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POST-OROGENIC PERMIAN GRANITIC ROCKS IN THE WESTERN CARPATHIAN-PANNONIAN AREA: GEOCHEMISTRY, MINERALOGY AND EVOLUTION

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Abstract: Small intrusions of post-orogenic Permian granites — POG (290-250 Ma; U-Pb and Rb-Sr ages) occur in the Western Carpathians (Slovakia) and Pannonian area (Hungary). Group (1) hypersolvus to subsolvus Turčok, Upohlav, Velence and Hrončok biotite (leuco)granites, microgranites and granite porphyries show A-type characteristics high Si, K, REE, Ga/Al, sometimes Na, Rb, Zr, Nb; low Ti, Mg, Ca, P, Ba, Sr and V contents. Group (2) Spiš-Gemer two-mica leucogranites and porphyries show the specialized S-type characteristics: high Si, K, Rb, Sn, B, F; and low Zr and REE. Data indicate highly temperature (solidus T~750 °C), dry (1-3 % H_2O), and variable oxygen fugacity of magma for group (1); and low temperature (T_s ~ 600-650 °C), low fO_2 and water + fluorine-rich magma for group (2). Emplacement pressure conditions for both groups were estimated at 2 kb for granites s.s. to 0.5-1.5 kb for porphyry and microgranite dikes. POG originated after Variscan orogeny in transtensional-extensional regime, probably from middle-lower crustal (meta)igneous protolith for group (1), and middle-upper crustal metasedimentary or mixed protolith for group (2).

Key words: Western Carpathians, Pannonian area, Permian, granitoids, geochemistry, biotite, zircon, accessory minerals.

Introduction

The differences of the Spiš-Gemer granites as compared with the main areas of Variscan Central Western Carpathian granitoids have been studied over several decades. The Sn-W-(Li-Nb-F) ore mineralization and ambiguous age determinations (Permian ? or Jurassic-Cretaceous ?) have been the subject of controversal discussion up to now (e.g. Kamenický & Kamenický 1955; Kantor 1957; Baran et al. 1970; Tauson et al. 1978; Grecula 1982; Kovách et al. 1986; Cambel et al. 1989). Similarly, much attention has been paid to the pebbles and boulders of exotic origin observed in Cretaceous-Paleogene flysch conglomerates of the Pieniny Klippen Belt (e.g. Zoubek 1931; Krivý 1969; Šímová 1985).

Many petrographic, geochemical and mineralogical data have been collected from the Velence Mts. granites in the Transdanubian Central Range, Hungary (e.g. Jantsky 1957; Buda 1969, 1985, 1993; Buda & Nagy 1995; Pantó 1975; Gbelský & Határ 1982). On the other hand, the Hrončok and especially the Turčok granites have received only limited attention due to the small size of their exposures and the strong tectonic deformation (e.g. Zoubek 1936;087Ončáková 1954; Cambel et al. 1961).

Only recent studies determined the characteristics about the above mentioned rocks as the Permian post-orogenic granites (POG); Uher & Gregor 1992, Uher & Marschalko 1993, Uher et al. 1994, Petrík et al. 1994, 1995, Uher & Broska 1995. This paper provides a brief summary of present knowledge and possible petrogenetic scenario for POG.

Occurrences

POG occur as several small massifs: Turčok, Velence, Hrončok and Spiš-Gemer granites, or only as pebbles or boulders in Cretaceous-Paleogene conglomerates, i.e. Upohlav granites (Fig. 1).

The Turčok Granite occurs as small, lenticular, strongly tectonized bodies near the northern boundary linking the Gemeric and the Veporic Units, 5 km SE from the town of Revúca. Host rocks are phyllites and metapsammites of the Silurian-Lower Devonian Gelnica group. Unfortunately, direct thermal contacts with the granites were not observed due to Alpine tectonic reworking of the exposures. Tectono-metamorphic overprint caused strong deformation of quartz and feldspars to form quartz II, chess-board albite and fine-grained muscovite.

The Upohlav type granitic rocks are found only as pebbles or boulders (1-150 cm in size) in marginal facies of Middle Cretaceous to Eocene wildflysch turbiditic sequences of Klape, Kysuca-Pieniny and Proč units, along more than 400 km distance of the Pieniny Klippen Belt suture (Marschalko 1986; Mišík et al. 1991). Primary source areas of these granitic as well as other "exotic" rocks (mainly carbonates, basalts, blueschists and clastic sediments) are unknown so far, and have provoked a lot of discussions (e.g. Mišík & Marschalko 1988).

The largest, ca. 15 × 7 km area, of post-orogenic granites is the Velence Mts. in Transdanubian Central Range, NW Hungary. Velence granites intruded Lower Paleozoic phyllites and

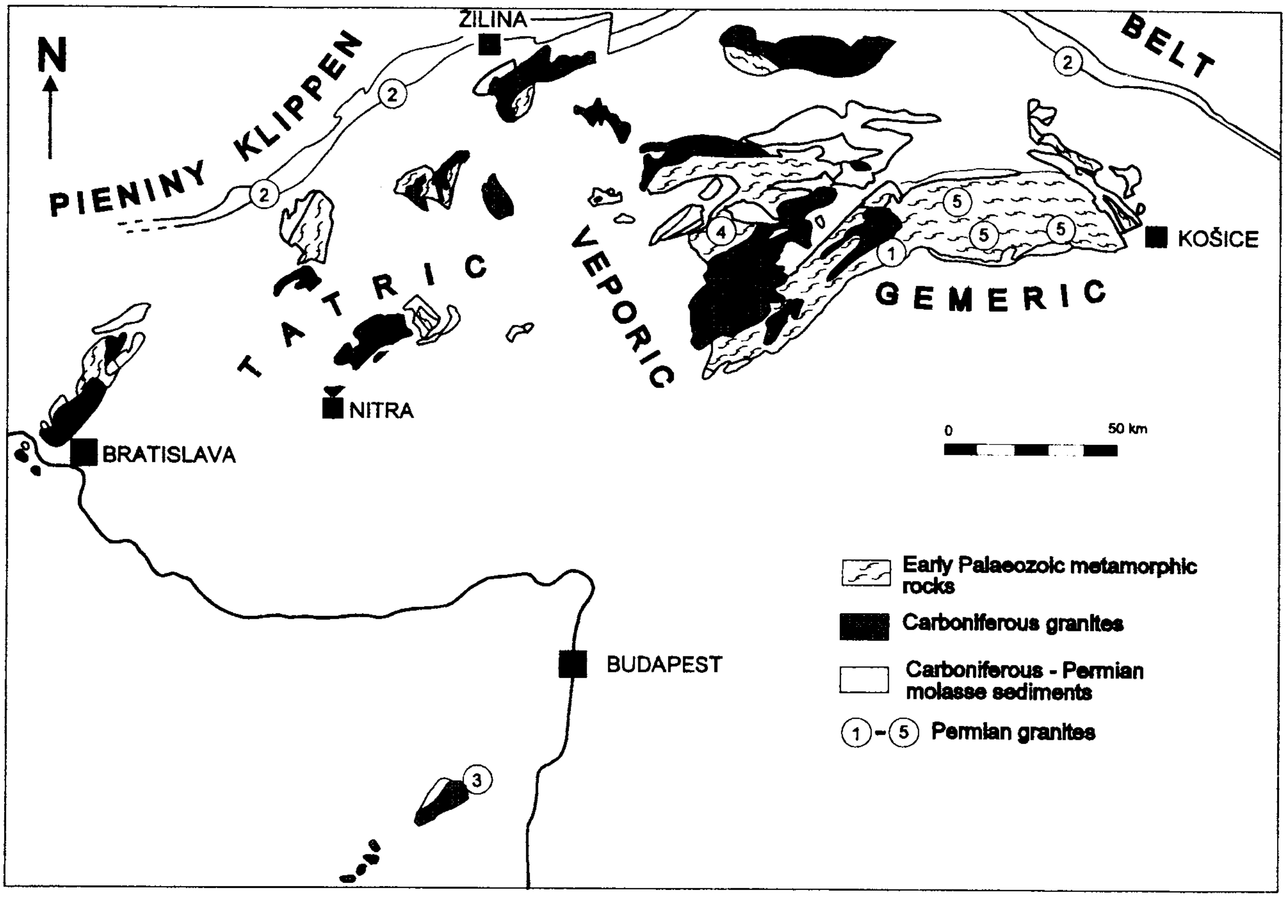

Fig. 1. The occurrences of POG in the Western Carpathian and Pannonian area: 1 — Turčok, 2 — Upohlav (in pebbles), 3 — Velence, 4 — Hrončok, 5 — Spiš-Gemer.

caused andalusite hornfels grade thermal metamorphism near contacts (Jantsky 1957; Buda 1993). These biotite leucogranites with pink K-feldspar megacrysts are locally cut by dikes of granite porphyry. Dark tonalitic enclaves of magmatic origin occur locally and metasedimentary Al-rich xenoliths are also present (Buda 1993). According to gravimetric and borehole data, these or similar granites occur under surface, along the Balaton-Velence lineament at the distance up to 150 km to the WSW (Buda & Nagy 1995).

The Hrončok granitic rocks are exposed in NW part of the Veporic Unit, 10 km SW from the town of Brezno. They consist of a main 6 × 1.5 km body of biotite ± muscovite porphyritic granite and several separate small intrusions and dikes of very fine-grained aplitic leucogranites (aplites to microaplites), all intruded Lower Paleozoic mica schists and gneisses (Petrík et al. 1995). Like the Turčok Granite, Hrončok bodies are strongly affected by Alpine tectonics.

The Spiš-Gemer granites are exposed in several massifs which intruded Lower Paleozoic metapelites-metapsammites as well as acid metavolcanics (rhyolites to dacites and their pyroclastic equivalents) of the Gelnica group, Gemeric Unit. These leucocratic biotite and biotite-muscovite granites are accompanied by granite porphyries (Betliar body), and sometimes by greisens and albitites in granitic cupolas with Sn-W-(Li-Nb-Ta) mineralization (Hnilec, Dlhá Valley; Malachovský 1983). On the basis of gravimetric, magnetic and borehole data, granite occurrences form larger massifs or only one intrusion at greater depths of over 2-10 km (Plančár & Snopko, in Mahel' 1986). In exocontacts of the intrusions, contact aureoles have a thickness of up to 1 km with andalusite and cordierite in metapelites (Faryad, in Krist et al. 1992).

Characteristics of granitic rocks

Petrography

All of the studied granites are light-coloured, leucocratic rocks with a small amount of biotite (generally < 5 vol. %). They occur as very fine aplitic to coarse-grained varieties, locally porphyritic with 0.5-10 cm feldspar megacrysts. Four main varietes of POG can be recognized: (1) equigranular fine- to coarse-grained granites s.s. (in all occurrences); (2) granitic porphyries (Upohlav, Velence and Spiš-Gemer); (3) very fine-grained aplitic leucogranites to microaplites (Turčok and Hrončok); (4) greisenized granites and albitites (Spiš-Gemer granitic cupolas).

One mesoperthitic alkali feldspar in granites and granophyric quartz + alkali feldspar intergrowths in porphyries locally occur (Fig. 2a), both indicate a hypersolvus to transsolvus (Bonin 1986) nature for most of the Turčok and Upohlav POG, and also some of the Hrončok aplitic leucogranites (Petrík et al. 1995). On the other hand, Velence, most of Hrončok and Spiš-Gemer granites show two distinct alkali feldspars (plagioclase and K-feldspar) and hence they belong to the subsolvus granites (Fig. 2b). Locally, late chessboard albite replaces older feldspars. Quartz occurs usually as anhedral grains, but locally as early euhedral b-quartz inclusions in feldspars.

Biotite forms three distinct habits: (1) early-magmatic < 30 µm euhedral-subhedral inclusions inclusions in zircon, (2) 0.1-3 µm subhedral, rarely euhedral brown to green-brown biotite laths in matrix with quartz and feldspars (Fig. 2c), and (3) the latest anhedral 20-50 µm (brown)-green crystals usually in irregular clusters at Upohlav and Hrončok POG (Fig. 2d).

Li-rich biotite to zinnwaldite is locally present in greisenized parts of Spiš-Gemer granites (Malachovský 1983). Primary late-magmatic muscovite is typical only for the Spiš-Gemer and Hrončok granites, and only rarely is it found in Velence and Upohlav.

Age determinations

On the basis of field and paleontological data, all studied granites, with the exception of Upohlav pebbles, postdate the Lower Paleozoic, since they intruded pre-Upper Carboniferous fossiliferous host rocks. On the other hand, they did not intrude any of the Mesozoic sequences exposed near the Turčok, Velence and Spiš-Gemer massifs.

More precise information was supplied by isotopic U-Pb and Rb-Sr dating (Tab. 1). Almost all isotopic data indicate ages from the Permian-Carboniferous boundary to the Upper Permian; 290-250 Ma. Only in case of the Spiš-Gemer did some samples yielded a Jurassic Rb-Sr isochrone ages, 140-180 Ma (Kovách et al. 1986). However, these Alpine ages were obtained from greisenized varieties where primary Rb-Sr isotopic system was disturbed by post-magmatic fluids (Cambel et al. 1990).

Major-element chemistry

The studied rocks have acid compositions with elevated contents of SiO_2 (mostly > 70 wt. %) and alkalis, especially K_2O (> 4 %). On the contrary, low Al_2O_3 (12.5-13.5 wt. %), MgO (< 0.5 wt. %), CaO (< 1 wt. %), TiO_2 and P_2O_5 is also characteristic (Tab. 2).

A/NK vs. A/CNK plot points to their peraluminous character (Fig. 3) and late-orogenic, syn-collision or anorogenic tendencies in R1-R2 diagram (Fig. 4).

Trace-element chemistry

Trace-element distribution (Tab. 2, Figs. 5-8) can be used to subdivide the Western Carpathian-Pannonian post-orogenic granites into the following groups:

(1) A-type group shows high to moderate REE, Y, Zr, Nb, Ga and Zn, but low to very low Ba, Sr and V contents (Turčok, Upohlav, Velence and Hrončok).

(2) S-type, tin-bearing specialized Spiš-Gemer POG: high Sn, W, Li, Rb, Cs, Nb, Ga, B, F, but low to very low REE, Y and Zr equally as Ba, Sr and V contents.

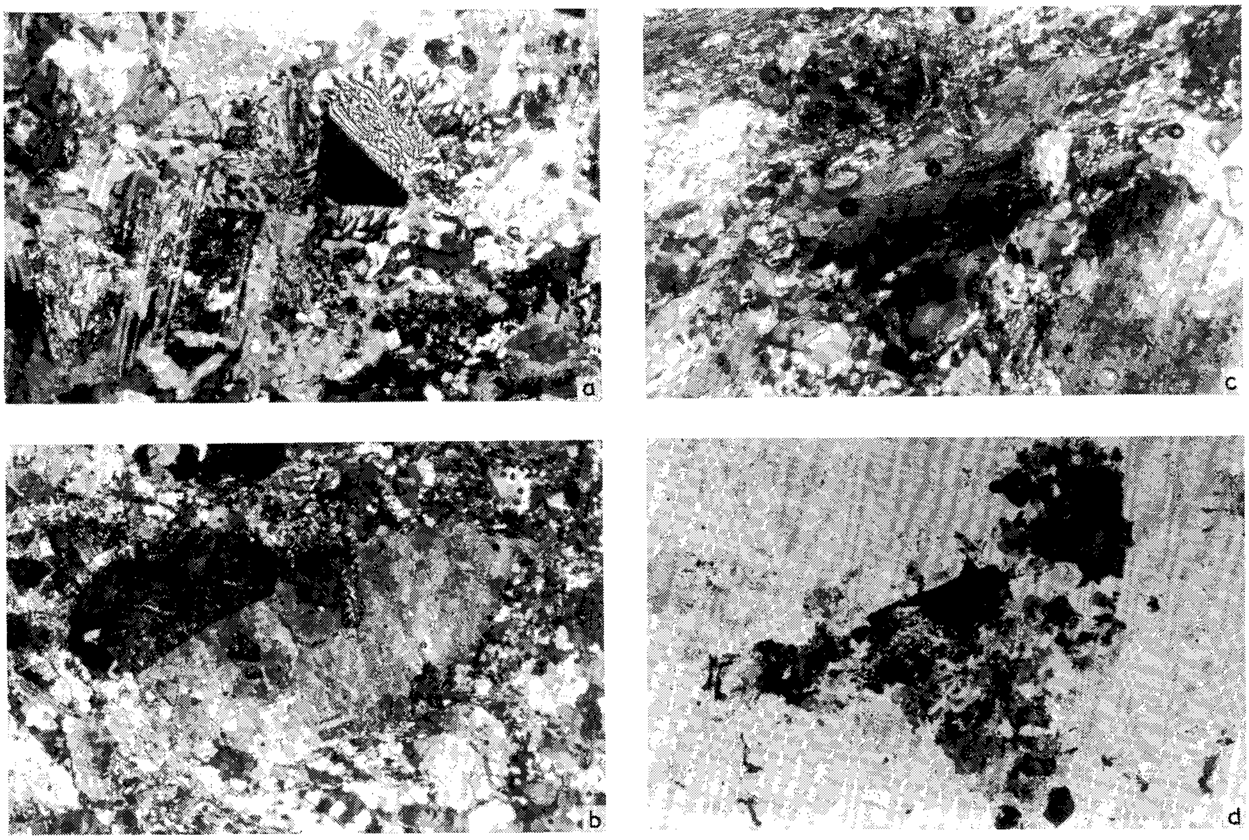

Fig. 2. The microphotographs of post-orogenic granites: **a** — granophyric quartz+alkali feldspar intergrowths, loc. Cetuna, Upohlav POG. **b** — K-feldspar phenocryst with Carlsbad twinning, Hrončok POG. **c** — Subhedral biotite with sagenite inclusions, Hrončok POG. **d** — Late anhedral biotite, loc. Divinka, Upohlav POG. Longer side of microphotographs is 4.6 mm (b), 2.8 mm (a, d) or 1.4 mm (c). Crossing (a-c) or parallel (d) polaroids.

Table 1: Results of POG isotope dating. Zrn — zircon, Bt — biotite, WR — wall rock.

Granite	Age (Ma)	Method	Reference
UPOHLAV	274 ± 13	U-PbZr	Uher & Pushkarev 1994
VELENCE	280±7	Rb-SrBt	Buda 1985
HRONČOK	278±11	U-PbZrn	Kotov et al. 1996
	285±5	Rb-SrWR	Cambel et al. 1989
	253±2	Rb-SrWR	Cambel et al. 1989
SPIŠ-GEMER	290±40	Rb-SrWR	Kovách et al. 1986
	251±16	Rb-SrWR	Kovách et al. 1986
	282±2	Rb-SrWR	Cambel et al. 1989

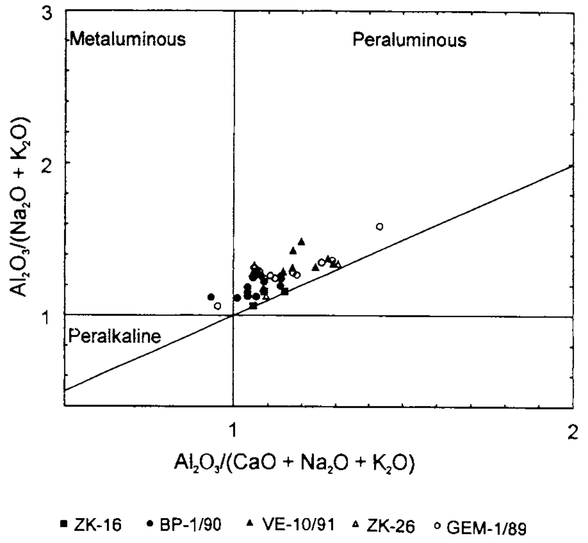

Fig. 3. A/NK vs. A/CNK diagram of post-orogenic granites.

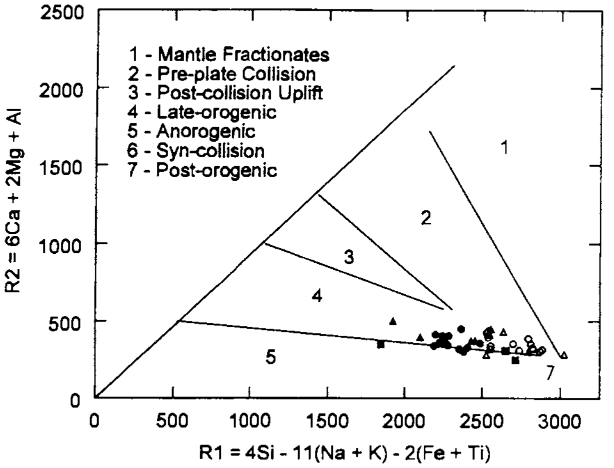

Fig. 4. R1-R2 diagram (Batchelor & Bowden 1985) of post-orogenic granites. Symbols as Fig. 3.

Biotite composition

All studied biotite compositions (Tab. 3) fall into annite field with Al atoms per formula unit < 3.3 and broad Fe/(Fe+Mg) atomic ratio: 0.54–0.94 (Fig. 9). The lowest ratio is reached by early magmatic magnesian annite from Turčok which forms only 3-20 µm mainly euhedral inclusions in zircon, the highest ratio is for the subhedral to anhedral interstitial late biotite from Upohlav and Hrončok. Althought the earlier biotites are iron-poor compared with the late ones, no correlation between biotite composition and A-type (hypersolvus to subsolvus) versus S-type POG were observed (Fig. 9).

The Fe^{3+}/Fe^{2+} values determined by wet chemical analysis and Mössbauer spectroscopy are relatively high: 27–34 % for Upohlav (Petrík & Uher, unpubl. data), 23 % for Hrončok (Petrík et al. 1995) and 8–45 % for Spiš-Gemer granites (Rub et al. 1977). The F, and especially Cl, values are generally also high (max. 0.7 wt. % F and 0.5 wt. % Cl) in the comparison with biotite from common granitic rocks (cf. Deer et al. 1992).

Zircon chemistry, typology and saturation temperature

Electron microprobe analyses of early magmatic, transparent zircon crystals (Tab. 4) reveal medium to high wt. % Zr/Hf ratios at central parts of crystals: 38–77 (50–65 on average). On the contrary, the rims exhibit generally lower Zr/Hf ratios: 16–70 (30–60 on average). Crystals from Turčok, Upohlav and Spiš-Gemer are usually unzoned or slighly oscillatory zoned (for Upohlav, see Uher & Marschalko 1993), zircon from Velence and Hrončok often exhibit clear oscillatory zoning in BSE images.

Zircon typological diagram (Pupin 1980) of hypersolvus-transsolvus A-type POG (Turčok and Upohlav) show very high alkalinity as well as temperature indices: (I.A, I.T) > 680 (Fig. 10). Both values indicate high alkalinity or (Na+K)/Al ratio and temperature (> 850 ± 50 °C) of the parental magma. A similar I.A, but lower I.T, is reached mainly by subsolvus A-type POG: Velence (I.T = 490-650) and especially Hrončok (I.T. = 330-460), both reveal lower temperatures, ca. 700-800 ± 50 °C (Gbelský & Határ 1982; Határ & Greguš 1989; Uher & Broska 1995; Petrík et al. 1995). On the contrary, specialized S-type Spiš-Gemer granite shows distinctly different typological patterns with both (I.A, I.T) = 360-450, which indicate again lower temperatures, ca. 700 ± 50 °C (Jakabská & Rozložník 1989; unpubl. data of PU and IB).

A calculation of zircon saturation temperature (Watson & Harrison 1983) gave the following results, in °C (average/N): Turčok 860-940 (900/3), Upohlav 820-890 (850/12), Velence 720-810 (790/8), Hrončok 780-790 (785/3) and Spiš-Gemer 700-800 (730/4). For comparison, monazite saturation or LREE melt/crystal equilibrium temperature (Montel 1993) are nearly identical, or up to 50 °C lower than zircon values for these rocks, mainly due to some post-magmatic leaching of LREE and non-precise, only estimated water content used in this calculation.

Accessory mineral assemblages

The principal magmatic accessory minerals of the studied granites are listed in Tab. 5. An occurrence of allanite-(Ce) and absence of monazite-(Ce) within Turčok, Upohlav and a major part of the Velence granites suggests higher temperatures (cf. Broska & Uher 1991) than those within Hrončok, Spiš-Gemer and smaller parts of Velence POG where monazite-(Ce) predominate over allanite-(Ce).

Turčok and locally Upohlav POG contain abundant magnetite which is an indicator of high oxygen fugacity of magma (fO_2). Intermediate fO_2 values are substantiated by allanite-(Ce) + ilmenite ± magnetite assemblage in Upohlav and

Table 2: Representative chemical analyses of POG (wt. %, ppm). **BtG** — biotite granite, **alG** — aplitic leucogranite, **GP** — (biotite) granite porphyry, **MsG** — muscovite granite. Locations: **Turčok**: BtG Štyri chotáre hill (ZK-16); alG Turčok village (Gem-3). **Upohlav**: BtG Beňov (BP-20); GP Vršatské Podhradie (BP-14.5). **Velence**: BtG Sukoró, Rigóhegy (Ve-10); GP Pátka quarry (Ve-5). **Hrončok**: BtG Kamenistá Valley (ZK-26); alG Vydrovo Valley (ZK-69). **Spiš-Gemer**: MsG Hnilec, Medvedí potok (Gem-1), GP Betliar (Gem-5). *Methods*: XRF for major elements, Rb, Sr, Ba, Zr, Zn, V, Th, U (Univ. Ottawa, Canada), ICP-MS: REE, Y, Nb (Univ. St. John's, Canada), OES: B, Ga, Sn (Geol. Inst. Slovak Acad. Sci., Bratislava), F: ISE (Geol. Inst. Czech Acad. Sci., Prague), F contents for Spiš-Gemer from Matula et al. (1983).

	TURČOK		UPOHLAV		VELENCE		HRONČOK		SPIŠ-GEMER	
	BtG	alG	BtG	GP	BtG	GP	BtG	alG	MsG	GP
SiO_2	75.76	72.16	71.64	73.91	73.36	70.08	73.31	76.19	75.67	73.49
TiO_2	0.17	0.23	0.25	0.16	0.20	0.36	0.26	0.07	0.07	0.28
Al_2O_3	12.55	15.69	13.74	13.21	13.48	14.55	13.32	13.20	13.49	13.54
Fe_2O_3	2.09	1.39	3.08	1.33	2.27	3.51	2.94	0.81	1.26	2.17
MnO	0.02	0.00	0.03	0.02	0.05	0.05	0.07	0.03	0.04	0.04
MgO	0.45	0.75	0.12	0.11	0.35	0.94	0.43	0.06	0.16	0.33
CaO	0.38	0.06	0.66	0.87	1.23	0.23	1.39	0.20	0.31	0.54
Na_2O	4.75	7.99	3.75	3.50	3.33	3.54	3.32	4.19	3.45	3.06
K_2O	2.79	0.36	5.01	4.94	4.68	4.64	4.23	4.44	3.90	5.10
P_2O_5	0.02	0.04	0.02	0.03	0.05	0.11	0.10	0.01	0.23	0.16
L.O.I.	1.50	1.60	0.90	1.40	1.20	1.90	1.10	1.00	1.60	1.20
Total	100.48	100.27	99.20	99.48	100.20	99.91	100.47	100.20	100.18	99.91
Rb	66	15	216	187	226	188	214	276	758	342
Sr	16	21	63	29	112	55	104	10	12	41
Ba	481	50	1294	478	262	438	316	39	40	245
B	5	10	13	22	10	9	20	5	282	58
Ga	22	35	19	18	20	17	25	17	30	23
Ce	113	159	112	133	60.6	66.3	55.9	24.8	7.12	50.1
Yb	8.7	11.8	4.5	5.1	3.9	2.9	3.1	5.6	0.76	2.7
Y	79	100	40	53	37	27	29	34	11	23
Zr	465	649	374	280	143	146	154	135	39	160
Nb	18	29	19	16	17	12	18	33	20	10
Sn	8.0	6.6	3.4	<3.0	<3.0	3.7	20	1.2	63	18
Zn	9	<1	59	16	38	110	56	45	43	38
V	1	7	16	5	18	37	16	1	4	23
Th	12	16	22	23	23	17	13	25	9	24
U	5	7	3	6	6	5	3	4	6	3
F	350	n.a.	n.a.	n.a.	n.a.	n.a.	500	n.a.	6700	500

Velence, locally Hrončok granites. The lowest fO_2 values are illustrated by the ilmenite ± almandine-spessartine assemblage within Hrončok and Spiš-Gemer POG. In addition, measurements of magnetic susceptibility of the highly magnetic Turčok and some Upohlav granites gave values ranging from 1 to 15 × 10^{-3} SI units, while the other occurrences yield only 0.05-0.3 × 10^{-3} SI units.

Fayalite, an iron-rich mineral typical for anorogenic or post-orogenic Al-undersaturated conditions (Bonin 1986), occurs in coarse-grained pegmatitic nests in Velence granites (Buda 1993).

Schorl, fluorite, cassiterite, wolframite and scarce manganocolumbite plus Nb-Ta-rich rutile are typical accessory minerals for tin-bearing Spiš-Gemer granites especially for their greisenized zones, e.g. Dlhá Valley (Malachovský 1983).

Discussion and conclusions

Classification

Group (1): Above described Turčok, Upohlav, Velence and Hrončok POG bears typical features of hypersolvus to subsolvus post-orogenic, post-collisional, felsic plutonic suites with mildly alkaline A-type character. The following features confirm their post-orogenic A-type character according to recent classifications and knowledge (e.g. Pitcher 1983; Whalen et al. 1987):

(i) Small granite massifs with hypoabyssal porphyry or aplitic granite dikes, with a shallow level of emplacement. Possible genetic relationships to the adjacent Permian acidic volcanic rocks (Upohlav, Velence and Hrončok).

(ii) The presence of granophyric textures, which is an indicator of rapid cooling from a hot and dry magma (Turčok and Upohlav).

(iii) Biotite of annite > siderophyllite composition with high Fe/Mg and low Al, and often Fe^{3+}-rich.

(iv) The leucocratic character as indicated by high SiO_2 and K_2O, Fe >> Mg, K > Na and low MgO, CaO and P_2O_5 whole rock compositions.

(v) Relatively higher Rb, Nb, Zr, Zn and Ga/Al, low Sr, Ba, V.

(vi) High to moderate REE + Y with a pronounced negative Eu-anomaly.

(vii) Zircon typology with high alkalinity index and a high to low temperature index (cf. Pupin 1980).

(viii) High zircon Zr/Hf ratio which is typical for alkaline granites (Pupin 1991).

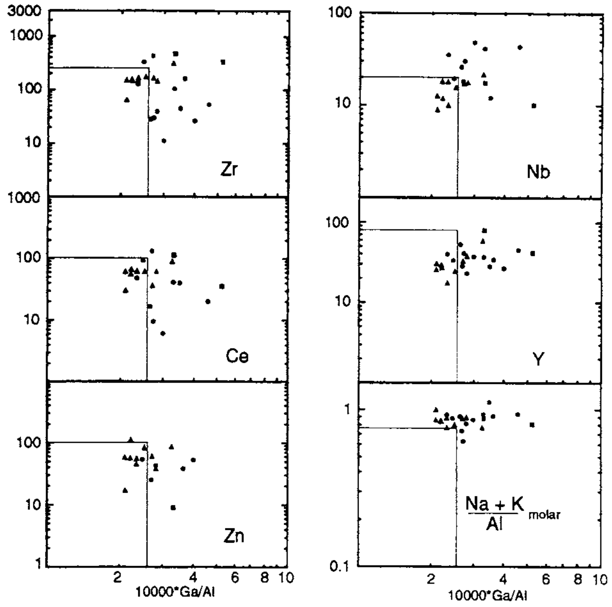

Fig. 5. Trace elements vs. 10000 Ga/Al diagrams (Whalen et al. 1987) of post-orogenic granites. Symbols as Fig. 3.

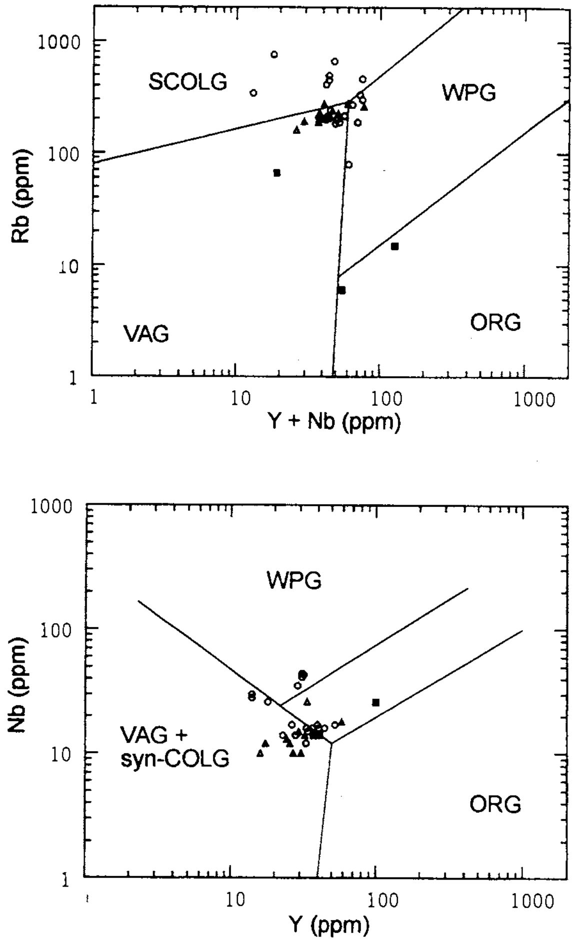

Fig. 6. Nb vs. Y and Rb vs. Y + Nb diagrams (Pearce et al. 1984) of post-orogenic granites. Symbols as Fig. 3.

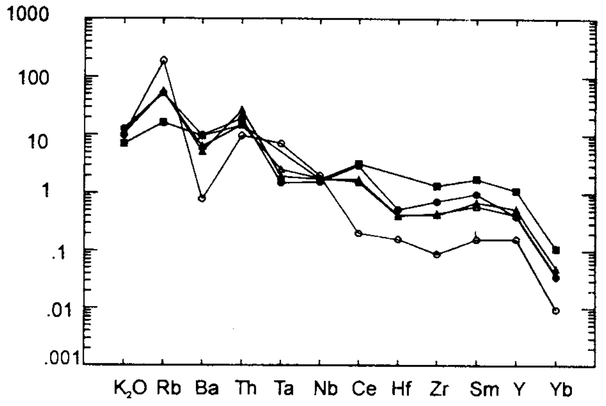

Fig. 7. Ocean ridge granite (ORG) normalised patterns (spiderographs — Pearce et al. 1984) of post-orogenic granites. Symbols as Fig. 3.

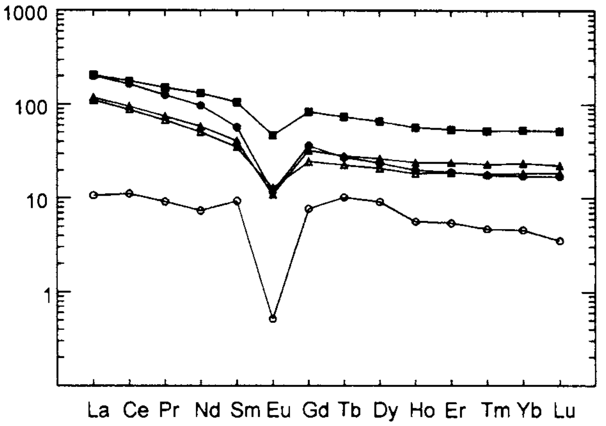

Fig. 8. Chondrite normalised REE patterns of post-orogenic granites. Symbols as Fig. 3.

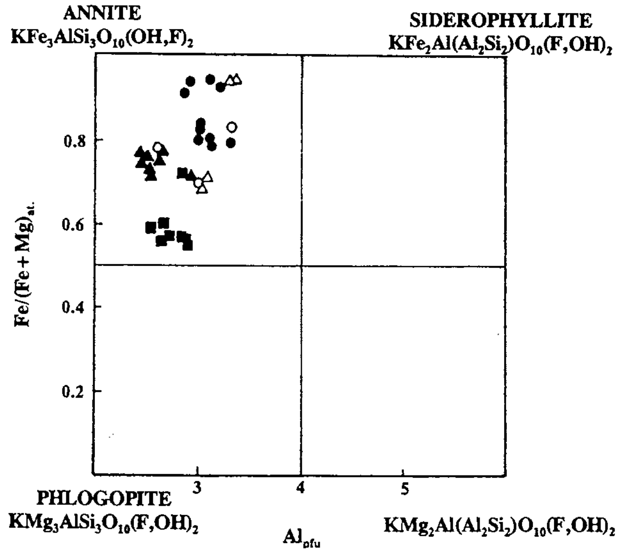

Fig. 9. Biotite quadrilateral diagram (Deer et al. 1992) of post-orogenic granites, atomic proportions. Symbols as Fig. 3.

Table 3: Representative microprobe (1-8) and wet chemical (9-10) analyses of POG biotite (wt.%). Formulas on the basis of 22 oxygens. **Zrn**: biotite inclusion in zircon, **Mat**: matrix biotite. **Total**: -F, ClsO, FeMg=Fe/(Fe + Mg) atom. **Anal. 1, 3-7** were obtained on CAMECA SX-50 elecron microprobe (Univ. of Manitoba, Winnipeg, Canada), 15 kV, 20 nA, 1-3 mm beam diam., 20-40 sec count. times, natural standards. **Anal. 2 and 8-10**: JEOL JCXA-733 Superprobe (Geol. Survey of Slovak Rep., Bratislava) at analogous conditions. 1-8 BtG, 9 MsG, 10 GP (see Tab. 2). **Locations**: 1: Štyri chotáre hill (ZK-16B4); 2: dtto (Tu-1B3); 3: Podbranč (BP-1B4); 4: Divinka (BP-7.1B9); 5: Sukoró, M7 highway (Ve-1B1); 6: Sukoró, Rigóhegy (Ve-10B3); 7: Kamenistá Valley (ZK-26B2); 8: dtto (VG-41), Petrík et al. (1995), orig. with 5.51 wt.% Fe_2O_3, determined by Mössbauer spectroscopy; 9: Hnilec, Medvedí potok, orig. with (wt.%): 3.02 Fe_2O_3, 0.12 Li_2O, 0.15 Rb_2O, 0.01 Cs_2O, 3.22 H_2O; 10: Betliar, orig. with (wt.%): 10.90 Fe_2O_3, 0.06 Li_2O, 0.16 Rb_2O, 0.01 Cs_2O, 3.97 H_2O; 9-10 from Rub et al. (1977). Formulas 8-10 were newly recalculated, without Fe^{3+}, Li, Rb, Cs and (OH).

	TURČOK		UPOHLAV		VELENCE		HRONČOK		SPIŠ-GEMER	
	1 Zrn	2 Zrn	3 Mat	4 Mat	5 Mat	6 Mat	7 Zrn	8 Mat	9 Mat	10 Mat
P_2O_5	0.00	0.09	n.a.	0.00	0.00	0.00	0.04	n.a.	n.a.	n.a.
SiO_2	35.02	35.44	33.29	34.79	34.23	34.49	36.05	35.52	33.97	36.42
TiO_2	2.21	3.04	1.59	1.54	3.76	2.52	0.31	1.54	3.03	2.77
Al_2O_3	15.27	14.84	15.82	15.89	13.61	12.84	16.14	16.69	18.32	16.97
Cr_2O_3	0.01	0.02	0.03	0.00	0.00	0.00	0.01	0.00	n.a.	n.a.
FeO_t	21.24	23.72	31.06	29.20	26.01	28.58	24.18	24.36	26.70	22.03
MnO	0.03	0.09	0.16	0.46	0.31	0.76	0.21	0.36	0.13	0.39
MgO	9.71	5.17	1.13	3.22	4.90	5.46	6.28	5.60	4.33	5.34
CaO	0.00	0.04	0.01	0.12	0.14	0.00	0.00	0.02	0.38	1.28
Na_2O	0.05	0.12	0.02	0.00	0.08	0.10	0.04	0.08	0.08	0.11
K_2O	9.38	9.21	8.90	9.44	8.98	8.74	9.03	9.45	8.77	8.03
F	0.63	0.54	n.a.	0.19	0.47	0.56	0.29	0.61	0.06	0.93
Cl	0.30	0.37	n.a.	0.22	0.42	0.51	0.17	n.a.	n.a.	n.a.
Total	93.52	92.38	92.10	94.94	92.62	94.21	92.59	93.97	95.74	93.88
P	0.000	0.013	n.a.	0.000	0.000	0.000	0.006	n.a.	n.a.	n.a.
Si	5.556	5.751	5.614	5.638	5.644	5.669	5.800	5.662	5.344	5.710
Al^{IV}	2.444	2.236	2.386	2.362	2.356	2.331	2.194	2.338	2.656	2.290
Al^{VI}	0.412	0.602	0.758	0.673	0.289	0.157	0.866	0.798	0.741	0.846
Ti	0.263	0.371	0.201	0.188	0.466	0.311	0.038	0.185	0.358	0.327
Cr	0.001	0.002	0.004	0.000	0.000	0.000	0.002	0.000	n.a.	n.a.
Fe	2.819	3.219	4.380	3.957	3.586	3.929	3.254	3.248	3.513	2.888
Mn	0.004	0.013	0.022	0.063	0.044	0.107	0.028	0.049	0.017	0.052
Mg	2.296	1.252	0.283	0.779	1.204	1.337	1.505	1.330	1.015	1.248
ΣY	5.795	5.459	5.648	5.660	5.589	5.841	5.693	5.610	5.644	5.361
Ca	0.000	0.006	0.002	0.020	0.025	0.000	0.000	0.004	0.064	0.215
Na	0.016	0.039	0.008	0.000	0.026	0.032	0.012	0.025	0.025	0.033
K	1.898	1.908	1.914	1.951	1.889	1.833	1.853	1.921	1.760	1.606
ΣX	1.914	1.953	1.924	1.971	1.940	1.856	1.865	1.950	1.849	1.854
F	0.316	0.277	n.a.	0.097	0.245	0.291	0.148	0.307	0.030	0.462
Cl	0.080	0.102	n.a.	0.059	0.117	0.142	0.045	n.a.	n.a.	n.a.
Fe_{Mg}	0.55	0.72	0.94	0.84	0.75	0.75	0.68	0.71	0.78	0.70

(ix) Lower Permian isotopic age which is analogous with other European post-Hercynian A-type suites (Bonin 1990).

Thus, A-type POG are well comparable with other post-orogenic to anorogenic A-type suites, such as Gabo and Mumbulla suite in Southeastern Australia (Collins et al. 1982), peraluminous biotite granites in Evisa complex, Corsica (Whalen et al. 1987; Bonin 1988), or biotite granite in West Moose River pluton, Nova Scotia, Canada (Pe-Piper et al. 1991).

Group (2): The Spiš-Gemer tin-bearing granites belong to the post-orogenic highly fractionated and specialized S-type suite. The Spiš-Gemer POG are rich in Si, K, Li, Sn, W, B, Rb, Nb and F, but very poor in REE, Y and Zr. They are comparable with other specialized tin-bearing and high-fluorine granites in post-Hercynian Europe, e.g. Erzgebirge (Tischendorf 1989), Beauvoir Granite (Cuney et al. 1992) and Homolka Granite (Klečka & Šrein 1992). Their mineralogy is distinctly different from above mentioned A-type POG. For example, presence of Al- and B-rich phases such as almandine-spessartine (Faryad & Dianiška 1989), topaz and schorl as well as zircon typology with lower I.A. and I.T., which indicated S- rather than A-type affinity. However, another features of Spiš-Gemer granites are similar with the A-type group, e.g. their leucocratic character, presence of porphyries, alkali abundances and Lower Permian isotopic age.

Protolith

The question of source-rocks in A-type magmatism is still an object of discussion. Due to the large mineralogical as well as geochemical variability, including a broad range of initial $^{87}Sr/^{86}Sr$ ratios (ISr = 0.703 to over 0.720 — Collins et al.

Table 4: Representative microprobe analyses of POG zircon (wt.%). Formulas on the basis of 16 oxygens. **Cen**: central part, **Rim**: rim of crystal. **Total**: -F, ClsO. CAMECA microprobe, anal. conditions see Tab. 3, 30 nA and 40 sec count. time for U to Cl. **Zr/Hf**: weight ratio.

	TURČOK		UPOHLAV		VELENCE		HRONČOK		SPIŠ-GEMER	
	Cen	Rim	Cen	Rim	Cen	Rim	Cen	Rim	Cen	Rim
P_2O_5	0.22	0.14	0.09	0.10	0.12	0.12	0.19	0.41	0.21	0.40
SiO_2	32.20	32.88	32.30	32.34	32.42	32.72	32.67	32.60	32.49	31.51
ZrO_2	65.38	65.39	65.58	66.52	65.66	64.21	65.51	65.98	65.19	64.40
HfO_2	0.77	0.90	0.88	0.83	1.05	1.73	0.87	1.79	1.46	1.43
UO_2	0.05	0.07	0.00	0.07	0.05	0.19	0.01	0.24	0.00	0.16
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04
Sc_2O_3	0.00	0.00	0.02	0.03	0.04	0.00	0.02	0.00	0.00	0.00
Y_2O_3	0.51	0.35	0.00	0.00	0.08	0.05	0.48	0.40	0.01	0.33
Ce_2O_3	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.01	0.00
Sm_2O_3	0.02	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.06	0.01
Tb_2O_3	0.03	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.03
Dy_2O_3	0.09	0.00	0.00	0.06	0.00	0.11	0.12	0.00	0.00	0.00
Er_2O_3	0.06	0.07	0.05	0.03	0.08	0.05	0.09	0.12	0.04	0.11
Yb_2O_3	0.09	0.11	0.01	0.03	0.07	0.07	0.15	0.14	0.05	0.11
CaO	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.03	0.00
F	0.09	0.17	0.10	0.02	0.08	0.00	0.09	0.00	0.06	0.02
Cl	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.02	0.02	0.02
Total	99.48	100.07	99.00	100.03	99.65	99.28	100.18	101.72	99.64	98.56
P	0.023	0.015	0.009	0.010	0.012	0.013	0.020	0.042	0.021	0.043
Si	3.975	3.986	4.001	3.969	3.975	4.041	3.998	3.952	3.999	3.939
Zr	3.935	3.938	3.953	3.981	3.926	3.867	3.909	3.900	3.913	3.925
Hf	0.027	0.032	0.031	0.029	0.037	0.061	0.030	0.062	0.051	0.051
U	0.001	0.002	0.000	0.002	0.001	0.005	0.000	0.007	0.000	0.004
Fe	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.004
Sc	0.000	0.000	0.002	0.003	0.005	0.000	0.003	0.000	0.000	0.000
Y	0.033	0.023	0.000	0.000	0.005	0.003	0.032	0.026	0.000	0.023
Ce	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000
Sm	0.001	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000
Tb	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001
Dy	0.003	0.000	0.000	0.002	0.000	0.004	0.005	0.000	0.000	0.000
Er	0.002	0.003	0.002	0.001	0.003	0.001	0.003	0.004	0.002	0.004
Yb	0.003	0.004	0.000	0.001	0.002	0.003	0.006	0.005	0.002	0.004
Ca	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.001	0.004	0.000
F	0.036	0.065	0.040	0.009	0.031	0.000	0.035	0.000	0.025	0.008
Cl	0.000	0.003	0.001	0.000	0.000	0.001	0.000	0.003	0.004	0.004
Σcat	8.002	8.005	7.998	7.999	7.970	7.999	8.008	8.000	7.998	7.998
Zr/Hf	74.5	63.3	65.2	70.0	54.7	32.3	65.8	32.3	39.1	39.4

1982) authors favour a either lower crustal granulite protolith (Collins et al. 1982; Whalen et al. 1987) or older, mainly I-type tonalite — granodiorite protolith (e.g. Clemens et al. 1986), or at least a partly mantle origin (Bonin 1988). Sr-isotopic data indicate matured crustal protolith for the Hrončok (ISr = 0.7101, Petrík et al. 1995) and especially for the Spiš-Gemer granites (ISr > 0.710, Kovách et al. 1986), isotopic data from other occurrences are not known. On the other hand, rare mafic enclaves of biotite tonalite composition at Velence (Uher & Broska 1995) could be a marker of unmixing or anatexis from more basic lower crustal to upper mantle protolith.

P-T-X conditions

Assuming all of above data is correct, the following conditions of origin could be suggested for hypersolvus A-type (Turčok, Upohlav), subsolvus A-type (Velence, Hrončok) and Sn-bearing S-type (Spiš-Gemer) granites.

Temperature of the liquidus could be at least 850-900 °C for Turčok and Upohlav, ca. 800 °C for Velence and Hrončok and around 750-800 °C for Spiš-Gemer granite magmas, as indicated by both zircon saturation and typology temperatures. The zircon data are in good agreement with the experimental data yielding minimum melt or liquidus temperature for dry A-type granite over 830 °C (Clemens et al. 1986). The solidus temperature of emplacement level estimated from haplogranite minimum composition (cf. Holtz & Johannes 1994) vary from ca. 750 °C (Turčok, Upohlav) to 600-650 °C (Spiš-Gemer) for 2 kb lithostatic pressure, hypabyssal dikes of granite porphyries and microgranites cooled rapidly at ca. 0.5-1.5 kb. The pressure data are derived from recognized

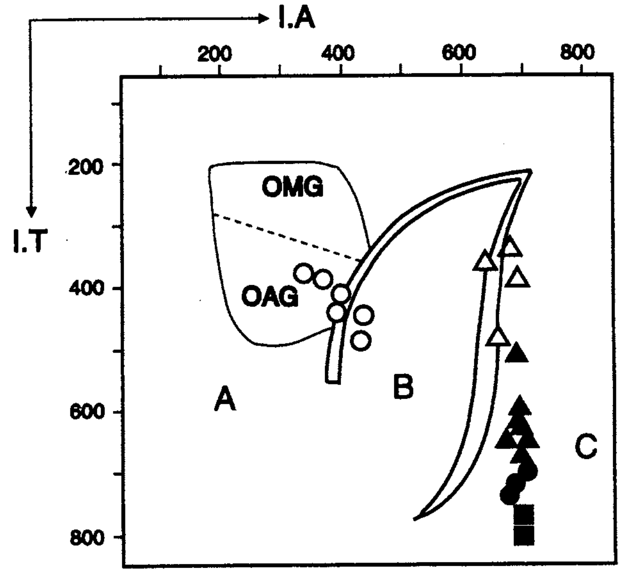

Fig. 10. Zircon typological mean points (Pupin 1980) of post-orogenic granites. Symbols as Fig. 3.

Table 5: Characteristic assemblages of principal accessory minerals. Content: **XX** — very common, **X** — common, x — rare, in brackets — occurrence only locally.

	TURČOK	UPOHLAV	VELENCE	HRONČOK	SPIŠ-GEMER
Zircon	**XX**	**XX**	**X**	**X**	x
Fluorapatite	x	(x)	x	x	x
Monazite-(Ce)	—	—	(x)	(x)	x
Xenotime-(Y)	x	—	(x)	—	(x)
Allanite-(Ce)	**X**	**X**	**(X)**	(x)	(x)
Magnetite	**XX**	**(X)**	—	(x)	—
Ilmenite	—	(x)	**X**	(x)	x
Almandine	—	(x)	—	**(X)**	**XX**
Schorl	x	(x)	—	—	**XX**
Topaz	—	—	—	—	**(X)**
Cassiterite	—	—	—	(x)	**X**
Fluorite	—	—	—	—	**(X)**

low-pressure andalusite ± cordierite contact metapelite aureoles around Velence and Spiš-Gemer massifs.

A-type magmas are generally considered as highly water undersaturated (e.g. Clemens et al. 1986). Our calculations of monazite saturation temperatures (Montel 1993) are in relative good accordance with zircon saturation temperatures (Watson & Harrison 1983) at the following estimated water contents: 1-2 % for hypersolvus-transsolvus A-type POG, 2-3 % for subsolvus A-type POG and 5 % for Spiš-Gemer S-type. These water concentrations we interpret as magma water content for early magmatic crystallization near liquidus, when zircon as well as LREE phases were saturated. On the contrary, the youngest iron-rich anhedral biotite indicates a distinguished increase of water contents in the magma during the late-magmatic stage. For example, analogous annite-rich biotite is stable between 725-750 °C at 2 kb and 4 % H_2O (Clemens et al. 1986). Only for tin-bearing Spiš-Gemer granites do we expect a considerably higher water content as indicated by the abundance of muscovite and especially the development of greisens.

The fluorine and chlorine activity was probably higher for all studied post-orogenic granites, as indicated by elevated F and Cl contents in biotite (0.2-0.9 wt. %), however F in the wall rock is low for A-type POG (≤ 500 ppm). Only Spiš-Gemer granites, especially their topaz and fluorite-bearing greisenized cupolas contain significantly higher fluorine content in rocks, on average 300-1200 ppm F, and 700-4000 ppm F in greisenized rocks (Matula et al. 1983), Tab. 2.

Magma oxygen fugacity (fO_2) is variable for the studied rocks. The fO_2 value can be estimated from the mineral assemblage in the granite, although some caution is required especially for the possible presence of secondary subsolidus magnetite (cf. Lyakhovich 1968). According to Ishihara (1981) classification, Turčok and locally Upohlav POG typically belong to the magnetite-series and the other POG to the ilmenite-series.

Scenario of origin

The above mentioned data yield us to propose a model, or rather a scenario, of possible origin for the West-Carpathian-Pannonian Permian POG, especially for the A-type group (Fig. 11).

After the major Devonian-Carboniferous collisional, and Carboniferous trans-pressional stages, transtensional to extensional relaxation regimes was achieve since 300 ± 20 Ma (Ziegler 1986; Bonin 1987; Neugebauer 1988). The evolution from collisional to extensional regime is reflected by large scale shear faulting in the whole of Europe. New paleogeographic and tectonic pattern induced changes to the P-T-X conditions and consequent evolution from orogenic calc-alkaline to post- and anorogenic alkalic plutonic volcanism (Bonin 1987, 1990). The first post-orogenic granites which were pro-

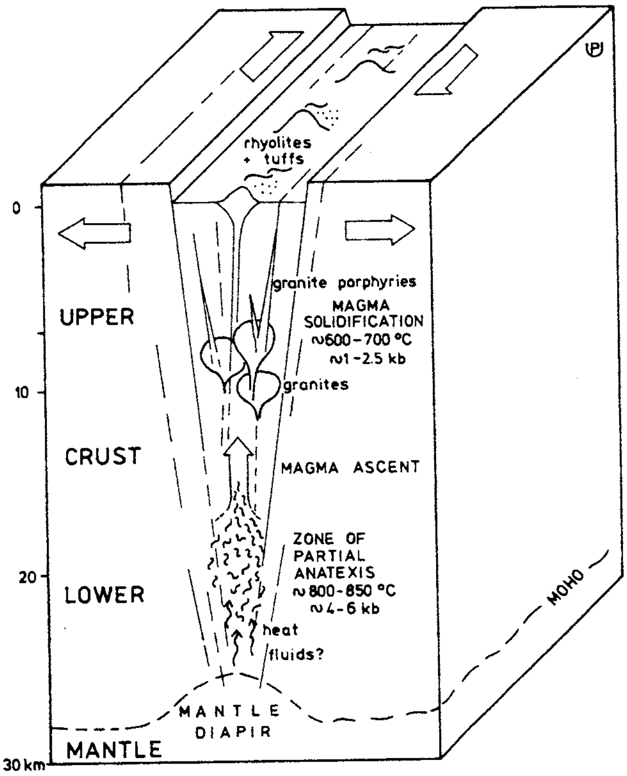

Fig. 11. The possible scenario of origin of post-orogenic granites in the Western Carpathian-Pannonian area.

duced during the Lower Permian exhibit transitional calc-alkaline to mildly alkaline, peraluminous trend. On the contrary, often metaluminous to peralkaline, post-orogenic to anorogenic granite-rhyolite suites were originated during Upper Permian to Triassic (Bonin 1987). Western Carpathian-Pannonian post-orogenic and peraluminous A-type granites belong to the older, Lower Permian group.

If the mean MOHO level of a thinning, highly eroded continental crust within a large strike-slip fault zone of post-orogenic region is assumed at around 25-30 km, lower crustal levels around 20 km could contribute sites of partial anatexis of older (meta)acidic rocks. The lithostatic pressure at 20 km depths is ca. 5.5 kb in the mean continental crust, if the mean density of crustal rocks is 2700 kg.m^{-3}. Melt ascent from the zone of partial anatexis to the zone of final emplacement and solidification was favoured by transtensional or extensional tectonic environment along huge and deep strike-slipe fault systems (cf. Lameyre 1988; Bonin 1987, 1990) and produced granite at the middle levels as well as porphyries and microgranites at the upper crustal levels. The fault-controlled distribution of small POG massifs are well documented in the Pannonian area where hidden intrusions occur at the distance of ca. 150 km from the Velence Mts. along the Balaton-Velence tectonic line (Buda & Nagy 1995). Similarly, the elongated shape of the Hrončok granite along the Pohorelá fault could be explained as a result of their emplacement on the active strike-slip line, lately rejuvenized during the Alpine orogeny (Petrík et al. 1995). Unfortunately, extensive Alpine nappe tectonics and mylonitization at Turčok or only secondary position as pebbles to boulders at Upohlav do not allow an estimation of the original shape and emplacement evolution of both of these most characteristic Western Carpathian A-type POG. The above mentioned possible scenario for the origin of the West-Carpathian-Pannonian Permian post-orogenic granites is still a first coarse attempt and needs further geochemical (e.g. isotopic), mineralogical (e.g. fluid inclusions) and experimental data to improve upon its origin.

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