) in which the investigated clinopyroxenes show a different change in composition if compared with oceanic basalts.

For classifying metabasalts from Rakovec with some of magmatic series we have used also Ti/Ca + Na diagram for clinopyroxenes (Leterrier et al., 1982; Fig. 12). In the diagram, the full line separates the field of subalkaline basalts (tholeiites, calc-alkaline basalts; field T) from that alkaline basalts (A). The analyzed clinopyroxene phenocrysts fall within the field of subalkaline basalt clinopyroxenes.

In Ti + Cr/Ca diagram of clinopyroxenes (Fig. 13), the analyses of clinopyroxenes that fell within field T in the preceding diagram (Fig. 12) are projected in correspondence with the suggestion of Leterrier et al. (1982). Though Cr contents have not been detected in the investigated clinopyroxenes, their projection points fall within the field of clinopyroxenes of non-orogenic basalts.

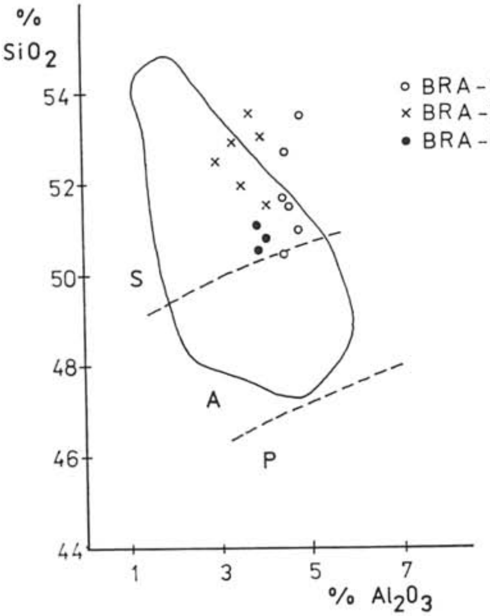


Fig. 10.

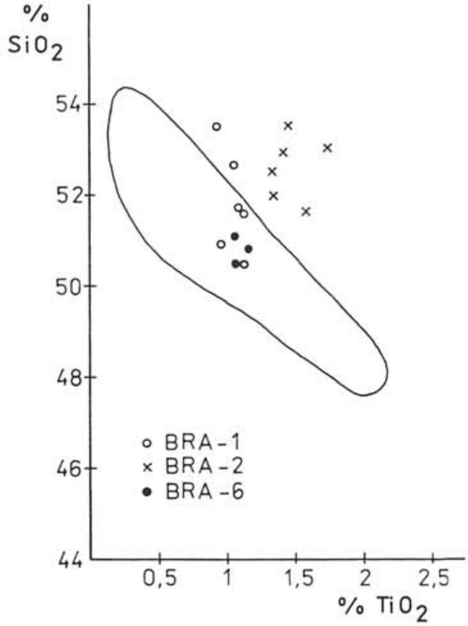


Fig. 11.

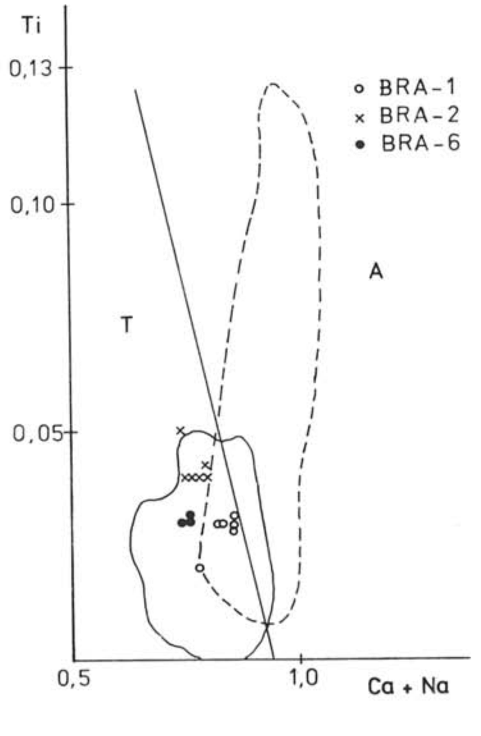


Fig. 10. Discrimination diagram of basalt cpx (Le Bas, 1962); S — subalkaline, A — alkaline, P — peralkaline fields. Limited field — ocean floor basalts (OFB).

Fig. 11. Discrimination diagram of basalt cpx (Le Bas, 1962); limited field corresponds to OFB.

Fig. 12. Ti:Ca+Na discrimination diagram of clinopyroxenes (Leterrier et al., 1982). Full line separates the field T (92 % of cpx phenocrysts in tholeiites and calc-alkaline basalts from the field A (86 % of cpx phenocrysts) in alkaline basalts. The dashed field limits the projection points of phenocrysts of alkaline basalt clinopyroxenes (A), full line limits the field of the projection points of porphyric clinopyroxenes in tholeiites and calc-alkaline basalts (T).

### Amphiboles

In metabasalts from Rakovec, there have been detected three types of amphiboles. Brown (probably kaersutite) amphibole has been found only as rare inclusions in clinopyroxene phenocrysts. It is a relict of magmatic mineral association. The other two types of amphibole – the older blue and the younger light-green ones show metamorphic origins.

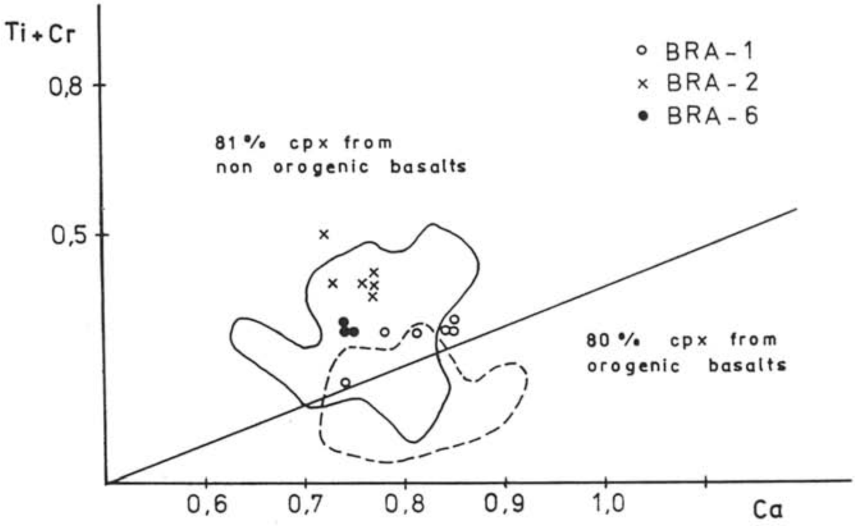


Fig. 13. Ti+Cr:Ca discrimination diagram for clinopyroxenes (Leterrier et al., 1982). Fields of distribution (full and dashed lines) as in the preceding case (Fig. 12).

*Blue amphibole* occurs in prismatic even spicular shapes which are locally arranged into oriented nest-like aggregates (Fig. 8). Most single grains and aggregates are preferentially oriented in one direction. The results from analyses of blue amphibole are presented in Tab. 3. According to the classification by Leake (1978) by its composition it corresponds to the boundary calcic and sodic-calcic amphiboles (boundary criterion $Na_B = 0.67$) and that in spite of high Na contents. This is due to rather high contents of the other cations in C and B positions. A number of amphiboles falling within calcic types would thus correspond to sodian magnesian hastingsitic hornblende, sodic-calcic types to alumino-taramite. If, however, a different normalization ($\Sigma Na = 13$) used which is more suitable for amphiboles showing such compositions (Stout, 1972; Laird–Albee, 1981; Thurston, 1985) they unambiguosly belong (due to the value $Na_B \gtreqless 0.67$) to sodic-calcic amphiboles (Fig. 14).

The younger *light-green even colourless,* and/or *locally light-blueish amphibole* most often forms pseudomorphs after spicules, and/or displaces the prismatic shapes of blue amphibole. With a certain part of samples it forms margins of usually bigger porphyroblasts of the older amphibole. The occurence of big (to 2 mm) amphibole porphyroblasts has been seldom found. Its composition

Table 3

Chemical composition of blue amphiboles

| Sample | | | | | VRA-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| analysis | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| $SiO_2$ | 41.18 | 41.50 | 41.15 | 41.22 | 41.31 | 42.92 | 42.43 | 42.69 | 43.20 |
| $TiO_2$ | 0.21 | 0.26 | 0.36 | 0.42 | 0.26 | 0.43 | 0.42 | 0.13 | 0.59 |
| $Al_2O_3$ | 13.74 | 14.74 | 16.06 | 16.87 | 13.55 | 15.56 | 15.52 | 13.30 | 15.00 |
| $Cr_2O_3$ | — | 0.39 | 0.33 | 0.24 | 0.17 | 0.52 | 0.50 | 0.25 | 0.00 |
| $FeO^+$ | 23.18 | 20.15 | 19.92 | 20.48 | 22.11 | 19.75 | 19.05 | 20.91 | 19.56 |
| MnO | 0.43 | 0.31 | 0.31 | 0.29 | 0.37 | 0.36 | 0.27 | 0.41 | 0.32 |
| MgO | 7.01 | 6.64 | 6.49 | 5.50 | 7.09 | 5.94 | 6.34 | 6.59 | 6.23 |
| CaO | 6.69 | 7.57 | 7.21 | 6.98 | 7.72 | 7.35 | 7.23 | 7.92 | 7.24 |
| $Na_2O$ | 4.52 | 4.80 | 4.95 | 5.40 | 4.09 | 5.02 | 4.81 | 4.35 | 4.98 |
| $K_2O$ | 0.76 | 0.48 | 0.54 | 0.50 | 0.57 | 0.47 | 0.47 | 0.54 | 0.54 |
| Total | 97.72 | 97.04 | 97.32 | 97.90 | 97.24 | 98.32 | 97.04 | 97.09 | 97.66 |
| Formula calculated to 23 (0) | | | | | | | | | |
| Si | 6.35 | 6.35 | 6.26 | 6.25 | 6.37 | 6.44 | 6.43 | 6.54 | 6.51 |
| $Al^{IV}$ | 1.65 | 1.65 | 1.74 | 1.75 | 1.63 | 1.56 | 1.57 | 1.46 | 1.41 |
| $Al^{VI}$ | 0.84 | 1.01 | 1.14 | 1.26 | 0.83 | 1.19 | 1.20 | 0.94 | 1.17 |
| Ti | 0.02 | 0.03 | 0.04 | 0.05 | 0.03 | 0.05 | 0.05 | 0.02 | 0.07 |
| $Fe^{2+}{}_{tot}$ | 2.99 | 2.58 | 2.54 | 2.60 | 2.85 | 2.48 | 2.41 | 2.68 | 2.46 |
| Mn | 0.06 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 | 0.04 |
| Mg | 1.61 | 1.56 | 1.47 | 1.24 | 1.63 | 1.33 | 1.43 | 1.50 | 1.40 |
| Ca | 1.05 | 1.24 | 1.18 | 1.13 | 1.28 | 1.18 | 1.17 | 1.30 | 1.17 |
| Na | 1.35 | 1.42 | 1.46 | 1.59 | 1.22 | 1.46 | 1.41 | 1.29 | 1.46 |
| K | 0.15 | 0.09 | 0.10 | 0.10 | 0.11 | 0.09 | 0.09 | 0.11 | 0.10 |
| Mg/Mg+Fe | 0.35 | 0.38 | 0.37 | 0.32 | 0.36 | 0.35 | 0.37 | 0.36 | 0.36 |

Table 3 continued

| Sample | | | VRA-2A | | | | RAK-X | | |
|---|---|---|---|---|---|---|---|---|---|
| analysis | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 |
| $SiO^2$ | 41.74 | 41.51 | 43.63 | 42.24 | 40.00 | 41.18 | 40.15 | 41.18 | 40.22 |
| $TiO_2$ | 0.36 | 0.11 | 0.42 | 0.30 | 0.30 | 0.44 | 0.31 | 0.21 | 0.26 |
| $Al_2O_3$ | 13.48 | 15.02 | 14.02 | 15.77 | 13.02 | 13.43 | 13.76 | 13.74 | 12.32 |
| $FeO^+$ | 21.15 | 20.94 | 20.27 | 20.00 | 22.50 | 21.99 | 23.14 | 23.18 | 22.90 |
| MnO | 0.35 | 0.35 | 0.36 | 0.29 | 0.37 | 0.39 | 0.43 | 0.43 | 0.45 |
| MgO | 6.88 | 7.49 | 6.21 | 6.02 | 6.82 | 7.43 | 6.35 | 7.01 | 7.30 |
| CaO | 7.83 | 8.02 | 7.25 | 7.54 | 6.98 | 6.29 | 6.70 | 6.69 | 7.13 |
| $Na_2O$ | 4.27 | 3.88 | 4.64 | 4.82 | 4.16 | 4.23 | 4.15 | 4.52 | 3.97 |
| $K_2O$ | 0.49 | 0.57 | 0.44 | 0.56 | 0.79 | 0.65 | 0.79 | 0.76 | 0.68 |
| Total | 96.60 | 97.93 | 97.24 | 97.54 | 94.94 | 96.03 | 95.78 | 97.72 | 95.23 |
| Formula calculated to 23 (0) | | | | | | | | | |
| Si | 6.44 | 6.30 | 6.61 | 6.40 | 6.35 | 6.41 | 6.33 | 6.34 | 6.38 |
| $Al^{IV}$ | 1.56 | 1.70 | 1.39 | 1.60 | 1.65 | 1.59 | 1.67 | 1.66 | 1.62 |
| $Al^{VI}$ | 0.90 | 0.99 | 1.12 | 1.21 | 0.79 | 0.87 | 0.88 | 0.84 | 0.68 |
| Ti | 0.04 | 0.01 | 0.05 | 0.03 | 0.03 | 0.05 | 0.04 | 0.02 | 0.03 |
| $Fe^{2+}{}_{tot}$ | 2.73 | 2.66 | 2.57 | 2.53 | 2.98 | 2.86 | 3.05 | 2.99 | 3.04 |
| Mn | 0.05 | 0.04 | 0.05 | 0.04 | 0.05 | 0.05 | 0.06 | 0.05 | 0.06 |
| Mg | 1.58 | 1.70 | 1.40 | 1.36 | 1.61 | 1.72 | 1.50 | 1.61 | 1.71 |
| Ca | 1.30 | 1.30 | 1.18 | 1.22 | 1.19 | 1.05 | 1.13 | 1.10 | 1.21 |
| Na | 1.28 | 1.14 | 1.36 | 1.41 | 1.28 | 1.28 | 1.27 | 1.31 | 1.22 |
| K | 0.10 | 0.11 | 0.08 | 0.11 | 0.16 | 0.13 | 0.16 | 0.14 | 0.14 |
| Mg/Mg+Fe | 0.37 | 0.39 | 0.35 | 0.35 | 0.36 | 0.38 | 0.33 | 0.36 | 0.36 |

has been investigated only to a limited extent in two samples (Tab. 4). According to Leake's classification it is actinolite (Fig. 15).

Sodic-calcic amphiboles of similar compositions to metabasalts from Rakovec are generally connected with blueschist metamorphism as the product of tran-

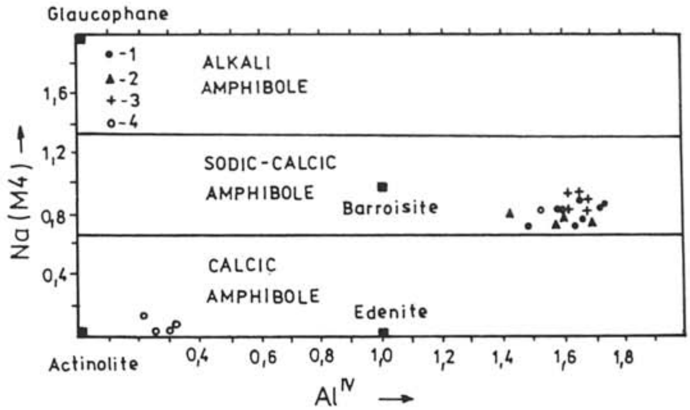


Fig. 14. $Na_{M4}$: $Al^{IV}$ classification diagram of monoclinic amphiboles. Analyses of amphiboles: 1 — Sample VRA-2 (Tab. 3), 2 — sample VRA-2A (Tab. 3), 3 — sample RAK-X (Tab. 3), 4 — actinolitic amphibole (Tab. 4).

Table 4

| | Actinolite | | | | Epidote | | | | Albite |
|---|---|---|---|---|---|---|---|---|---|
| | BRA-6 | | RAK-X | | BRA-6 | | | | RAK-X |
| $SiO_2$ | 51.70 | 51.79 | 52.85 | 52.17 | 40.07 | 39.69 | 39.89 | 40.09 | 68.75 |
| $TiO_2$ | 0.08 | 0.10 | 0.11 | 0.09 | 0.19 | 0.12 | 0.00 | 0.07 | 0.06 |
| $Al_2O_3$ | 2.74 | 1.99 | 1.66 | 2.34 | 24.20 | 23.51 | 20.92 | 22.73 | 21.29 |
| $FeO^+$ | 15.60 | 14.43 | 15.66 | 15.17 | 11.90 | 12.72 | 15.90 | 13.99 | 0.04 |
| MnO | 0.38 | 0.37 | 0.34 | 0.30 | 0.12 | 0.00 | 0.39 | 0.24 | 0.00 |
| MgO | 14.72 | 15.19 | 16.55 | 15.15 | 0.01 | 0.03 | 0.00 | 0.00 | 0.00 |
| CaO | 9.75 | 10.07 | 10.02 | 9.65 | 20.91 | 19.62 | 18.84 | 21.06 | 0.11 |
| $Na_2O$ | 0.65 | 0.44 | 0.69 | 1.06 | 0.01 | 0.00 | 0.00 | 0.00 | 9.71 |
| $K_2O$ | 0.11 | 0.36 | 0.12 | 0.10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 |
| Total | 95.73 | 94.74 | 98.00 | 96.03 | 97.41 | 95.69 | 95.94 | 98.18 | 100.00 |
| Formula calculated to 23 (0) | | | | | | 12.5 (0) | | | 32 (0) |
| Si | 7.68 | 7.75 | 7.68 | 7.78 | 3.22 | 3.24 | 3.31 | 3.23 | 11.90 |
| $Al^{IV}$ | 0.32 | 0.25 | 0.32 | 0.22 | 2.29 | 2.27 | 2.05 | 2.16 | 4.35 |
| $Al^{VI}$ | 0.16 | 0.10 | — | 0.19 | | | | | |
| Ti | — | 0.01 | 0.01 | — | 0.01 | 0.01 | — | — | 0.01 |
| Fe | 1.94 | 1.81 | 1.90 | 1.88 | 0.80 | 0.87 | 1.10 | 0.94 | 0.00 |
| Mn | 0.05 | 0.05 | 0.04 | 0.04 | 0.01 | — | 0.03 | 0.02 | — |
| Mg | 3.25 | 3.39 | 3.58 | 3.33 | — | — | — | — | — |
| Ca | 1.55 | 1.61 | 1.56 | 1.53 | 1.80 | 1.72 | 1.68 | 1.82 | 0.01 |
| Na | 0.18 | 0.13 | 0.20 | 0.30 | — | — | — | — | 3.25 |
| K | 0.02 | 0.07 | 0.02 | 0.02 | — | — | — | — | 0.01 |

sition stage to greenschist. This stage can be prograde (Trzienski et al., 1984; Gibbons–Gyopari, 1986; Mposkos, 1987), but more often retrograde (Ernst, 1979; Laird—Albee 1981 a, 1981 b; Yardley, 1982; Armstrong, et al. 1983; Thurston, 1985; Oberhänsli, 1986; Guiraud et al., 1987 and others). According to the mentioned authors (l. c.) sodic-

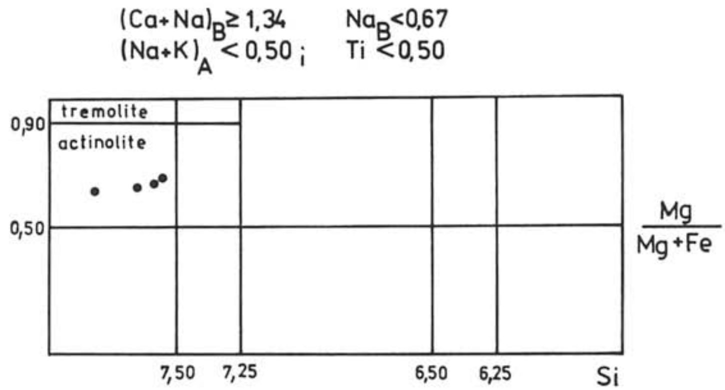


Fig. 15. Classification diagram of monoclinic amphiboles (Leake, 1978).

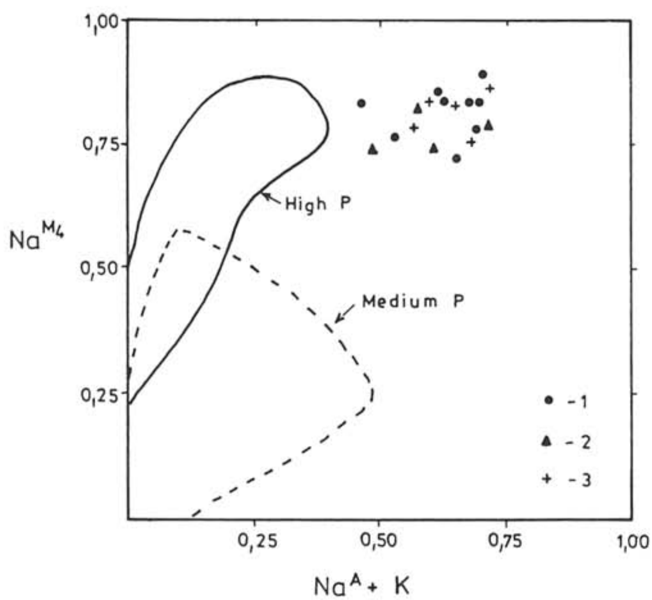


Fig. 16. Discrimination diagram $Na_{M4}$:$Na_A$+K of monoclinic amphiboles. Fields for high-pressure as well as for medium-pressure amphiboles are limited; 1—3 see Fig. 14.

-calcic amphiboles show rather varying composition within one locality, and/or rock body. In most cases, they show higher Si and lower Al contents (usually barroisite in Leake's classification, 1978) than those we have studied, but amphiboles of analogous compositions are not exception (c.f. Ernst, 1979; Gomez—Pugnaire et al., 1985; Mposkos, 1987). Their common feature, if compared to the amphiboles of greenschist facies, is glaucophane substitution [$Na_{M4}$, $(Al^{VI} + Fe^{3+} + Ti + Cr) \rightleftharpoons Ca(Fe^{2+}, Mg, Mn)$] having taken place to a higher degree and which according to Laird and Albee (1981 b) is typical of high-pressure facies of metamorphism while edenite [$(Na^A + K), Al^{VI} \rightleftharpoons Si$] and tschermakite [$(Al^{VI} + Fe^{3+} + Ti + Cr), Al^{VI} \rightleftharpoons (Fe^{2+} + Mg + Mn), Si$] components are typical of low-pressure facies. $Na_{M4}$ value then reflects metamorphic pressure and can serve as a geobarometer (Brown, 1977). This geobarometer is

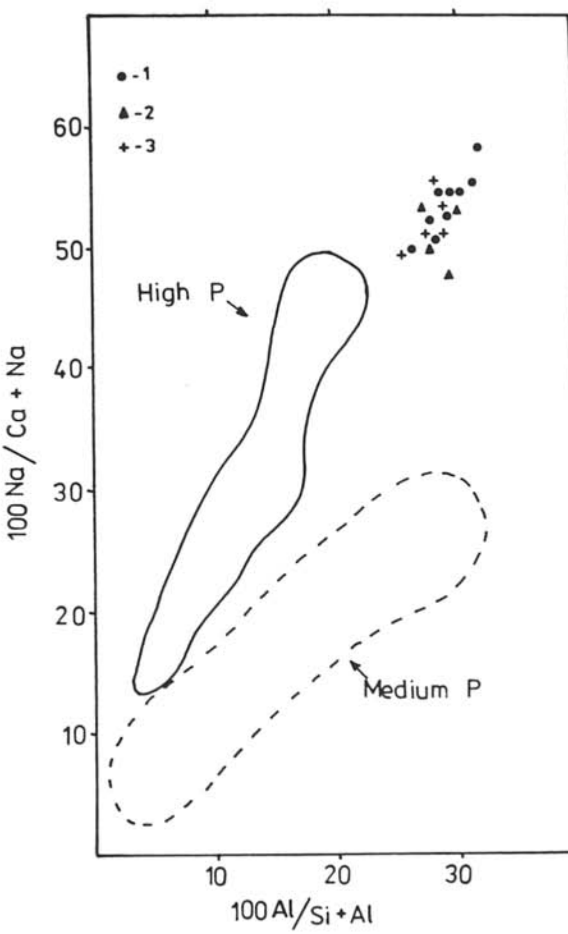


Fig. 17. Discrimination diagram 100Na/Ca+Na:100Al/Si+Al (Laird—Albee, 1981 b); 1—3 see Fig. 14.

not, however, calibrated for higher $Al^{VI}$ values, so that with the investigated amphiboles one can state their affinity to the amphiboles of the Sanbagawa belt in Japan which are the product, and/or connected with high-pressure metamorphism. PT-conditions of the origin of sodic-calcic amphiboles (especially barroisite) occurring in association with blueschist minerals (especially glaucophane) have not been datailly known. Most authors agree with Ernst (1979) that they are lying in transition zone between typical greenschist and blueschist (provisional values 4—5 kbar at c. 350 °C and 5—7 kbar at c. 450 °C). These amphiboles, according to Laird and Albee (1981 b), however, differ from typical amphiboles of medium-grade metamorphites with higher glaucophane substitution. In diagrams $Na_{M4}/Na + K$ (Fig. 16) and $100\ Na/(Ca + Na) : 100\ Al/(Si + Al)$ (Fig. 17) projection points, however falling out of the field of characteristic composition of high-pressure amphiboles, but they are projected in the prolongation of the mentioned field. This suggests that the blue amphiboles of metabasalts from Rakovec may be genetically related to high--pressure metamorphism in these rocks. The observed shift in comparison with the field of amphiboles of high-pressure metamorphism as defined by Laird and Albee (l. c.) must have been caused (1) by a different protolith, and/or (2) higher temperature during metamorphism (i. e. $Al^{IV}$ increase, Brown, 1977).

Actinolitic hornblende rimming the cores of blue amphiboles, and/or forming individuals – spicular and prismatic shapes – perhaps pseudomorphs is considered a product of younger metamorphic stage (c. f. Laird–Albee 1981 a, 1981 b). Alternative explanation immiscibility gap cannot be taken into consideration as shown by Ernst (1979), Laird–Albee (1981 a), Thurston (1985) as well as our observations of spatial relations of these two monoclinic amphibole types. Actinolite blasthesis was due to PT-change of metamorphic recrystallization corresponding to greenschist facies ($P \approx 2–4$ kbar according to Brown's geobarometer, 1977). As there is continuous mixing of actinolites with Na-Ca amphiboles, the presence of transition members between both the types can be expected in analyses of other samples or amphiboles. This is suggested by various colours of actinolite – colourless, light-green, blue-green.

### Albite

In metabasalts from Rakovec, albite occurs in the form of pseudomorphs after primary plagioclases (Fig. 6), fine-grained aggregate as a component of matrix and clusters and veins originated within metamorphic recrystallization. The analysis of albite from association actinolite — chlorite — epidote — albite ($\pm$ relicts of Na-Ca amphibole) corresponds to nearly pure albite which is in agreement with the last metamorphosis of the rock under the conditions of greenschist facies.

### Minerals of epidote group

The samples containing only Na-Ca amphibole are depleted in epidote. Only scarcely epidote together with chlorite occurs in the form of grains in obviously younger veins concordant with the rock foliation. Sometimes it is slightly zoned with colourful rims. Epidote represents essential components in the rocks with

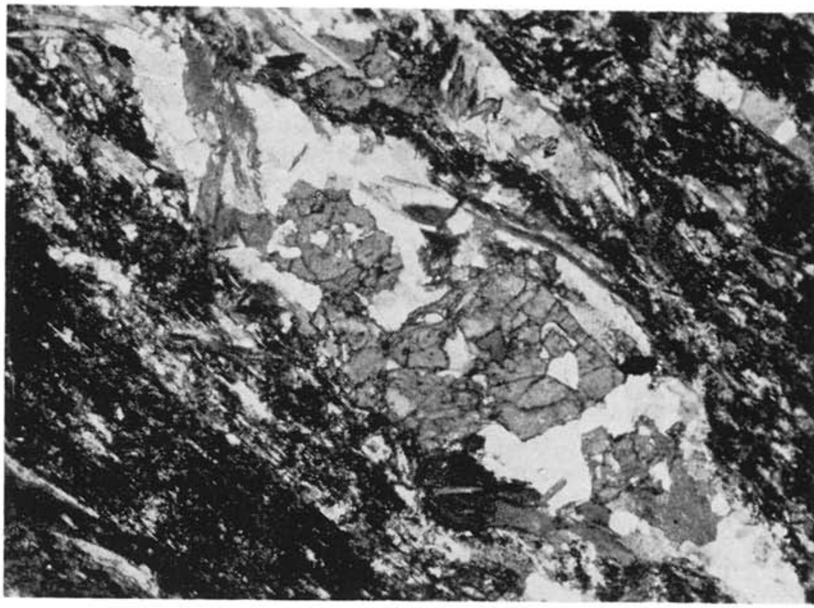

Fig. 18. Cumuloblast of garnets in calcite amygdale with chlorite and albite. In the lower part of amygdale (below right) blue amphibole aggregate. Magn. 48x, partly X polars.

both amphibole types only with actinolite. By its composition it corresponds to ferrous member fo the group — epidote (Tab. 4).

### Garnet

Garnet has been found only in metabasalts with the development of the metamorphic recrystallization 1st stage mineral association the major member of which is blue amphibole. It forms irregular mostly, however, isometric cumuloblasts of grains (to 5 mm) and atoll habitus of cumuloblasts often occurs. Optically garnet shows to be anomalus (anisotropic) with suggestions of slight sector structure. It always occurs in the form of lenticular clusters (Fig. 18) even conform carbonate layers. The rims of garnets in atoll cumuloblasts contain pure aggregate of albite. Some garnet grains contain enclosures of deep-green low-temperature biotite, and/or stilpnomelane. The observed planparallel layers of chlorite and epidote displace green biotite/stilpnomelane.

Analyses (with system EDAX) have shown that the garnets belong to the group of andradite – grossular garnets with low spessartine molecule. This composition different from that of common garnets in blueschist reflects the composition of local environment (probably amygdales) in the rock.

Table 5

Composition of metabasalts

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 50.51 | 49.91 | 48.99 | 46.18 | 44.71 | 45.47 | 50.43 | 46.10 |
| $TiO_2$ | 1.51 | 0.96 | 1.09 | 0.69 | 1.20 | 1.00 | 1.31 | 0.59 |
| $Al_2O_3$ | 18.66 | 17.72 | 18.88 | 17.64 | 16.39 | 21.66 | 22.26 | 16.82 |
| $Fe_2O_3$ | 6.61 | 2.58 | 6.29 | 6.71 | 3.51 | 2.07 | 3.41 | 3.30 |
| FeO | 6.39 | 8.56 | 6.37 | 4.94 | 7.55 | 7.84 | 7.55 | 8.86 |
| MnO | 0.16 | 0.20 | 0.18 | 0.20 | 0.27 | 0.22 | 0.19 | 0.17 |
| MgO | 3.32 | 6.16 | 2.88 | 4.61 | 6.49 | 2.85 | 1.94 | 6.47 |
| CaO | 4.21 | 7.80 | 5.30 | 8.23 | 10.45 | 9.40 | 3.47 | 3.95 |
| $Na_2O$ | 4.36 | 1.38 | 4.39 | 3.84 | 2.76 | 2.12 | 4.66 | 3.31 |
| $K_2O$ | 0.28 | 0.32 | 0.47 | 0.50 | 0.26 | 0.48 | 0.23 | 2.24 |
| $P_2O_5$ | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.90 |
| $H_2O^-$ | 0.20 | 0.08 | 0.33 | 0.30 | — | — | 0.09 | 0.22 |
| Loss of ign. | 3.32 | 3.93 | 4.30 | 5.89 | 6.04 | 6.39 | 4.11 | 3.98 |
| Total: | 99.55 | 99.62 | 99.49 | 99.75 | 99.65 | 99.52 | 99.67 | 98.99 |
| trace elements (in ppm): | | | | | | | | |
| Rb | — | 13.6 | 36.0 | 14.0 | — | — | — | 49.5 |
| Cs | 14.0 | 4.9 | 69.2 | 50.7 | — | 0.69 | 0.84 | 1.95 |
| Sr | 35.0 | 14.0 | 155.0 | 380.0 | 200.0 | 96.0 | 74.0 | 90.0 |
| Ba | 68 | 50 | 126 | 316 | 28 | 105 | 24 | 340 |
| Th | 1.44 | 0.55 | 1.4 | 1.33 | 1.23 | 0.45 | 3.6 | 3.1 |
| U | 0.47 | — | 0.52 | — | 0.28 | 0.33 | 1.43 | 2.50 |
| V | 263 | 251 | 316 | 282 | 380 | 209 | 141 | 205 |
| Zr | 129 | 126 | 100 | 89 | 120 | 96 | 126 | 253 |
| Y | 25 | 22 | 36.2 | 30 | 49 | 31 | 105 | 32 |
| Cr | | 1202 | | 6 | 32 | 1047 | 6 | 98.5 |
| Ni | | 316 | | | 50 | 200 | | 33 |
| Co | 24 | 59 | 25 | 35 | 50 | 58 | 20 | 23.4 |
| Cu | 10 | 16 | 5 | 9 | 126 | 8 | 9 | 10 |
| Ga | 13 | 10 | 12 | 13 | 13 | 8 | 18 | |
| La | 15.7 | 6.95 | 13.3 | 12.8 | 15.0 | 8.0 | 41.3 | 25.7 |
| Ce | 38.3 | 13.0 | 27.0 | 24.0 | 31.8 | 12.4 | 95.6 | 61.2 |
| Nd | 21.0 | 8.5 | 16.0 | 20.1 | 26.5 | 7.3 | 56.1 | 60 |
| Sm | 7.37 | 2.82 | 5.85 | 4.91 | 5.80 | 3.35 | 13.3 | 9.1 |
| Eu | 2.51 | 1.05 | 2.11 | 1.84 | 2.2 | 1.08 | 4.56 | 2.55 |
| Gd | — | — | — | 3.4 | — | 2.1 | 0.8 | 8.6 |
| Tb | 1.1 | 0.42 | 0.97 | 0.81 | 0.88 | 0.59 | 1.90 | 1.35 |
| Ho | 1.2 | 0.66 | 1.07 | 0.85 | 1.0 | 0.37 | 1.86 | 1.40 |
| Tm | 0.5 | 0.18 | 0.40 | 0.32 | 0.38 | 0.22 | 0.80 | 0.57 |
| Yb | 2.6 | 0.75 | 2.0 | 1.24 | 1.9 | 1.66 | 4.73 | 3.2 |
| Lu | 0.34 | 0.12 | 0.31 | 0.30 | 0.26 | 0.25 | 0.80 | 1.2 |

Oxides of petrogenic elements (1—7) in Bajaník (1976), (8) orig.; trace elements (determined by emission spectral analysis) in Bajaník (1980); REE (determined by INAA) in Bajaník (1981).
In anal. No. 8 also 8.0 ppm of Hf and 2.40 ppm of Ta have been determined.

## *Geochemistry*

Analytical data on metabasalts from Rakovec are summed up in Tabs. 5, 6. With regard to their complicated metamorphic development the abundances of petrogenic elements are not considered suitable for the investigation of primary composition and membership of some of petrogenetic series. More confident results can be expected from the study of distribution of those trace elements which indicate geodynamic conditions of origin and at the same time belong partically to immobile elements during metamorphic processes. They are rare earth elements (REE), high field strength elements (HFSE) — Zr, Hf, Nb, Ta, Th and partially Ti and V as well. Immobility of these elements, and/or at the most their coherent mobility is considered for low-degree metamorphism by most authors (Humphris–Thompson, 1979; Bartley, 1986, and others), though several cases suggest the need for carefulness in this relation (Hellmann et al., 1979; Murphy–Hynes, 1986).

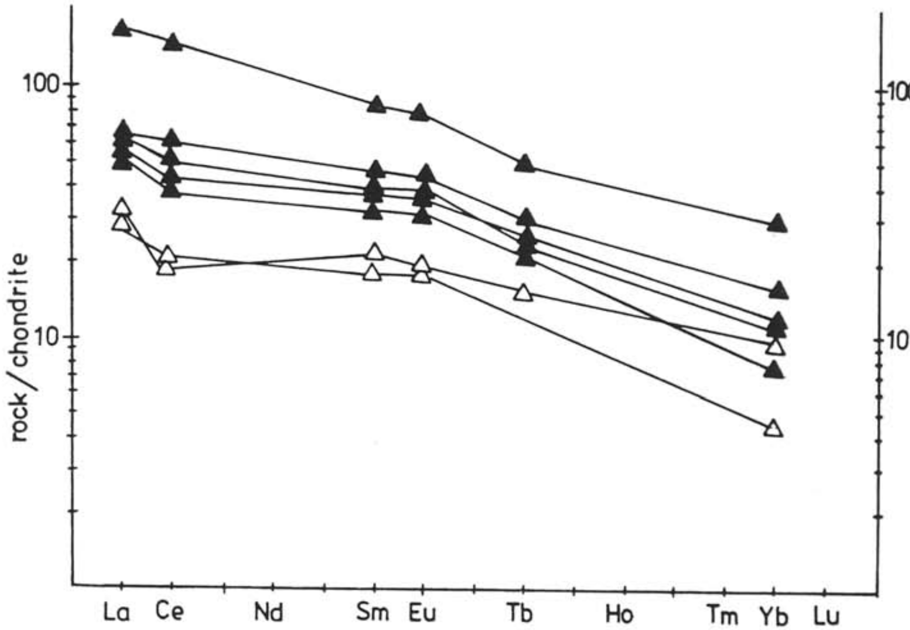


Fig. 19. Chondrite normalized REE pattern of metabasalts from Rakovec. Analytical data in Bajaník (1981) — see Tab. 5 Normalized according to Evenson et al. (1978). Symbol explanation: see Fig. 20.

In the study of REE distribution in metabasalts from Rakovec we have exploited besides our own analyses the analytical data from the paper by Bajaník (1981). Chondrite-normalized distribution patterns for both data groups are shown in Figs. 19 and 20. Both the groups show to be well consistent with each other and on the whole show broken REE pattern due to metamorphic processes. The exception are two samples from the set of data of Bajaník (l. c.) with which this author gave relict porphyric texture. The difference in REE pattern is in our opinion related to wrong choice of samples (metamorphosed tuffites?). The differences in particular metamorphic stages taking place

(Na-Ca amphibole, actinolite, and/or amphiboles replaced by chlorite) did not affect REE patterns in the other samples. Elevated absolute values of REE contents in the samples from Dobšiná — correspond with their petrographic character — types corresponding with basaltoid andesite (Tab. 5, anal. 8).

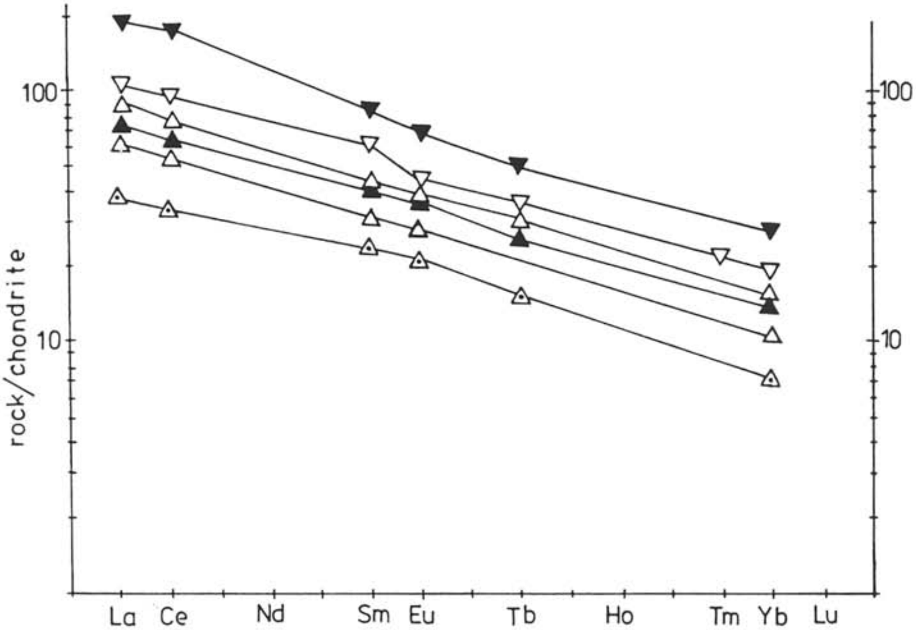


Fig. 20. Chondrite normalized REE pattern of metabasalts and basaltoid andesites from Rakovec and Dobšiná resp. Original analytical data. Normalized according to E v e n s o n et al. (1978).
*Symbols:* open triangles — metabasalts with amphiboles; full triangles — metabasalts without amphiboles; triangles with down-oriented apex — basaltoid andesites from Dobšiná; triangle with dot — pyroxene-rich metabasalt.

The course of normalization curves demonstrates enrichment in light REE and the shape shows affinity to the normalization curves of enriched middle oceanic ridge basalts (E-MORB) and the basalts of oceanic island tholeiites (OIT), and/or to the calc-alkaline basalts of destructive lithospheric plate margins. The first two possibilities appear to be more probable (c. f. S a u n d e r s, 1984; M a r r i n e r—M i l l w a r d, 1984; H o l m, 1985; B u d a h n—S c h m i d t, 1985). Their reliable distinction from calc-alkaline basalts (CAB) may often be rather difficult (W h i t e—P a t c h e t t, 1984; S m e d l e y, 1986). Similar difficulties occur with distinction between E-MORB and OIT (H o l m, 1985).

Transitive character of metabasalts from Rakovec between typical MORB and CAB has been shown in all diagrams in which other immobile elements are used of. In $TiO_2/Zr$ (P e a r c e et al., 1981; Fig. 21), and/or V : Ti/1000

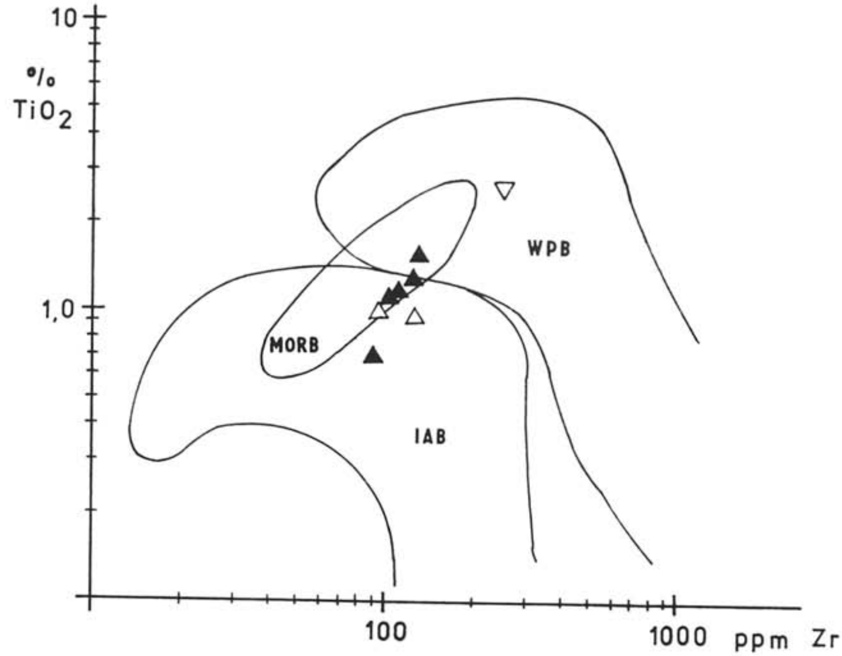


Fig. 21. $TiO_2$:Zr discrimination diagram (P e a r c e et al., 1981), symbol explanation: see Fig. 20.

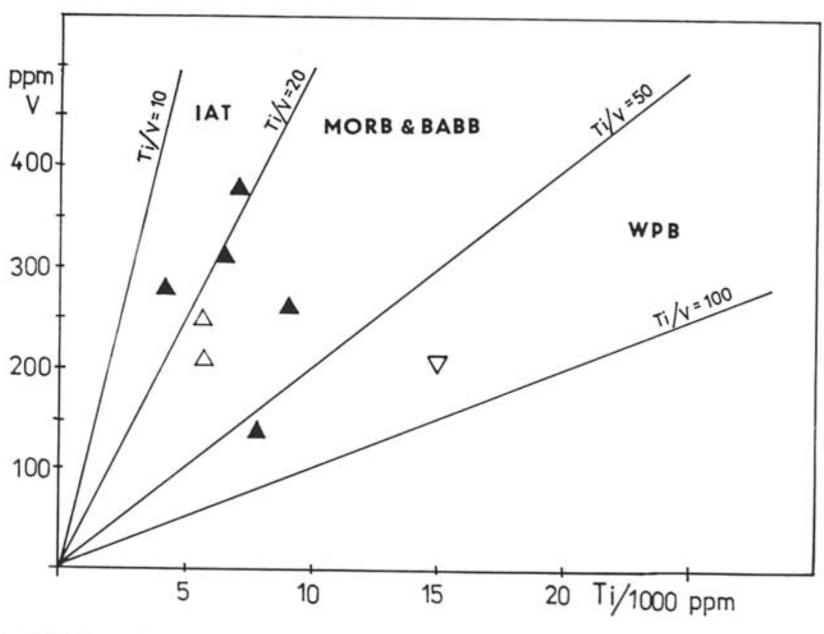


Fig. 22. V:Ti/1000 discrimination diagram (S h e r v a i s, 1982). Symbol explanation: see Fig. 20.

(S h e r v a i s, 1982; Fig. 22) diagrams projection points lie within the fields limiting the compositions of MORB and CAB. Diagrams Th/Yb : Ta/Yb (P e a r c e et al., 1981; Fig. 23), and/or Th : Hf/3 : Ta (W o o d, 1980; Fig. 24), however, unambiguously classify the metabasalts under study with E-MORB, and/or OIT types.

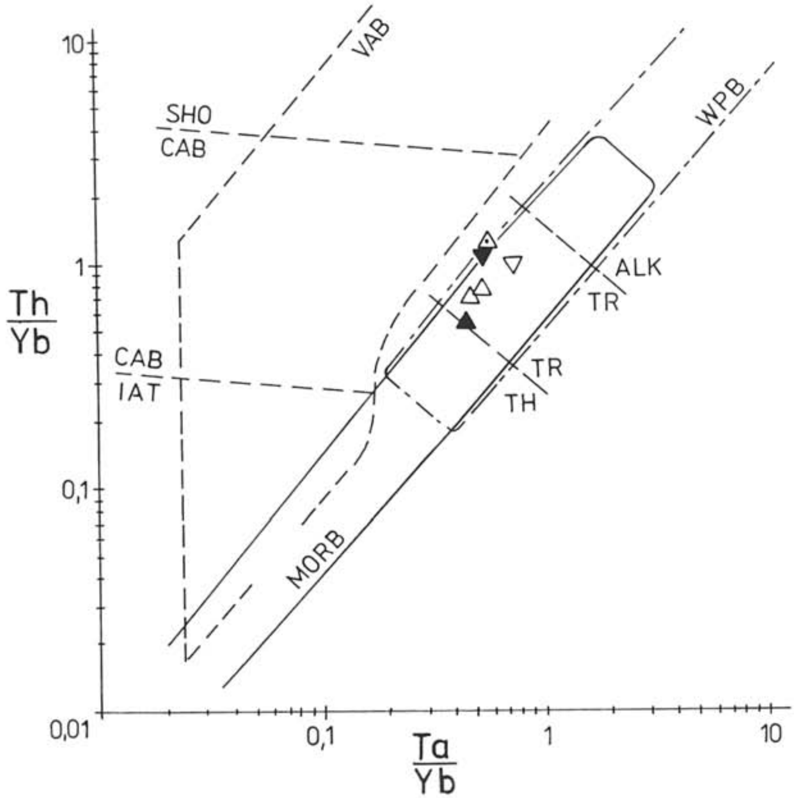


Fig. 23. Th/Yb : Ta/Yb discrimination diagram (P e a r c e et al., 1981). TR — field of transitional basalts. Symbol explanation: see Fig. 20.

*Discussion*

The data we have obtained on the compositions of metabasalts from Rakovec, especially as for the contents of petrogenetically relevant trace elements and the composition of clinopyroxenes and amphiboles from them, enable us to explain some problems of genesis and metamorphic developments of these rocks.

Table 6

REE determination

| | RA-O | VRA-2 | VRA-12 | FHN-3 | FD-152 |
|---|---|---|---|---|---|
| La | 21.8 | 15.1 | 17.7 | 9.2 | 46.5 |
| Ce | 48.0 | 33.5 | 40.5 | 21.6 | 111 |
| Nd | 30.0 | 24.3$^{+}$ | 15.6$^{+}$ | | 55.5 |
| Sm | 6.5 | 4.8 | 6.2 | 3.6 | 12.6 |
| Eu | 2.20 | 1.60 | 2.20 | 1.20 | 3.9 |
| Gd | 15.3 | | 13.6$^{+}$ | | 39.5 |
| Tb | 1.15 | 1.05 | 0.96 | 0.56 | 1.95 |
| Ho | 1.20$^{+}$ | | | 1.00$^{+}$ | 1.95 |
| Tm | 0.69$^{+}$ | 0.60$^{+}$ | 0.68 | 0.36$^{+}$ | 0.80 |
| Yb | 2.50 | 1.75 | 2.30 | 1.15 | 4.7 |
| Lu | 0.62$^{+}$ | | 0.32$^{+}$ | 0.33$^{+}$ | 0.78 |
| Ta | 1.40 | 0.86 | 1.05 | 0.55 | 2.60 |
| Hf | 5.2 | 3,5 | 4.9 | 2.45 | 11.8 |
| Th | 1.90 | 1.20 | 1.20 | 1.40 | 5.0 |
| U | 3.2$^{+}$ | | 2.00$^{+}$ | 1.45 | |
| Cr | 11.0$^{+}$ | 69.5 | 54.0 | 795 | |
| Co | 47.0 | 34.0 | 40.5 | 73.0 | 12.1 |
| Zn | 188 | 116 | 148 | 160 | 92.5 |

*Explanation* to Tables:
BRA-1: Cpx» Plg phyric metabasalt with Aph, Ep, Chl and ore minerals in matrix; BRA-2; Cpx» Plg phyric metabasalt with Ab, Ep, Tnt, Chl, and ore minerals in matrix; BRA-6: Plg» Cpx (seldom) phyric metabasalt with fine-grained matrix (Ab, blue Aph, Act, Ep, Tnt, Chl); VRA-2: Cpx phyric, originaly amygdaloidal basalt with blue Aph, Ab, Chl, Ep, ore minerals; VRA-2A: Cpx phyric, originaly amygdaloidal basalt with Ab, blue Aph, Act, Chl, Ep, ore minerals; VRA-O: Fine-grained metabasalt. Composition: Cpx, blue Aph, Ab, Act, Chl, Ep, Tnt, ore minerals; VRA-12: Fine-grained metasabalt. Composition: Ab, Chl, Et, Tnt, ore minerals; FD-152: Basaltoid andesite, Dobšiná — 1 km NNE of settlement Vyšný Hámor; middle of the lava flow.

All REE determination have been carried out in Central Laboratories of the Czechoslovak Uranium Industry, Stráž pod Ralskem under leadership of Ing. K o t a s.

The diagrams by Le B a s (1982) and L e t e r r i e r et al. (1982) have shown that the composition of clinopyroxene phenocrysts as practically the only relict of magmatic stage minerals suggests the original sub-alkaline, tholeiitic, non-orogenic character of basalt magma. At the same time, pyroxene, however, suggests a composition different from the pyroxenes of the most common tholeiitic non-orogenic basalts of MORB type.

Similar conclusions result from chondrite-normalized REE pattern and diagrams by W o o d et al. (1979) and P e a r c e et al. (1981) based on the elements the least mobile during metamorphism — Ta, Hf, Th, Yb. On the basis of preceding data we can classify metabasalts from Rakovec with the types close to E-MORB, and/or OIT. This classification, however, does not solve unambiguously the geodynamic conditions under which their magma was produced. E-MORB basalts occur with coincidences of hot spots with oceanic rifts (S a u n d e r s, 1982; H o l m, 1985) and OIT accompany characteristic product of oceanic hot spots – alkaline basalts. The surveys in recent years, however, have shown that basalts similar to E-MORB or OIT occur in the environment of the destructive margins of lithospheric plates (Marriner–Millward, 1984; Nye–Reid, 1986; Smedley, 1986). From typical E-MORB, and/or OIT they differ in little lower HFSE contents. Ti and elevated LILE contents. They are supposed to have been generated from melting mantle the composition of which is close to the source of MORB contamined to variable degree, and/or the

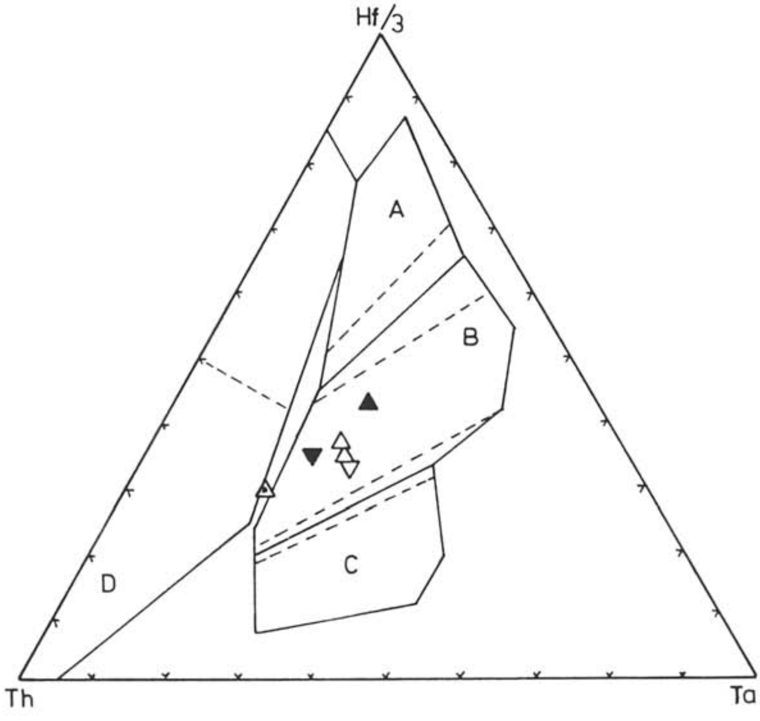


Fig. 24. Hf/3 : Th : Ta discrimination diagram (Wood et al., 1979). A — N-MORB, B — E-MORB, C — WPB, D — basalts of destructive plate margins.

source of OIB in the wedge over subducting plate, by the effects of fluids given off this plate (Arculus–Powell, 1986; Nye–Reid, 1986; White–Patchett, 1986). We find metabasalts from Rakovec more probable to be generated under the conditions of destructive margins of lithospheric plates for the following reasons: (1) metabasites from the neighbouring Rakovec and Gelnica groups indicate a transition from E-MORB, and/or OIT (Rakovec group) to CAB (Gelnica group; Ivan in prep.); (2) the Rakovec group except prevailing metamorphosed basalts and basaltoid andesites contain also intermediary and acid volcanites and volcanoclasts (Bajaník, 1969). It will be able to make more definite conclusions only if more knowledge on geological structure and geodynamic background of volcanites from the other Gemeric Paleozoic units is available. Now we can say that the conception of the Rakovec group as a representative of ophiolite sequence (Bajaník, 1976; Grecula, 1982) does not correspond to the findings presented in this work.

The presented interpretation of the origin of metabasalts from Rakovec seems to be strongly supported by the character of their metamorphosis. The metabasalts have been found to bear Ca-Na amphiboles with compositions analogous, and/or, similar to those occurring in the region with blueschist metamorphism (Ernst, 1979; Laird–Albee, 1981 b; Mposkos, 1987 and others) where they represent prograde, and/or retrograde middle stage of metamorphism. According to Thurston (1985) they may be a product of high-pressure metamorphism at increased temperatures. The occurrence of younger actinolitic hornblende is related to pressure retrograde stage of metamorphism under conditions similar to greenschist (Brown, 1977; Thurston, 1985). The youngest metamorphosis appears to be chlorite replacement of amphibole, i. e. the forming of chlorite + epidote + albite + carbonate association which may be related to extensive hydrothermal activity within the whole Paleozoic of the Gemeric unit.

So far, it has not been able to reconstruct truly the development of PT-conditions of metamorphism. This is disabled by a small amount of samples for study and the missing of direct products of the main high-pressure metamorphic stage, such as glaucophanes. In spite of this, high-pressure metamorphism taking place in the region under study can be considered very probable. The fact that the basalts showing affinity to subduction conditions, not typical MORB, would have undergone this metamorphism is not decisive — there are also cases in which such basalts were metamorphosed in blueschist facies, e. g. in the Western Alps (Oberhänsli, 1986).

Missing radiometric dating does not allow to solve the age of metamorphism. Paleozoic as well as Mesozoic ages can be considered. Recent years have brought information that the Paleozoic blueschist complexes are no exception either in Europe (Guiraud – Burg, 1984; Guiraud et al. 1987; Ohta et al., 1986) or overseas (Armstrong et al., 1983; Laird – Albee 1981 a; Trzcienski et al. 1984 and others).

## *Conclusions*

1. Metabasalts from Rakovec are characteristic for considerable variability of types. There occur aphyric as well as porphyric types with clinopyroxene phenocrysts, and/or albitized plagioclase phenocrysts. Amygdaloidal varieties are common as well. Basalts form lava flows, sometimes with pillow structure.

2. The study of clinopyroxene composition — the only preserved mineral phase of magmatic stage — suggests subalkaline, tholeiitic magma typical of non-orogenic environments, however, not wholly equal to MORB.

3. With the distribution of REE and elements considered immobile during metamorphism (Th, Ta, Hf, Y, Zr) metabasalts from Rakovec show affinity to enriched MORB, and/or OIT. We consider more probable that the basalts were generated in the environment of destructive margins of lithospheric plates rather than in that of intraplate or divergent contact of lithospheric plates. It corresponds with: (i) the latest data on the occurrence of these types in island arcs, (ii) suggestions of transition from E-MORB to CAB in the neighbouring

Gelnica group and (iii) occurrences of acid and intermediary volcanites and volcanoclasts in the Rakovec group.

4. The metamorphism of basalts from Rakovec showed polyphase character. The oldest so far detected phase has been related with the generating of blue Ca-Na amphibole. Its PT-conditions suggest its position between greenschist and blueschist metamorphism. The second phase related with the generating of actinolitic hornblende took place under the greenschist conditions. The youngest metamorphic phase (especially amphibole chloritization) may be related with hydrothermal activity of regional extent. It is probable that the metamorphism of basalts from Rakovec originally reached blueschist facies. The data on metamorphic age have not been available.

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