"PARAÍBA TOURMALINE" IN PEGMATITES OF THE BORBOREMA PEGMATITE PROVINCE, NE BRAZIL: GEOLOGICAL AND GEOCHEMICAL CONTROLS.

Hartmut Beurlen[1]
Odúlio J.M. de Moura[2]
Dwight R. Soares[3]
Marcelo R.R. da Silva[1]
Dieter Rhede[4]

[1] Depto. Geologia, CTG UFPE beurlen@ufpe.br ;
[2] H&R Exportação e Importação de Minérios, Governador Valadares, MG oduliomoura@uol.com.br ;
[3] Centro Fedreal de Educação Tecnológica, Campina Grande-PB;
[4] GeoForschungsZentrum Potsdam, Telegrafenberg B 120 D 14473Potsdam, Germany.

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INTRODUCTION

The "neon-" or "electric"-blue elbaitic tourmaline, with unique gemological qualities and known by the fashion name of "Paraíba Tourmaline" (*"PT"*), is certainly the most famous mineral product of the Borborema Pegmatite Province (BPP), in northeastern Brazil. Despite its importance, very little is known about the differences between the four known *"PT"* hosting pegmatites (PThP) and the other pegmatites in the province. Several thousand sterile and more than 750 Be–Li–Ta-mineralized pegmatites of the rare-element (RE) class and LCT family have come to light since World War II as a result of the important production of Ta ore. The literature about the *"PT"* recognizes the presence of high contents of copper, between 1.0 and 4.5 wt% CuO, as the main cause of the peculiar color and brightness of the *"PT"*, in some cases with inclusions of native copper. Copper sulfide disseminations were reported in some of the "PT" hosting pegmatites. The copper contents are usually explained as the result of late-hydrothermal stages in the formation of the hosting pegmatites (Cook 2002, Wilson 2002, Furuya 2007, Bhaskara Rao and Castro 2001). It is also known that the host pegmatites are emplaced in quartzites or metaconglomerates of the Neoproterozoic Equador Formation. These characteristics, however, are all shared by several dozens of other elbaite-bearing pegmatites in the BPP devoid of *"PT"*. As contribution to this problem, a comparison of petrographic, geological and geochemical features of the *"PT"* hosting pegmatites with pegmatites barren in *"PT"* and EPMA analyses in different growth-zones in multicolored zoned crystals of tourmaline are discussed.

GEOLOGICAL SETTING

The BPP covers an area of 150 × 75 km in the eastern part of the NNE-striking Seridó Foldbelt (SFb) in the Northern Domain of the Borborema Tectonic Province. The SFb is composed

of a Paleoproterozoic gneissic-granitic-migmatitic basement and a Neoproterozoic supracrustal metavolcanosedimentary sequence, the Seridó Group, which comprises, from base to top, gneisses and marbles (Jucurutu Formation), quartzites and metaconglomerates (Equador Formation) and garnet–cordierite–sillimanite schists (Seridó Formation). Several types of Neoproterozoic granite are found intruding the Seridó Group. The youngest one consists of several small intrusions of pegmatitic granite with peraluminous, S-type characteristics (Da Silva et al. 1995), with age determinations between 480 and 530 Ma (Baumgartner et al. 2005, Beurlen et al. 2009). These pegmatitic granites are the most likely source of the over 750 RE granitic pegmatites mineralized in Be–Li–Ta plus several thousand sterile pegmatites of the BPP. About 70% of the pegmatites are hosted in rocks of the Seridó Formation, around 10% in the Equador Formation, and the remaining are intruded in the basement rocks, granites and the Jucurutú Formation.

GEOLOGICAL FEATURES OF THE "PT" HOSTING PEGMATITES (PThP)

Four of five known occurrences of *"PT"* in the BPP are hosted by discordant pegmatites intruded in quartzites or metaconglomerates of the Equador Formation, south of 6°40' S latitude, namely the deposits of Batalha, Capoeira, Quintos and Glorious pegmatites. The fifth occurrence is found in alluvium covering the same quartzites. There is no known occurrence of *"PT"* hosted neither in the Seridó Formation, which hosts more than 70% of the pegmatites of the BPP, nor in other host rocks. The Equador Formation, however, hosts also more than a hundred mineralized granitic pegmatites of the RE class, barren in *"PT"*. Additional geological controls must therefore be at work that distinguish the PThP. There is no difference in strike and dip between the PThP and other pegmatites in the BPP. All PThP have maximal thicknesses below 20 m. In common with many other pegmatites of the BPP, they present internal mineralogical and textural zoning, and other features typical for well-fractionated pegmatites (in the case of Batalha and Glorious, these features are partially hidden by intensive shearing and kaolinization. The most striking feature common to the Capoeira 2, Quintos, and Batalha PThP is the presence of comb- textured black tourmaline (dravite) between the border and wall zones. The same feature is observed in another pegmatite hosting *"PT"* (Carrascão, recently identified by the first author), where uneconomic grades of *"PT"* occur as relics in lepidolitized zones of elbaite growth. Another common feature is the occurrence of *"PT"* as fan-like, radial groups of wedge-shaped crystals of elbaite intergrown with albite (with a light bluish hint) and some quartz (commonly light citrine), at the transition between the inner intermediate, albite-rich zone (IIZ) and a massive quartz core or pocket. Aggregates of both the elbaite and albite, and in some cases the associated rosettes of lepidolite (at Carrascão), are invariably indicating an unidirectional growth of crystals oriented toward the pockets or continuous core of massive quartz in the center of the pegmatite. This feature indicates a primary origin of these minerals and is well observed in the Capoeira 2, Quintos and Carrascão pegmatites.

VARIATIONS OF THE CHEMICAL COMPOSITION OF THE BPP ELBAITE

New EPMA data of color-zoned crystals of elbaite along sections crosscutting several color-zones from core (usually pink) followed by colorless

to very light blue, medium blue (*"PT"*) and a light green to dark green rim, were obtained to observe the differences between the *"PT"* zones and zones with other colors. The samples are from the *"PT"* -bearing Capoeira 2, Quintos and Carrascão and from the *"PT"*-lacking Boqueirão pegmatites (Fig. 1). The highest Al, $^{x}Vac_{(calc)}$ and Mn contents are typical of the pink and colorless to light blue crystals cores. The highest $Li_{(calc)}$, F, and Cu values, and lower Mn values, distinguish the medium blue *"PT"* zones (usually in the intermediate crystal-growth zone). The Fe and Mn contents increase again, at the expense of a decrease in Li and Al, in the green rinds of the multicolored near-end-member elbaite crystals of the *"PT"* -bearing pegmatites and represent a late regressive trend (Soares et al. 2008). These green rinds may still have enhanced Cu contents. Pink zones of near-end-member elbaite of the Boqueirão pegmatite (barren in *"PT"*) are richer in Fe than those of the "PT" -bearing pegmatites.

It must be emphasized that *"PT"* growth zones in multicolored elbaite crystals are distinguished from growth zones with other colors not only by the highest Cu contents, as well known from the literature, but also by the highest Li and F contents (some zones consist of fluor-elbaite) and the lowest Mg, Fe, Mn and vacancy contents. The chromotophore importance of Cu notwithstanding, high contents of Cu are not sufficient for the electric-blue color, brightness and transparency of the *"PT"*: as well shown by the color-zoned crystal of the Carrascão pegmatite, the increasing Fe contents in the rind, even maintaining high Cu contents, impose a common bottle-green color.

CONCLUSIONS

"PT" occurs only in zoned and highly fractionated pegmatites that are: 1) rich in primary Li minerals, mainly spodumene or lepidolite or both; 2) rich in boron, with dravitic black comb-textured tourmaline at the border zone; 3) enclosed in iron-poor quartzites or metaconglomerates of the Equador Formation; *"PT"* in these pegmatites occurs: 4) at the transition between the albitic inner intermediate zone and the quartz core (or lenticular quartz pockets) in the center of the pegmatites; 5) in primary crystals of near-end-member elbaite, wedge-shaped and in fan-like, radial or comb-textured crystal groups in the IIZ or quartz core; 6) most commonly in the intermediate growth-zone of color-zoned elbaite crystals with green to dark green rinds; 7) in pegmatites with intensive late replacement of primary minerals (mainly of K-feldspar, spodumene, tourmaline and, in some cases, Li phosphates like montebrasite and lithiophilite) by lepidolite; the lepidolite replacement of color-zoned elbaite crystals is highly selective, with the replacement beginning in the pink core followed by the light blue intermediate zones, with preferential preservation of the green rinds. 8) Homogeneous blue-colored *"PT"* crystals are most frequently preserved from lepidolite replacement when completely enveloped in quartz of the core.

The *"PT"* therefore is most commonly formed by direct crystallization from the pegmatite- generating melt or fluid medium, at the early stage of formation of the quartz core and prior to lepidolitization and other late hydrothermal stages. The difference between *"PT"*-bearing and other elbaite-rich pegmatites may not necessarily be the failure to produce primary *"PT"*, but the failure to preserve it from late lepidolitization. The origin of the *"PT"* formation may be linked with low content of mafic minerals in the wallrock and in the pegmatite itself (primary apatite and Li phosphates instead of Fe–Mn phosphates).

The always enhanced B contents of the *"PT"* hosting pegmatites may be, perhaps, linked with high B contents in the quartzite walls, which commonly contain bands rich in pink foitite and uvite disseminated along foliation planes and fractures.

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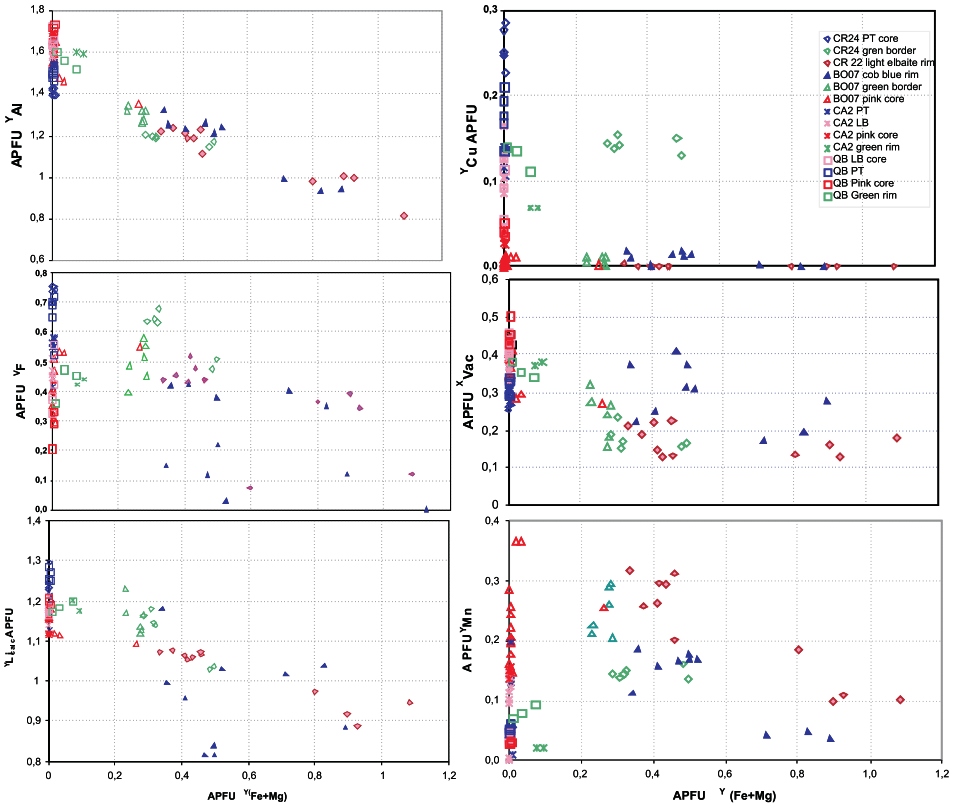

Figure 1- Most important variations of the chemical composition in multi-colored zoned elbaite crystals. Legend: CR-24 PT core ("Paraíba Tourmaline, crystal core), CR24 green border (border of the same crystal), CR22 elbaite border of a zoned schorl-elbaite crystal; BO 07 cobalt blue, nearly opaque elbaite rim, green border and pink core of a zoned crystal in vugs of replacement bodies;CA2 PT= Paraíba tourmaline zone, between pink core, colorless to light blue (LB) zone and green border of two elbaite crystals in the transition between inner intermediate albite zone and quartz core of the pegmatite. QB PT = Paraíba tourmaline zone between light blue to colorless (LB) and pink core and green rim from two crystals in the transition between albite zone and quartz core.