New Constraints on the Pressure–Temperature–time History of the Manhattan Schist from Garnet Sm-Nd Petrochronology

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The crystalline bedrock of New York City comprises the physiographic region known as the Manhattan Prong, and is thought to record a complex history of metamorphism and deformation associated with the closure of the Neo- Iapetus Ocean during the Taconic orogeny (~520-470 Ma) and the accretion of Avalonia during the Acadian orogeny (~416-360 Ma). Though many models for the tectonometamorphic evolution of the Manhattan Prong have been proposed, the historical paucity of phase equilibria and geochronologic data has impeded efforts in decisively constraining this history. Here we present the results of detailed petrography, phase equilibria modeling, garnet Sm-Nd geochronology, and *in situ* monazite U-Pb geochronology for a sample of the Manhattan Schist in Northern Central Park.

Our sample is a garnet-kyanite-biotite-muscovite migmatite with well-preserved reaction and deformation microstructures. The matrix is dominated by foliated biotite and subordinate

muscovite. Kyanite occurs in two habits: a) ~1mm long grains in oriented plagioclase+muscovite+quartz pods interpreted to represent recrystallized partial melts, and b) smaller <0.5 mm long syn-kinematic porphyroblasts in foliation-defining biotite. Sillimanite occurs as fibrolite inclusions in texturally late muscovite, fibrolite pseudomorphs after kyanite pods, and <0.5 mm-long laths cross-cutting kyanite. Garnet occurs as ~0.5-1 mm diameter subidioblastic grains. Garnet grains appear pre-kinematic, with mica+quartz tails, and rotated inclusions. Garnet grains preserve prograde growth zoning in both major and trace elements. Mn-content decreases from core to rim, while Fe, Ca, and Mg increase. Garnet also preserves heavy rare earth element growth zoning.

Monazite inclusions in garnet rims and monazite grains in the matrix were dated by La-ICP-MS at the TEMPO Lab at Johns Hopkins University. Both groups of monazite record ages of c. 420 Ma, and preserve steeply depleted chondrite-normalized REE-patterns. Bulk garnet was dated via ID-TIMS at the Boston College Center for Isotope Geochemistry. Four garnet aliquots and one whole rock aliquots were measured. These aliquots produced an isochron age of c.386 Ma with an MSWD<1.

The synthesis of thermodynamic modeling with reaction textures and the method of intersecting isopleths (Spear et al., 1984) suggest a typical Barrovian clockwise P–T path: 1) garnet nucleation and growth constrained by core isopleths at to ~550 °C and 4-6 kbar, 2) burial and heating to kyanite grade anatexis at ~750 °C and 9-11 kbar, and 3) cooling and exhumation to garnet rim conditions at ~700 °C and 6 kbar.

Though monazite inclusions in garnet rims record an age of c. 420 Ma, the preservation of major and trace element growth zoning in garnet and the small MSWD of our isochron suggests that our age (c. 386 Ma) dates prograde garnet growth, as ~420 Ma aged cores and rims would be preserved and would manifest as a large degree of noise in our isopleths, and an MSWD at least 2 orders of magnitude higher (e.g. Harvey et al., 2021). We interpret the monazite ages to reflect sub garnet-grade metamorphic growth in the presence of xenotime, which accounts for the depleted HREE profiles. The lack of C. 386 Ma monazite in the matrix suggests that monazite is decoupled from the polymetamorphic record (e.g. March et al., 2023)

Taken as a whole, we propose that the Manhattan schist in Central Park records: 1) early sub-garnet grade metamorphism recorded by monazite, and 2) prograde metamorphism and development of the dominant fabric as a result of crustal thickening during the Acadian orogeny, recorded by garnet. In short, the bulk of metamorphism, from garnet-grade to anatexis, and deformation recorded in the Manhattan Schist is associated with the Devonian Acadian orogeny, with only a weak Camrbo-Ordivican Taconic signature preserved. This study adds to the growing body of literature that recognizes high-grade Acadian metamorphism on the Laurentian margin (Bosbyshell et al., 2016; George et al., 2024).

Works Cited

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