The chemical differences in tourmaline between simple and complex pegmatites in southwestern Maine

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INTRODUCTION

Tourmaline is a common mineral in both complex (mineralogically zoned) and simple (unzoned) pegmatites. Mineral chemistry can vary significantly between complex and simple pegmatites, and between zones of minerals in individual complex pegmatites. In complex pegmatites containing tourmaline, boron has been found to be a major factor in their mineral zoning (Rockhold et al., 1987). Simple pegmatites, which show no zoning, are only distinguished as pegmatites by their large crystal size and high water content. Since tourmaline is common in both types of pegmatites,we have used it to find chemical trends between the two types of pegmatites in southwestern Maine.

Tourmaline is a late-crystallizing, complex borosilicate that can have a variety of cations in a variety of sites. Determining site occupancies and substitution equations in tourmaline can be rather complex, because the same element may reside in more than one site. It has highly variable composition, and is characterized by the formula $XY_3Z_6(BO_3)_3Si_6O_{18}(OH)_4$. The sites are characterized as X, Y, Z, or T sites. In most tourmalines the large X site is occupied by sodium, but some tourmalines have calcium as the characteristic X site occupant. The smaller (octahedral) Y site is occupied by various cations of various valences, including Fe^{2+}, Fe^{3+}, Mg, Mn, Li, and Al. The distorted, octahedral Z site is commonly occupied by Al, but substitution of Fe^{2+}, Fe^{3+}, Ti, Mg, Cr, and V^{3+} is possible. Aluminum can also substitute for Si in the tetrahedral (T) sites, but this substitution is limited. The anions can be variable as well, with F and O^{2-} substituting for the OH^- in the hydroxyl site. The boron atoms in their triangular sites are assumed to be constant, although this is debatable because there are few previous data on the boron content of tourmalines.

FIELD OBSERVATIONS

Southwestern Maine is famous for its tourmaline-bearing pegmatites. However, due to economic interests, only its complex pegmatites have been studied extensively (Francis et al., 1993; Sidle, 1992). To analyze some of the chemical differences between simple and complex pegmatites, a series of samples was taken from the following sites: Black Mountain (complex pegmatite), Mt. Mica (complex), Nevel Quarry (complex), Whitecap Mountain (simple), Whispering Pines quarry (simple), Windham (simple), Streaked Mountain (simple), and other sites associated with the Sebago Granite. Since there are numerous differences in tourmaline chemistry in complex pegmatites, they are categorized according to mineralogic zone; the more uniform simple pegmatites are referred to as only "simple."

Sample #	Description	Pegmatite Type
BMT-3 black wall	schorl	wall zone (Black Mtn.)
BMT-75 black wall	schorl	wall zone (Black Mtn.)
BMT-47 green wall	elbaite	wall/1st intermediate zone (Black Mtn.)
BLKMNTN-33	dravite	1st intermediate zone (Black Mtn.)

BMT-20 dark blue	elbaite	1st intermediate zone (Black Mtn.)
BMT-11 dark blue	elbaite	1st intermediate zone (Black Mtn.)
Nevel Quarry	schorl	2nd intermediate zone (Black Mtn.)
BMT-65 blue-green	schorl	2nd intermediate zone (Black Mtn.)
BMT-19 pink	olenite	2nd intermediate zone (pod) (Black Mtn.)
BMT-17 pink	olenite	2nd intermediate zone (pod) (Black Mtn.)
BLKMTN-44 green	elbaite	2nd intermediate zone (Black Mtn.)
BMT-A pink	olenite	core (Black Mtn.)
MM-E1, -E2, -D, -F	schorl	wall zone (Mt. Mica)
Harney Peak 2-1, 5-1, 6-1	schorl	simple (Harney Peak, SD)
MW-1B, MW-1C	schorl	simple (Whispering Pines)
MW-2A, MW-2C	schorl	simple (Sebago Batholith)
MW-3A, MW-3D	schorl	simple (Windham)
MW-4A, MW-4D	schorl	simple (Streaked Mt.)
Sebago Granite DLUX#1	schorl	simple (N. Windham)
Sebago Granite RT12	schorl	simple (Sebago Batholith)
Whitecap-1	schorl	simple (Whitecap Mt.)
STRGR-2	schorl	simple (Streaked Mt.)
SEBGR-2	schorl	simple (Sebago Batholith)

METHODS

Tourmaline crystals were hand picked with the aid of microscopes from ground whole rock samples, and analyzed with a variety of methods. Mössbaur analysis was used to determine Fe^{2+}/Fe^{3+} ratios, Particle-Induced Gamma-ray Emission (PIGE) was used to find light elements (B, F, and Li), electron microprobe was used to find major elements, and hydrogen analysis was used to find hydrogen content.

The data were normalized using Excel™ spreadsheets, and the resulting quantities of each individual element were based on 31 total oxygens (there are 31 oxygens per ideal tourmaline formula). However, the PIGE boron data for the Mt. Mica and MW samples were anomalously low, which made the amounts of the rest of the elements, particularly silica, appear too high. This is especially important when considering substitutions of boron in the T site, or substitutions of silica in the boron site. Therefore, the boron data were not used directly in the formula calculations, and the oxygen factor was reset to 26.5, by subtracting the 4.5 net boron oxygens.

Site occupancies for each element were allocated roughly in order of charge. The silica site was filled first, then the boron site, then the Z, Y, and X sites, respectively. The elements were put into their sites using "if-then" statements.

RESULTS

Our graphs show a variety of substitution trends and marked differences in element distribution between the different types of pegmatites and the different zones in complex pegmatites.

In the Y-site of the simple pegmatites, there is a 1:1 Fe^{2+} vs. Mg substitution, but a more complicated substitution is taking place in the inner complex pegmatites, due to the lack of either of these elements (Fig. 1).

There is a general 1:1 substitution between (Al + Li) and (Mg + Fe^{2+}) in the Y-site (Fig. 2), where Al and Li increase as Mg and Fe^{2+} decrease from simple pegmatites to the inner zones of complex pegmatites.

There is significantly more Fe^{2+} than Fe^{3+} in all the samples, except for the inner zones of the complex pegmatite where there is no Fe at all. This lack of a trend shows us that the ratio between Fe^{2+} and Fe^{3+} does not appear to be affected by zoning in pegmatites; rather, it depends upon the composition of the melt (Fig. 3).

It also appears that there is almost no lithium in the simple pegmatites, Harney Peak (also a simple pegmatite), the wall zone of Black Mountain (excluding tourmaline of one sample), or Mt. Mica (also a wall zone). However, Li is present in in tourmaline from the inner zones of the complex pegmatites (Fig. 4).

DISCUSSION

These trends seem to indicate that the simple pegmatites are chemically quite different from the inner zones of the complex pegmatites, but not particularly different from the wall rocks of complex pegmatites (provided that they came from the same melt). Although there is much variation within the complex pegmatites themselves, the simple pegmatites appear to be primarily different from the inner zones with regard to iron, magnesium, lithium, and Y-site aluminum content.

It is assumed that pegmatites crystallize from the outside to the inside, that lithium is highly incompatible, and that lithium is also only present in the inner zones of complex pegmatites. Therefore, it appears that Li is incorporated into the Y-site of tourmaline during the later stages of cooling. Additionally, iron and magnesium are rarely present in any inner zones of complex pegmatites. Lithium and Y-site aluminum appear to be a function of the lack of Fe and Mg in the inner zones, since the Fe and Mg do not appear to be displaced into other minerals in the inner zones. Therefore, the Fe and Mg present in complex pegmatites have been depleted by the time the melt has cooled enough to form the inner zones of the pegmatite. In the simple pegmatites and the wall zones of the complex pegmatites, however, Fe and Mg are present while Li is not. This suggests that the simple pegmatites either cooled earlier in the melt's history, or contained high enough amounts of Fe and Mg to displace any Li present in the melt, or both. The lack of Mg and Fe in the inner mineralogic zones of complex pegmatites complicates the original substitution ratio of Mg to Fe^{2+} in the Y-site.

Although there may be many other factors influencing the formation of simple and complex pegmatites, it appears that the factors described above have a significant role in the differences between the two. Whether the two types of pegmatites differentiate because of these factors or because of the effect of a physical component (i.e. temperature) must still be determined. However, the similarities between the simple pegmatites and the wall zones of the complex pegmatites suggest that simple pegmatites may simply be a part of the melt that has cooled very slowly, giving the rock a pegmatitic texture, and the wall zones represent the rest of the "normal" granitic melt, before the more unusual minerals are concentrated enough to form crystals.

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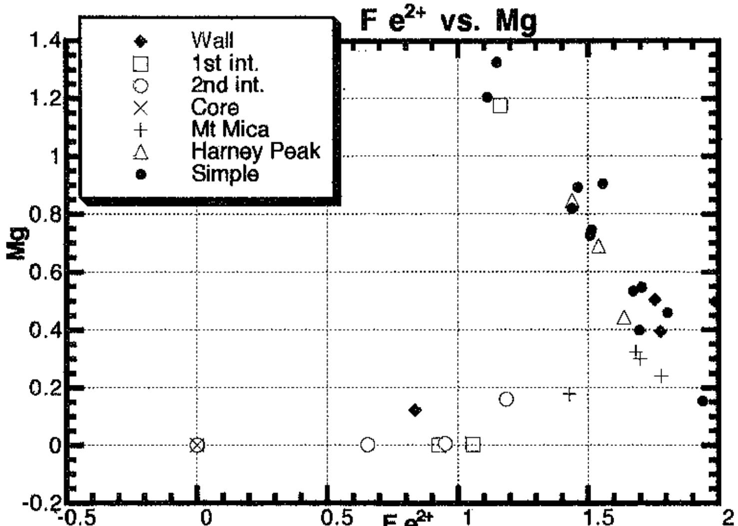

Figure 1

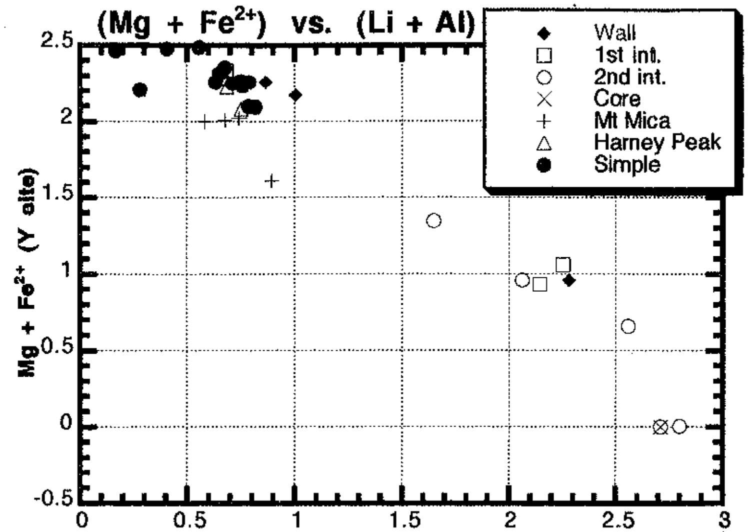

Figure 2

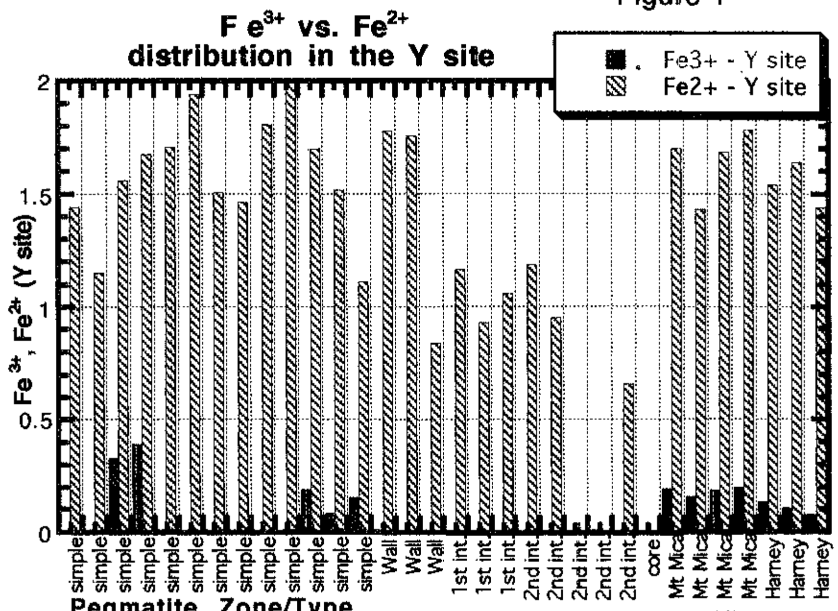

Figure 3

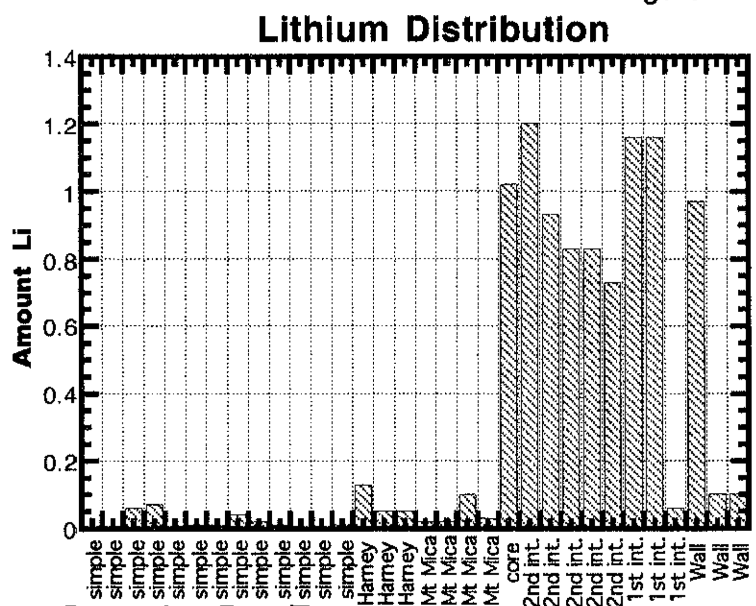

Figure 4