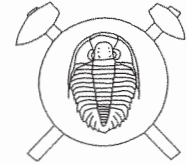


## Tourmaline from the Příbyslavice peraluminous alkali-feldspar granite, Czech Republic

Turmalín z příbyslavického peraluminiového alkalicko-živcového granitu, Česká republika (Czech summary)



(5 text-figs.)

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Chemical composition of tourmaline from the Příbyslavice alkali-feldspar granite (3 km<sup>2</sup>) in Moldanubian metamorphosed series in eastern Bohemia, is characterized by five wet and 43 microprobe analyses. The composition of the tourmaline varies considerably from magnesium-rich Fe<sub>61</sub> Mg<sub>36</sub> Al<sub>3</sub> to magnesium-poor Fe<sub>84</sub> Mg<sub>9</sub> Al<sub>7</sub> proton- and alkali-deficient schorl. Zoning of tourmaline is weak, however, the chemical differences between cores and rims are systematic: the iron content lowers from core to rim. A small deficiency of Si in the tourmalines is characteristic. In terms of the genetic classification, based on the proportion Al-Fe-Mg, the studied tourmalines belong to association of Li-poor granitoids, their pegmatites and aplites.

**Key words:** tourmaline, peraluminous granite, crystalchemistry, Příbyslavice body, Czech Republic

### Introduction

Tourmalines from the Příbyslavice alkali-feldspar granite (PAFG) similarly as tourmalines from the other granites of the Bohemian Massif were studied above all as isolated mineral phases. (Povondra 1981). The geochemistry of tourmalines and their host rocks were described in many granites from various countries e.g. Portugal (Neiva 1974), Mongolia (Vladykin et al. 1975), Thailand (Manning 1982) and in more detail from Southwest England (London - Manning 1995). Present paper attempts to solve more detailed crystallochemistry of prevailing tourmalines from the small metagranite body because the previous paper (Povondra et al. 1987) describes the rock forming minerals generally with a special focusing on the phosphates.

The Příbyslavice metagranite body crops out in an area cca 3 km<sup>2</sup>, about 6 km SSE of the town Čáslav, eastern

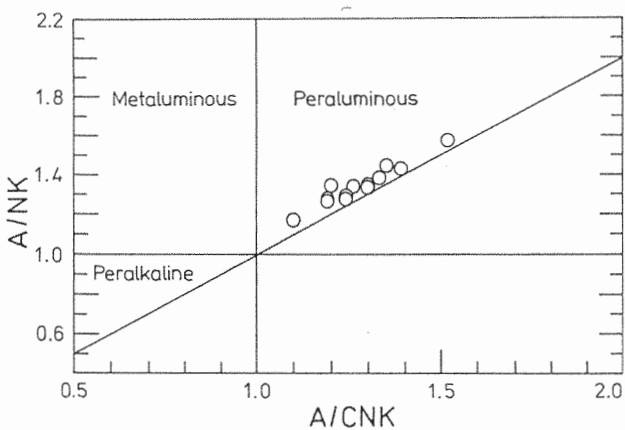


Fig. 1. Granite discrimination diagram A/CNK-A/NK (Maniar - Piccoli 1989). A = Al<sub>2</sub>O<sub>3</sub>, C = CaO, N = Na<sub>2</sub>O, K = K<sub>2</sub>O in mole per cent

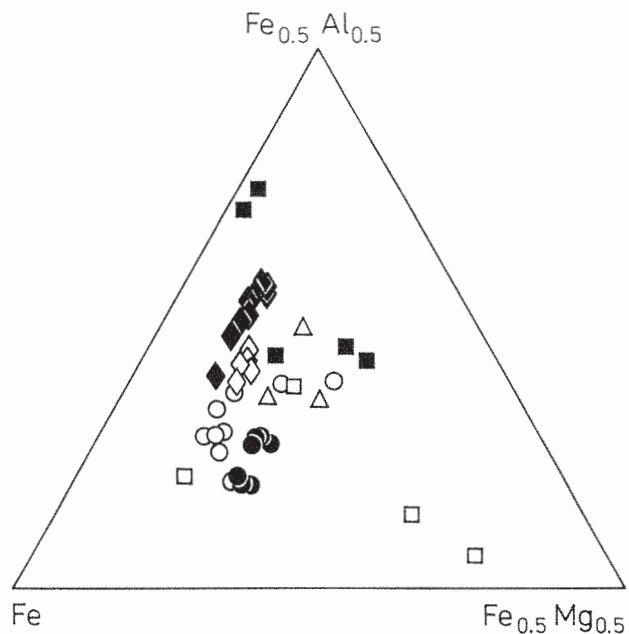


Fig. 2. Ternary Fe-Al-Mg plot (ions p.f.u.) ratios in external octahedra of tourmalines: schorl-olenite-dravite. Wet analyses of tourmalines: *open squares* - granites; *full squares* - pegmatite (all analyses from Povondra et al. 1987). EMPA of tourmalines (see Table 3): Sample No.: 8681 - *open circle*; 8682 - *full circle*; 8683 - *open diamond*; - 8684 - *full diamond*; 8685 - *open triangle*

Bohemia. A simplified geological situation is in Fig. 1 and 2 of the paper by Povondra et al. (cited above) which includes a more detailed localization of the studied samples.

### General petrographic features of the host rock

PAFG is a typical rock with index of peraluminosity ASI {molar [Al<sub>2</sub>O<sub>3</sub>/(CaO + Na<sub>2</sub>O + K<sub>2</sub>O)]} (Clarke 1981) varying from 1.08 to 1.51,  $x = 1.24$  (.11)  $n = 15$  (Fig. 1, Maniar - Piccoli 1989). According to distribution diagram

R1-R2 of Batchelor - Bowden (1985) PAFG corresponds to granite of late- or post-orogenic origin. The prevailing granite types of PAFG are: (i) medium grained, locally fine grained muscovite-tourmaline to tourmaline-muscovite granite; (ii) hybrid medium to coarse grained biotite-muscovite-tourmaline granite; (iii) muscovite granite. A characteristic mineralogical composition is in Table 1. Tourmaline distribution in the studied rock type is irregular. Tourmaline up to 10 wt.% in (i), the rock type (ii) contains about 5 wt.%, whereas the type (iii) only 0.3 wt.%. These amounts were calculated from the boron contents in the average samples 5-10 kg from which tourmalines were separated. Presence of abundant irregular pegmatite nests with well-known phosphates, coarse grained rocks passing into pegmatite types, and an exceptional vein of muscovite pegmatite with Li, Sn, Nb-mineralisation (Povondra et al. 1987) is characteristic.

Table 1. Minerals of peraluminous metagranite from Přebyslavice

Main and subordinate minerals	Accessory minerals	Secondary minerals
quartz	graphite	chlorite
potassium feldspar	pyrite	hematite
plagioclases	arsenopyrite	goethite
biotite	sphalerite	limonite
muscovite	chalcopyrite	Mn-oxides
tourmaline	cassiterite	
apatite	nigerite	
garnet	gahnite	
Li-Fe-Mn-Ca-Zn phosphates	titanite	
	ilmenite	
	rutile	
	niobite	
	sillimanite	
	staurolite	
	dumortierite	
	siderite	

## Samples and methods

The studied tourmalines originate from rocks variable in chemical as well as modal composition. Tourmaline was separated using common electromagnetic and density-related techniques and then purified by hand picking. Concentrates thus obtained were subject to standard wet analysis (Povondra 1981). Chemical analyses recalculated to 31 (O,OH,F) are presented in Table 2, together with other relevant crystallochemical data as alkalis, sum of cations in Y position, vacancies, and the  $F^* = Fe_{tot}/(Fe_{tot} + Mg)$ , or alkalinity  $N^* = Na/(Na + Ca)$  indexes. Thin sections of typical rock facies (Nos. 8681-8685) were used for wavelength-dispersive microprobe analyses carried out on a JEOL JXA-50A under the following conditions: accelerating voltage 15 and 20 kV, beam current 30 nA, beam diameter 2  $\mu$ m, counting time 100 seconds. Probe analyses were standardized by tourmaline Pr1 from the same locality, which had been analyzed repeatedly by wet techniques. Raw data were processed by the ZAF correction program. With spectrometer settings used, determination of Mn and K could not be obtained. Microprobe partial ana-

lyses (50 points) were treated to yield mean composition of tourmaline from individual rock types and these, in turn, calculated to formulas based on 24.5 (O). Numbers of ions p.f.u. and their standard errors ( $x \pm s$ ) are in Table 3. To document trends of zonal development of the tourmaline, two line scans across transversal sections of the largest grain, including ten analytical points per 2.3 mm, were performed (Table 4).

Table 2. Wet chemical analyses of the PAFG tourmalines. Samples: Pr 1, Pr 2 muscovite-tourmaline to tourmaline-muscovite granite; Pr 3, Pr 6 two mica tourmaline granite; Pr 8 muscovite granite

Sample No.	Pr 1	Pr 2	Pr 3	Pr 6	Pr 8
SiO <sub>2</sub>	34.88	34.72	35.12	35.11	34.99
TiO <sub>2</sub>	0.67	1.25	1.1	0.99	n.d.
B <sub>2</sub> O <sub>3</sub>	10.18	10.1	10.25	10.12	10.37
Al <sub>2</sub> O <sub>3</sub>	32.31	30.77	30.89	30.34	35.67
Fe <sub>2</sub> O <sub>3</sub>	1.2	2.77	3.31	1.83	n.d.
FeO	12.66	12.76	10.1	10.1	13.99
MnO	0.21	0.25	0.14	0.11	0.24
MgO	1.6	0.97	3.39	4.14	0.17
CaO	0.41	0.74	0.52	0.8	0.08
Na <sub>2</sub> O	2.24	1.96	2.21	2.7	1.46
K <sub>2</sub> O	0.23	0.12	0.09	0.14	0.05
Li <sub>2</sub> O	0.06	0.052	0.046	0.036	n.d.
H <sub>2</sub> O+	2.57	2.6	2.65	3.06	3.58
F <sub>2</sub>	0.61	0.71	0.39	0.38	n.d.
Total	99.83	99.772	100.206	99.856	100.6
Number of ions based on 31(O, OH, F)					
Si <sup>4+</sup>	6	6.016	5.979	5.974	5.865
Ti <sup>4+</sup>	0.087	0.162	0.141	0.127	-
B <sup>3+</sup>	3.022	3.021	3.012	2.972	3
Al <sup>3+</sup>	6.551	6.285	6.199	6.086	7.045
Fe <sup>3+</sup>	0.155	0.361	0.425	0.234	-
Fe <sup>2+</sup>	1.821	1.849	1.438	1.438	1.875
Mn <sup>2+</sup>	0.031	0.036	0.02	0.016	0.035
Mg <sup>2+</sup>	0.41	0.251	0.86	1.05	0.045
Ca <sup>2+</sup>	0.075	0.167	0.094	0.146	0.015
Na <sup>+</sup>	0.747	0.658	0.729	0.891	0.475
K <sup>+</sup>	0.051	0.026	0.019	0.015	-
Li <sup>+</sup>	0.041	0.036	0.032	0.025	-
OH-	2.95	3.006	3.019	2.474	4
F-	0.323	0.389	0.21	0.204	-
O <sup>2-</sup>	0.718	0.605	0.78	0.322	-
alk	0.877	0.821	0.842	1.052	0.49
Y	3.096	2.98	3.115	2.975	2.995
vacancy	0.127	0.179	0.158	-	0.51
F*	0.818	0.885	0.679	0.611	0.956
N*	0.856	0.801	0.866	0.847	0.969

Explanations: alk=Na+K+Ca; Y=sum of cations in Y(VI) position;  $F^* = Fe/(Fe+Mn+Mg)$ ;  $N^* = Na/(Na+K+Ca)$

## Optical properties of tourmaline

Tourmalines are predominantly xenomorphic, poikilitic, patchy or concentric zoned (especially in sections  $\perp c$ ). They often replace early crystallized mica. In more evolved stadium of granite, the feldspars are partly or completely replaced by tourmaline and quartz. When occurring with biotite, the tourmaline is mostly intensive zoned with deep blue core and green rim or pale greyish blue (greenish, yellowish) rim and bluish grey core with brown patches. In the case when the biotite is replaced wholly by

Table 3. Electron microprobe analyses of the PAFG tourmalines. Samples: 8681 - two mica granite, Tisá skála (eastern part of the PAFG body); 8682 - two mica tourmaline granite; 8683 - tourmaline-muscovite granite; 8684 - tourmaline-pegmatite granite; 8685 - two mica tourmaline granite

Sample No.	8681		8682		8683		8684		8685	
	(n=8)	s.d.	(n=9)	s.d.	(n=10)	s.d.	(n=11)	s.d.	(n=5)	s.d.
SiO <sub>2</sub>	34.07	(0.62)	34.78	(0.22)	34.25	(0.50)	34.93	(0.44)	35.07	(0.43)
Al <sub>2</sub> O <sub>3</sub>	32.12	(0.62)	31.52	(0.35)	32.12	(1.10)	34.03	(1.02)	33.86	(0.32)
TiO <sub>2</sub>	0.33	(0.16)	0.4	(0.08)	0.33	(0.09)	0.22	(0.03)	0.34	(0.04)
FeO <sub>tot</sub>	15.52	(1.19)	15.02	(0.29)	15.35	(0.57)	13.1	(0.33)	12.92	(0.18)
MgO	1.26	(0.33)	1.54	(0.07)	1.01	(0.05)	0.72	(0.04)	1.36	(0.22)
CaO	0.3	(0.13)	0.15	(0.18)	0.35	(0.25)	0.4	(0.12)	0.36	(0.02)
Na <sub>2</sub> O	1.98	(0.11)	2.01	(0.04)	2.04	(0.15)	2.19	(0.08)	2.33	(0.17)
F <sub>2</sub>	0.47	(0.07)	0.49	(0.01)	0.55	(0.13)	0.63	(0.04)	0.62	(0.04)
Total	86.05		85.91		86		86.22		86.86	
Number of ions based on 24.5 (O)										
Si <sup>4+</sup>	5.828	(0.093)	5.931	(0.030)	5.851	(0.98)	5.884	(0.075)	5.909	(0.059)
Al <sup>3+</sup>	6.475	(0.080)	6.336	(0.063)	5.463	(0.175)	6.71	(0.085)	6.569	(0.108)
Ti <sup>4+</sup>	0.046	(0.019)	0.051	(0.019)	0.042	(0.011)	0.027	(0.004)	0.043	(0.005)
Fe <sup>2+(3+)</sup>	2.213	(0.214)	2.142	(0.048)	2.195	(0.089)	1.844	(0.050)	1.814	(0.024)
Mg <sup>2+</sup>	0.322	(0.024)	0.39	(0.017)	0.258	(0.012)	0.181	(0.011)	0.313	(0.017)
Ca <sup>2+</sup>	0.055	(0.023)	0.042	(0.026)	0.065	(0.045)	0.073	(0.220)	0.065	(0.004)
Na <sup>+</sup>	0.655	(0.032)	0.664	(0.013)	0.673	(0.052)	0.715	(0.027)	0.762	(0.056)
F <sup>-</sup>	0.256	(0.040)	0.265	(0.007)	0.298	(0.069)	0.337	(0.020)	0.33	(0.022)
alk	0.71	(0.050)	0.706	(0.032)	0.741	(0.046)	0.788	(0.047)	0.827	(0.058)
Y	3.058	(0.177)	2.914	(0.036)	2.958	(0.116)	2.785	(0.068)	2.739	(0.083)
vacancy	0.266	(0.092)	0.294	(0.032)	0.259	(0.046)	0.212	(0.002)	0.174	(0.058)
F*	0.86	(0.036)	0.846	(0.004)	0.893	(0.006)	0.91	(0.002)	0.853	(0.006)
N*	0.915	(0.028)	0.942	(0.012)	0.911	(0.012)	0.909	(0.011)	0.921	(0.006)

For explanation see Table 2

tourmaline, the pleochroic colours are pale brown or yellow to green. The tourmalines in pegmatites are present commonly as automorphic crystals (up to 4 x 1 cm). Some tourmalines belong to the so called "blue schorl" and have an elevated content of lithium (Povondra et al. 1987). Elbaite, verdelite and indigolite observed in the pegmatite frequently during the early stages of quarrying are now mined away.

### Chemical study and results

Minerals in a compositionally strongly differentiated body can be expected to have a correspondingly variable composition, and this is clearly the case of tourmaline. Data in

Tables 2 and 3 give overview of the occupancies of structural positions in the formula  $XY_3Z_6(BO_3)_3Si_6O_{18}(OH,F)(OH,O)_3$ .

The anion groups  $BO_3$  and  $SiO_4$  of tourmaline analysed by wet technique exhibit a full occupancy. One sample (Pr 8) from muscovite granite is exceptional. This tourmaline differs in its appearance from the others because it represents so called "blue schorl", high in Al and Fe, deficient in Mg and exhibiting a considerable vacancy in the X position. In EMPA (Table 3), there is a systematic small deficiency of silicon; this deficiency does not represent an analytical error, but a result of the Si ↔ Al substitutions (eg., Al, Na, Si<sub>-1</sub> or B, H, Si<sub>-1</sub> respectively).

The (O,OH)<sub>3</sub> group contains an increased number of O

Table 4. Electron microprobe line-scan analysis of tourmaline from a rock sample 8681, atoms p.f.u.

Point	1	2	3	4	5	6	7	8	9
SiO <sub>2</sub>	34.70	35.00	35.80	35.10	35.10	35.50	35.30	35.30	35.80
Si	5.659	5.559	5.555	5.525	5.622	5.669	5.637	5.67	5.6
Al	6.38	6.576	6.497	6.503	6.457	6.402	6.478	6.409	6.5
Ti	0.104	0.099	0.115	0.101	0.055	0.06	0.039	0.072	0.104
Fe <sub>t</sub>	1.595	1.717	1.747	1.856	1.918	1.914	1.959	1.912	1.603
Mg	0.661	0.521	0.535	0.474	0.32	0.268	0.286	0.306	0.663
Ca	0.048	0.049	0.04	0.037	0.033	0.031	0.018	0.018	0.036
Na	0.72	0.779	0.754	0.75	0.781	0.76	0.808	0.75	0.72
F	1.481	1.287	1.439	1.505	1.596	1.692	1.529	1.578	1.366
alk	0.768	0.828	0.794	0.787	0.814	0.791	0.826	0.768	0.768
Y	2.74	2.913	2.894	2.934	2.75	2.644	2.762	2.699	2.87
vacance	0.232	0.172	0.206	0.213	0.186	0.209	0.174	0.232	0.232
F <sup>+</sup>	0.707	0.767	0.766	0.8	0.857	0.877	0.873	0.862	0.707
N <sup>+</sup>	0.938	0.941	0.95	0.953	0.959	0.961	0.978	0.977	0.952

For explanation see Table 2

atoms - a result of heterovalent substitutions in Y position. Also, in the (OH,F) group, there is a small (5-10 %) homogenous substitution of OH with F between 0.208 and 0.376, with a mean at 0.30 (5) atoms p.f.u. In Sturger's division into six classes ( $n = 41$ ), there is a clear bimodal distribution. The line scan analyses across a grain from rock sample 8681 lie completely outside of this trend. It has an unusually high fluorine, 1.50 (12) atoms p.f.u., which might indicate an elevated  $Fe^{3+}$  in the mineral (Table 4).

The X position is occupied mainly by sodium. The occupancy of X is characterized by alkalinity index  $N^*$ , which displays a clear lognormal distribution with a mean at 0.93 (4) atoms p.f.u. Vacancy in the X position is a result of heterovalent substitutions in the Y position. Admittedly, these values may be slightly biased because EMPA do not contain the  $K_2O$  determination, but wet analyses have shown that potassium is present in subordinate to trace quantities.

The  $Z_6$  position is fully occupied by  $Al^{3+}$  or  $Fe^{3+}$ . The three inner octahedra  $Y_3$  are occupied by  $Fe^{2+}$ ,  $Mg^{2+}$ ,  $Mn^{2+}$ ,  $Al^{3+}$ ,  $Fe^{3+}$ , and  $Li^+$ . The ratio  $Fe : Mg : Al$  (Al above six atoms p.f.u.) can be used to characterize the variation in the present set. The ternary, dravite-schorl-olenite, appears in Fig. 2 and shows that the composition of Příbyslavice tourmalines varies considerably, from magnesium-rich schorl  $Mg_{36}Fe_{61}Al_3$  to magnesium-poor,  $Mg_9Fe_{84}Al_7$ . Some tourmalines from pegmatites are poor in the dravite component, similarly as in "blue schorl" in sample PR 8. Mole percentages of individual components (EMPA) vary as follows,  $Mg_{5-26}$ ,  $Fe_{53-66}$ ,  $Al_{9-28}$ . The high olenite contents (9-18 % mol.) agree with the high schorl contents (53-66 mol.%) (Povondra 1981). Tourmalines from PAFG confirmed the previously observed linear dependency of miscibility of Al and Fe components.

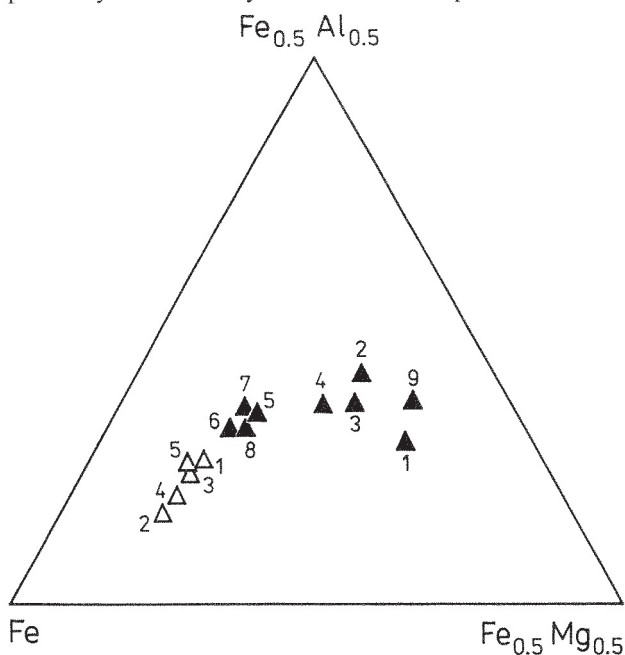


Fig. 3. Ternary Fe-Al-Mg plot (in p.f.u.) of external octahedra of tourmalines (schorl-olenite-dravite). The EMPA across one grain of tourmaline. Open triangle - sample 8683; full triangle - sample 8681

The Příbyslavice tourmalines exhibit a high degree of heterovalent substitutions according to the reactions, (i)  $R^{3+} \square \leftrightarrow R^{2+}, Na^+$  and (ii)  $R^{3+}, O^{2-} \leftrightarrow R^{2+}, OH^{-1}$ . The analyses in Table 2 indicate that reaction (ii) is dominant, leading to proton-deficient tourmaline. A similar situation holds true for EMPA, for the relation between  $\Sigma(Na + R^{2+})$  vs.  $\Sigma R^{3+}$ .

The considerable variability of tourmaline composition follows also from other data in Tables 2 and 3. So,  $Fe^{3+}$  constitutes 8-25 per cent of  $Fe_{tot}$ ; similar to the fluctuation of contents of Mn and Li. Variable is also the content of Ti; EMPA indicate a range of 0.020-0.115 atoms p.f.u. with a mean at 0.045 (25). The higher Ti contents detected by wet analyses are apparently due to contamination with ilmenite that could not be eliminated by mechanical procedures during separation.

### Zoning of tourmaline

Spot analyses with electron microprobe provided information on compositional zoning of the tourmaline studied. As a rule, two points located in the centre and two points positioned in the rim of tourmaline crystal were analysed. The differences between core and rim compositions are relatively small but consistent: iron and aluminium decrease from core to rim while magnesium and the sum of alkalis show an inverse pattern. Compositional profiles up to 2.3 mm long including ten measured points in tourmaline single crystal in rock samples 8681 and five points in sample 8683 gave a more detailed information on zoning. The analyses on tourmaline 8681 are given in Table 4 and Fig. 4, which show the inverse relation in the numbers of Fe and Mg atoms. Aluminium also shows a significant variation along the profile, but no simple relation to variation in other cations is seen. A significant negative correlation of F and Al is indicated by correlation coefficient  $r = -0.75$ . The pair F and Fe shows a positive correlation with the coefficient  $R = 0.71$ , suggesting possible transport of iron as the complex  $(FeF_n)^{(n-2)-}$ , with  $n = 3$  to 6. The variation in the sum  $Fe + Mg$  and in Na, Ti, and Ca abundances is insignificant.

The variation in composition of tourmaline sample 8681 during its crystallisation is documented in triangle, Fig. 3. Rim analyses 1 and 9 correspond to Fe 58-60, Mg 24-25, Al 15-18 mol.% of respective end-members, the transitional zone characterized by analyses 2, 3 and 4 has an average composition, and the core analyses 5 to 8 correspond to Fe 72-74, Mg 10-12 and Al 15-17 mol.% of end members. A similar, though less clearly defined variation occurs in tourmaline 8683. The line scan includes five tourmaline analyses. Rim analyses 1 and 5 correspond to Fe 84, Mg 8.5, Al 8. A uniform "ferrugineity" index  $Fe^*$  is 0.90, the alkalinity index  $N^*$  is 0.91-0.96 and Mg content of 0.23-0.27 atoms p.f.u. is also nearly constant.

The tourmaline No.8681 has somewhat lower value  $F^* = 0.71-0.88$  and closely similar  $N^*$  value of 0.92-0.94. However, it shows notable deficiency of the Y positions, 2.82-2.89 atoms p.f.u., and a significant silica deficiency

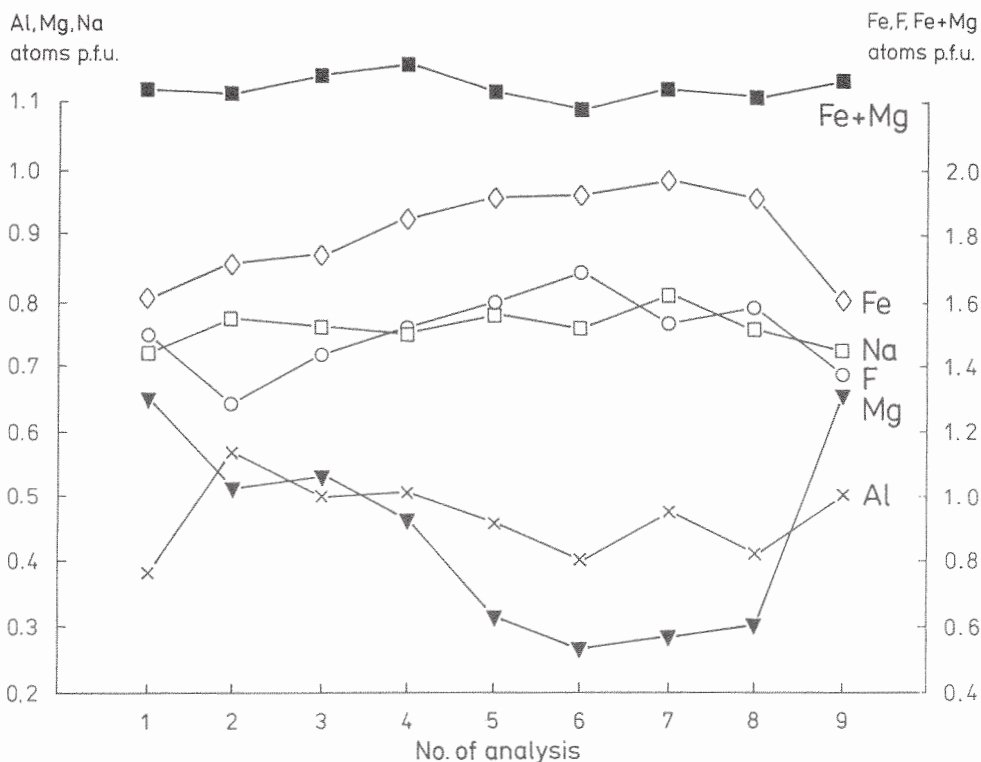


Fig. 4. Zonality of tourmaline 8681 (line-scan length of profile 2.3 mm), atoms p.f.u. Cross - Al; open diamond - Fe; full triangle - Mg; open square - Na; open circle - F; full square - Fe + Mg

(5.53-5.66 atoms p.f.u.). These relations suggest that a significant part of iron is present as Fe<sup>3+</sup> or, alternatively, Si is replaced by B following the scheme B<sup>3+</sup>, H<sup>+</sup>= Si<sup>4+</sup> (Schreyer 1997). The alternative possibilities can not be resolved without a complete chemical analysis. Data in Table 4 show that compositions in points 1 and 9 are identical.

**Summary**

Tourmaline shows irregular distribution and variable content in the individual rock types of the PAFG. It tends to be more abundant in the central part of granite and diminishes towards contact with the country rock. Tourmaline in granite tends to be enriched in parallel stripes, nests or patches. The most common form of occurrence is in euhedral crystals 2 to 3 mm long, but coarser-grained portions of granite carry euhedral tourmaline crystals up to 4 by 1 cm in size.

Tourmaline in various types of PAFG shows a relatively uniform composition and optical properties, in spite of significant variation in whole rock composition involving mainly variable Fe/Al ratio, while the content of Mg remains nearly constant. The differentiation trends for individual rock types are remarkably uniform and analyses of "bulk" tourmaline samples correspond well to these trends (Fig. 2). The tourmalines in PAFG are characterized by high Fe/Mg ratios and increased F and Al contents. These compositional features and Fe<sup>3+</sup> content result in deprotonisation and dealcalisation substitutions. The relatively uniform composition of individual crystals, high F\* values and optical properties including pleochroism in brown and olive green colours, minor optical zoning and

in particular the absence of minute (micron-scale) zoning corresponds to characteristics of primary magmatic tourmalines. With regard to these features, textural relations and distribution in granite, the tourmaline corresponds to disseminated tourmaline of London - Manning (1995).

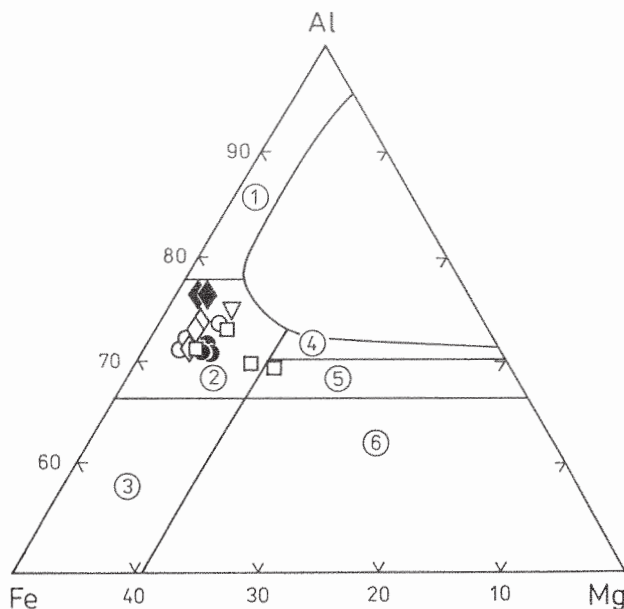


Fig. 5. Ternary Fe<sub>10t</sub>-Al<sub>10t</sub>-Mg plot (in p.f.u.) discrimination diagram of tourmalines (Henry - Guidotti 1985). Fields: (1) Li-rich granites, their pegmatites and aplites, (2) Li-poor granitoids, their pegmatites and aplites, (3) Fe<sup>3+</sup>-rich quartz-tourmaline rock (altered), (4) metapelites and metapsamites with Al-saturated phase, (5) metapelites and metapsamites without Al-saturated phase, (6) Fe<sup>3+</sup>-rich quartz-tourmaline rocks, calcisilicate rocks and metapelites. For symbols see Fig. 2

However, the tourmaline probably did not crystallize as primary phase directly from melt but by reaction of primary biotite with restitic melt enriched in water, fluorine, boron and notably enriched in aluminium (ASI = 1.2 to 1.3). In respect of chemical composition, tourmaline in PAFG is classified as alkali-and proton-deficient Mg, Al-schorl. In the  $Al_{tot}$ - $Fe_{tot}$ -Mg triangle of Henry - Guidotti (1985) individual tourmalines from various rocks types of PAFG plot in the field of tourmalines from low -Li granitoids and associated pegmatites and aplites. This situation corresponds to petrological and chemical properties of PAFG (Povondra et al. 1981).

London - Wolf (1997) studied formation of schorl-dravite in place of biotite experimentally. The results indicate that peraluminosity of melt and boron concentration are the critical factors controlling stability of tourmaline.

The following mode of tourmaline formation in PAFG is proposed. Granite magma was derived by anatexis melting of a crustal domain dominated by metapelites carrying tourmaline, other B-bearing minerals, feldspars and ferromagnesian minerals. During ascent and cooling of magma, fractional crystallization of biotite or possibly cordierite, quartz and feldspars resulted in enrichment of the melt in boron. After sufficient concentration of boron (approximately 2 wt.%  $B_2O_3$ ) and surplus aluminium content was attained, the reaction of ferromagnesian minerals to tourmaline took place. If contents of Fe and Mg were too low, a significant part of boron remained in residual fluid-gaseous phase which migrated towards country rocks and participated in metasomatic tourmalinization and formation of pegmatites, such processes are indicated by intense tourmalinization and an apatite enrichment around granite apophyses (Povondra et al. 1981).

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#### References

- Batchelor, R. A. - Bowden P. (1985): Petrogenetic interpretation of granitoid rock serie using multicationic parameters. - Chem. Geol., 48, 43-55. Amsterdam.
- Clarke, D. B. (1981): The mineralogy of peraluminous granites: a review. - Canad. Mineralogist, 19, 3-17. Ottawa.
- Henry, D. J. - Guidotti, C. V. (1985): Tourmaline as a petrogenetic indicator mineral: an example from the staurolite-grade metapelites of NW Maine. - Amer. Mineralogist, 70, 1-15. Washington.
- London, D. - Manning D. A. C. (1995): Chemical variation and significance of tourmaline from southwest England. - Econ. Geol., 90, 495-519. New Haven.
- London, D. - Wolf, M. B. (1997): The boron cycle in metasedimentary-peraluminous granite systems. Tourmaline 1997 Internat. Sympos. on Tourmaline, Abstracts 47-48. Moravian Museum Brno.
- Maniar, P. D. - Piccoli, P. M. (1989): Tectonic discrimination of granitoids. - Geol. Soc. Amer. Bull., 101, 635-643. New York.
- Manning, D. A. C. (1982): Chemical and morphological variation in tourmalines from the Hub Kapong batholith of peninsular Thailand. - Mineral. Mag., 45, 139-147. London.
- Neiva, A. M. R. (1974): Geochemistry of tourmaline (schorlite) from granites, aplites and pegmatites from Northern Portugal. - Geochim. Cosmochim. Acta., 38, 1307-1317. London.
- Povondra, P. (1981): The crystal chemistry of tourmalines of the schorl-dravite series. - Acta Univ. Carol., Geol., 3, 223-264. Praha.
- Povondra, P. - Pivec, E. - Čech, F. - Lang, M. - Novák, F. - Prachař, I. - Ulrych, J. (1987): Příbyslavice peraluminous granite. - Acta Univ. Carol., Geol., 3, 183-283. Praha.
- Schreyer, W. (1997): Experimental studies on tourmaline end-members. - Tourmaline 1997 Internat. Sympos. on Tourmaline, Abstracts 89-90. Moravian Museum Brno.
- Vladykin, N. V. - Antipin, V. S. - Kovalenko, V. I. - Afonina, G. G. - Lapides, I. I. - Novikov, V. M. - Gormasheva, G. C. (1975): Chemical composition and genetic grouping of tourmalines from Mesozoic granitic rocks of Mongolia. Zap. Vses. Mineral. Obshch., 104, 403-412. Leningrad. (in Russian)

## Turmalín z příbyslavického peraluminiového alkalicko-živcového granitu, Česká republika

Turmalín v rámci tělesa příbyslavického peraluminiového alkalicko-živcového granitu až metagranitu vykazuje nepravidelnou distribuci. Jeví obecnou tendenci k akumulaci ve střední části tělesa, zatímco směrem k okrajům spíše ubývá. Vyskytuje se v paralelně uspořádaných pruzích, event. větších akumulacích. Nejrozšířenější formou výskytu jsou idiomorfne omezené krystalky 2-3 mm dlouhé, ale v hrubozrnějších typech horniny dosahují i větších rozměrů. Turmalínové tělesa, až na drobné výjimky, jeví poměrně blízké chemické složení a optické vlastnosti; nejvýznamnějšími variacemi je měnící se poměr Fe/Al, zatímco obsah Mg je poměrně konstantní. Studované turmalíny charakterizuje vysoký poměr Fe/Mg a zvýšený obsah F a Al. Tyto rysy v jejich složení a obsah  $Fe^{3+}$  vedou k deprotonizaci a dealkalizační substituci. Chemické vlastnosti, zónalnost a optické vlastnosti turmalínu jeví rysy primárně magmatického vzniku a odpovídají rozptýleným turmalínům ve smyslu práce London - Manning (1995). Turmalíny příbyslavického granitu pravděpodobně nekystalizovaly jako primární fáze přímo z taveniny, ale reakcí primárního biotitu a zbytkové taveniny obohacené volatiliemi (vodou, fluorem, borem) a alumiem (ASI = 1,2-1,3).

Na základě chemického složení lze turmalín označit jako alkáliemi a protony deficitní Mg, Al-skoryl, padající v klasifikačním diagramu Henry - Guidotti (1985) do pole Li-chudých granitoidů a s nimi spjatých pegmatitů a aplitů.

Autoři předpokládají s ohledem na výsledky experimentálních prací následující model vzniku turmalínu v příbyslavickém granitu: granitové magma vzniklo anatexí korových, převážně metapelitických hornin s turmalínem a jinými minerály s obsahem boru, živci a ferromagneziálními minerály. Během výstupu a chladnutí, frakcionovanou krystalizací biotitu, popř. cordieritu, křemene a živců, došlo k naboacení taveniny borem. Při dostatečné koncentraci boru (přibližně 2 váh.%  $B_2O_3$ ) a nadbytku Al došlo ke krystalizaci turmalínů. V opačném případě bor zůstal v reziduální plyno-kapalně fázi, která dále migrovala a docházelo k turmalinizaci v okolních horninách a tvorbě pegmatitů.