



Looking for Neon Blue in tourmaline: The Impact of Heat Treatment on Paraíba samples from Mozambique

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In the gem market, color is a crucial factor in determining the value of gemstones, often serving as the primary criterion that distinguishes valuable specimens from less desirable ones. In fact, color is one of the most appreciated and imitated properties of minerals since antiquity. Tourmalines, chemically complex borosilicates, are a perfect example of the extreme chromatic variability observed in minerals, and for this reason, they are considered highly valuable gemstones [1]. Through various chemical-physical mechanisms, they can exhibit a wide range of hues across the entire visible spectrum, from red to violet.

Among tourmalines, the most prized variety for its vivid colors, ranging from turquoise-green to neon blue, is Paraíba [2]. This rare Cu-bearing tourmaline, found in Brazil, Nigeria, and Mozambique, is currently among the most expensive gems on the market, with prices reaching up to USD 50,000 per carat. Specimens displaying intense blue hues owe their distinctive color to Cu, present at concentrations of several hundred ppm by weight, while Fe remains below 1 wt% [3]. More generally, in tourmaline, transition elements such as Ti, V, Cr, Mn, Fe, and Cu act as the main chromophores by occupying octahedrally coordinated sites within the structure, thus influencing both the tone and intensity of the color [2,4,5]. However, defects caused by impurities and polyhedral distortion may also impact the perceived color [4]. Understanding the mechanisms underlying both natural and treated coloration, particularly the precise distinction between the two, remains an open challenge in the crystal chemistry of tourmaline and demands further investigation.

In this study, to examine the effect of heat treatments on the color of tourmaline, more than 40 Cu-bearing tourmaline samples with different color tones were heated in controlled-atmosphere furnaces. These samples originated from the Mavuco area (Alto Ligonha, Mozambique), the largest and most recent known alluvial deposit of Cu-bearing tourmalines worldwide [6]. The color of each tourmaline was classified using the Munsell system (World of Color), under both transmitted and incident light, and observed along the two crystallographic directions, *a* and *c*, before and after each heating cycle. Samples that developed improved coloration toward neon blue tones, along with a representative selection of the main color categories, were subjected to crystal-chemical characterization through electron microprobe analysis (EMP), optical absorption spectroscopy (OAS), and Fourier-transform infrared spectroscopy (FTIR).

The results indicate that the studied Paraíba tourmalines exhibit elbaitic and liddicoatitic compositions, and that their color is primarily determined by the combination, concentration, and oxidation state of Cu, Mn, Fe, and Ti.



In particular, purple and bicolored samples (purple and bluish-gray) shifted more effectively toward neon blue hues after heating, compared to other color categories (Fig.1). This marked color change is attributed to the reduction of Mn^{3+} , responsible for the reddish-purple hue, to Mn^{2+} , a less intense chromophore. When Mn is present in the +2 oxidation state, and in the absence of significant amounts of Fe and Ti, the tourmalines exhibit a “neon” blue color due to strong absorptions by Cu^{2+} .

In contrast, heat treatment of Cu-bearing tourmalines containing high concentrations of Ti and Fe leads to a green coloration. Green samples heated up to 600°C show only minor color variations, shifting toward yellowish-green hues due to strong absorption linked to the Mn^{2+} – Ti^{4+} pair.



Figure 1: Heat treatment of a Cu-bearing violet tourmaline in a reducing environment, with increasing temperatures at each heating cycle, until the desired color is achieved.

Further analyses, including single-crystal X-ray diffraction and electron paramagnetic resonance (EPR) spectroscopy, are currently underway to refine the crystal-chemical model regarding the origin of color in both natural and heat-treated Cu-bearing tourmalines. A similar approach was recently applied with success to the colorless neotype of elbaite from Elba Island (acroite variety) to study the transition to red coloration (rubellite variety) induced by electron irradiation, and its subsequent return to colorless through heating. To fully understand the chemical-physical processes governing the characteristic neon blue color of Paraíba tourmalines, and to develop an analytical protocol capable of describing their chromatic evolution as a function of chemical composition and treatment conditions, it will be essential to construct a “high-resolution” crystal-chemical model.

This approach will not only clarify the mechanisms behind color variation but also define reliable diagnostic criteria to distinguish treated material from natural, thereby contributing to greater transparency and regulation in the gem market.

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