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Tourmaline as a petrogenetic indicator mineral: where are we in 2011?

Darrell Henry and Barbara Dutrow
Louisiana State University, Geology and Geophysics, Baton Rouge, United States (glhenr@lsu.edu)

A once obscure and overlooked mineral, tourmaline has now become a primary contributor to understanding petrogenetic history of nearly all rock types. In 1985, with the publication of "Tourmaline as a petrogenetic indicator mineral: an example from the staurolite-grade metapelites of NW Maine" (Am. Min, v.70, 1-15), tourmaline rose to relevance among the suite of minerals that could be used to extract information about the rocks in which they formed. Two of the significant findings were that tourmaline (1) exhibited systematic element partitioning with other minerals that formed during metamorphism and (2) inherited a distinctive chemical signature from the rock type that it developed. Consequently, tourmaline could be an extremely useful petrogenetic indicator mineral, if sufficient background information was attained so that the chemical signatures of tourmaline could be properly interpreted. This required a significant amount of allied investigations of tourmaline in disparate fields. Since 1985 tremendous advancements have been made understanding of tourmaline including the following: Crystallographic nature of tourmaline. The general structural formula of tourmaline is now known to be: $XY_3 Z_6(T_6O_{18})(BO_3)_3V_3W$ where the common ions at each site are X = Na^{1+}, Ca^{2+}, K^{1+} and vacancy: Y = Fe^{2+}, Mg^{2+}, Al^{3+}, Li^{1+}, Fe^{3+} and Cr^{3+}; Z = Al^{3+}, Fe^{3+}, Mg^{2+} and Cr^{3+}; T = Si^{4+}, Al^{3+} and B^{3+}; B = B^{3+}; V = OH^{1-} and O^{2-}; and W = OH^{1-}, F^{1-} and O^{2-}. Several crystallographic and chemical issues influence the stability range and its interaction with its petrologic environment. (1) Tourmaline exhibits a wide array of heterovalent and homovalent coupled substitutions. (2) Within the tourmaline structure F^{1-} occurs only in the W site, and (3) Short-range bond-valence requirements and order-disorder reactions control the type and crystallographic positions of ions in the structure. With this knowledge a new nomenclature for the tourmaline supergroup minerals has been established, with 18 approved species. The extremely low diffusion rate and wide stability range of tourmaline is likely related to these crystallographic features. In addition, chemical changes in tourmaline are a function of both crystallographic constraints and the petrologic environment e.g. F^{1-} incorporation in the W site with different X-site occupancy. Temperature-pressure-fluid stability range of tourmaline. Tourmaline is known to be stable over most of the crustal PT conditions. Tourmaline has been found in diagenetic evaporitic and hydrothermal environments that record temperatures of $<150^{\circ}$C and pressures of < 1 MPa. At the upper T extreme tourmaline has been found to be stable at $>900^{\circ}$C in experiments and is locally found in granulite-facies rocks. The upper P stability is high – based on experiments tourmaline is stable up to 7 GPa and it can be associated with high with high-P minerals such as coesite and diamond. Within the extensive PT stability range, tourmaline is unstable in environments that have fluids with high pH and selected aqueous species. Temperature and fluid determination using tourmaline. Tourmaline is a crystallographically asymmetric mineral that incorporates different concentrations of cations at opposite poles of the crystal as a function of temperature. This has been empirically calibrated as a thermometer that can be used to infer much of the thermal growth history of metamorphic tourmaline. In addition, experiments have shown that X-site Na and Ca contents can be related to the composition of the dissolved species in an aqueous fluid phase. Isotopic signatures in tourmaline. B, O and H stable isotopes have been extensively used for determination of T as well as the sources of the fluids that are associated with tourmaline formation. With the advent of very sensitive mass spectrometers, $^{40}Ar/^{39}Ar$ systematics in tourmaline has been developed as a thermochronometer.