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Isotopic evidence for multiple contributions to felsic magma chambers: Gouldsboro Granite, Coastal Maine

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Abstract

The Gouldsboro Granite forms part of the Coastal Maine Magmatic Province, a region characterized by granitic plutons that are intimately linked temporally and petrogenetically with abundant co-existing mafic magmas. The pluton is complex and preserves a felsic magma chamber underlain by contemporaneous mafic magmas; the transition between the two now preserved as a zone of chilled mafic sheets and pillows in granite. Mafic components have highly variably isotopic compositions as a result of contamination either at depth or following injection into the magma chamber. Intermediate dikes with identical isotopic compositions to more mafic dikes suggest that closed system fractionation may be occurring in deeper level chambers prior to injection to shallower levels. The granitic portion of the pluton has the highest Nd isotopic composition (ε_{Nd}=+3.0) of plutons in the region whereas the mafic lithologies have Nd isotopic compositions (ε_{Nd}=+3.5) that are the lowest in the region and similar to the granite and suggestive of prolonged interactions and homogenization of the two components. Sr and Nd isotopic data for felsic enclaves are inconsistent with previously suggested models of diffusional exchange between the contemporaneous mafic magmas and the host granite to explain highly variable alkali contents. The felsic enclaves have relatively low Nd isotopic compositions (ε_{Nd}=+2 – +1) indicative of the involvement of a third, lower ε_{Nd} melt during granite petrogenesis, perhaps represented by pristine granitic dikes contemporaneous with the nearby Pleasant Bay Layered Intrusion. The dikes at Pleasant Bay and the felsic enclaves at Gouldsboro likely represent remnants of the silicic magmas that originally fed and replenished the overlying granitic magma chambers. The large isotopic (and chemical) contrasts between the enclaves and granitic dikes and granitic magmas may be in part a consequence of extended interactions between the granitic magmas and co-existing mafic magmas by mixing, mingling and diffusion. Alternatively, the granitic magmas may represent an additional crustal source. Using granitic rocks such as these with abundant evidence for interactions with mafic magmas complicate their use in constraining crustal sources and tectonic settings. Fine-grained dike rocks may provide more meaningful information, but must be used with caution as these may also have experienced compositional changes during mafic–felsic interactions.

Keywords: Enclaves; Granite; Magma-mingling; Isotopes; Maine

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1. Introduction

Detailed studies of felsic rocks, coupled with analytical advances, have made it clear that the origin and evolution of felsic magmas is a complex and multi-faceted process. Multiple magma sources, variable melting processes, fractional crystallisation, wall rock assimilation, residual components from the source, magma mixing, magma mingling and diffusional exchange between co-existing magmas are but some of the processes that can contribute to the final, and often apparently homogeneous, geochemical composition of a felsic rock. The importance of mafic magmas during the evolution of some felsic magma chambers has become increasingly recognized, both from a chemical and thermodynamic viewpoint (e.g., Bacon, 1986; Huppert and Sparks, 1988; Wiebe, 1994; Folch and Martí, 1998; Snyder and Tait, 1998; Streck and Grunder, 1999; Koyaguchi and Kaneko, 2000; Snyder, 2000). Exposures preserving interactions between mafic and felsic magmas are often spectacular and reveal the complexities of the late stages of magma evolution prior to solidification, although it may be more difficult to deduce the significance of these and other processes during the early history of the magma when it was warmer, less viscous and contained fewer crystals.

In addition to the geological complexity resulting from inputs of mafic magmas into felsic magma chambers, it is also becoming increasingly recognized that the felsic component in many granitic plutons is also complex and may represent the end result of multiple inputs of dike-fed crustal melts (e.g., Hutton, 1992; Petford, 1996; McNulty et al., 1996), often derived from multiple, heterogeneous crustal sources (e.g., Krogstad and Walker, 1996) and subsequently homogenized to varying degrees. The significance of replenishment of mafic magmas chambers by new mafic magmas has long been recognized (e.g., RTF model of O'Hara, 1977). However, perhaps because the field evidence for felsic replenishment of felsic magma chambers is more subtle and much less impressive than mafic replenishment of the same chambers, its importance to granitic magmatism has perhaps been overlooked in the geological literature.

The significance of mafic magmas during pluton formation is particularly inescapable in the Coastal Maine Magmatic Province (Hogan and Sinha, 1989) where spectacular coastal exposures reveal abundant evidence of co-mingling of mafic and felsic magmas (e.g., Taylor et al., 1980; Chapman and Rhodes, 1992; Wiebe, 1993, 1994; Seaman et al., 1995, 1999) and the identification of a new variety of layered intrusion, the mafic and silicic layered intrusion (MASLI) (Wiebe, 1996).

Studies of these plutons have contributed significantly to our understanding of the processes occurring during mafic–silicic magma interactions. In these intrusions, felsic magma chambers have been repeatedly injected and replenished by mafic magmas, which subsequently interacted with the resident felsic magmas thermally, physically and chemically to form hybridized and mingled rocks with complex field, mineralogical, chemical and isotopic systematics (Wiebe, 1993, 1994, 1996; Wiebe and Collins, 1998; Waight et al., 2001a; Wiebe et al., 2001, 2002). In this study we present evidence that replenishment of silicic magmas also plays a role in the evolution of felsic magma chambers. Given that many plutons may be the end result of multiple injections of both mafic and felsic magmas, it is then unlikely that the geochemistry of the final products can provide easily decipherable information on the crustal source or sources that contributed to them.

The Gouldsboro Granite is typical of the Coastal Maine Magmatic Province in that it shows abundant evidence for mafic–felsic magma interactions (co-existing and cross-cutting mafic and felsic dikes, composite dikes, mingled gabbroids, rare microgranular enclaves, etc.). The granitic body is considered to be relatively thin and field relations display a transition upward through a zone of chilled mafic sheets and pillows in granite that dip gently to the south beneath the granite. The current exposure is interpreted to represent a transverse slice from the lowermost zones of the magma chamber in the north where it overlies contemporaneous mafic magmas, through to the upper regions of the magma chamber in the south. In one sense the pluton represents an end-member in MASLI as mafic magmas volumetrically dominate the system, therefore the consequences of interactions between felsic magmas and basic magmas are likely to be magnified.

Unlike other plutons intimately associated with mafic magmas, mafic microgranular enclaves are not common or widely distributed in the Gouldsboro Granite and are essentially absent or exist only as scarce, tiny 1–2 cm clots. However, the Gouldsboro Granite is interesting because it contains a spatially restricted swarm of relatively felsic enclaves intermediate in composition between the mafic magmas and granitic host. While mafic microgranular enclaves are generally interpreted as representing co-mingled more mafic magmas (e.g., Didier, 1973; Bacon, 1986; Holden et al., 1987; Barbarin, 1988; Vernon, 1990; Didier and Barbarin, 1991; Metcalf et al., 1995; Elburg, 1996; Poli et al., 1996; Maas et al., 1997; Waight et al., 2001b), more intermediate to felsic enclaves have been less commonly discussed in the literature. Such enclaves are generally considered to