

Tourmaline in Southwestern Maine

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INTRODUCTION

Tourmaline is an accessory mineral in a great many igneous, sedimentary, and metamorphic rocks. Tourmaline is a primary mineral in igneous rocks, especially granites and pegmatites. It is the only common mineral to contain significant quantities of boron and its abundance is one measure of the quantity of boron in a rock. Tourmaline is resistant to chemical and physical weathering so that it can be found in many sediments and in detrital sedimentary rocks. It is stable over a wide range of physical conditions and occurs in metamorphic rocks up to very high grades of metamorphism. The principal goal of this project was to discover more about how the chemical composition of tourmaline is related to its geological occurrence and history. With this knowledge it may be possible to increase the utility of tourmaline as a durable petrogenetic indicator.

Surprisingly few chemical data are available for tourmaline and many of those data come from southwestern Maine (Henry and Guidotti, 1985; Henry and Dutrow, 1986; Dyar et al., 1994). We elected to collect additional tourmaline samples from southwestern Maine to build upon the existing data set and to benefit in the field directly from the expertise of those familiar with both tourmaline and its geologic setting. We were guided to occurrences of tourmaline in metamorphic rocks by Charles Guidotti of the University of Maine. He took us to outcrops of the Rangely, Perry Mountain, and Smalls Falls formations in the Staurolite Zone (StZ), Lower Sillimanite Zone (LSZ), Upper Sillimanite Zone (USZ), and K-feldspar Sillimanite Zone (KSZ). We were guided to complex pegmatite occurrences of tourmaline by Carl Francis of the Harvard Mineralogical Museum. He took us to the Mt. Mica Pegmatite, the Berry Mine Pegmatite, the Pulsifer Pegmatite, the BB Mine Pegmatite, and the Songo Pond Pegmatite. We were guided to simple and complex pegmatite occurrences of tourmaline by Michael Wise of the National Museum of Natural History, Smithsonian Institution. He showed us the Whispering Pines Pegmatite, simple pegmatites around the Sebago Batholith and on Streaked Mountain, and the Black Mountain Pegmatite. Most of the pegmatites visited are near to the Sebago Batholith and may be genetically related to it.

TOURMALINE CRYSTAL CHEMISTRY

Tourmaline is a ring silicate in which silicon-oxygen tetrahedra are arranged in six-member rings (see Figure 1). Normally these tetrahedra are filled with Si, but in some tourmaline crystals Al and possibly B may be found in the tetrahedral sites. The tetrahedral rings are held together by a network of octahedrally-coordinated cations. There are three distinct types of octahedra. The Z-site is a small octahedron that normally holds Al, but may also contain Fe⁺³, Ti, Cr, V, Fe⁺², and Mg. The Y-site is an octahedron of intermediate size that may contain Fe⁺², Mg, Mn, Li, Al, and Fe⁺³. Both the Z-site and Y-site octahedra are labeled on Figure 1. The X-site is also six-coordinated, but is a very large site that is normally occupied by Na and may contain Ca as well. The X-site is shown by white spheres representing the sodium atoms. Boron, the element that makes tourmaline unique, resides in a three-coordinated site. Boron is shown in Figure 1 as small gray spheres in the center of open triangles. Hydrogen is also an important part of the tourmaline structure. It is bound to the oxygen atoms of the X and Y octahedra that are not also shared with silicon. Hydrogen is not shown in Figure 1. The many sites in the tourmaline structure make a wide range of tourmaline compositions possible. A general formula for tourmaline would be $XY_3Z_6(BO_3)_3(Si_6O_{18})(OH)_4$, with the letters X, Y, and Z standing for the cation sites described above. Common tourmaline end members are schorl $NaFe^{+2}_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$, dravite $NaMg_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$, and elbaite $Na(Li,Al)_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$.

DATA COLLECTION

Collecting in the field was a group effort, but focused projects were being formulated and participants were choosing among them during the field work. A large number of samples was collected, many of which contained visible tourmaline, but some of which had an unknown tourmaline content -- especially the metamorphic rocks. Samples were prepared for chemical analyses at Smith College. Again this was a group effort, although specific projects had been identified and sample preparation was guided by the project needs and the project students. Where

possible, tourmaline mineral separates were prepared by "hand picking" of tourmaline grains with the aid of a dissecting microscope and a Frantz Magnetic Separator. Grain mounts of most samples were prepared for electron beam chemical analyses. Thin section chips were cut for the metamorphic rocks and sent to a commercial preparer of polished thin sections.

Tourmaline powders were sent to J. David Robertson of the University of Kentucky for particle-induced gamma ray emission (PIGE) measurement of the light elements B, Li, and F. Tourmaline powders were sent to Ian Richards and Kurt Ferguson of Southern Methodist University for H₂O analysis and for oxygen and hydrogen isotope analysis. Tourmaline powders were mounted and sent to Joseph Stucki of the University of Illinois for Mössbauer spectroscopy. Additional details of these analyses can be found in the paper by Brook Holcombe and Monique Velasquez (this volume) and the references therein. Tourmaline crystals in polished grain mounts were sent to Jeremy S. Delaney for analysis of major elements with the electron microprobe at Rutgers University. Tourmaline in polished thin sections of metamorphic rocks was analyzed for major elements with the energy dispersive x-ray spectrometer on the scanning electron microscope at Amherst College with the assistance of John T. Cheney and Peter D. Crowley. X-ray diffraction data were collected on tourmaline powders with the x-ray diffractometer at Smith College. Clearly this project was a group effort that benefited from the special aid and cooperation of many individuals.

SPECIFIC PROJECTS

(1) The chemical differences in tourmaline between simple and complex pegmatites. Ruben Acosta of the California State Polytechnic University at Pomona and Sarah Carmichael of Smith College compared the chemistry of tourmalines from chemically complex pegmatites that contain unusual minerals and perhaps chemical zoning with tourmalines from simple pegmatites (very coarse granitic bodies of simple mineralogy and large grain size). They observed that the tourmaline in simple pegmatites are very similar to tourmaline in the wall zones of complex pegmatites suggesting that the two types of pegmatites may in fact be produced by similar magmatic processes. They also show that the Y-site substitution $\text{LiAl} = (\text{Mg,Fe})$ is an important variable for pegmatitic tourmaline.

(2) The variation of tourmaline chemistry with metamorphic grade. Carlos Alonso of the University of New Orleans, Gregory Brown of Amherst College, and Karen Jager of Pomona College examined the chemistry of tourmaline and associated garnet and biotite in metamorphic rocks from three formations over four metamorphic grades. They found that the Fe-Mg partitioning among these minerals changed systematically with grade in spite of the complex chemistry of the tourmaline. They observed that the mineral compositions in the assemblage tourmaline-garnet-biotite became more iron-rich as the metamorphic grade increased. They also found that the chemical zoning in tourmaline that is common in Staurolite Zone rocks is not present in K-feldspar Sillimanite Zone rocks.

(3) The chemical variation of tourmaline chemistry across pegmatite-country rock contacts. Dan Core of the College of Wooster and Kate Wearn of Williams College studied the chemistry of tourmaline in the complex pegmatites at Mt. Mica and Black Mountain and in the adjacent country rocks. In both cases it appears that fluids from the pegmatite have exchanged boron with the country rock in some cases leading to the growth of tourmaline that is influenced by the chemistry of the country rock. They found that the chemistry of tourmaline in the country rock was somewhat different in the two cases, reflecting a different degree of interaction with the pegmatite. This conclusion was also supported by the hydrogen isotope data.

(4) The stable isotopes of the pegmatite systems associated with the Sebago Batholith. Brook Holcombe of Colorado College and Monique Velasquez of the University of New Orleans examined the hydrogen and oxygen isotopes of tourmalines from several simple and complex pegmatites and adjacent country rocks. Isotopic data from all of the samples define a trend away from typical metamorphic δD and $\delta^{18}\text{O}$ values, which is consistent with vapor fractionation. Data for the tourmaline of the Black Mountain pegmatite are consistent with an origin involving the Sebago Batholith, whereas the isotopic data for tourmaline from the Mt. Mica pegmatite is consistent with a different source. Isotopic and elemental data for the simple pegmatites show a strong signature of the surrounding country rock.

(5) The relationship between color, chemical composition, and unit cell size in tourmaline. Renee Geyer of Trinity University and Judy Wilson of the University of New Orleans measured the unit cell parameters for twenty-two tourmaline samples. They compared their results with the unit cell data for an additional fifty-four tourmaline samples that had been collected previously (Dyar, personal communication). They found that there is a relationship between Fe and Al content and unit cell size. Samples with more Fe have a larger unit cell; samples with more Al have smaller unit cells. Their data are consistent with much of the color in green to black tourmaline being a result of Fe²⁺ to Fe³⁺ charge transfer.

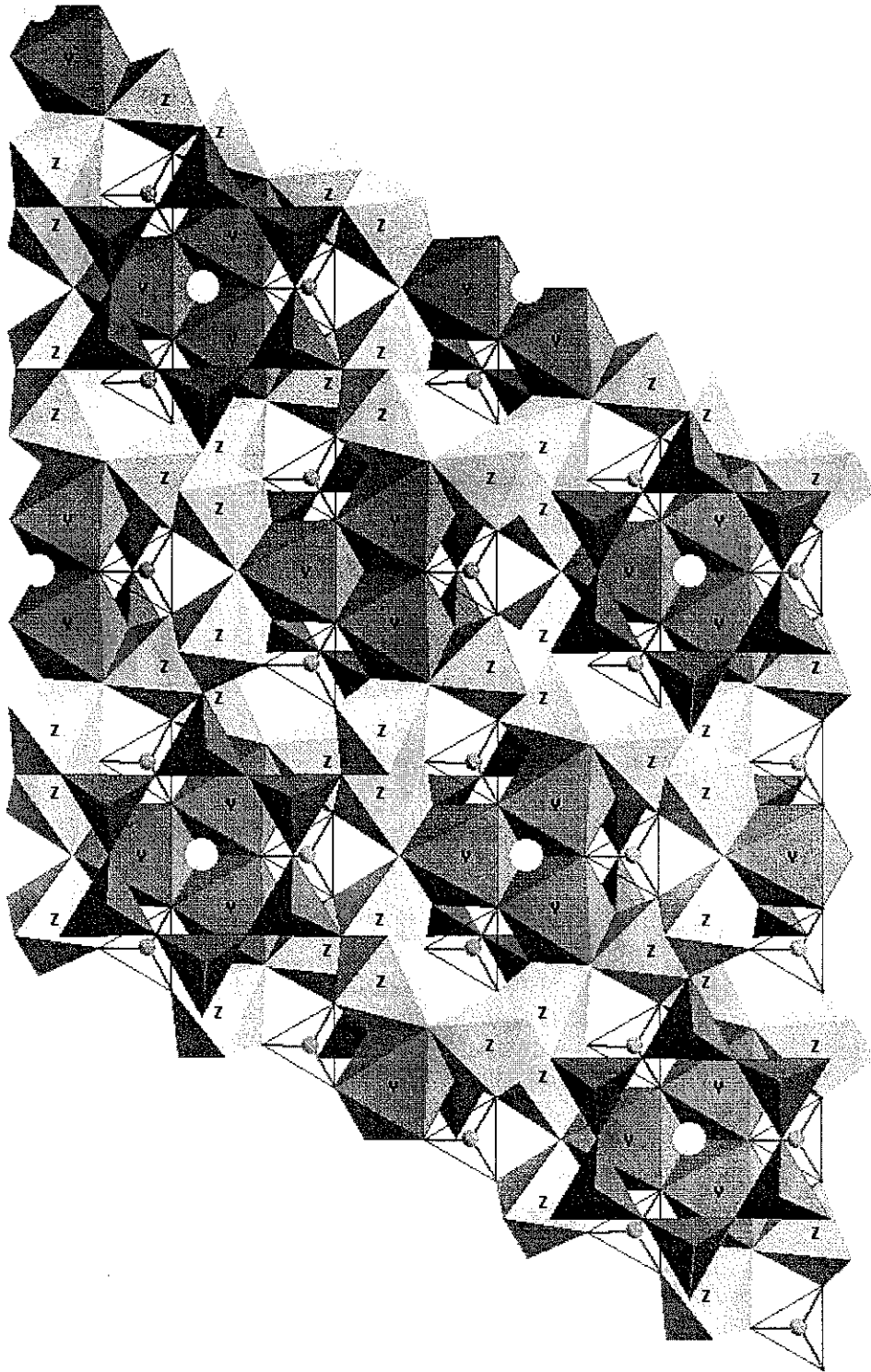


Figure 1. A polyhedral representation of the crystal structure of tourmaline.

SUMMARY

The complex chemistry of tourmaline has been an impediment to its use in geothermobarometry and as an indicator of petrologic processes. We have gathered a large quantity of new data on the chemistry of tourmaline from the simple and complex pegmatites of southwestern Maine and from the metamorphic rocks in which they occur. Our data demonstrate that the chemistry of tourmaline is responsive to the environment of tourmaline growth. Tourmaline in metamorphic rocks changes systematically with metamorphic grade. Tourmaline in the contact zones of pegmatites records the exchange of boron with the pegmatite. Tourmaline in simple pegmatites shows the effects of hydrogen added from the surrounding metamorphic rocks. Tourmaline in complex pegmatites bears the isotopic signature of the parent granite. Tourmaline in all rocks has unit cell parameters and a color that is related in a systematic way to their chemistry. In sum, we have demonstrated that tourmaline is a useful petrogenetic indicator and we have added significantly to the available tourmaline data needed to understand the petrologic significance of specific tourmaline compositions.

REFERENCES CITED

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