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# The role of silicic magmatism in the Western Carpathians: from Variscan collision to Early-Alpine extension

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*Abstract:* Silicic (mainly granitic and rhyolitic) magmatism played an important role during whole Variscan to Early-Alpine time from Devonian early-orogenic to Triassic post-orogenic evolution. The oldest magmatic collisional transpression stages produced (1) Early-Variscan (~410–380 Ma) S-type orthogneisses, followed by (2) Meso-Variscan (~370–340 Ma) S- to I-type granites to tonalites and pegmatites. (3) Late-Variscan (~310–290 Ma) I-type tonalites to granodiorites represent a final Variscan stage. The collisional orogenic regime gradually changed to transtensional – extensional post-orogenic conditions with production of (4) Post-Variscan (~280–250 Ma) mainly A-type granites, granite porphyries and rhyolites-rhyodacites, and rare-element S-type leucogranites to granite porphyries up to final (5) Early-Alpine (~250–235 Ma) A-type leucogranites and rhyolites.

*Key words:* Western Carpathians, granites, rhyolites, Variscan orogeny, Alpine orogeny.

## Introduction

After first summarizing of a Variscan granite knowledge in the Western Carpathians (e. g. Cambel 1980, Hovorka, 1980), a plenty of data were gathered during the past 20 years which shed a new light on their origin. The recent data concerning Upper Paleozoic to Triassic acid volcanic rocks are still scarce (e. g. Broska et al., 1993, Vozár, 1997). Although genetic subdivision, mineralogy, geochemistry, protolith and petrogenetic aspects of Variscan granitic rocks were investigated in numerous papers (e. g. Cambel & Walzel, 1982; Petrík et al., 1994; Uher & Broska, 1996; Petrík & Kohút, 1997; Petrík, 2000), the tectonic aspects of these processes were`t fully appreciated, and only possible granite position in Variscan nappes was examined (e. g. Bezák et al., 1997). The aim of this review is a first attempt to categorize the West-Carpathian silicic magmatism (including volcanic rocks) into frame of Variscan to Early Alpine tectonic development stages and to show the main changes of their evolution on the basis of recent knowledge.

## Evolutionary stages of silicic magmatism

**(1) Early-Variscan (Devonian, ~410–380 Ma) S-type metagranites (orthogneisses)** occur in the Nízke Tatry Mts. (e. g. Struhár orthogneiss – Bezák & Klinec, 1980), Západné Tatry Mts., Veľká Fatra Mts. and Považský Inovec Mts. (the Tatric Superunit), as well as in the Veporic Superunit, mainly Ľubietová (Kamenický, 1982) and Muráň orthogneisses (Hovorka et al., 1987). The rocks are represented by muscovite-biotite metagranites, locally with K-feldspar phenocrysts, they often show a distinct schistosity and a presence of sillimanite, locally also garnet and kyanite due to Meso-Variscan medium- to high-grade metamorphic overprint. The orthogneisses, especially with banded metamorphic texture, were partly interpreted as migmatites and paragneisses (e. g. Zoubek, 1951; Krist et al., 1992), however Ba distribution in K-feldspar and zircon morphology indicate magmatic origin of the rocks (Nízke Tatry Mts., Petrík & Kohút, 1997). Geochemistry of the rocks, Al-Fe-rich biotite composition, zircon typology (I. T<300) and monazite-(Ce) indicate their peraluminous calc-alkaline S-type character (Petrík & Kohút, 1997). Recent U-Pb single zircon dating of the West-Tatra orthogenisses yielded ~405 Ma age for Early-Variscan magmatic crystallization and ~360 Ma for Meso-Variscan metamorphic overprint (Poller et al., 2000).

**(2) Meso-Variscan (Late Devonian to Lower Carboniferous, ~370–340 Ma) S- to I-type granites to (leuco)tonalites** represent a main Variscan magmatic stage with producing large volume of orogenic granitic rocks. Two basic petrogenetic group could be distinguished (e. g. Broska & Uher, 1991; Hovorka & Petrík, 1992; Petrík & Broska, 1994; Petrík et al., 1994; Uher & Broska, 1995): (i) S-type monazite-ilmenite-bearing two-mica granites, rarely leucotonalites to granodiorites and (ii) I-type allanite-magnetite-bearing biotite tonalites to granodiorites. Formerly, the (ii) group was understanding more broadly for all Variscan I-type allanite-magnetite-bearing granitic rocks (Sihla type sensu lato, Broska & Petrík, 1993a) related to Upper Carboniferous subduction (e. g. Petrík et al., 1994). Based on isotope dating, now we recognize two distinct generations of I-type granitic rocks: older, Meso-Variscan and younger, Late-Variscan (= Sihla s. s.) ones.

(i) Meso-Variscan monazite-ilmenite granites occur mainly in mountains of Tatric Superunit: Malé Karpaty (Bratislava Massif), Považský Inovec, Suchý & Malá Magura, Žiar, Veľká Fatra, partly in the Tribeč, Malá Fatra, Branisko, Nízke and Vysoké Tatry; rarely in the

Veporic Superunit: Rimavica pluton. The (i) group is characterized by S-type peraluminous calc-alkaline compositions depleted in Mg, Ca, Sr, Ba, Zr, REE`s and Cr. Monazite-(Ce), ilmenite, zircon (I. T<350), dusky apatite, almandine and xenotime-(Y) belong to typical accessory phases; they indicate lower-temperature and reducing conditions during magma solidification (e. g. Petrík et al., 1994). Granitic pegmatites, locally with beryl and Ti-poor Nb-Ta minerals (columbite group, ferrotapiolite), are widespread (Uher et al., 1994; Uher & Broska, 1995). U-Pb zircon isotope dating gave ~370–350 Ma ages (Bibikova et al., 1988; Kohút et al., 1997; Kráľ et al., 1997; Bezák et al. 1999, Poller et al., 1999, 2000).

(ii) Meso-Variscan allanite-magnetite-bearing granites occur in Tatric Superunit (Modra Massif of Malé Karpaty Mts., Malá Fatra Mts., Nízke and Vysoké Tatry Mts.) and also in the Veporic Superunit (the Kráľova Hoľa Complex). The (ii) granites show I-type metaluminous to peraluminous calc-alkaline chemistry elevated in Ca, Mg, Ti, Sr, Ba, Zr, REE`s and Cr in comparison to the (i) group. Allanite-(Ce), magnetite, zircon (I. T>350), apatite, titanite and epidote documented higher-temperature, water-rich and high oxygen fugacity ($fO_2$) regime during magma crystallization (Petrík et al., 1994, Petrík & Kohút, 1997). Mafic fine-grained dioritic enclaves are locally widespread (Broska & Petrík, 1993b). Granitic pegmatites are rare, locally with beryl and Ti-rich Nb-Ta-phases (Uher & Broska, 1995, Uher et al., 1998). U-Pb isotope zircon and EMPA monazite dating yielded ~360–340 Ma (Michalko et al., 1998; our unpubl. data).

**(3) Late-Variscan (Upper Carboniferous, ~310–290 Ma) calc-alkaline I-type tonalites to granodiorites** occur as equigranular Sihla s.s. and porphyric Vepor types in the Veporic Superunit (Vepor and Čierna Hora Mts.) as well as in S-E part of the Tatric Superunit (Tribeč Mts.). A composition and mineral assemblage of (3) are analogous to the Meso-Variscan allanite-magnetite granites, the mafic magmatic enclaves are also widespread (Broska & Petrík, 1993a, b). Nevertheless, the zircon U-Pb ages are distinctly younger, ~300 Ma (Broska et al., 1990; Bibikova et al., 1990; Michalko et al., 1998).

**(4) Post-Variscan (Permian, ~280-250 Ma) mainly A-type granites, granite porphyries and rhyolites-rhyodacites and rare-element S-type leucogranites and granite porphyries** represent small intrusions, dykes and lava flows which occur through whole West-Carpathian area (Tatric, Veporic, Gemeric and Zemplinic Superunits).

(i) A-type magmatites appear as peraluminous biotite (annite-rich) leucogranites to granite porphyries enriched in Si, K, Rb, Ga, Zr, REE`s and Nb; they are hypersolvus-transsolvus (Turčok, Upohlav) to subsolvus (Velence); allanite-(Ce) or monazite-(Ce), magnetite and/or ilmenite and zircon (I. T = 800–400) show a broad temperature and $fO_2$ variability of the group (Uher & Broska, 1996). Volcanic members reveal transitional calc-alkaline (Harnobis rhyodacites) to alkaline trend (e. g. Malé Karpaty and Gemeric rhyolites) documented by zircon typology (Broska et al., 1993). Lower Permian age (~280 Ma) of the Upohlav granite is documented by U-Pb zircon isotope dating (Uher & Pushkarev, 1994).

(ii) Rare-element Sn-bearing specialized leucogranites to granite porphyries of the Spiš-Gemer type show peraluminous trend with elevated Si, Al, K, Na, P, Rb, Cs, B, Sn, Nb, Ta, F and strongly depleted in Ca, Mg, REE`s and Zr (Uher & Broska, 1996). These tourmaline-bearing granites with cassiterite, topaz and Nb-Ta-W-phases in greisen- and albitite-bearing cupolas (Dlhá Valley, Hnilec) originated from matured crustal protolith ($I_{sr}$ < 0.710) by evolved fractional crystallization at low temperature and $fO_2$ conditions. U-Th-Pb EMPA monazite as well as U-Pb single zircon dating clearly evidence their Permian age (~275 to 250 Ma, Finger & Broska, 1999; Poller et al., 2000).

**(5) Early-Alpine (Early to Middle Triassic, ~250–235 Ma) A-type leucogranites and K-rich rhyolites** were recognised only recently (Putiš et al., 2000; Uher et al., in prep.), however small occurrences of "quartz porphyries" in Triassic carbonate sequences were known before (e. g. Zorkovský, 1959; Slavkay, 1965). The group represents Hrončok granite in the Veporic Superunit (suggested formerly as Permian intrusion, Petrík et al., 1995) and rhyolites in the Silicic Superunit (Drienka, Telgárt, Veľká Složka). Composition and accessory phases (monazite-(Ce), zircon: I. A~700, I. T < 300) indicate alkaline, lower temperature conditions for the Hrončok granite (Petrík et al., 1995; Uher & Broska, 1996), whereas K-rich rhyolites solidified from hot and dry alkaline magma (zircon: I. A~700, I. T=700–800). Middle Triassic age of the Hrončok granite was detected by U-Pb zircon isotope dating (~240 Ma, Putiš et al., 2000).

## Concluding remarks

The character of silicic magmatism during the Early- and Meso-Variscan stages indicate origin in the relatively close system when the granite batholiths were emplaced in the depths under ~12–15 km and the numerous pegmatite differentiates are formed. Such conditions are resulted by the continental collision, whereas the problem of the batholith space could be understanding by feeding of the magma chamber by dykes under transpression regime (Clemens & Mawer, 1992). Transpression regime is suggested also for emplacement of Late-Variscan I-type granites (cf. Schalteger & Corfu, 1995, Schermaier et al., 1997). On the contrary, A-type granites and rhyolites and probably also rare-element S-type Spiš-Gemer granites originated on the strike-slipe lineaments under transtensional or extensional regime (Petrík et al., 1995) during Post-Variscan (Permian to Triassic) stages, connected with the devolatization of granites without pegmatite production as well as the formation of the hypoabyssal granite porphyries. Consequently, the compositional changes of West-Carpathian silicic magmatism through Variscan orogeny to Early-Alpine platform stages, from orogenic S- and I-type to post-orogenic mainly A-type magmatites, impressively reflected tectonic evolution of the region from Devonian to Carboniferous transpression period followed by Permian to Triassic transtension to extension regime.

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