GEOLOGICA CARPATHICA, 52, 2, BRATISLAVA, APRIL 2001
79–90

WHOLE-ROCK CHEMISTRY AND GENETIC TYPOLOGY OF THE WEST-CARPATHIAN VARISCAN GRANITES

IGOR BROSKA and PAVEL UHER

Geological Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 842 26 Bratislava, Slovak Republic

(Manuscript received June 9, 2000; accepted in revised form March 15, 2001)

Abstract: The geochemistry of 166 new whole-rock analyses from West-Carpathian Variscan granitic rocks are presented on the basis of their division into four principal groups: S-, I-, A- and specialized S-type (S_S). The contribution shows some discrimination diagrams which are useful for the recognition of these principal granite groups and also give a possible outline of the geodynamic scenario of their origin. All studied groups belong to mainly crustal aluminic (S_S-, S-type) and aluminocafemic (I-, A-, partly S-type) associations, mantle-derived cafemic dioritic rocks are rare. Generally, the S- and I-type groups show predominantly Na_2O/K_2O ratio > 1, whereas A- and S_S-type granites usually exhibit Na_2O/K_2O < 1. I-types are more Si-poor and Fe, P-rich than other groups, however, a part of the S_S-type group belongs to the P-rich evolved granites (>0.2 wt. % P_2O_5) and the A-types are generally very poor in P. The Zr vs. SiO_2 diagram clearly discriminates Zr and Si-rich hypersolvus A-type from other groups, similarly the A-types show the highest Zr/Hf-ratio and Y contents (>20 ppm). Ba-Sr and Sr-Rb diagrams successfully divide plagioclase-rich I-type from S-, A-type and especially from K,Na-feldspar-rich S_S-type. The newly modified Rb-Ba-Sr diagram reliably discriminates the groups: poorly (I, S), mildly (S, A, rarely I) and strongly evolved granites (S_S, rarely S and A) were recognized. REE rock/chondrite normalized diagram discriminate all groups: REE-rich I-type without Eu-anomaly, from REE-rich A-type with negative Eu-anomaly and REE-poor S- and especially S_S-type with pronounced negative Eu-anomaly. In this sense of the geotectonic position, the S- and I-type can be considered as orogenic granites, in contrast, the A-type and S_S-type granites are post-orogenic members.

Key words: Western Carpathians, geochemistry, granitic rocks, S-, I-, A-, S_S- types.

Introduction

New analytical data, for the most part unpublished have been gathered in chemical laboratories at Ottawa University, Canada and in Memorial St. John's University, Canada. These data permit a new study of the chemical variability of granitic rocks in the Western Carpathians. A subset of the samples which were analysed and published previously (mainly "ZK" series, Cambel & Walzel 1982; "BP" series, Uher et al. 1994) were re-analysed. Consequently, this set is the first complete large database of major and trace elements of all principal genetic types of West Carpathian Variscan granitic rocks.

Geochemical studies of the West-Carpathian granites until now, usually did not take into account variations between the genetic groups of the granites but they were based mainly on the investigation of granitic groups according to the IUGS classification and composition variations between granites, granodiorites and tonalites. The West-Carpathian Variscan granitic rocks were considered as genetically more-or-less coherent group which shows primary differentiation caused mainly by fractional crystallization. Tonalite, granodiorite to granite sequences were regarded as common differentiation trend characterized by the decreasing of compatible elements, such as P, Zr, Hf, Cr, Ni, Co, V, and by the increasing of incompatible elements, such as Rb, Sn (e.g. Cambel & Vilinovičová 1981; Cambel & Vilinovič 1987; Jacko & Petrík 1987; Hovorka & Petrík 1992; Kohút & Janák 1994). Occasionally, besides the crystal fractionation, wall-rock assimilation has been emphasized (Jacko & Petrík 1987). In the past, the granite rock-forming minerals (feldspars, micas) were studied in detail (e.g. Macek et al. 1979, 1982; Petrík 1980, 1982b; Vilinovičová 1989). Later geochemical granite subdivision into I- and S-types were realized (Klomínský et al. 1981; Cambel & Petrík 1982; Cambel et al. 1985), the subdivision of the Veľká Fatra granites into two separate independent groups on the basis of bulk rock compositions was proposed (Kohút 1992).

Using the fundamental mineralogical criteria, especially accessory mineral assemblages, zircon typology and allanite-monazite dichotomy, together with geochemical and isotopic data led to a subdivision of the West-Carpathian granites, into monazite-ilmenite and allanite-magnetite group (Broska & Uher 1991; Broska & Gregor 1992; Petrík & Broska 1994). Later, the identification of post-orogenic A-type granites mainly on the basis of zircon typology and trace-element chemistry (Uher & Gregor 1992; Uher & Broska 1996) shed a new light on the understanding of granite development in the Western Carpathians. It resulted to the division of the West-Carpathian granites into S-, I-, A-type groups (Petrík et al. 1994).

The aim of this paper is to characterize Variscan West-Carpathian granites on the basis of 166 new analyses in terms of recently used genetic classification, based on S, I, A typology (Chappell & White 1974; Whalen et al. 1987), except the Devonian metagranites (orthogneisses), which were not included into the sample set. For this purpose, we subdivided studied set of West-Carpathian granite analyses into the four geochemical groups: (1) S-type granites, meso-Variscan (2) I-type,

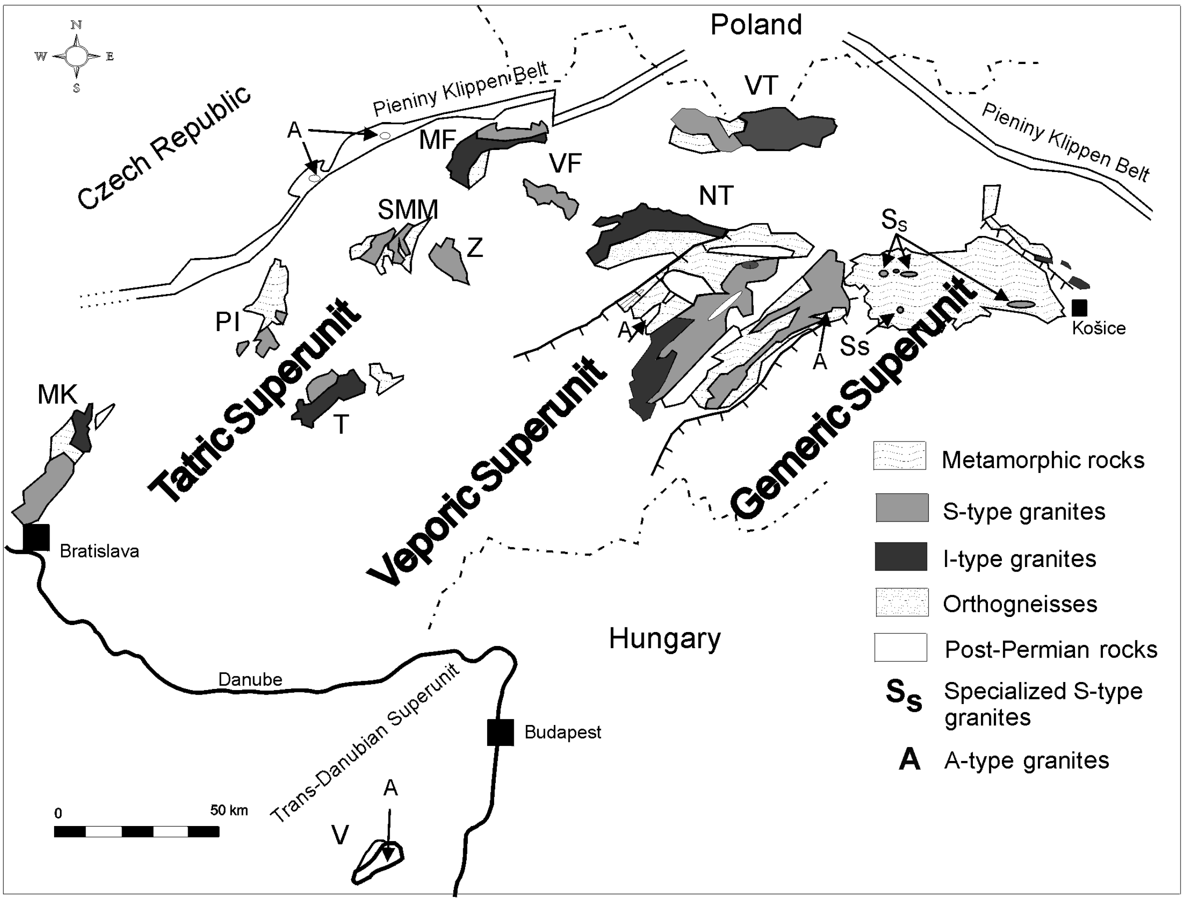

Fig. 1. Schematized geological map of the distribution of Variscan West-Carpathian granites. *Explanations:* **MK** — Malé Karpaty Mts, **T** — Tribeč Mts, **PI** — Považský Inovec Mts, SMM Suchý and Malá Magura Mts, **MF** — Malá Fatra Mts, **VF** — Veľká Fatra Mts, **NT** — Nízke Tatry Mts, **VT** — Vysoké Tatry Mts, **V** — Velence Mts (Hungary).

meso- + late-Variscan, (3) A-type, post-Variscan and (4) post-Variscan specialized rare-element S-type granites (S_S-type).

Despite plotting of numerous discrimination diagrams of granitic rocks, we present only the most distinctive ones in order to demonstrate the chemical variability of the granite groups. The contribution also illustrates an outline of the possible geotectonic scenario of the West-Carpathian Variscan granites in sense of their time and spatial relationship.

Occurrences of the West-Carpathian Variscan granitic rocks

Variscan magmatic activity is manifested by intrusions of several granitoid plutons, separated tectonically in the principal West-Carpathian Alpine superunits: Tatric, Veporic and Gemeric (Plašienka et al. 1997) Fig. 1. The granites often occur as sheet-like bodies (Kohút & Janák 1994) or laccoliths (Lexa & Bezák 1996) and they are emplaced into metapelites to metapsammites of amphibolite facies, locally contact thermal metamorphism caused by granitoid intrusions occurs (e.g. Krist et al. 1992). The protolith of the granites was represented mostly by the metapelites, metagreywackes or older metagranites (Petrík 2000). The inhomogeneties in Sm/Nd system are interpreted as the evidence of contamination and/or magma mixing (Kohút et al. 1996, 1999a) and a Proterozoic recycling component in granite protoliths is supposed (Kohút et al. 1995, 1999a). At the present tectonic position, relatively large granitic plutons crop out in the Tatric and Veporic Superunits, in contrast to small and mostly hidden granitic bodies in the Gemeric Superunit. The Velence granites in the Trans-Danubian Superunit (Hungary), occur to the N of the Balaton lineament and belong to the Western Carpathians (cf. Plašienka et al. 1997). U-Pb and Rb-Sr isotope dating of the West-Carpathian granitic rocks reveal a relatively wide time span of their origin, around 150 Ma (e.g. Cambel et al. 1990; Petrík & Kohút 1997; Petrík 2000; Uher & Broska 2000; Poller et al. 2000).

Typology of the West-Carpathian Variscan granitic rocks

S-type granites

They represent peraluminous biotite and two-mica granites to granodiorites locally accompanied by numerous pegmatites. They are characterized by the dominance of monazite-(Ce) over allanite-(Ce) or absence of allanite accompanied with xenotime-(Y). The allanite-monazite dichotomy or antagonism has been observed in the West-Carpathian granitic rocks for over three decades (e.g. Hovorka & Hvožďara 1965; Chovan & Határ 1978; Hvožďara 1979; etc.), and together with zircon typology, and presence of almandine and ilmenite, it became one of the basic criteria for the genetic subdivision of the West-Carpathian granites into the S- and I-type granite groups (Broska & Uher 1991; Broska & Gregor 1992; Petrík & Broska 1994). Zircon typology of the S-type granites (mainly S_{1-2}, S_{6-7}, L_{1-2}, G_1 subtypes) indicates low-temperature crustal aluminous character of the granites according to the Pupin (1980) classification. Apatite locally show a dusky brown (smoky) colour due to minute carbon-bearing inclusions, which indicates low fO_2 conditions of crystallization (Broska et al. 1992). These features are typical for peraluminous granitic rocks which represent the most abundant granite type in the Western Carpathians. They have been formed probably by biotite and/or muscovite dehydration melting of upper crustal quartzo-feldspathic rocks, such as greywackes, due to crustal thickening and prograde metamorphism during Carboniferous collision (Petrík et al. 1994). In accordance with isotopic dating (e.g. Cambel et al. 1990; Kráľ et al. 1997), the monazite-(ilmenite)-bearing granites formed during the Meso-Variscan, Lower Carboniferous period with the culmination of formation at about 350 Ma.

I-type granites

I-type, allanite-bearing granites are metaluminous to slightly peraluminous biotite (leuco)tonalites to granodiorites, rarely biotite to muscovite-biotite granites, locally with pink K-feldspar phenocrysts. Except of allanite-(Ce), the typical primary accessory mineral assemblage is represented by magnetite and titanite. Zircon typology (mainly S_{12}, S_{16} subtypes) indicates a medium-temperature crustal to crustal-mantle character. The U-Pb zircon and Rb-Sr wall-rock dating show a wide age span of I-type group granite formation, from meso-Variscan, Late Devonian–Early Carboniferous (~370–340 Ma) to late-Variscan, Late Carboniferous (~310–290 Ma) — Broska et al. (1990), Bibikova et al. (1990), Cambel et al. (1990), Michalko et al. (1998). On the basis of recent data, their origin is connected with lower crustal continental melting with a contribution of infracrustal or mantle material (Petrík et al. 1994; Kohút et al. 1999). Locally abundant microgranular mafic enclaves in these granites, which are products of mixing of melts, as well as the bulk chemistry is evidence for such processes (Broska & Petrík 1993).

A-type granites

The recognition of the zircon typology with dominant high-temperature and high-alkaline P- and D- zircon subtypes in granites was the first impulse for the determination of these post-orogenic A-type granites (Uher & Gregor 1992; Uher et al. 1994). They form small intrusions of biotite leucogranites to granite porphyries with hypersolvus, transsolvus to subsolvus textures (Uher & Broska 1996). The accessory mineral assemblage includes allanite-(Ce), magnetite or ilmenite, rarely monazite-(Ce) (Uher & Broska 1996). U-Pb isotopic geochronology of zircon showed the Permian to Triassic age of the A-type granites (Uher & Pushkarev 1994; Putiš et al. 2000).

Specialized S-type granites

Specialized tin-bearing biotite-muscovite to muscovite leucogranites, and rare granite porphyries from the Gemeric Superunit (the Spiš-Gemer type) are the most evolved S-type granites in the Western Carpathians. Locally greisen and albitite cupolas with disseminated rare element Li, Sn, Nb, Ta, W, F mineralization occur (Malachovský 1992 in Grecula 1995). Accessory minerals of the Spiš-Gemer granites comprise tourmaline (schorl to foitite), almandine, topaz, zircon, apatite, locally also rare monazite-(Ce), cassiterite, wolframite and Nb-Ta phases (e.g. Faryad & Dianiška 1993). Zircon of S_8 subtype predominate. The character of zircon typology is distinct and distinguished these granites from the rest of the West-Carpathian granites (Jakabská & Rozložník 1989; Broska & Uher 1991). The granites show Permian Rb-Sr WR and mineral ages and they are characterized by very high initial Sr isotope ratios, I_{Sr} above 0.720 (Kovách et al. 1986; Cambel et al. 1990). The Permian age was also constrained by monazite probe dating (Finger & Broska 1999) and single-grain isotopic dating of zircon (Poller et al. 2000).

Analytical methods

All 166 analyzed samples were obtained from the crushed homogenized rocks of 3–12 kg in weight. Major elements and Rb, V, Cr, Co, Ni, Zn, Sr, Ba, Th and U of the rocks were determined by XRF at Ottawa University (Canada), and REE, Y, Nb, Ta, Zr and Hf by ICP-MS in Memorial University of Newfoundland (Canada). The analytical procedure of ICP-MS was as follows: (1) sintering of a 0.2 g sample aliquot with sodium peroxide, (2) dissolution of the sinter cake, separation and dissolution of REE hydroxide-bearing precipitate, (3) analysis by ICP-MS using the method of internal standardization to correct for matrix and drift effects. Natural rocks and pure quartz reagent (blank) were used as reference standards. For detailed information on the ICP-MS method see Jenner et al. (1990) and Longerich et al. (1990).

Results

Major element geochemistry

Representative chemical analyses of the major elements of all four geochemical granite groups are presented in Table 1, statistical parameters are shown in the Table 2. The complete data used for the construction of diagrams are available as Table 3 on request in the Editorial Office or from the authors.

The chemical analogue of the modal IUGS classification by Streckeisen & Le Maitre (1979) using the Mielke & Winkler mesonormative calculation (1979), shows the prevalence of tonalites and granodiorites in the I-type granite group, the S-type type of granitic rocks are granites, granodiorites, rarely tonalites and the A- as well as the S_S-type belong to feldspar granites and syeno- as well as monzo-granites (Fig. 2).

Another rock classification diagram expressing the balance between characteristic peraluminous minerals (e.g. micas, garnets) and metaluminous Al-poor, Ca-rich minerals (e.g. hornblende, epidote, titanite) after Debon & Le Fort (1983) shows the distinct peraluminous character of practically all studied West-Carpathian rocks except part of the subaluminous and metaluminous I-type tonalites and diorites. The diagram reveals their dominantly crustal origin, with aluminic to aluminocafemic associations (Fig. 3). Cafemic association (field IV) is represented almost only by amphibole-biotite-bearing diorites as well as microgranular mafic enclaves of tonalite-diorite composition in I-type granites, which indicate their mantle origin (cf. Debon & Le Fort 1983). Amphibole-bearing tonalites are very rare in this region, and the majority of granitic rocks belong to biotite and two-mica types. S-type and specialized S-type granites are plotted in field I (Ms>Bt), which is in accordance with the petrographic data. Biotite-bearing A-type leucogranites (~4–5 vol. % Bt) and especially biotite-rich I-type granites (~5–10 vol. % Bt) lie in the Bt>Ms (II) and Bt (III) fields (Fig. 3).

A Na_2O/K_2O vs. SiO_2 diagram is plotted in Fig. 4. The prevalence of Na_2O over K_2O is dominant for the S- and I-type granites as was described earlier (e.g. Hovorka & Petrík 1992), on the contrary, the A-type and S_S-type granites show the prevalence of K_2O. The I-type granitic group shows a regular trend of decreasing Na_2O/K_2O vs. SiO_2 content, whereas the S-types exhibit distinctly scattered Na_2O/K_2O values and the A- and S_S-type granites are almost invariably below the value of 1 (Fig. 4). Locally, high albite content, especially in the S-type, cause the shift of Na_2O/K_2O ratio over 3. Other lithophile elements, as Mg, Ti and Mn do not discriminate the West-Carpathian granite types distinctly.

The iron content is slightly higher in the A-type granites than in the I- and S-type granites, whereas the specialized S-type granites show generally low iron (Fig. 5).

Decreasing of P_2O_5 content during the differentiation process, caused mainly by apatite fractionation, is well documented for the I- and A-type granites while P_2O_5 vs. SiO_2 distribution in both S- and S_S-type granites show large irregularities (Fig. 6). The P_2O_5 content in S-type decreases with SiO_2 only in early less fractionated members (<70 % SiO_2), whereas the more fractionated and peraluminous granites (>70 % SiO_2) reveal scattered to increased content of P_2O_5 (Fig. 6). The A-type granites form a distinct group with the lowermost P_2O_5 and apatite contents in comparison to the I- and S-type granites.

Trace element geochemistry

Although zirconium and hafnium systematically decrease with increasing of SiO_2, there are a significant differences in the distribution of these elements for A-type granites in comparison to the other granite groups (Fig. 7). The Hf vs. Zr diagram shows a high positive correlation (R = 0.98, Fig. 8), however, the diagram reveals a different trend for the A-type in comparison with the rest of granite groups due to the higher Zr/Hf ratio.

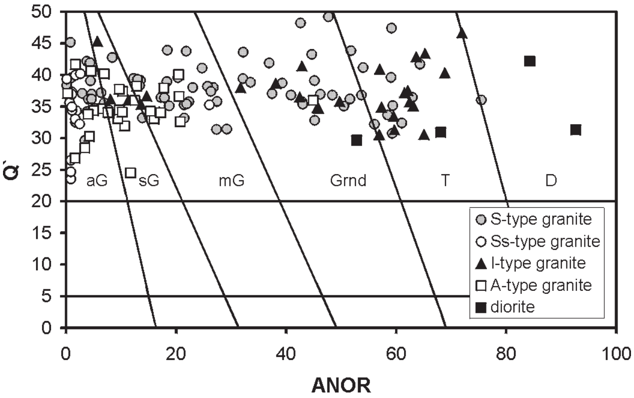

Fig. 2. Mesonormative Q'-ANOR diagram of the Variscan West-Carpathian granitic rocks. *Explanations:* **aG** — alkali-feldspar granite; **sG** — syenogranite; **mG** — monzogranite; **Grnd** — granodiorite; **T**— tonalite; **D** — diorite (without BMF-8).

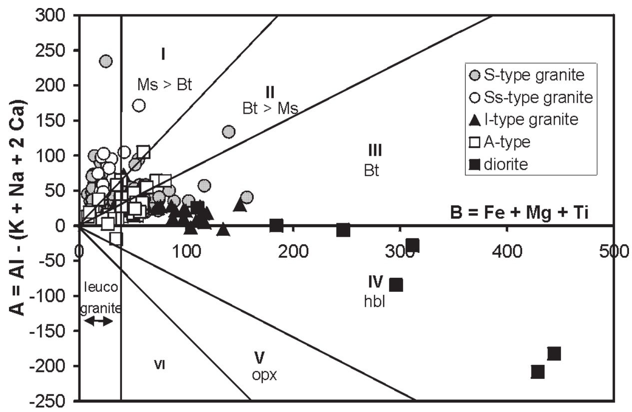

Fig. 3. A-B multicationic diagram (Debon & Le Fort 1983) of the Variscan West-Carpathian granitic rocks.

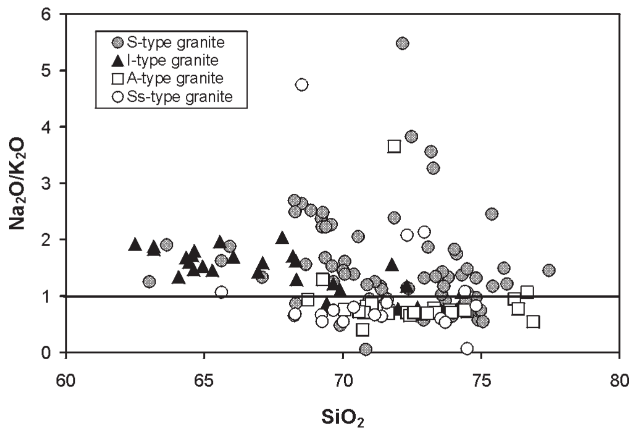

Fig. 4. Na_2O/K_2O vs. SiO_2 plot of the Variscan West-Carpathian granitic rocks documenting the discrimination of the A-type granites. Na_2O/K_2O ratio below 1 is characteristic for the post-orogenic granites.

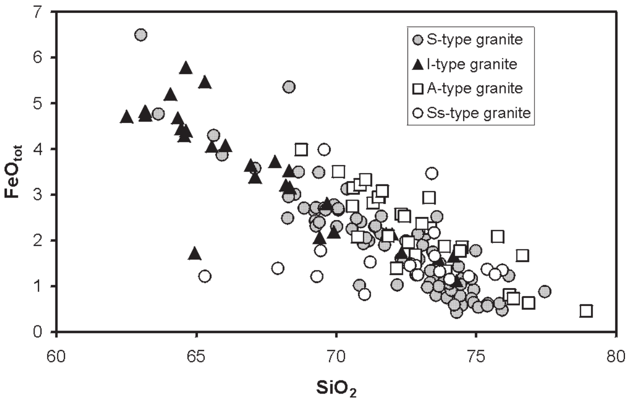

Fig. 5. FeO_{tot} vs. SiO_2 plot of the Variscan West-Carpathian granitic rocks.

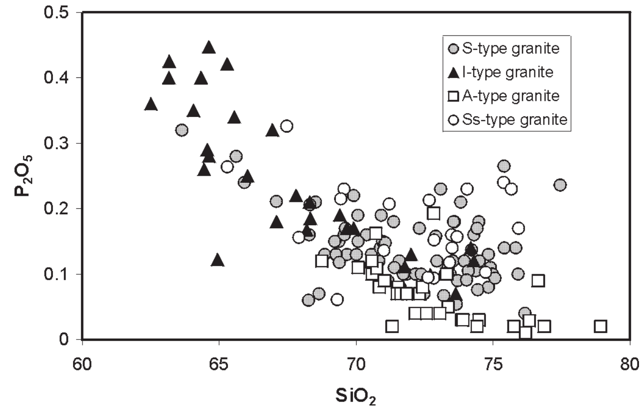

Fig. 6. P_2O_5 vs. SiO_2 plot of the Variscan West-Carpathian granitic rocks.

Binary Ba vs. Rb and Sr vs. Rb and the ternary Rb-Ba-Sr diagram (modified after El Bouseily & Sokkary 1975) clearly discriminate relatively poorly evolved I- and S-type group from mildly to highly evolved S-, A- and especially S_S-type granite groups (Figs. 9–11).

Chondrite-normalized rare earth element data show distinct differences among S-, I- and A-type granites. The average patterns of the normalized values show the highest value of the REE and especially HREE for the A-type group (Fig. 12). The HREE enrichment of the A-type group is documented also by high yttrium concentrations — more than 20 ppm (Fig. 13). The higher contents of the LREE are characteristic of the I-types in comparison with both S-types, nevertheless the HREE average content is almost identical for both granite groups (Fig. 12). The similar slope of the rock/chondrite normalized plot indicate similar differentiation tendencies of the S- and I-type granites: Ce_N/Yb_N is 11.4 and 16.7, respectively. On the contrary, the S_S- and A-type granite groups clearly reveal HREE enrichment: Ce_N/Yb_N is 2.8 and 5.6, respectively. The more pronounced Eu-negative anomaly is typical of specialized S-type granites (Eu/Eu* = 0.2) and for the A-type (Eu/Eu* = 0.4), on the other hand it is only 0.6 for the S-type group, and the I-type group has an insignificant Eu-anomaly (Eu/Eu* = 0.8).

Discussion

Geochemistry

The results show differences between all four groups of Variscan West-Carpathian granitic rocks. The mesonormative Q'-ANOR diagram (Fig. 2) is generally concordant with older modal and mesonormative diagrams (Petrík 1982a), however, studied differentiated I-type granites lie mainly in granodiorite and monzogranite fields, whereas common tonalite compositions were described by Petrík (1982a). The multicationic A-B diagram (Debon & Le Fort 1983) reveals generally aluminous crustal±alumino-cafemic character of all granite groups, although with some tendency of I-type to metaluminous mainly mantle domain which is typical of amphibole-bearing dioritic rocks and enclaves (Fig. 2). These results are in accordance with mainly crustal character of S-, A- and especially S_S-type groups and with some mantle contribution in the origin of the I-type group (Petrík et al. 1994; Uher & Broska 1996; Petrík & Kohút 1997).

The exclusive character of the A-type group is documented in Na_2O/K_2O vs. SiO_2 and FeO vs. SiO_2 plots (Figs. 4, 5) which reflects presence of the K-feldspar and annite-rich bi-

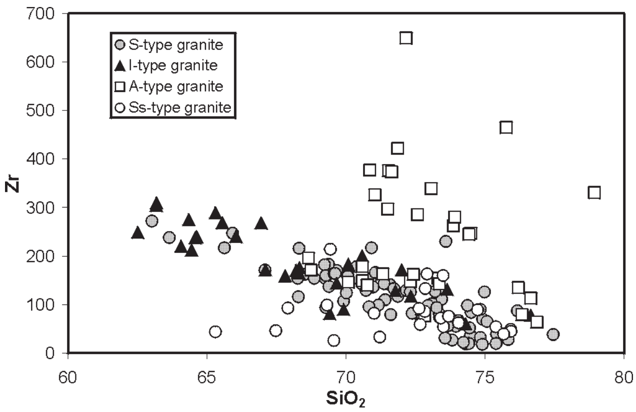

Fig. 7. Zr vs. SiO_2 plot of the Variscan West-Carpathian granitic rocks.

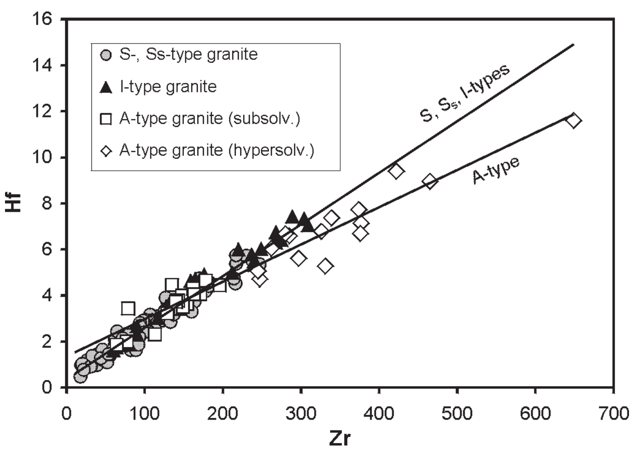

Fig. 8. Hf vs. Zr plot of the Variscan West-Carpathian granitic rocks.

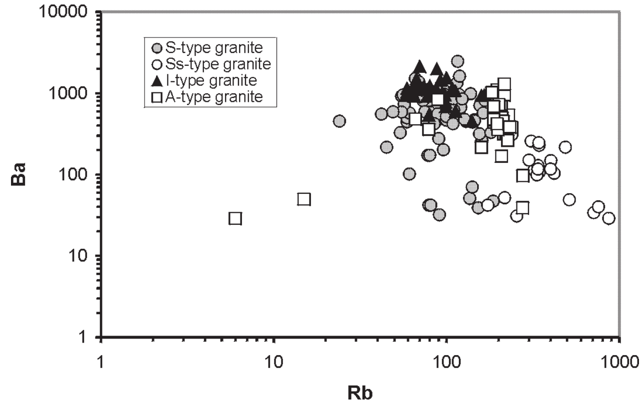

Fig. 9. Ba vs. Rb plot of the Variscan West-Carpathian granitic rocks. Note: The Turčok type represents anomalous A-type granite with low Rb content (Gemeric Superunit).

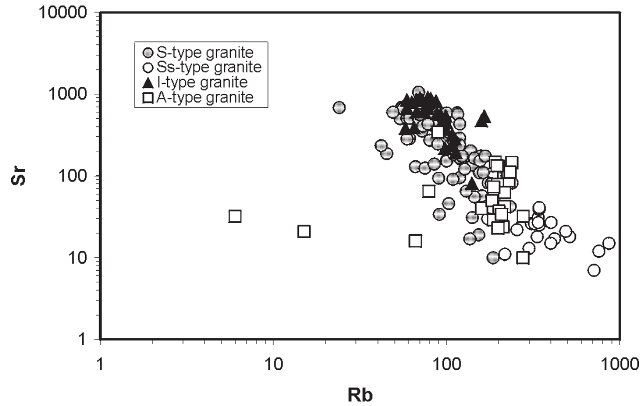

Fig. 10. Sr vs. Rb plot of the Variscan West-Carpathian granitic rocks.

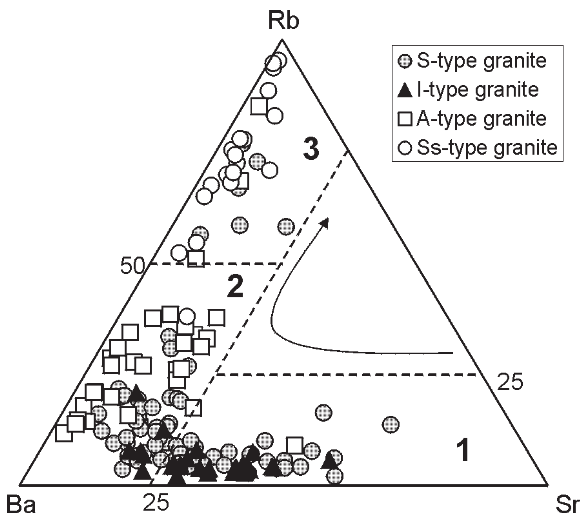

Fig. 11. Rb-Ba-Sr ternary discrimination diagram of the Variscan West-Carpathian granitic rocks. *Explanations:* 1 — poorly evolved granites, 2 — mildly evolved granites, 3 — highly evolved granites.

otite in the granite group (Uher & Broska 1996). These geochemical features are generally prominent in A-type granites (Whalen et al. 1987). The tendency of K_2O to predominate over Na_2O is evident also for the S_S-type group, whereas, S- and especially I-type group are sodium-rich (Fig. 4). Consequently, the older meso- and late-Variscan granites are mainly plagioclase-bearing rocks, whereas the post-Variscan A- and S_S-type exhibit K-feldspar dominance.

The very low P_2O_5 contents in the A-type group (Tables 1–3, Fig. 6) is comparable with other anorogenic granites world-wide (cf. Whalen et al. 1987), and it should be one of the typical feature of A-type granites, reflected in low amount of apatite in these Ca, P-poor rocks. Low P contents in the A-type granites could be explained by formation from melt-depleted lower crust after main granite production during Variscan orogeny. The I-type group shows negative correlation between P_2O_5 vs. SiO_2 due to apatite preferential precipitation in the early differentiation members. On the contrary, scattered P_2O_5 contents is the consequence of the higher P_2O_5 solubility with increasing A/CNK in late fractionated members (Pichavant et al. 1992). Moreover, positive correlation between P_2O_5 and SiO_2 in more evolved members of S- and especially S_S-type groups (>70 wt. % SiO_2) is connected with incompatible behaviour of P in strongly peraluminous, alkali- and fluid-rich magmas which resulted in enrichment of P and its entry into alkali feldspar structure in fractionated alkali-rich leucogranites (e.g. Pichavant et al. 1992; London 1992, 1998; Breiter 1998). Such a trend is characteristic especially for phosphorus-rich rare-element peraluminous granites of the Spiš-Gemer type (S_S-group) where K-feldspar contains up to 0.5 wt. % P_2O_5 (Broska et al. in prep.).

The content and behaviour of trace elements during differentiation processes clearly characterize the differences between the S-, I- and A-type granitic rocks. Of special importance are the findings on the compatibility or incompatibility of trace elements during differentiation. Some elements, such as Sr, Sc, V, Zr, Cr and Co behave compatibly in all granite types. Low Th and U content are not suitable for discrimination purposes as was formerly proposed by Yates et al. (1982). On the contrary, Zr is a very useful element for granite discriminations. The Zr vs. SiO_2 diagram (Fig. 7) strongly discriminates some of the A-type group from each other: high and irregular distribution of Zr (Tables 1–3) is another characteristic feature of alkali granites (e.g. Whalen et al. 1987). Very strong positive Hf vs. Zr correlation (Fig. 8) indicates the close and exclusive relationship between zirconium and hafnium in granitic magmas which resulted in crystallization of zircon as an essential Zr, Hf-bearing phase in all studied groups of granitic rocks. Different Zr/Hf ratio in hypersolvus A-type group in comparison to the other granites is probably related to contrasting solubility of Zr and Hf in (per)alkaline Al-poor F-rich A-type magmas in comparison to peraluminous H_2O-rich S- and I-type granites. This is also reflected in higher Zr/Hf ratios in zircon from post-orogenic and anorogenic granite suites (Pupin 1992) and is also documented for zircon of West Carpathian A-type group (Uher & Broska 1996).

The geochemical separation among granite types is strongly apparent in the distribution of Rb, Sr and Ba, which are concentrated mainly in the feldspars and micas. The highest contents of Rb show specialized S- and A-type groups due to

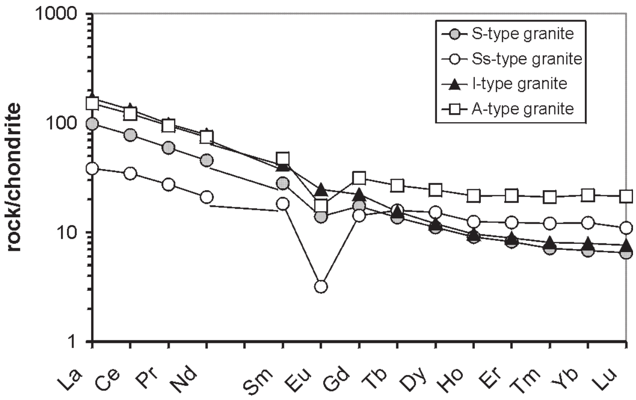

Fig. 12. Averages of the chondrite normalized REE patterns of the Variscan West-Carpathian granitic rocks.

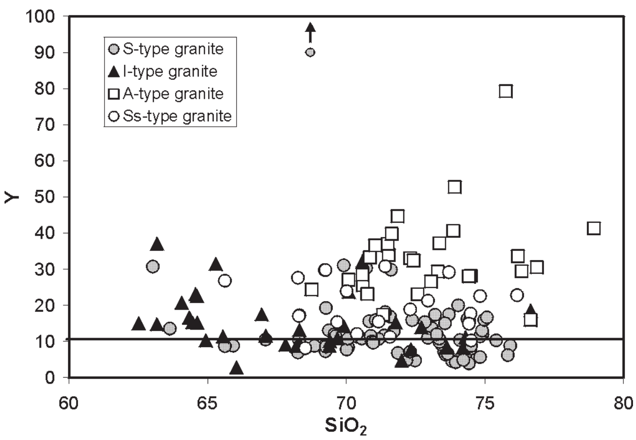

Fig. 13. Y vs. SiO_2 plot of the Variscan West-Carpathian granitic rocks.

their higher level of fractionaction and K-feldspar enrichment. On the contrary, less evolved, plagioclase-rich I- and S-type granites exhibit the highest Ba and Sr but the lowest Rb contents (Tables 1–3, Figs. 9–11). A general Rb-Sr-Ba differentiated trend toward the specialized granites described by El Bouseily & Sokkary (1975) is evident also in the West-Carpathian granitic suites (Fig. 11). However, in our opinion, fields such as "anomalous or normal granites, granodiorites etc." in the diagram of El Bouseily & Sokkary (1975) do not discriminate the natural granite types properly and they are inadequatly defined, in addition some of the West-Carpathian granites s.s. plot in the granodiorite field or vice versa. Therefore, we propose new categories for this ternary Rb-Ba-Sr diagram according to their degree of differentiation: poorly-evolved, mildly-evolved, to highly evolved granites (Fig. 11). Such modification of the diagram allow us to use Rb, Sr and Ba as the important discrimination parameters for the classification of the West-Carpathian Variscan granite suites and could be more generally useful.

REE,Y-distribution as well as the presence or absence of a negative Eu-anomaly also discriminate all four geochemical groups of the West Carpathian granites (Tables 1–3, Figs. 12, 13). Again, the A-type group strongly differs from each other with high Y contents, generally over 20 ppm (Fig. 13). The Y and HREE enrichment in the A-type granites is due to the high content of zircon and locally also the presence of xenotime-(Y) and garnet (Uher & Broska 1996). The bulk REE distribution is controlled by essential REE-bearing phases, such as allanite-(Ce), monazite-(Ce) and xenotime-(Y), however a contribution of almandine and zircon for bounding of HREE and Y as well as apatite for LREE-fixing is also important (e.g. Wark & Miller 1993). The wider range of the rare earth elements abundance for the S-, but also for A-type granite, in comparison with I-type is also a significant feature of the bulk-rock chemistry of the West-Carpathian granites. Although the I-type granite set also comprises differentiated dykes, the rare earth elements pattern range is narrower mainly in the LREE part of the diagram and max/min REE values are around 10, in contrast to max/min REE values for the S-types of around 100 due to their more heterogeneous nature. We can only speculate that such a difference in pattern is a result of the compositionally different precursor of I-type granites as well as their rapid ascent and differentiation.

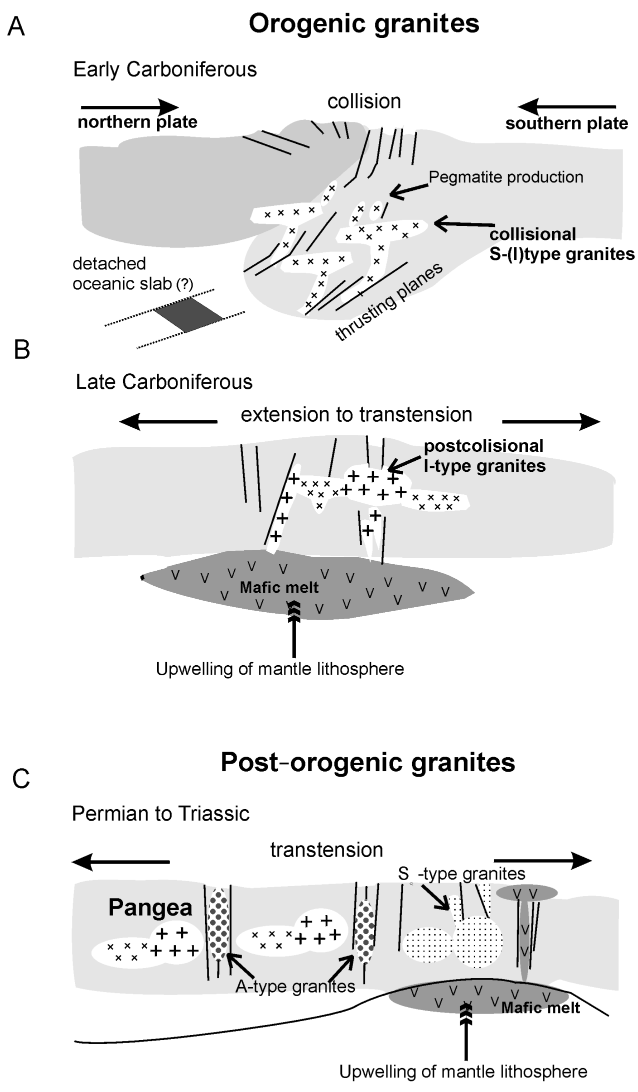

Fig. 14. Simplified geodynamic evolution of the principal granitic groups in the Western Carpathians.

Table 1: Representative chemical analyses of the basic group of the West-Carpathian Variscan granites. Main elements (in wt. %), trace elements V to U (in ppm) are analysed by XRF, REE's, Zr, Hf, Nb and Ta (in ppm) by ICP-MS. (Abr. tr. = trace content). *Explanations:* **MK** — Malé Karpaty Mts, **T** — Tribeč Mts, **PI** — Považský Inovec Mts, **MF** — Malá Fatra Mts, **SGR** — Slovenské rudohorie Mts (Gemeric Superunit), **Vepor** — Slovenské rudohorie Mts (Veporic Superunit), **V** — Velence Mts (Trans-Danubian Superunit, Hungary), **PKB** — Pieniny Klippen Belt (pebbles).

Sample	ZK-48	T-87	Z-4/89	I-3	BMF-1	ZK-13	GZ-1	GZ-15	T-88	T-60/86	VG-54	ZK-118	BP-1	BP-35	VG-86	VE-4
type	S	S	S	S	S	Ss	Ss	Ss	I	I	I	I	A	A	A	A
Mts.	MK	T	Z	PI	MF	SGR	SGR	SGR	T	T	Vepor	Vepor	PKB	PKB	Vepor	V
SiO_2	69.67	71.37	72.95	73.44	68.26	74.05	71.21	72.85	64.63	74.30	64.57	65.55	74.49	71.85	70.72	76.87
TiO_2	0.40	0.37	0.19	0.21	0.34	0.11	0.04	0.21	0.79	0.12	0.80	0.78	0.15	0.27	0.33	0.05
Al_2O_3	15.64	14.87	14.62	14.00	16.71	14.65	16.14	14.89	16.30	13.87	16.34	16.26	13.18	14.09	15.00	12.59
FeO_{tot}	1.96	2.31	1.59	1.75	2.49	1.15	1.53	1.32	4.40	1.12	4.29	4.06	1.86	2.10	2.48	0.63
MnO	0.05	0.05	0.04	0.03	0.04	0.02	0.02	0.02	0.07	0.02	0.07	0.05	0.03	0.02	0.06	0.01
MgO	0.85	0.87	0.36	0.36	0.71	1.60	0.24	0.91	1.77	0.25	1.62	1.56	0.09	0.82	0.99	0.04
CaO	2.61	1.73	1.19	1.18	2.81	0.34	0.30	0.26	3.55	0.89	3.59	3.24	0.36	1.25	0.26	0.50
Na_2O	3.88	3.54	4.21	3.27	5.09	0.27	5.92	3.41	4.22	4.26	4.36	4.22	3.73	5.63	2.09	2.96
K_2O	3.10	3.02	3.18	4.39	1.89	4.46	1.25	3.19	2.34	4.00	2.54	2.16	5.16	1.54	5.28	5.37
P_2O_5	0.13	0.18	0.12	0.10	0.06	0.23	0.21	0.15	0.28	0.12	0.29	0.34	0.03	0.07	0.16	0.02
LOI	0.80	1.30	0.80	0.70	1.30	2.90	1.00	1.50	1.30	0.70	1.70	2.30	0.60	2.40	1.80	0.90
TOTAL	99.09	99.61	99.25	99.43	99.70	99.78	97.85	98.72	99.65	99.65	100.17	100.52	99.68	100.04	99.17	99.94
V	34	44	17	16	25	8	3	17	93	10	82	84	10	7	32	7
Cr	15	16	4	9	16	22	tr.	1	20	1	18	24	5	16	8	5
Co	4	15	1	2	2	33	8	6	11	tr.	7	6	7	2	5	1
Ni	tr.	4	tr.	tr.	tr.	5	5	6	5	tr.	4	3	tr.	3	9	2
Zn	58	60	50	53	60	19	78	24	77	20	89	76	73	25	18	17
Rb	119	92	101	138	54	400	173	300	72	113	67	59	209	79	233	277
Sr	289	482	261	203	498	15	30	13	852	193	860	850	24	65	42	32
Zr	170	143	98	111	154	62	33	133	240	60	237	268	247	422	129	64
Hf	5	4	2	3	4	2	1	3	5	2	6	6	5	9	3	2
Nb	11	9	8	12	7	14	4	10	13	8	18	14	14	16	10	10
Ta	0.75	0.84	0.46	0.77	0.34	5.46	2.38	1.19	0.59	0.85	1.35	0.53	1.07	1.18	1.22	1.56
Ba	830	854	844	988	327	117	42	150	1105	602	1263	1144	499	358	347	97
Th	12	9	7	13	9	9	15	21	10	9	9	12	19	20	14	30
U	1	4	3	2	3	5	3	4	5	0	4	9	1	2	2	4
Y	14.07	11.62	10.96	9.09	6.94	17.73	8.12	26.82	15.18	11.1	23.01	11.31	28.23	44.68	30.33	30.57
La	32.32	25.52	25.38	36.04	28.52	13.97	2.84	13.33	43.66	17.73	52.52	61.97	48.96	64.45	17.38	14.74
Ce	64.45	49.94	50.97	75.34	59.14	26.49	6.82	25.83	87.9	36.15	116.75	124.77	104.96	131.49	36.95	30.2
Pr	7.35	5.64	5.86	8.63	6.79	3.11	0.92	3.68	10.21	4.37	14.12	14.15	12.08	15.75	4.41	3.99
Nd	27.21	21.15	22.56	31.69	25.91	11.56	3.17	14.48	38.47	16.35	55.61	50.58	45.86	60.47	16.96	14.89
Sm	5.0	3.8	4.32	6.48	4.79	2.87	1.27	3.86	6.45	3.45	10.27	8.24	8.77	11.77	4.51	3.89
Eu	1.08	1.1	0.7	0.93	1.03	0.45	0.02	0.3	1.58	0.6	2.38	1.87	0.68	1.64	0.59	0.19
Gd	3.97	2.84	3.21	4.73	3.19	2.9	1.28	4.46	4.61	2.79	7.27	5.18	7.42	9.98	4.89	3.83
Tb	0.52	0.4	0.43	0.53	0.37	0.56	0.3	0.79	0.6	0.4	0.92	0.61	1.02	1.56	0.84	0.68
Dy	2.85	2.28	2.25	2.41	1.72	3.5	1.73	5.22	3.11	2.27	4.71	2.89	6.05	9.25	5.19	4.69
Ho	0.51	0.43	0.39	0.32	0.26	0.58	0.24	0.99	0.57	0.42	0.84	0.46	1.13	1.79	1.04	1.02
Er	1.38	1.11	0.97	0.69	0.6	1.45	0.62	2.88	1.49	1.13	2.42	1.09	3.16	5.0	3.04	3.27
Tm	0.19	0.15	0.13	0.09	0.09	0.2	0.09	0.45	0.21	0.16	0.36	0.13	0.45	0.74	0.46	0.52
Yb	1.26	0.95	0.83	0.42	0.62	1.17	0.55	2.99	1.27	1.05	2.19	0.94	2.83	4.69	2.83	3.9
Lu	0.19	0.14	0.13	0.07	0.1	0.15	0.06	0.43	0.19	0.14	0.32	0.14	0.43	0.68	0.4	0.63

An explanation of the Eu-anomaly is found mainly in the different oxygen fugacity or water activity of the primary melts. In concordance with Puchelt & Emmermann (1976), Williams (1997), Sha & Chappel (2000), we regard the negative anomaly as an indicator of lower fO_2 provided that the whole rock was not depleted in europium. The negative Eu-anomaly originated under reducing conditions, when europium occurs only in the divalent state and it is incorporated into plagioclase. Lower fO_2 or water activity in the melts in comparison with I-type granites was actually assumed for S-type groups also on the basis of Fe^{2+}-rich accessory mineral paragenesis (presence of almandine and ilmenite, absence of magnetite, allanite and titanite). Biotite composition indicated the I-type granitoids originated in relatively oxidized and water-rich conditions (about 5–6 wt. % of water), on contrary, the S-type granites crystallized from a relatively reduced magma with low water content (2–3 wt. %) (Petrík & Broska 1994; Petrík & Kohút 1997). The oxidized conditions in the I-type melt provided the trivalent state of Eu and it explains, why europium was not able to fractionate with feldspars in these granites.

Geodynamic scenario of granite origin

The compositional variations and differences among the granitic groups of the Western Carpathians reflected their genesis including the geotectonic position and source rocks. The geotectonic position of the S and I-type granites was

Table 2: Average and ranges of granitic rock compositions (distribution see in the Fig. 1). Note: 6 diorite analyses are not presented.

	S-type n = 78				spec. S-type n = 22				I-type n = 29				A-type n = 30			
Sample	av.	st. dev.	max.	min.	av.	st. dev.	max.	min.	av.	st. dev.	max.	min.	av.	st. dev.	max.	min.
SiO_2	71.84	2.89	77.45	63.02	72.04	2.83	75.93	65.30	67.82	3.60	74.30	62.51	72.86	2.45	78.93	68.65
TiO_2	0.26	0.19	0.89	0.02	0.17	0.17	0.73	0.04	0.57	0.32	1.25	0.09	0.24	0.10	0.46	0.05
Al_2O_3	14.90	0.99	18.48	12.84	14.78	1.67	19.18	13.07	15.35	1.18	18.85	13.50	13.77	0.88	15.69	12.45
Fe_{tot}	1.96	1.16	6.50	0.43	1.63	0.75	3.99	0.82	3.37	1.34	5.79	1.12	2.27	0.92	3.99	0.46
MnO	0.04	0.04	0.23	0.00	0.04	0.07	0.37	0.01	0.06	0.02	0.10	0.02	0.05	0.10	0.59	0.00
MgO	1.02	3.38	30.00	0.06	4.42	19.34	91.00	0.05	1.32	0.65	2.98	0.19	0.43	0.29	1.00	0.02
CaO	1.38	0.90	3.03	0.14	0.38	0.35	1.88	0.14	2.40	1.12	3.79	0.30	0.74	0.51	2.20	0.04
Na_2O	3.94	0.79	5.51	0.27	3.42	1.33	5.92	0.13	3.98	0.67	6.83	3.03	3.92	1.09	7.99	2.96
K_2O	3.17	1.08	5.31	0.90	4.23	1.48	5.87	0.37	3.20	1.14	7.07	1.94	4.18	1.35	5.37	0.10
P_2O_5	0.15	0.07	0.57	0.04	0.18	0.06	0.33	0.06	0.24	0.11	0.45	0.07	0.07	0.04	0.19	0.01
V	26.0	22.4	97	1.0	10.0	10.0	41	1.0	63.1	33.9	125	10.0	14.9	11.2	43	tr.
Cr	14.0	23.5	184	tr.	8.6	7.1	22	1.0	21.5	10.3	53	1.0	15.2	19.5	108	2.0
Co	6.5	6.5	30	tr.	8.6	9.5	40	tr.	10.0	7.8	34	1.0	5.5	7.6	33	1.0
Ni	6.1	12.9	83	tr.	6.2	5.7	29	1.0	5.7	5.0	27	tr.	4.4	6.4	33	tr.
Zn	43.6	27.2	139	2.0	37.7	16.1	78	14.0	66.2	27.7	114	15.0	49.9	23.3	110	9.0
Rb	103.0	39.2	233	24.0	400.7	179.3	868	173.0	86.1	23.6	159	58.0	185.4	65.9	277	6.0
Sr	300.5	219.0	1056	10.0	24.8	15.4	82	7.0	599.2	242.8	906	81.0	74.8	65.4	344	10.0
Zr	113.1	60.6	272	18.0	82.8	47.5	214	26.0	185.6	79.1	309	46.0	241.7	132.2	649	64.0
Nb	8.1	2.9	18	1.0	11.2	4.0	18	1.0	11.1	4.4	21	5.0	15.1	3.8	26	9.0
Ba	693.4	399.0	2469	32.0	120.7	84.0	310	29.0	1100	365.2	2146	455.0	479.1	312.6	1294	29.0
Nd	22.7	12.5	53	tr.	12.4	10.2	41	0.0	37.8	17.8	85	5.0	38.6	17.9	84	3.0
Th	8.2	6.2	42	tr.	19.2	17.7	95	8.0	11.2	6.3	35	4.0	19.4	7.5	52	10.0
U	2.5	1.7	8	tr.	20.5	62.2	298	2.0	4.1	2.9	14	tr.	3.4	2.2	8	tr.
Y	12.00	6.05	31.07	3.91	20.27	7.20	30.77	8.12	14.70	7.95	37.02	2.79	38.90	27.81	157.59	15.34
Nb	8.00	3.52	21.96	1.22	14.30	4.29	22.32	6.69	10.88	5.14	25.40	3.56	16.41	5.61	32.74	2.86
La	23.34	12.99	70.91	0.84	9.37	6.26	25.35	2.60	40.90	18.92	86.91	12.96	38.28	20.27	78.84	4.81
Ce	48.00	25.60	126.98	1.58	22.06	14.39	55.55	6.82	84.58	39.84	179.40	22.90	81.00	42.15	175.60	9.10
Pr	5.52	2.87	13.09	0.18	2.64	1.58	6.77	0.88	9.45	4.90	19.32	1.09	9.69	5.25	21.33	1.87
Nd	20.73	10.63	47.55	0.50	9.96	6.04	26.04	3.17	37.02	17.84	70.73	10.46	37.30	20.65	84.29	8.54
Sm	4.03	1.78	8.66	0.19	2.81	1.27	6.14	1.27	6.43	3.01	13.56	2.34	8.12	5.05	26.57	2.66
Eu	0.80	0.35	1.87	0.02	0.19	0.17	0.68	0.02	1.43	0.68	3.19	0.46	0.97	0.63	2.92	0.03
Gd	3.15	1.36	7.52	0.19	2.90	1.15	5.64	1.28	4.53	2.20	10.36	1.57	7.58	5.69	32.46	2.36
Tb	0.45	0.19	1.18	0.07	0.59	0.18	0.94	0.30	0.58	0.29	1.42	0.14	1.21	0.92	5.26	0.42
Dy	2.44	1.15	6.56	0.67	3.87	1.23	5.76	1.73	3.04	1.57	7.57	0.62	7.49	5.38	30.48	2.87
Ho	0.44	0.22	1.22	0.13	0.71	0.28	1.14	0.24	0.55	0.29	1.40	0.10	1.49	1.07	5.97	0.54
Er	1.16	0.63	3.41	0.31	2.04	0.93	3.41	0.62	1.47	0.84	3.81	0.30	4.33	2.91	15.91	1.55
Tm	0.16	0.09	0.52	0.02	0.31	0.15	0.54	0.09	0.21	0.13	0.55	0.05	0.63	0.37	1.81	0.23
Yb	1.00	0.57	3.42	0.04	2.02	1.02	3.38	0.55	1.31	0.80	3.51	0.36	4.17	2.23	11.82	1.56
Lu	0.15	0.08	0.51	0.05	0.28	0.16	0.51	0.06	0.19	0.11	0.50	0.07	0.63	0.33	1.76	0.21
Hf	2.99	1.38	6.46	0.48	2.00	0.83	4.74	1.21	4.69	1.80	7.42	1.46	5.27	2.23	11.60	1.85
Ta	0.73	0.43	2.03	0.10	2.67	1.24	5.46	1.19	0.74	0.38	1.50	0.23	1.33	0.45	3.06	0.57
Th	8.35	6.06	42.36	0.56	10.72	2.72	18.64	7.21	11.69	6.01	35.04	3.79	17.59	7.55	51.03	6.16

firstly discussed by Petrík et al. (1994), and the A-type granites by Uher & Broska (1996). In addition, we propose a modified outline of the genesis of all four principal Variscan granitic groups in the Western Carpathians, subdivided according to the presented mineralogical and geochemical criteria (Fig. 14). Early Carboniferous continental collision, which in generally operated in the European Variscides (Matte 1986; Finger & Steyrer 1990; von Raumer & Neubauer 1993; Stampfli 1996 among others), led to crustal thickening along thrusting planes, formation of the Variscan nappes and partial melting of the lower crust in the zone of contraction of the lithospheric slab. After subduction of oceanic crust along destructive active plate margins (Stampfli 1996), the lower density of the continental crust, which is buoyant and remains on the upper surface of the lithosphere, led to thickening of the collided continents and crust (Fig. 14A). Emplacement of the S-type granite, which originated mainly from the metagreywacke protoliths (Petrík 2000) as well as granites with transitional features between the S- and I-type group probably from the amphibolite-bearing lower crust (Kohút et al. 1999b), occurred in the extension zones, which occur locally in the framework of the continental collision (Schaltegger 1997) or in the upper part of the flexures of the lithosphere plate (Fig. 14A) (c.f. Coward 1994). A local extension zone is indicated for example by the presence of laccolith (Lexa & Bezák 1996) but also by the sheet-like shape of the emplaced plutons (Kohút & Janák 1994). However, the numerous pegmatites accompanying the S-type granites in the Western Carpathians show the general collisional (compression) conditions. On the other hand, post-collisional tectonics associated with the gravitational instability of thickening lithosphere started the process of thinning of the lithosphere and extensional regime, which resulted in the production of the I-type granites with lesser pegmatite formation in the region. The origin of the I-type granites show the distinct influence of the mantle or infracrustal contribution and process of their melting was triggered by heating of the crust due to the underplated mafic lithospheric mantle melt (Fig. 14B) which was primarily activated by previous detaching of the oceanic slab and its injection into the mantle (Fig. 14A). Uplift into a vertical tectonic extensional fault system is followed by formation of larger batholiths (Hutton 1987) in the middle crust which is observed mainly in the Veporic Superunit. The thermal influence of the huge chambers of I-type granite melts in the middle crust also caused the partial melting of the middle crust and origin of a new generation of the S-type granite (Hraško et al. 2000). The S- and I-type granite can be regarded as orogenic granites. In contrast, the A-type granites which were formed in the Pangaea continent (Late Paleozoic to Mesozoic supercontinent — see e.g. Johansson 2000) belong already to post-orogenic granite suites which are typically distributed in European Variscan terrain along the strike-slip lineaments and faults in the crust (Bonin 1990) (Fig. 14C). The process of A-type granites formation is associated with melting of granitic sources (Petrík 2000) and emplaced during extension and transtension regime. The specialized S-type granites (S_S-type), which occurred in the same period as the A-type granites, were probably melted from the muscovite metapelites (Petrík 2000) in the middle crust and during continuation of the thermal event caused by underplated mafic melts, which, through deep rifts to the mantle, also formed numerous volcanic extrusions in the Permian or Permian–Triassic age (Fig. 14C). The rifting process, which opened the Meliata-Hallstadt ocean in Triassic, could have been a thermal source for melting of the middle crust.

Conclusions

The results presented generally support the subdivision of the Variscan West-Carpathian granites into four genetic geochemical groups based on older mineralogical, geochemical and isotope data.

The S-type group exhibits typical features of orogen-related crustal granites with a relatively wide span of fractionation level. The I-type group represents relatively poorly evolved rocks enriched in compatible elements such as Ba, Sr, Zr and REE's with a possible contribution of mantle material during their origin. The A-type group represents a specific post-orogenic hot and dry granite with a relatively high fractionation level rich in compatible (REE, Y, Zr) as well as alkali elements (K, Rb). The S_S-type group belongs to the highly-evolved B, Sn peraluminous and P-enriched suite with rare-element specialization (high Si, K, Ta, Sn, F, Rb, Nb). The different character of these principal granite groups in the Western Carpathians is reflected in their geotectonic positions. The S- and I-type granites as representatives of the orogenic granites are directly connected with collisional and extensional regime during/after continent collission with a various contribution of mantle lithospheric melt especially in the post-collisional tectonics. On the other hand, the A- and S_S granite types formed in post-orogenic conditions.

Finally, the major and trace-element geochemistry together with the accessory mineral paragenesis clearly document a complex and long history of Variscan granite origin in the West-Carpathian area from early-orogenic to post-orogenic stages and it could contribute to the understanding of such evolution in analogous orogenic belts.

Acknowledgements: The work was supported by NSERC Research Grant and a Major Installation Grant to P. Černý, Univ. of Manitoba, Winnipeg, Canada, during Post-Doctoral Fellowship of P. U. in Canada. The evaluation of the samples was financed by VEGA Grant #7074. The authors thank to M. Kohút and I. Petrík for providing some samples for fruitful discussion which improved the early version of the manuscript. We are also grateful to D. Plašienka and W.E. Stephens for their comments and to L. Zahradník for his assistance with PC. The paper is a contribution to the UNESCO "International Geological Correlation Project #373" headed by R. Seltmann.

References

Bibikova E.V., Korikovsky S.P., Putiš M., Broska I., Goltzman Z.V. & Arakeliants M.M. 1990: U-Pb, Rb-Sr and K-Ar dating of Sihla tonalites of Vepor pluton (West Carpathian Mts.). *Geol. Zbor. Geol. Carpath.* 41, 427–436.

Breiter K. 1998: Geochemical evolution of P-rich granite suites: Evidence from Bohemian massif. *Acta Univ. Carol. Geol.* 42, 7–19.

Bonin B. 1990: From orogenic to anorogenic settings: evolution of granitoid suites after a major orogenesis. *Geol. J.* 25, 261–270.

Broska I. & Uher P. 1991: Regional typology of zircon and their relationship to allanite-monazite antagonism (on example of Hercynian granitoids of the Western Carpathians). *Geol. Carpathica* 42, 271–277.

Broska I. & Gregor T. 1992: Allanite-magnetite and monazite-ilmenite granitoid series in the Tríbeč Mts. In: Vozár J. (Ed.): Western Carpathians, Eastern Alps, Dinarides. *Spec. Vol. IGCP 276, Dionýz Štúr Institute of Geology Publ.,* Bratislava, 25–37.

Broska I. & Petrík I. 1993: Magmatic enclaves in granitoid rocks of the Western Carpathians. *Miner. Slovaca* 25, 104–108 (in Slovak with English summary).

Broska I., Bibikova E.V., Gracheva T.V., Makarov V.A. & Caňo F. 1990: Zircon from granitoid rocks of the Tribeč-Zobor crystalline complex: its typology, chemical and isotopic composition. *Geol. Zbor. Geol. Carpath.* 41, 393–406.

Broska I., Dikov Y.P., Čelková A. & Mokhov A.V. 1992: Dusky apatite from the Variscan granitoids of the Western Carpathians. *Geol. Carpathica* 43, 195–198.

Cambel B. & Petrík I. 1982: The West Carpathian I/S classification and genetic implications. *Geol. Zbor. Geol. Carpath.* 33, 255–267.

Cambel B. & Vilinovič V. 1987: Geochemistry and petrology of the granitoid rocks of the Malé Karpaty Mts. *Veda,* Bratislava 1–247 (in Slovak with English summary).

Cambel B. & Vilinovičová Ľ. 1981: Petrochemistry and geochemistry of selected granitoid samples from the West Carpathian region. *Geol. Zbor. Geol. Carpath.* 32, 517–546.

Cambel B. & Walzel E. 1982: Chemical analyses of granitoids of the Western Carpathians. *Geol. Zbor. Geol. Carpath.* 33, 573–600.

Cambel B., Kráľ J. & Burchart J. 1990: Isotopic geochronology of the West Carpathian crystalline complex with catalogue of data. *Veda,* Bratislava, 1–183 (in Slovak with English summary).

Cambel B., Petrík I. & Vilinovič V. 1985: Variscan granitoids of the Western Carpathians in the light of geochemical-petrochemical study. *Geol. Zbor. Geol. Carpath.* 36, 204–218.

Coward M. 1994: Continental collision. In: Hancock P.L. (Ed.): Continental deformation. *Pergamon Press,* 264–287.

Chappell B.W. & White A.J.R. 1974: Two contrasting granite groups. *Pacif. Geol.* 8, 173–174.

Chovan M. & Határ J. 1978: Accessory minerals of some rock types of Veporic crystalline. *Miner. Slovaca* 45, 187–212 (in Slovak with English summary).

Debon F. & Le Fort P. 1983: A chemical-mineralogical classification of common plutonic rocks and associations. *Trans. Roy. Soc. Edinburgh Earth Sci*. 73, 135–149.

El Bouseily A.M. & El Sokkary A.A. 1975: The relation between Rb, Ba and Sr in granitic rocks. *Chem. Geol.* 16, 207–219.

Faryad W. & Dianiška I. 1993: Garnets from granitoids of the Spišsko-Gemerské Rudohorie Mts. *Geol. Carpathica* 40, 715–734.

Finger F., Frasl G., Haunschmid B., Lettner H., Schermeier A., Schindlmaier A.O., Steyrer H.P. & von Quadt A. 1993: The Zentralgneisse of the Tauern Window (Eastern Alps) — insight into an intra-Alpine Variscan batholite. In: von Raumer J. & Neubauer F. (Eds.): Pre-Mesozoic geology in the Alps. *Springer Verlag,* Berlin, 375–391.

Finger F. & Steyer H.P. 1990: I-type granitoids as indicators of a late Paleozoic convergent ocean-continent margin along the southern flank of the central European Variscan orogen. *Geology* 18, 1207–1210.

Finger F. & Broska I. 1999: The gemeric S-type granites in southeastern Slovakia: Late Palaeozoic or Alpine intrusion? Evidence from the electron-microprobe dating of monazite. *Schweiz. Mineral. Petrogr. Mitt.* 79, 439–443.

Grecula P. (Ed.) 1995: Mineral deposits of the Slovak Ore Mountains Volume 1. *Geocomplex*, Bratislava, 1–834.

Henderson P. 1996: The rare earth elements: introduction and review. In: Jones A.P., Wall F. & Williams C. T. (Eds.): Rare earth minerals: chemistry, origin and ore deposits. *Chapman & Hall,* Bodmin, 1–19.

Hovorka D. & Hvožďara P. 1965: Accessory minerals of Veporid granitoid rocks. *Acta Geol. Geogr. Univ. Comen. Geol.* 9, 145–179 (in Slovak with English summary).

Hovorka D. & Petrík I. 1992: Variscan granitic bodies of the Western Carpathians — the backbone of the mountain chain. In: Vozár J. (Ed.): The Palaeozoic geodynamic domains of the Western Carpathians, Eastern Alps and Dinarides. *Spec. Vol. IGCP 276,* Bratislava, 57–66.

Hraško Ľ., Broska I. & Bezák V. 2000: Upper Carboniferous granitoid stage in the Veporic Unit (Western Carpathians): transition from I- to S-type magmatic event. *Slovak Geol. Mag.* 6, 431–440.

Hutton D.H.W. 1987: Granite emplacement mechanism and tectonic controls: inferences from deformation studies. *Trans. Roy. Soc. Edinburgh Earth Sci.* 245–255.

Hvožďara P. 1979: Accessory and prospective minerals of Veporic crystalline rocks. In: Petrogenesis and geochemistry of geological processes. *Veda Publ.,* Bratislava, 209–214 (in Slovak with English summary).

Jacko S. & Petrík I. 1987: Petrology of the Čierna Hora Mts. granitoid rocks. *Geol. Zbor. Geol. Carpath.* 38, 515–544.

Jakabská K. & Rozložník L. 1989: Zircons of Gemeric granites (Western Carpathians — Czechoslovakia). *Geol. Zbor. Geol. Carpath.* 40, 141–159.

Jenner G.A., Longerich H.P., Jackson S.E. & Fryer B.J. 1990: ICP-MS — A powerfull tool for high-precision trace-element analysis in Earth sciences: Evidence from analysis of selected U.S.G.S. reference samples. *Chem. Geol.* 83, 133, 148.

Johansson A. 2000: Midgardia — a new name for the Mesoproterozoic supercontinent. *European Geologist* 15–17.

Klomínský J., Palivcová M., Cambel B. & Gurbanov A.G. 1981: Petrochemical correlation and I/S classification of Variscan granitoids from the Czech massif, Western Carpathians (Czechoslovakia), and the Caucasus Mts. (USSR). *Geol. Zbor. Geol. Carpath.* 32, 307–315.

Kohút M. 1992: The Veľká Fatra granitoid pluton — an example of a Variscan zoned body in the Western Carpathians. In: Vozár J. (Ed.): The Paleozoic geodynamic domains of the Western Carpathians, Eastern Alps and Dinarides. *Spec. Vol. IGCP 276, Dionýz Štúr Institute of Geology Publ.*, Bratislava, 79–92.

Kohút M. & Janák M. 1994: Granitoids of the Tatra Mts., Western Carpathians: field relations and petrogenetic implications. *Geol. Carpathica* 45, 301–311.

Kohút M., Kotov A.B., Salnikova E.B., Kovach V.P. & Michalko J. 1995: Hercynian granitic rocks of the Western Carpathians: Products of crustal reactivation. In: The origin of granites and related rocks. Third Hutton symposium Abstracts. *US Geol. Surv. Circ.* 81–82.

Kohút M. & Nabelek P.I. 1996: Sources of the Veľká Fatra granitoid rocks, Slovakia: Isotopic constraints or crustal reactivation. *Pol. Miner. Soc. Spec. Pap.* 7, 47–50.

Kohút M., Kovach V.P., Kotov A.B., Salnikova E.B. & Savatenkov V.M. 1999a: Sr and Nd isotope geochemistry of Hercynian granitic rocks from the Western Carpathians — implications for granite genesis and crustal evolution. *Geol. Carpathica* 50, 477–487.

Kohút M., Poller U., Todt W., Nabelek P. & Janák M. 1999b: Na-rich and High-Al granitoid magma in the Tatra Mts. (Western Carpathians, Slovakia) — melting of the amphibolitic lower crust. *Geol. Carpathica*, *Spec. Issue* 50, 107–108.

Kovách A., Svingor E. & Grecula P. 1986: Rb-Sr isotopic ages of granitoids from the Spišsko-Gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia. *Miner. Slovaca* 18, 1–14.

Kráľ J., Hess J.C., Kober B. & Lippolt H.J. 1997: $^{207}Pb/^{206}Pb$ and $^{40}Ar/^{39}Ar$ age data from plutonic rocks of the Strážovské vrchy Mts. basement, Western Carpathians. In: Grecula P. et al. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca Monograph* 253–260.

Krist E., Korikovsky S.P., Putiš M., Janák M. & Faryad W. 1992: Geology and petrology of metamorphic rocks of the Western Carpathians crystalline complex. *Comenius Univ. Publ.*, Bratislava, 1–324.

Lexa O. & Bezák V. 1996: Porhyric granitoids in the western part of Slovenské rudohorie Mts.: Emplacement and deformation in shear zones. *Slovak Geol. Mag.* 3–4, 189–197.

London D. 1992: Phosphorus in S-type magmas: the P_2O_5 content of feldspars from peraluminous granites, pegmatites, and rhyolites. *Amer. Mineralogist* 77, 126–145.

London D. 1998: Phosphorus-rich peraluminous granites. *Acta Univ. Carol. Geol.* 42, 64–68.

Longerich H.P., Jenner G.A., Fryer B.J. & Jackson S.E. 1990: Inductively coupled plasma-mass spectrometric analysis of geological samples: A critical evaluation based on case studies. *Chem. Geol.* 83, 105–118.

Macek J., Cambel B., Kamenický L. & Petrík I. 1982: Documentation and basic characteristics of granitoid rock samples of the Western Carpathians. *Geol. Zbor. Geol. Carpath*. 33, 601–621.

Matte Ph. 1986: Tectonics and Plate tectonics model for the Variscan belt of Europe. *Tectonophysics* 196, 309–337.

Matějka D. & Janoušek V. 1998: Whole-rock geochemistry and petrogenesis of granites from the northern part of the Moldanubian Batholith (Czech Republic). *Acta Univ. Carol. Geol*. 41, 73–79.

Mielke P. & Winkler G.F. 1979: Eine bessere Berechnung der Mesonorm für granitische Gesteine. *Neu. Jb. Miner. Mh.* H10,

471–480.
Michalko J., Bezák V., Kráľ J., Huhma H., Mäntäri I., Vaasjoki M., Broska I., Hraško Ľ. & Határ J. 1998: U/Pb zircon data from the Veporic granitoids (Western Carpathians). *Krystalinikum* 24, 91–104.
Petrík I. 1980: Biotite from the granitoid rocks of the Western Carpathians and their petrogenetic importance. *Geol. Zbor. Geol. Carpath.* 31, 215–230.
Petrík I. 1982a: Selected samples of the West Carpathian granitoids: classification and modal composition. *Geol. Zbor. Geol. Carpath.* 33, 569–572.
Petrík I. 1982b: The position of biotite in granitoid rocks of the Small Carpathian Mts. and its relation to their genesis. In: Cambel (Ed.): Symposium on geochemistry of endogenous and exogenous processes. *Veda Publ.,* Bratislava, 96–105.
Petrík I. 2000: Multiple sources of the West Carpathian Variscan granitoids: a review of Rb/Sr and Sm/Nd data. *Geol. Carpathica* 51, 3, 145–158.
Petrík I. & Broska I. 1994: Petrology of two granite types from the Tribeč Mountains, Western Carpathians: an example of allanite (+magnetite) versus monazite dichotomy. *Geol. J.* 29, 59–78.
Petrík I. & Kohút M. 1997: The evolution of granitoid magmatism during the Hercynian orogen in the Western Carpathians. In: Grecula P. et al. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca Monograph* 235–252.
Petrík I., Broska I. & Uher P. 1994: Evolution of the West Carpathian granite magmatism: source rock, geotectonic setting and relation to the Variscan structure. *Geol. Carpathica* 45, 283–291.
Pichavant M., Montel J.M. & Richard L.R. 1992: Apatite solubility in peraluminious liquids: Experimental data and an extension of the Harrison-Watson model. *Geochim. Cosmochim. Acta* 56, 3855–3861.
Plašienka D., Grecula P., Putiš M., Hovorka D. & Kováč M. 1997: Evolution and structure of the Western Carpathians: an overview. In: Grecula et al. (Eds.): Geological evolution of the Western Carpathians. *Miner. Slovaca Monograph* 1–24.
Poller U., Broska I., Finger F., Uher P. & Janák M. 2000: Permian age of gemeric granites constrained by single EMPA monazite dating. *Miner. Slovaca* 32, 189–190.
Poller U., Janák M., Kohút M. & Todt W. 2000: Early Variscan in the Western Carpathians: U/Pb zircon data from granitoids and orthogneisses of the Tatra Mountains (Slovakia). *Int. J. Earth Sci.* 89, 336–349.
Puchelt H. & Emmermann R. 1976: Bearing of rare earth patterns of apatites from igneous and metamorphic rocks. *Earth. Planet. Sci. Lett.* 31, 279–286.
Pupin J.P. 1980: Zircon and granite petrology. *Contr. Mineral. Petrology* 73, 207–220.
Pupin J.P. 1992: Les zircons des granites océaniques et continentaux: couplage typologie-géochimie des éléments en traces. *Bull. Soc. Géol. France* 193, 495–507.
Putiš M., Kotov A.B., Uher P., Salnikova E.B. & Korikovsky S.P. 2000: Triassic age of the Hrončok pre-orogenic A-type granite related to continental rifting: a new result of U-Pb isotope dating (Western Carpathians). *Geol. Carpathica* 51, 56–66.
Sha L.K. & Chappell B.W. 1999: Apatite chemical composition, determined by electron microprobe and laser-ablation inductively coupled plasma mass spectrometry, as a probe into granite petrogenesis. *Geochim. Cosmochim. Acta* 63, 3861–3881.
Schaltegger U. 2000: Magma pulses in the Central Variscan Belt: episodic melt generation and emplacement during lithospheric thinning. *Terra Nova* 9, 242–245.
Schermaier A., Haunschmid B. & Finger F. 1997: Distribution of Variscan I- and S-type granites in the Eastern Alps: a possible clue to unravel pre-Alpine basement structure. *Tectonophysics* 272, 315–333.
Stampfli G.M. 1996: The Intra-Alpine terrain: A Paleothethyan remnant in the Alpine Variscides. *Eclogae Geol. Helv*. 89, 13–42.
Streckeisen A. & Le Maitre R.W. 1979: A chemical approximation to the modal QAPF classification of the igneous rocks. *Neu. Jb. Mineral. Abh.* 136, 2, 169–206.
Uher P. & Broska I. 1996: Post-orogenic Permian granitic rocks in the West Carpathian-Pannonian area: geochemistry, mineralogy and evolution. *Geol. Carpathica* 47, 311–321.
Uher P. & Broska I. 2000: The role of silicic magmatism in the Western Carpathians: from Variscan collision to Early-Alpine extension. *Slovak Geol. Mag.* 6, 2–3, 278–280.
Uher P. & Gregor T. 1992: The Turčok granite — a product of postorogenic magmatism of A-type. *Miner. Slovaca* 24, 301–304 (in Slovak with English summary).
Uher P. & Puskharev Yu. 1994: Granitic pebbles of the Cretaceous flysch of the Pieniny Klippen belt, Western Carpathians: U/Pb zircon ages. *Geol. Carpathica* 45, 375–378.
Uher P., Marschalko R., Martiny E., Puškelová Ľ., Streško V., Toman B. & Walzel E. 1994: Geochemical characterization of granitic rock pebbles from Cretaceous to Paleogene flysh of the Pieniny Klippen Belt. *Geol. Carpathica* 45, 171–183.
Vilinovičová Ľ. 1989: K-feldspars of the granitoid rocks from the Strážovské vrchy crystalline complex. *Geol. Zbor. Geol. Carpath*. 40, 5, 599–620.
von Raumer J.F. & Neubauer F. 1993: Late Proterozoic and Paleozoic evolution of the Alpine basement — an overview. In: von Raumer J.F. & Neubauer F. (Eds.): Pre-Mesozoic Geology of Alps. *Springer,* Berlin, Heidelberg, New York, 625–639.
Wark D.A. & Miller C.F. 1993: Accessory mineral behavior during differentiation of a granite suite: monazite, xenotime and zircon in the Sweetwater Wash pluton, southeastern California, U.S.A. *Chem. Geol.* 110, 49–67.
Whalen J.B., Currie K.L. & Chappell B.W. 1987: A-type granites: geochemical characteristics discrimination and petrogenesis. *Contr. Mineral. Petrology* 95, 407–419.
Yates A.N., Wyatt B.W. & Tucker D.H. 1982: Application of gamma-ray spectrometry to prospecting for tin and tungsten granites, particularly within the Lachlan Fold Belt, New South Wales. *Econ. Geol.* 77, 1725–1738.