Using publicly available national geoscience and geochemical geographic data sets to predict the probable presence of the rare blue tourmaline Paraiba in the United States

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GEL 4970 UR Geology

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February 26, 2023

Paraiba tourmaline is a rare gemstone originally found in Paraiba Brazil in 1989. The very specific factors that host the environments that can create and preserve this mineral are limited making it one of the most valuable forms of tourmaline, considered rarer than a diamond costing upwards of $20,000 per carat. A lot of extensive research has been conducted surrounding this topic including Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and Electron Microprobe Analysis (EMPA) to determine chemical composition of different tourmalines as well as examining the different environmental factors that provide a suitable condition to produce and maintain this precious mineral.

Tourmaline is a diverse and unique mineral containing many different colors, chemical compositions, and host environments. Hobart M. King, the manager and publisher of Geology.com and a doctor of geology with over 40 years of experience states that "the wide range of compositions and color zoning within crystals causes tourmaline to occur in more colors and color combinations than any other mineral group" (King), Vincent J. van Hinsberg, an academic researcher from McGill University, Darrell J. Henry, an academic researcher from Louisiana State University, and Horst R. Marschall, an academic researcher from Goethe University Frankfurt say that "tourmalines can adjust their composition to suit a wide variety of environments and therefore display a remarkable range in stability in terms of pressure, temperature, fluid composition, and host-rock composition" (van Hinsberg and others, 2011). Van Hinsberg et. al. (2011) further discuss the variegation of tourmalines and what factors into the array of numerous colors and species that have been found.

There are many factors that make Paraiba tourmaline rare and widely sought after. Intensity of color and rare host environments are the main reason this type of tourmaline is so expensive and exclusive. Many scientists that have studied this gem agree that the vibrant blue coloration is due to copper content in the mineral. Donald Clark, Certified Supreme Master Gemcutter (CSM) and founder of the International Gem Society goes into detail on the history and value of Paraiba tourmaline. He avows that Paraiba tourmaline was found in the state of Paraiba, Brazil in 1989 and receives its blue coloration from the presence of copper. Clark infers that "color is more important than clarity" (Clark) explaining why other forms of this blue tourmaline found in Nigeria or Mozambique are less valuable due to its lessened color saturation. After LA-ICP-MS and EMPA conducted on 151 tourmaline samples from Brazil, 116 elbaite and 17 liddicoatite samples from Mozambique, and 17 samples from Nigeria, Yusuke Katsurada, a senior staff gemologist at Gemological Institute of America (GIA) in Tokyo, Ziyin Sun, an academic researcher from Gemological Institute of America, Christopher M. Breeding, a senior research scientist at Gemological Institute of America in Carlsbad, California, and Barbara L. Dutrow, a Williams Distinguished Alumni professor at Louisiana State University in Baton Rouge and a Gemological Institute of America governor concluded that "iron may [also] create the blue color in tourmaline, but the vivid blue color present in Paraiba tourmaline is sourced from copper. The blue coloration from copper exceeds the intensity and hue of blues obtained from iron" (Katsurada and others, 2019).

The host environments and chemical content for this rare blue tourmaline are very specific and uncommon. Extensive LA-ICP-MS and EMPA have been conducted to determine the particulars of the chemical compositions in different tourmalines, specifically Paraiba tourmaline. Hartmut Beurlen, a doctor of geology, concentrates on the most recent research in the Pegmatic Province of Borborema, in northeastern Brazil. Odúlio J.M. de Moura, an academic researcher, Dwight R. Soares and Marcelo R.R. da Silva, academic researchers from Federal University of Pernambuco, and Dieter Rhede, an academic researcher from University of Potsdam all contributed to the study of why this blue tourmaline is so unique. Beurlen et. al. (2011) state that "Paraiba tourmaline crystal-zones are distinguished not only by high Cu contents, but also by higher values of Li and F (mostly fluor-elbaite), Fe concentrations near zero, and lower concentrations of Mn than the contiguous zones with other colors" (Beurlen and others, 2011). Andreas Ertl, Gerald Giester, and Ekkehart Tillmanns, academic researchers from University of Vienna, Ulrich Schüssler and Martin Okrusch, academic researchers from University of Würzburg, Helene Brätz, an academic researcher from University of Erlangen-Nuremberg, and Hermann Bank, an academic researcher, attempted to chemically characterize and compare sixteen copper and manganese-bearing tourmalines, eight from Brazil and eight from Mozambique, using LA-ICP-MS and EMPA. They concluded that "all these samples are rich in Al, Li and F (fluor-elbaite) and contain significant amounts of CuO and MnO" (Ertl and others, 2012) which contradicts with what Beurlen (2011) previously said about tourmalines being manganese poor. Okrusch et. al (2016) affirm that analysis from thirty-eight tourmaline samples from Brazil, Mozambique, and Nigeria using EMPA and LA-ICP-MS revealed that the Paraiba-type tourmalines are "virtually Mg-free and Fe-poor elbaite" (Okrusch and others, 2016) which verifies Beurlen's (2011) analysis. Because of a weak correlation between manganese-oxide and copper-oxide, Ertl et. al (2012) believe that the copper content in tourmaline is essentially dependent on the availability of copper, correlating with Brown and Ayuso's (1985) statement that "the compositions of tourmalines [in the North Gouverneur area] are clearly a function of the bulk composition of the rock" (Brown and Ayuso, 1985).

Aside from specific chemical composition, host rock and environments are extremely important in maintaining this rare tourmaline. Igneous crystalline rock, hydrothermal activity, and lithium-rich minerals are crucial in the formation and preservation of this gemstone. Beurlen et. al.'s (2011) study implies that "Paraiba tourmaline-bearing pegmatites are rich in spodumene [or lepidolite] and are emplaced in iron-poor quartzites or meta conglomerates" (Beurlen and others, 2011), while also arguing that the rarity of this gemstone could be due to spodumene or lepidolite replacing the tourmalines in late-stage mineral conversion. Spodumene "is a pyroxene mineral that is typically found in lithium-rich pegmatites, usually associated with other lithium minerals such as lepidolite, eucryptite, and petalite" (King). Katsurada et. al (2019) infer that Paraiba-type tourmalines were "formed by direct crystallization from a hydrous melt, rich in boron and lithium with an unusual concentration of copper prior to the appearance of secondary lepidolite and other late hydrothermal minerals" (Katsurada and others, 2019)

Many scientists examining this topic agree that pegmatites are crucial in the creation and conservation of tourmalines and other gemstones. Ertl et. al (2012) further discuss the significance of pegmatites in the formation of tourmalines. King concludes that pegmatites are igneous rocks that form during the final stage of magma crystallization and "contain exceptionally large crystals and [sometimes] contain minerals that are rarely found in other types of rocks" (King), making them a prime host for rare gemstones such as aquamarine and other beryl jewels, emerald, garnet, topaz, and tourmaline. Beurlen et. al. (2011) observed that "all Paraiba tourmaline-hosting pegmatites have maximal thicknesses less than 20 meters" (Beurlen and others, 2011) and Katsurada et. al. (2019) agree that "most of Brazil's Paraiba tourmaline mining sites are primary deposits in pegmatites that intruded quartzites or meta conglomerates between 530 and 480 million years ago" (Katsurada and others, 2019).

Ervin Brown, an academic researcher, and Robert A. Ayuso, a doctor of geology and a research geologist with the United States Geological Survey, conducted a study examining twenty-three tourmaline-bearing specimens within a ten-mile radius of the North Gouverneur area in New York. Brown and Ayuso compiled tables with parts-per-million (ppm) values of the elemental oxides using EMPA. Brown and Ayuso state that "these analyses are necessarily incomplete because Fe_2O_3, H_2O, B_2O_3, and LiO_2 are not determined by means of the microprobe" (Brown and Ayuso, 1985) which is a major flaw in this research as these are important elements in the formation of tourmalines. The researchers could have expanded the reliability of their results by gathering samples from a wider radius giving them more diversity in their samples and by using other methods such as the LA-ICP-MS to make their data complete.

While King and Clark are credible sources due to their background, their web articles do not state where they got their information. By revealing where this knowledge was acquired, they could have increased validation of their work. A restraint with Hinsburg's (2011) examinations is that the authors referenced other researchers and compiled information from many sources but failed to conduct further analysis to include original input on this subject. One flaw in Katsurada's (2019) information is that the authors did not discuss in detail why and how chemical zoning complicates interpretations and what that means in the identification of Paraiba-type tourmalines. Beurlen's (2011) study used reliable professional equipment and orchestrated many LA-ICP-MS tests analyzing fourteen elements from elbaite samples using the standards of wollastonite, anorthite, fayalite, spessartine, diopside, microcline, albite, fluorite, and copper making it attested data. Beurlen et. al (2011) commonly referred to past studies and how their observations correspond with what other scientists have observed. Tourmalines supplied from Harvard University were measured in Ertl's (2012) study to verify accuracy making this information dependable, but the researchers could have sampled more than sixteen specimens to get more reliable results. Okrusch's (2016) material is highly credible as the experiments were conducted on trustworthy instruments and explained thoroughly. Although Okrusch (2016) used thirty-eight samples, it is significantly less than Katsurada's (2019) analysis making this slightly less definitive.

The environmental factors that host Paraiba tourmaline are quite specific and rare, making it a semiprecious gemstone. Elemental concentration values in parts per million from Katsurada (2019), Beurlen (2011), Ertl (2012), and Okrusch (2016) will be examined closely and averaged. Combined with the knowledge about pegmatites, hydrothermal activity, and lithium-rich minerals from Katsurada (2019) and Beurlen (2011), maps will be constructed displaying possible areas in the United States where Paraiba-type tourmaline host environments my exist.

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