

Stable isotope variations in the pegmatite systems associate with the Sebago Batholith, southwestern Maine

Brook Holcombe

Department of Geology, The Colorado College, 902 N. Cascade, Colorado Springs, CO 90946
Faculty sponsors: Kathleen Johnson, University of New Orleans; Bruce Loeffler, The Colorado College

Monique Velasquez

Department of Geology and Geophysics, University of New Orleans, Lakefront, New Orleans, LA 70148
Faculty sponsor: Kathleen Johnson, University of New Orleans

INTRODUCTION

Stable Isotope comparisons of peraluminous granites and associated pegmatites have been the focus of recent studies (Nabelek et al. 1992; Taylor et al. 1992; France-Lanord et al. 1988; Taylor et al. 1979), in part to gain a better understanding of the processes that have produced the rare element pegmatites. The Sebago Batholith in southwestern Maine, provides an excellent setting in which to study the fluid/rock systems that generate pegmatites. Previous studies of the Sebago Batholith and associated pegmatites have focused on either the general petrology of the batholith (DeYoreo et al. 1989), or detailed descriptions of the mineralogy of the pegmatites (Francis et al. 1993). None of the previous investigations have examined fluid transport or fluid/rock interactions.

Stable isotope data can provide information essential to understanding of the processes involved in the generation, transport, and emplacement of pegmatite fluids associated with the Sebago Batholith. In particular, the ubiquitous occurrence of tourmaline (a hydrous boro-silicate) in the pegmatites, batholith, and metamorphic country rock, make this mineral one of the most useful sources of information for defining this complex fluid/rock system. In addition to its abundance, the chemical stability of tourmaline throughout a wide range of petrologic conditions suggests that it should preserve the stable isotope composition of the pegmatite generating fluid (Henry and Dutrow 1996; Kotzer et al. 1993; Taylor et al. 1992).

In this study, stable isotope compositions of tourmaline from the pegmatites and country rock associated with the Sebago Batholith have been determined. The nature and role of fluids related to pegmatite petrogenesis are discussed.

ANALYTICAL TECHNIQUES

Tourmaline-bearing whole rock samples were collected from various locations throughout southwestern Maine for analysis. Samples were crushed and ground in acetone using mortar and pestle, and grains were hand picked to 99% purity. All samples were analyzed for oxygen and hydrogen isotope compositions. A subset of samples were prepared for Particle Induced Gamma-ray Emission (PIGE) spectroscopy.

Hydrogen and Oxygen isotopic compositions of tourmaline were determined using standard procedures (e.g. (Bigeleisen et al. 1952; Clayton and Mayeda 1963; Borthwick and Harmon 1982). A method for volumetric measurement of water vapor extracted from silicates was used to calculate the weight percent of structural water in tourmaline following Holdaway et al. (1986). Estimates of analytical error are $\pm 0.2\text{‰}$ for $\delta^{18}\text{O}$ and $\pm 2\text{‰}$ for δD . All isotope data are reported in the standard 'delta' notation as per mil (‰) units.

Major and minor elemental compositions were determined using a JEOL 8600 Superprobe with Noran (Tracor Northern) automation. Analytical errors are $\pm 10 - 20\%$ for minor elements and $\pm 0.5 - 2.0\%$ for major elements. Boron concentrations were determined by Particle Induced Gamma-ray Emission (PIGE) spectroscopy. Methods for the analysis of geological samples are described by Lappalainen et al. (1985), Brissaud et al. (1986), and Dyar et al. (1994).

RESULTS

New stable isotope data and elemental chemical data are presented for tourmaline samples from simple (White Cap Mountain, Streaked Mountain, Whispering Pines Quarry, and Windham Quarry) and complex (Mt Mica and Black Mountain) pegmatites. Simple pegmatites are considered together because of

the overall coherent chemical behavior noted for tourmaline from these locations (Acosta and Carmichael, 1997). All of these pegmatites are spatially and temporally associated with the Sebago Batholith. Data from the study of Dyar et al. (1994) for tourmaline samples from southwestern Maine are also evaluated here.

Stable isotope data for tourmaline from the complex pegmatites, contact zone metamorphic rocks, and some of the simple pegmatites appear to define an array trending away from metamorphic water towards more depleted δD values at a range of $\sim 20\text{‰}$ in $\delta^{18}O$ (Figure 1) forming a possible vapor fractionation trend. It is significant to note that the Black Mountain country rock contact zone (open squares) and both Mt Mica contact and pegmatite samples (open and closed circles) define this trend. This suggests the derivation of pegmatite fluids from the partial melting of a metasedimentary source (London et al. 1996). There is a slight trend towards higher δD in the Black Mountain samples as the water content increases (Figure 2). However tourmaline from the other localities, including the Mt Mica complex pegmatite, do not follow this trend. With the exception of two of the simple pegmatites, oxygen remains fairly constant as water increases.

When considered along with the water content, stable isotope data for tourmaline from the different localities is not consistent with a single vapor fractionation trend or fluid source. Boron data further show that fluids in the two complex pegmatites behave differently (Figure 2c) and may have different sources. Black Mountain pegmatite tourmaline has a boron content that appears to have evolved from the Sebago Batholith, whereas Mt Mica pegmatite tourmaline shows a relationship to both contact zone and simple pegmatite tourmaline compositions (Figure 2c and Figure 3).

DISCUSSION

It has been hypothesized that the Sebago Batholith is a reasonable source for pegmatite generating fluids in southwestern Maine (Wise and Francis, personal communication). Peraluminous granites generated by the partial melting of a metasedimentary source commonly do have associated pegmatites (France-Lanord et al. 1988; Nabelek et al. 1992; London et al. 1996). Stable isotope and boron data for tourmaline from Black Mountain support this hypothesis for the origin of pegmatite generating fluids. Contact zone tourmaline has a distinctly different boron concentration than pegmatite core tourmaline, but a similar δD composition, suggesting that the boron source was in situ (e.g. boron-rich micas), and tourmaline crystallization may have been catalyzed by the infiltration of hydrothermal pegmatite waters.

Conversely, at Mt Mica, data for both contact zone and pegmatite tourmaline suggests interaction of the country rock with pegmatite fluids. As noted by Core and Wearn (1997) country rock structure at Mt Mica has prevented pervasive exchange of pegmatite fluids with the country rock, causing tourmaline to be present only in the proximal contact zone. Yet the fluid interaction that has occurred at Mt Mica appears to control the composition of tourmaline formed there, and is dominated by the pegmatite component.

Tourmaline from simple pegmatites show stable isotope and boron compositions similar to contact zone country rocks from Black Mountain. This may be interpreted to suggest that tourmaline in simple pegmatites has an origin analogous to contact zone pegmatites. The overall chemistry of simple pegmatite tourmaline appears to support this conclusion (Acosta and Carmichael 1997).

CONCLUSIONS

Tourmaline forming fluids for the Black Mountain Pegmatite show the most direct chemical correlation with the Sebago Batholith. Mt Mica may have a different source, or may simply show a unique trend in fluid evolution given very different structural and emplacement circumstances. Isotopic and elemental data for tourmaline from the simple pegmatites indicate that their fluid evolution is dominated by the enclosing country rock.

REFERENCES CITED

- Acosta, R. and Carmichael, S. (1997) The chemical differences in tourmaline between simple and complex pegmatites in southwestern Maine. Tenth Keck Research Symposium in Geology Proceedings (This Volume).
- Bigeleisen, J., Perlman, M.L., and Prosser, H.C. (1952) Conversion of hydrogenic materials to hydrogen for isotopic analysis. *Analytical Chemistry* v. 24 #8, pp. 1356-1357.
- Borthwick, J., Harmon, R.S. (1982) A note regarding ClF_3 as an alternative to BrF_5 for oxygen isotope analysis. *Geochimica et Cosmochimica Acta* v. 46, pp. 1665-1668.
- Brissaud, I., DeChateau-Thierry, A., Frontier, J.P., and Lagarde, G. (1986) Analysis of geological standards with PIXE and PIGE techniques. *Journal of Radioanalytical Chemistry*, vol. 102, 131-141

- Clayton RN, Mayeda TK (1963) The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis. *Geochimica et Cosmochimica Acta* 27: 43-52.
- Core, D. and Wearn, K. (1997) Geochemical characterization of tourmaline across pegmatite-country rock boundaries in the Southwestern Maine Pegmatite Field. Tenth Keck Research Symposium in Geology Proceedings (This Volume).
- DeYoreo, J.J., Lux, D.R., and Guidotti, C.V., 1989, A thermal model for carboniferous metamorphism near the Sebago batholith in western Maine. Maine Geological Survey, Jackson Commorative Volume.
- Dyar M.D., Francis C.A., Wise M.A., Guidotti C.V., McGuire A.V., and Robertson JD, (1994) Complete Chemical Characterization of Tourmaline. EOS Transactions of the American Geophysical Union (Spring Meeting) vol. 75 # 16, 187.
- France-Lanord, C., Sheppard S.M.F. and Le Fort, P., (1988) Hydrogen and oxygen isotope variations in the high Himalaya peraluminous Mansalu leucogranite: Evidence for heterogeneous sedimentary source. *Geochimica et Cosmochimica Acta* v. 52, pp. 513-526.
- Francis, C.A., Wise, M.A., Kampf, A.R., Brown, C.D., and Whitmore, R.W. (1993) Granitic Pegmatites in Northern New England. In: Field Trip Guidebook for the Northeastern United States. Ed: J.T. Cheney and C.J. Hepburn. University of Massachusetts, Department of Geology, Amherst. 1.E-1 to 1.E-24.
- Henry, D.J. and Dutrow, B.L. (1996) Metamorphic Tourmaline. In: Boron mineralogy, petrology and geochemistry, ed. E.S. Grew and L.M. Anovitz, Reviews in Mineralogy, vol. 33, Mineralogical Society of America, pp. 503-557.
- Holdaway, M.J., Dutrow, B.L., Borthwick J., Shore, P., Harmon, R.S., Hinton RW (1986) Staurolite water content as determined by hydrogen extraction line and ion microprobe. *American Mineralogist*, v. 71, pp. 1135-1141.
- Kotzer, T.G., Kyser, T.K., King, R.W., and Kerrich, R. (1993) An empirical oxygen- and hydrogen-isotope geothermometer for quartz-tourmaline and tourmaline-water. *Geochimica et Cosmochimica Acta*, v. 17, 3421-1426.
- Lappalainen, R., Raisanen, J., and Anttila, A. (1985) Analysis of boron using the (p,α) reaction. *Nuclear Instruments and Methods in Physics Research*, vol. B9, 55-59.
- London, D., Morgan, G. B., and Wolf, M. B., 1996, Boron in granitic rocks and their contact aureoles. In: Boron mineralogy, petrology and geochemistry, ed. E.S. Grew and L.M. Anovitz, Reviews in Mineralogy, vol. 33, Mineralogical Society of America, pp. 299-325.
- Nabelek, P.I., O'Neil, J.R., and Papike, J.J.. (1983) Vapor phase exsolution as a controlling factor in hydrogen isotope variation in granitic rocks: the Notch Peak Granitic Stock, Utah. *Earth and Planetary Science Letters*, v. 66, pp. 137-150.
- Nabelek P.I., Russ-Nabelek, C., and Haussler, G.T. (1992) Stable isotope evidence for the petrogenesis and fluid evolution in the Proterozoic Harney Peak leucogranite, Black Hills, South Dakota. *Geochimica et Cosmochimica Acta* v. 56, pp. 403-417.
- Taylor, B.E., Foord, E.E., and Friedrichsen, H.. (1979) Stable isotope and fluid inclusion studies of GEM-bearing granitic pegmatite-aplite dikes, San Diego Co., California. *Contributions to Mineralogy and Petrology*, v. 68, pp. 187-205.
- Taylor, B.E., and Slack, J.F.. (1984) Tourmalines from Appalachian-Caledonian massive sulfide deposits: textural, chemical, and isotopic relationships. *Geology*, v. 356, pp. 1703-1726.
- Taylor, R.P., Ikingura J.R., Fallick A.J., Huang, Y., and Watkinson, D.H. (1992) Stable isotope compositions of tourmalines from granite and related hydrothermal rocks of the Karagwe-Ankolean belt, northwest Tanzania.

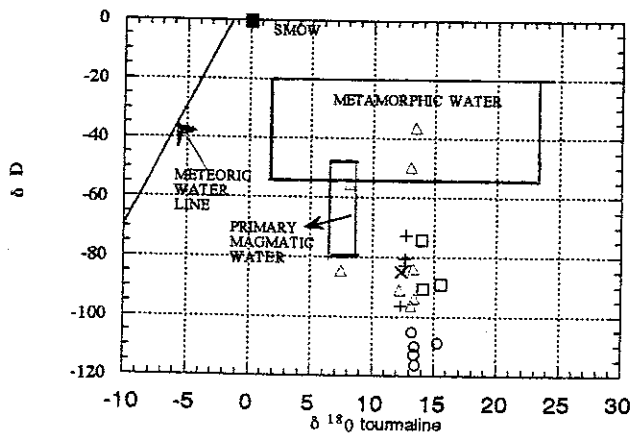


Figure 1.

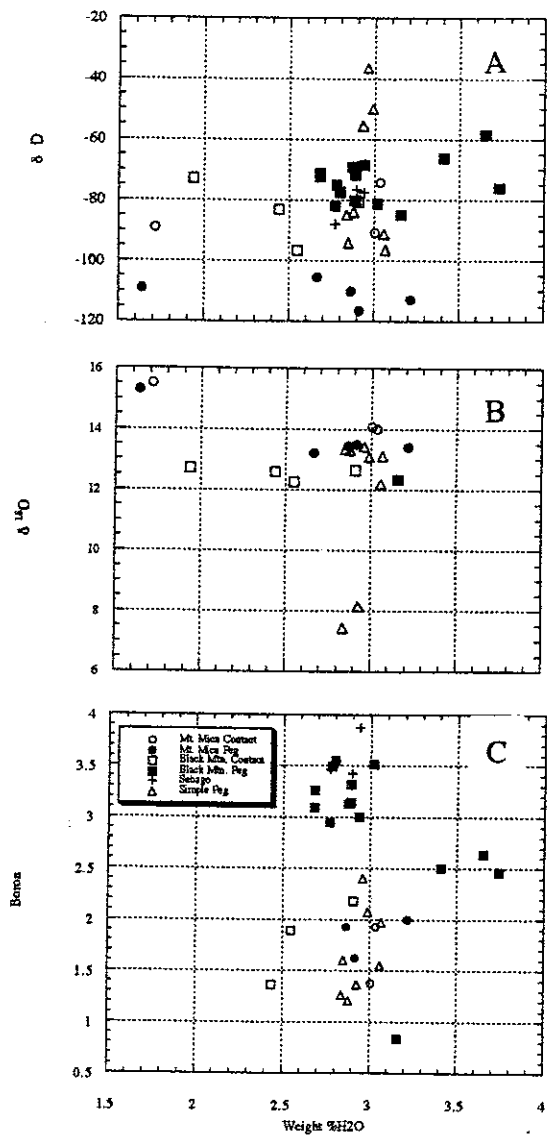


Figure 2.

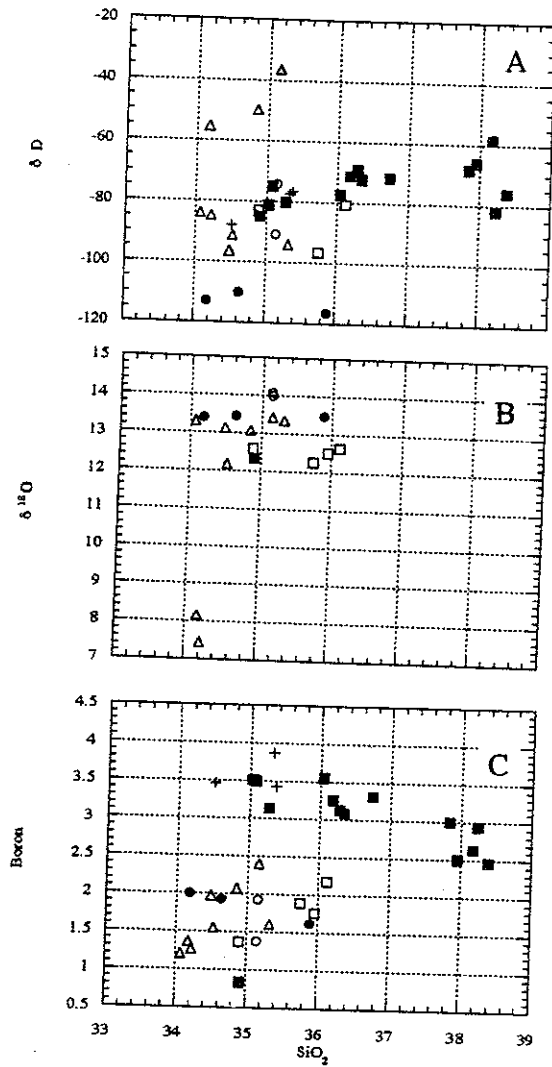


Figure 3.