TOURMALINE FROM THE RARE-ELEMENT BERGER PEGMATITE (THE SOUTHERN TIN BELT, CENTRAL NAMIBIA): CHEMICAL VARIATION AND IMPLICATIONS FOR THE PEGMATITIC EVOLUTION

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ABSTRACT

The Berger pegmatite (Southern Tin Belt, Namibia) is a zoned rare-element pegmatite, mined for tin and gem tourmaline. This mineral is an ubiquitous constituent in the pegmatite, occurring in the intermediate and core zones, as well as in the replacement units. Tourmaline chemistry changes depending on the pegmatite facies. Schorl is abundant in the intermediate zone. Multicolored elbaite occurs in the core zone, frequently showing watermelon texture. In that case, pink elbaite shows up to ~35% and ~9% of rossmanite and liddicoatite components, respectively. In the replacement bodies greenish to bluish tourmalines of the schorl-elbaite series are common. The broad compositional range shown by the tourmalines correlates well with the pegmatite zoning. The main mechanism that accounts for the chemical variation of tourmalines during crystallization seems to be $^{Y}Fe^{2+}_{-2}{}^{Y}Al_{1}{}^{Y}Li_{1}$. The presence of Ca in the pink elbaites of the watermelon textures may be explained by the $CaLi(NaR^{2+})_{-1}$ exchange vector. The chemical variation in tourmaline is consistent with an inward crystal fractionation model for the evolution of the Berger pegmatite.

Keywords: tourmaline, Berger pegmatite, mineral chemistry

INTRODUCTION

Tourmaline is a common accessory mineral in a variety of sedimentary, igneous and metamorphic rocks, as well as in associated hydrothermal rocks. It is stable over a wide range of P-T-Xi space and it is able to record the processes that have affected the host rocks. Therefore, tourmaline is particularly useful in the study of ore-forming fluids. Thus, an understanding of the paragenesis, textural relationships and chemical variations in tourmaline can contribute to understand the geological history of the surrounding rocks.

This study deals with tourmalines associated with the Berger rare-element pegmatite from the Southern Tin belt (Central Namibia). We examine the petrographic characteristics and chemical variability of tourmaline in relation to the pegmatitic facies where it appears, and then we discuss the petrologic implications.

GEOLOGICAL SETTING AND GEOLOGY OF THE PEGMATITE

The geology of Central Namibia is characterized by the presence of metasedimentary and igneous rocks that form the Damaran orogen (Keller et al., 1999). This orogen is divided into several zones on the basis of the stratigraphy, structure, grade of metamorphism, types of granitoids and geochronology (Miller, 1983). The tourmalines under discussion occur in a pegmatite from the Southern portion in the Central Zone of the Damara Orogen.

The Central zone is a high-temperature and low-pressure terrain of the orogen including sillimanite-cordierite metamorphic assemblages in where have intruded numerous granitoids. Deep stratigraphic levels crop out in the Southern portion of the Central zone, which are floored by a 1700 to 2000 m.y. old granite gneiss basement (Abbabis inlier). This basement is overlain by quartzites of the Late Proterozoic Nosib group and metamorphic rocks of the Swakop group, mainly marbles (Karibib formation) and metapelites or metagreywackes (Kuiseb formation). The numerous occurrences of pegmatites at the Damara Province of Central Namibia can be grouped in various characteristic belts. The Southern tin belt is located in the Southern portion of the Central zone, and follows with its northern termination the Omaruru lineament up to the Karoo intrusives of the Erongo mountains. The pegmatites usually occur in metasediments of the Kuiseb formation which crop out on the northern slope of Karibib marble bands. They form part of antiform structures of which the Roiberg dome is the most prominent.

The Southern tin belt can be subdivided into three portions from the western part towards the east: the Ameib-Davib-Sandamap portion, the Etiro-Daheim portion, and the Omapyu-Otjimbojo portion (Fig. 1). The Berger pegmatite belongs to this last portion. Host rocks comprise micashist and marble of the Damara sequence. The pegmatites of this portion has been mined not only for Sn, but also for gem tourmaline. The main characteristics of the Berger pegmatite are sketched in Table 1.

Table 1. Main characteristics of the Berger pegmatitic units and the associated tourmaline.

ZONE	MINERALOGY	TEXTURES	TOURMALINE Grain Size
Border	Ksp, Qtz	-	-
Intermediate	granitic, Ksp BLACK TOURM	circular an elliptical rings and suns	fine to medium
Core	Qtz, lep, cass, MULTICOLOURED TOURMALINE	subhedral zoned crystals (water-melon, dark-green cores and pink rims) also individual pink or green crystals	fine to medium
Replacement unit	Li-mica, Qtz, amb, ab, apt greisen (white mica) BLUE-GREEN TOURMALINE	dark blue to light green coloured sub- to anhedral crystals	fine to medium

In "Mineralogy", the following abbreviations have been used: Qtz-quartz; Ksp-K-feldspar; ab-albite; amb-amblygonite; cass-cassiterite; apt-apatite; lep-lepidolite; *Grain size: very fine = <6 mm; fine = 6 mm to 2.5 cm; medium = 2.5 cm to 10 cm; coarse = >10 cm.

SAMPLING AND ANALYTICAL METHODS

The tourmaline samples have been selected from the different units in the studied pegmatite. Microprobe analyses were carried out on representative tourmaline samples at the University of Granada, using a Cameca SX50 microprobe equipped with four wavelength-dispersive spectrometers. Operating conditions were 20 kV accelerating voltage, 20 nA beam current, and a beam diameter of about 2µm. Natural and synthetic standards were used: fluorite (F), sanidine (K), pollucite (Cs), $MnTiO_3$ (Ti, Mn), diopside (Ca), $BaSO_4$ (Ba), Fe_2O_3 (Fe), albite (Na), natural periclase (Mg), SiO_2 (Si), apatite (P), sphalerite (Zn), Cr2O3 (Cr) and Al_2O_3 (Al).

LA-ICP-MS analyses were conducted with a 213 nm Mercantek Nd-YAG laser coupled to an Agilent 7500 ICP-MS with a shielded plasma torch, using the NIST-610 glass as standard. The ablation was carried out in a He atmosphere. The laser beam was fixed to a 95 microns wide square section. The spot was pre-ablated for 45 seconds using a laser repetition rate of 10 Hz and 40% output energy. Then the spot was ablated for 60 seconds at 10 Hz with a laser output energy of 75.

TOURMALINE OCCURRENCE AND PETROGRAPHIC CHARACTERISTICS

Tourmaline is common in the intermediate and core zones of the Berger pegmatite, and it is also abundant in the replacement units (Keller et al., 1999). Depending on the pegmatitic facies, tourmaline shows different textures. In the intermediate zone black tourmaline is common, mainly associated with quartz, K-feldspar and muscovite. It occurs often as circular or elliptical rings and suns. In the case of the core zone, tourmaline is fine to medium grained, with variable colour and pronounced crystal zoning in some cases, giving rise to the so-called "watermelon" textures. Moreover, pinkish or light greenish subhedral tourmaline crystals are also common in this unit. In that case, the crystals are quite homogeneous in color. Finally, in the replacement units very heterogenous, dark blue to light green coloured tourmaline occurs in lepidolite- and greissen-bands at the marginal parts of the quartz cores. The greissen consists of pearly white mica, quartz, amblygonite and bluish albite.

TOURMALINE CHEMISTRY AND DISCUSSION

Tourmaline structural formulae have been calculated on the basis of 24.5 atoms of oxygen (Table 2). The amount of B_2O_3 corresponding to three boron cations in the structural formula was calculated from stoichiometric constraints. Tourmaline compositions have been recast into end-member components according to the scheme of Pesquera et al. (2008). Overall, all the tourmalines from the Berger pegmatite are alkali tourmalines (Fig.1, Table 1), although important contents of Ca and/or vacancies are present. The analyzed tourmalines can be described in the schorl-elbaite-rossmanite-foitite quadrilateral and along the line liddicoatite-elbaite-rossmanite. Light greenish tourmaline from the core zone is elbaite, with significant contents of schorl (< 24%), rossmanite (< 18%), foitite (< 9%), liddicoatite (< 9%), Mn-dravite (< 9%) and Mn-foitite (< 6.0%). The multicolored tourmaline (watermelon crystals) shows a complex chemistry as well. The green zone is mainly elbaite (42.1-43.3%), with important contents in schorl (27.7-29.9%), foitite and rossmanite (9.4-16.9% and 5.8-9.2%, respec-

tively) and olenite (< 8%). The pink zone of the watermelon crystals is also elbaite (45.7-56.9%), but the vacancies are much more abundant, with contents in rossmanite in the range ~18-35%. The olenite and liddicoatite components are also important with percentages of 2.4-14.7%, and 5.6-9.4%, respectively. Minor amounts of Mn-dravite and Mn-foitite are also remarkable (0.5-6.4% and 1.1-4.8% respectively). Finally, the tourmaline associated with the replacement bodies has also a broad compositional range. The darkest zones belong to schorl (~66%), with important contents of foitite (~23%), and minor elbaite and dravite contents (~4% and 3%, respectively). The greenish zones vary from schorl to elbaite, with contents in these components ranging from 9 to 43% and from 40 to 66.0% respectively. Foitite (~4-9%) and rossmanite (~3-14%) are also relatively important.

Table 2. Structural formulae and components of tourmalines from the Berger pegmatite. CZ=Core Zone, RU= Replacement Unit, WT= Watermelon, G=green, P= Pink, DB= Dark-blue, LG= Light-green.

	CZ WT-G	CZ WT-G	CZ WT-P	CZ WT-P	RU DB	RU B	RU G	RU LG	CZ G	CZ G
Si	5,50	5,821	6,126	6,094	5,901	6,068	6,128	6,131	6,180	6,031
Al	7,048	7,078	7,594	7,660	6,315	6,765	7,074	7,256	6,963	7,291
Ti	0,010	0,011	0,000	0,000	0,053	0,032	0,004	0,008	0,003	0,004
Cr3+	0,007	0,012	0,000	0,000	0,002	0,000	0,003	0,000	0,000	0,004
Fe2+	1,143	1,204	0,002	0,004	2,347	1,197	0,664	0,453	0,723	0,159
Mn	0,085	0,063	0,143	0,096	0,036	0,022	0,053	0,036	0,114	0,387
Mg	0,001	0,006	0,008	0,001	0,117	0,067	0,006	0,014	0,001	0,001
Zn	0,041	0,064	0,026	0,008	0,066	0,025	0,015	0,015	0,034	0,000
Li	0,734	0,721	1,166	1,167	0,055	0,864	1,216	1,340	1,075	1,107
□Y	3,020	2,980	2,939	2,936	2,892	2,971	3,033	3,123	2,912	2,952
Ca	0,023	0,026	0,092	0,065	0,015	0,019	0,063	0,082	0,020	0,088
Na	0,782	0,806	0,610	0,596	0,723	0,872	0,796	0,720	0,802	0,651
K	0,005	0,013	0,000	0,000	0,014	0,005	0,009	0,009	0,000	0,007
Vac (X)	0,190	0,155	0,298	0,339	0,248	0,104	0,131	0,189	0,178	0,254
F	0,615	0,853	0,559	0,689	0,326	0,767	0,834	0,743	0,787	1,045
Cl	0,003	0,001	0,000	0,006	0,007	0,000	0,000	0,002	0,006	0,000
OH	3,381	3,146	3,441	3,305	3,667	3,233	3,166	3,256	3,207	2,955
Schorl	28,1	28,8	0,0	0,0	65,7	31,8	16,1	9,3	18,5	2,2
Dravite	0,0	0,1	0,1	0,0	2,8	1,4	0,1	0,3	0,0	0,0
Olenite	5,1	8,0	7,6	7,5	1,0	0,0	0,0	0,0	0,0	0,7
Elbaite	43,0	43,1	49,4	49,6	3,3	53,8	62,7	62,4	58,5	53,1
Uvite	0,0	0,0	0,1	0,0	0,1	0,1	0,0	0,1	0,0	0,0
Feruvite	1,4	1,6	0,0	0,0	1,4	1,1	2,2	2,1	0,8	1,1
Liddicoatite	0,9	1,0	9,4	6,6	0,0	0,8	4,1	6,1	1,2	7,8
Rossmanite	7,1	5,6	27,1	32,0	0,5	4,2	8,3	13,7	10,0	17,3
Foitite	11,1	9,4	0,0	0,1	22,8	5,8	4,5	4,6	6,7	2,5
Mg-foitite	0,0	0,0	0,2	0,0	1,1	0,3	0,0	0,1	0,0	0,0
Cr-dravite	0,1	0,2	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,1
Mn-dravite	2,3	1,8	2,7	1,5	1,0	0,7	1,5	1,0	3,1	9,1
Mn-foitite	0,8	0,5	3,3	2,6	0,3	0,1	0,4	0,4	1,1	6,0

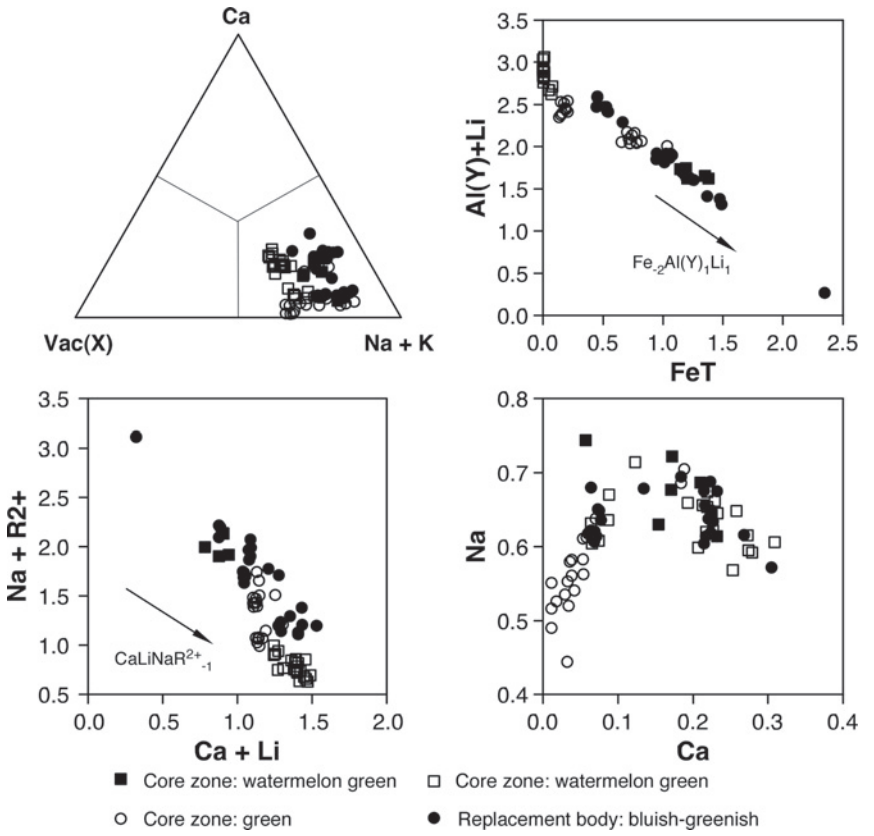

Figure1- Chemical composition of tourmalines from the Berger pegmatite.

The compositional variation of the Berger tourmalines is interpreted to be controlled by the substitution $^{Y}Fe^{2+}_{-2}{}^{Y}Al_{1}{}^{Y}Li_{1}$ (Fig. 1), except for the "watermelon" tourmalines from the core zone which have appreciable Ca contents. In these latter the Ca may have been incorporated via the substitution $CaLi(NaR^{2+})_{-1}$. This may be due to either as the partitioning of Na into coexisting albite was more important during the late stages of primary pegmatitic crystallization, or that this alkali-deficient tourmaline crystallized from a melt that was depleted in alkalis due to albite precipitation, as it is reported in other evolved pegmatites (e. g. Roda et al. 2004).

The paragenesis textural relationships, and chemical evolution of the tourmaline support a model of fractional crystallization for this pegmatite body, from the border to the core zones.

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