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Intracrystalline redistribution of Pb in zircon during high-temperature contact metamorphism

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Abstract

Zircons in the high-*T* (700–900 °C) contact aureole surrounding the Makhavinekh Lake Pluton (MLP), northern Labrador, were studied using conventional thermal ionization mass spectrometry (TIMS) and sensitive high-resolution ion microprobe (SHRIMP) geochronology to test for evidence of high-*T* Pb mobility. Metasedimentary gneisses in the country rocks (Tasiuyak Gneiss) contain ~1850 Ma zircons that formed during regional (M1) metamorphism that were reheated in the aureole during emplacement of the MLP at 1322 Ma (M2). M1 zircons that experienced M2 temperatures <750 °C are concordant at ~1850 Ma and were, thus, virtually unaffected by M2 contact metamorphism. In contrast to this well-established baseline, sector-zoned M1 zircons in samples that reached *T*>800 °C scatter along a discordant array between M1 and M2 are locally reversely discordant and commonly return younger apparent ages for lower-U cores than higher-U rims. These data collectively require widespread intracrystalline Pb redistribution during M2. Isometric M1 overgrowths and inherited magmatic cores in the same samples were unaffected, indicating that susceptibilities to subsequent Pb redistribution may have been controlled by variations in M1 zircon growth mechanisms. The scatter of U–Pb ages in sector-zoned M1 grains is consistent with Pb expulsion from low-U domains (e.g., broad bright-CL sector boundaries) that had accumulated high lattice strains prior to M2. Lattice strain is inferred to have resulted from a combination of high intrinsic growth defects compounded by self-induced internal stresses from expanded metamict high-U sectors. Recovery of strained domains occurred while high-U sectors were partly metamict, allowing Pb to accumulate in the remaining amorphous fraction.
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Keywords: Zircon; Metamorphism; Granulites; Pb redistribution; Makhavinekh Pluton

1. Introduction

The physical and isotopic stability of zircon is one of its most widely documented and exploited properties. Experimental evidence (Cherniak and Watson, 2000) indicates that volume diffusion of

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Pb in crystalline zircon is negligible at the temperatures and timescales encountered in the crust, so resetting of the U–Pb isotopic "clock" in zircon via this mechanism is unlikely in undamaged crystals. As a result, zircon that has remained crystalline since the time of its growth should yield concordant U–Pb ages (a test of closed- vs. open-system behavior of Pb isotopes in zircon). Whereas experimental studies provide constraints on the behavior of Pb in ideal zircon, there is an emerging consensus that isotopic resetting in natural zircon may occur as a result of numerous natural processes, such as microfracturing and hydrothermal alteration (Ashwal et al., 1999; Carson et al., 2002; Chakoumakos et al., 1987; ; Geisler et al., 2001, 2003a), recovery of strain induced by high concentrations of impurities (Hoskin and Black, 2000; Pidgeon, 1992; Pidgeon et al., 1998; Schaltegger et al., 1999), or high-temperature recovery of metamict damage (McLaren et al., 1994; Nasdala et al., 2002; Williams et al., 1984). Pb-loss associated with these processes rarely affects the entire crystal but may instead be localized to domains within a zircon that are particularly susceptible to Pb migration (i.e., fractured or metamict domains). Depending on the chemistry and zoning, accumulated radiation damage, and thermal history, Pb migration in zircon may occur at a variety of scales ranging from sub-micron redistribution of Pb between growth zones (Mattinson et al., 1994) to whole-grain net Pb-loss.

We present here the results of a combined thermal ionization mass spectrometry (TIMS) and sensitive high-resolution ion microprobe (SHRIMP) study of zircons from the high-temperature contact aureole surrounding the Makhavinekh Lake Pluton (MLP), northern Labrador. Based on the age of M1 regional metamorphic zircon (Scott, 1998; Scott and Gauthier, 1996), the age of M2 contact heating, and estimates for the thermal evolution of the surrounding country rocks (McFarlane et al., 2003), U–Pb ages for zircon in the aureole were determined over a range of distances from the intrusion. The high sensitivity and high spatial resolution of the ion-microprobe allowed isotopic characterization of different growth zones and provided a test of whether Pb migration occurred during high-temperature (700–900 °C) M2 contact heating.

2. Geological setting

The MLP is part of the Mesoproterozoic Nain Plutonic Suite (NPS) of northern Labrador (Fig. 1). It is a large (>1000 km^2) composite intrusion that contains a core of leuconorites, troctolites, and anorthosites surrounded by a sheath of locally charnockitic granite, monzonite, and granodiorite (Ryan, 1991). The age of the troctolite core of the MLP has been previously dated at 1322±2 Ma by Hamilton et al. (1994) using conventional TIMS zircon and baddeleyite geochronology. TIMS zircon U–Pb ages for the granitic margins of the pluton from our work are presented below. Throughout the study area, the MLP intrudes into the Tasiuyak Gneiss, a garnetiferous psammitic paragneiss of anatectic origin that formed under granulite-facies conditions (~800 °C, 8–10 kbar) during the Paleoproterozoic terminal collision (Torngat Orogen) of the Archean Nain and Rae tectonic provinces (Mengel and Rivers, 1997). Geochronological studies (Bertrand et al., 1991, 1993; Scott, 1998; Scott and Gauthier, 1996; Van Kranendonk, 1992) in the northern extension of the Tasiuyak Gneiss identified a range of detrital zircon ages between 2100 and 1940 Ma. An 1895 Ma quartz diorite that intrudes the Tasiuyak Gneiss places a minimum age on sedimentation, bracketing deposition of the protolith between ~1940 Ma (the youngest detrital grains) and ~1895 Ma. M1 metamorphism during the Torngat Orogeny is constrained to be younger than 1870 Ma based on monazite believed to have formed during upper-amphibolite metamorphism in the psammitic portions of the Tasiuyak Gneiss (Scott, 1998). Rounded metamorphic zircons and overgrowths on detrital zircon cores analyzed by Bertrand et al. (1991, 1993) yielded near-concordant ages between 1860 and 1825 Ma, interpreted as dating two discrete zircon-forming events related to melting and/or late stage deformation. The waning stages of metamorphism, left-lateral shearing, and subsequent uplift in the Tasiuyak Gneiss occurred between ~1800 and 1790 Ma based on emplacement of late leucogranites and syn- and post-tectonic pegmatites that intrude the strong N–S mylonitic fabric. Additional discussion of the regional metamorphism, deformational fabrics, and age constraints for the

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