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VARISCAN GRANITOIDS OF THE WEST CARPATHIANS IN THE LIGHT OF GEOCHEMICAL—PETROCHEMICAL STUDY

(Figs. 3)

Abstract: In the paper West Carpathian granitoids are briefly characterized from the point of view of their geological occurrence, age relations and metamorphosis. Characteristics of main petrographical and geochemical features, macrochemical composition, trace elements behaviour, including REE and of some isotopic ratios is given. Some results of modelling a macrochemical composition (by means of mixing program GENMIX), as well as trace elements are presented on an example of the Malé Karpaty Mts. On the basis of these results, the authors present a view on differentiation of granitoid magma by Rayleigh crystal fractionation of mineral assemblage: bio + plg + Qz ± K-feldspar + + accessory minerals from parental magma of tonalite-granodiorite composition.

Резюме: В статье коротко характеризованы гранитоиды Западных Карпат с точки зрения их геологического проявления, отношений возраста и метаморфизма. Дается характеристика основных петрографических и геохимических признаков, макрохимического состава, поведения элементов-примесей, включая редкоземельные элементы, и некоторых изотопных отношений. На примере Малых Карпат приводятся некоторые результаты моделирования макрохимического состава (при помощи смешивающей программы GENMIX), а также элементов-примесей. На основе этих результатов авторы представляют мнение о дифференциации гранитоидной магмы фракционной кристаллизацией Рэлея минеральной ассоциации: биотит + плагиоклаз + кварц ± калиевый полевой шпат + акцессорные минералы из исходной магмы тоналит-гранодиоритового состава.

The geochemical-petrological investigation of Late Paleozoic granitoid massif of the West Carpathians taking place already for several years at the Geological Institute of the Slovak Academy of Sciences and Department of Geochemistry and Mineralogy of the Faculty of Natural Sciences at the Comenius University in Bratislava has brought a series of new results. The objective of our contribution is to summarize the obtained results, to try for an interpretation and to point to some problems. The problems of interpretation are mainly caused by the insufficient number of isotopic data and data of REE contents in all varieties of granitoids, but are mainly lying in complicatedness of the proper geological occurrence of West Carpathian granitoids. The mostly bad uncovering of the terrain and complicated tectonic situation render clearing up of intrusive mechanizms and linkings, contact effects on the surroundings, several-phases character of intrusion or contingent zonality of the massifs difficult. The allo-

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chtonity of whole mountain massifs of crystalline rocks supposed by some authors, caused by the Alpine orogeny also forces to be careful in connection of the massifs into comagmatic groups, differentiation orders or larger batholiths.

Variscan magmatic activity was manifested in the West Carpathians by intrusion of several, not large, particular granitoid plutons, often subsequently separated tectonically. At present these form with their metamorphic mantle the cores of the so called core mountains. The schistose crystalline rocks were metamorphosed regionally to lower grades already before the intrusion, but the main metamorphic effects are connected with granitoid plutonism of the Variscan orogeny. In some plutons (Malé Karpaty Mts., Kohút and Sinec bodies of the Veporides) the resulting contact metamorphism caused by granitoid intrusion is also proved. The age of regional meatmorphism of gneissose-amphibolite crystalline rocks is considered as Early Paleozoic (C a m b e l, 1962). In the most investigated area of the West Carpathians (Malé Karpaty Mts.) this age is confirmed by Rb/Sr dating with whole rock isochrone: 387 ± 38 mil. years, initial ratio 0.7100 (B a g d a s a r j a n et al., 1983) and in the whole region of the West Carpathians it is also confirmed by model ages obtained by K/Ar mtehod (C a m b e l et al., 1980; C a m b e l–V e s e l s k ý, 1981). Dating of contact-metamorphic biotite from metapelites by the mineral isochrone: biotite — whole rocks showed the age of contact metamorphism, which in the frame of error is identical with Rb/Sr age of granitoid intrusion (347 ± 4 mil. y., B a g d a s a r j a n et al., 1982).

In the gneissose-amphibolite crystalline complex of the Malé Karpaty Mts. metamorphic zones were characterized and distinguished on the basis of mineral associations (B r o s k a—J a n á k, 1984; K o r i k o v s k i j et al., 1984). The highest - temperature regional periplutonic zone is the staurolite-chlorite zone with temperatures of 490—508 °C according to the garnet-biotite thermometer. The immediate contact effect of the intrusion was manifested by formation of the superimposed highest - temperature staurolite-sillimanite zone with temperature 550—560 °C (K o r i k o v s k i j et al., l. c.) to 593 °C (C a m b e l et al., 1981 a; P e r č u k et al., 1983). Depth of intrusion probably corresponded to 350 MPa. The Modra granodiorite massif of the Malé Karpaty Mts., on the contrary, ascended to a higher level corresponding to pressure 150 MPa (K o r i k o v s k i j et al., 1984).

The presence of contact metamorphism accompanied with formation of andalusite-bearing hornfelse spotted schist has been already stated by C a m b e l (1954).

Another granitoid pluton in the region of the Veporides (Sinec body) with a contact-metamorphic aureole also forms a hornfelse mineral association biotite--cordierite corresponding to pressure less than 100 MPa (K a m e n i c k ý, 1977). On the contrary, further granitoid bodies (Vysoké Tatry Mts.) have a metamorphic mantle with high-pressure association disthene-sillimanite-staurolite (K a h a n, 1968), or are surrounded by migmatite zones (Nízke Tatry Mts.).

The uplift of the core mountains of the West Carpathians to present-day horst structures is the result of the Alpine orogeny. This was confirmed by dating by the method of uranium fission tracks by K r á ľ (1977) and B u r c h a r t—K r á ľ (1982). Dating of uplifts has shown that earliest – in the Upper Cretaceous – the Vepor pluton began to rise (FT age of apatites: 54—84 mil. y.). From the Tatride mountains the Nízke Tatry Mts. massif was rising first (Eocene, 45 mil. y.), later in the Miocene (10—20 mil. y.) the other core mountains were uplifted. These processes also strongly influenced the model ages established by K/Ar method.

The modal (Streckeisen, 1976) and also chemical classification of granitoid rocks (Streckeisen—Le Maitre, 1979) with application of mesonorm provide identical results: the predominating rock types of the Tatrides and Veporides are biotite granodiorites to tonalites (trondhjemites) sporadically containing amphibole and biotite to two-mica monzogranites. These two rock types in from of medium-grained or porphyric varieties are represented in various proportions practically in all massifs.

The West Carpathian granitoids from the view-point of macrochemical composition form a suite limited in composition: the extent of SiO_2 content is 60—78 weight %. The average values for tonalite are 66.3 %, biotite granite — granodiorite 71.3 %, leucocratic granite — granodiorite 73.9 % (Cambel—Walzel, 1982). The variations of the individual oxides are characteristic. With increasing SiO_2 content only K_2O rises, Na_2O keeps at an approximately equal level and other oxides decrease. The Na_2O/K_2O ratio is typically greater than 1 (Cambel — Vilinovičová, 1981). A considerable part of granitoids is peraluminous. These chemical features are expressed in prevalence of granodiorites over granites and in frequent occurrence of two-mica varieties.

As comagmatism of granitoids in the individual massifs is indubitable, we tried to quantify this relation by the generalized petrological mixing model (Le Maitre, 1979) and interactive program GENMIX (Le Maitre, 1981). The program calculates the proportions of individual minerals in the crystallizing association as well as the fraction of residual melt by solving an equation, for instance:

$$\text{magma } 1 = \text{magma } 2 + \text{plagioclase} + \text{biotite} + \text{K-feldspar} + \text{quartz},$$

where the entering data are chemical analyses of granodiorite (magma 1), its minerals and monzogranite (magma 2). The example of one solution for granitoids of the Malé Karpaty Mts. is in Fig. 1.

As to trace elements, our granitoids may be characterized as follows. The trace elements correlate with SiO_2 as expected: the contents of Sr, Ba, Sc, Co, Cr, Ni and Zr decrease with the degree of differentiation (i. e. elements behave compatibly), Rb, B, Be and partly also Pb contents increase with differentiation (the elements behave incompatibly). For granitoids of the Tatrides and Veporides the extent of rubidium concentrations of 50—160 ppm, rarely higher, is typical. The granites of the Gemerides differ in distincly higher contents: Rb = 200—500 ppm (Cambel et al., 1983). Sr attains maximum in tonalites of the Modra massif of the Malé Karpaty (500—1000 ppm) and Tríbeč Mts. (700—800 ppm). With differentiation it sinks to 200 ppm and in aplites also below 100 ppm. Barium sinks from the maximum values of 1400 ppm even below 200 ppm in aplite types (Cambel — Medveď, 1981).

Solution of differentiation of the concrete granite suite by mixing model by means of GENMIX program is a suitable starting-point for interpretation of behaviour of trace elements. Modelling of Rb, Sr and Ba trends with using of the distribution coefficients and mineral proportions obtained with mixing has confirmed unambiguously that Rayleigh fractional crystallization of plagioclase, biotite, quartz and K-feldspar is able to explain the observed distribution of Rb, Sr and Ba. An example of Sr and Ba distribution together with curves of fractional crystallication is in Fig. 2. In this case the decrease in Ba contents is explicable by fractional crystallization of biotite, later also K-feldspar, the

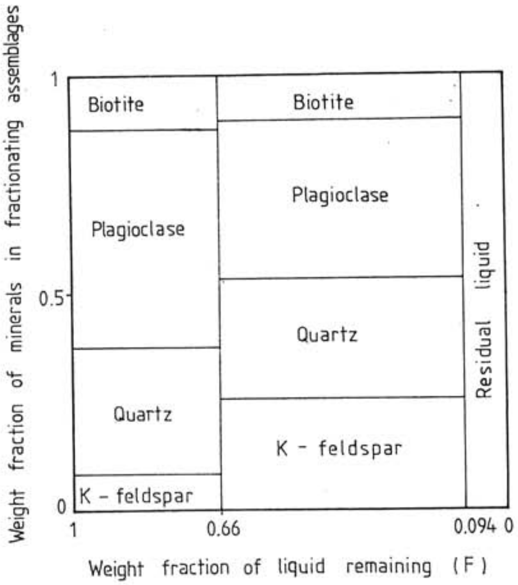

Fig. 1. Crystallization of granodiorite magma of the Bratislava massif of the Malé Karpaty, as modelled by GENMIX program (Le Maitre, 1981). From the parental magma (F = 1) biotite, plagioclase, quartz and K-feldspar crystallize in the first stage in the calculated proportions with formation of monzogranite melt (F = 0.66), which provides syenogranite (F = 0.094) in the second stage by crystallization of the same minerals in changed proportions (Vilinovič — Petrík, in press).

decrease in Sr contents is caused by fractionation of plagioclase and K-feldspar. Modelling has also confirmed the conclusions of McCarthy–Hasty (1976), that equilibrium crystallization of the mentioned minerals does not explain the actual distribution of trace element in rocks. It has also turned out that is probable, the cumulus mineral being plagioclase. This is also testified by high Sr contents (up to 1000 ppm) and the presence of moderate positive Eu-anomalies in whole rock REE distribution patterns.

The most distinct feature of REE distribution in the fundamental types of granitoids (biotite granodiorite to tonalites) are steep REE patterns with distinct prevalence of LREE over HREE practically without Eu-anomaly (Fig. 3). With increasing acidity of rocks negative Eu-anomaly is forming and in the last differentiates is a distinct decrease mainly of LREE. We consider such a trend as the result of fractional crystallization of accessory allanite (LREE), zircon (HREE), or monazite, apatite and titanite together with plagioclase and later with K-feldspar (cf. e. g. Fourcade – Allégre, 1981).

Amphibole-biotite diorites to gabbroids which are present in granitoid massifs in form of enclaves several tens of metres large are not falling into the above-

-mentioned trend of differentiation. According to present opinions these diorite rocks can be a product of anatectic effects of granitoid magma on metabasites — amphibolites, which together with gneisses are part of the metamorphic mantle as well as xenoliths in granitoids. It cannot be, however excluded — and

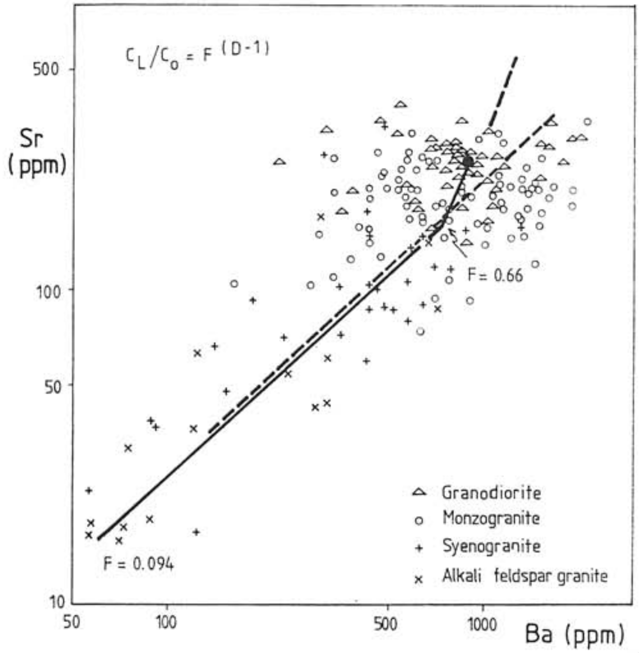

Fig. 2. Sr—Ba relationship for granitoids of the Bratislava massif of the Malé Karpaty Mts. with calculated curves of fractional crystallization.
Explanations: Solid lines follow the direction of evolution of liquid compositions, dashed lines follow the evolution of compositions of coexisting solids. Initial composition of magma C_O = 250 ppm Sr, 890 ppm Ba. C_L = concentration of elements in evolving liquid at the given value of F. The states and values of F are taken over from Fig. 1. D is the bulk distribution coefficient of fractionating mineral assemblage calculated assuming distribution coefficients recommended by McCarthy — Groves (1979). Analyst: J. Medveď.

the trace elements, mainly the high content of REE and missing Eu-anomaly testify to this fact — that part of these diorite rocks is a product of basic-intermediate magmatism, which may be in certain relation with granitoid plutonism.

The West Carpathian granitoids may be so designated as restricted in composition. In this connection it is problematic to range them to some of the petrogenetic series: extrapolation of Peacock's index indicates their competence rather to calcic than calc-alkaline series. Among the West Carpathian Variscan granitoids metaluminous as well as peraluminous types with various per cent representation in the individual massifs are present. As, however, amphibolic members are missing, the model of formation of peraluminous magmas by fractional crystallization of amphibole presented by Cawthorn—Brown (1976) cannot be applied. In deeper parts of the massifs, however the presence of amphibolic varieties cannot be excluded. Peraluminous character is mostly ma-

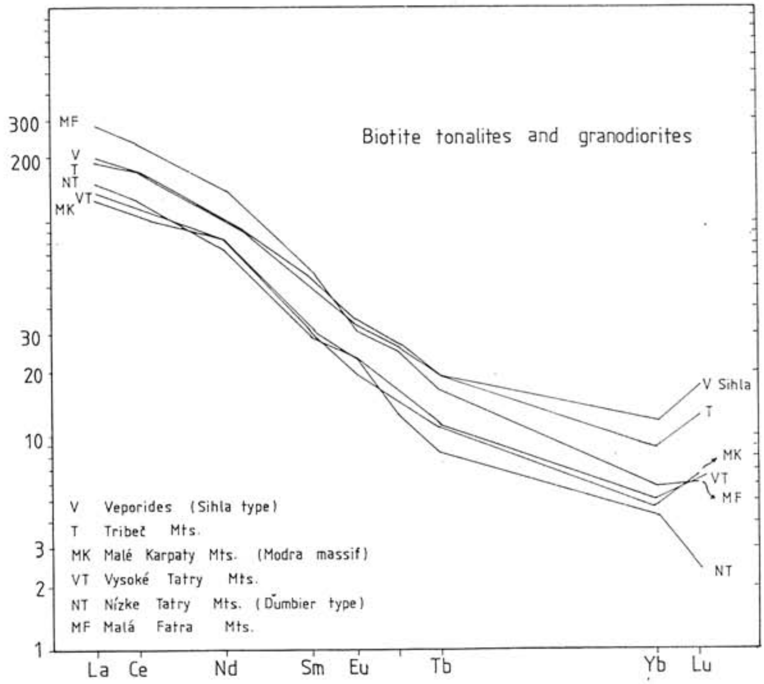

Fig. 3. REE distribution in fundamental rock types (biotite tonalites and granodiorites) of the West Carpathians. Normalized according to Evensen et al. (1978). Analyst. P. Kotas.

nifested by the presence of muscovite + biotite ± sillimanite, in leucocratic varieties and pegmatites by the presence of muscovite + garnet ± tourmaline.

Another of the problems occurring in the study of the West Carpathian granitoids, is the non-unambigous result of I/S classification of Chappell—White (1974) or White—Chappell (1983). The rocks as well as whole massifs posses often characteristics of both types. The only unambiguous representative of S-type granite with explicitly crustal initial ratio $(^{87}Sr/^{86}Sr)_0$ = 0.7195 are Gemeride granites, which are also the youngest intrusions of the Variscan cycle (Kovách et al., 1979). Other granitoids of the Tatrides and Veporides have a much lower initial ratio (0.705 to 0.707) deducing from the results of the Vysoké Tatry (Burchart, 1968) and Malé Karpaty Mts. (Bagdasarjan et al., 1982). From tonalites to almost the most acid varieties these granitoids are of sodium character, inclining to I-type with prevailing mafic mineral biotite. Between Na_2O and K_2O is, however, negative correlation on the contrary to type Australian granitoids. It is possible to mention from world literature several examples of mixed I—S character of granitoids and therefore one can agree with statement of Pitcher (1983), that granitoids of S.E. Australia, on which I/S classification was defined, are mineralogically and chemically quite exceptional. Without doubt a possitive step in the typology of granitoids was Pitcher's (1983) subdivision of I-type into the Cordilleran and Caledonian. It turns out that our Variscan granitoids of the Tatrides and Veporides, namely biotite tonalites and granodiorites correspond in their character mostly to Caledonian I-type. The low magnetic susceptibility at the same time points to their competence to the ilmenite series of Ishihara (1977; 1981).

In solving of the genesis of West Carpathian granitoids it is set out from the conception of anatexis of the metasedimentary series and palingenic origin of granitoid magma (Cambel, 1980). The source rock was probably of greywacke composition, anatexis set in at the boundary of the upper and lower crust (Hovorka, 1979). Further studies based on interpretation of alkalies (Cambel et al., 1981 b) and isotopic relations (Cambel—Petrík, 1982) have, however, shown that the source material must have contained a considerable portion of basic, probably mantle material. This is mainly testified by relatively low initial ratios of Sr isotopes: 0.705—0.707. The way, in which the material with low Rb/Sr ratio was incorporated in granitoid magma, is sought in the mixed--hybrid character of the source material so far, most acceptable is the presumption of anatexis of argillaceous-siliceous and greywacke metamorphites with layers of tholeiite rocks as products of submarine volcanism of mantle origin.

According to the latest results, several granitoid types of the core mountains have a higher initial isotope ratio (0.7150) too, e. g. granitoids of the Králička type in the Nízke Tatry Mts.,what evidences of lithological variability of the rocks from which the West Carpathian granitoids have been formed.

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