Chemistry and mineralogy of orthogneisses in the northeastern part of the Moldanubicum

Chemické a minerální složení ortorul severovýchodní části moldanubika

(9 figs, 9 tabs)

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Two principal types of lower Palaeozoic orthogneisses were distinguished in the northeastern part of the Moldanubicum, Bohemian Massif, Czech Republic. Biotite orthogneisses are distributed in outer parts of the area, whereas leucocratic two-mica and muscovite-tourmaline orthogneisses form a SW-NE trending belt running through the entire area. All the rock types are peraluminous. The most fractionated two-mica orthogneisses are characterised by enrichment in boron, phosphorus, tin and tungsten and their chemical composition resembles tin granites. Typical mineralogical features comprise P-enrichment of both K-feldspar and albite, common occurrence of tourmaline (schorl) and occasionally phosphorus-enriched almandine-spessartine garnet. Zircon from fractionated orthogneisses is often zoned, and enriched in P, U, Al, Fe and Sc. Attempt to use monazite for age determination of magmatic precursor of orthogneisses was unsuccessful; all obtained ages are Variscan (316–327 Ma). Nevertheless, from whole-rock chemistry and similarities in mineral composition with the well dated Hluboká orthogneiss it is possible to conclude that all studied rocks are products of one extensive lower Palaeozoic magmatic event, which was important in the northeastern part of the Moldanubicum. This magmatic event produced peraluminous magmas with source probably in metasedimentary formations. Near-minimum melting involving muscovite enriched the primary melt in boron. Successive fractionation led to enrichment in phosphorus and tin. The most fractionated products of this event form a discontinuous belt between the Blaník hill in the southwest and Přibyslavice in the northeast.

Key words: orthogneiss; chemistry; petrology; mineralogy; Moldanubicum

1. Introduction

Geochemical and mineralogical composition of Pre-Variscan, probably lower Palaeozoic orthogneisses in Moldanubicum is still poorly understood. Beneš et al. (1963) and Kodym et al. (1963) compiled geological and petrographic data in the explanations to geological maps at the scale of 1:200 000. Němec – Páša (1986) published several analyses of orthogneisses from the northeastern part of Moldanubicum; unfortunately only mean values of major elements from poorly defined rock groups were presented. Povondra et al. (1987) published detailed mineral and chemical data from Přibyslavice orthogneiss, however, the authors did not consistently distinguish samples from the orthogneiss and from associated granite and pegmatite. Later, Slabý (1991) studied orthogneisses in the southwestern part of Moldanubicum and Klečka et al. (1992) published some chemical and mineral data from the Blaník orthogneiss. Povondra – Vrána (1993, 1996) published detailed petrological and mineralogical data and Vrána – Kröner (1995) presented geochronological data from the leucocratic Hluboká orthogneiss. Other investigators focused on structural aspects of the orthogneiss evolution (e.g. Rajlich et al. 1992).

We studied whole-rock chemical composition and mineralogy of biotite and leucocratic orthogneisses in order to define relations among individual orthogneiss bodies and their possible magmatic precursors. We omitted the study of deformation of these rocks, because the original shape of the bodies was completely changed during Variscan event and actual relations between orthogneisses and their envelope give no information about mode of the intrusion (compare Povondra – Vrána 1993).

The studied area extends from the town of Tábor in the SW to the town of Čáslav in the NE, covering the northeastern part of the Bohemian Moldanubicum between the Blanice graben in the W and the Kutná Hora Crystalline Unit in the E.

2. Main types of orthogneisses and their geological position

Two principal types of orthogneisses are traditionally distinguished in the studied area: biotite orthogneisses and leucocratic two-mica (Blaník-type) orthogneisses. Although this division oversimplified the real situation, we follow it in this paper, too.

Biotite (±muscovite) orthogneisses form two discontinuous belts (Fig. 1, Table 1). Bodies at Želiv, Arneštovice, Pacov, Cetoraz and Psárov and several smaller bodies (Beneš et al. 1963) are situated in the southern belt. Bodies at Kácov, Vlastějovice and Římovice form the northern belt. Biotite orthogneisses are generally medium-grained and well foliated, mineralogically and structurally homogeneous, without visible internal fractionation. Only the largest Želiv body is chemically slightly variable. Biotite is the exclusive mafic phase. Muscovite appears only scarcely, garnet has not been found.

Leucocratic two-mica and muscovite-tourmaline orthogneisses build a discontinuous, generally SW-NE trending belt through the central part of the area. They can be divided into three regional groups.

Table 1 Main geological features of studied orthogneiss bodies.

Name	Area (approx.)	Orientation or shape	Mineralogy
Želiv	11×1.5 km	NNE-SSW	Bt
Arneštovice	3×1 km	NE-SW	Bt (+Ms)
Pacov	4×0.5 km	ENE-WSW	Bt
Cetoraz	3×1.5 km	E-W	Bt (+Ms)
Psárov	1.5×1.5 km	equant	Bt (+Ms)
Kácov	4.5×0.5 km	E-W	Bt
Vlastějovice	3.5×0.5 km	NE-SW	Bt
Římovice	1×0.3 km	E-W	Bt
Choustník	3×0.5 km	NE-SW	Bt-Ms
Mladá Vožice	7×1 km	N-S	Bt-Ms
Malý Blaník	1×1 km	equant	Bt-Ms
Velký Blaník	1.5×1.5 km	equant	Bt-Ms
Křížov-Pravonín	6×1 km	E-W	Bt-Ms, Ms-Tur
Javorník-Keblov	8×1 km	E-W	Ms-Tur, Ms-Bt
Trhový Štěpánov	1.5×0.5 km	E-W	Ms-Tur
Leština-Sázavka	group of small bodies	ENE-WSW	Bt-Ms-Tur-Grt
Přibyslavice	8 km long belt of several small bodies	E-W	Bt-Ms-Tur-Grt

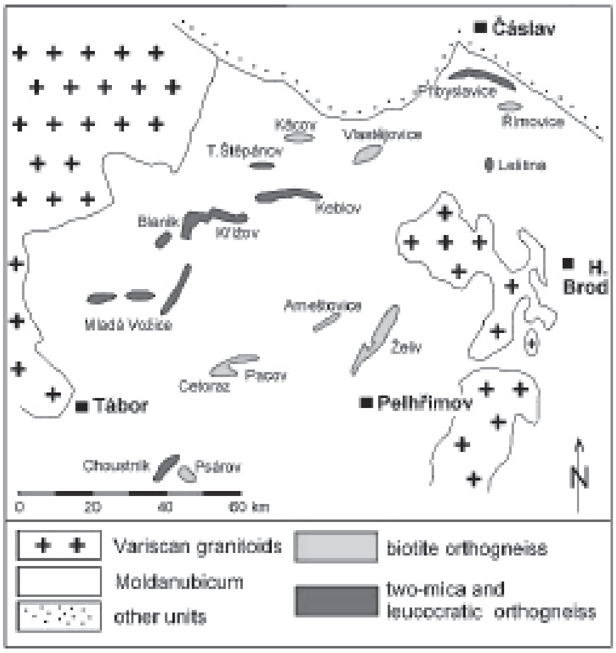

Fig. 1 Sketch map of orthogneiss distribution in the northeastern part of Moldanubicum.

A group of three larger and several smaller bodies between Mladá Vožice in the SW and the Želivka River in the NE includes rocks traditionally termed as "Blaník orthogneiss". Individual bodies in this area have different texture, mineralogy and chemistry, so the term "Blaník orthogneiss" should be better understood geographically than lithologically. The southernmost body at Mladá Vožice is two-mica orthogneiss, chemically less evolved and well foliated. The central body of Velký Blaník is very inhomogeneous in detail: from fine-grained well foliated two-mica orthogneiss to coarse-grained muscovite-tourmaline metagranite. Garnet appears locally as minor phase (quarries at Křížov and Keblov). The bodies in the NE (at Křížov-Pravonín and Javorník-Keblov) comprise both two-mica and muscovite-tourmaline facies, they are generally less foliated, chemically most evolved and contain small nests of tourmaline-bearing pegmatites (Klečka et al. 1992). In contrast, the tourmaline-muscovite body near Trhový Štěpánov is chemically less evolved. The Choustník two-mica orthogneiss is situated in the SW of studied area. It is in all aspects similar to the Blaník orthogneiss; relicts of porphyritic metagranite were found locally within this orthogneiss (Zikmund 1983).

Several small bodies of mineralogically variable orthogneiss crop out near Sázavka and Leština at the eastern margin of the Moldanubicum. Two-mica, muscovite-tourmaline and muscovite-garnet facies have been found here.

The Přibyslavice orthogneiss is situated at the NE corner of the entire Moldanubicum. It forms about 10 km long belt of several small bodies elongated E-W. Biotite to two-mica facies forms external bodies at Březí in the W and at Golčův Jeníkov in the E. The central body at Přibyslavice is formed by chemically more fractionated muscovite-tourmaline±garnet facies.

3. Chemical composition

Chemical composition of representative samples is characterised by whole-rock analyses presented in Table 2, the relations between important chemical elements in Figs 2–4.

Biotite orthogneisses can be chemically divided into two types. The Si-poor bodies at Římovice, Psárov, Cetoraz and Želiv (SiO_2 about 70 wt. %) are rich in Fe (2.2–3.1 wt. % Fe_2O_{3tot}), Ca (0.9–1.7 wt. % CaO), Ba, Sr, Zn, Zr, Th, V, and LREE. The other, Si-richer bodies (73–76 wt. % SiO_2) are poorer in Fe (1.0–1.5 wt. % Fe_2O_{3tot}), Ca (0.6 wt. % CaO) and REE, and slightly enriched in Rb. Contents of alkalis, P and F are relatively uniform.

The "Blaník" orthogneiss is chemically variable with 72–75 wt. % SiO_2. With increasing Si the Al, Fe, Ca and P slightly decrease, while Na, K, Rb, Sr a Zr are nearly constant. Contents of REE and other compatible elements are much lower and contents of LILE higher than those in biotite orthogneisses.

The Choustník orthogneiss is similar to typical Blaník orthogneiss, the only exception being enrichment in Rb (up to about 500 ppm).

Orthogneisses from Leština are chemically homogeneous, in comparison with Blaník orthogneiss slightly richer in Si (75–76 wt. % SiO_2) and K (4.5–5.0 wt. % K_2O) and poor in Na (3.3–3.5 wt. % Na_2O).

Přibyslavice orthogneiss is the most variable body. The SiO_2 content increases from 71 wt. % in biotite-bearing facies at periphery to 73–75 wt. % in muscovite facies

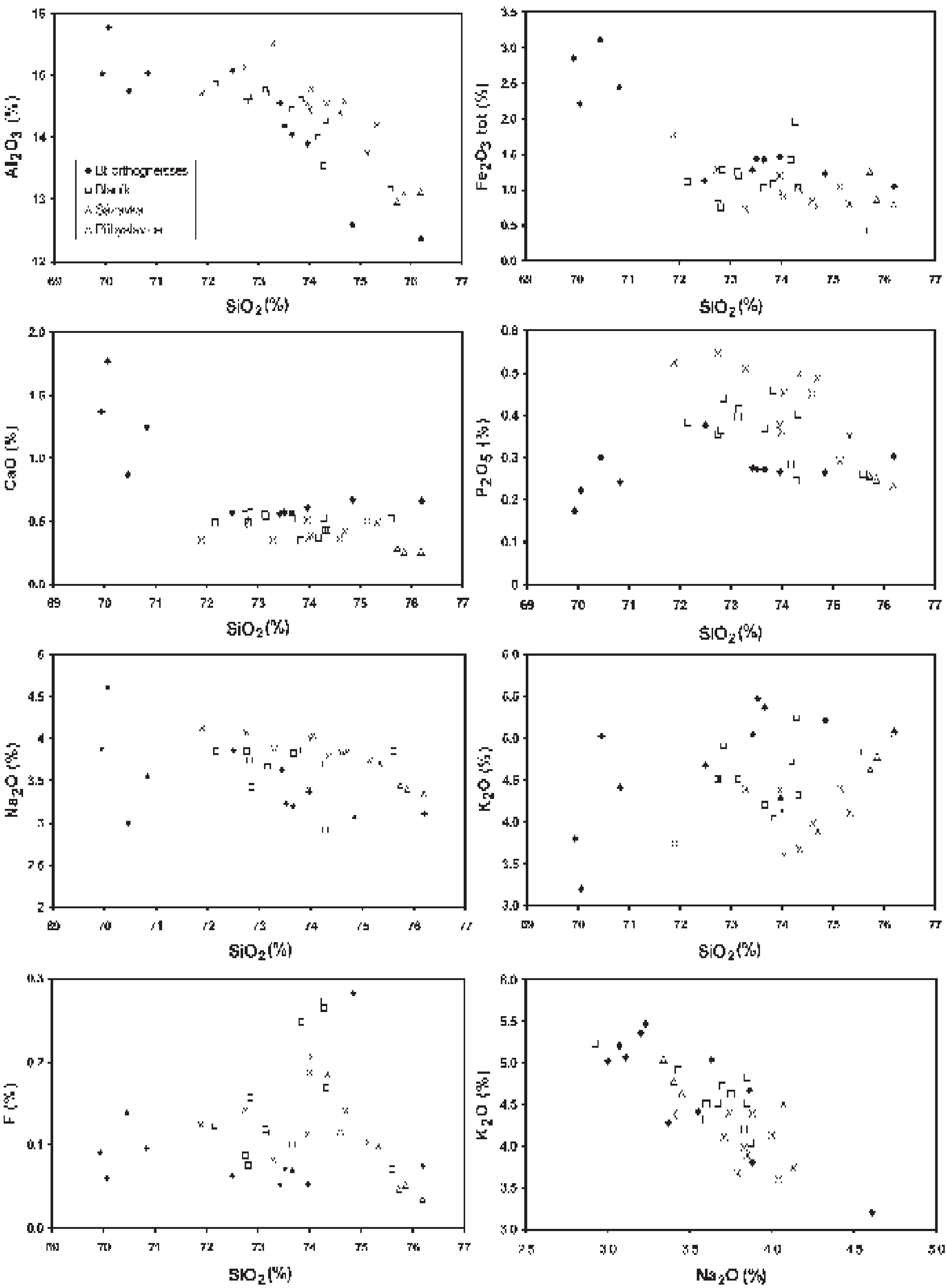

Fig. 2 Harker diagrams and Na_2O vs. K_2O of orthogneisses.

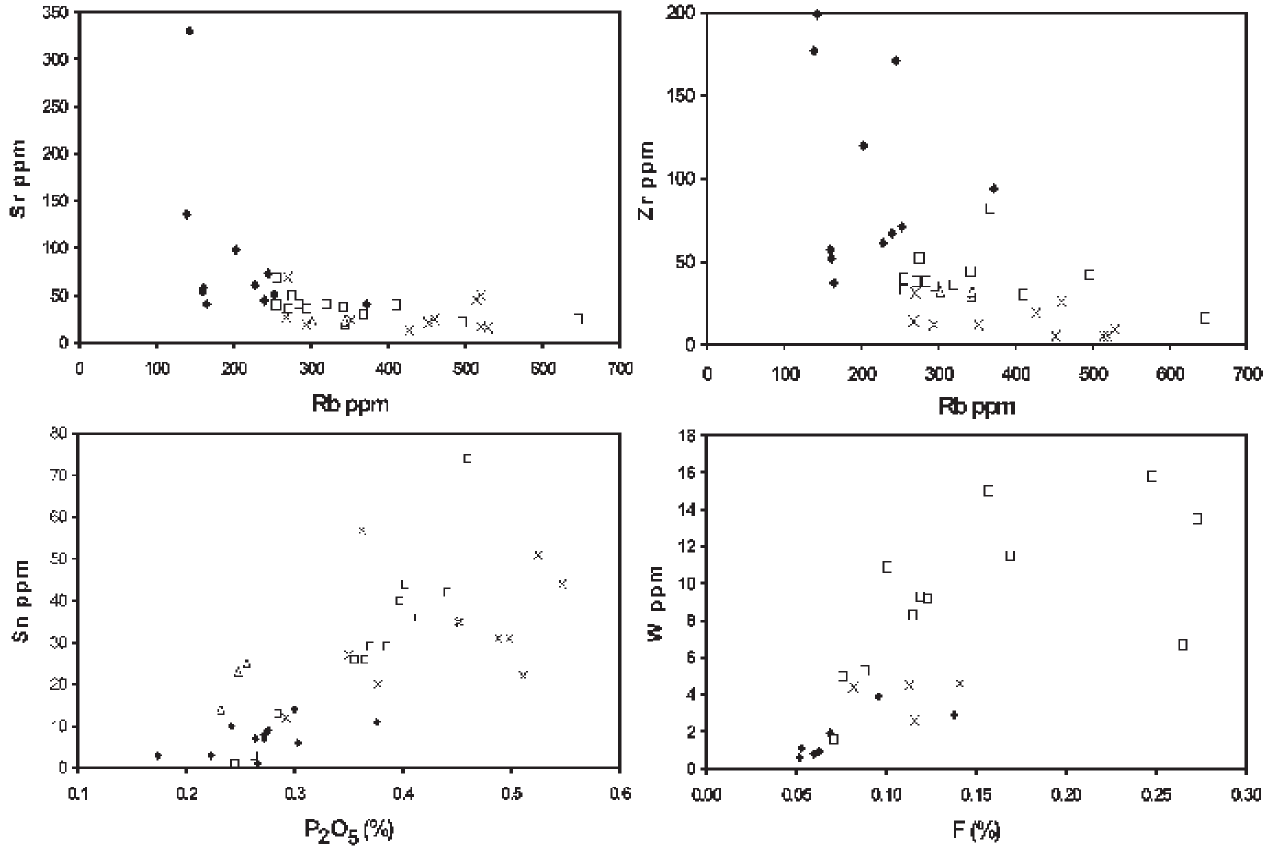

Fig. 3 Trace element contents in orthogneisses.

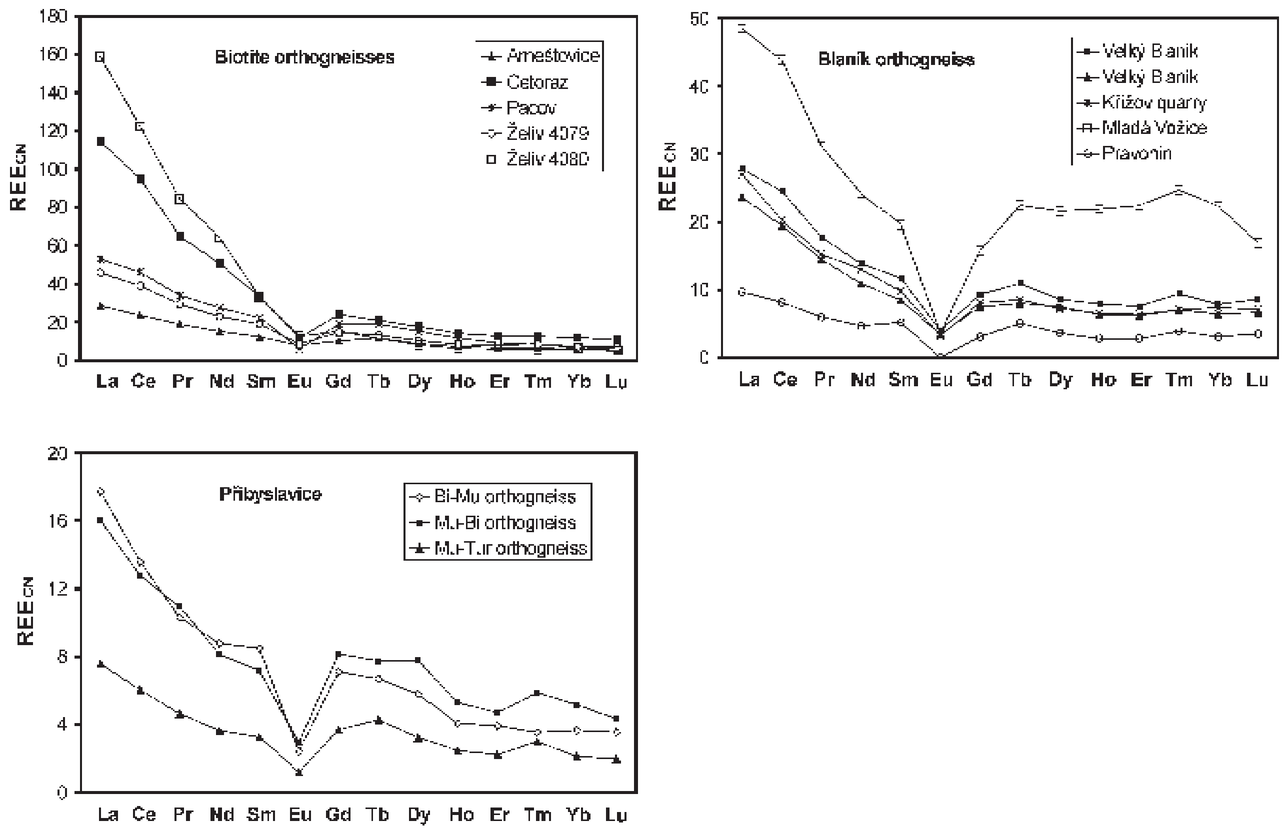

Fig. 4 Chondrite-normalised REE distribution patterns of orthogneisses.

T a b l e 2 Chemical composition of orthogneisses. Major elements in wt. %, trace elements in ppm.

Locality	Želiv	Římovice	Cetoraz	Vlastějovice	Kácov	Mladá Vožice	Trhový Štěpánov	Velký Blanik	Velký Blanik	Javorník	Sázavka	Březí	Podmoky	Přibyslavice	Přibyslavice
No.	**4080**	**3775**	**4069**	**3795**	**3806**	**4072**	**3798**	**4074**	**4075**	**4077**	**3484**	**3266**	**3770**	**3262**	**3342**
SiO_2	70.06	69.94	70.83	74.85	76.2	74.28	75.60	72.85	73.66	74.32	75.73	73.96	72.75	74.7	73.83
TiO_2	0.35	0.33	0.31	0.14	0.10	0.16	0.04	0.13	0.14	0.11	0.08	0.10	0.06	0.04	0.05
Al_2O_3	15.77	15.02	15.03	12.59	12.36	13.54	13.16	14.57	14.44	14.27	12.97	14.54	15.13	14.58	15.36
Fe_2O_3	0.880	0.740	0.480	0.260	0.410	0.500	0.190	0.480	0.340	0.410	0.348	0.165	0.410	0.369	0.233
FeO	1.210	1.920	1.780	0.880	0.580	1.330	0.220	0.730	0.620	0.560	0.830	0.940	0.800	0.361	0.411
MnO	0.630	0.066	0.560	0.022	0.023	0.220	0.022	0.200	0.190	0.140	0.079	0.051	0.111	0.031	0.021
MgO	0.041	0.670	0.053	0.150	0.130	0.029	0.100	0.058	0.034	0.040	0.090	0.150	0.160	0.050	0.020
CaO	1.77	1.37	1.25	0.67	0.66	0.53	0.52	0.57	0.52	0.43	0.29	0.51	0.47	0.42	0.29
Li_2O	0.015	0.012	0.021	0.015	0.003	0.017	0.002	0.029	0.011	0.027	0.004	0.030	0.024	0.061	0.060
Na_2O	4.61	3.88	3.55	3.07	3.11	2.92	3.85	3.43	3.83	3.56	3.45	3.40	4.07	3.85	4.99
K_2O	3.20	3.80	4.41	5.21	5.07	5.24	4.83	4.91	4.20	4.32	4.63	4.38	4.51	3.89	3.45
P_2O_5	0.223	0.174	0.242	0.264	0.303	0.245	0.262	0.441	0.370	0.402	0.256	0.377	0.547	0.488	0.363
F	0.060	0.091	0.096	0.282	0.075	0.265	0.071	0.157	0.101	0.169	0.047	0.113	0.142	0.141	0.117
H_2O^+	0.840	1.020	0.780	0.650	0.600	0.920	0.410	0.950	0.990	0.750	0.478	0.783	0.740	0.627	0.539
H_2O^-	0.12	0.20	0.05	0.12	0.10	0.06	0.10	0.08	0.14	0.06	0.09	0.09	0.08	0.05	0.06
Total	99.77	99.23	99.45	99.18	99.72	100.25	98.83	99.59	99.59	99.57	99.36	99.57	100.00	99.63	99.77
As	5	6	6	5	4	11	4	5	5	5	8	< 7	7	18	8
B	10		9			11	405	546	49	789		190	833	822	
Ba	891		503			112	222	126	194	100		80	79	5	
Be	3		1			2	< 0.5	3	<1	<1			1		
Co	3		3			1		1	1	1		< 0.5		< 0.5	
Cs	5		16			18	1	46	19	22		19	11	14	
Cu	6	7	6	5	5	4	3	4	4	4	11	< 7	4	< 7	5
Ga	22		21			21	20	22	20	22		23	26	31	
Hf	5		4			3	3	2	2	2		2	1	2	
Nb	9	14	13	14	10	12	13	14	12	15	8	17	23	19	20
Pb	19	19	19	< 2	6	4	4	14	11	7	9	15	6	< 7	< 2
Rb	143	139	203	372	228	368	275	342	256	410	344	294	460	520	571
Sn	3	3	10	7	6	< 2	3	42	29	44	25	20	44	31	50
Sr	330	136	98	41	61	30	50	38	69	40	19	19	25	17	19
Ta	1		2			2	3	4	2	4		2	4	1	
Th	18	15	12	18	10	13	12	4	6	5		1.5	2	0.6	0.4
U	5	4	3	8	6	5	10	5	< 2	6	4	6.1	4	6.5	3.5
V	23		23			6	< 5	<5	5	<5		< 5	< 5	< 5	
W	1		4			7	2	15	11	12		5	5	5	
Zn	60	57	84	30	30	49	17	70	36	61	42	43	6	46	81
Zr	199	177	120	94	61	82	52	44	33	30	29	12	26	5	11
Y	11.10	*28.60*	25.00	*42.60*	*23.00*	37.10	14.10	14.60	12.20	9.40	*6.20*	10.40	7.50	4.00	*3.00*
La	37.70	*35.70*	27.20	*12.60*	*5.70*	11.50	2.10	6.60	5.60	4.50	*2.30*	3.80	4.20	1.00	*0.80*
Ce	74.90	*77.90*	58.10	*34.60*	*14.10*	26.90	4.50	15.00	11.90	9.50	*5.00*	7.80	8.30	2.40	*2.10*
Pr	8.01	*7.80*	6.18	*3.30*	*2.00*	2.96	0.58	1.69	1.38	1.16	*<0.70*	1.04	0.98	0.29	
Nd	30.00	*30.30*	23.70	*14.30*	*6.40*	11.30	2.20	6.50	5.10	4.70	*<2.00*	3.80	4.10	0.90	
Sm	5.10	*6.94*	5.10	*4.19*	*2.14*	3.00	1.00	1.80	1.30	1.20	*0.54*	1.10	1.30	0.60	*0.54*
Eu	0.73	*0.96*	0.69	*0.70*	*0.31*	0.21	0.06	0.23	0.20	0.13	*<0.08*	0.17	0.14	<0.05	
Gd	3.12	*5.81*	4.92	*4.59*	*2.37*	3.26	1.25	1.92	1.55	1.18	*0.70*	1.68	1.46	0.75	*0.69*
Tb	0.43	*<0.70*	0.78	*<0.70*	*<0.70*	0.84	0.31	0.41	0.30	0.26	*<0.70*	0.29	0.25	0.13	
Dy	2.05	*5.27*	4.50	*7.58*	*4.00*	5.49	2.12	2.19	1.92	1.62	*1.05*	1.97	1.47	0.75	*0.70*
Ho	0.35	*1.11*	0.80	*1.38*	*0.56*	1.24	0.43	0.45	0.36	0.30	*<0.50*	0.30	0.23	0.11	
Er	0.96	*3.86*	2.12	*6.00*	*2.68*	3.71	1.49	1.26	1.03	0.91	*<0.40*	0.78	0.65	0.33	
Tm	0.14	*0.52*	0.32	*0.78*	*0.53*	0.63	0.25	0.24	0.18	0.14	*<0.30*	0.15	0.09	< 0.05	
Yb	1.09	*3.00*	2.03	*5.04*	*2.94*	3.79	1.84	1.34	1.10	0.97	*1.13*	0.88	0.62	0.52	*0.40*
Lu	0.13	*0.37*	0.27	*0.58*	*0.38*	0.43	0.24	0.22	0.17	0.16	*0.17*	0.11	0.09	0.08	*0.06*

in the centre. Contents of Fe and P decrease with increasing SiO_2; Fe decreases due to disappearance of biotite, P due to decrease of K-feldspar (the main P-host), in the domains of the intrusion most enriched in quartz. Contents of alkalis are very variable and reflect changes in the ratio between K-feldspar and albite in the muscovite facies. Contents of compatible trace elements Sr, Zr, Th and REE are low, namely in the muscovite-tourmaline facies. Among lithophile elements, Rb and Sn have tendency to strong enrichment (200→600 ppm and 10→60 ppm, respectively), while F and Li are relatively low (0.1–0.2 wt. % F, 0.02–0.06 wt. % Li_2O).

All orthogneisses are generally peraluminous with aluminium saturation index (ASI) 1.15–1.30. Less peraluminous (ASI = 1.05) are only the quartz-rich and mica-poor varieties of both biotite and leucocratic types of orthogneisses (Vlastějovice, Kácov and Trhový Štěpánov).

Boron is typically enriched in two-mica orthogneisses, with abundances ranging between 300 and 1200 ppm. There are no clear correlations between boron and F or P contents.

4. Mineralogy

Feldspars

Plagioclase and K-feldspar are, together with quartz, the main constituents of all studied rocks. The less siliceous biotite orthogneisses contain P-free oligoclase (An13–20) and P-poor K-feldspar with max. of 0.1 wt. % P_2O_5.

Albite and K-feldspar in two-mica and muscovite orthogneisses are enriched in phosphorus: albite contains about 0.3–0.5 wt. % P_2O_5, K-feldspar about 0.5–0.8 wt. % P_2O_5. Texture of both feldspars, together with their high content of phosphorus, indicate that feldspars survived the Variscan metamorphism without significant changes of composition.

Micas

Micas, biotite and/or muscovite, play important role in all studied orthogneisses. Biotite is the most important carrier of Fe, Mg, Mn and Ti. Among trace elements, both micas are major host of F, Li and Zn, and important host of Rb, Cs and Be (Tables 3 and 4).

All biotites (Fig. 5a) should be termed as annite. Fe/Mg-ratio and ^{IV}Si-occupancy varied among individual samples only slightly. Remarkable is the finding that there is no difference in contents of major elements between annites from the biotite orthogneisses and those from the two-mica orthogneisses. Of course, important differences are observed in minor elements: Li, Rb, Cs, Zn and F are enriched and Ba, Be and V depleted in biotite from the most fractionated muscovite orthogneisses in comparison with biotite from biotite orthogneisses (Fig. 5c).

Muscovite occurs as an accessory phase in some biotite orthogneisses and becomes a major phase in the two-mica and muscovite-tourmaline orthogneisses. In biotite orthogneisses, muscovite is relatively Mg-rich and Si-poor, in leucocratic orthogneisses muscovite becomes Fe-rich and sometimes also Si-richer (Fig. 5b).

In comparison with associated biotites, muscovites in all orthogneisses are relatively Mg-enriched. Among trace elements, contents of Rb in muscovite are well comparable with those in biotite, but Li, Cs, F and Zn are systematically more enriched in biotite.

Tourmaline

Tourmaline is present only in the most leucocratic and peraluminous types of orthogneisses, generally as the exclusive Fe-Mg-bearing mineral in association with muscovite (Trhový Štěpánov, Javorník, Přibyslavice). In the less fractioned part of the Přibyslavice orthogneiss at Golčův Jeníkov, only accessory tourmaline in association with scarce biotite has been found. Where tourmaline occurs in association with garnet (Přibyslavice), the garnet is clearly younger.

All tourmalines should be classified as schorl (Table 5, Fig. 6). Schorl is relatively rich in Al, total Al is 6.0–7.0 apfu. Some Al probably enters the T-site (usually 0.1–0.2 apfu, max. 0.3 apfu), the Z-site is fully occupied by Al and ^{Y}Al is 0.0–0.8. In the X-site, Na (0.7–0.9 apfu.) clearly prevails above the vacancies (0.1–0.3 apfu) and Ca (<0.04 apfu); only tourmaline from Trhový Štěpánov contains about 0.1 apfu Ca (Fig. 6a). The most variegated is the occupancy of Y-site: content of Al ranges from less than 0.1 atoms (Trhový Štěpánov) to 0.4–0.7 atoms (Přibyslavice), while the Fe/Fe+Mg-ratio increases from 0.6–0.7 in Trhový Štěpánov and Golčův Jeníkov, to 0.9–0.95 in Přibyslavice (Figs 6 b, c). ^{Y}Al correlates negatively with Mg.

Taken together, tourmaline evolved from relatively Al, Na-poor, Mg-enriched, to Al, Na, Fe-enriched schorl.

Garnet

Garnet is a common accessory to minor phase in some two-mica orthogneiss bodies. Its position in crystallisation sequence varies from the early crystallised disseminated accessory grains (two-mica orthogneis of the Blaník type in the Keblov quarry) through the late magmatic (?) crystallisation of quartz-garnet nodules (Leština, Přibyslavice) to late metamorphic crystallisation on shear-zones cutting the foliation (two-mica orthogneiss of the Blaník type in the Křížov quarry).

All analysed garnets are almandine with 10–20 % of spessartine component. Contents of grossular and pyrope components are low to negligible (together always < 5 mol.%). A characteristic feature of all garnets from studied Moldanubian orthogneisses is enrichment in phosphorus, usually between 0.1 and 0.4 wt. % P_2O_5. The substitution $\square + 2P \leftrightarrow R^{2+} + 2Si$ and/or alluaudite-type substitution $Na + \square + 3P \leftrightarrow 2R^{2+} + 3Si$ seem the most likely mechanisms of phosphorus incorporation in garnet structure (Breiter et al. 2005). Yttrium concentration is usually below detection limit (350 ppm). Garnets are only slightly zoned with relatively Mn (+Ca, Mg, P)-enriched core and Fe-enriched rim.

In biotite orthogneisses, garnet has not been found.

Table 3 Chemical composition (wt. %) and empirical formulae (based on 46 positive charges) of micas.

Mica	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
Locality	Psárov	Malý Blaník	Mladá Vožice	Keblov	Trhový Štěpánov	Podmoky	Přibyslavice	Želiv	Psárov	Vlastějovice	Cetoraz	Mladá Vožice	Choustník	Keblov	Podmoky	Přibyslavice
Sample	**4066**	**4073**	**4072**	**3796**	**3798**	**3770**	**3264**	**4080**	**4066**	**3795**	**4069**	**4072**	**4065**	**3796**	**3770**	**3266**
SiO_2	45.72	46.57	46.75	45.56	46.93	46.36	45.20	35.30	34.57	35.78	34.21	35.18	35.66	34.48	33.97	34.24
Al_2O_3	35.26	35.34	33.32	34.40	29.57	33.14	33.64	18.17	19.15	17.91	19.62	18.65	19.56	19.53	20.08	20.18
TiO_2	1.03	0.35	0.37	0.70	1.23	0.53	0.14	3.17	3.030	2.68	2.56	1.14	2.32	2.28	2.04	2.64
FeO	0.88	1.44	2.96	1.69	3.85	2.21	3.05	21.16	21.31	26.96	22.19	27.72	24.55	23.80	24.95	25.75
MgO	0.53	0.59	0.96	0.75	1.75	0.82	0.51	7.61	6.46	2.49	6.16	3.00	2.28	4.09	3.17	2.39
MnO	0.00	0.00	0.00	0.13	0.01	0.08	0.28	0.27	0.40	0.35	0.38	0.52	0.53	0.40	0.43	0.48
CaO	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.00
BaO	0.01	0.00	0.00	0.02	0.09	0.04	n.a.	0.19	0.00	0.05	0.00	0.11	0.01	0.05	0.00	
Na_2O	0.60	0.53	0.55	0.72	0.48	0.63	0.96	0.10	0.07	0.10	0.13	0.07	0.08	0.14	0.06	0.41
K_2O	10.67	10.27	10.18	10.44	10.43	10.46	10.34	9.79	9.78	9.81	9.73	9.39	9.71	9.40	9.35	9.19
Total	94.72	95.12	95.13	94.44	94.37	94.35	94.10	95.76	94.75	96.14	94.99	95.79	94.76	94.26	94.13	95.27
Si	6.122	6.195	6.273	6.147	6.410	6.269	6.171	5.423	5.369	5.615	5.324	5.557	5.597	5.435	5.390	5.384
Al	5.565	5.542	5.270	5.471	4.761	5.281	5.413	3.291	3.505	3.312	3.598	3.472	3.618	3.628	3.756	3.741
Ti	0.104	0.035	0.038	0.071	0.126	0.054	0.014	0.366	0.354	0.316	0.300	0.135	0.274	0.270	0.243	0.312
Fe	0.098	0.160	0.332	0.190	0.440	0.250	0.348	2.719	2.768	3.539	2.888	3.662	3.222	3.138	3.311	3.386
Mg	0.105	0.117	0.193	0.151	0.355	0.166	0.103	1.743	1.496	0.583	1.430	0.706	0.534	0.962	0.750	0.561
Mn	0.000	0.000	0.000	0.015	0.001	0.010	0.032	0.036	0.052	0.047	0.050	0.070	0.071	0.054	0.057	0.064
Ca	0.002	0.000	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.008	0.000	0.000
Ba	0.000	0.000	0.000	0.001	0.005	0.002	0.000	0.012	0.000	0.003	0.000	0.007	0.001	0.004	0.000	0.000
Na	0.155	0.136	0.144	0.189	0.128	0.166	0.254	0.031	0.022	0.031	0.039	0.023	0.024	0.042	0.019	0.126
K	1.823	1.743	1.742	1.798	1.817	1.805	1.801	1.919	1.938	1.963	1.932	1.893	1.943	1.890	1.892	1.843

Table 4 Trace elements in biotite from orthogneisses (F and Li_2O in wt. %, other in ppm).

Locality	No.	F	Li_2O	Sr	Ba	V	Be	Zn	Rb	Cs
Želiv	**4079**	0.33	0.19	9	101	55	1.5	765	826	83
Zeliv	**4080**	0.47	0.14	35	616	142	5.9	564	818	50
Psárov	**4066**	0.70	0.13	4	205	185	0.9	506	1089	126
Bácovice	**4067**	0.36	0.10	17	111	107	1.3	567	475	35
Cetoraz	**4069**	0.61	0.18	3	247	188	<0.8	838	1148	131
Pacov	**4071**	0.53	0.21	8	87	42	<0.8	843	1117	132
Vlastějovice	**3795**	2.88	0.18	6	103	35	2.1	549	2256	73
Kácov	**3806**	0.85	0.05	8	149	22	<0.8	577	1366	21
Choustník	**4065**	2.45	0.56	4	62	71	1.6	622	3161	686
Mladá Vožice	**4072**	1.83	0.17	3	91	36	1.5	635	2064	202
Malý Blanik	**4073**	0.90	0.18	9	117	49	<0.8	1016	1839	379
Velký Blanik	**4074**	1.09	0.47	27	48	35	1.5	1218	2258	756
Velký Blanik	**4075**	0.86	0.20	7	104	70	<0.8	651	1676	424
Velký Blanik	**4076**	1.14	0.33	4	91	39	1.1	1001	1800	491
Keblov	**3796**	1.10	0.19	6	50	68	<0.8	978	1844	387
Keblov	**3797**	1.07	0.25	6	47	68	<0.8	1021	1870	319
Křížov	**3799**	1.31	0.59	3	52	64	<0.8	1077	2191	451
Javorník	**4077**	1.67	0.51	11	83	51	<0.8	1126	2710	418
Podmoky	**3770**	1.67	0.54	5	29	23	<0.8	1584	3615	269
Podmoky	**3771**	0.92	0.27	8	26	4	<0.8	1321	2545	124
Leština	**3787**	0.95	0.10	6	25	14	<0.8	1026	2615	368

Fluorapatite

Fluorapatite is the major carrier of phosphorus in biotite orthogneisses. In two-mica and muscovite orthogneisses apatite is also common, but substantial part of phosphorus is hosted in alkali feldspars. All studied apatites are homogeneous fluorapatites without any compositional zoning. Contents of Cl, U, Th, Sr and Ba are negligible. REE contents are low, too – about 0.1–0.2 wt. % Ce_2O_3 and about 0.1–0.4 wt. % Y_2O_3, with a slight tendency to enrichment in more peraluminous samples (Table 6).

Fluorapatites from biotite orthogneisses are nearly pure apatites with very low contents of Mn and Fe (<0.1 apfu), while fluorapatites from two-mica and muscovite orthogneisses are substantially enriched in Mn and slight-

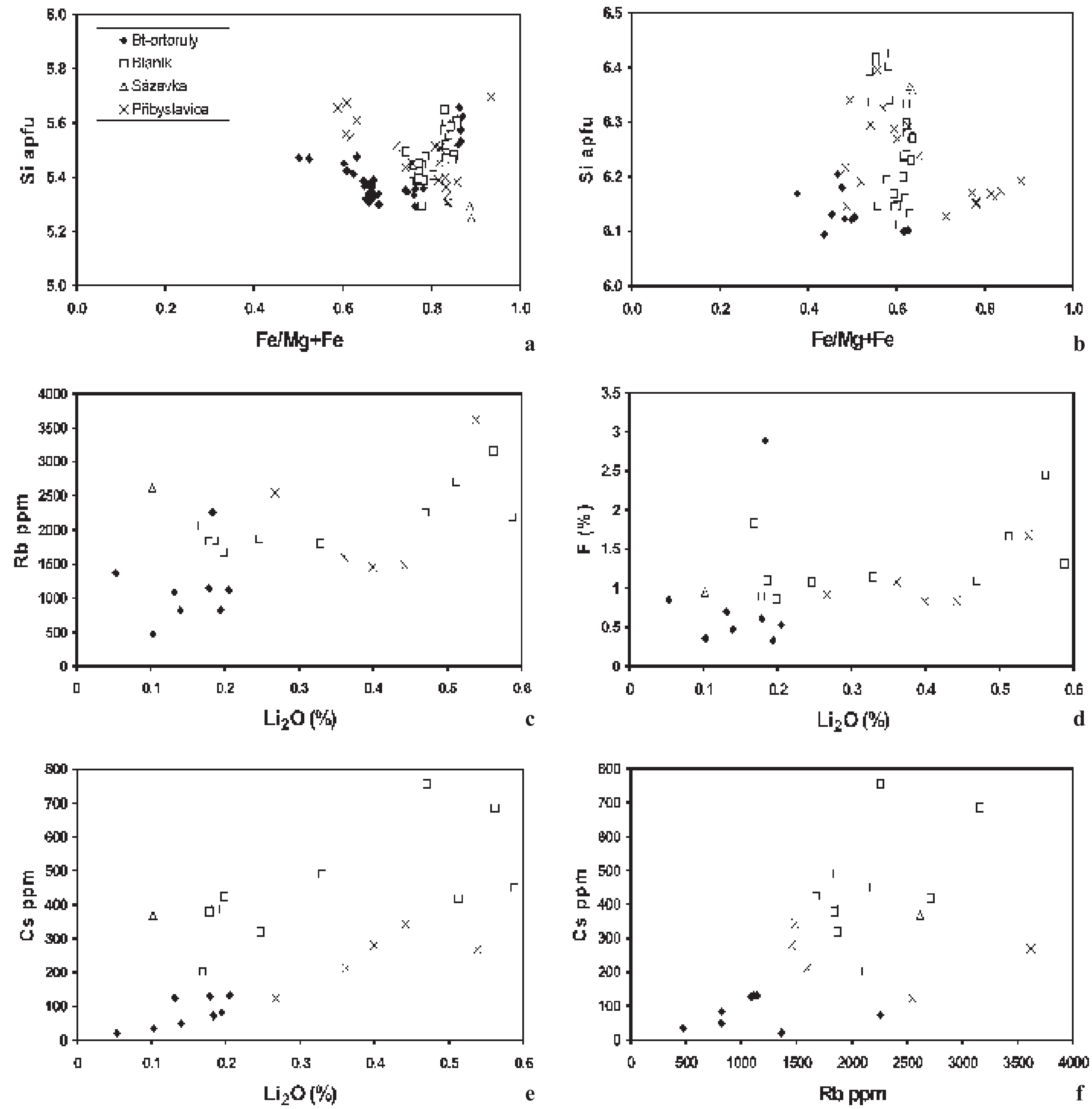

Fig. 5 Chemical composition of micas: a – Fe/(Fe+Mg) vs. Si apfu in biotite; b – Fe/(Fe+Mg) vs. Si apfu in muscovite; c – Li_2O vs. Rb in biotite; d – Li_2O vs. F in biotite; e – Li_2O vs. Cs in biotite; f – Rb vs. Cs in biotite.

ly also in Fe (Fig. 7). The most Mn-rich (0.3–0.6 apfu) apatites were found in tourmaline-bearing orthogneisses.

Zircon

Zircon is common in biotite and two-mica orthogneisses, but scarce in muscovite and muscovite-tourmaline orthogneisses. Biotite orthogneisses contain simple homogeneous zircon crystals with chemical composition near ideal $ZrSiO_4$. Phosphorus, if present, is compensated by Y, according to xenotime substitution (Si+Zr ↔ P+Y) (Table 7, Fig. 8). Zircons from more fractionated two-mica orthogneisses are more complicated, often zoned and enriched in P, U, Al, Fe and Sc. In this case, P in tetrahedral position is coupled with U, Fe and Sc in the Zr-position [Si+Zr ↔ P+(U, Fe, Sc)] and partially also with Al in tetrahedral position, according to berlinite substitution 2 Si ↔ P+Al.

Monazite

Monazite is a common accessory mineral in all types of biotite and two-mica orthogneisses. With only rare exceptions, all studied monazites are homogeneous without any type of zoning or alteration. Monazite from biotite orthogneisses is Th-, U- and Ca-poor (3.4–8.3 wt. % ThO_2, and uranium usually below 1 wt. % UO_2), but with variable Y, also within one thin section (sample from Želiv, Fig. 9a, Table 8). The incorporation of Th and U in the monazite from biotite orthogneisses took place by almost

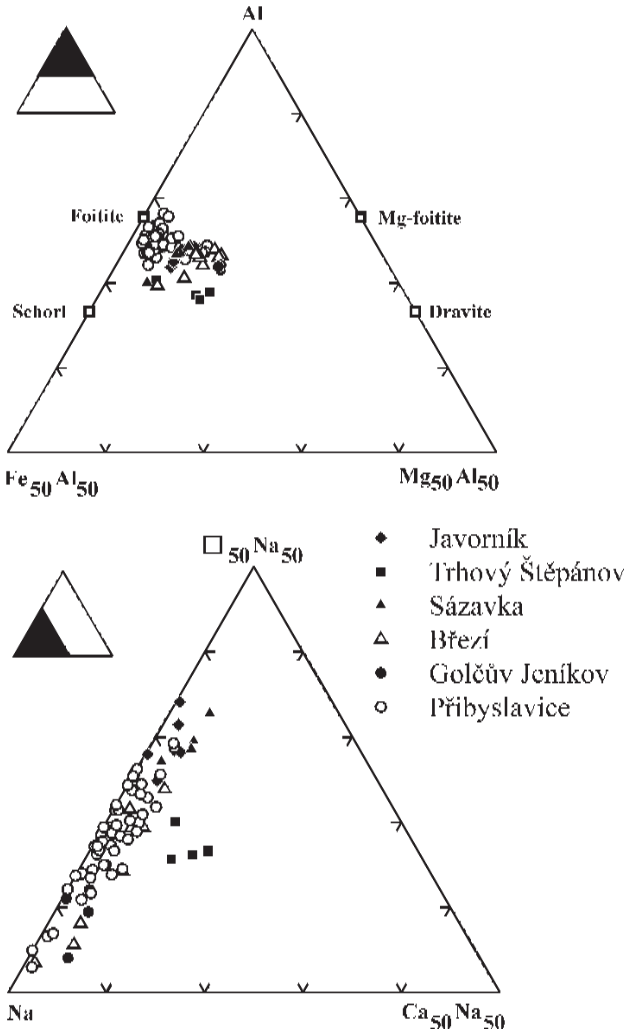

Fig. 6 Tourmaline: upper triangle – totAl-Fe-Mg diagram; lower triangle – X-site occupancy.

pure brabantite substitution (up to 7 % brabantite component) (Fig. 9a).

Monazites from two-mica orthogneisses are more variable, substantially enriched in U (sample from Keblov) or in Th (sample from Mladá Vožice). In Keblov, majority of monazite grains are extremely U-rich (8.4–10.5 wt. % UO_2), however, U enrichment is not accompanied by enrichment in Th (1.0–3.5 wt.% ThO_2). The Th-richer monazite grain (33.9–37.3 wt. % ThO_2; 0.30–0.33 apfu Th) has a composition closer to cheralite-(Ce). Monazite grains from Mladá Vožice sample are rich in Th (11.6–19.0 wt. % ThO_2), with relatively low U (0.6–1.8 wt. % UO_2). Th and U enter the monazite structure dominantly by brabantite substitution (4–14 %), however, huttonite substitution (1–10 %) is also significant. Distribution of chondrite-normalised REE-contents is generally regular with slightly higher content of LREE in monazites from the biotite orthogneisses than from the two-mica orthogneisses. The lowest REE content has been found in Th-rich monazite grains from Keblov (Fig. 9b).

Four orthogneiss samples analysed by U-Th-Pb monazite chemical geochronological method yield late Variscan age of 306–326 Ma (Table 9), which can be attributed to the cooling of Moldanubian crust after Variscan metamorphism.

Ti-oxides

The whole-rock contents of Ti are low in biotite orthogneisses (max. 0.3 wt. % TiO_2) and even lower in leucocratic orthogneiss (0.05–0.15 wt. % TiO_2). Majority of Ti is bound in biotite (2–3 wt. % TiO_2), Ti-bearing oxides are scarce. Ilmenite from biotite orthogneisses is typically rich in Mn (5–9 wt. % MnO). Rutile from biotite orthogneiss is nearly pure TiO_2, but individual grains with up to 1 wt. % Nb_2O_5 and 1.5 wt. % Ta_2O_5 were found in Blaník orthogneiss.

5. Discussion

The age of magmatic precursors of tourmaline-muscovite Moldanubian orthogneisses is poorly understood. The only trustworthy age is that published by Vrána and Kröner (1995) from the Hluboká orthogneiss. Six individually evaporated zircon grains yielded $^{207}Pb/^{206}Pb$ age of 508±7 Ma. Our attempt to use monazite for dating of studied orthogneisses was unsuccessful. All analysed monazite grains yielded a late Variscan age of 316–327 Ma (Table 9), which should be attributed to the late-Variscan metamorphic and post-metamorphic effects (decompression and cooling).

Typical chemical feature of Moldanubian two-mica and muscovite orthogneiss is enrichment in phosphorus (0.3–0.5 wt. % P_2O_5), tin (30–70 ppm Sn) and tungsten (5–15 ppm W). From this point of view, two-mica orthogneisses are well comparable with peraluminous class of Variscan tin granites through the Bohemian Massif (Breiter 1998). Tin is enriched in both Blaník and Přibyslavice orthogneisses, while tungsten is enriched only in the Blaník orthogneiss. Both elements positively correlate with F and P (Fig. 3), which may play an important role in tin transport in late- and/or postmagmatic fluids. However, no indications of tin mineralization within the orthogneisses, nor in surrounding rocks have been found until now. Tin minerals, cassiterite and nigerite, already reported from Přibyslavice (Čech et al. 1978, Povondra et al. 1987) are

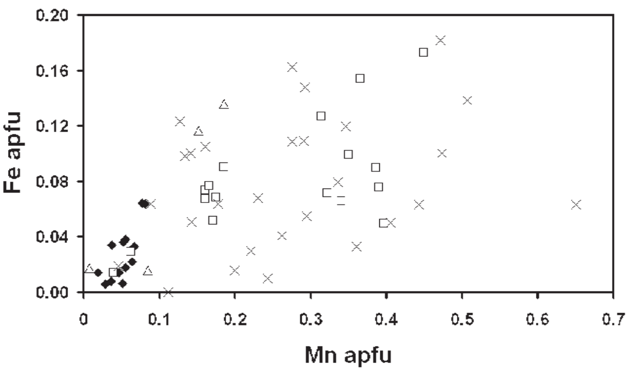

Fig. 7 Contents of Mn and Fe in fluorapatite (atoms per formula unit).

Table 5 Chemical composition (wt. %) and empirical formulae (based on 49 positive charges) of tourmaline.

Locality	Javorník	Javorník	Trhový Štěpánov	Trhový Štěpánov	Sázavka	Sázavka	Březí	Březí	Přibyslavice	Přibyslavice	Přibyslavice	Pribyslavice
No.	4077	4077	3798	3798	3485	3485	3267	3266	3283	3283	3270	3270
SiO_2	35.02	35.98	35.45	35.33	34.95	34.56	35.25	34.88	35.33	35.14	35.19	33.97
TiO_2	0.84	1.00	0.33	0.72	0.68	1.12	0.93	0.74	0.27	1.02	0.49	0.66
Al_2O_3	32.99	31.46	30.80	30.46	32.94	32.97	32.96	32.09	33.17	33.15	32.59	33.93
FeO	12.70	13.10	15.19	12.40	13.00	13.41	10.46	13.88	14.98	11.40	14.84	13.10
MnO	0.19	0.00	0.02	0.03	0.10	0.18	0.00	0.28	0.00	0.20	0.25	0.00
MgO	2.05	1.91	1.71	3.91	2.03	1.97	3.64	2.77	0.49	2.98	0.93	2.00
CaO	0.15	0.02	0.37	0.65	0.11	0.23	0.25	0.12	0.00	0.15	0.00	0.03
Na_2O	2.09	1.95	2.16	2.13	2.14	1.91	2.52	2.57	2.20	2.22	2.37	2.51
K_2O	0.05	0.11	0.10	0.09	0.06	0.06	0.00	0.15	0.11	0.00	0.17	0.02
Total	86.09	85.61	86.14	85.70	86.04	86.40	86.18	87.49	86.56	86.32	86.83	86.22
Si	5.889	6.083	6.045	5.985	5.889	5.818	5.859	5.840	5.962	5.856	5.940	5.726
Ti	0.106	0.128	0.042	0.092	0.086	0.141	0.116	0.093	0.034	0.128	0.063	0.083
Al	6.537	6.269	6.190	6.081	6.544	6.543	6.456	6.335	6.598	6.511	6.483	6.742
Fe	1.785	1.853	2.166	1.756	1.833	1.888	1.454	1.944	2.115	1.589	2.095	1.847
Mn	0.026	0.000	0.002	0.005	0.014	0.026	0.000	0.040	0.000	0.029	0.035	0.000
Mg	0.514	0.482	0.435	0.987	0.510	0.494	0.903	0.693	0.124	0.739	0.235	0.503
Ca	0.028	0.004	0.068	0.118	0.019	0.041	0.044	0.022	0.000	0.026	0.000	0.005
Na	0.683	0.640	0.714	0.698	0.699	0.624	0.812	0.835	0.721	0.717	0.774	0.820

Table 6 Chemical composition (wt. %) and empirical formulae (based on 25 positive charges) of apatite.

Locality	Želiv	Cetoraz	Mladá Vožice	Keblov	Blaník	Javornik	Přibyslavice	Přibyslavice	Přibyslavice	Přibyslavice
No.	4080	4069	4072	3796	4076	4077	3262	3282	3674b	3674a
SiO_2							0.00	0.09	0.09	0.11
TiO_2							0.16	0.00	0.04	0.00
Al_2O_3							0.00	0.00	0.11	0.17
FeO	0.11	0.20	0.20	1.07	1.00	2.41	1.93	1.54	0.43	0.47
MnO	0.51	0.65	0.55	2.27	4.45	6.18	6.97	3.86	3.11	5.12
MgO							0.00	0.06	0.00	0.00
CaO	54.83	54.34	54.46	51.54	50.50	47.24	45.89	49.52	50.72	49.15
Na_2O	0.12	0.10	0.25	0.23	0.12	0.20	0.33	0.27	0.08	0.00
K_2O							0.01	0.00	0.00	0.14
P_2O_5	41.28	41.30	41.89	41.29	41.25	41.37	41.67	42.66	43.13	43.57
Total	100.95	100.87	102.31	100.48	101.29	101.13	96.96	98.00	97.70	98.73
Si							0.000	0.008	0.008	0.009
Ti							0.011	0.000	0.002	0.000
Al							0.000	0.000	0.011	0.017
Fe	0.008	0.014	0.014	0.077	0.072	0.173	0.138	0.109	0.030	0.033
Mn	0.037	0.047	0.039	0.165	0.322	0.449	0.507	0.275	0.221	0.361
Mg							0.001	0.007	0.000	0.000
Ca	5.004	4.969	4.932	4.739	4.628	4.345	4.225	4.468	4.555	4.382
Na	0.020	0.017	0.041	0.038	0.020	0.033	0.055	0.044	0.013	0.000
K							0.001	0.000	0.000	0.014
P	2.977	2.984	2.998	3.000	2.987	3.006	3.032	3.041	3.061	3.070

genetically linked to small intrusion of Variscan highly fractionated granite intruding into orthogneiss body (Breiter and Škoda, in press). Small tungsten mineralization found in quartz stockwork at Cetoraz (Němec and Tenčík, 1976, Němec and Páša, 1986) was interpreted as metamorphosed pre-Variscan greisen and attributed genetically to the Cetoraz orthogneiss. According to our chemical data, the Cetoraz-Pacov orthogneiss is poor in tungsten (2–4 ppm W) and this interpretation seams to be problematic.

In contrast to the above mentioned general similarity between leucocratic orthogneisses and Variscan tin granites, enrichment in boron, represented macroscopically by tourmaline, is a specific feature only of the orthogneiss (Čadková et al. 1984). We found no correlation between boron and tin, therefore boron does not play a significant role in tin transport and enrichment.

High content of Al, P, B together with low content of Ca in leucocratic orthogneisses is compatible with their

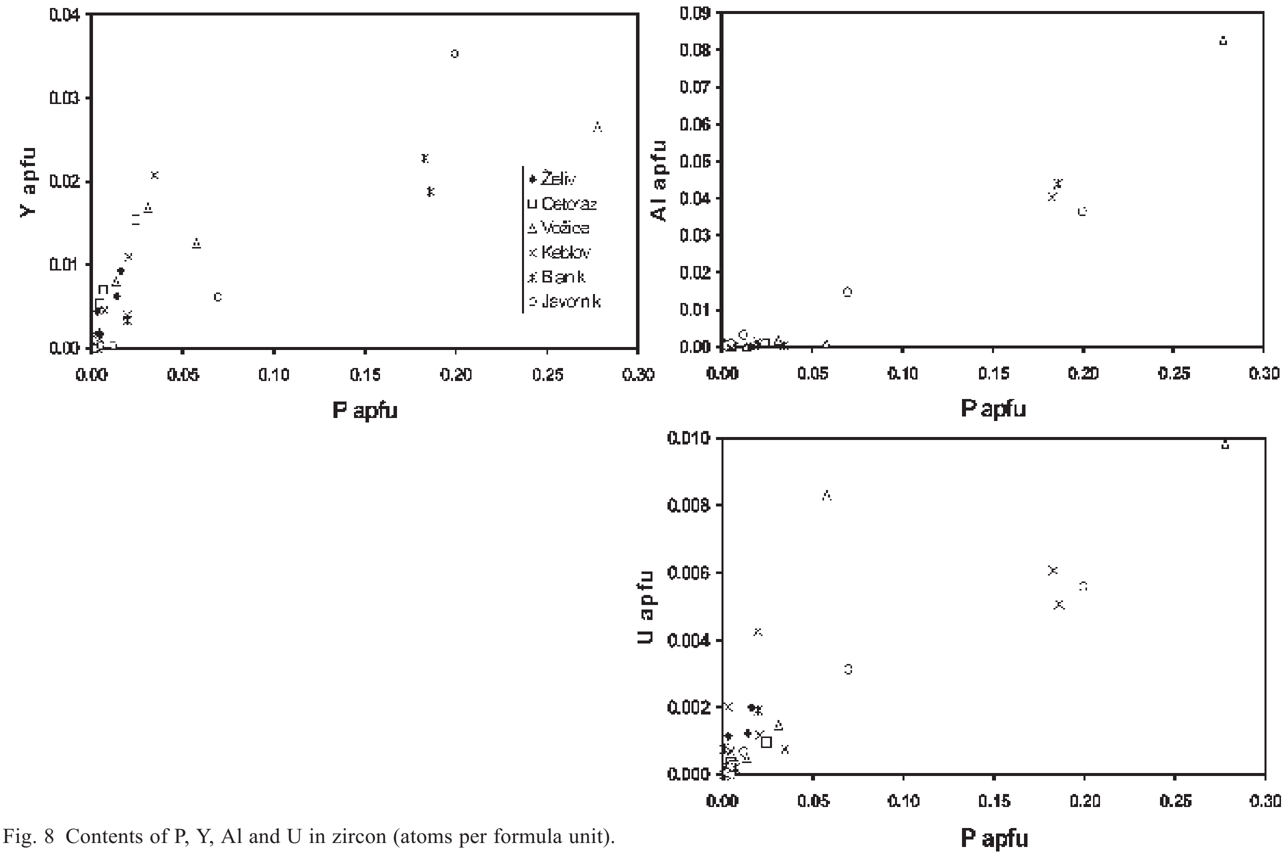

Fig. 8 Contents of P, Y, Al and U in zircon (atoms per formula unit).

Table 7 Chemical composition (wt. %) and empirical formulae (based on 8 positive charges) of zircon.

Locality	Želiv	Cetoraz	Mladá Vožice	Mladá Vožice	Velký Blaník	Velký Blaník	Velký Blaník	Velký Blaník
No.	**4080**	**4069**	**4072**	**4072**	**4076**	**4076**	**4077**	**4077**
SiO_2	32.37	31.64	31.27	18.93	24.16	32.31	31.50	21.04
ZrO_2	65.97	64.15	64.79	53.91	57.73	64.90	64.35	54.50
HfO_2	0.98	1.15	1.29	1.88	2.00	2.24	2.23	1.79
Al_2O_3	0.01	0.00	0.00	2.03	1.16	0.02	0.09	0.91
P_2O_5	0.18	0.24	0.51	9.50	6.84	0.04	0.45	6.92
CaO	0.03	0.03	0.00	0.90	1.33	0.01	0.06	2.24
ThO_2	0.05	0.12	0.00	0.13	0.01	0.00	0.00	0.05
UO_2	0.05	0.04	0.07	1.28	0.71	0.00	0.10	0.74
FeO	0.12	0.39	0.00	1.32	1.26	0.01	0.14	1.21
MnO	0.00	0.02	0.00	0.05	0.09	0.02	0.02	0.07
Y_2O_3	0.11	0.42	0.48	1.44	1.10	0.00	0.02	1.95
Yb_2O_3	0.05	0.13	0.17	0.39	0.31	0.01	0.00	0.51
Sc_2O_3	0.04	0.04	0.03	0.14	0.30	0.03	0.07	0.77
F	0.00	0.00	0.00	1.01	0.82	0.00	0.01	0.96
Total	99.95	98.37	98.61	92.90	97.82	99.60	99.03	93.65
Si	0.993	0.989	0.977	0.653	0.776	0.999	0.982	0.716
Zr	0.987	0.978	0.987	0.908	0.904	0.979	0.978	0.905
Hf	0.009	0.010	0.012	0.019	0.018	0.020	0.020	0.017
Al	0.000	0.000	0.000	0.083	0.044	0.001	0.003	0.037
P	0.005	0.006	0.013	0.278	0.186	0.001	0.012	0.199
Ca	0.001	0.001	0.000	0.033	0.046	0.000	0.002	0.082
Th	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
U	0.000	0.000	0.000	0.010	0.005	0.000	0.001	0.006
Fe	0.003	0.010	0.000	0.038	0.034	0.000	0.004	0.034
Mn	0.000	0.001	0.000	0.001	0.002	0.001	0.001	0.002
Y	0.002	0.007	0.008	0.026	0.019	0.000	0.000	0.035
Yb	0.000	0.001	0.002	0.004	0.003	0.000	0.000	0.005
Sc	0.001	0.001	0.001	0.004	0.008	0.001	0.002	0.023
F	0.000	0.000	0.000	0.110	0.083	0.000	0.001	0.103

Table 8 Chemical composition (wt. %) and empirical formulae (based on 8 positive charges) of monazite.

Locality	Cetoraz	Cetoraz	Želiv	Želiv	Vožice	Vožice	Keblov	Keblov
No.	4069	4069	4080	4080	4072	4072	3796	3796
P_2O_5	30.08	29.11	30.03	29.90	29.78	28.60	29.94	28.68
SiO_2	0.20	0.63	0.16	0.19	0.46	1.07	0.15	0.85
UO_2	2.27	0.54	1.34	0.71	1.65	1.34	9.05	3.26
ThO_2	5.04	6.07	6.54	3.41	13.38	19.05	1.23	37.28
Al_2O_3	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02
La_2O_3	12.88	13.98	12.38	13.53	11.55	11.26	11.54	7.34
Ce_2O_3	27.12	27.94	26.71	28.52	24.51	22.32	25.38	10.94
Pr_2O_3	2.96	2.93	2.93	3.10	2.45	2.11	2.72	0.92
Nd_2O_3	10.55	10.03	10.45	11.95	7.64	6.35	9.43	2.72
Sm_2O_3	2.18	2.02	2.56	2.51	1.50	1.20	1.92	0.44
Gd_2O_3	1.55	1.39	1.80	1.75	0.99	0.82	1.45	0.22
Dy_2O_3	0.74	0.69	0.74	0.59	0.66	0.57	0.76	0.06
Er_2O_3	0.15	0.14	0.15	0.10	0.18	0.16	0.17	0.03
Y_2O_3	2.25	2.18	2.25	1.69	2.30	2.03	2.52	0.28
PbO	0.19	0.12	0.16	0.09	0.28	0.33	0.44	0.68
CaO	1.47	0.87	1.63	0.80	2.79	3.28	2.22	7.75
Total	99.61	98.64	99.82	98.84	100.13	100.47	98.91	101.48
P	0.995	0.978	0.993	0.998	0.983	0.954	0.996	0.952
Si	0.008	0.025	0.006	0.007	0.018	0.042	0.006	0.033
U	0.020	0.005	0.012	0.006	0.014	0.012	0.079	0.028
Th	0.045	0.055	0.058	0.031	0.119	0.171	0.011	0.333
Al	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
La	0.186	0.205	0.178	0.197	0.166	0.163	0.167	0.106
Ce	0.388	0.406	0.382	0.412	0.350	0.322	0.365	0.157
Pr	0.042	0.042	0.042	0.045	0.035	0.030	0.039	0.013
Nd	0.147	0.142	0.146	0.168	0.106	0.089	0.132	0.038
Sm	0.029	0.028	0.034	0.034	0.020	0.016	0.026	0.006
Gd	0.020	0.018	0.023	0.023	0.013	0.011	0.019	0.003
Dy	0.009	0.009	0.009	0.008	0.008	0.007	0.010	0.001
Er	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.000
Y	0.047	0.046	0.047	0.035	0.048	0.043	0.053	0.006
Pb	0.002	0.001	0.002	0.001	0.003	0.003	0.005	0.007
Ca	0.062	0.037	0.068	0.034	0.116	0.138	0.093	0.326

Table 9 Age of monazite analysed by U-Th-Pb method.

Locality	Rock	Age of monazite
Želiv	Biotite orthogneiss	306 ± 19 Ma
Cetoraz	Biotite orthogneiss	318 ± 25 Ma
Mlada Vožice-Šelmberk	Two-mica orthogneiss	319 ± 15 Ma
Keblov	Two-mica orthogneiss with garnet	326.6 ± 9.9 Ma

source in (meta-)pelitic rocks. Near-minimum melting based on breakdown of muscovite may have enriched primary melt particularly in B and Sn. Later behaviour of tin during fractionation was more influenced by concentration of fluorine.

Studied Blaník-type orthogneisses can be well correlated with the Hluboká and Radonice orthogneisses from the southern part of Moldanubicum (Slabý 1991). Povondra and Vrána (1996) stressed relatively more magnesian composition of the Radonice orthogneiss (MgO/FeO_{tot} about 0.2) in comparison to the Hluboká orthogneiss (MgO/FeO_{tot} about 0.1), but similar differences in Mg/Fe ratio can be found also within the Blaník orthogneisses. The bodies at Keblov and Trhový Štěpánov are from this point of view similar to Radonice orthogneiss, the other bodies are similar to the Hluboká orthogneiss (MgO/FeO_{tot} <0.1).

Studied biotite orthogneisses are in all aspects well comparable with biotite orthogneisses from the south-western part of the Moldanubicum (Bechyně and Nové Hrady, Slabý 1991).

Figs 5a and 5b compare Si, Fe and Mg contents in coexisting biotite-muscovite pairs. In biotite orthogneisses, both biotite and muscovite are relatively close to ideal annite, resp. muscovite compositions. In more evolved leucocratic and more silicic rocks, biotite is depleted in Fe+Mg (and Si+Al-enriched), while muscovite is substantially Fe, Mg-enriched. There are, unfortunately, no sufficient criteria for interpretation of the relative roles of magmatic or metamorphic processes in this resulting pattern.

Němec (1980) studied phengitic muscovite from the orthogneisses in Moldanubicum (Blaník and Přibyslav-

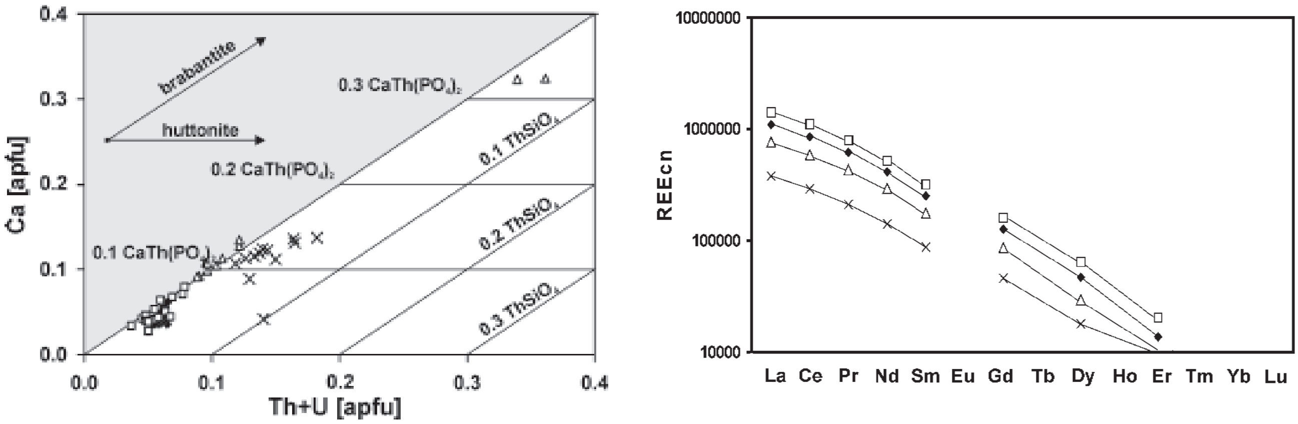

Fig. 9 Monazite: left – brabantite and huttonite substitution; right – chondrite-normalised REE distribution.

ice) and in the Svratka anticline. He found 0.24–0.59 apfu Fe+Mn+Mg and 0.5–2.5 wt. % F. According to our data, the Blaník orthogneisses contain muscovite with 0.25–0.55 apfu (occasionally 0.80 apfu) Fe+Mg and 0.5–1.5 wt. % F, which is generally well comparable.

Fluorapatites from the Přibyslavice and Blaník orthogneiss preserve their primary magmatic composition, as follows from a close compositional similarity to primary fluorapatites in tourmaline pegmatites and alkali-feldspar granites from worldwide localities. Fluorapatites from biotite orthogneisses differ significantly by being much closer in their composition to ideal Ca-phosphate. The former have a composition comparable with fluorapatite from Hluboká (2.11–2.84 wt. % MnO, 0.86–2.38 wt. % FeO and 2.88–3.18 wt. % F), which was together with tourmaline interpreted as a primary magmatic phase by Povondra and Vrána (1993, 1996). The Mn- and Fe-content in fluorapatite is significant in the context of fractionation of the magmatic precursors of orthogneisses, which was, of course, much higher in the case of the two-mica and tourmaline-bearing orthogneisses than in biotite orthogneisses.

The monazite structure prefers Th to U, and concentration of UO_2 in monazite from granitic rocks rarely exceeds 2.5 wt.% UO_2. Concentration of U in monazite from Keblov ranges from 8.4 to 10.5 wt. % UO_2. Such high U content is known in monazite from U-rich leucogranite from Albuquerque, Spain, which contains up to 13.8 wt. % UO_2 (Bea 1996), or from several granitic pegmatites contaning ~ 9.5 wt. % UO_2 (Gulson and Krogh 1973) and ~ 15.6 wt. % UO_2 (Gramaccioli and Segelstad 1978). Uranium-enriched and Th-depleted monazites from Keblov yield an extreme Th/U ratio in the range of 0.1–0.3. In the typical monazite the Th/U ratio is higher or equal to 10; monazites from peraluminous granites of the Erzgebirge-Fichtelgebirge region, Germany, show Th/U ratios close to or below 1 (Förster 1998). Podor et al. (1995), based on the experimental work, found no crystal-chemical limit to entry of U in the monazite structure and supposed influence of U and Th content in the melt on the Th/U ratio in monazites. On the other hand, U-rich melts are likely to produce monazite with predominance of Th over U and uraninite and uranothorite (Förster 1998). Pan (1997) described simultaneous formation of Th-poor and Th-rich monazite in gneisses by breakdown of pre-existing REE- and Th- rich minerals (titanite, zircon). The sample from Keblov has a low whole-rock concentration of U and Th, similar to the other two-mica or muscovite-tourmaline orthogneisses.

6. Conclusions

Our attempt to use monazite to determine age of magmatic precursor of orthogneisses was unsuccessful. Nevertheless, from the whole-rock chemistry and similarities in mineral composition we can conclude that all the studied rocks are probably products of one extensive lower Palaeozoic magmatic event, which was important in the northeastern part of Moldanubicum. This magmatic event was characterised by peraluminous melts, with sources probably dominated by metasedimentary formations in a deeper level of Moldanubicum. Near-minimum melting involving muscovite enriched the primary melts in boron. Following fractionation led to enrichment in phosphorus and tin. The most fractionated rocks of this event form a discontinuous belt between the Blaník hill in the SW and Přibyslavice in the NE at the present denudation level.

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Appendix

Whole rock analyses were performed in chemical laboratory of CGS Praha: major elements by wet chemistry, trace elements As, Cu, Nb, Rb, Sn, Zn and Zr in all samples by XRF and REE in some samples (in italic in Table 2) by ICP-OES. Other trace elements and REE were analysed by ICP-MS in ACME Vancouver.

Trace elements in biotites were analysed from monomineralic concentrates (more than 99 % purity) by wet chemistry in laboratory of CGS Praha.

Rock-forming minerals (feldspar, micas, tourmaline) from locality Přibyslavice were analysed in laboratory of CGS Praha using CamScan 4-90DV electron microscope equipped with LINK eXL X-ray analyser. Rock-forming minerals from other localities were analysed in laboratory of Geological institute of Academy of Science of Czech Republic in Praha on the CAMECA SX100 microprobe in WDS mode.

Microprobe analyses of accessory minerals and dating of monazite were performed in Joint laboratory of electron microscopy and microanalysis of CGS and Masaryk University in Brno. For more analytical details see Breiter et al. (2005) and Breiter – Sulovský (2005).

Chemické a minerální složení ortorul severovýchodní části moldanubika

V severovýchodní části moldanubika, východně od blanické brázdy, jsou rozlišovány dva základní typy spodně paleozoických ortorul. Biotitické ortoruly se vyskytují na periferii oblasti, kdežto leukokrátní dvojslídné a muskovit-turmalinické ortoruly tvoří pruh výskytu orientovaný SV-JZ ve střední části oblasti. Oba typy ortorul jsou peraluminické. Nejvíce frakcionované typy leukokrátních ortorul jsou obohaceny borem, fosforem, cínem a wolframem a svým chemickým složením se blíží cínonosným granitům. Z mineralogického hlediska je typické obohacení obou živců (K-živce a albitu) fosforem, častá přítomnost turmalínu a výskyt fosforem obohaceného granátu almandin-spessatinového složení. Zirkon z frakcionovaných ortorul je často zonární a obohacený o P, U, Al, Fe a Sc. Pokus o využití monazitu pro určení stáří magmatického protolitu ortorul pomocí analýzy U-Th-Pb na mikrosondě se nezdařil – všechna zjištěná stáří ekvilibrace jsou variská (316–327 Ma). Nicméně z hlediska chemické a minerální podobnosti studovaných ortorul a spolehlivě datované hlubocké ortoruly lze všechny tyto ortoruly považovat za produkt jedné rozsáhlé spodně paleozoické magmatické události, která postihla celé sv. moldanubikum. Tavením (meta)-sedimentárních hornin bohatých muskovitem vznikaly peraluminické taveniny blízké granitovému minimu, současně však obohacené borem. Následná frakcionace vedla k obohacení fosforem a cínem. Nejsilněji frakcionované ortoruly tvoří na dnešním povrchu pruh mezi Blaníkem na JZ a Přibyslavicemi u Čáslavi na SV.