

THE CONTAMINATION HISTORY OF THE BOOT LAKE GRANODIORITE, NOVA SCOTIA

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INTRODUCTION

The Boot Lake Granodiorite is a strongly peraluminous pluton ($Al_2O_3/CaO+Na_2O+K_2O > 1.1$) located in the north central region of the South Mountain Batholith (Sanders-Lackey et al., this volume). Because the source of peraluminous granitic bodies is interpreted to be a combination of both mantle and lower crustal melts (Patiño-Douce, 1999; Lackey et al. 2006), The Boot Lake Granodiorite provides the opportunity to study the interaction between magmas and their wallrocks and how they affect the end product seen today. In order to explore these interactions it is necessary to find a proxy that remains unaffected by long time periods and metamorphic processes.

Oxygen isotopes are sensitive to crustal contamination in magmas. The refractory minerals garnet and zircon will preserve the oxygen isotopic ratios acquired during their crystallization almost indefinitely. Because of the high closure temperatures and slow oxygen diffusion (Valley et al., 1994; Peck et al. 2003) these minerals are able to overcome the problems of metamorphic overprinting and maintain a record of the magmatic conditions to the present day.

Values of $\delta^{18}O$ zircon and garnet provide a proxy for the conditions of the bulk rock isotopic ratios at the time of their crystallization. Because zircon and garnet do not crystallize at the same time comparisons of the $\delta^{18}O$ of each

mineral can indicate the nature of contamination (King and Valley, 2001). By studying the nature of this relationship and how it compares to other properties of the rocks we hope to expand upon the current means for tracking magmatic contamination processes.

GEOLOGIC SETTING

The Boot Lake Granodiorite was produced at relatively the same time as the rest of the South Mountain Batholith. However it contains within it several large metasedimentary bodies of the Halifax Formation of the Meguma Group. The Granodiorite is small, about 4km in diameter, making it ideal for a transect study, and the presence of the large Meguma Group metasedimentary blocks allows for exploration further into the interaction of crustal rocks and intrusive magmas.

Samples were taken from the Boot Lake Granodiorite and metasedimentary bodies contained with it, as well as the surrounding Scrag Lake Monzogranite and Cloud Lake Monzogranite. These samples were collected in a transect from west to east (Fig. 1). Larger 10kg samples were taken for granitic rocks for zircon separations.

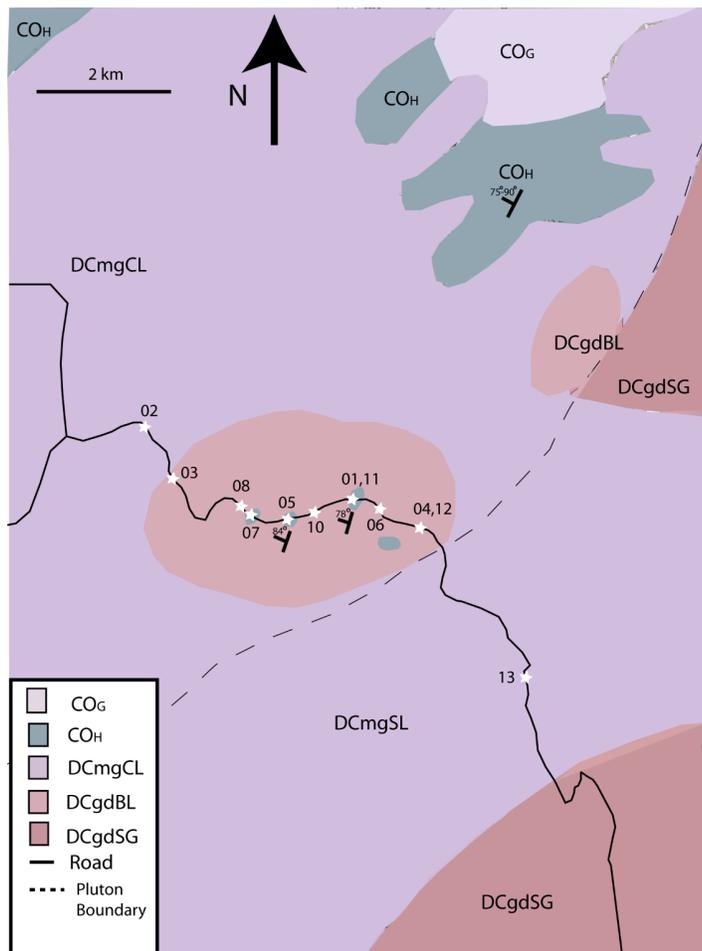


Figure 1. The north central region of the South Mountain Batholith. The Boot Lake Granodiorite (DCgdBL) on the boundary of the Cloud Lake Monzogranite (DCmgCL) to the north and the Scrag Lake Monzogranite (DCmgSL) to the south. The country rock is the Halifax Formation (COH).

METHODS

Upon return from the field, thin sections were prepared for petrographic analysis and representative pieces from each sample were cleaned of weathered faces and sent to Washington State University for X-Ray Fluorescence (XRF) of major and trace element oxides (Johnson et al., 1999).

Zircon separates were produced through crushing of the rocks into a fine sand and hydrologic isolation of the heavy minerals by gold panning. Methylene Iodine ($r > 3.32$) was used for heavy liquid separation of the

zircon and garnet. A Frantz Magnetic separator was used to remove the remaining unwanted minerals including metamict zircons. Finally nitric and hydrofluoric acids were used to clean the separates of any remaining mineral impurities.

Oxygen isotopes were analyzed at the University of Wisconsin-Madison Stable Isotope Lab by means of carbon dioxide laser fluorination. Samples were first powdered and then placed within the reaction chamber, there they were heated by laser and reacted with bromine pentafluoride to liberate oxygen gas. The gas is converted to CO_2 and analyzed by mass spectrometry. All samples were standardized by comparison to the UGW-2, Gore Mountain garnet standard (Valley et al., 1995).

PETROGRAPHY

A petrographic study of several of the samples revealed interesting textures and mineral content. The metamorphic textures include chlorite coronas on biotite grains, seritization of the plagioclase, and some granophyric textures suggesting localized partial melting of the melting textures. Some of the samples show distinct foliation, while in others the foliation is not obvious but can be inferred from changes in grain size in thin sections. In some of the samples pinnate replaces cordierite, and sillimanite (late) co-exists with andalusite (early). Still other samples show large (2-3 cm) garnet porphyroblasts. The garnets within the metasediments show strong parting as well as inclusions of quartz and opaque minerals.

Samples taken from the granitic rocks of the region exhibit similar mineralogy throughout. Samples from the Boot Lake Granodiorite are finer grained and show in general less alteration than those from the surrounding regions. A general pattern of decreased seritization of plagioclase was observed from west to east in

the pluton.

One sample was taken of a small xenolith located within the Boot Lake Granodiorite. It contained abundant amphibole which is not seen in any of the exposed Halifax Formation rocks. The xenolith is inferred to be derived from the near complete melting and recrystallization of Meguma Group metasedimentary rocks, probably wallrock originally..

RESULTS

Geochemical analysis that all samples, with the exception of one, are highly peraluminous. The results also indicate a great deal of compositional continuity within the granitic rocks of the region. This compositional continuity is not expressed within the metasedimentary bodies. These samples indicate two separate groups. Samples 06-BM-01 and 06-BM-11 illustrate similar characteristics and samples 06-BM-05 and 06-BM-07 illustrate similar characteristics.

Petrographic analysis has indicated that there was both andalusite and sillimanite contained within samples of the metasedimentary units. This indicates a pressure of no greater than 3.8 kb and a temperature of no less than 500°C during metamorphism of these units. These P-T conditions are consistent with the regional metamorphic conditions described (Clarke et al. 1993).

Structural measurements of bedding in the metasedimentary bodies indicate that they are similarly orientated and match the reported values for the Halifax Formation exposed immediately north of the batholith. Both have strong northeast trending strikes (~225°) with very steep dips (~75°-85°) (MacDonald, 2001).

Oxygen isotope analysis resulted in a wide range of values for zircon, garnet, and quartz. Most prominent among these trends is a low $\delta^{18}\text{O}$ zircon value in the middle eastern region

of the Boot Lake pluton. The average value for zircon $\delta^{18}\text{O}$ within the Boot Lake Granodiorite was (8.19±0.26‰). Garnet showed $\delta^{18}\text{O}$ values higher than zircon (8.14‰ to 8.89‰). Quartz $\delta^{18}\text{O}$ is high 11.51‰ to 12.24‰ and is in disequilibrium with zircon and garnet.

Whole rock geochemical data were used for the calculation of zircon saturation temperatures (Watson and Harrison, 1983), which ranged from 755°C to 855 °C, the average temperature was 814°C.

DISCUSSION

The average oxygen isotopic values for zircon crystals formed in the mantle are 5.3±0.3‰ (Valley et al. 1998). The average values for peraluminous plutons of the Sierra Nevada Batholith are 7.9‰ (Lackey et al. 2006). High overall $\delta^{18}\text{O}$ values of zircons as compared to other studies of peraluminous granitoids (Lackey et al. 2006) are likely the result of partial melting of supercrustal rocks contained within the Avalon Terrane, which lies below the superimposed Meguma Terrane. This concept is expanded to the entire South Mountain Batholith where it is concluded that the high whole rock values result from the partial melting of metasedimentary rocks and that periodic low whole rock analysis through out the batholith represent mafic magma interaction (Longstaffe et al. 1979). Furthermore, the high geothermal gradient, moderate depth, and temperatures of greater than 800°C, required for the production of S-type granites could imply the interaction of mantle derived material with existing crustal material during their genesis (Clemens and Wall, 1981). Therefore, the initial higher bulk rock average $\delta^{18}\text{O}$, caused by crustal interaction, resulted in the elevation of the zircon $\delta^{18}\text{O}$ values.

Garnet and zircon show that a high $\delta^{18}\text{O}$ contaminant affected the isotopic ratios for the whole rock after zircon crystallization. Garnet

and zircon are shown to exist out of equilibrium with each other by means of their isotopic disequilibrium (Fig. 2).

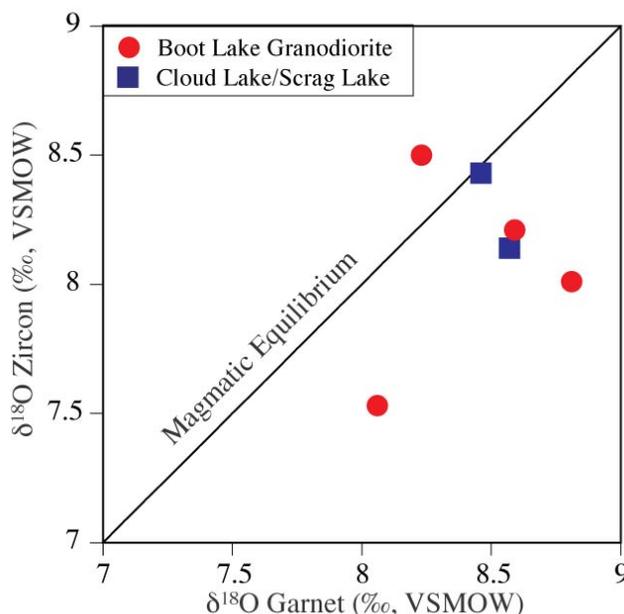


Figure 2. Zircon δ¹⁸O as compared to garnet δ¹⁸O showing that they crystallized out of equilibrium.

Therefore, because zircon saturation has been established as prior to garnet, it is possible to say that a high δ¹⁸O contaminant affected the whole rock isotopic ratio in the time period between their relative crystallizations. The difference between the zircon and garnet ratios illustrates in all cases but one, 06BM06, an increase in δ¹⁸O during the time between their crystallization. This can then be inferred to be a result changes in the δ¹⁸O content of the magma in this time interval.

Confirmation of this observation is possible by comparing how δ¹⁸O garnet and δ¹⁸O zircon covary relative silica content. The higher the silica content of a magma the more evolved it is, so if there is a high δ¹⁸O contamination source then the garnet values should reflect an increase in contamination with an increase in silica content.

Zircon reflects this pattern quite well, with the exception of one outlier (Fig. 3).

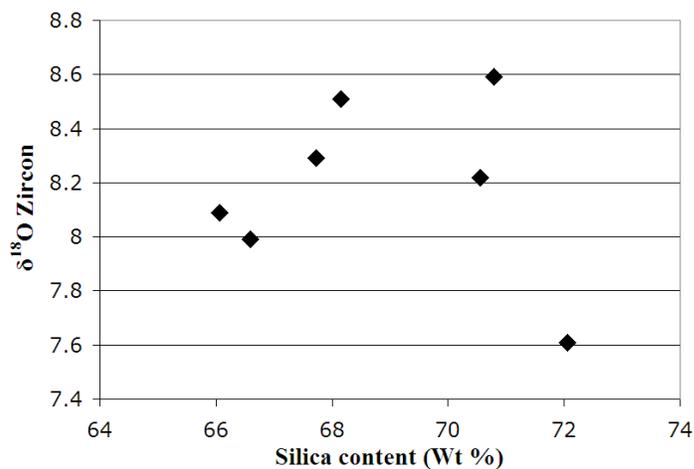


Figure 3. Progressive contamination is shown through a comparison of δ¹⁸O of zircon and SiO₂ content. As the magma evolves it becomes more contaminated.

However, garnet shows the exact opposite trend. A strong correlation between garnet δ¹⁸O and silica content shows that this is a variation in response to magmatic evolution, but the inverted trend illustrates that garnet is not tracking contamination (Fig. 4).

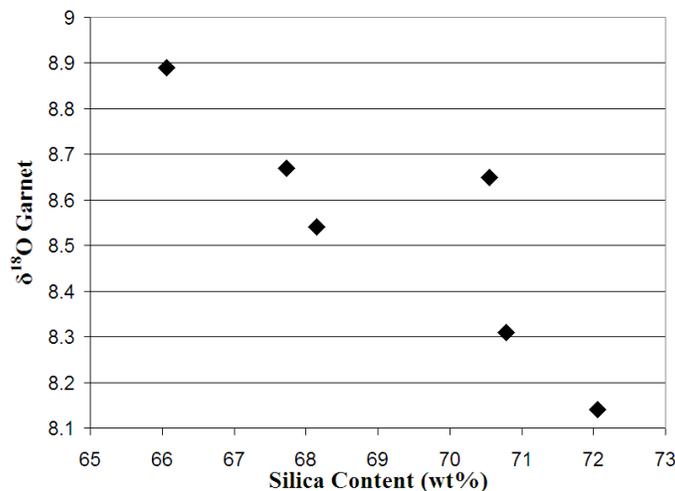


Figure 4. The decrease in garnet δ¹⁸O as silica content increases seen here can be interpreted to mean that garnet is not tracking progressive contamination.

Were the magma to be homogenous through out, then zircon saturation temperatures would show no range at all. However because it does show a range (Fig. 5)

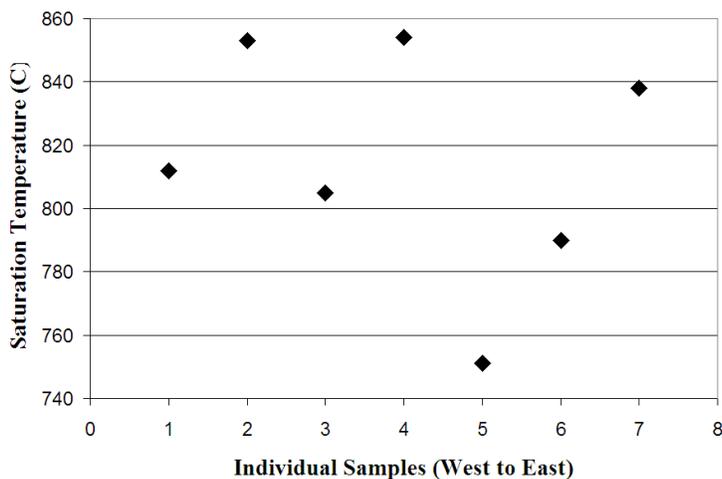


Figure 5. Zircon saturation temperature is showing a wide range of values illustrating that there is a progressive contamination which effects the whole rock composition of the Boot Lake Granodiorite.

we suggest that there is a relationship between magmatic contamination and zircon saturation. Because zircon saturation is dependent upon major and trace element concentrations it is possible that the contamination of a magma by country rock source alters these ratios regionally and causes zircon to crystallize with different timing regionally.

There is an observed pattern of correlation between garnet $\delta^{18}\text{O}$ and zircon saturation temperature. This is indicating a link between garnet $\delta^{18}\text{O}$ (relative crystallization timing) and major element geochemistry, the first observed instance such an occurrence.

Relating the distance between sample sites and the nearest metasedimentary rocks revealed that the regional effect is not strongly related to distance. It is possible then the contamination of the magma is quickly distributed through out the entire magma or restricted to having a strong affect only very near to the metasediments.

CONCLUSIONS

The Boot Lake Granodiorite is the result of partial melting of the underlying sedimentary rocks and their interaction both with mantle and crustal contaminants. This is supported by the high $\delta^{18}\text{O}$ values observed in both zircon and garnet samples taken from the region. The lack of equilibrium between minerals indicates variable or progressive contamination in the time periods between their respective crystallizations. Timing of crystallization for zircon can be linked to the amount of contamination within a given magma. Although garnet crystallization appears to be linked to major element geochemistry, this relationship is not as well defined as by zircon.

Zircon saturation temperatures allow for comparisons between relative timing of crystallization, relative rate of contamination, and major element geochemistry. In the future it may be possible to link these techniques in such a way to establish a saturation temperature calculation for garnet, among other refractory minerals.

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