Characterizing reactions and fluid pulses in 30 Myr of continuous retrograde metamorphism using LASS monazite petrochronology

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Although the Appalachians formed one of the largest mountain belts on Earth, their early history remains elusive in part because this early history has been overprinted. This study focuses on newly discovered garnet-kyanite-cordierite schists from the Goshen Dome of Western Massachusetts that provide direct evidence of the earliest phase of mountain building in the Appalachians. Previous work has demonstrated that these rocks were subducted to depths greater than 200 km (ultrahigh-pressure conditions). Constraints on the timing and character of the path of these rocks to the surface are therefore vital to understanding the dynamics of mountain building processes, as well as understanding ultrahigh-pressure processes.

To quantify the path these rocks took to the surface, I used a laser to drill 10 micrometer spots in monazite grains to extract geochemical and geochronological information to reconstruct the ~30 Myr metamorphic history of this terrane. Monazite is an ideal mineral for this analysis because compositional domains within the mineral reflect changes in the mineral assemblage of the rock (Fig. 1). I used a scanning electron microscope to image over 200 monazite grains in order to guide our laser spot locations. I then collected 875 analyses of monazite at the laser ablation facility at UC Santa Barbara. To interpret the data, I used Y concentrations, Gd/Yb ratios, and kernel density estimates (KDEs) to constrain the chronology of garnet-forming/breakdown, melting, and/or fluid pulsing events, as well as the timing of growth of major mineral phases. In interpreting monazite data, I interpreted decreasing Gd/Yb and elevated Y concentrations as compatible with garnet breakdown, increasing Gd/Yb and low Y concentrations as compatible with garnet growth/stability, and highly variable Gd/Yb ratios as indicative of widespread melting and/or fluid pulses. I interpreted spot analysis age data from monazite included within a particular mineral phase to be representative of the timing of growth of that mineral phase.

My collaborators and I constructed cumulative histories from two samples based upon monazite data collected from seven thin sections (Fig. 2). Both samples suggest that an initial phase of garnet growth must have occurred pre-390 Ma – this is evident in low Gd/Yb ratios reflecting the breakdown of that garnet generation. Sample B (n = 644 analyses) indicates a second phase of garnet growth (high/variable Gd/Yb) that lasted from 382 to 373 Ma. Sample G (n = 231 analyses) indicates two additional phases of garnet growth (high/variable Gd/Yb); the second phase lasted from 387 to 383 Ma and the third phase lasted from 379 to 374 Ma. The final growth event in both samples (second phase in B, third phase in G) culminated in widespread melting that lasted from 375 to 365 Ma.

These data provide the first nearly continuous record of metamorphism during the early phases of mountain building in the Appalachians. Furthermore, the metamorphic reactions preserved in these rocks can only be interpreted by analyzing the geochronologic data in conjunction with the geochemical data and the petrographic context of each grain, thereby underscoring the importance of our analytical technique.
**Figure 1:** 2D compositional map and sketch for monazite grain from sample B. High-Y core compatible with garnet breakdown pre-381 Ma; low-Y mantle compatible with garnet growth ~382-373 Ma; medium- to high-Y rim compatible with garnet breakdown ~373-365 Ma.

**Figure 2:** Timeline constructed for sample B. From top to bottom: KDEs for mineral phases, major mineral phases present, schematics of garnet growth/breakdown/fluid events, and timing of growth (paired with Gd/Yb trends) for all minerals.

Mineral symbols: Crd (cordierite), Qz (quartz), Chl (chlorite), Ky (kyanite), Pl (plagioclase), Bt (biotite), Grt (garnet)
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