Companion Report to Accompany

Bedrock Geologic map of the southern part of the Shelburne 7.5' Quadrangle, New Hampshire

J. Dykstra Eusden Jr., Peter Dunbar and Eli Gundersen
Department of Earth and Climate Sciences, Bates College, Lewiston, Maine, 04240

This geologic map was funded in part by the USGS National Cooperative Geologic Mapping Program under StateMap award number #G21AC10863

Shane Csiki, Ph.D.
State Geologist and Director, New Hampshire Geological Survey
29 Hazen Drive, PO Box 95, Concord, NH 03302
September, 2022

BEDROCK GEOLOGIC HISTORY OF THE SOUTH PART OF THE SHELBURNE, NH 7.5' QUADRANGLE

Introduction The bedrock geology of the southern half of the Shelburne, NH 7.5' quadrangle has been remapped at a publication scale of 1:24,000 during the field season of 2022. The work was done in conjunction with Bates College Earth and Climate Sciences and the New Hampshire Geological Survey supported by the United States Geological Survey's StateMap Program. This part of the quadrangle lies entirely within the Central Maine Belt. The geology consists of the Silurian Rangeley, Perry Mountain, Smalls Falls Formations and Devonian Littleton Formation of the Central Maine Belt, and intrusions of Devonian quartz diorite, Carboniferous two mica granites, ubiquitous pegmatite (Permian?), three types of dikes (see below), and a volcanic vent. Previously a bedrock geologic map and report that includes the quadrangle was made at 1:62,500 scale by Billings et al. (1979) and two 1:250,000 regional geo-tectonic compilations that also include the area were completed for the New Hampshire Bedrock geologic map (Lyons et al., 1997) and the Sherbrooke-Lewiston area (Moench et al.,1999). The mapping for this project was done by Prof. Dykstra Eusden of Bates College and assisted by Bates geology majors Peter Dunbar ('23) and Eli Gundersen ('23). Arizona Laserchron Center performed the crystallization and detrital zircon geochronology of samples in the study area reported below and assistance was provided in reducing this data by Dwight Bradley (retired USGS) and Ian Hillenbrand (USGS and UMass).

Rock Types The geology consists of the Rangeley stratigraphy including many members of the Silurian Rangeley Formation (a wide variety of gray and rusty schists and quartzites, gray and rusty granofels, and common calc-silicate pods, see photos 1-3), Silurian Perry Mountain Formation (gray quartzites and schists, photo 4), Silurian Smalls Falls Formation (rusty schists and quartzites), Silurian Madrid Formation (gray granofels, photo 5), and Devonian Littleton Formation (gray schist and quartzites photo 6). These are intruded by a fairly significant amount of Devonian quartz diorite sill-like plutons and in turn by significant but less abundant Carboniferous two-mica granite sill-like plutons (photo 7. Only one mappable Permian–Carboniferous pegmatite was found, though many exist on the meter-scale, too small to map. The other remaining rock types are extrusive. Three types of dikes have been found: 1) basalt dikes of Mesozoic age; 2) granofels dikes of Mesozoic age (?) derived from remobilized metasedimentary granofels; and 3) meta-basalt dikes cut by two mica granites and pegmatites of Devonian age(?, photo 8). A rare, small, Mesozoic volcanic breccia was also found in Leadmine brook.

Deformation and Metamorphism The deformation consists of early Devonian isoclinal, nappe-stage folding (schistosity forming), later Devonian thrust faulting along the Stevens Point thrust, later Devonian-Carboniferous folding (and possibly an additional even later stage of faulting), ubiquitous Mesozoic jointing and minor late normal (?) faults both too small to map. The Devonian and Carboniferous (?) metamorphism is complex with pseudomorphs in schists of aluminosilicate phases (sillimanite and andalusite sometimes present), coarse late mica spangles in schists, and pervasive migmatite (greater than 30% melt) throughout the entire southeast part of the quadrangle.

Geochronology Crystallization and detrital zircon U-Th-Pb ages were determined for four samples from the study area. These included crystallization ages from the quartz diorite (Dgd) and the Two-Mica Granite (CDtmg), and detrital zircon ages from the Madrid (Sm) and Rangeley (Sr) Formations.

Crystallization ages: The quartz diorite sample (Dgd) yielded and age of 374 +/- 4 Ma (Fig. 9) confirming its crystallization age in the Devonian and agreeing well with other intermediate plutons nearby (Wamsutta and Songo) as reported by Eusden et al. (2022). The two-mica granite sample (CDtmg) yielded an age of 325 +/- 3 Ma (Fig. 10) supporting a Carboniferous age. This age agrees well with those from similar two mica granites in the region as reported by Eusden et al. (2022). No ages for the pegmatites were obtained but Bradley et al. (2016) suggest that pegmatites in this region range in age from the Carboniferous to the Permian.

Detrital zircon ages: Both of the detrital zircon samples were sampled from quartz + plag + biotite granofels that appeared identical but were interpreted as the Madrid and Rangeley Formations respectively. The Rangeley Formation granofels sample (Srsqg) also shows an Ordovician maximum depositional age 447 +/- 4 Ma (Fig. 11). The Madrid Formation granofels sample (Sm) yielded an Ordovician maximum depositional age of 442 +/- 4 Ma (Fig. 12) . Both formations are interpreted to be Silurian in age and these Ordovician maximum depositional ages likely reflect a major zircon source from the 440-445 Ma Oliverian Jefferson granite nearby in the Berlin quadrangle. The Madrid Formation probability density plot or "bar code" shows an abundance of Oliverian ages and few older ages whereas the Rangeley Formation bar code shows both the Oliverian ages and abundant older ages (Figs. 13 and 14). The bar code differences argue that these two samples are not from the same formation and hence supports their distinction on the bedrock map. The MDS plot (Fig. 15) shows where these two samples plot with respect to others in the region as well as composite samples from both Eusden et al. (2022), Bradley and O'Sullivan (2017), and Karabinos et al. (2017). On this plot the Madrid Formation sample plots near other Rangeley samples suggesting it may have been derived from eroding Rangeley Formation. Also, the Rangeley Formation sample plots near the composite Laurentia sample suggesting a variable source region (Laurentia and/or Gondwana) during deposition of the Rangeley.

Sequence of geologic events Silurian and Devonian marine sedimentation in the Central Maine Belt in an active tectonic setting, probably a forearc basin, developed first. Deposition is recorded by the Rangeley, Perry Mountain, Smalls Falls, Madrid, and Littleton Formations. All of these rocks were subsequently deformed and metamorphosed. D1 nappe-stage folding was followed by D2 faulting along the Stevens Point Thrust in the early Devonian Acadian orogeny. D3 folding of the units likely occurred in the Late Acadian or Neoacadian Orogeny perhaps coeval with the intrusion of the quartz diorites around 374 Ma, sometime before the end of the Devonian period. Meta-basalt dikes also intruded around this time and may be related to the quartz diorites. Intrusion of the Carboniferous two mica granites and associated pegmatites crystallized around 325 Ma and were likely derived from partial melts of thickened Appalachian crust. Episodes of pegmatite intrusion likely continued from the Carboniferous into the Permian, though radiometric ages are few. Lastly, late mafic and granofels dikes probably developed under tensile stresses in the Jurassic as rifting continued.

References

Billings, M. P., Fowler-Billings, K., 1975. Geology of the Gorham Quadrangle, New Hampshire-Maine, Concord: State of New Hampshire Department of Resources and Economic Development; Bulletin No. 6. 120 p. plus 1:62,500 bedrock map

Bradley, D.C., Shea, E., Buchwaldt. R., Bowring, S., Benowitz, J., O 'Sullivan, P.B., and McCauley, A, 2016, Geochronology and tectonic context of lithium-cesium-tantalum pegmatites in the Appalachians: The Canadian Mineralogist, v. 54, p. 945-969.

Bradley, D. C., and O'Sullivan, P., 2016, Detrital Zircon Geochronology of Pre- and Syncollisional Strata, Acadian Orogen, Maine Appalachians: Basin Research, v. 29, no. 5, p 571-590.

Eusden, J. Dykstra, 2010, The Presidential Range: Its Geologic and Tectonic History; Durand Press, Lyme, New Hampshire, 62 p and 1:20,000 map.

Eusden, J. D., Jr., Garesche, J., Johnson, A., Maconochie, J., Peters, S. C., Rosbrook, J., and Widmann, B., 1996, Stratigraphy, and ductile structure of the Presidential Range, N. H.: Tectonic implications for the Acadian orogeny: *Geological Society of America Bulletin*, v. 108, pp. 417-436.

Eusden, J. Dykstra, Choe, Saebyul, Divan, Erik, Eusden, Riley, Watermulder, Sula, and Wheatcroft, Audrey, 2018, Bedrock geology of the Gilead quadrangle, Maine: Maine Geological Survey, Open-File Map 18-12, scale 1:24,000. Maine Geological Survey Maps. 2069. https://digitalmaine.com/mgs_maps/2069

Eusden, J. Dykstra, Folsom, E., Galloway, P., Hamilton, F., Martin, E.,Sargent, M., and Sheils, T. 2021, Bedrock Geologic map of the Berlin 7.5' Quadrangle, New Hampshire: New Hampshire Geological Survey, Open-File GEO-039-024000-BMOF

Eusden, J.D., Hillenbrand, I.W., Folsom, E., Merrill, T., Niiler, K., and Wheatcroft, A., 2022, Evolution of the Bronson Hill arc and Central Maine basin, northern New Hampshire to western Maine: U-Pb zircon constraints on the timing of magmatism, sedimentation, and tectonism, in Whitmeyer, S.J., Williams, M.L., Kellett, D.A., and Tikoff, B., eds., Laurentia: Turning Points in the Evolution of a Continent: Geological Society of America Memoir 220, p. 1–28, https://doi. org/10.1130/2022.1220(26).

Karabinos, P., Macdonald, F.A., and Crowley, J.L., 2017, Bridging the gap between the foreland and hinterland I: Geochronology and plate tectonic geometry of Ordovician magmatism and terrane accretion on the Lau-rentian margin of New England: American Journal of Science, v. 317, p. 515–554, https://doi.org/10.2475/05.2017.01.

Lyons, J.B., Bothner, W.A., Moench, R.H., & Thompson Jr., J.B., 1997, Bedrock geologic map of New Hampshire: US Geological Survey, scale 1:250,000.

Moench, R..H., Boudette, E.L., and Bothner, W.A., 1999, Tectonic lithofacies, geophysical, and mineral-resource appraisal maps of the Sherbrooke-Lewiston area, Maine, New Hampshire, and Vermont, United States, and Quebec., Canada: U.S. Geological Survey, Miscellaneous Investigations Series Map, 1-1898-E, 114 p, 3 sheets

1: Silurian Rangeley Formation gray quartzite and schist with calc-silicate pods (Srsqc). North Road, Shelburne, NH

2: Silurian Rangeley Formation rusty schist and quartzite (Srsr). Lary Brook, Shelburne, NH. Camera shadow is 20 cm in length on outcrop.

3: Silurian Rangeley Formation granofels (Srsqg) and two-mica granite dike. Judson Pond, Shelburne, NH.

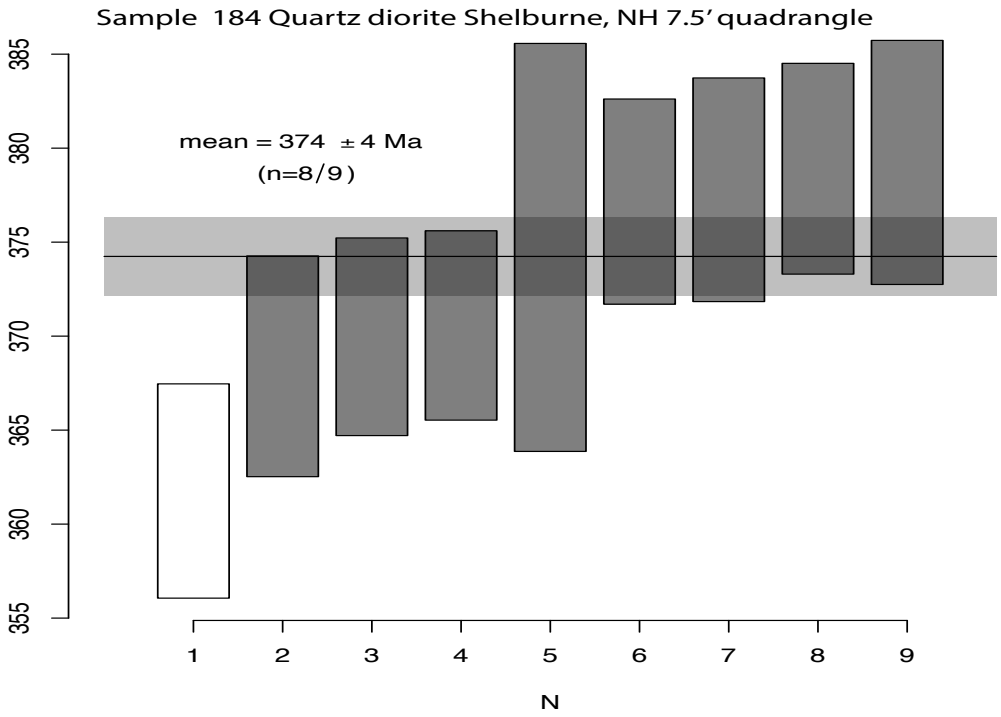
4: Silurian Perry Mountain Formation quartzite and schist (Spm). Appalachian Trail, Mahoosuc Range, near Dream Lake.

5: Silurian Madrid Formation granofels (Sm), geochronology site, Rattle River, Shelburne, NH. Stick is 30 cm long.

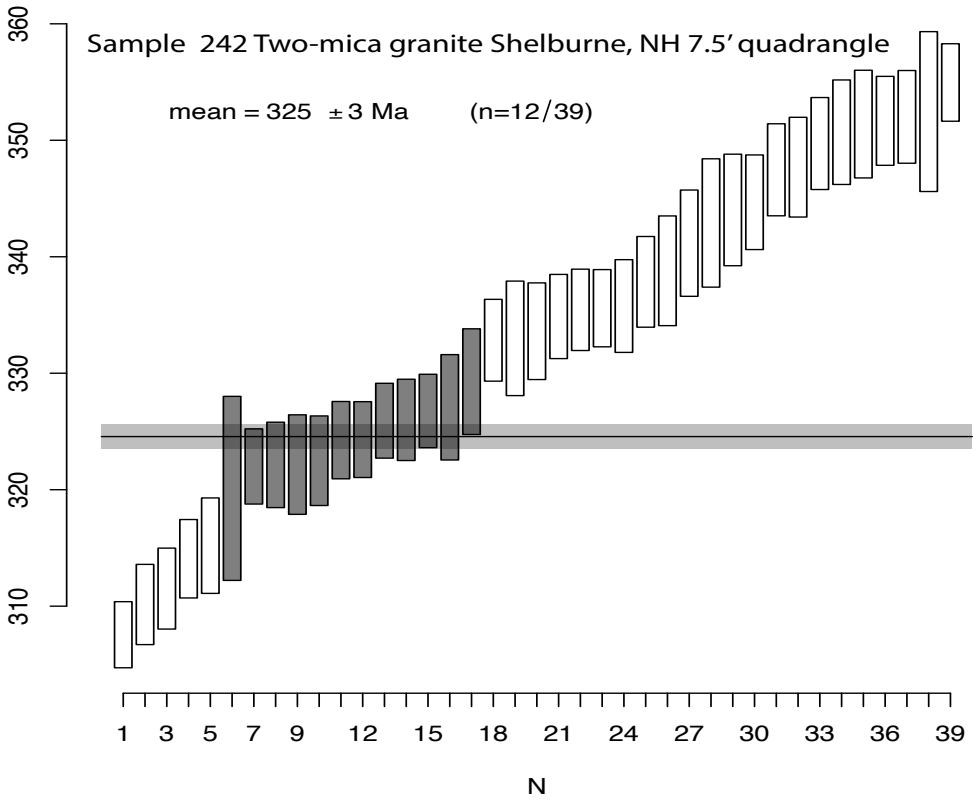
6: Devonian Littleton Formation schists and quartzites (Dl), Rattle River, Shelburne, NH.

7: Devonian dark gray quartz diorite (Dgd) cut by light two-mica granite (CDtmg), Rte. 2 highway cut near former state wayside area.

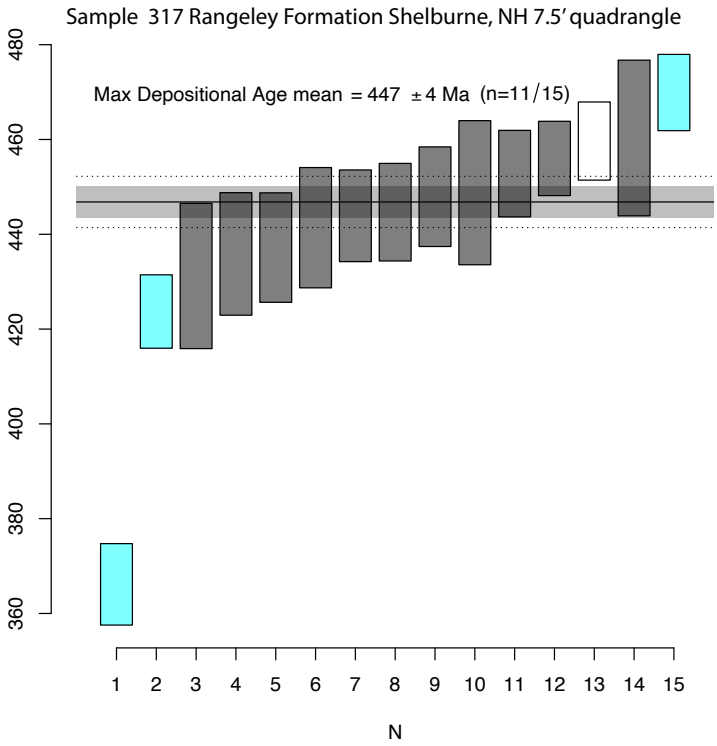
8: Meta-basalt dike (Devonian?) cross cut by Carboniferous two-mica granite and pegmatite, Shelburne Dam spillway.



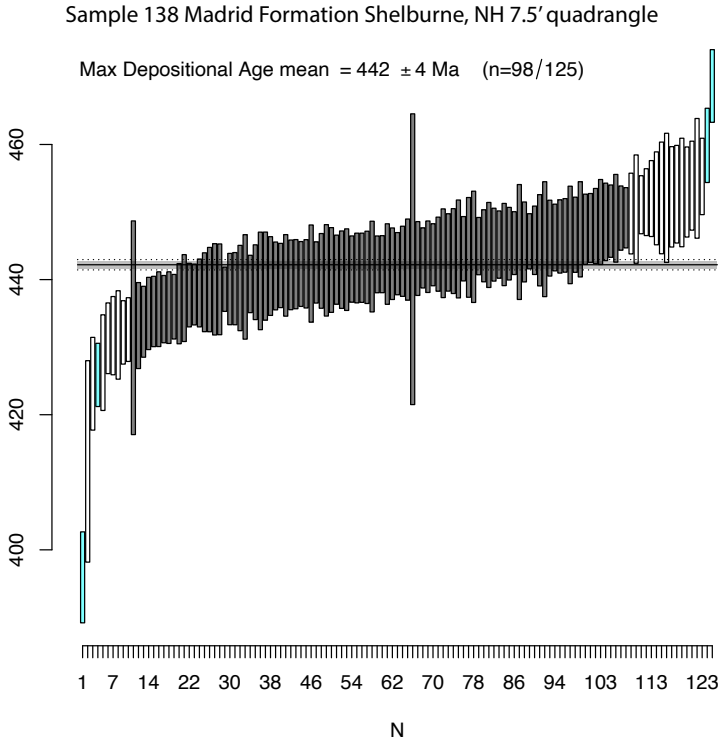
9: Weighted mean plot of zircons from the quartz diorite yielding an age of 374 +/- 4 Ma.



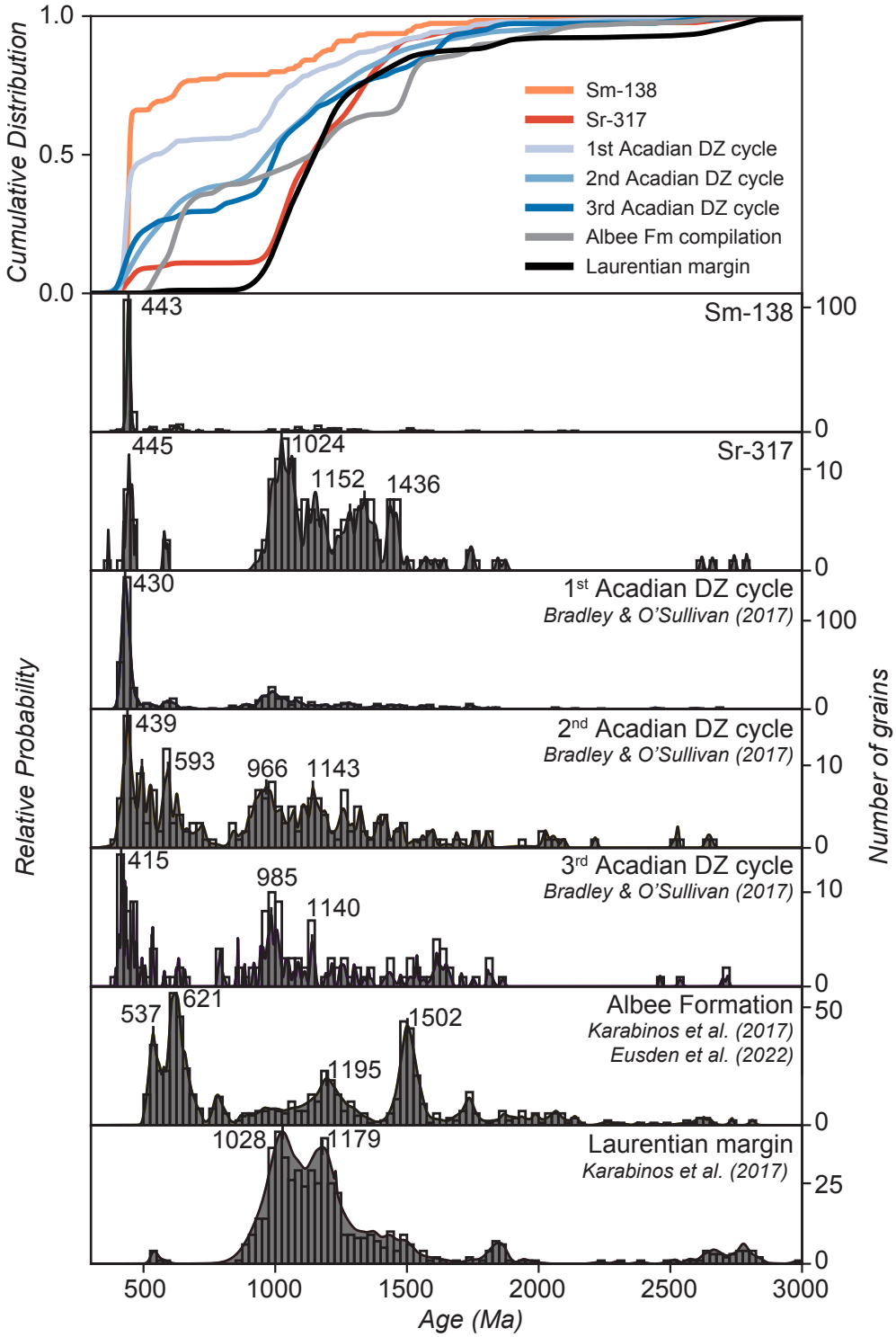
10: Weighted mean plot of zircons from the two-mica granite yielding an age of 325 +/- 3 Ma.



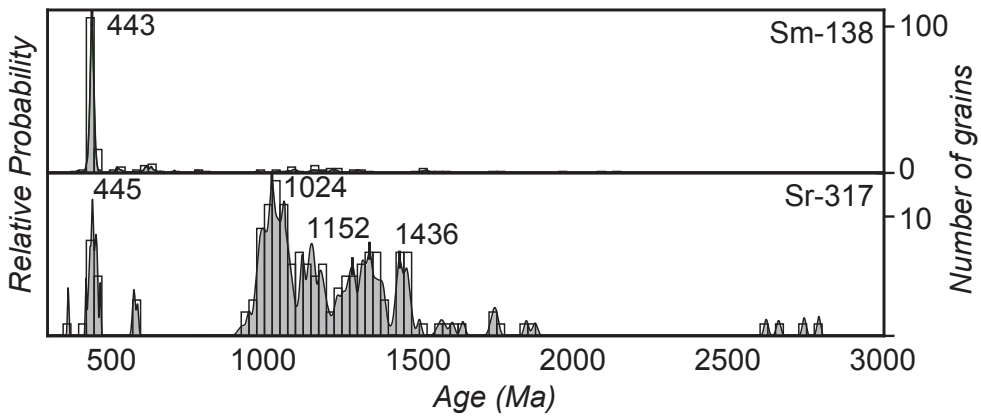
11: Weighted mean plot of youngest ages showing a maxmum depositional age of 447 +/- 4 Ma for the Rangeley Formation.



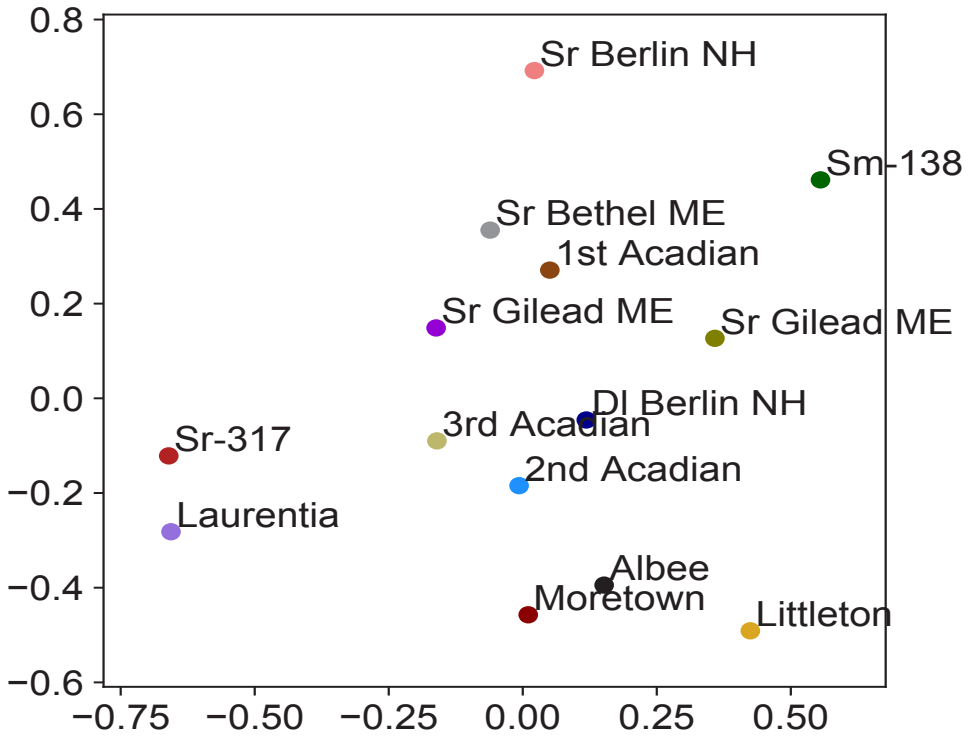
12: Weighted mean plot of youngest ages showing a maxmum depositional age of 442 +/- 4 Ma for the Madrid Formation.



13: Probability density plots for the Madrid and Rangeley samples as well composite samples from the region taken from Bradley and O'Sullivan (2017), Karabinos et al. (2017), and Eusden et al. (2022).



14: Probability density plots for the just the Madrid and Rangeley samples as well as other nearby samples and composite samples from the region.



15: MDS plot showing clustering of the Madrid and Rangeley samples as well as other nearby samples and composite samples from the region.