Timing and style of deformation in the Nashoba Formation of the Nashoba terrane, eastern MA

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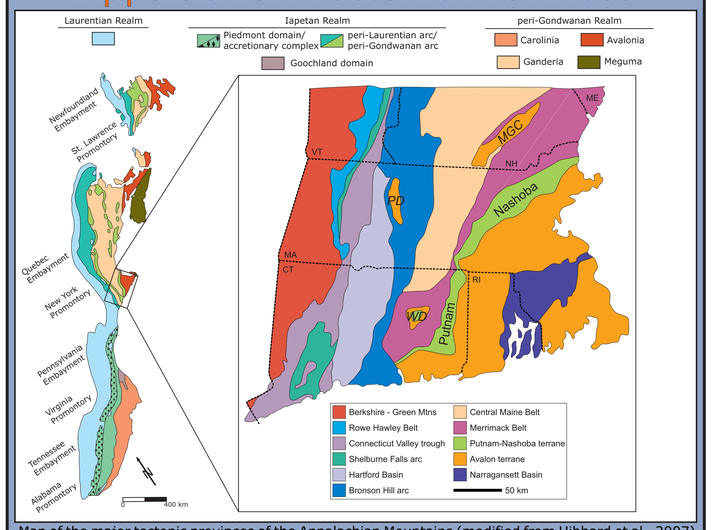
Abstract

The Nashoba terrane (NT) is a moderately northwest-dipping fault-bounded block within the New England Appalachians and is located between the Avalon terrane to the southeast and terranes of Ganderian affinity to the northwest. The NT is a multiply deformed Cambrian-Ordovician arc-backarc complex metamorphosed up to sillimanite + potassium feldspar conditions, resulting in migmatization. This package was intruded by Silurian to earliest Carboniferous granitic and calc-alkaline intermediate-composition plutons. The Nashoba Formation (NF) in the NW portion of the NT is the best exposed metasedimentary unit in the NT and preserves a complex deformational history. The NF is comprised of biotite-feldspar-quartz +/- garnet +/- sillimanite +/- muscovite +/- amphibole +/- magnetite gneiss with interlayered calc-silicate, impure quartzite, marble and sillimanite-bearing pelitic schist.

Deformation in the Nashoba Formation is dominated by isoclinal folds, overprinted by top-down-to-the-NW asymmetric folds. These folds and gneissosity in the northwest portion of the formation is cut by subvertical NW-side-down ~0.5 m wide shear zones, and later local steeply NW-dipping top-down-to-the-NW ultra-cataclasites. U-Pb zircon chemical abrasion – thermal ionization mass spectrometry (CA-TIMS) geochronology was used to bracket the ages of folding within the Nashoba Formation. A ~418 Ma pegmatitic dike cross-cuts isoclinal folds. Three migmatitic dike samples were dated and contain metamorphic, igneous, and inherited zircon. All ages reported below are interpreted as crystallization ages based on zircon morphology and high Th/U ratios. A migmatitic dike folded only by top-down-to-the-NW asymmetric folds is 364.6 +/- 0.6 Ma. A planar migmatitic dike that crosscuts the asymmetric folds yielded ~364-361 Ma zircon. These two samples appear to constrain the age of asymmetric folding between ~365 and ~361 Ma. However, an isoclinally folded dike, refolded by top-down-to-the-NW asymmetric folds, is 361.4 +/- 0.3 Ma, suggesting that both generations of folding are younger than that. Perhaps, folding and anatexis are diachronous across the field area, or there is possible mixing of age domains within zircon grains.

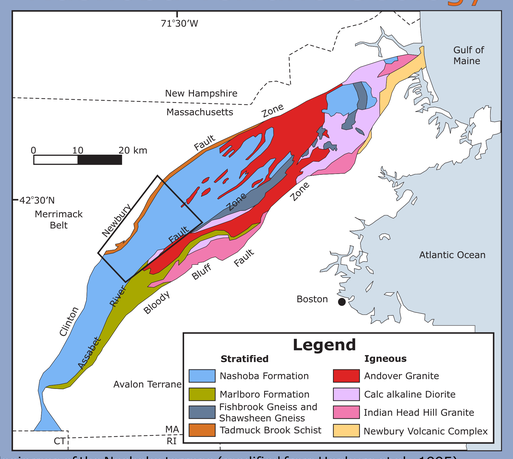
The leucosome crystallization ages presented above indicate crustal melting conditions existed between ~365 and ~361 Ma. Such Late Devonian, post-Acadian migmatitic melting has not been recognized previously in this portion of the Nashoba Formation. Partial melting may have resulted from either Neo-Acadian accretion of the Meguma terrane to the composite Laurentian margin, or from post-Acadian exhumation of the Nashoba terrane.

Appalachian Tectonic Provinces



Map of the major tectonic provinces of the Appalachian Mountains (modified from Hibbard et al., 2007) with an inset of New England terranes (modified from Moecher et al., 1997; Karabinos et al., 1998)

Nashoba Terrane Geology

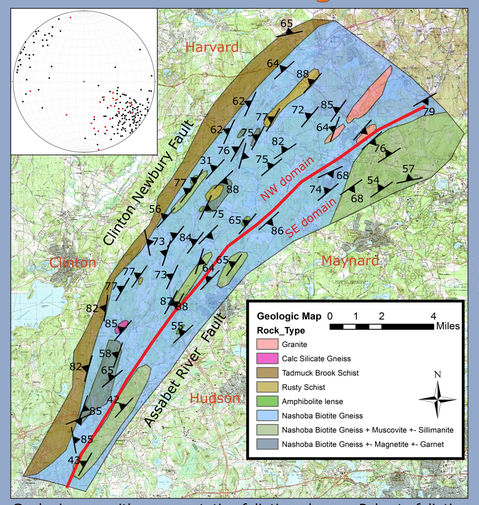


General geologic map of the Nashoba terrane (modified from Hepburn et al., 1995).

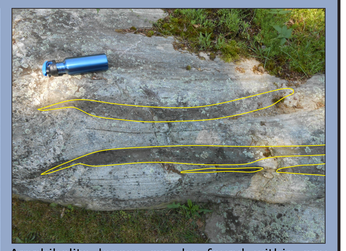
Nashoba Formation Lithologies and Structure

Biotite + Muscovite + Plagioclase + Quartz gneiss. Muscovite bearing biotite gneiss may also contain sillimanite in several localities.

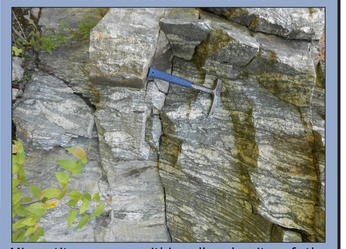
Alternating layers of Sillimanite + Magnetite rich layers with plagioclase and quartz within the Nashoba Formation.



Geologic map with representative foliation planes. Poles to foliation planes are plotted on the lower hemisphere stereographic projection in the inset. Foliations from the SE domain are represented in red and those from the NW domain in black (n=200).



Amphibolite lenses can be found within any subunit of the Nashoba Formation and vary in size from 10 cm to 100's of meters wide.



Migmatites occur within all subunits of the Nashoba Formation, but are more prevalent towards the NW of the formation.

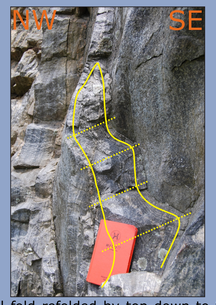
Nashoba Formation Folding

Isoclinal folds with shallowly NW plunging fold hinges.

Shallowly plunging top-down-to-the-NW asymmetric folds.

Geologic map with representative fold hinge line measurements. Fold hinge lines are plotted on the lower hemisphere stereographic projection in the inset. SE domain is represented in red and those from the NW domain in black (n=57).

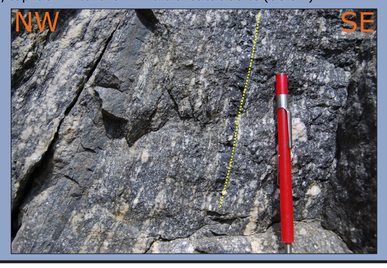
Close fold with shallowly NW plunging fold hinge.



Isoclinal fold refolded by top-down-to-the-NW asymmetric folds.

Late Stage Movement

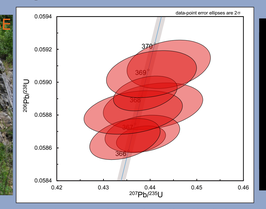
~0.5 meter wide mylonitic shear zones cutting foliation and prior top-down-to-the-NW asymmetric folds (left). Movement direction can be noted from drag folds, but also preserved within rotated clasts and S-C fabrics in the mylonites. Brittle top-down-to-the-NW movement shown by the layer displacement (right). NW dipping, top-down-to-the-NW ultra-cataclasite (below).



CA-TIMS U/Pb Zircon Dating

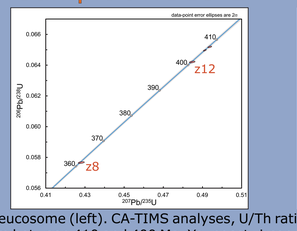
To constrain the timing of folding, both cross cutting and folded dikes were collected. Zircons were separated from the dikes at the Colorado School of Mines Mineral Separation Lab and dated in the summer of 2013 at the Massachusetts Institute of Technology using chemical abrasion thermal ion mass spectrometry (CA-TIMS) yielding high precision crystallization ages.

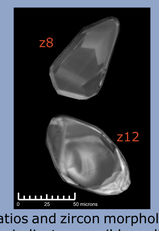
Sample JWB13-1



Sample JWB13-1 is a tonalitic intrusive body that has been isoclinally folded (left). CA-TIMS analyses indicate crystallization at ~368 Ma (middle). Representative zircon images taken using cathodoluminescence (CL; right).

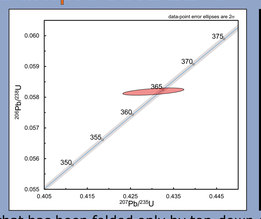
Sample JWB13-2

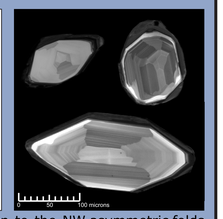




Sample JWB13-2 is a refolded leucosome (left). CA-TIMS analyses, U/Th ratios and zircon morphology indicate possible metamorphism between 410 and 400 Ma. Youngest zircon indicates possible melting at 363 Ma (middle). Images of zircon in CL from analyses (right).

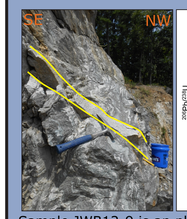
Sample JWB12-3

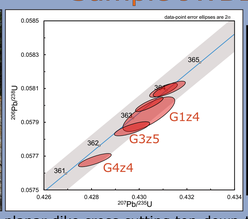


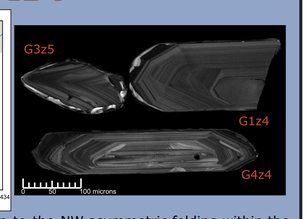


Sample JWB12-3 is a leucosome that has been folded only by top-down-to-the-NW asymmetric folds (left). CA-TIMS analyses have discovered a youngest zircon with a crystallization age of 365 Ma (middle). Representative zircon images taken using cathodoluminescence (CL; right).

Sample JWB12-9







Sample JWB12-9 is an planar dike cross cutting top-down-to-the-NW asymmetric folding within the Nashoba Formation (left). CA-TIMS analyses indicate crystallization between 364 and 361 Ma (middle). Images of zircon in CL used in CA-TIMS analyses (right).

Conclusions

- Structural analysis shows that the Nashoba Formation was first isoclinally folded, and then refolded by top-down-to-the-NW asymmetric folds. Isoclinal and asymmetric folds are cut by top-down-to-the-NW sub-vertical normal shear zones, NW dipping top-down-to-the-NW ultra-cataclasites, and later normal brittle faults.
- CA-TIMS U/Pb zircon dating indicates that folded dikes are 368 Ma, 365 Ma and 363 Ma and a cross-cutting dike is 364-361 Ma. The timing of folding within the Nashoba Formation is not simple, and may be diachronous across the field area.
- Crystallization ages for migmatitic melts within the Nashoba Formation are ~35 Ma younger than previously dated within the terrane (Hepburn et al., 1995). These new ages could possibly be related to either the accretion of the Meguma terrane, or to decompression melting related to the exhumation of the Nashoba terrane from depth.