GROWTH HISTORY OF ZIRCON CRYSTALS IN COARSE-GRAINED GRANITE, VINALHAVEN INTRUSION, COASTAL

MATTHEW HOFFMAN
Denison University
Advisor: David Hawkins

INTRODUCTION

The Vinalhaven intrusive complex is a shallowly emplaced, subvolcanic granite intrusion that was constructed incrementally through the input of successive batches of both felsic and mafic magma (Hawkins and Wiebe, this volume). The two main units, a gabbro-dioroite-granite interlayered unit at the intrusion base and an overlying unit of cg biotite granite, preserve a stratigraphic record of the processes that led to construction of the intrusion (e.g., Wiebe et al., 2004; Hawkins and Wiebe, 2004). These processes include magma mingling and mixing, the remobilization of granitic mush, mafic and felsic replenishment via feeder dikes, convective stirring, fractional crystallization, and eruption (Wiebe et al., 2004; 2007; Hawkins and Wiebe, 2004), all of which influence the temperature, composition and/or effective pressure of melt on a variety of spatial scales. Thus, crystals suspended in the melt that record and retain compositional zoning should record a stratigraphic sequence reflective of those processes. One such mineral is zircon, a highly refractory mineral that crystallizes from a variety of melt compositions, and preserves detailed zoning revealed by both back-scattered electron (BSE) and cathodoluminescence (CL) imaging (Watson and Harrison, 1983; Corfu et al. 2003; Hanchar and Watson, 2003). The purpose of this study is to characterize and compare the zoning of zircon crystals separated from cg granite collected at three stratigraphic positions in the intrusion.

SAMPLING RATIONALE AND FIELD RELATIONSHIPS

To evaluate the role of mafic-silicic magma mixing, as well as other magmatic processes, on the growth histories of zircon crystals, three field occurrences of coarse-grained granite were chosen with regards to their proximity to the mingled and mixed magmas of the layered gabbro-diorite unit: within the gabbro-diorite unit (locality MRH6-2 at Arey Neck); near the top of the gabbro-diorite unit (locality MRH6-4 at Vinal Cove); and stratigraphically far above the gabbro-diorite unit (locality MRH6-5 at the 1900's quarry) (Fig. 1). Each locality offers excellent exposures with clear field relationships that are described below.

Granite Within the Gabbro-Diorite Unit
Coarse-grained granite at Arey Neck (Fig. 1) occurs in a tens-of-meters thick layer sandwiched between two mafic sheets; the hybridized dioritic top to an underlying mafic sheet and the quenched gabbroic base of an overlying mafic sheet. Meter-scale xenoliths of metamorphic country rocks occur within the hybridized diorite near the base of the granite layer. The granite is petrographically and geochemically typical of the coarse-grained Vinalhaven granite and contains sparse felsic to mafic enclaves and subtle schlieren (Guenthner, this volume). Field relationships suggest that the granite layer is the crystallization product of
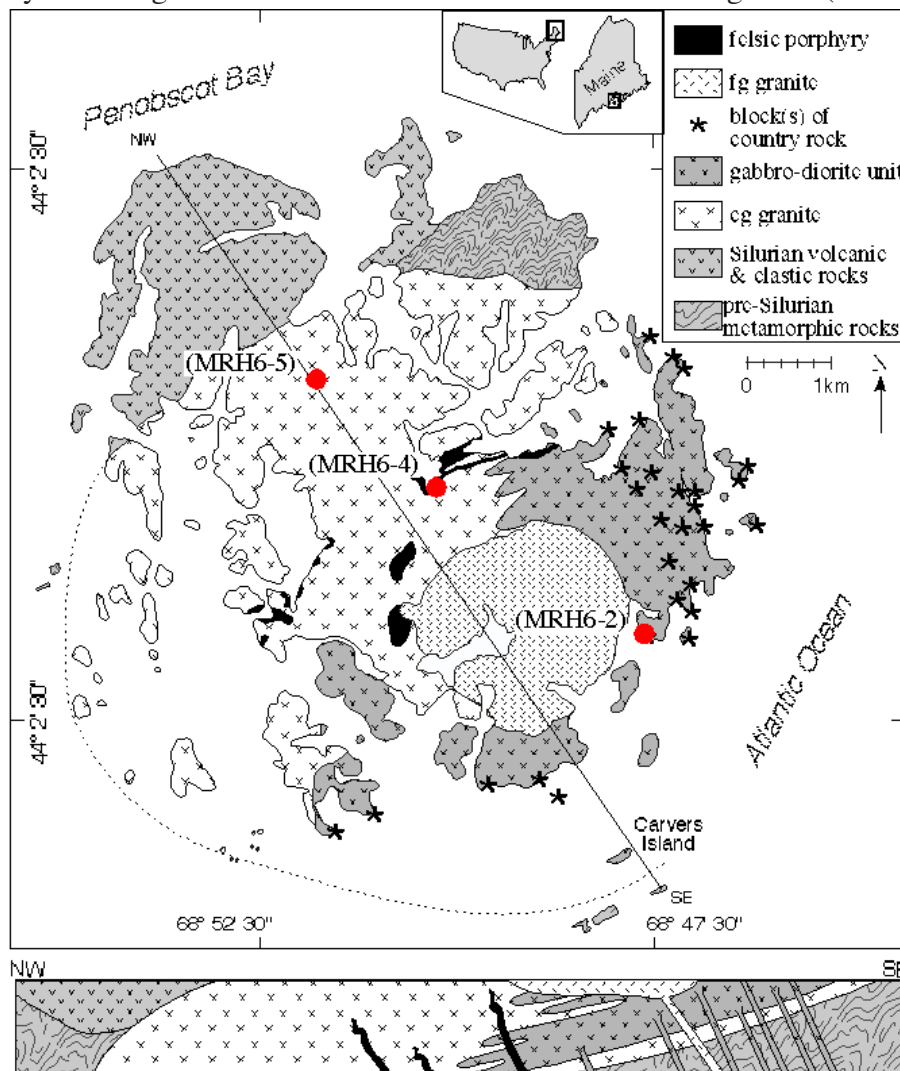
silcic magma immediately following the input, emplacement and concomitant hybridization of the underlying mafic sheet. The sample obtained for this study (MRH6-2) was collected 3-4 meters from the contact with the underlying hybridized gabbro.

Fig. 1. Geologic map of Vinalhaven Island with plotted sample locations MRH6-2, MRH6-4, and MRH6-5. (modified from Weibe etal., 2004)

Granite from the Top of the Gabbro-Diorite Unit

Coarse-grained granite at the southern end of Vinal Cove is located along strike from the stratigraphic and lateral termination of the gabbro-diorite unit (Fig. 1). A younger mafic intrusion that locally remelted granite mush to form the nearby Vinal Cove porphyry complex (Wiebe et al., 2004) is exposed about 40 meters

from the area studied herein. There is no field evidence to suggest the granite sampled here was remelted by this later intrusion. The granite is petrographically and geochemically indistinguishable from typical Vinalhaven granite (Wiebe et al., 2004), and contains sparse felsic to intermediate enclaves (Colman, this volume). The sample obtained for this study was collected about 40 meters from the mafic intrusion.

Granite Far Above the Top of the Gabbro-Diorite Unit

Coarse-grained granite exposed in the 1900's quarry (locality MRH6-5) is located near the top of the intrusion, kilometers from the nearest mafic sheet or mafic pillow complex (Fig. 1). The granite is petrographically and geochemically indistinguishable from typical Vinalhaven granite and contains sparse felsic to mafic enclaves and a variety of subtle schlieren structures (Colman, this volume).

ANALYTICAL METHODS

Zircon crystals were separated from coarse-grained granite by standard crushing, density, and magnetic separation techniques at the Massachusetts Institute of Technology (MIT). Approximately 40 individual zircon grains per sample were hand-picked for both BSE and CL imaging based on size, clarity, and structural condition. Selected grains were mounted in one-inch epoxy rounds according to size, ground to their centers, polished, carbon-coated, and imaged on a JEOL JXA-733 Superprobe at MIT using both BSE

and CL.

The relative brightness on BSE and CL images reflect variation in the chemical composition of the zircon. In BSE images, brighter areas have higher average atomic numbers than darker areas, and in CL images brightness reflects the relative abundance of rare-earth elements that emit light in the visible spectrum when excited by the electron beam (Nazdala et al. 2003). In this study, I used both BSE and CL images for interpreting grain histories, but only present the CL images herein because the zoning is clearer (Fig. 2).

CHARACTERIZATION OF GROWTH HISTORIES

Zircons from the Vinalhaven intrusion have complex internal structures characterized by obvious (perhaps xenocrystic) cores of unknown origin, domains with primary growth zones, unconformities that truncate growth zones, mineral inclusions, crystallized melt inclusions, fractures and secondary domains with indistinct zoning. Despite the complexity, all of these features uphold superposition and/or display cross-cutting relationships that can be exploited to construct growth histories for each grain. To accomplish this goal, I first determined if a grain contained an obvious core, identified by both a significant unconformity and a distinct contrast in zoning style and/or brightness. I then characterized the magmatic domains, which in these grains is typified by fine-scale compositional zoning truncated by unconformities (Fig. 2). To characterize the magmatic growth history, the main goal of this study, I counted the number of zoned growth domains and the intervening unconformities, which must represent time periods of resorption/dissolution.
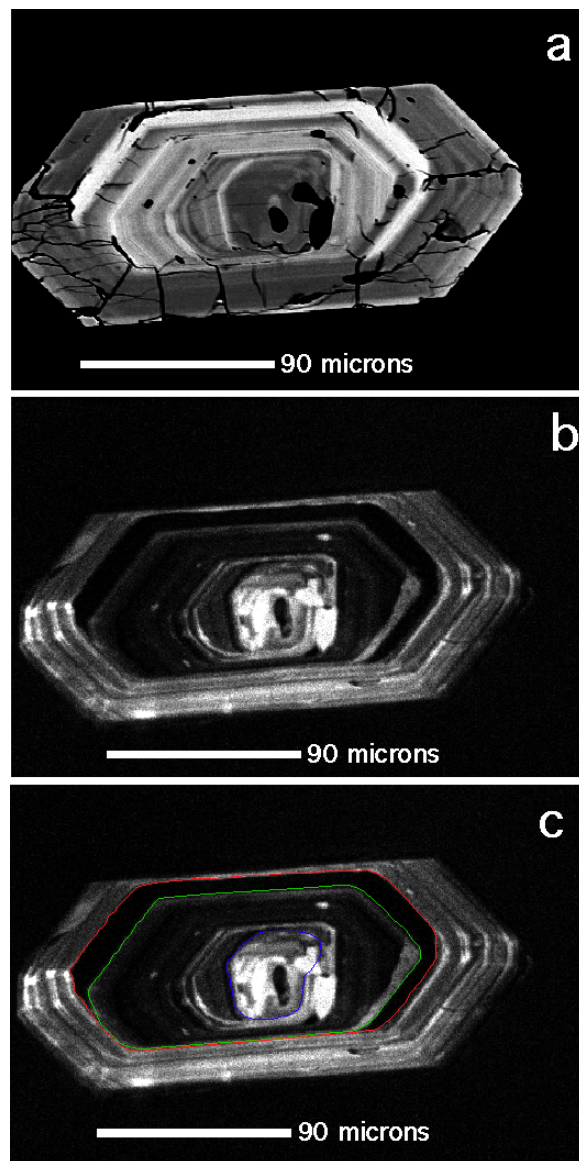
Fig. 2. Zircon grain from Vinal Cove: a) BSE image. b) CL image c) CL image with outlines of unconformities that separate packages of growth zoning.

As an illustration of this approach, consider the grain shown in figure 2. The grain contains an obvious core, surrounded by a domain characterized by growth zoning, which is truncated by an unconformity. The unconformity is overlain by a dark domain that lacks obvious growth zoning, which is, in turn, truncated by a second unconformity. The final stage of growth is signified by a zoned domain that extends to the grain margin. Thus, the magmatic growth history of this grain appears

to involve 3 periods of zircon crystallization from the melt separated by two periods of zircon dissolution back into the melt.

RESULTS

A wide variety of zircon growth histories are present within each granite sample (Figs. 3-5) and that variation is summarized below for each sample locality.

Granite Within the Gabbro-Diorite Unit

A total of 42 grains were imaged from the sample at Arey Neck (MRH6-2) (Fig. 3). Of these 42 grains, 22 grains (52%) contain obvious cores with either chaotic zoning (17 cores) or no zoning at all (5 cores). The remaining 20 grains (48%) lack obvious cores and display magmatic zoning from the grain center to the grain margin. The magmatic domains of the 42 grains show a wide range of histories. Eighteen grains (43%) display two periods of growth separated by one unconformity, 19 grains (45%) display three periods of growth separated by two unconformities, 4 grains (10%) display four periods of growth separated by three unconformities, 2 grains (5%) display five periods of growth separated by 4 unconformities, and 1 grain shows one period of growth that is uninterrupted by unconformities. Nine grains (21%) from all of the groups above exhibit at least partial resorption at the grain margin. Finally, all of the grains that display 4 or 5 periods of growth lack obvious cores.

Granite from the Top of the Gabbro-Diorite Unit

A total of 45 grains were imaged from the sample at the southern end of Vinal Cove (MRH6-4) (Fig. 4). Of these 45 grains, 31 grains (69%) contain obvious cores with either chaotic zoning (21 cores) or no zoning at all (10 cores).
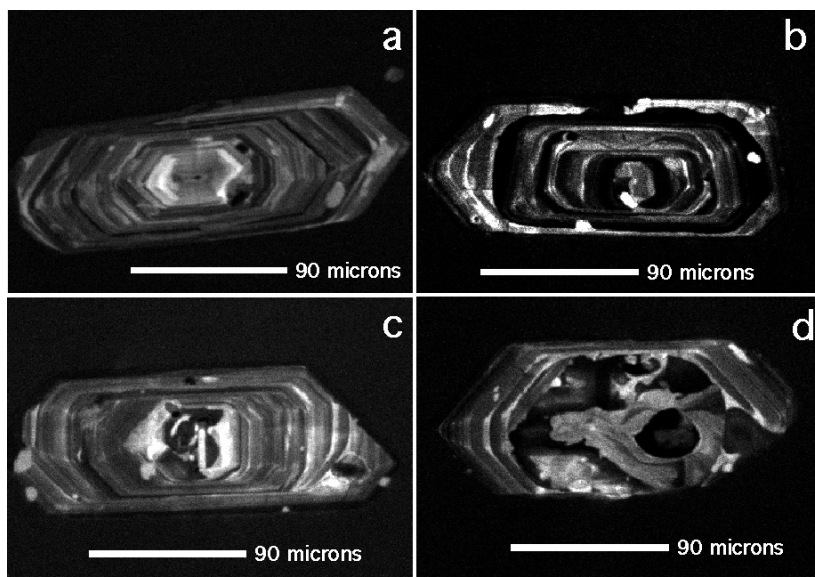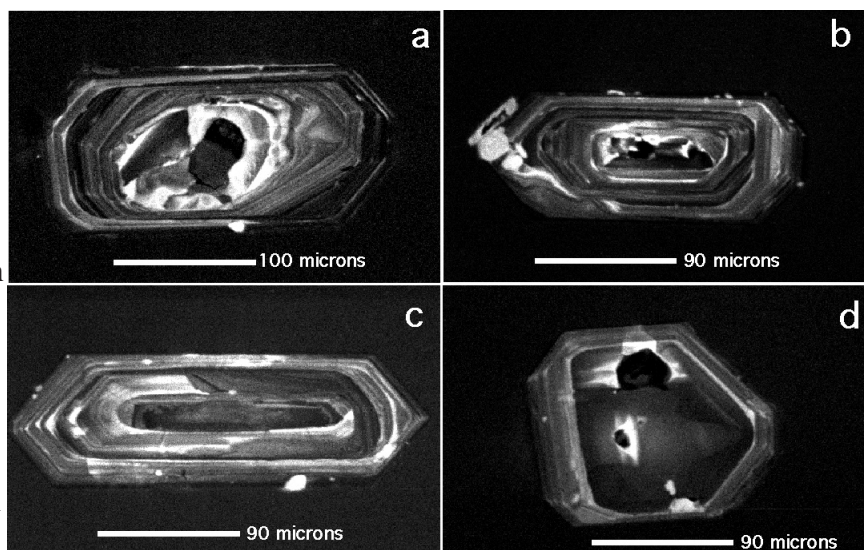

Fig. 3. Various zoning styles found in zircons from granite within the gabbro-diorite unit at Arey Neck: a) magmatic zoning from grain center to a margin with 1 unconformity separating two periods of growth; margin displays partial resorption b) magmatic zoning from grain center to margin with 5 periods of growth separated by 4 unconformities c) core surrounded by 3 periods of growth separated by 2 unconformities d) core surrounded by 2 periods of growth separated by 1 unconformity.

The remaining 14 grains (31%) lack obvious cores and display magmatic zoning from the grain center to margin. The magmatic domains of the 45 grains show a wide range of histories. Nineteen grains (47%) display two periods of growth separated by one unconformity, 23 grains (51%) display three stages of growth separated by two unconformities, and 3 grains (7%) display four periods of growth separated by three unconformities. Nine grains (20%) from all of the groups above exhibit at least partial resorption at the grain margin.
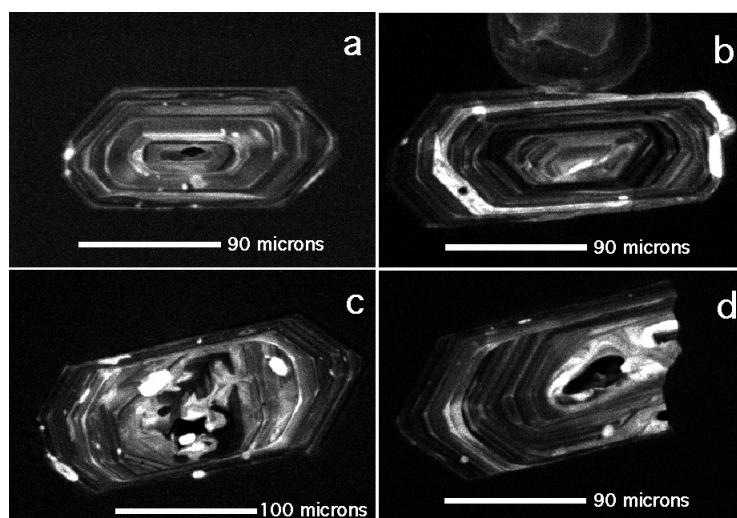
Granite Far Above the Top of the Gabbro-Diorite Unit

A total of 39 grains were imaged from the 1900s quarry (locality MRH6-5) (Fig. 5). Of these 39 grains, 29 grains (74%) contain obvious cores with either chaotic zoning (14 cores) or no zoning at all (15 cores). The remaining 10 grains (26%) lack obvious cores and display

magmatic zoning from the grain center to the grain margin. The magmatic domains of the 39 grains show a wide range of histories. Twenty-one grains (54%) display two periods of growth separated by one unconformity, 17 grains (44%) display three stages of growth separated by two unconformities, and 1 grain shows one period of growth that is uninterrupted by unconformities. Eight grains (21%) from all of the groups above exhibit at least partial resorption at the grain margin.

Fig. 5. (above) Various zoning styles found in zircons from cg granite far from the top of the gabbro-diorite unit at the 1900s quarry: a) core surrounded by 3 periods of growth separated by 2 unconformities b) core surrounded by 4 periods of growth separated by 3 unconformities c) magmatic zoning from grain center to margin with 3 periods of growth separated by 2 unconformities. d) core surrounded by 1 period of growth.

Fig. 4. Various zoning styles found in zircons from cg granite from the top of the gabbro-diorite unit at Vinal Cove: a) magmatic zoning from grain center to margin with 4 periods of growth separated by 3 unconformities b) magmatic zoning from grain center to margin with 3 periods of growth separated by 2 unconformities; partial resorption of margin. c) core surrounded by 3 periods of growth separated by 2 unconformities. d) core surrounded by 2 periods of growth separated by 1 unconformity.

DISCUSSION

This study focused on 126 zircon crystals hand-selected from 3 rock samples and is therefore a biased sample lacking statistical significance. Despite these limitations, the grains studied provide insights into the utility of zircon growth histories as a tool for insight into magmatic processes.

Obvious cores are present in zircon crystals at all straigraphic levels. Whether these cores are, in fact, xenocrysts is best determined by U-Pb geochronology, although the nature of the

zoning suggests these cores are metamorphic in origin (e.g., Corfu at al., 2003). Their presence at all stratigraphic levels is consistent with an incremental growth model for the intrusion, and/or widespread recycling of granitic mush during replenishment.

The fact that individual crystals in a given sample display a variety of magmatic growth histories suggest that these grains did not grow in the same batch of magma. The key question is whether this variation reflects small-scale variation in melt composition within or transport of individual crystals from different parts of the system prior to deposition in the mush that formed the sampled rock. However, the variation in zircon growth histories is consistent with both macroscopic and microscopic mineral textures (e.g., Wiebe et al, in press).

The major variations in the magmatic growth histories between the three samples seem to correlate with stratigraphic position. Zircon crystals from the layered gabbro-diorite unit appear to have more unconformities, periods of resorption of zircon back into the melt, than zircons from samples more distant from mafic sheets. This suggests that zircons record the influence of the mafic magmas on silicic melts. Furthermore, the presence of multiple growth domains bounded by unformities in zircons far from the mafic sheets, suggests that either zircon crystals influenced by mafic input are recycled by replenishment or granite from the 1900's quarry once resided close to mafic sheets subsequently displaced by subsidence (e.g., Hawkins and Wiebe, 2004), or that processes other than mafic input - convective stirring, assimilation of country rocks, eruption, rejuvenation of mush, etc. - result in resorption. Further analysis of these grains, including Ti-thermometry, trace element mineral chemistry, Hf isotope chemistry, and U-Pb geochronology is needed to resolve these issues, but the growth histories characterized here provides a basis for that work.

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