# Constraining cooling histories of the Pokiok Batholith, New Brunswick, Canada, using combined zircon, allanite, titanite, and apatite U-Pb geochronology from the Hartfield tonalite

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The ~415 Ma Hartfield tonalite is the earliest member of the Pokiok Batholith, SW New Brunswick, which was constructed through sequential intrusion of the Hawkshaw (411 ± 2 Ma), Skiff Lake (409 ± 2 Ma), and Allandale (402 ± 1 Ma) plutons as previously measured using TIMS U-Pb geochronology. The Hartfield tonalite contains a largely unaltered major- and accessory-mineral assemblage that is well-suited for geochronological studies. The sequential closure of U-Pb ages for accessory minerals from this intrusion should, therefore, help reveal the timescales of cooling of the batholith as a whole. The sample used for this study was collected from a fresh road-side outcrop with no visible alteration at the hand-sample scale (45°57'24.26"N, 67°21'18.00"W) and a heavy mineral separate was produced. Zircon needles, prismatic titanite, blocky allanite and epidote and apatite were picked, mounted in epoxy, and polished. Application of LA ICP-MS geochronology to these accessory phases produced a hierarchy of ages ranging from 417 ± 2 Ma for zircon, 414 ± 2 Ma for allanite, 413 ± 2 Ma for titanite, and 408 ± 6 Ma for apatite. Assuming that zircon records incipient crystallization of the tonalite magma at ca. 417 Ma the ca. 408 Ma apatite age must reflect almost 10 Myr of evolution above the closure temperature of for Pb-diffusion in apatite. Based on previous work the 50–100 μm diameter apatite grains analyzed here should close to Pb-diffusion at temperatures between 420 and 450°C for cooling rates between 1 and 10°C/Ma respectively. Two-dimensional numerical simulations using KWare HEAT3D using estimates for intrusion depth, geometry, and initial temperatures shows that simple instantaneous intrusion and conductive cooling models are insufficient to maintain temperatures >450°C for more than a few 100 ka. In contrast, temperatures above those sufficient to maintain efficient Pb-diffusion in apatite can be maintained if: (1) an incremental intrusion history is adopted for the three main phases of the batholith; (2) magma advection is possible; (3) convection is allowed in the host rocks. These models predict crystallization of the Hartfield tonalite in <1 Ma followed by maintenance at *T*>425°C until 409 Ma. This long-lived high-*T* thermal history has important implications for the initiation and sustainability of convective circulation cells that could drive intrusion-proximal ore deposition. Future work will explore U-Pb dating of apatite of different size fractions to more fully refine Pb-diffusion parameters in a well-constrained natural setting.

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