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# THE MALÉ KARPATY ROCKS ALTERED BY METASOMATISM

*(Tabs. 5, Figs. 24)*

Abstract: The paper deals with the geochemistry, of potassium and sodium metasomatism of altered rocks, their petrography and petrochemistry, and presents chemical analyses of the principal granitoid types (biotite granodiorite of the Modra type) and their dyke differentiates. On the basis of petrographical, petrochemical and geochemical data the K-metasomatism is considered to be a high-temperature process and the Na-metasomatism a lower-temperature alteration. The two metasomatic processes occur independently of each other and at different sites.

Резюме: Авторы занимаются в статье геохимической оценкой калиевого и натриевого метасоматизмов измененных пород, петрографией и петрохимией, они дают химические анализы основных типов гранитоидов (биотитический гранодиорит модранского типа) и их жильных дифференциатов. На основе петрографических, петрохимических и геохимических данных К-метасоматизм считают высоко температурным и Na-метасоматизм ниже температурным. Оба метасоматические процессы проходят независимо друг от друга на разных местах.

## Geological setting

A special problem concerning the granitoid rocks and crystalline schists of the Malé Karpaty (Little Carpathian Mts.) is encountered in studying the rocks altered by metasomatism. They occur in the area of Dolinkovský vrch Hill NE of the town of Modra (Fig. 1) near the village Harmónia and near the village Píla-Častá, some 4 km NW of Píla, S of the ruin Kobylé (Fig. 2). The Harmónia area is built up of biotite granodiorite of the Modra type and of the Devonian-Lower Carboniferous Harmónia Formation which is contact-metamorphosed by the granitoids.

The find of albitites and K-metasomatites is first mentioned in the paper of B. Cambel — J. Valach of 1956. In this publication a petrographic characterization of these rock was presented and the metasomatic phenomena in the crystalline schists of the Harmónia Formation were described. At that time the geological and genetic position of these products of metasomatism was impossible to establish without man-made exposures. Only sporadic boulders and minor fragments of the altered rocks were found in the field. Only the trench that was excavated in 1979 in the area of Dolinkovský vrch (el. point 392.1) had thrown some light on this problem. It was revealed that only parts of the granitoid apophyses had been affected by K-metasomatism and that these metasomatites are a product of the last phases of the consolidation of granitoid

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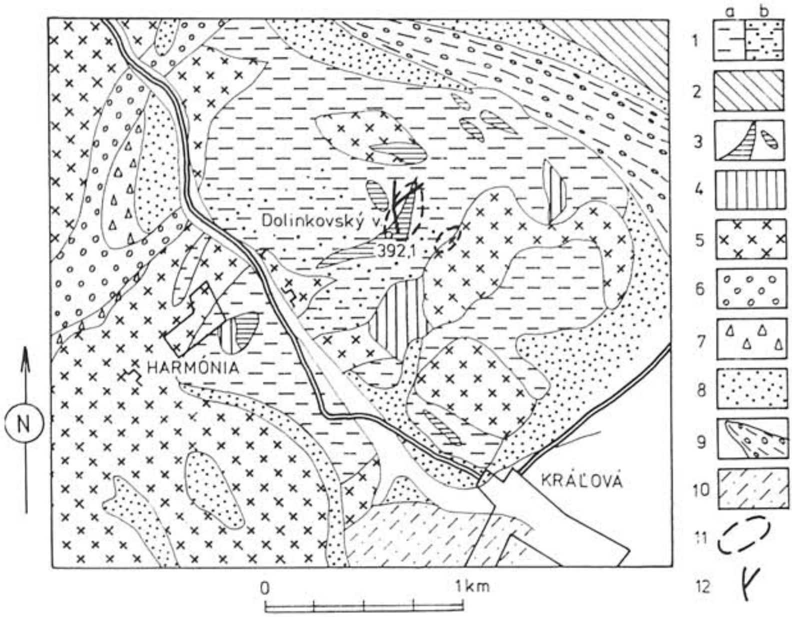


Fig. 1. Geological setting of the occurrence of K-metasomatites in the area of Dolinkovský vrch Hill, NE of the town of Modra near the village Harmónia (the situation of the exploration trench indicated).
1 a – schists of the Harmónia Formation, 1 b – spotted schists showing signs of contact metamorphism, 2 – schists of the transitional type, 3 – amphibolites, 4 – Devonian limestones, 5 – granodiorites, 6 – Middle Triassic to Permian quartzites, 7 – arkosic quartzites, 8 – loam, debris, Quaternary, 9 – alluvial cones, 10 – Quaternary alluvium, 11 – area metasomatites, 12 – trench

magma. Their generation was genetically linked with the formation of pegmatites and aplitoids. Hydrothermal alteration of the mantle rocks have also been recognized. The rocks affected by the highest-grade metasomatism are actually albitites (area of Píla–Častá) or orthoclasites (area of Harmónia, on the summit of Dolinkovský vrch, el. point 392.1).

The area of Dolinkovský vrch Hill is characterized by different types of granitoids, which penetrate the medium-grained biotite granodiorite or its fine-grained derivatives. The origin of this fine-grained rock type is tentatively explained in terms of contamination of the granodiorite magma in marginal or mobile parts of the plutonic granitoid body, due to fairly intensive assimilation and resorption of the schistose mantle.

North of the village Harmónia, in the area of Dolinkovský vrch, there are also different types of aplite, aplitoid granitoids and more or less coarse-grained pegmatite or pegmatitoid granitoids rich in microcline, zircon, apatite, orthite, garnet, amphibole and other minerals. It is to be noted that increased radioactivity and the occurrence of K-metasomatites of granodiorites are associated with the presence of K-pegmatites. The aplitoid granitoids in the metamorphosed limestones of the Harmónia Formation contain unusual minerals

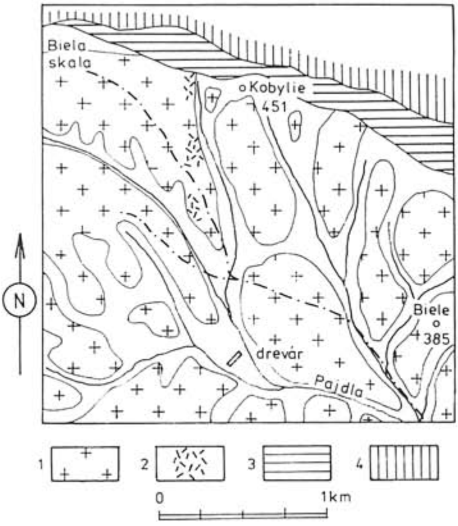


Fig. 2. Geological setting of the occurrence of Na-metasomatites (albitites) in the area of Píla.
1 — granites, 2 — migmatites, 3 — Triassic quartzites, 4 — limestones

such as large amphiboles at the margins of dykes, garnets, etc. With regard to the occurrence of both K-pegmatitoid dyke rocks and Na-pegmatitoids it can be assumed that these two types of dyke differentiates originated in different phases of evolution and consolidation of granodiorite magma. The differentiates form in the schist complex transverse intrusions dykes) or, more frequently, subparallel intrastratal tabular bodies (sills). The metasomatic derivatives of biotite granodiorite at the outcrops form small circular accumulations of fragments in detritus (10—15 m in diameter). This implies that only small parts of granitoid apophyses are affected by metasomatism. The metasomatically altered rocks are characterized by a relatively light colouring with dark spots, which have remained after biotite in the form of cavities rimmed with Fe-oxides. These rocks occur at several places on the ridge of Dolinkovský vrch, north of el. point 392.1 over a length of about 300—500 m. The nat. corporation Uranium Exploration excavated a ca. 400 m long trench in order to recognize, the occurrence of metasomatites in the granitoid rocks and/or in their schistose mantle and their relationship to the parent granodiorites, and to elucidate the causes of the increased total radioactivity of the rocks. Scheme of the trench profile is in Fig. 3.

The schists sequence of the Harmónia Formation (Devonian, Lower Carboniferous) in the area of Dolinkovský vrch shows an unusually variable lithology. The schists are contact-metamorphosed by the granodiorite intrusion of Modra type and by the later leucocratic dyke differentiates. Metabasites, particularly metapyroclastics contain accessory, finely dispersed pyrite or pyrrhotite, part of which may be even of impregnation-epigenetic character in the zones hydrothermally affected. The primary clay-siliceous sediments display fine flyschoid sedimentation: thin, more detrital layers with clastogenic feldspars, often observable with the naked eye, alternate with pelitic seams enriched in organic carbonaceous component. These sediments were metamorphosed into spotted schists containing biotite and andalusite, muscovitized in a considerable degree. The sequence also comprises limestones which at the contact with or near the granitoids are altered into calc-silicate hornfels with diopside, andradite, vesuvian, wollastonite and other minerals. The manifestations of hydrothermal activity in the wider area around the metasomatites on Dolinkovský vrch indicate that hydrothermal process was part of the closing phase of granitoid plutonism.

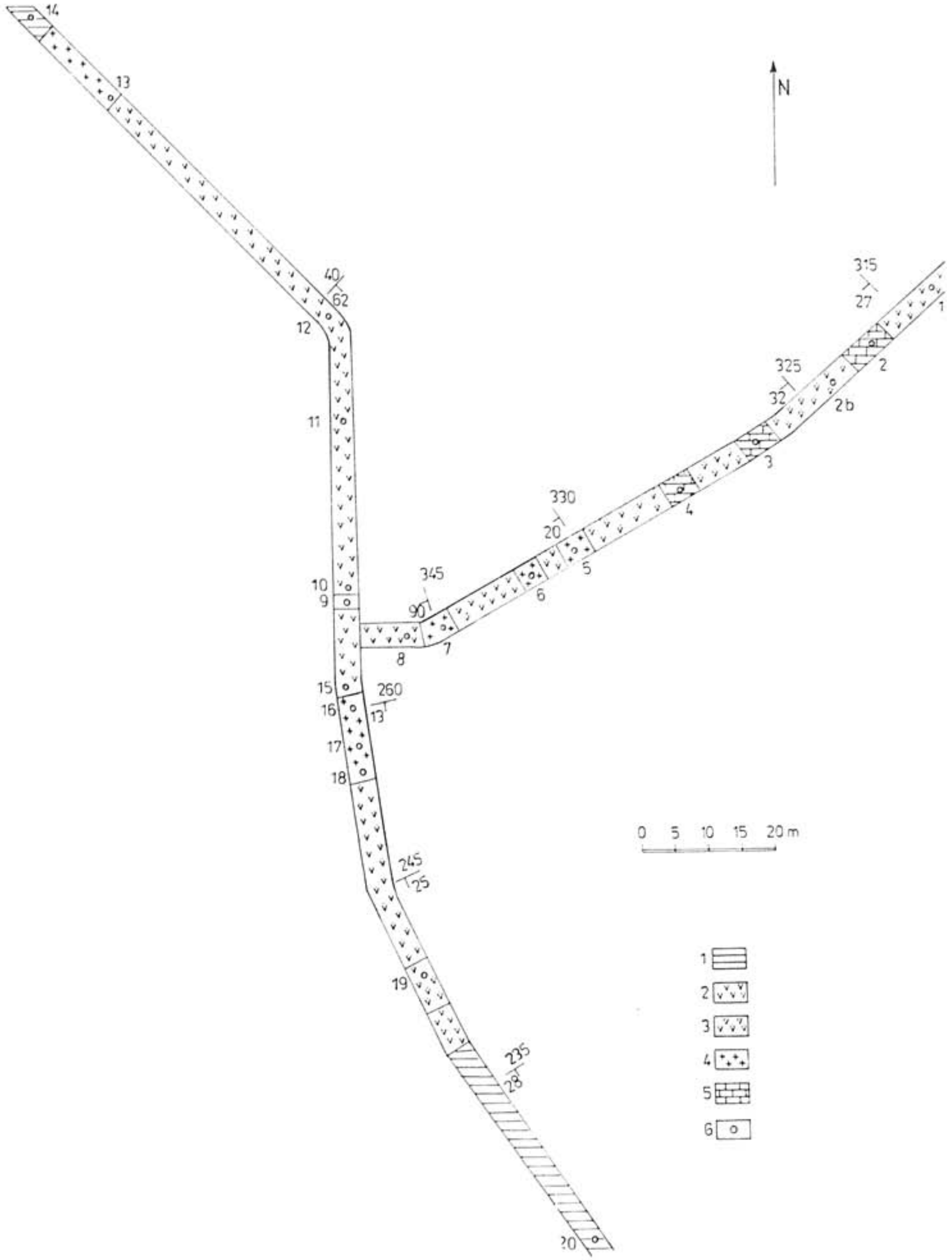
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Fig. 3 a.

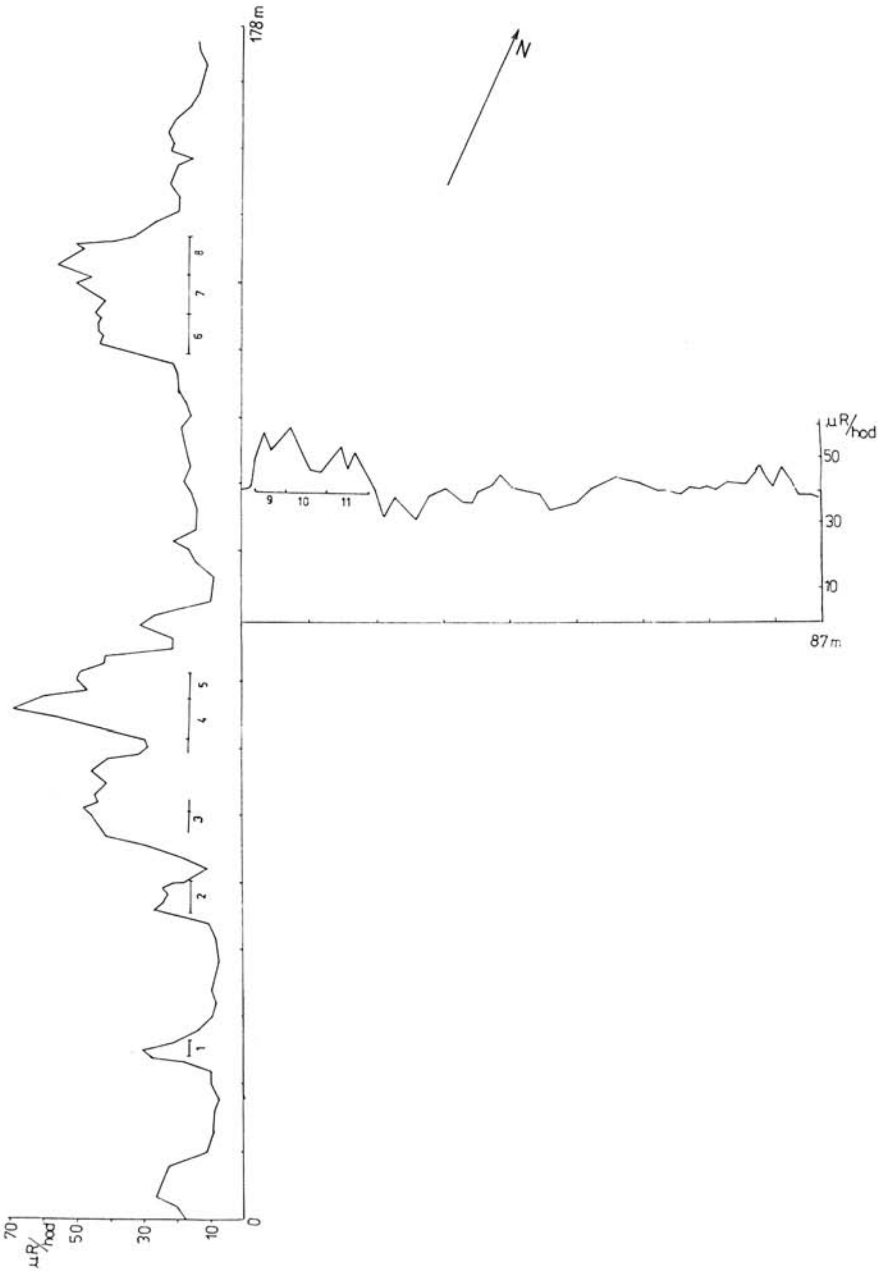



Fig. 3 b.

Fig. 3 a, b. Sketch showing the geological situation of the trench on Dolinkovský vrch. 1 — graphitic schists, 2 — amphibolites, 3 — spotted ore-bearing amphibolites, 4 — granite, 5 — metamorphosed limestones, 6 — sampling locality; (b) Natural radioactivity in the trench

The whole area of Dolinkovský vrch shows increased total radioactivity: the measurements conducted in the trench have revealed that the radioactivity is associated not only with metasomatism but also with the presence of pegmatites containing zircon, apatite, orthite and other minerals.

The study of K-metasomatites from the Dolinkovský vrch area has confirmed that owing to the small distribution of their high-potassium types no major accumulation of potassium-bearing rocks can be expected. The origin of a monomineral orthoclase accumulation is likewise only local, being a product of progressive metasomatism of granitoids. The rock types of initial and medium-intensive metasomatism are common.

Thirty-three granitoid samples studied have been divided into groups, which are characterized petrographically, petrochemically and geochemically in the tex below:

1. Primary unaltered types and their dyke differentiates

a) primary type – Modra biotite granodiorite, medium- and fine-grained, in the areas of Dolinkovský vrch and NW of the village Píla (Table 1),

b) granitoid dyke rocks, aplite, pegmatite, leucocratic granitoid rocks with Na-prevalence over K (Table 2),

c) granite-pegmatoid dyke rocks to pegmatite with K-predominance over Na (Table 3).

2. Rocks affected by metasomatism

a) granitoids altered by K-metasomatism in three alteration degrees (Table 4),

b) granitoids altered by Na-metasomatism in three degrees (Table 5).

In conclusion to the introduction it should be noted that our correlation work was enabled by the studies of albitites from the Bohemian Massif. This concerns the works of E. Pivec (1973, 1975), who studied albitite occurrences in the area of Příbram, the papers of J. Vachtl (1932), A. Dudek – F. Fediuk (1965 a, b) and M. Palivcová (1967). These Czech classical works on Na-metasomatism (albititization) of granitoid rocks show many analogies with the Na-metasomatites in Slovakia. Although the albitites in the Příbram area are accessible to field observation, and the Slovakian albitites in detritus, more or less analogous processes can be presumed. We wish here to thank the authors mentioned above for lending us the offprints and publications.

The relatively complicated process of metasomatism has been studied by many authors. We have correlated our results with the findings of the following authors, whose papers were available to us: M. Čajková, – E. Šamajová (1960); D. S. Koržinskij (1969, 1976, 1978); L. S. Borodin – A. S. Pavlenko (1974); P. V. Kovaľ (1975); E. I. Popolitov (1975); J. Babčan (1976); J. H. Weare et al. (1976); M. Foteilles (1978); V. G. Krjukov (1978); O. A. Bogatikov (1979); M. Šimová – E. Šamajová (1979) and others.

## *Brief petrographical characterization of the rocks studied*

The description is oriented to the evaluation of the submitted petrography and planimetric analyses, as is in the intentions of the work. The mode of description follows the scheme given in the Chapter on geological setting.

1.a) The Modra medium- to fine-grained biotite granodiorite in the areas of Dolinkovský vrch and NW of the village Píla (Table 1).

The following samples have been classed with this group: M – 3; 7; 18; 19; 20; R – 18 and rock samples from the paper of B. Cambel – J. Valach (1956): II.1/1; II.1/2; II.1/3 and II.1/4.

Macroscopically the rocks are of light to grey colour and formed of quartz, feldspar and micas, chiefly biotite; they have hypidiomorphic-granular texture. According to angles of extinction in the symmetric zone, plagioclases belong to oligoclases of higher basicity to acid andesine with an average content of anorthite component An = 28 %. In sample M-18 (Píla) plagioclases show a zonal structure, the cores of grains being more intensely sericitized than the marginal parts. Potassium feldspars are represented almost exclusively by orthoclase. Quartz is relatively strongly cataclastic, which is manifested by undulosity and granoblastic disintegration of grains. Biotite is markedly pleochroic with brownish tints and often encloses zircon and apatite; it underwent secondary alterations: chloritization, baueritization and epidotitization. Accessory minerals are short-prismatic zircon, columnar apatite, sphene, orthite, epidote – zoisite, magnetite and hematite.

*Planimetric analyses of the above rocks:*

| | Q | K-f | Plg | Bi | Amph | Musc | Acc | Q | A | P |
|---|---|---|---|---|---|---|---|---|---|---|
| M-3 | 29 | 21 | 38 | 6 | – | 5 | 1 | 33 | 24 | 43 |
| M-7 | 28 | 13 | 41 | 11 | – | 5 | 2 | 34 | 16 | 50 |
| M⁺-18 | 28 | 9 | 48 | 11 | | 4 | | 33 | 11 | 56 |
| M⁺-19 | 31 | 3 | 54 | 10 | | 2 | | 35 | 4 | 61 |
| M⁺-20 | 31 | 0 | 57 | 9 | | 3 | | 35 | 0 | 65 |
| R-18 | 26 | 19 | 41 | 5 | – | 3 | 6 | 30 | 22 | 48 |
| II.1/1 | 24.33 | 24.41 | 38.13 | 9.62 | 22 | – | 1.48 | 28 | 28 | 44 |
| II.1/2 | 19.65 | 14.45 | 43.09 | 16.93 | 4.63 | – | 1.29 | 25 | 19 | 56 |
| II.1/3 | 20.89 | 18.05 | 46.55 | 14.83 | acc. | – | unmeas. | 24 | 21 | 55 |
| II.1/4 | 26.59 | 25.28 | 39.31 | 8.42 | acc. | – | 0.20 | 29 | 28 | 43 |

Note: ⁺Planimetric analyses taken from J. Macek et al. (1979).

1. b) Granitoid dyke rocks, aplites, leucocratic granitoids with a prevalence of sodium over potassium (Table 2). This group comprises samples M-1; 2; 6; 8; 12; 17; R-7. The rocks are lightto milky-grey, in places with brownish tint. The essential rock-forming minerals are quartz, feldspars, biotite and sporadically hornblende; their texture is hypidiomorphic-granular. Plagioclases belong to oligoclases with an average content of anorthite component An = 13 %; they are often of pericline habit and form perthites. Orthoclase is the representative of potassium feldspars. Quartz is usually well preserved. Biotite is chloritized and baueritized. Hornblende constitutes clusters, occurs in certain zones of dykes and encloses orthite with pleochroic haloes. It is usually corroded and resorbed by K-feldspar. The mineral is common amphibole. Sphene, orthite, epidote and zoisite are accessories.

Primary rock types of the Modra granitoid massif

| | M-3 | M-7 | M-18 | M-19 | M-20 | R-18 | II 1/1 | II 1/2 | II 1/3 | II 1/4 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.89 | 69.03 | 64.84 | 65.76 | 66.81 | 69.55 | 66.17 | 66.13 | 66.91 | 70.10 | 67.72 |
| $TiO_2$ | 0.26 | 0.50 | 0.73 | 0.67 | 0.66 | 0.47 | 0.40 | 0.12 | 0.73 | 0.14 | 0.47 |
| $Al_2O_3$ | 15.57 | 15.94 | 16.67 | 16.49 | 15.97 | 15.07 | 17.46 | 16.25 | 16.60 | 13.94 | 15.99 |
| $Fe_2O_3$ | 0.48 | 1.11 | 0.72 | 1.13 | 0.36 | 1.55 | 0.42 | 1.51 | 0.80 | 1.20 | 0.93 |
| FeO | 0.98 | 1.20 | 2.73 | 2.13 | 2.50 | 0.69 | 3.05 | 2.36 | 2.19 | 0.75 | 1.86 |
| MnO | 0.06 | 0.06 | 0.07 | 0.07 | 0.09 | 0.05 | 00.03 | 0.02 | 0.06 | 0.01 | 0.05 |
| CaO | 0.92 | 2.36 | 3.59 | 2.80 | 2.27 | 1.70 | 3.42 | 4.25 | 3.10 | 3.45 | 2.79 |
| MgO | 0.42 | 0.72 | 1.57 | 1.53 | 1.79 | 0.47 | 1.38 | 1.73 | 1.79 | 3.20 | 1.43 |
| $Na_2O$ | 4.88 | 4.80 | 5.20 | 5.20 | 5.46 | 6.03 | 5.59 | 4.30 | 3.98 | 4.73 | 5.02 |
| $K_2O$ | 3.50 | 3.04 | 2.64 | 3.04 | 2.60 | 3.07 | 2.13 | 2.53 | 1.84 | 1.42 | 2.57 |
| $P_2O_5$ | 0.18 | 0.15 | 0.26 | 0.22 | 0.22 | 0.19 | 0.10 | 0.02 | 0.13 | 0.39 | 0.19 |
| $H_2O^+$ | 0.05 | 0.10 | 0.05 | 0.01 | 0.01 | 0.26 | 0.70 | 0.50 | 1.39 | 0.27 | 0.33 |
| $H_2O^-$ | 1.01 | 1.11 | 0.98 | 1.13 | 1.19 | 1.13 | 0.07 | 0.45 | 0.09 | 0.52 | 0.77 |
| | 100.20 | 100.12 | 100.08 | 100.18 | 99.93 | 100.23 | 100.95 | 100.27 | 99.52 | 100.12 | 100.13 |
| Be | 3.5 | <3 | <3 | <3 | <3 | <3 | — | — | — | — | 3.08 |
| B | 18.2 | 11.2 | 24.5 | 17.8 | 16.6 | <10 | — | — | — | — | 16.38 |
| Sn | 10 | 10 | 14.1 | 5.7 | <3 | <3 | — | — | — | — | 7.63 |
| Cu | 74 | 151 | 200 | 11.5 | 6.8 | 10.2 | — | — | — | — | 75.58 |
| Mo | 18.2 | 24 | 5.5 | 6.2 | 5.9 | <3 | — | — | — | — | 10.47 |
| V | 12.6 | 36 | 93 | 45 | 46 | 36 | — | — | — | — | 44.77 |
| Ni | 115 | 8.7 | 5.6 | 7.2 | 4.9 | 26 | — | — | — | — | 27.90 |
| Co | <3 | 3.3 | 4.7 | 8.7 | 8.1 | 11.8 | — | — | — | — | 6.60 |
| Y | 12.3 | 17 | 13.8 | 14.5 | 14.8 | 19 | — | — | — | — | 15.23 |
| Zr | 107 | 145 | 191 | 166 | 151 | 129 | — | — | — | — | 148.17 |
| Ba | 830 | 1150 | 1320 | 890 | 710 | 1820 | — | — | — | — | 1120 |
| Sr | 204 | 500 | 600 | 780 | 810 | 590 | — | — | — | — | 580,67 |
| Cr | 263 | 39 | 68 | 68 | 45 | 8.9 | — | — | — | — | 81.98 |
| Sc | 3.7 | 4.4 | 7.4 | 9.5 | 9.8 | 5.1 | — | — | — | — | 6.65 |
| Ag | — | — | — | — | — | 4.8 | — | — | — | — | |
| Ga | — | — | — | — | — | 24 | — | — | — | — | |
| La | — | — | — | — | — | 41 | — | — | — | — | |
| Pb | — | — | — | — | — | 14.8 | — | — | — | — | |

*Explanations:* M-3 — biotite granodiorite (margin of the vineyard, SE slope of Dolinkovský vrch, el point 392); M-7 — granodiorite, transverse veins in limestones of Harmónia Form. (Dolinkovský vrch, margin of the vineyard, SE of el. point 392); M-18 — medium-grained albitized granodiorite (Píla, Pailanská dolina, W of gamekeeper's lodge Kobylé, NW of el. point); M-19 — biotite tonalite 23/63/SE (Harmónia, NE of Modra, abandoned quarry in the Žliabok brook valley, below el. 477.7 m, 800 m from Harmónia); M-20 — biotite tonalite 25/63/SE (Harmónia near Modra, central quarry of Veľký Quarry, valley of the Kamenný brook, N slope, near the road to Piesky); R-18 — primary Modra granodiorite (8 m, S arm of the trench); II 1/1 biotite granodiorite with sporadic feldspar phenocrysta (NW of Píla, 400 SE of the cottage U Rybníčka); II 1/2 biotite granodiorite (Harmónia, quarry in the valley, S of el. point 313); II 1/3 biotite granodiorite (Piesky); II 1/4

| M-1 | Q | Kf | Plg | Bi | Amph | Musc | Acc | Q | A | P |
|---|---|---|---|---|---|---|---|---|---|---|
| M-1 | 39 | 26 | 32 | 1 | — | — | 2 | 40 | 27 | 33 |
| M-2 | 30 | 29 | 32 | 3 | 2 | 1 | 3 | 33 | 32 | 35 |
| M-6 | 36 | 27 | 26 | 3 | — | 6 | 2 | 41 | 30 | 29 |
| M-8 | 18 | 24 | 39 | 3 | 8 | 4 | 4 | 22 | 30 | 48 |
| M-12 | 26 | 21 | 37 | 2 | 3 | 3 | 8 | 31 | 25 | 44 |
| M-17 | 34 | 25 | 37 | 2 | — | — | 2 | 35 | 26 | 39 |
| R-7 | 35 | 23 | 33 | 4 | — | 2 | 3 | 38 | 26 | 36 |

1. c) Pegmatitoid granitoid dyke rocks to pegmatites with a prevalence of potassium over sodium (Table 3).

Rock samples labelled M-4; 5; 9; R-6; 21; 24; 27 and 39 are placed in this group. The rocks are grey, milky-white and brownish in colour. Plagioclases are oligoclases with anorthite component An = 17 %. Potassium feldspars are represented by microcline and orthoclase. Quartz is often undulatory, cataclastic, graphically intergrown with orthoclase. Biotite encloses apatite and zircon and is often baueritized and chloritized. Garnets are euhedral to anhedral, cumulated into clusterrs and optically anomalous. Sphene, orthite, muscovite, epidote, zoisite and zircon are accessory minerals.

| | Q | Kf | Plg | Bi | Ampf | Musc | Acc | Q | A | P |
|---|---|---|---|---|---|---|---|---|---|---|
| M-4 | 33 | 32 | 27 | 4 | — | 1 | 3 | 36 | 35 | 29 |
| M-5 | 27 | 32 | 26 | 5 | — | 3 | 7 | 32 | 38 | 30 |
| M-9 | 26 | 24 | 23 | — | — | — | 27* | 35 | 33 | 32 |
| R-6 | 35 | 27 | 28 | 7 | — | 2 | 1 | 39 | 30 | 31 |
| R-21 | 29 | 44 | 18 | 3 | — | — | 6 | 32 | 48 | 20 |
| R-24 | 27 | 47 | 21 | 2 | — | — | 3 | 28 | 49 | 23 |
| R-27 | 37 | 34 | 23 | 2 | — | — | 4 | 39 | 36 | 25 |
| R-39 | 27 | 33 | 24 | 6 | — | 4 | 6 | 32 | 39 | 29 |

* The figure relates to garnets, in which the rock cutting across carbonates is enriched at the margins.

2. a) Granitoids altered by K-metasomatism of three degrees (Table 4).

The following rock samples have been ranked with this group: M-11; 16; R-13 (1st degree); R-23; 29 (2nd degree); M-13; 14; 15; R-32 (3rd degree). The boundaries between the degrees have been determined conventionally on the basis of $K_2O$ content:

1st degree: $K_2O$ content in the rock < 6 %
2nd degree: $K_2O$ content in the rock 6—8 %
3rd degree: $K_2O$ content in the rock 8—10 %.

Macroscopic observation shows that K-metasomatism causes a change in the colouration of rock. In the zones of a granitoid rock K-metamorphism is manifested by the changing colour of the rock from light through grey to brown and reddish-brown. Rocks affected by K-metasomatism of degree 3 are dark-grey. In the rock there are cavities after leached biotite, coloured by limonite

Table 2
Hypabyssal aplitoid derivatives with sodium predominating over potassium

| | M-1 | M-2 | M-6 | M-8 | M-12 | M-17 | R-7 | Average |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 74.15 | 69.44 | 71.81 | 70.00 | 69.56 | 69.59 | 72.02 | 70.94 |
| $TiO_2$ | 0.19 | 0.36 | 0.23 | 0.24 | 0.53 | 0.17 | 0.19 | 0.27 |
| $Al_2O_3$ | 12.34 | 15.19 | 15.95 | 16.12 | 14.66 | 14.74 | 14.60 | 14.80 |
| $Fe_2O_3$ | 0.27 | 1.10 | 0.45 | 0.37 | 0.43 | 0.45 | 1.06 | 0.58 |
| FeO | 0.68 | 1.26 | 0.61 | 1.31 | 1.76 | 0.93 | 0.42 | 0.99 |
| MnO | 0.02 | 0.07 | 0.04 | 0.07 | 0.10 | 0.07 | 0.02 | 0.06 |
| CaO | 1.40 | 3.92 | 1.06 | 3.14 | 3.90 | 2.24 | 0.79 | 2.35 |
| MgO | 0.12 | 0.64 | 0.44 | 0.44 | 0.74 | 0.32 | 0.57 | 0.47 |
| $Na_2O$ | 5.40 | 6.00 | 4.74 | 6.04 | 5.37 | 6.00 | 5.24 | 5.54 |
| $K_2O$ | 4.88 | 0.80 | 3.68 | 1.46 | 2.04 | 3.86 | 4.17 | 2.98 |
| $P_2O_5$ | 0.03 | 0.13 | 0.20 | 0.08 | 0.20 | 0.09 | 0.36 | 0.16 |
| $H_2O^+$ | 0.04 | 0.06 | 0.03 | 0.05 | 0.00 | 0.10 | 0.28 | 0.08 |
| $H_2O^-$ | 0.36 | 1.02 | 0.88 | 0.68 | 0.64 | 1.38 | 0.70 | 0.81 |
| | 99.88 | 99.99 | 100.13 | 100.00 | 99.93 | 99.94 | 100.42 | 100.03 |

| | M-1 | M-2 | M-6 | M-8 | M-12 | M-17 | R-7 | Average |
|---|---|---|---|---|---|---|---|---|
| Be | <3 | <3 | 15.1 | <3 | <3 | 6.7 | <3 | 5.20 |
| B | <3 | 25.7 | 14.1 | 12 | 15.1 | 51 | <10 | 18.70 |
| Sn | 10 | 12.5 | 10 | 10 | 10.1 | 12.3 | <3 | 9.71 |
| Cu | 135 | 229 | 56 | 141 | 162 | 129 | 4.1 | 122.30 |
| Mo | 26.3 | 20 | 7.8 | 17.4 | 20.4 | 17.4 | <3 | 16.04 |
| V | 5.4 | 31 | 11.2 | 37 | 87 | 9.5 | 3 | 26.30 |
| Ni | <3 | 4.4 | 52 | <3 | 129 | 110 | 5.5 | 43.84 |
| Co | <3 | <3 | <3 | <3 | 3.1 | <3 | <3 | 3.01 |
| Y | 34 | 29.5 | 12.6 | 20.4 | 155 | 9.1 | 13.2 | 39.11 |
| Zr | 45 | 56 | 87 | 42 | 63 | 60 | 59 | 58.86 |
| Ba | 2510 | 620 | 760 | 460 | 830 | 955 | 710 | 977.86 |
| Sr | 209 | 540 | 191 | 550 | 500 | 234 | 123 | 335.29 |
| Cr | 44 | 275 | 93 | 36 | 229 | 234 | 4.3 | 130.76 |
| Sc | 3.1 | 3.1 | <3 | 12.3 | 34 | <3 | 4.8 | 9.04 |
| Ag | — | — | — | — | — | — | <3 | |
| Ga | — | — | — | — | — | — | 20 | |
| La | — | — | — | — | — | — | <30 | |
| Pb | — | — | — | — | — | — | 20 | |

*Explanations:* M-1 — aplitoid granite veins cutting the limestones of Harmónia Form. (Harmónia, Dolinkovský vrch, SE of el. point 392); M-2 — hypabyssal granitoid at the contact with limestones of Harmónia Form. (Dolinkovský vrch, SE of el. point); M-6 — aplitoid granitoid vein in microgranite (S slope of Dolinkovský vrch, road); M-8 — transverse vein of medium-grained granitoid in limestones of Harmónia Form., quarry (Dolinkovský vrch, margin of the vineyard, SE of el. point 392); M-12 hypabyssal leucocratic granitoid with amphiboles (SE of el. point 392, Dolinkovský vrch); M-17 — aplitoid granodiorite, transverse vein in limestone (limestone quarry S of Dolinkovský vrch); R-7 — aplitoid mica-free granodiorite (NE arm of the trench, 81 m)

along the margins. Their number increases with the intensity of K-metasomatism.

The rocks are composed of quartz, feldspars and relict biotite. Original minerals are also plagioclases of immeasurable basicity, which in the final phase are most strongly altered, decomposed and replaced by orthoclase. The metaso-

Table 3

Hypabyssal pegmatitoid granitoids to pegmatites with potassium in predominance over sodium

| | M-4 | M-5 | M-9 | R-6 | R-21 | R-24 | R-27 | R-39 | Average |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 72.73 | 66.00 | 64.58 | 73.68 | 69.10 | 70.42 | 72.38 | 72.78 | 70.21 |
| $TiO_2$ | 0.15 | 0.65 | 0.55 | 0.17 | 0.44 | 0.35 | 0.25 | 0.20 | 0.35 |
| $Al_2O_3$ | 14.59 | 17.75 | 16.49 | 14.17 | 15.26 | 16.55 | 13.78 | 13.93 | 15.32 |
| $Fe_2O_3$ | 0.32 | 0.54 | 0.18 | 0.83 | 1.18 | 0.60 | 1.11 | 0.35 | 0.60 |
| FeO | 0.60 | 0.58 | 0.71 | 0.30 | 0.82 | 0.51 | 0.23 | 0.19 | 0.49 |
| MnO | 0.04 | 0.05 | 0.05 | 0.02 | 0.06 | 0.03 | 0.02 | 0.02 | 0.04 |
| CaO | 1.09 | 2.64 | 3.48 | 0.78 | 1.44 | 1.35 | 1.59 | 0.84 | 1.35 |
| MgO | 0.10 | 0.52 | 0.80 | 0.13 | 0.33 | 0.41 | 0.01 | 0.84 | 0.39 |
| $Na_2O$ | 4.46 | 4.80 | 4.96 | 2.73 | 4.01 | 2.52 | 3.95 | 2.62 | 3.76 |
| $K_2O$ | 5.70 | 4.80 | 6.72 | 6.23 | 6.01 | 6.30 | 5.88 | 6.89 | 6.07 |
| $P_2O_5$ | 0.17 | 0.17 | 0.13 | 0.40 | 0.47 | 0.63 | 0.18 | 0.18 | 0.29 |
| $H_2O^+$ | 0.04 | 0.13 | 0.03 | 0.25 | 0.21 | 0.17 | 0.13 | 0.15 | 0.14 |
| $H_2O^-$ | 0.34 | 1.12 | 1.22 | 0.57 | 1.00 | 0.51 | 0.82 | 0.59 | 0.77 |
| | 100.33 | 99.75 | 99,90 | 100.26 | 100.33 | 100.35 | 100.33 | 99.89 | 100.03 |
| Be | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 | 3 |
| B | 9.5 | 25.7 | 12.6 | <10 | <10 | <10 | 10 | <10 | 12.23 |
| Sn | 11.7 | 12.3 | 14.1 | <3 | <3 | <3 | <3 | <3 | 6.64 |
| Cu | 115 | 74 | 132 | <3 | 3.2 | <3 | 12.9 | <3 | 43.23 |
| Mo | 27 | — | 8.7 | <3 | <3 | <3 | <3 | <3 | 6.34 |
| V | 3 | 55 | 35 | <3 | 18 | 6.2 | 30 | <3 | 19.15 |
| Ni | <3 | 4.2 | 50 | 12.3 | 32 | 14 | 16.6 | <3 | 16.89 |
| Co | <3 | <3 | <3 | 5.7 | 9.1 | <3 | 5 | <3 | 4.35 |
| Y | 12.6 | 24.5 | 24.5 | 13.2 | 29 | 32 | 10.2 | <10 | 19.50 |
| Zr | 43 | 166 | 101 | 42 | 62 | 26 | 81 | 39 | 70.00 |
| Ba | 1200 | 2750 | 2390 | 480 | 2880 | 3800 | 1700 | 1740 | 2117.50 |
| Sr | 117 | 540 | 510 | 135 | 410 | 320 | 162 | 178 | 296.50 |
| Cr | 74 | 35 | 93 | 5.1 | 6.9 | 4.1 | 19 | 6.8 | 30.49 |
| Sc | <3 | 4.7 | 4.8 | 3.4 | 5.3 | 3.7 | 3 | <3 | 3.86 |
| Ag | | | | 3.4 | 2.8 | 3 | 5.2 | 2.4 | 3.36 |
| Ga | | | | 17 | 20 | 19 | 24 | 12.9 | 18.58 |
| La | | | | <30 | <30 | <30 | <30 | <30 | 30 |
| Pb | | | | 13.5 | 23 | 29 | 11.2 | 12.6 | 17.83 |

*Explanations:* M-4 – aplitoid part of pegmatite amphibole-bearing vein cutting through the limestone of Harmónia Formation (margin of the vineyard, SE slope of Dolinkovský vrch, el. point 392); M-5 leucocratic muscovite-biotite granodiorite enclosed in subjacent granodiorite (margin of the vineyard, SE slope of Dolinkovský vrch, el. point 392); M-9 – leucocratic granodiorite vein at the contact with erlan (Dolinkovský vrch, margin of the forest and vineyard, SE of el. point 392); R-6 – fine-grained aplitoid granodiorite (NE arm of the trench 68 m); R-21 – pegmatitoid granitoid rock (Dolinkovský vrch, at the trench); R-24 – pegmatitoid granitoid rock (Dolinkovský vrch, at the trench); R-27 – pegmatitoid granitoid rock (Dolinkovský vrch, at the trench); R-39 – pegmatitoid granitoid rock (Dolinkovský vrch, the ridge)

Table 4
Granitoids altered by K-metasomatism in three degrees

| | I. stage | | | | II. stage | | | III. stage | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M-11 | M-13 | R-13 | Average | R-23 | R-29 | Average | M-13 | M-14 | M-15 | R-32 | Average |
| $SiO_2$ | 70.83 | 63.13 | 57.55 | 63.17 | 62.63 | 64.48 | 63.56 | 61.57 | 60.44 | 61.53 | 60.86 | 61.10 |
| $TiO_2$ | 0.20 | 0.54 | 0.33 | 0.37 | 0.71 | 0.73 | 0.72 | 0.54 | 0.71 | 0.71 | 0.63 | 0.69 |
| $Al_2O_3$ | 14.73 | 16.33 | 16.74 | 15.96 | 18.72 | 19.29 | 19.01 | 19.35 | 19.18 | 18.42 | 18.52 | 18.87 |
| $Fe_2O_3$ | 0.23 | 0.43 | 0.81 | 0.51 | 0.67 | 0.56 | 0.62 | 0.13 | 0.31 | 0.32 | 0.30 | 0.36 |
| FeO | 0.35 | 0.79 | 0.91 | 0.79 | 0.59 | 0.33 | 0.46 | 0.63 | 0.67 | 0.63 | 0.33 | 0.53 |
| MnO | 0.04 | 0.03 | 0.05 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.07 | 0.03 | 0.05 |
| CaO | 1.34 | 2.64 | 1.28 | 1.75 | 2.09 | 2.19 | 2.14 | 1.93 | 3.20 | 2.50 | 1.75 | 2.35 |
| MgO | 0.40 | 1.20 | 0.63 | 0.79 | 0.83 | 0.93 | 0.91 | 0.37 | 1.00 | 1.11 | 1.35 | 1.21 |
| $Na_2O$ | 3.00 | 4.50 | 4.14 | 4.91 | 4.03 | 1.96 | 3.02 | 3.56 | 4.26 | 3.36 | 4.31 | 4.05 |
| $K_2O$ | 4.13 | 3.00 | 5.36 | 5.51 | 3.17 | 8.03 | 8.10 | 10.04 | 8.92 | 9.88 | 9.42 | 9.57 |
| $P_2O_5$ | 0.21 | 0.19 | 0.57 | 0.32 | 0.22 | 0.22 | 0.22 | 0.09 | 0.23 | 0.20 | 0.23 | 0.19 |
| $H_2O$ | 0.01 | 0.02 | 0.21 | 0.03 | 0.24 | 0.20 | 0.22 | 0.06 | 0.04 | 0.03 | 0.20 | 0.11 |
| $H_2O^-$ | 0.92 | 0.32 | 0.73 | 0.84 | 1.08 | 0.97 | 1.03 | 1.16 | 0.97 | 0.93 | 0.90 | 0.99 |
| | 99.80 | 100.16 | 100.47 | 100.14 | 100.12 | 99.92 | 100.00 | 100.17 | 99.97 | 100.05 | 100.10 | 100.12 |
| Be | 8.3 | <3 | <3 | 4.77 | <3 | <3 | 3 | <3 | <3 | <3 | <3 | 3 |
| B | 15.9 | 12 | <10 | 9.30 | <10 | <10 | 10 | 11.2 | 16.6 | 13.5 | <10 | 12.83 |
| Sn | 12.3 | 10 | <3 | 8.43 | <3 | <3 | 3 | 10.4 | 19.5 | 15.1 | <3 | 12 |
| Cu | 39 | 315 | 3 | 34.53 | 3 | <3 | 3 | 46 | 71 | 81 | <3 | 50.25 |
| Mo | 17 | 10.7 | <3 | 10.23 | <3 | <3 | 3 | 7.6 | 7.9 | 5.5 | <3 | 6.25 |
| V | 12.9 | 73 | 16 | 34.97 | 43 | 44 | 45 | 68 | 87 | 80 | 49 | 73.25 |
| Ni | 3.1 | 32 | 24 | 29.70 | 5.3 | 5.6 | 5.95 | 51 | 55 | 45 | 5.2 | 39.05 |
| Co | <3 | <3 | <3 | 3 | 4.3 | 3 | 3.65 | <3 | 4.3 | 3 | 3 | 3.33 |
| Y | 10.4 | 10.2 | 40 | 20.20 | 14.5 | 17 | 15.75 | 15.9 | 17 | 8.3 | 14.1 | 13.83 |
| Zr | 73 | 138 | 89 | 101 | 191 | 173 | 184.5 | 159 | 145 | 129 | 148 | 145.25 |
| Ba | 510 | 1500 | 3500 | 1833.67 | 4100 | 4000 | 4050 | 2340 | 1740 | 6300 | 4100 | 3320 |
| Sr | 200 | 575 | 355 | 379.67 | 540 | 650 | 595 | 600 | 710 | 660 | 550 | 630 |
| Cr | 32 | 132 | 7.3 | 80.57 | 9.3 | 8.7 | 9 | 98 | 117 | 115 | 7.8 | 84.45 |
| Sc | 3.1 | 3.8 | 6 | 4.30 | 6.9 | 7.1 | 7 | <3 | 4 | 3.3 | 7.9 | 4.55 |
| Ag | — | — | <3 | | <3 | <3 | 3 | — | — | — | <3 | |
| Ga | — | — | 17 | | 30 | 20 | 25 | — | — | — | 25 | |
| La | — | — | <30 | | 59 | 89 | 79 | — | — | — | 102 | |
| Pb | — | — | 20 | | 18 | 20 | 19 | — | — | — | 23 | |

*Explanations:* M-11 – granodiorite metasomatized, degree 1 (Dolinkovský vrch, margin of the forest and vineyard, SE of el. point 392); M-16 – granodiorite altered by metasomatism, degree 1 (NE of el. point 392, Dolinkovský vrch); R-13 – granodiorite altered by metasomatism, degree 2 (N arm of the trench, 76 m); R-23 – granodiorite altered by metasomatism, degree 2 (Dolinkovský vrch, at the trench); R-29 – granodiorite altered by metasomatism, degree 2 (Dolinkovský vrch, ridge); M-13 – granodiorite altered by metasomatism, degree 3 (NE of el. point 392.1, Dolinkovský vrch); M-14 – granodiorite altered by metasomatism, degree 3 (NE of el. point 392.1, Dolinkovský vrch); M-15 – granodiorite altered by metasomatism, degree 3 (NE of el. point 392.1, Dolinkovský vrch); R-32 – granodiorite altered by metasomatism, degree 3 (Dolinkovský vrch, ridge) matic rock contains very little quartz; it is of uncertain position being for the most part relict quartz. The original biotite is difficult to discern, and it occurs in the form of relicts. The metasomatites contain amphiboles of two types: strongly altered, epidotized anhedral individuals and unaltered, pure and subhedral amphibole. The latter together with a small amount of muscovite occur in paragenesis with orthoclase. Orthoclase does not show any pressure effects and is anhedral; it replaced virtually all older mineral components.

Potassium feldspar separated from sample M-14 appeared to be orthoclase with was triclinized (see diffraction pattern, Fig. 4). The content of microcline is 20—25 % with triclinity T = 0.65—0.70, the content of orthoclase is 75—80 % with triclinity T < 0.15. The mineral is partly perthitized and contains 10—

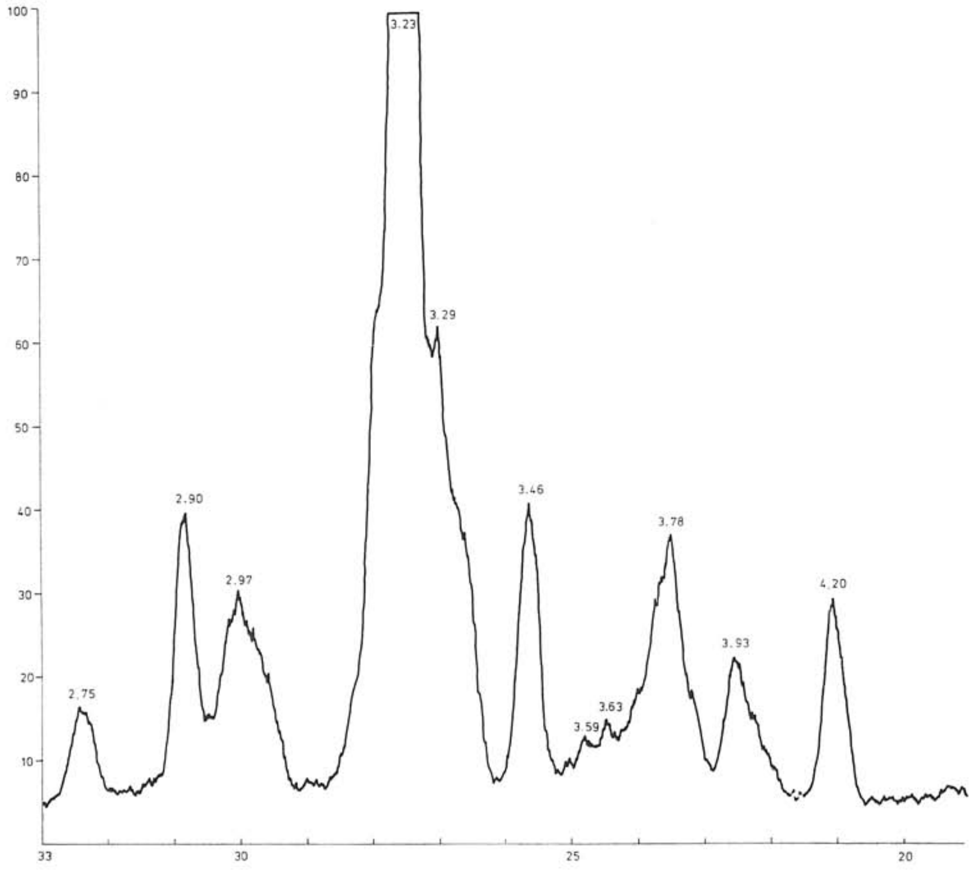



Fig. 4. X-ray diffraction record of potassium feldspar separated from sample M-14.

15 % albite (Š. Dávidová et al., 1979). The symbol of the mineral is RDM. Chemical analysis of the orthoclase:

| Na % | $Na_2O$ % | K % | $K_2O$ % | Rb ppm | Ca % | CaO % | Sr ppm |
|---|---|---|---|---|---|---|---|
| 1.27 | 1.71 | 10.8 | 13.01 | 238 | 0.15 | 0.21 | 685 |

The effects of Na-metasomatism manifested themselves after K-metasomatism had been completed and temperature had dropped, as is in ferrable from the albite veinlets of metasomatic origin.

Accessory and secondary minerals are represented by apatite, sphene, zircon, orthite, epidote, zoisite, sericite and limonite (the last two are secondary).

The radiometric dating of the orthoclase by K-Ar method gave a model age of 177.6 Ma, which indicates that metasomatism occurred in Variscan times, taking into consideration an easy liberation of argon in feldspars during tectonic processes.

The structure and texture of metasomatic rocks are depicted in Fig. 5 a, b.

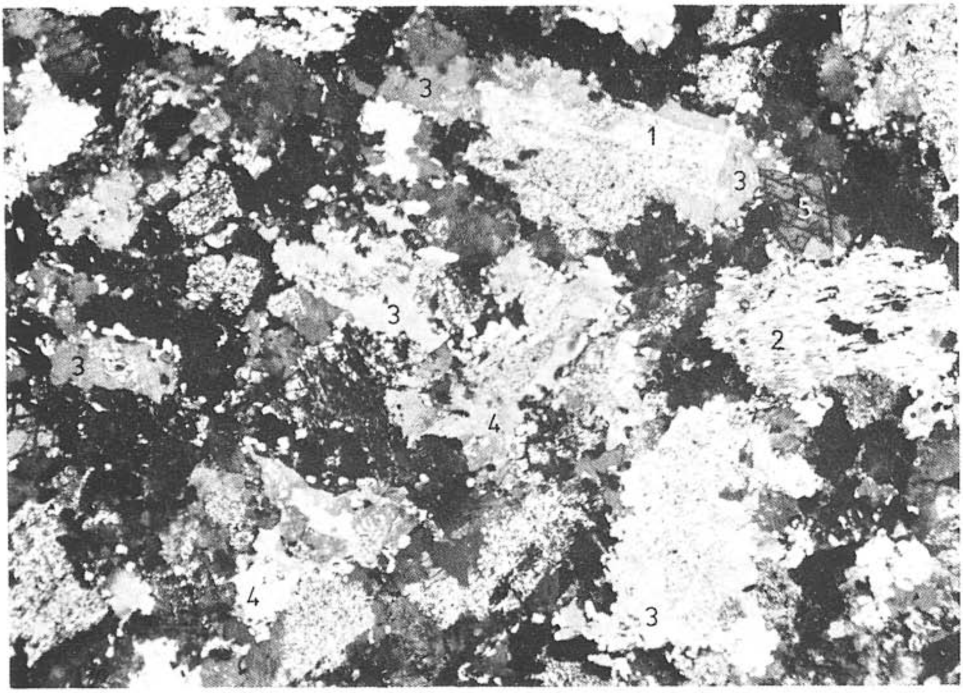
| | Q | Kf | Plg | Bi | Amph | Musc | Acc | Q | A | P |
|---|---|---|---|---|---|---|---|---|---|---|
| M-11 | 24 | 30 | 31 | 2 | 4 | 2 | 7 | 29 | 35 | 36 |
| M-16 | 19 | 42 | 26 | 2 | 7 | 1 | 3 | 22 | 48 | 30 |
| R-13 | 22 | 47 | 21 | 3 | 4 | — | 3 | 24 | 53 | 23 |
| R-23 | 10 | 54 | 26 | 3 | 2 | 1 | 4 | 11 | 60 | 29 |
| R-29 | 12 | 51 | 29 | 3 | 1 | 1 | 3 | 13 | 55 | 32 |
| M-13 | 8 | 60 | 21 | 2 | 3 | 2 | 4 | 8 | 67 | 25 |
| M-14 | 7 | 57 | 23 | 3 | 3 | 3 | 4 | 8 | 66 | 26 |
| M-15 | 7 | 58 | 20 | 1 | 9 | 2 | 3 | 8 | 68 | 24 |
| R-32 | 8 | 56 | 20 | 3 | 4 | 2 | 7 | 9 | 67 | 24 |

2. b) Granitoids altered by Na-metasomatism in three degrees (Table 5)

This group comprises samples M-21; 22; 23 and samples V. 2/1 and V. 2/2, which are taken from the paper of B. Cambel – J. Valach (1956); the rocks analysed were albitites and hematitealbitites. The rocks of M samples are light-yellow or brownish-red in colour, porous with cavities after biotite, (which are rimmed with limonite or hematite) and of hypidiomorphic-granular texture. The principal mineral is albite An = 6–8 %, other minerals occur in

Fig. 5 a. Granitoid rock altered by K-metasomatism with relict of still euhedral sericitized plagioclase (1), partly decomposed horn-blende (2) and anhedral orthoclase (3). Fine-grained quartz (4) is anhedral, interstitial. Other minerals: sphene (5), zircon, apatite and muscovite. Photo by Oswald, crossed nicols, × 35.

Fig. 5 b. Albitized granitoid rock (albite 1) with primary anhedral to subhedral plagioclases (2) and K-feldspars (3). Slightly undulatory quartz (4) is anhedral. Apatite, zircon, muscovite and hematite (5) are common minerals. Photograph by Oswald, crossed nicols, × 35.


3
1
3
5
3
2
3
4
4
3


1
5
3
1
4
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4
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1
4
1

Table 5
Granitoids altered by Na-metasomatism in three degrees

| | M-22 | M-21 | M-23 | V 2/1 | V 2/2 | Average |
|---|---|---|---|---|---|---|
| $SiO_2$ | 64.17 | 65.70 | 66.21 | 65.23 | 66.25 | 65.51 |
| $TiO_2$ | 0.55 | 0.68 | 0.50 | 0.35 | 0.32 | 0.48 |
| $Al_2O_3$ | 19.16 | 19.00 | 17.89 | 18.91 | 18.80 | 18.75 |
| $Fe_2O_3$ | 1.48 | 0.30 | 0.91 | 1.60 | 0.50 | 0.96 |
| FeO | 0.59 | 0.55 | 0.84 | 0.81 | 0.71 | 0.70 |
| MnO | 0.05 | 0.02 | 0.04 | 0.03 | 0.03 | 0.03 |
| CaO | 0.92 | 0.84 | 0.95 | 0.55 | 0.60 | 0.77 |
| MgO | 0.33 | 0.24 | 0.44 | 0.15 | 0.15 | 0.27 |
| $Na_2O$ | 9.24 | 9.04 | 8.44 | 9.50 | 9.31 | 9.11 |
| $K_2O$ | 2.18 | 2.50 | 2.30 | 2.50 | 2.15 | 2.33 |
| $P_2O_5$ | 0.19 | 0.19 | 0.18 | 0.09 | 0.07 | 0.14 |
| $H_2O^+$ | 0.14 | 0.13 | 0.18 | 0.64 | 0.77 | 0.37 |
| $H_2O^-$ | 1.00 | 0.83 | 1.18 | 0.18 | 0.09 | 0.66 |
| | 100.05 | 100.02 | 100.06 | 100.54 | 99.90 | 100.03 |
| Be | <3 | <3 | 3 | – | – | 3 |
| B | 50 | 57 | 25.1 | – | – | 40.03 |
| Sn | 10 | <10 | <3 | – | – | 7.67 |
| Cu | 81 | 83 | 6.6 | – | – | 56.87 |
| Mo | 3.9 | 4.3 | 4.4 | – | – | 4.20 |
| V | 47 | 65 | 42 | – | – | 51.33 |
| Ni | 3.4 | 3.4 | 3.5 | – | – | 3.43 |
| Co | <3 | <3 | 3.6 | – | – | 3.20 |
| Y | 9.3 | 16.2 | 10.1 | – | – | 11.87 |
| Zr | 151 | 145 | 135 | – | – | 143.67 |
| Ba | 680 | 540 | 630 | – | – | 454.67 |
| Sr | 440 | 390 | 330 | – | – | 403.33 |
| Cr | 16 | 20 | 16 | – | – | 17.33 |
| Sc | 3.7 | 3.5 | 5 | – | – | 4.07 |

*Explanations:* M-21 – granodiorite altered by metasomatism, degree 2 (village Píla, Pailanská dolina, 250 m S of Biela skala); M-22 – granodiorite altered by metasomatism, degree 3 (village Píla, Pailanska dolina, 250 m S of Biela skala); M-23 – granodiorite altered by metasomatism, degree 1 (village Píla, Pailanská dolina, 250 m S of Biela skala); V 2/1 fine-grained albitite, degree 3 (W of Píla, valley side S of the ruin Kobylé); V 2/2 coarse-grained albitite, degree 3 (W of Píla, valley side S of the ruin Kobylé)

very small amounts – quartz, K-feldspar and hematite. Accessories are represented by apatite and zircon, and hematite, muscovite, which are of metasomatic origin and fill the joints.

| | Q | Kf | Plg | Bi | Amph | Musc | Acc | Q | A | P |
|---|---|---|---|---|---|---|---|---|---|---|
| M-21 | 15 | 16 | 51 | – | – | 8 | 10 | 18 | 20 | 62 |
| M-22 | 8 | 20 | 56 | – | – | 7 | 9 | 10 | 24 | 66 |
| M-23 | 10 | 15 | 53 | – | – | 12 | 10 | 13 | 19 | 68 |
| V.2/1 | 8.0 | – | 87.0 | 1.0 | – | – | not meas. | 8 | 0 | 92 |
| V.2/2 | 7.0 | – | 89.0 | 1.0 | – | – | not meas. | 7 | 0 | 93 |

*Geochemical-petrographic characteristics of metasomatites and the primary rocks*

The discussion is based on the data in Tables 1–5 and on the data plotted on graphs. The histograms and correlation graphs of two- and three-componental interdependences are compiled from the simple relations between element contents, or with the use of petrochemical Niggli's, Zavarickij's or CIPW values, and on the basis of modal and mineral analyses or normative data computed from the CIPW values.

In the Tables of chemical analyses there are also arithmetical means of individual sets of samples. The chemistry of the fundamental type of biotite granodiorites and of Na- and K- differentiates is clearly seen from the Tables. Of interest are Tables 4 and 5, in which the analyses of metasomatites are classified according to the degree of metasomatic alteration.

The comparison of the values shows that the contents of the oxides $SiO_2$, $Fe_2O_3$, FeO, CaO, MgO and $P_2O_5$ gradually decrease, relative to the primary rock, with the increase in K- or Na-metasomatism. $Na_2O$ derceases with increasing intensity of K-metasomatism and $K_2O$ with Na-metasomatism. Boron slightly decreases but $TiO_2$, $Al_2O_3$ increase in content as well as the microelements Sn, Cu, V, Zr, Ba, Sr and Cr. The contents of essential and trace elements in analysed samples are apparent from the histograms.

The following comments relate to Fig. 6:

The largest $SiO_2$ contents have been found in light-coloured differentiates of granitoids and the smallest in intensely altered granitoids. This relation is reverse in $Al_2O_3$.

The contents of titanium are higher in metasomatites than in granitoid dyke differentiates and roughly equal to those in the principal granodiorite types.

The FeO content is smallest in metasomatites but the values are relatively similar to the values established in the granitoid dyke types. Bivalent iron amount, however, is considerably smaller in metasomatites than in the primary unaltered granodiorites.

This finding also holds for trivalent iron ($Fe_2O_3$) even if not so explicitly. The scatter of the values is wider because of, among others, a higher $Fe_2O_3$ content in some albitites (hematite albitite).

The MgO, MnO and CaO contents in metasomatites also occupy a particular place in the histograms. The K-metasomatites stand approximately in the centres of histograms, being distributed within the same intervals as in the primary types. The Na-metasomatites show lower Ca and Mg values due to the loss of Ca and Mg at the replacement of plagioclases and biotite for alkaline feldspars. The loss of Mg is particularly marked in albitites, because the K-metasomatites are richer in Mg probably as a result of higher P-T conditions at metasomatic processes.

During the rock alterations the alkalies (Fig. 7) substitute each other, i. e. the higher Na amount in metasomatites is compensated by lower K content. This regularity also follows from the average values of chemical analyses in both primary rock types and leucocratic derivatives. The primary granodiorite types contain approximately the same amount of potassium as the albitites. Phosphorus remains at the level of the primary rocks also in metasomatites, $H_2O^+$ increases only slightly, and $H_2O^-$ holds the same level.

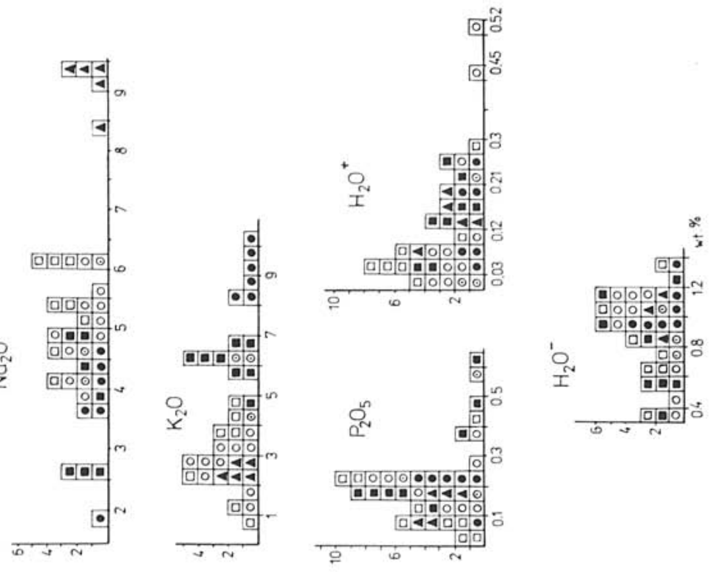

Na2O
K2O
P2O5
H2O+
H2O−
wt %

Fig. 7.

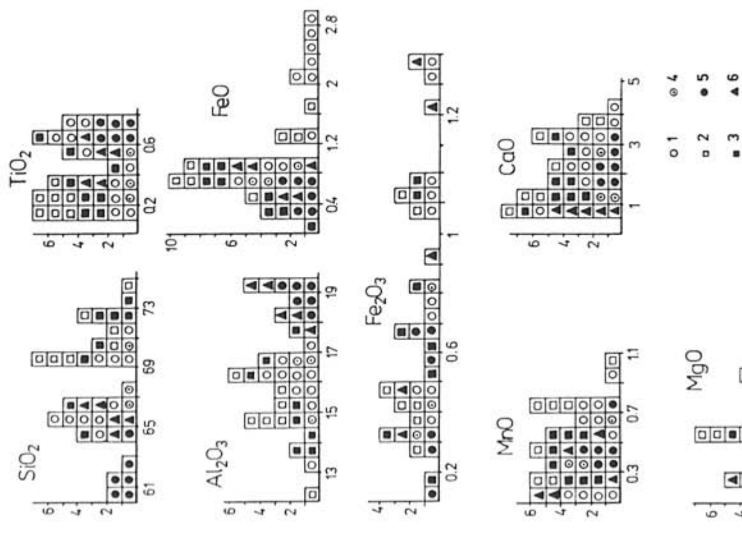

SiO2
TiO2
Al2O3
FeO
Fe2O3
MnO
CaO
MgO
1
2
3
4
5
6

Fig. 6.

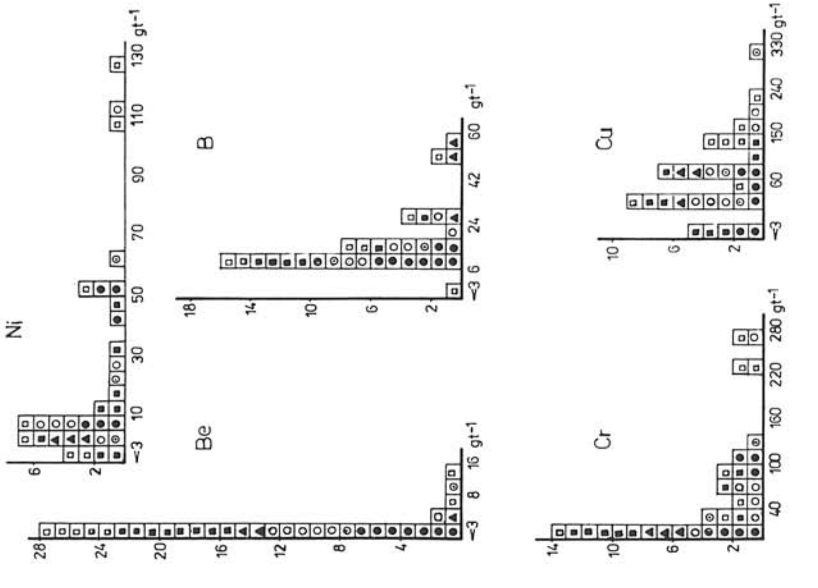



Fig. 9.

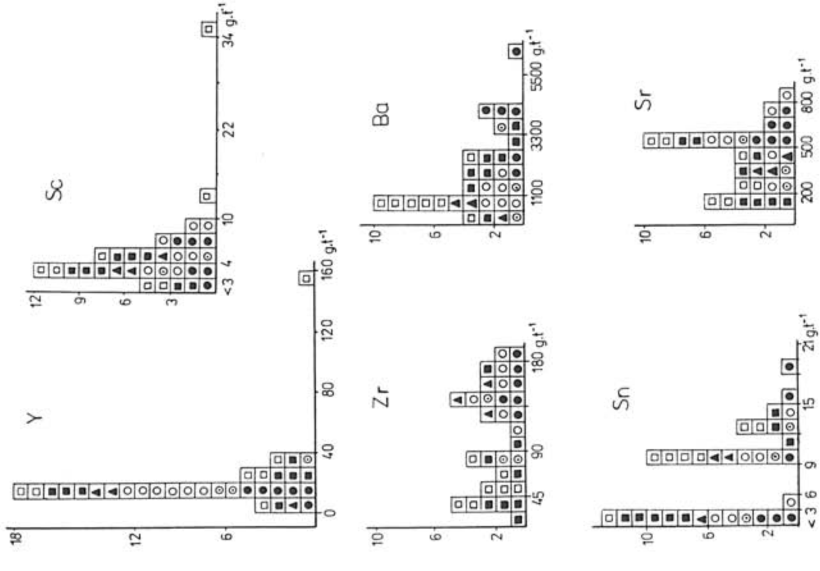
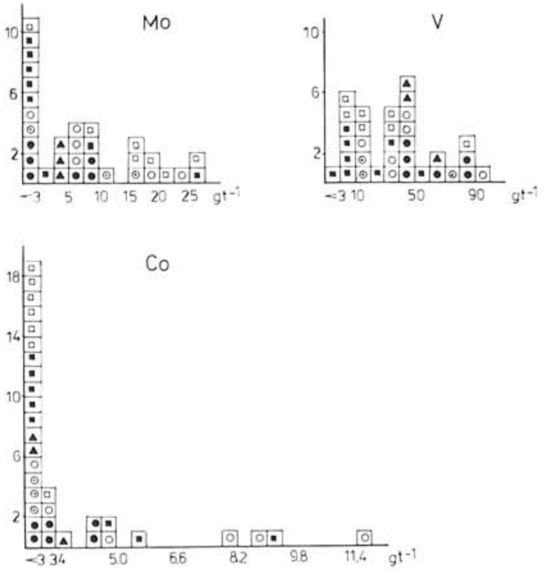



Fig. 8.

Figure 8 indicates that yttrium and scandium amounts do not change in metasomatites and show in general only a small scatter. In K-metasomatites barium is present in metasomatites in unusually increased amounts, in accord with the increase of potassium in rocks. The same is true for pegmatitoid dyke rocks rich in K. In contrast, Na-metasomatites (albitites) have the same (or slightly higher) Ba as the primary rocks. The higher or analogous Ba and Sr contents in granitoids, metasomatites and primary rocks indicate that the metasomatites were produced by the processes associated with the plutonism that gave rise to primary granodiorites and their leucocratic derivatives. The contents of zirconium are increased relative to their contents in leucocratic dyke rocks but approximately the same as in the unaltered granodiorites; this implies that the metasomatic process did not disturb the total content of accessory zircon. Tin is most abundant in primary acid Na- and K-differentiates, but on the whole the greater part of metasomatites does show increased tin amounts.

According to Fig. 9, beryllium, nickel, boron, chromium and copper amounts in metasomatites and primary biotite granodiorites are essentially unchanged (except for a few samples) or slightly increased. The contents of chromium increase in albitites; copper also shows an increase but it is most abundant in primary leucocratic differentiates. Boron, chromium and nickel have displayed




Figs. 6—10. Histograms of essential macroelements (in weight %) and microelements (in ppm) in primary and dyke rock types and in metasomatic rocks.
1 — primary rock type, biotite granodiorite, fine to medium-grained (Modra type); 2 — leucocratic hypabyssal differentiates of granitoids with sodium predominant over potassium, including aplites; 3 — hypabyssal pegmatitoid differentiates of granitoids with potassium predominant over sodium, including pegmatites; 4 — transitional granitoids in the initial (1st) stage of K-metasomatism; 5 — granitoid rocks intensely altered by K-metasomatism (degrees 2 and 3); 6 — rocks, mainly biotite granitoids altered by Na-metasomatism, albitites. (For explanation see Fig. 6).

a decrease in some samples and an increase in others. The above-said suggests that the K-alterations occurred under the influence of the same sources and conditions, not very different from the processes that produced granitoids.

Figure 10 shows that the contents of Mo, V and Co are similar in both metasomatized granitoids, K-pegmatitoid granitoids and primary granodiorites. The Mo-contents, however, are distinctly lower in metasomatites than in Na-aplitoids. Cobalt is most abundant in primary granitoids, and vanadium contents in metasomatites are similar to those in the primary rocks.

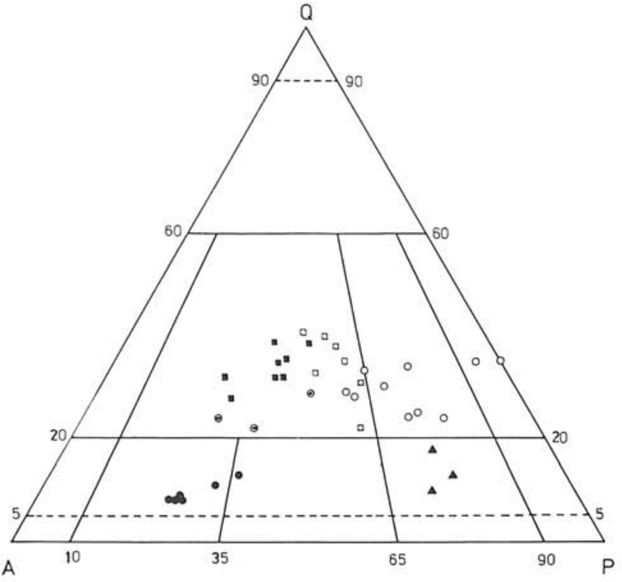



Fig. 11. Classification graph of rocks, after international classification system, IUGS, 1973. (For explanation see Fig. 6).

Figure 11 depicts the classification graph of rocks according to the international modal classification IUGS, from 1973. From the graph it is evident that most of the primary rocks belong to the granodiorite group, two samples in the granite group and two in the tonalite group. Pegmatitoid and aplitoid differentiates are ranked with granitoids. K-metasomatites are placed in the group of quartz syenite and quartz monzodiorite, and albitites in the group of quartz--monzodiorite, quartz monzogabbro to quartz diorite or quartz gabbro. Metasomatites of degree 1 (circled points) stand at the granite/quartz syenite boundary.

The Niggli's variation diagram in Fig. 12 shows the changes of element contents, expressed in Niggli's parameters. In the case of the similar values in all graphs (a – e) the variation of the values of all rock groups can be correlated. The K-pegmatitoid dyke rocks and K-metasomatites show the widest range and albitites the smallest.

Niggli's ternary QLM graph in Fig. 13 divides the samples analysed into metasomatically altered derivatives and primary rocks (granodiorites and dyke differentiates). The concentration of points near the tie-line QL suggests relatively low contents of mafic minerals.

In the al-alk-c+fm diagram the primary granitoid types occupy one field in contrast to more acid differentiates and metasomatites occurring jointly.

Niggli's diagram of k/mg ratio (Fig. 14) indicates a direct relationship between the above-mentioned Niggli's values: K-metasomatites have higher mg values and Na-metasomatites considerably lower. Petrochemical study has confirmed that the predominant part of the rocks examined corresponds in Niggli's classification to the series of calc-alkaline magmas of the granodiorite (5 samples), yosemitite-granite (7 samples) and engadinite-granite (9 samples) types. Samples affected by K-metasomatism could be ranged to the series of K-magmas of the K-normarkite (3 samples) and K-gibelite (6 samples) types. These samples exhibit a negative value -qz, but it should be noted that this classification cannot be applied to metasomatites, i. e. non-magmatic derivatives. Albitites belong to the series of sodium magmas of the alkali syenite-aplite (albitite) magma type (3 samples).

Zavarickij's diagrams (ACBS) are in Fig. 15 a. In the upper part all rock samples are plotted and in the lower only the samples of rocks metasomatically altered. In the sense of Zavarickij's classification, the predominant part of samples (22) of dyke rocks and metasomatites are rocks of normal composition; 10 samples, especially of primary granodiorite, are rocks oversaturated with $Al_2O_3$ and one sample belongs to rock highly oversaturated with alkalies.

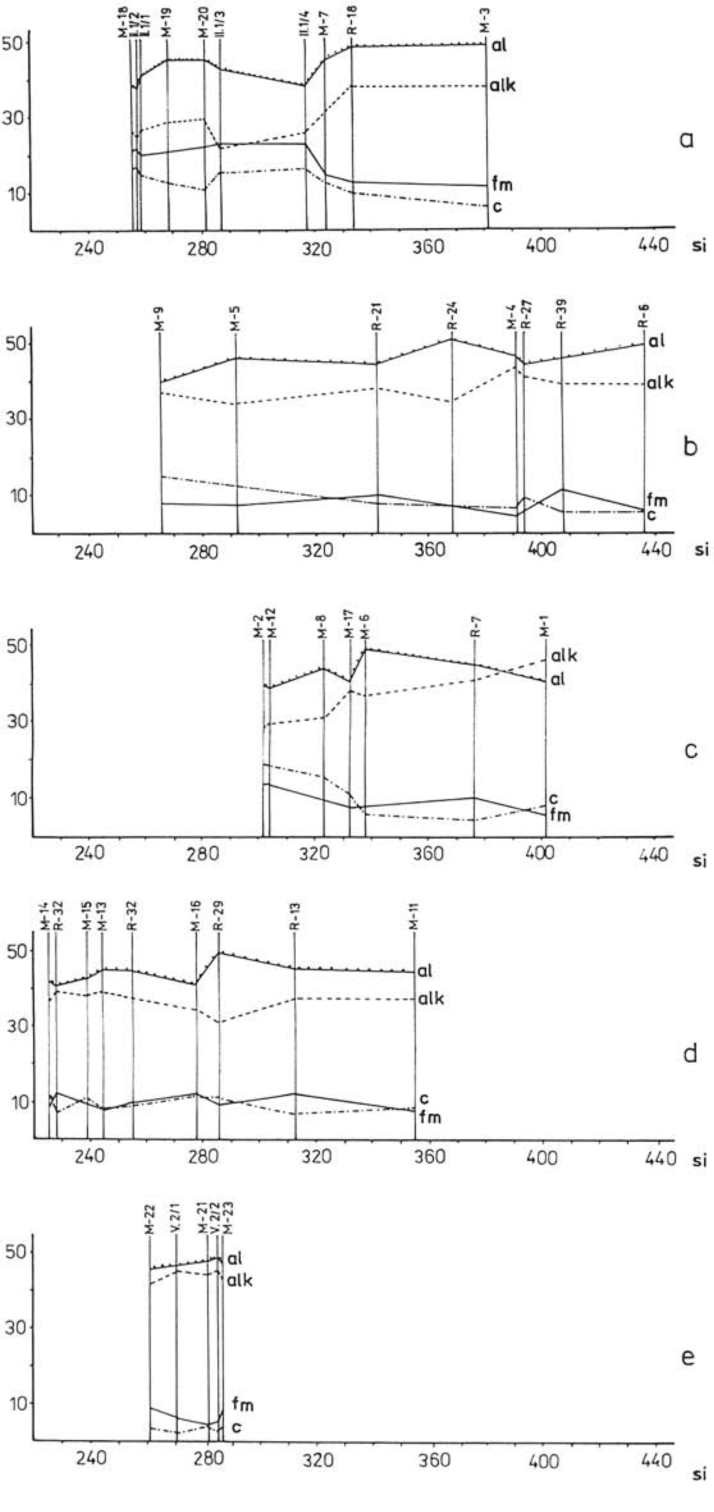
Classification graph of rocks according to Shand (1927) is in Fig. 15 b. Normative corundum has especially in pegmatitoid differentiates K prevalence over Na within the interval 0–4.61 % (sample No. R-24) and in Na-aplitoid differentiates within the interval 0–2.7 %. Natrium metasomatites have lower normative corundum contents than K-pegmatitoid differentiates, but higher than K-metasomatites. All West Carpathian granitoids and their basic types are peraluminous (low contents of alkalies and calcium). The above mentioned classification cannot be applied to these rocks.

The ternary Q-Or-An-Ab graphs calculated from CIPW values (Fig. 16, for explanation see Fig. 6) indicate that the individual rock types occupy different fields, the metasomatites, primary rock types, or primary types and leucocratic differentiates cumulate separately.

In the CIPW classification system all the rocks studied are grouped with class 1 (granites, granodiorites, leucogranites, granitoid dyke rocks, aplites, pegmatites and K- and Na-metasomatites). The synoptical table showing the percentage representation of the rocks according to CIPW classification gives the following results.

Fig. 12 a–e. Variation diagrams of Niggli's values for primary and metasomatic rocks. (For explanation see Fig. 6).

12 a) primary rock type – Modra biotite granodiorite; 12 b) hypabyssal pegmatitoid granitoids to pegmatites with potassium predominant over sodium; 12 c) hypabyssal aplitoid granitoids with sodium predominant over potassium; 12 d) granitoid rocks altered by K-metasomatism of three degrees, 12 e) granitoids altered by Na-metasomatism – albitites.


M-18
I.1/2
I.1/1
M-19
M-20
II.1/3
II.1/4
M-7
R-18
M-3
al
alk
fm
c
a
M-9
M-5
R-21
R-24
M-4
R-27
R-39
R-6
b
M-2
M-12
M-8
M-17
M-6
R-7
M-1
c
M-14
R-32
M-15
M-13
R-32
M-16
R-29
R-13
M-11
d
M-22
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320
360
400
440
si

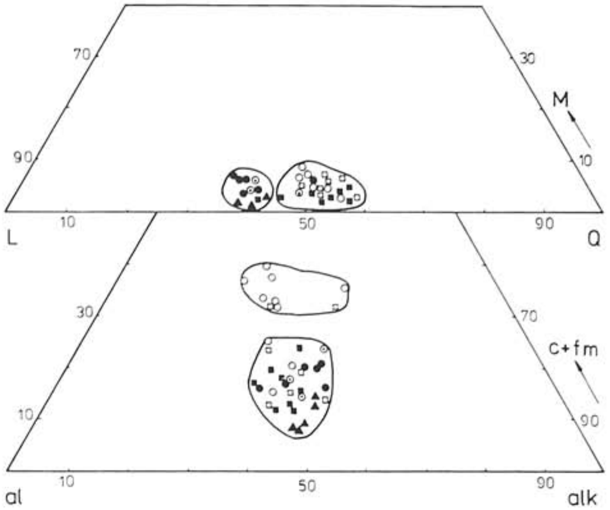


Fig. 13. Niggli's ternary diagrams QLM and al – alk – (c + fm). (For explanation see Fig. 6).

| Symbol | Number of analyses | % | Symbol | Number of analyses | % |
|---|---|---|---|---|---|
| I.4.1.2. | 1 | 3 | I.4.2.5. | 1 | 3 |
| I.4.1.3. | 6 | 18 | I.4.9.4. | 1 | 3 |
| I.4.1.4. | 6 | 18 | I.5.1.2. | 1 | 3 |
| I.4.2.2. | 1 | 3 | I.5.1.3. | 2 | 6 |
| I.4.2.3. | 1 | 3 | I.5.1.4. | 3 | 9 |
| I.4.2.4. | 6 | 18 | I.5.2.2. | 1 | 3 |
| | | | I.5.2.3. | 3 | 9 |

From the total number (12) of K- and Na-metasomatically altered rocks in the CIPW classification system 75 %, i. e. 9 analyses occur under the symbols I.5.1.3 to I.5.2.3.

The graphs of $Na_2O + K_2O/SiO_2$ and $Na_2O/K_2O$ ratios are depicted in Fig. 17 (for explanation see Fig. 6). From the first graph it follows that the trend of

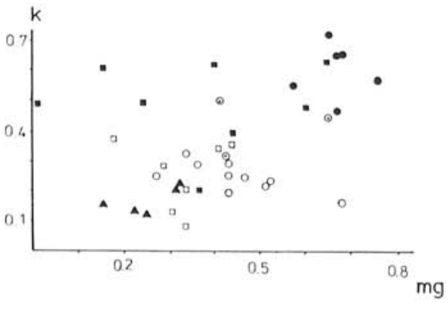


Fig. 14. Niggli's diagram of k/mg ratio. (For explanation see Fig. 6).

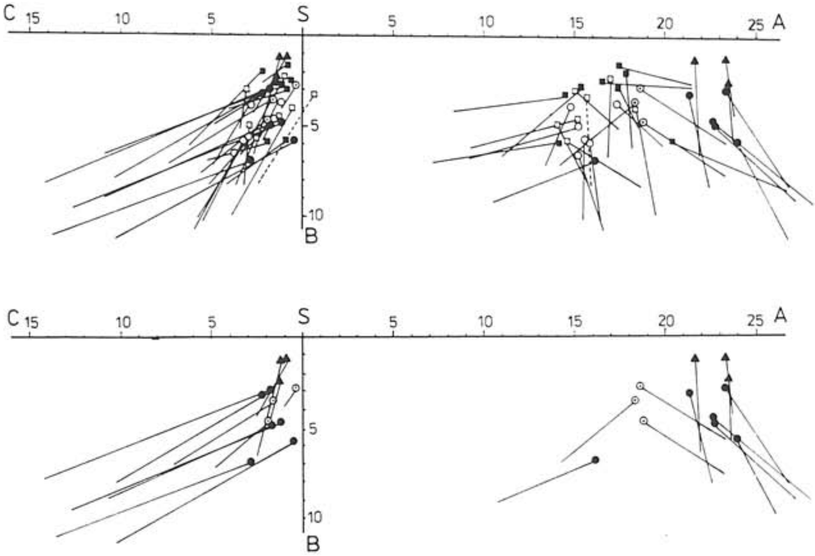


Fig. 15 a. Zavarickij's diagram (ACBS). (For explanation see Fig. 6).

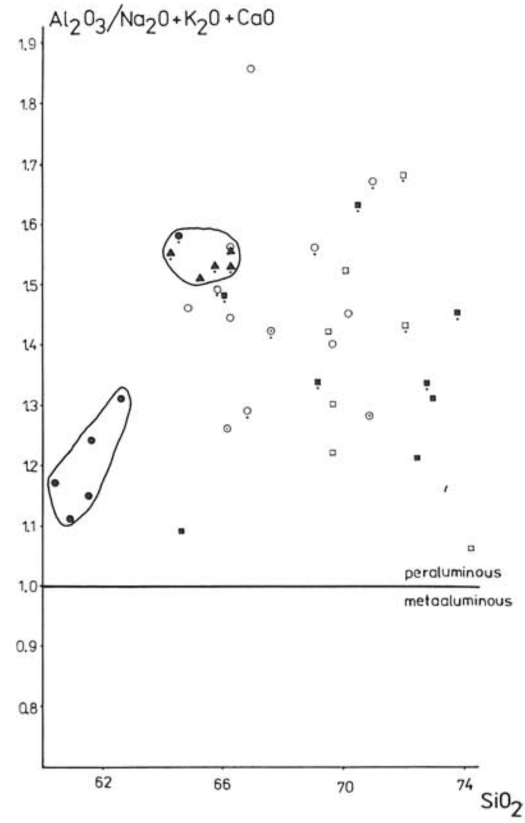


Fig. 15 b. Classification graph of rocks according to Shand (1927). (Explanations at Fig. 6; dot at mark denotes rock samples with the contents of normative corundum.)

normal differentiation is of positive character, and the trends of the ratios of alkalies and $SiO_2$ show a negative course at metasomatic alterations. The graph of $Na_2O/K_2O$ ratio indicates a positive trend in metasomatites; the ratio has higher values in dyke rock differentiates, and the lowest values up to negative correlation has been established in granodiorites.

In Fig. 18 there are graphs of the ratios $TiO_2/Al_2O_3$, $SiO_2/TiO_2$ and $Na_2O + K_2O/TiO_2$. The $TiO_2/Al_2O_3$ graph reveals a positive correlation, the highest $TiO_2$ values being in K-metasomatites. A negative correlation has been established in $SiO_2/TiO_2$ ratio for unaltered rocks (primary and acid differentiates), the same but of lower values for metasomatites. The $Na_2O + K_2O/TiO_2$ correlation is not obvious in unaltered rock types and is positive in metasomatites.

Graphs of the ratios $Na_2O + K_2O/Al_2O_3$, $SiO_2/Al_2O_3$ and $CaO/Na_2O + K_2O$ in Fig. 19 show that metasomatites and unaltered rock types occupy separate fields. The ratios of oxides are positively correlative. The $SiO_2/Al_2O_3$ graph distinguishes still more sharply between the K-metasomatites and Na-metaso-

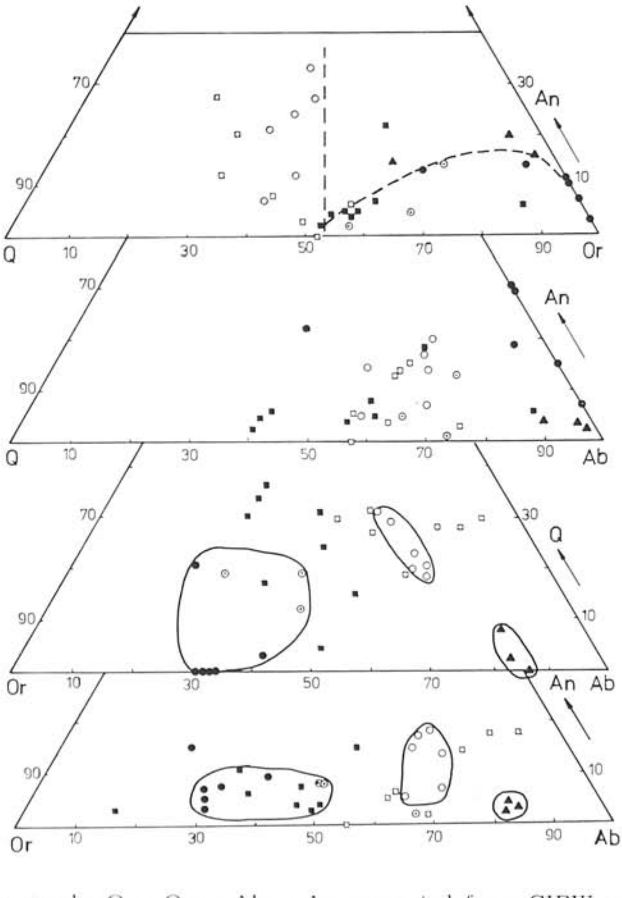


Fig. 16. Ternary graphs Q – Or – Ab – An computed from CIPW values. (For explanation see Fig. 6).

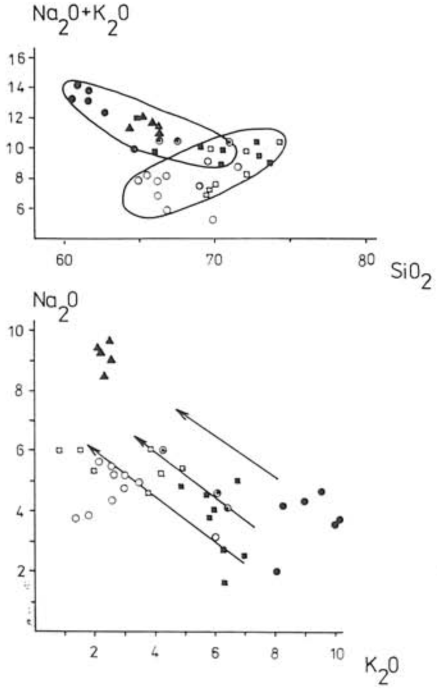


Fig. 17. Graphs of the $Na_2O + K_2O/SiO_2$ and $Na_2O/K_2O$ ratios. (For explanation see Fig. 6).

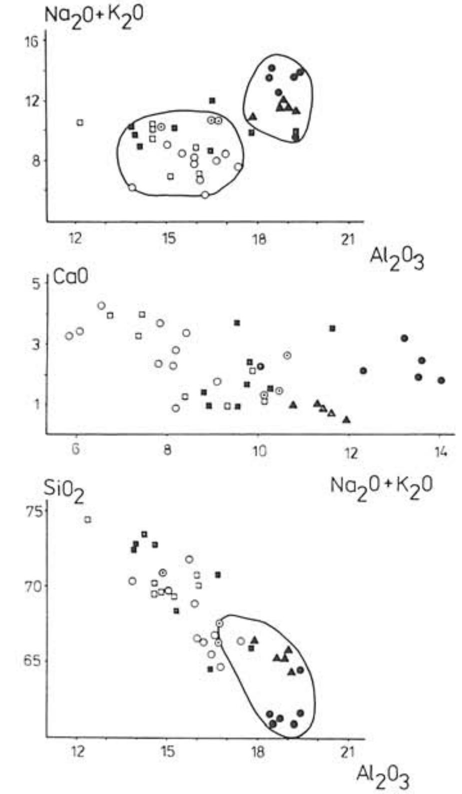


Fig. 19. Graphs of the ratios $Na_2O + K_2O/Al_2O_3$; $CaO/Na_2O + K_2O$; $SiO_2/Al_2O_3$.

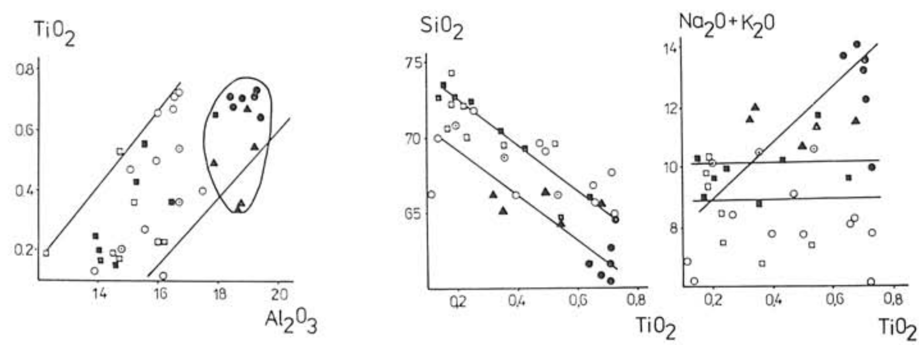


Fig. 18. Graphs of the ratios $TiO_2/Al_2O$; $SiO_2/TiO_2$; $Na_2O + K_2O/TiO_2$. (For explanation see Fig. 6).

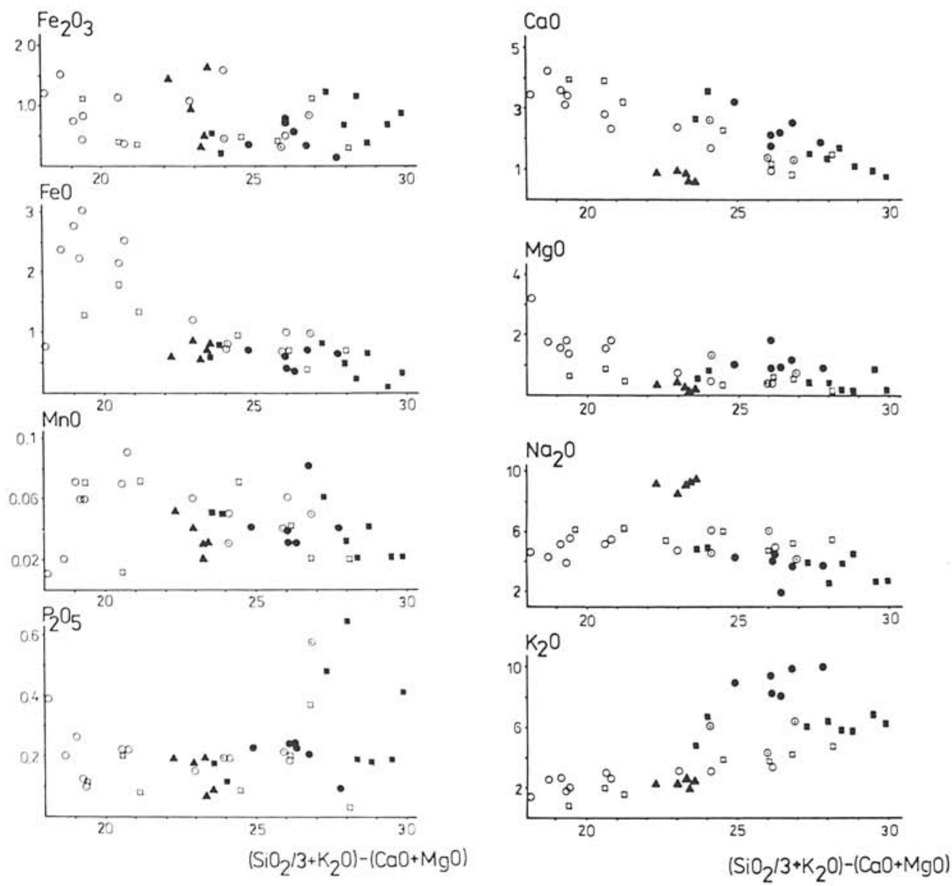


Fig. 20 a, b. Dependence of the content of m croelement oxides on Larsen's coefficient $(SiO_2/3 + K_2) - (CaO + MgO)$. (For explanation see Fig. 6.)

matites and between these rocks and the unaltered types. In general, the correlation is negative for the oxides mentioned above in all rocks.

In graphs in Fig. 20 a, b, expressing the dependence of elements on Larsen's coefficient, many elements show a more or less positive or even negative correlation. The primary rocks are located on the left side of the graphs and metasomatites on the right side (higher Larsen's coefficient), and almost invariably separately; the K-metasomatites, however, often occur together with granite pegmatitoids.

Positive correlation is also evident from Fig. 21, where K-metasomatites form almost a separate field due to the Mg content. The ratio of $SiO_2$ to mafic coefficient is positively correlated. The ratio of felsic index to $SiO_2$ suggests a negative correlation of the development of metasomatites from the primary rocks, whereas the differentiation process (granodiorites — leucogranites) has a positive correlation.

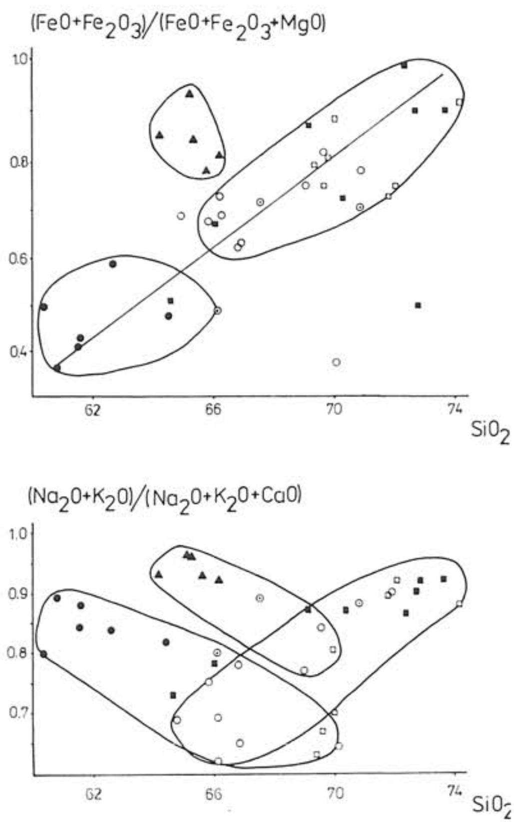


Fig. 21. The ratio of mafic and felsic indices to $SiO_2$ content. (For explanation see Fig. 6).

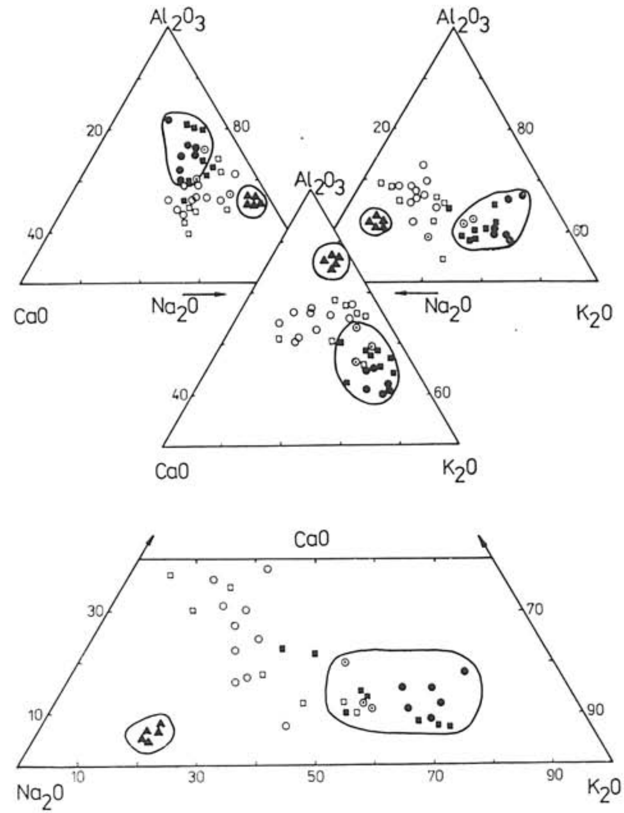


Fig. 22. Ternary three-componental graphs showing the ratios of $K_2O$, $Na_2O$, $Al_2O_3$ and CaO. (For explanation see Fig. 6).

The ternary graphs of $Al_2O_3$, CaO, $Na_2O$ and $K_2O$ in Fig. 22 indicate that the individual rock types occupy particular sites in these graphs, which is in accord with the petrochemistry and geochemistry of the separate types of rocks.

In Fig. 23 the $SiO_2$/Zr graph indicates a positive correlation and the $Na_2O$ + $K_2O$/Zr graph a negative correlation. The negative relation of alkalies to Zr does not concern the primary granodiorites.

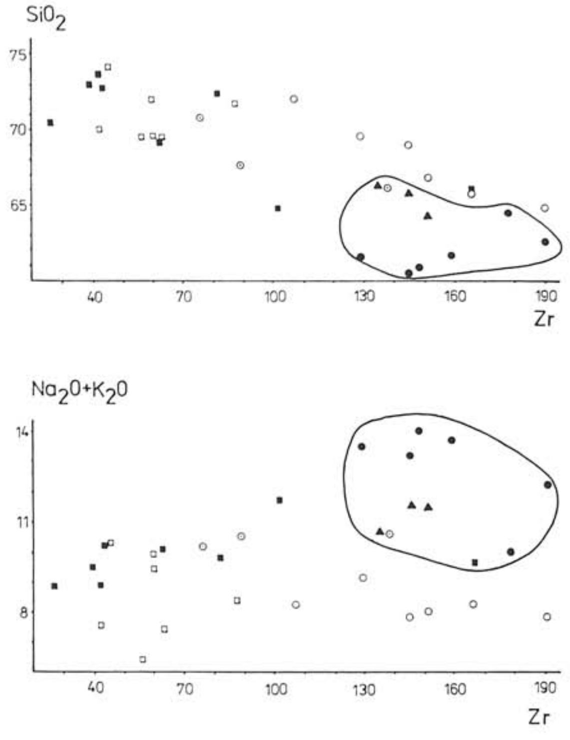


Fig. 23. Correlation graphs of $SiO_2$/Zr and $Na_2O$ + $K_2O$/Zr. (For explanation see Fig. 6).

The relations between CaO, $K_2O$, Ba and Sr (Fig. 24 a, b) confirm positive correlation of CaO/Sr and $K_2O$/Ba ratios. A minimum correlation exists between the ratios $K_2O$/Sr and CaO/Ba. The location in the graph is specific for every rock type studied.

*Conclusion*

The authors studied the geochemical and petrochemical properties of the groups of parent rocks in the areas of K- and Na-metasomatite occurrences in the area of Dolinkovský vrch near Harmónia-Modra and around the ruin Kobylé NE of Píla — Častá) in the Malé Karpaty Mts. Near Dolinkovský vrch Hill the

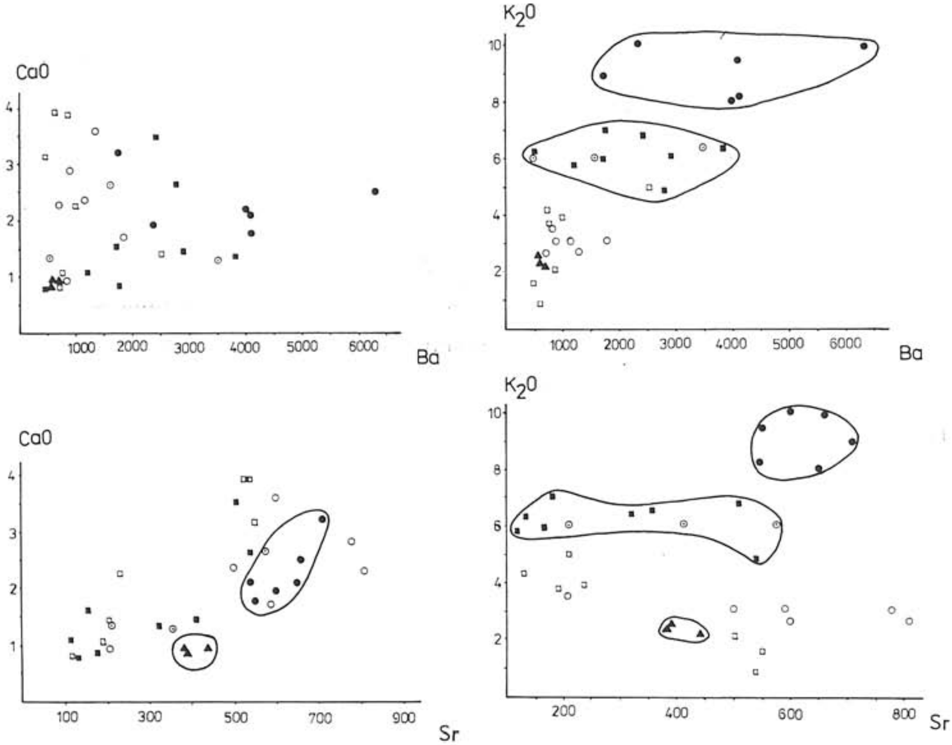


Fig. 24 a, b. Correlation graphs of CaO, $K_2O$, Ba and Sr. (For explanation see Fig. 6).

pattern of rocks is unusually varied (aplitoid Na-granitoids and aplites with a prevalence of Na over K, and pegmatitoid granitoids and pegmatites with K predominating over Na). In these areas there also occur biotite granodiorites of Modra type metasomatized to different degrees. The petrochemical – geochemical properties of metasomatites are being compared with the primary unaltered Modra granodiorite. In the author's opinion the K-metasomatism was a high-temperature process connected with the last phases of granodiorite-magma consolidation. Albitization and genesis of albitites in the area of Kobylé are products of low-temperature to hydrothermal alterations. Numerous graphs present petrochemical classification of the rock groups, their geochemical characteristics and correlations of element contents. K-metasomatites and albitites with an independent genesis occupy a separate position in the graphs. The geochemistry of metasomatites differing from that of unaltered rocks accounts for their specific location in the graphs. The K-metasomatites have evidently near geochemical and presumably also genetic relations to pegmatitoid K-granitoids and K-pegmatites. The Na-metasomatites show the same but not so close relations to aplitoid dyke rocks. The modal composition of the individual rock types has been applied to the classification and geochemical evaluations of the rocks.

Translated by H. Zárubová

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