Burial and exhumation of the New England Avalon terrane coincident with Alleghanian orogenesis and continental breakup documented with zircon and apatite (U-Th)/He thermochronometry

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Abstract

Spatial and temporal patterns of crustal heating and cooling derived from low-temperature thermochronometry document differential burial and unroofing during continental breakup. In the northern Appalachians, we use this approach to inform the buildup and collapse of a hypothesized Acadian plateau. We acquired new zircon and apatite (U-Th)/He (ZHe and AHe) thermochronometry data from six unmetamorphosed Ediacaran granite samples within the accreted Avalon terrane that surrounds the preserved Devonian-Carboniferous Narragansett Basin (Massachusetts, USA), spanning an area of ~3000 km2. ZHe results are spatially variable and have distinct date-effective uranium concentration (eU)-visual metamictization patterns. The southwesternmost sample, ~30 km from the Avalon accretionary margin, yields uniform ~150 Ma ZHe dates across a ~1600 ppm eU span with visually low radiation damage regardless of eU value. ZHe data from five samples to the north and east of the basin collectively define a negative date-eU trend with ~350-50 Ma dates over ~100-5000 ppm eU and display increasing visual metamictization with increasing eU. Dispersed intersample and intrasample AHe dates of ~260-60 Ma (mean ~150 Ma) are consistent with published regional apatite fission track and AHe data.

We integrate these data in thermal history models, which leverage previously published ID-TIMS zircon U-Pb crystallization ages of ~609-599 Ma from these samples and regional geologic constraints. For samples outboard of the accretionary margin, data patterns and model outcomes suggest <250 °C peak reheating between 300 and 200 Ma before slow cooling to surface conditions. We interpret model outcomes to reflect up to 8 km of Mesozoic sediment deposition in an Avalon basin larger than any preserved today. In contrast, the sample nearest the Avalon accretionary margin experienced peak temperatures >250 °C, limited radiation damage accumulation, and rapid cooling to near-surface conditions at ~150 Ma, consistent with deeper structural burial of southwest Avalon during the Alleghanian orogeny. Together, these results support the ~320-300 Ma collapse of an Acadian plateau to the west of the Avalon terrane, enabling post-Alleghanian basin growth and disparate timing and mechanisms of unroofing across the terrane.

Project Objectives

The research team aimed to apply recent (U-Th)/He thermochronometry techniques to the Avalon terrane in Southeastern Massachusetts, filling a substantial data gap in the New England region (cf. Hillenbrand et al 2021). This technique enabled us to reconstruct a first-order thermal history of bedrock in the area, which from the outset was intended to add previously inaccessible information to theories of New England tectonics over the last 600 Ma.

Methodology Used

We started with zircon and apatite helium diffusion data from six granite samples ringing the Narragansett Basin, a tens-of-kilometers wide feature south of present-day Boston, Massachusetts. Informed by best practices devised by the thermochronometry community (e.g. Ault et al 2018, Flowers et al 2015, Guenthner et al 2013, Johnson et al 2017), we used observations of raw data and modeling software HeFTy as our primary thermal history reconstruction tools. In particular, visual examination of

zircon crystal metamictization and date-eU trends suggested similar or divergent thermal histories among samples. With these patterns in mind, we ran inverse models on HeFTy given known geologic constraints on the region's thermal history (e.g. Thompson et al 2010, Thompson et al 2003). In addition, forward modeling data in HeFTy helped us iterate on possible time-temperature paths. Taken in combination, these data point to a narrow band of possible thermal histories.

Results Obtained

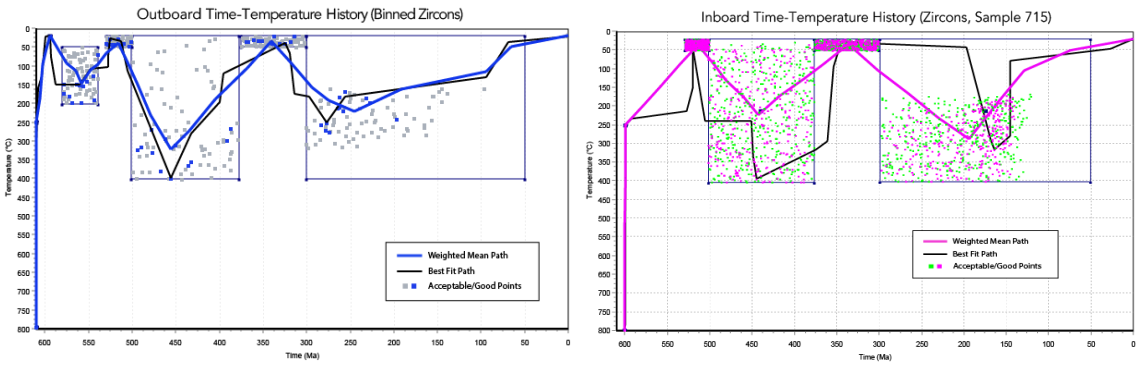
Two distinct thermal histories emerged from our analysis. Data from samples taken outboard of the Avalon accretion zone (to the north and east) suggest near-surface thermal histories between 550 and 300 Ma, then imply a rapid reheating (300-200 Ma) up to 250°C. After this peak, the samples likely cooled slowly to surface conditions by the present. Such results are supported by clear negative date-eU trends and visual metamictization that increases with eU concentrations, which are both suggestive of reheating below 250°C and slow cooling. In contrast, the sample to the southwest, nearest the Avalon accretionary zone, yielded reheating above 250°C between 300 and 200 Ma, then likely cooled rapidly to surface conditions by 150 Ma. This history is supported by a flat date-eU trend and uniform visual metamictization across a ~1800 ppm eU range, which both suggest reheating above 250°C and rapid cooling.

Significance and Interpretation of Results

We interpret these divergent patterns as signatures of differential burial and unroofing across the Avalon terrane. Farther from the accretionary zone (which lies in present-day Rhode Island and Connecticut), we conclude samples were buried to a depth of up to 8 kilometers between 300 and 200 Ma. The sediment overlying the present-day erosional surface likely came from upland sources in New England, though provenance could also be attributed to Gondwanan sources during the Alleghanian orogeny. The present-day Narragansett Basin and other sedimentary basins are likely remnants of a large Avalon basin covering the entire region. Timing of burial of Avalon batholith coincides with the collapse of the Acadian plateau hypothesized by Hillenbrand and colleagues (2021).

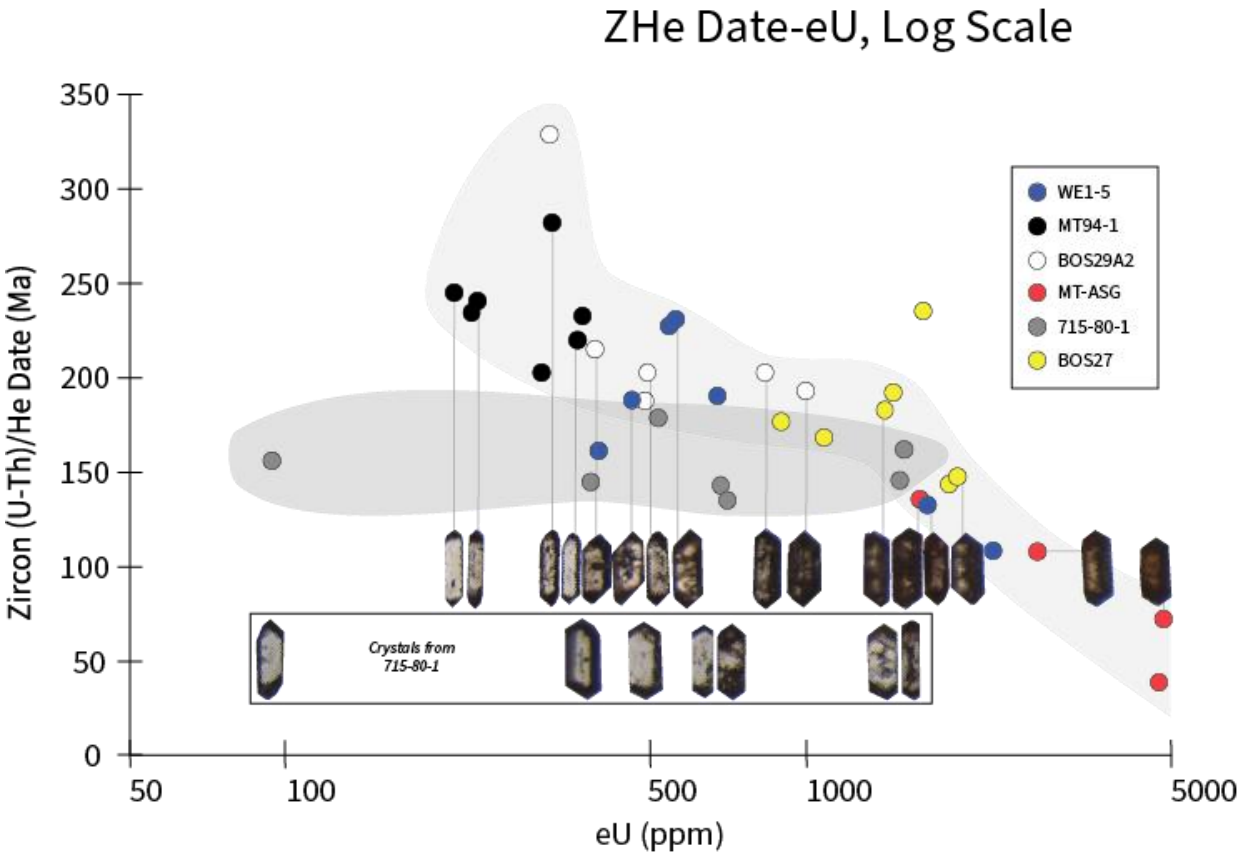
On the southwestern side of the terrane, however, we conclude that one sample was buried much deeper than the others between 300 and 200 Ma. It is conceivable that this segment of the terrain was underthrust beneath the overriding peri-Laurentian terranes. While subjected to intense friction and pressures that created metamorphic rock adjacent to the site, this sample would have reached temperatures far in excess of 250°C before being rapidly uplifted in isostatic rebound as the overlying crust was eroded during the collapse of the Acadian plateau. In total, our interpretations align with other recent thermochronology studies in New England and add a crucial data point to tectonic histories of eastern North America.

Figures



Above: Modeled time-temperature histories for samples outboard (blue) and more inboard (pink) of the Avalon accretion zone. Blue and pink squares, respectively, represent "good" fit points for attempted paths. Note zonation of points 300-200 Ma.

Below: Date-effective uranium correlations of all six samples, with representative zircon crystals images. Note negative correlation and increasing metamictization in main sequence, and flat correlation and uniform metamictization across sample 715.



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