GEM TOURMALINE CHEMISTRY AND PARAGENESIS FROM SIX WORLDWIDE LOCATIONS

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Summary

Gem tourmaline is known from many highly fractionated pegmatites throughout the world and considerable chemical variation exists in tourmaline from locality to locality. This study examines tourmalines from six worldwide pegmatite locations (Transbaikalia, Russia, two central Madagascar locations, two North American locations, and northern Brazil) to determine their chemical characteristics and pegmatite paragenesis.

All the tourmalines are dominantly elbaite or liddicoatite. Darker colored varieties contain a minor schorl component. Y-site chemistry strongly correlates with color and appears to be strongly influenced by the chemical characteristics of the pegmatites in which the tourmaline occurs. X-site vacancies of all tourmalines are less than 0.3 apfu. Fe and to a lesser extent Mn, Ti and Cu are the principal chromophores. Pink and green tourmalines from Transbaikalia are essentially elbaites, however, yellow zones within these crystals show a substantial liddicoatite component, coupled with elevated Ti and Mn contents. Tourmalines from the Antandrokomby pegmatite, Madagascar are members of the schorl-elbaite series with significant Mg and Ca contents. Even though the pegmatite occurs in a metadolomite, tourmaline Ca content is less than that of tourmaline from the classic Fianarantsoa and Anjanabonoina regions, Madagascar, where the tourmaline is liddicoatite and the pegmatites occur in pelitic country rocks. Tourmalines from both Madagascar locations have the lowest Y-site Al content. Tourmalines from San Diego County, California, and Newry, Maine, USA, are very similar chemically and belong to the schorl-elbaite series, with lighter colored, gemmy varieties approaching end-member elbaite. Paraíba tourmaline from Brazil is elbaitic in composition but contains significant Cu, which imparts a vivid blue color.

Introduction

Tourmaline is a well-known and widely mined gem mineral that is recovered almost exclusively from granitic pegmatites. The wide range in colors, good durability, and reasonably ample supply, make this mineral one of the most important gemstones. Its colorful varieties are largely restricted to the schorl-elbaite series and to a lesser extent to the liddicoatite-dravite series. Tourmaline color is related to its transition element content, notably Mn, Fe, and Ti. In the absence of Fe, Mn in lower concentrations may yield pink to red hues, but higher Mn content can result in yellow colors. The combination of Fe^{2+} absorption and Fe^{2+}-Ti^{4+} charge transfer produce green hues. In the absence of other ions, Fe^{2+} results in blue hues. Ti^{4+} coupled with Fe or Mn has a tendency to cause yellow to brown colors in some tourmaline. Recently Cu has also been shown to produce blue to purple hues. This study examines the color and chemistry from some well-known gem tourmaline producing pegmatites.

Transbaikalia, Siberia, Russia

The Transbaikalia region of southern central Siberia is famous for its gem tourmaline. Pegmatites of the Malkhanski district are currently being mined principally for gem quality polychrome tourmaline. The pegmatites appear to be related to Jurassic granitic plutons that have intruded Proterozoic metamorphic and igneous rocks. At least two hundred pegmatites are located within the Malkhanski district. Of these, seven are currently productive. These include the Mokhovaya, Svetlaya, Orieshnaya, Sosedka, Oktyabrskaya, Zapadnaya and Karkadilovaya pegmatites. The most extensive and productive of these is the Mokhovaya pegmatite, which is granitic in composition and contains abundant miarolitic pockets. The pocket mineralogy consists of gem rubellite, bicolor tourmaline, albite, and smoky quartz, with minor morganite, lepidolite, danburite, cookeite, and pollucite. In some pockets tourmaline is coated with a crust of fine-grained danburite. A few pockets contain large (up to 5 cm) gemmy orange danburite crystals. Additional accessory minerals identified in the Malkhanski district include manganocolumbite, monazite, ixiolite, strüverite, bismuthinite, bismutite, topaz, spessartine, cesian beryl, biotite, amazonite, and fluorite. Other minerals reported include xenotime, euxenite, bismutocolumbite, bismutomicrolite, microlite, hambergite, petalite, stilbite, and apatite.

A suite of polychrome tourmaline, collected from throughout the Malkhanski district, ranges in color from dark pink to yellow to green to brown. Electron microprobe analyses reveal that the tourmalines are principally elbaitic in composition (Figure 1) with fluorine contents of approximately 0.5 apfu. Color is found to correlate strongly with Y-site chemistry. Pink tourmaline approaches nearly end-member elbaite composition. Green caps and overgrowths on pink tourmaline contain higher total iron and manganese. The unusual yellow-orange to yellow colored tourmaline has the highest concentration of Mn (up to 8.1 wt.% MnO), but contains virtually no iron. Interestingly, yellow tourmaline contains less liddicoatite (Ca) component than do the rims of some elbaite crystals, which contain up to 42% Ca in the X-site. Overall, X-site vacancies are the highest in pink tourmaline, ranging up to 0.3 apfu. Calculated Li concentrations show a strong negative correlation with Mn content in all tourmalines. Although there is variability in the amount of Mn and Ti, there is a general trend of low Mn and Ti in pink tourmalines and high Mn and Ti in most yellow tourmalines. This suggests that the yellow color of Mn-rich, Fe-poor tourmaline may be the result of the Mn^{2+}-Ti^{4+} charge transfer.

The district is characterized by elbaite as the principal lithium mineral, which is more abundant than lepidolite, and by the low abundance of late-stage phosphate minerals. Tourmalines are Mn and F rich with low X-site vacancies. Elbaite is associated with late-stage danburite and hambergite. Based on these characteristics, the Malkhanski pegmatites can be classified as belonging to the elbaite subtype of the rare-element class of granitic pegmatites.

The Malkhanski pegmatites have an unusual late-stage chemistry very rich in calcium and boron as evidenced by the very late crystallization of danburite and hambergite as pocket minerals and overgrowths on miarolitic tourmaline. Tourmaline composition, especially that of the latest tourmaline, is influenced by this enrichment of calcium, which produces elbaite with significant calcium substitution for sodium in the X-site.

Central Madagascar

Antandrokomby pegmatite

The Antandrokomby pegmatite is a thin, steeply dipping dike

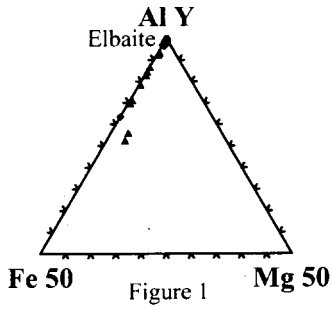

Figure 1

Y-site Fe-Al-Mg composition of Malkhanski tourmaline

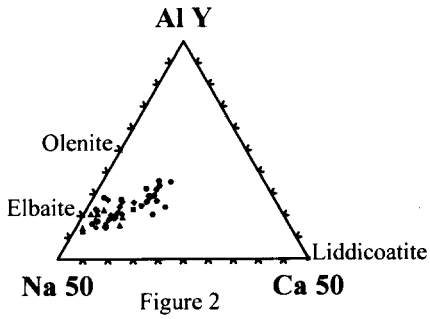

Figure 2

Na-AlY-Ca composition of Malkhanski tourmaline

located near the village of Ambatolampy, about 35 km south of Antsirabe, Madagascar. The pegmatite is hosted by dolomitic country rock and has exposed dimensions of 350 m x 1.2 m. Since 1900 the site has sporadically produced gem tourmaline as well as rhodizite and beryl. Recent mining during the summer of 1998 uncovered a large miarolitic cavity containing deep red tourmaline as well as a diverse suite of accessory minerals.

Tourmaline occurs throughout the pegmatite. In massive pegmatite near the footwall, earliest tourmaline forms a comb structure of prismatic crystals up to 30 cm in length, with pronounced dark olive-brown cores and thin, deep red rims. Within miarolitic cavities, later gem-quality reddish-purple tourmaline occurs as stubby crystals up to 4 cm in size. The crystals have dark olive-brown cores and deep red rims. Vibrant pink fibrous crystals encrust the pocket crystals and represent the final stages of tourmaline crystallization.

Electron microprobe analyses reveal that the tourmalines are principally schorl to elbaite in composition with appreciable Mg and Ca especially in the early Fe-rich cores (Figures 3 and 4). Fluorine contents are lower than that of the Malkhanski tourmaline, ranging from about 0.2 to 0.4 apfu. The concentrations of FeO, MnO, and TiO_2 show great variability. FeO in the early and miarolitic crystals ranges from 14.0 wt. % in the dark olive-brown cores, to less than 3.0 wt. % in the deep red rims. TiO_2 concentrations decrease from about 2.0 wt. % in the cores to less than 0.2 wt. % in the rims. MnO shows a similar decreasing trend from cores (1.0 wt. %) to rims (0.1 wt. %). The vibrant pink fibrous tourmaline has the lowest FeO (0.1 wt. %) and TiO_2 (0.2 wt. %) concentrations. MnO values for fibrous tourmalines are about 0.2 wt. %. All three types of tourmaline display relatively constant levels of Li_2O, Na_2O, and Al_2O_3. MgO averages about 0.5 wt. % and CaO remains below 2.0 wt. % in all tourmalines. Figures 3 and 4 show significant Mg and Ca substitution in the Y-site and suggest that the tourmaline chemistry reflects the fact that the pegmatitic melt was contaminated by the dolomitic country rock.

Lithium mineralization in the district is characterized by spodumene in the wall zone and minor elbaite, mostly in pockets. Lepidolite is significantly absent and there is very little late-stage phosphate mineralization. Tourmalines are Mn and F rich with X-site vacancies ranging from 0.0 in the early Fe-rich schorl to 0.28 in the later red tourmaline. Abundant rhodizite and londonite manifest extreme enrichment in Cs. These characteristics are virtually unique for any previously described pegmatites and thus the pegmatite is not easily classified. The Antandrokomby pegmatite could be considered to be a hybrid elbaite - spodumene type.

Early tourmalines fall within the elbaite-schorl series and have FeO-rich cores. TiO_2 in the brown tourmalines suggests that the brown color may be the result of charge transfer reaction between Fe^{2+} and Ti^{4+}.

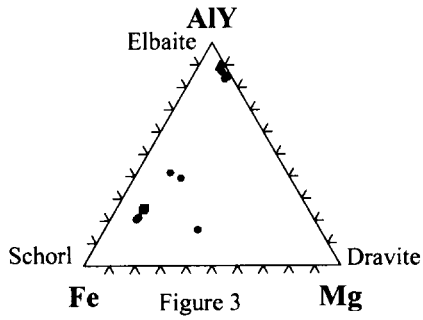

Figure 3

Y-site Fe-Al-Mg composition of Antandrokomby tourmaline

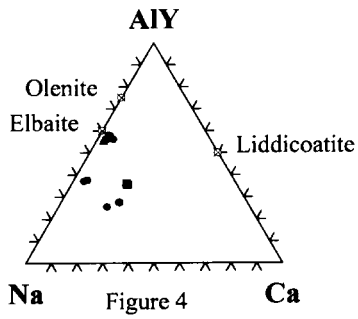

Figure 4

Na-AlY-Ca composition of Antandrokomby tourmaline

Fianarantsoa and Anjanabonoina Pegmatites

Large polychrome tourmaline has long been produced from the Fianarantsoa region in Madagascar; here tourmaline occurs in crystals over 10 cm long with deep red cores and green rims. Associated minerals include beryl (some morganite), quartz, feldspars and columbite-tantalite.

The Anjanabonoina area has been productive since the beginning of this century. For some time, this was the region that produced the majority of tourmaline from Madagascar. Most tourmaline is produced from placer deposits in valley sediments, notably in rice fields, the result of weathering of one or more large tourmaline-bearing pegmatites. The tourmalines from this area may exceed 20 cm in maximum dimension and are spectacularly color-zoned. Besides the 3-rayed star of deep-red color, pink, green, yellow and nearly colorless bands alternate repeatedly from core-to-rim. These bands are typically parallel to a trigonal prism.

Electron microprobe analyses of the oscillatory-zoned crystals reveal that the tourmalines are liddicoatite, with negligible Mg in the Fe-rich zones (Figure 5) and with about 0.7 apfu Ca in the X-site (Figure 6).

Fluorine contents are high ranging from about 0.8 to 1.5 apfu. FeO is low ranging from only about 2.6 wt. % in the green zones, to less than 0.06 wt. % in the red zones. TiO_2 concentrations are

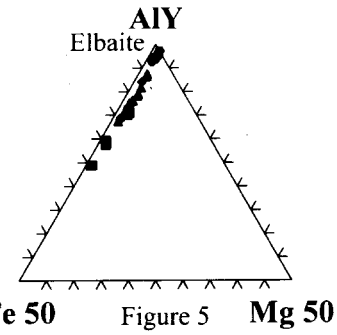

Figure 5

Y-site Fe-Al-Mg composition of Fianarantsoa and Anjanabonoina tourmaline

significantly lower than that of Antandrokomby tourmaline, ranging from 0.3 wt. % in the green zones near the core to less than 0.03 wt. % in the pink zone near the rim. MnO shows a pronounced oscillation from the green to the pink zones. The green zones all contain less than 0.1 wt.% MnO and the pink zones contain from about 0.2 to 0.9 wt. %. Na_2O is low, with all samples containing less than 1.0 wt. %

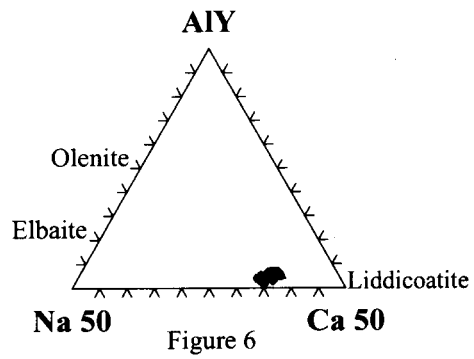

Figure 6

Na-AlY-Ca composition of Fianarantsoa and Anjanabonoina tourmaline

United States

Dunton Pegmatite, Newry, Maine

The Dunton pegmatite on Plumbago Mountain in the town of Newry is New England's best-known gem tourmaline location. The pegmatite belongs to the Oxford pegmatite field of southwestern Maine that consists of numerous moderately to highly fractionated LCT-type pegmatites that are mainly concentrated along the margins of the Carboniferous Sebago granite batholith. First operated for feldspar and mica in the beginning of the 20th century, the Dunton quarry was not known to have produced significant amounts of gem tourmaline until the discovery of a series of pockets in 1972. Over one ton of gem-quality green, pink and blue elbaite was recovered along with minor quartz, albite and lepidolite. Additional accessory minerals reported include beryl, spodumene, fluorapatite, microlite, cassiterite, manganocolumbite, manganotantalite, montebrasite, triphyllite, cookeite and pollucite.

Electron microprobe analyses show that the Dunton tourmalines are principally in the schorl-elbaite series (Figure 7). Samples show only minor Mg in the Fe-rich zones. FeO ranges from about 0.3 wt. % in the gemmy pink crystals to over 6.0 wt. % in the blue material. The samples are quite Na rich (Figure 8) with 0.6 to 0.9 apfu on the X-site. Fluorine content is about 0.4 apfu. MnO is lowest in the pink crystals ranging from about 0.9 to 1.4 wt. %. TiO_2 is relatively constant at about 0.07 wt. %.

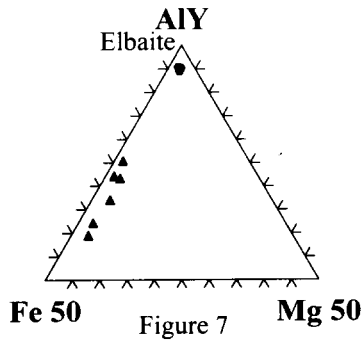

Figure 7

Y-site Fe-Al-Mg composition of Dunton tourmaline

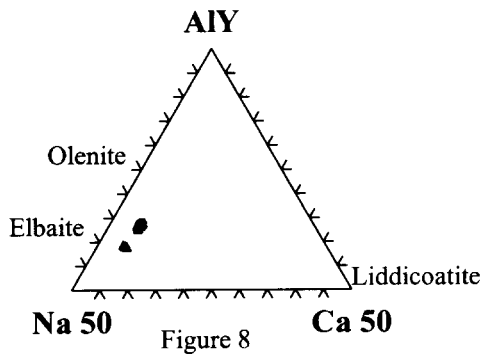

Figure 8

Na-AlY-Ca composition of Dunton tourmaline

Himalaya Pegmatite, Mesa Grande, California

Southern California pegmatites occur in the Mesozoic Peninsular Ranges batholith. The pegmatites are generally well-zoned, sub-horizontal, sheet-like bodies with an aplitic footwall, a pocket zone, and a coarse-grained hanging wall zone. In places, the aplitic footwalls of dikes display striking line rock features that are the result of diffusion-controlled oscillatory nucleation. Miarolitic cavities are relatively abundant, attesting to a shallow emplacement depth. The Himalaya pegmatite, in the Mesa Grande district, is one of the world's premier gem tourmaline producers and is a classic LCT-type pegmatite. The Himalaya mine has produced the largest amount of fine tourmaline in the southern California district, if not in the world. Conductive cooling models show that the Himalaya dike crystallized extremely rapidly cooling to about 350°C in 10 to 20 days. The mineralogy of the pockets consists of quartz, feldspars, schorl-elbaite series tourmaline, topaz, spessartine, lepidolite, spodumene, hambergite, and members of the columbite tantalite group, as well as stibiotantalite and rynersonite.

The relatively abundant pocket tourmaline ranges from black, schorlitic to indicolitic roots, to olive green, to colorless (achroite), to pink, and ultimately to dark green or blue caps. Electron microprobe analyses show that the tourmalines are principally elbaite in composition with a minor schorl component. Chemically, the tourmaline is similar to Dunton material, but with lower FeO and MgO content (Figure 9). FeO ranges from about 0.1 wt. % to about 2.8 wt. %. Na and Ca contents (Figure 10) are very similar to the Dunton material with X-site contents of Na between 0.7 to 0.8 apfu and Ca close to 0.1 apfu. Fluorine content is also similar to the Dunton tourmaline with about 0.4 apfu. MnO is also lowest in the pink crystals ranging from about 0.1 to 1.0 wt. % in the green zones. TiO_2 is relatively constant at about 0.06 wt. %.

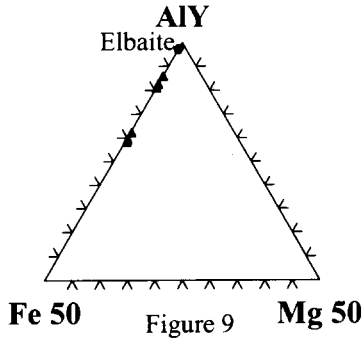

Figure 9

Y-site Fe-Al-Mg composition of Himalaya tourmaline

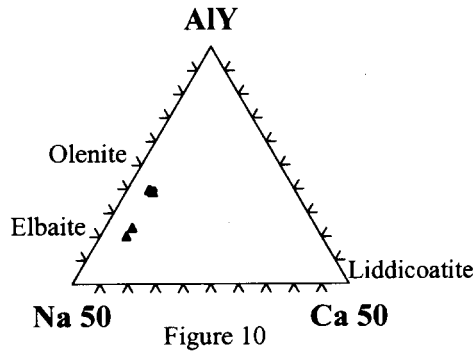

Figure 10

Na-AlY-Ca composition of Himalaya tourmaline

Paraíba, Brazil

The unusual and highly attractive cuprian elbaites from the state of Paraíba, Brazil have been met with intense interest since they first appeared on the market in 1989. The color ranges from a vivid blue to green to purple and treatment can easily alter the colors. These tourmalines come from a number of small, weathered pegmatites NE of the town of Salgadinho, near the village of São José da Batalha. The pegmatites are narrow dikes that cut across quartzite host rock. Most of the recovered gem tourmaline occurs as small crystals or crystal fragments, these pegmatites show evidence of extensive fracturing and shearing. Associated minerals include quartz, feldspar, Li-micas, spessartine, spodumene, and columbite-tantalite group minerals.

Electron microprobe analyses show that the tourmalines are elbaite in composition. Fe, Mg and Ca are the lowest of all the tourmaline examined (Figures 11 and 12). These tourmalines are unique with respect to their high Cu content. The Y-site contains from 0.1 to 0.3 apfu Cu. FeO is less than 0.2 wt. % and Mg was not detected. Na content is about 0.7 apfu. Ca is less than 0.07 apfu. Fluorine content is about 0.4 apfu. MnO ranges from about 0.6 to 1.0 Wt. %. TiO_2 is low, from about 0.01 to 0.04 wt.%.

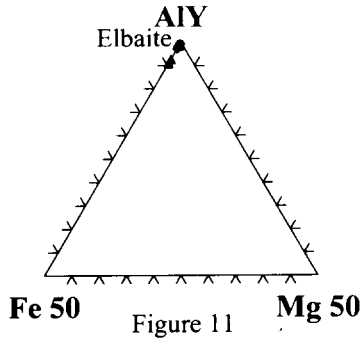

Figure 11

Y-site Fe-Al-Mg composition of Paraíba tourmaline

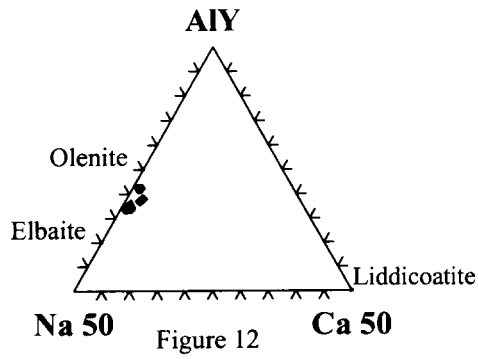

Figure 12

Na-AlY-Ca composition of Paraíba tourmaline

Conclusions

All the tourmalines are dominantly elbaite or liddicoatite. Darker colored varieties contain a minor schorl component. Y-site chemistry strongly correlates with color and appears to be strongly influenced by the chemical characteristics of the pegmatites in which the tourmaline occurs. X-site vacancies of all tourmalines are less than 0.3 apfu. Fe and to a lesser extent Mn, Ti and Cu are the principal chromophores. Pink and green tourmalines from Transbaikalia are essentially elbaites, however, yellow zones within these crystals show a substantial liddicoatite component, coupled with elevated Ti and Mn contents. Tourmalines from the Antandrokomby pegmatite, Madagascar are members of the schorl-elbaite series with significant Mg and Ca contents. Even though the pegmatite occurs in a metadolomite, tourmaline Ca content is less than that of tourmaline from the classic Fianarantsoa and Anjanabonoina regions, Madagascar, where the tourmaline is liddicoatite and the pegmatites occur in pelitic country rocks. Tourmalines from both Madagascar locations have the lowest Y-site Al content. Tourmalines from San Diego County, California, and Newry, Maine, USA, are very similar chemically and belong to the schorl-elbaite series, with lighter colored, gemmy varieties approaching end-member elbaite. Paraíba tourmaline from Brazil is elbaitic in composition but contains significant Cu, which imparts a vivid blue color.