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AN OXYGEN ISOTOPE STUDY ON THE ORIGINS OF GARNET IN THE PERALUMINOUS SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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INTRODUCTION

Nova Scotia represents a unique opportunity to study the origin of peraluminous granitoids. Peraluminous granites are characterized chemically by those in which the ratio A/CNK > 1. Mineralogically, they consist of quartz, two feldspars, biotite + one or more aluminous phases muscovite, garnet, cordierite, and aluminosilicates, among others (Clarke, 1981). Garnet, the focus of this study, is commonly found in high temperature metamorphic rocks, although garnets of magmatic origin may be found as well.

Oxygen is a common constituent of minerals; its stable isotopes (^{16}O, ^{17}O, and ^{18}O) are sensitive to temperature and can differentiate sources of rocks formed in the mantle versus those formed in crustal environments. Therefore, $\delta^{18}O$ analysis is a powerful tool to understanding magma origin and its evolution. Garnet has a slow rate of oxygen diffusion as described by Lackey et al. (2006a). Thus, the $\delta^{18}O$ of garnet is a function of the rock in which it crystallized and the temperature of growth. Moreover, laser fluorination, represents a significant analytical advance, which has let to significant advances in interpreting the origin of garnets in the last five years.

This study sampled garnet occurring in granitoids in the South Mountain Batholith and incorporates textural and $\delta^{18}O$ analysis to evaluate the origins of garnet (magmatic garnet from xenocrystic metamorphic garnet) in the batholith. The results are a crucial step towards the resolution of the origins of the peraluminous granitoids themselves.

BACKGROUND GEOLOGY

Nova Scotia lies on Canada's southeastern coast and represents the northernmost end of the Appalachian orogen. The Acadian orogeny is limited to the Devonian (~370 Ma) and northern Appalachians. The orogeny juxtaposed the Meguma and Avalon Zones at this time; the boundary represented by the Cobequid-Chedabucto fault system (Sanders-Lackey et al., this volume).

The South Mountain Batholith is an arcuate composite granitoid batholith that outcrops in southwestern Nova Scotia. The batholith occupies an area of approximately 7300 km^2. These granites and granodiorites are generally peraluminous, and contain muscovite, andalusite, garnet, and cordierite (MacDonald, 2001). Garnets are found on both sides of and at the contact between the South Mountain Batholith and Meguma Group rocks. Specifically, three different groups of garnet have been established based on $\delta^{18}O$ ratio findings of Lackey et al. (2006b), including magmatic, peritectic, and metamorphic garnet. Magmatic garnet ratios are typically lower, ranging from as low as 7.5 to 8.2‰. Peritectic garnet ratios are slightly higher, ranging from 8.3 to 9.0‰. Metamorphic garnet ratios are high, 9‰ and above. (Figure 1).

FIELDWORK AND PETROGRAPHY

Initial fieldwork took place July 15th through August 11th, 2006 in Nova Scotia, Canada. Sampling primarily took place in the Halifax Pluton. Furthermore, multiple samples were collected at Cranberry Head, Indian Point, and Peggy's Cove

felsic, slightly megacrystic but predominantly medium- to coarse-grained rocks, with abundant amounts of biotite, both primary and secondary muscovite, and trace amounts of garnet. Collecting garnet-bearing samples was the main objective in the field. Biotite clots, possible metasedimentary xenoliths, and single garnets were collected at each site (Sanders-Lackey et al., this volume).

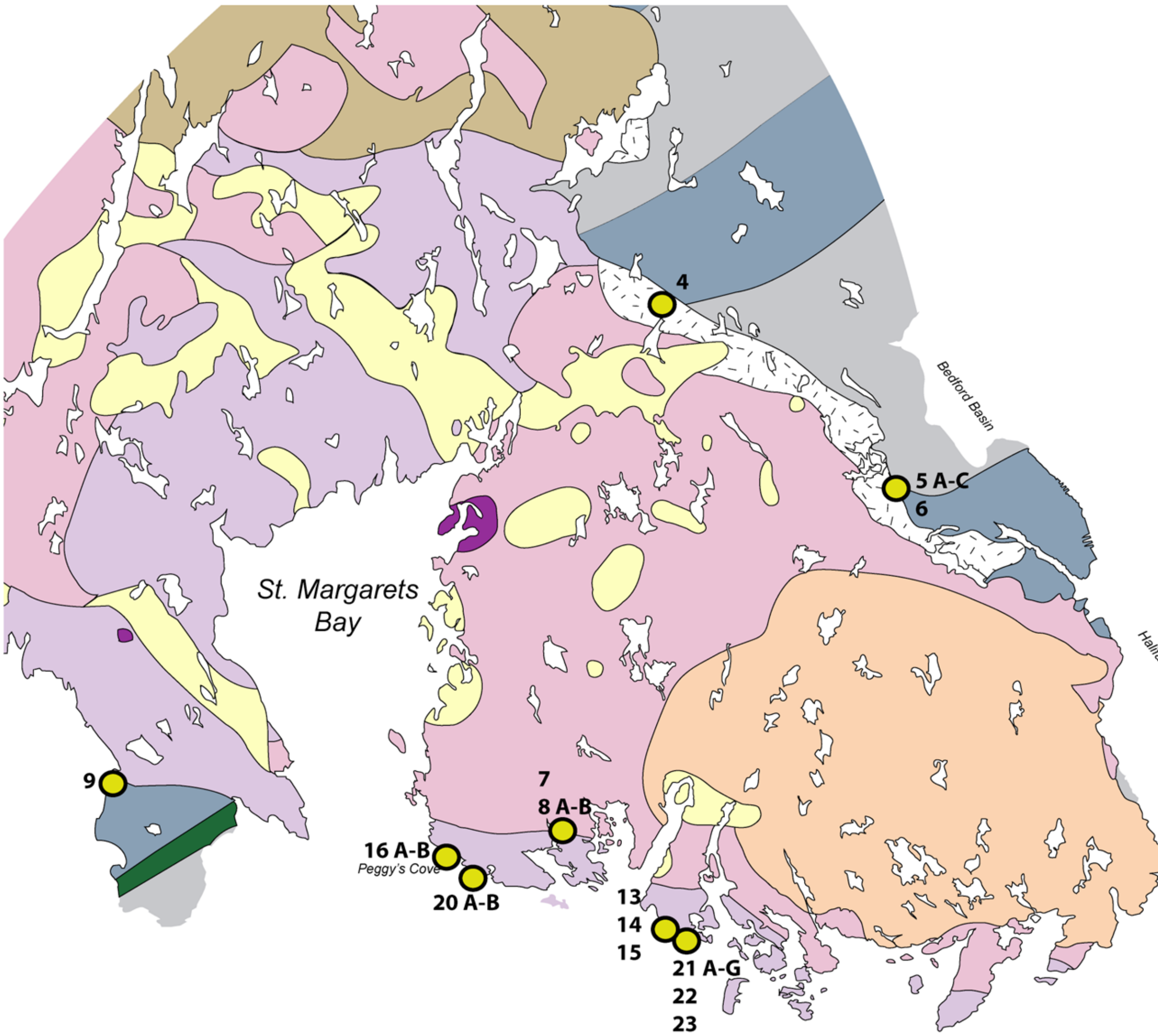


Figure 1. Halifax Pluton map outlining sample localities including Peggy's Cove, Indian Point, Cranberry Head, as well as various road cuts. 06JSH samples indicated in yellow. Map after MacDonald et al. (2001).

Geologically, Cranberry Head, Indian Point, and Peggy's Cove are part of the Peggy's Cove biotite-monzogranite which typically exudes

Biotite clots were 1cm by 1cm in size and no reaction rims were apparent. Mineralogically, they were biotite-rich and contained 20-50% garnet and some feldspar. A sharp transition with the surrounding felsic host rock suggests either a high concentration of biotite or the remains of an extensively assimilated xenolith. Garnet-bearing xenoliths with pelitic banding were also sampled, suggesting a sedimentary origin similar to that of the country-rock. Single garnet crystals were collected from surrounding felsic host rock near metasedimentary xenoliths in many cases. The absence of any reaction rim suggests a magmatic origin.

Study in thin section reveals a deeper analysis of samples taken from the South Mountain Batholith. Two main types of samples have been studied in thin section: granitoids and xenoliths. They contain larger amounts of quartz, plagioclase feldspar, biotite, muscovite and small amounts of microcline; samples may also be garnet-bearing. Granitoids are generally medium to coarse grained, while sometimes even exhibit megacrystic growth. Xenoliths, on the other hand then are generally very-fine to fine-grained. Quartz grains are pretty uniform in size and exhibit characteristic undulose extinction. Megacrsytic K-feldspar grains are common. A corona of feldspars surrounds a biotite grains and suggests a secondary growth after a breakdown of a mafic mineral. Biotite and muscovite are more common in xenoliths than granitoids. Both biotite and muscovite may appear foliated in thin section. Zircon grains are seen in thin section as well. Primary muscovite forms large-grained books while secondary muscovite, sericite, is finer-grained and appears as an alteration mineral in many plagioclase grains. Garnet displays interesting characteristic textures. Grains are generally subhedral to anhedral in form; however a couple euhedral grains have been seen as well. Specifically, one deformed garnet is broken apart possibly by a secondary crystallization of a plagioclase feldspar grain. This growth is indicative of synmetamorphic deformation. Another garnet exhibits concentric growth rings in which second, later-stage garnet has grown around an earlier one. Another garnet is surrounded by a rim of secondary muscovite indicative of a retrograde reaction.

RESULTS

Sample preparation was carried out as described in Lackey et al. (2006a). Oxygen isotope analyses were conducted by CO_2 laser fluorination at the University of Wisconsin-Madison as described by Valley et al. (1995). Twenty-five of the thirty-seven hand samples were analyzed for $\delta^{18}O$. All analyses were standardized by four analyses of the UWG-2, Gore Mountain garnet standard, and sample $\delta^{18}O$ values were corrected to the long-term accepted value of 5.80‰ VSMOW for UWG-2 (Valley et al, 1995). The average $\delta^{18}O$ of UWG-2 for one day of analysis of four standards is 5.74±0.06‰. The following results have been further grouped by location and lithology (Table 1).

TABLE 1. AVERAGE $\delta^{18}O$ VALUES OF GARNET SAMPLED AT DIFFERENT LOCATIONS AND LITHOLOGIES

LOCATION	$\delta^{18}O$ VALUES (GRT)
Indian Point	9.56 ± 0.73‰ (n=14)
Peggy's Cove/ Cranberry Head	9.24 ± 0.82‰ (n=5)
Boot Lake	9.13 ± 0.62‰ (n=3)
Others	9.15 ± 1.18‰ (n=3)
LITHOLOGY	
Single Grains	8.64 ± 0.60‰ (n=3)
Xenoliths	9.62 ± 0.70‰ (n=10)
Biotite Clots	9.40 ± 0.79‰ (n=12)

Note: Values of $\delta^{18}O$(Grt) are relative to Vienna Standard Mean Ocean Water (VSMOW); $\delta^{13}C$ is relative to Pee-dee belemnite (PDB).
$\delta^{18}O$(Grt) corrected to value of 5.80‰ VSMOW for UWG-2; average $\delta^{18}O$(Grt) after four standards is 5.74 ±0.06‰
Field type based on size, mafic content, garnet abundance, and presence or absence of sedimentary banding.

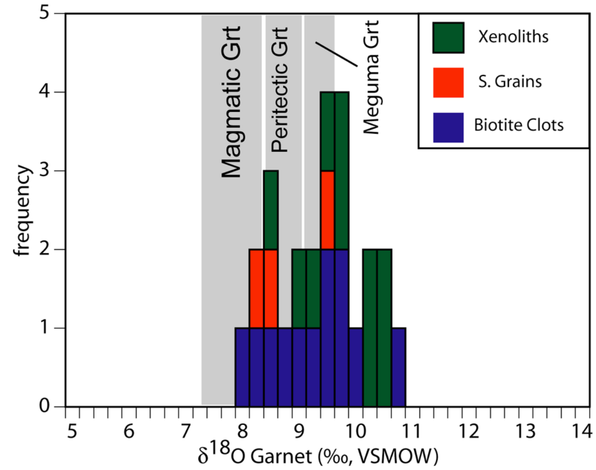
Samples were analyzed from four main locations: Indian Point, a combination of

Peggy's Cove and Cranberry Head, Boot Lake as well as various road cuts. Fourteen garnet samples were analyzed for $\delta^{18}O$ from Indian Point; the $\delta^{18}O$ = 8.16-10.92‰ and averages 9.56‰. Five garnet samples were analyzed for $\delta^{18}O$ from a combination of Peggy's Cove and Cranberry Head; the $\delta^{18}O$ = 8.36-10.50‰ and averages 9.24‰. Another three garnet samples were analyzed for $\delta^{18}O$ from Boot Lake; the $\delta^{18}O$ = 8.43-9.63‰ and averages 9.13‰. Three garnet samples were analyzed for $\delta^{18}O$ from a variety of road cuts within the South Mountain Batholith; the $\delta^{18}O$ = 8.17-10.46‰ and averages 9.15‰.

Likewise, three main lithologies were analyzed as well: single grains, xenoliths, and biotite clots. Three single-grains were analyzed for $\delta^{18}O$ ratios; the $\delta^{18}O$ 8.17-9.32‰ and averages 8.64‰. Ten garnet samples collected from a variety of xenoliths were analyzed for $\delta^{18}O$; the $\delta^{18}O$ = 8.40-10.50‰ and averages 9.62‰. Twelve garnet samples collected from a variety of biotite clots were analyzed for $\delta^{18}O$; the $\delta^{18}O$ = 8.16-10.92‰ and averages 9.4‰ (Figure 2).

DISCUSSION

The $\delta^{18}O$ of the garnets collected throughout the Halifax Pluton show a full range of values indicating magmatic, peritectic, and metamorphic origins. Two samples with $\delta^{18}O$(Grt) of 8.16 and 8.17 ± 0.06 ‰ have a magmatic origin, suggesting these garnets formed directly from the magma. Six samples ranging from 8.36 to 8.91‰ have a peritectic origin. Erdmann and Clarke (2006) suggest that partially melted metapelitic rocks of the Meguma Group may have released peritectic garnet into the SMB magmas. The remaining seventeen samples have $\delta^{18}O$(Grt) above the 9.0‰ metamorphic value and are divided into two separate groups. The first group covers five samples with $\delta^{18}O$(Grt) ranging from 9.10 to 9.36‰, similar to those found within the Meguma country rock.



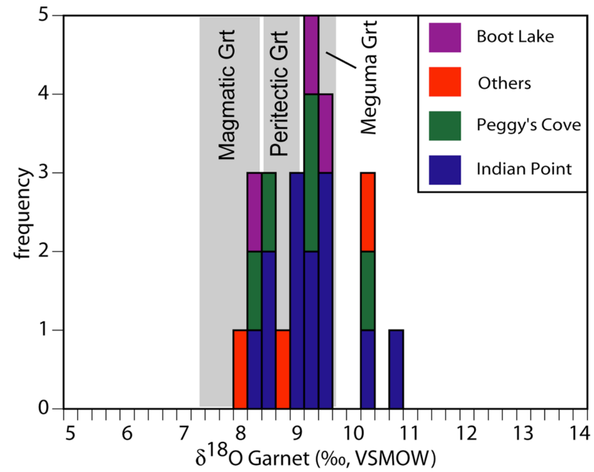


Figure 2. Histogram (top) comparing the resulting lithology δ18O ratios to recognized garnet standards. Histogram (bottom) comparing the resulting δ18O ratios of different locations to recognized garnet standards.

The second group's high $\delta^{18}O$ values suggest they must be from a lithology with higher $\delta^{18}O$(Grt) than any known metamorphic rock yet recognized. This study proposes the presence of a cryptic high $\delta^{18}O$(Grt) source rock that maybe in the Avalon basement but is previously unrecognized. If garnets have been entrained from the source, the garnets we see would represent a mixture of those from the source as well as those from the Meguma Group's metamorphic rocks. A variety of radiogenic isotopes tests including Sr, Nd, and Pb support this idea and also propose specific sources to the origins of the SMB and peraluminous granitoids (Figure 3).

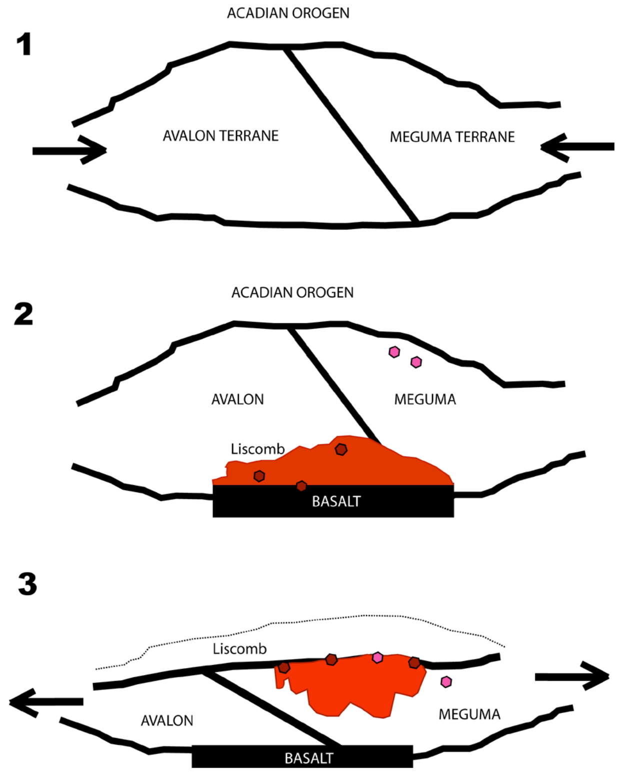


Figure 3. Figure of three-part time series of the source magma to the South Mountain Batholith. (1) Pre SMB juxtaposition of the Meguma and Avalon Terranes. (2) Basaltic underplating and melting within the Avalonian Basement; Liscomb gneisses and melting occur. (3) SMB magmas ascend and once thickened orogen begins to relax; uplift and erosion exposed rocks from 10-12km deep. Doming exposes Liscomb complex.

Three main areas have been examined as potential sources within the Avalon Zone: the Meguma Group, the Liscomb gneisses, and the Tangier granulites. Relative to the Meguma Group, Nd isotopic data indicated that the SMB had considerably higher values. Consequently, the Meguma Group could not be a suitable protolith for the batholith. Geochronological and isotopic analyses indicate that the Liscomb gneisses, on the other hand, should be considered as a possible source of the batholith. Comparable Nd and Sr isotopic signatures gathered from xenoliths also qualify the Tangier granulites as another potential source for the SMB (MacDonald, 2001). Overall, $\delta^{18}O$ results from this study confirm the presence of garnet entrained from the Avalon source region of the batholith. Even though such garnets ultimately became chemically unstable in eventual magmas where they are now found, they retained their original $\delta^{18}O$ despite a protracted residence time in the magmas. Thus, these results confirm the slow oxygen diffusion rates in garnet.

CONCLUSIONS

Oxygen isotopic analyses of garnets sampled in the Halifax Pluton indicate a full range of $\delta^{18}O$ values, establishing that magmatic, peritectic, and metamorphic garnets occur within the pluton. $\delta^{18}O$ values confirm a small number of magmatic garnet in the margin of the batholith with widespread xenocrystic garnets. Moreover, the $\delta^{18}O$ values confirm a wide range of metamorphic garnet values.

These results, in concert with previously determined radiogenic isotopic analyses help establish the potential source of the South Mountain Batholith and peraluminous granitoids. Neodymium isotopic data concluded that the Meguma terrane cannot be a possible protolith to the batholith, as the terrane's resulting values were much lower than the SMB's. Geochronological studies and comparable Nd and Sr isotopic data support the Liscomb Complex to be a possible source. Petrological and geochemical data also suggest that the Tangier granulites can be a potential source to the SMB. While the precise magmatic source has not yet been determined, it has been made clear through this study that the South Mountain Batholith is a dynamic granitic body with a complex geological history.

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