New England Intercollegiate Geological Conference 2017

NEIGC 2017 Day Three: October 1

Oct 1st, 2017

# C3: Transect From the Migmatized Central Maine Belt to the Bronson Hill Anticlinorium

J. Dykstra Eusden
*Bates College*, deusden@bates.edu

Sarah Baker
*Bates College*

Jordan Cargill
*Bates College*

Eric Divan
*Bates College*

Ian Hillenbrand
*Bates College*

***See next page for additional authors***

## Recommended Citation

Eusden, J.D., Baker, S., Cargill, J., Divan, E., Hillenbrand, I., O'Sullivan, P., and Wheatcroft, A., 2017, Transect From the Migmatized Central Maine Belt to the Bronson Hill Anticlinorium in Johnson, B. and Eusden, J.D., ed., Guidebook for Field Trips in Western Maine and Northern New Hampshire: New England Intercollegiate Geological Conference, Bates College, p. 287-304. https://doi.org/10.26780/2017.001.0016

**Presenter Information**
J. Dykstra Eusden, Sarah Baker, Jordan Cargill, Eric Divan, Ian Hillenbrand, Paul O'Sullivan, and Audrey Wheatcroft

# TRANSECT FROM THE MIGMATIZED CENTRAL MAINE BELT TO THE BRONSON HILL ANTICLINORIUM

By

J. Dykstra Eusden, Dept. of Geology, Bates College, Lewiston, Maine 04240
Sarah Baker, Dept. of Geology, Bates College, Lewiston, Maine 04240
Jordan Cargill, Dept. of Geology, Bates College, Lewiston, Maine 04240
Eric Divan, Dept. of Geology, Bates College, Lewiston, Maine 04240
Ian Hillenbrand, Dept. of Geology, Bates College, Lewiston, Maine 04240
Paul O'Sullivan, GeoSep Services, 1521 Pine Cone Road, Moscow, ID 87872
Audrey Wheatcroft, Dept. of Geology, Bates College, Lewiston, Maine 04240
email: deusden@bates.edu cell: (207) 240-9150

## INTRODUCTION

This trip will visit outcrops along a transect from the migmatized Central Maine Belt in Maine to the Bronson Hill Belt near the New Hampshire-Vermont border. We will roughly follow U.S. Rte. 2 starting in West Bethel, ME, with the migmatized Silurian Rangeley Formation and intrusions of two mica granite and pegmatite, then proceed west to Randolph, NH, and the Ordovician Ammonoosuc Volcanics and Oliverian Jefferson Dome. The trip ends in Lancaster, NH with the Cambrian Albee Formation and Ordovician Lost Nation Pluton (Figure 1). This is a good trip for those who are heading west or southwest after the conference.

The bulk of the research presented here was generously supported by the Maine and New Hampshire Geological Surveys through the U.S.G.S. StateMap program for bedrock mapping in the Bethel and Gilead, Maine and Jefferson and Mt Washington East, NH 7.5' quadrangles. Dr. Paul O'Sullivan of GeoSeps Services, Moscow, ID has provided the very important absolute age control with LA-ICP-MS ages on detrital and crystallization zircons. Much of the work was done by Bates College Geology seniors working on their theses and they are all co-authors of this fieldguide. Eusden is extremely grateful to all of them for their friendship and hard work.

## BETHEL-GILEAD, MAINE; MIGMATIZED CENTRAL MAINE BELT

### Previous Work

In the Maine portion of the fieldtrip, the bedrock geology has been summarized in regional maps by both Osberg et al. (1985) and Moench et al. (1999). The tectonic setting of the Bethel-Gilead region is within the Central Maine Belt, at the north end of the Sebago batholith, within the Migmatite-Granite Complex of Solar and Tomascak (2016), and along the Piscataquis Volcanic Arc (Bradley and Tucker, 2002, and Bradley et al., 2000). In the Gilead-Bethel Maine region the metasedimentary rocks shown on Osberg et al. (1985) and Moench et al. (1999) are dominated by the Devonian Littleton Formation with narrow belts of the Silurian Madrid, Smalls Falls, and to a lesser extent the Rangeley Formation. Brady (1991) mapped the eastern portion of the Bethel quad as part of his M.S. thesis at Orono, breaking out many units that were variably correlated to portions of the Siluro-Devonian Rangeley stratigraphy of Moench and Boudette (1987). The Rangeley stratigraphy was extended through this area and into adjacent New Hampshire by Hatch et al. (1983) and those correlations formed the basis of the most recent lithotectonic compilation of the Appalachians by Hibbard et al. (2006).

Gibson et al. (2017) have recently dated the Songo granodiorite to 364 +/- 1.3Ma.. The Songo pluton and numerous small quartz diorite-tonalite plutons we've mapped in the region (Eusden et al. 2017a) are part of the Piscataquis Magmatic Arc (Bradley and Tucker, 2002, and Bradley et al., 2000) that developed syntectonically on the leading edge of the migrating Acadian orogenic front in the Devonian.

Recent work done by Solar and Tomascak (2016) on the Sebago Pluton and the Migmatite-Granite Complex of western Maine suggests the Sebago is much diminished in map size, is 288 ± 13 to 297 ± 14 Ma, and is surrounded by rocks showing regional migmatization that occurred around 376 ± 14 Ma. Thus migmatization occurred well before the intrusion of the Sebago Pluton. Bradley et al. (2016) have dated many of the small pegmatite bodies in this region and some (e.g. Mt. Mica pegmatite) are as young as Permian (264-260 Ma), likely related to the Alleghanian orogeny.

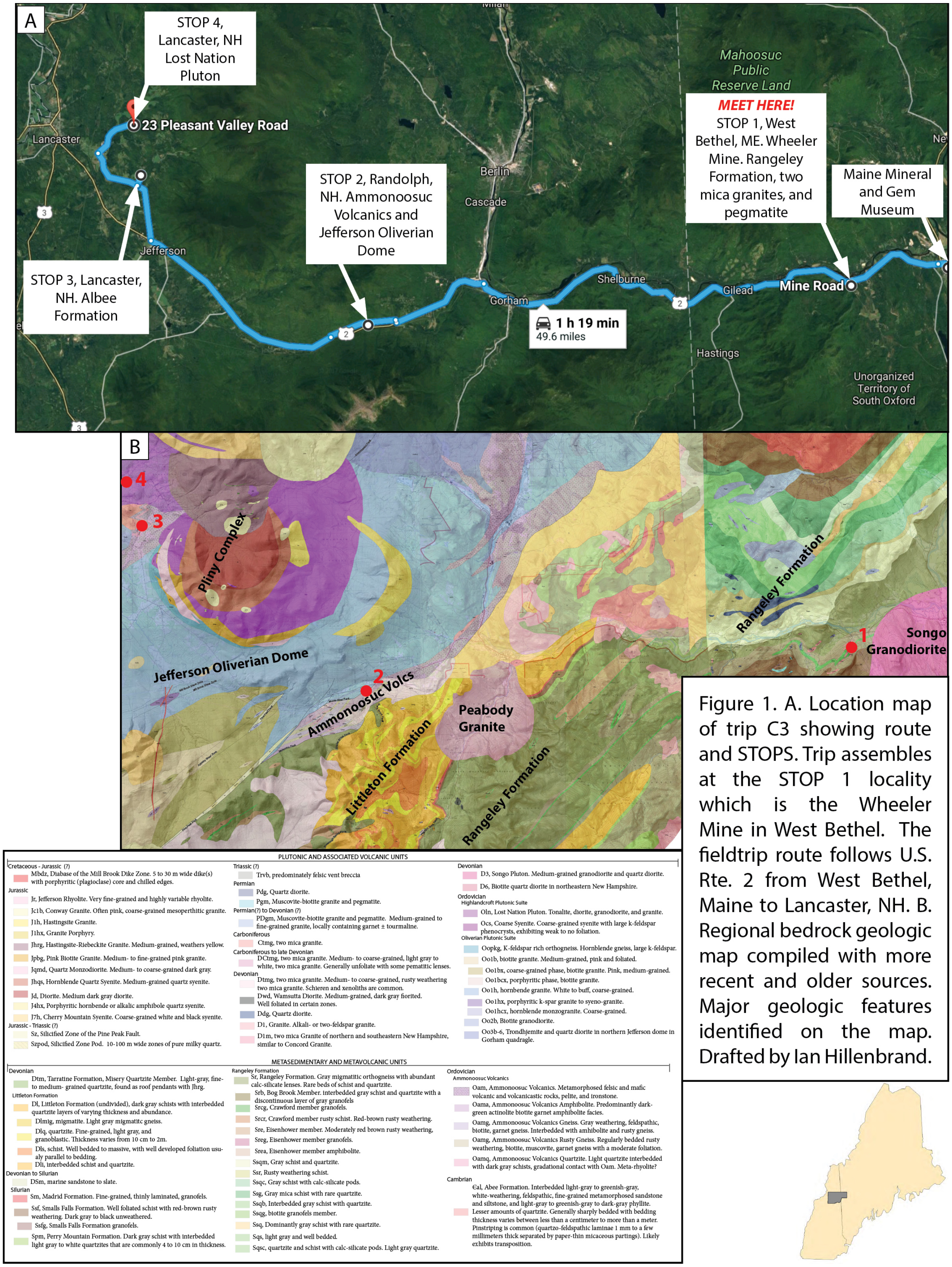

Figure 1. A. Location map of trip C3 showing route and STOPS. Trip assembles at the STOP 1 locality which is the Wheeler Mine in West Bethel. The fieldtrip route follows U.S. Rte. 2 from West Bethel, Maine to Lancaster, NH. B. Regional bedrock geologic map compiled with more recent and older sources. Major geologic features identified on the map. Drafted by Ian Hillenbrand.

## Current Work

Twelve new metasedimentary units have been mapped in the region and define a stratigraphy that overall best correlates to the Silurian Rangeley Formation (Figure 2). The new stratigraphy has terrible topping control with only a few scattered graded beds found in the region and it is pervaded by migmatite obscuring primary sedimentary features. Hence, correlation by lithologic similarity and sequence is the most useful, but the least certain, method to determine stratigraphic age. To provide absolute age control we have done detrital zircon age dating of two samples from one of the metasedimentary units, the Bog Brook Granofels, as well as crystallization zircon ages for two different cross cutting two-mica granites from Wheeler Mine (Wheatcroft, 2017). The presence of belts of rusty weathering schists and quartzites, biotite and calc-silicate granofels, and ubiquitous calc-silicate pods, blocks, and lenses are hallmarks of the Rangeley Formation in nearby New Hampshire (Eusden et al., 1996) and strengthen the arguments for the correlation to the Rangeley Formation. The new stratigraphic assignments will require significant changes to regional maps in western Maine and adjacent New Hampshire.

Detrital zircon age population density histograms for both Bog Brook granofels samples yield maximum depositional ages of 419.5 ± 3.9 Ma and 427.6 ± 3.9 Ma (Wheatcroft, 2017; Wheatcroft et al., 2017). Taking both ages together, the mean maximum depositional detrital zircon age of circa 422 Ma places this unit within the traditional age assignment for the Late Silurian Madrid Formation (Hatch et al., 1983). If the Bog Brook Granofels was the Madrid Formation, as correlated by traditional age assignments, one would expect it to be directly in contact with rusty schist, equivalent to the Smalls Falls Formation. That is not the case, instead the Bog Brook granofels is surrounded by the gray schist and quartzite with calc-silicate pods that are all characteristic of the Early Silurian Rangeley Formation to which we have correlated the Bog Brook Unit.

Interestingly, our younger detrital zircon ages are consistent with new detrital zircon ages done by Bradley and O'Sullivan (2016), which also yielded consistently younger than expected ages for many of the type sections in the Rangeley stratigraphy. Our new detrital zircon age spectra match incredibly well the first, inboard-derived cycle of the Ganderian-derived sediments (composite detrital zircon spectrum of Quimby, Rangeley, Perry Mountain and Smalls Falls Formations) within the Central Maine Basin (Bradley and O'Sullivan, 2016). The age discordance between traditional stratigraphic ages and newer detrital zircon-based ages does suggest that much more detrital zircon geochronology is needed for the Rangeley Stratigraphy and indeed remapping and reassessment of the type section may be in order. At a minimum, a middle Silurian rather than earliest Silurian age for the Rangeley Formation seems a logical conclusion from our work and that of Bradley and O'Sullivan (2016) (Figure 3).

Crystallization ages for two, two-mica granite sills from Wheeler Mine yielded ages of 349.2 ± 2.1 Ma and 355.3 ± 2.3 Ma respectively. This supports their intrusion as small mappable granites that post-date the Late Devonian-Carboniferous Migmatite-Granite Complex (376 ± 14 Ma) of Solar and Tomascak (2016) but pre-date the younger Sebago pluton (288-297 ± 14 Ma). These granites cut stromatic layering in the migmatized metasedimentary rocks as well as the macroscale Neoacadian D3 open, reclined folds (Divan et al., 2017) defined by the map pattern. The detrital zircon and crystallization zircon ages bracket the deposition, deformation, and metamorphism of this area to within a 65-79 million year time period. The numerous pegmatites exposed at Wheeler Mine cut the two mica granites as well as the Bog Brook Granofels. These have not been dated but are likely as young as Permian based on the recent pegmatite ages determined by Bradley et al. (2016).

In summary, the major geologic events in the Gilead and Bethel, Maine region are: (1) end of Rangeley Formation deposition at 422 Ma with minor D1 pre-metamorphic faulting; (2) Acadian D2 nappe-stage folding and the onset of regional metamorphism; (3) widespread migmatization occurring around 376 Ma (Solar and Tomascak, 2016); (4) Neoacadian D3 open, reclined folding: (5) Neoacadian emplacement of the Songo Pluton at 364 ± 1.3 Ma (Gibson et al., 2017), (6) Neoacadian two-mica granite emplacement at 349.2 ± 2.1 and 355.3 ± 2.3 Ma; and (7) Alleghanian emplacement of the Sebago-type plutons and even younger pegmatites within the region between 294-260 Ma (Solar and Tomascak, 2016; Bradley et al., 2016).

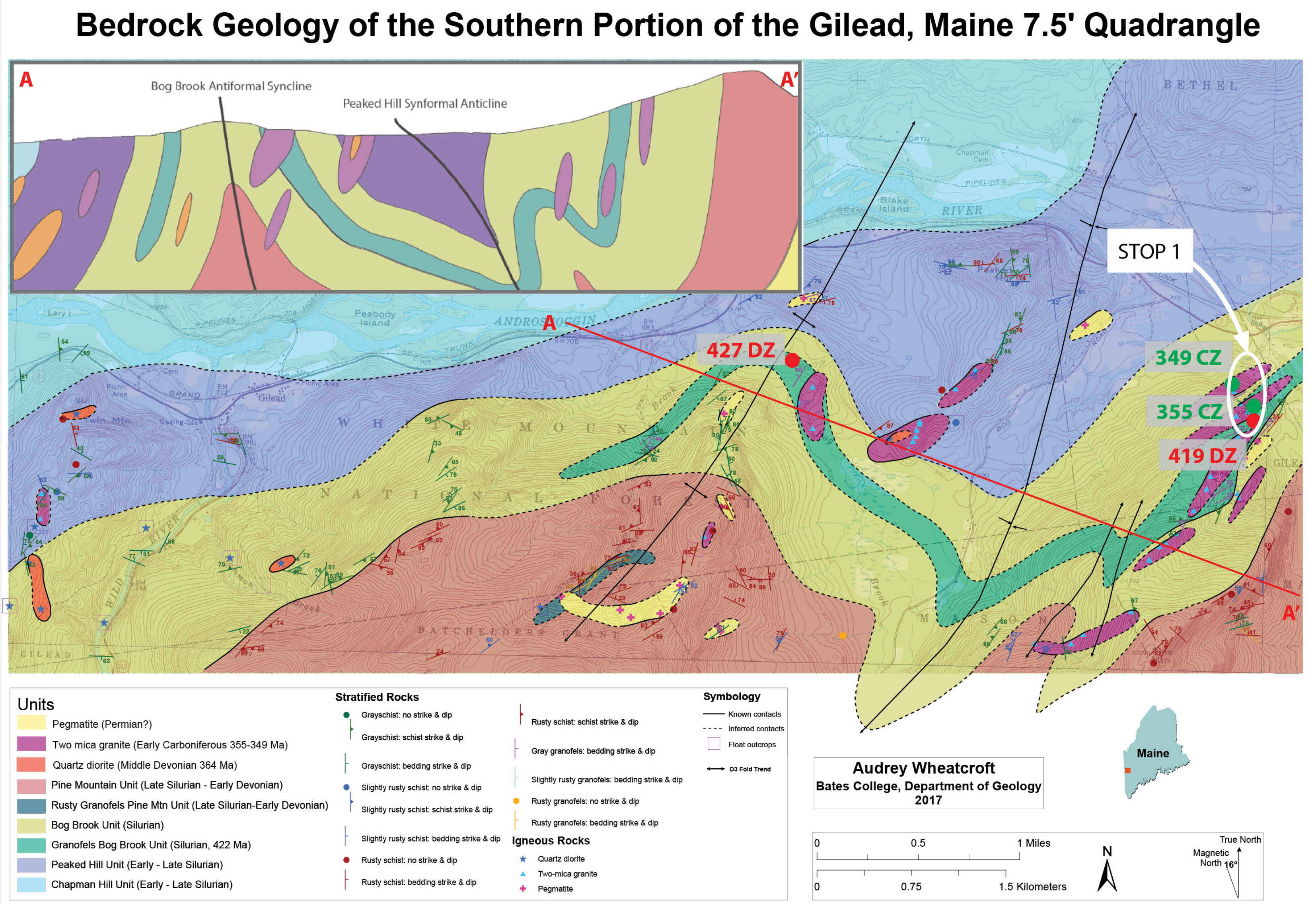

Figure 2. Bedrock geologic map of the Gilead, Maine region showing metasedimentary and igneous units. STOP 1 at Wheeler Mine is located by the white ellipse. Crystallization zircon ages (CZ) and detrital zircon ages (DZ) in Ma are indicated by the green and red dots respectively. Bedrock map made by Audrey Wheatcroft and cross section made by Eric Divan, both Bates '17.

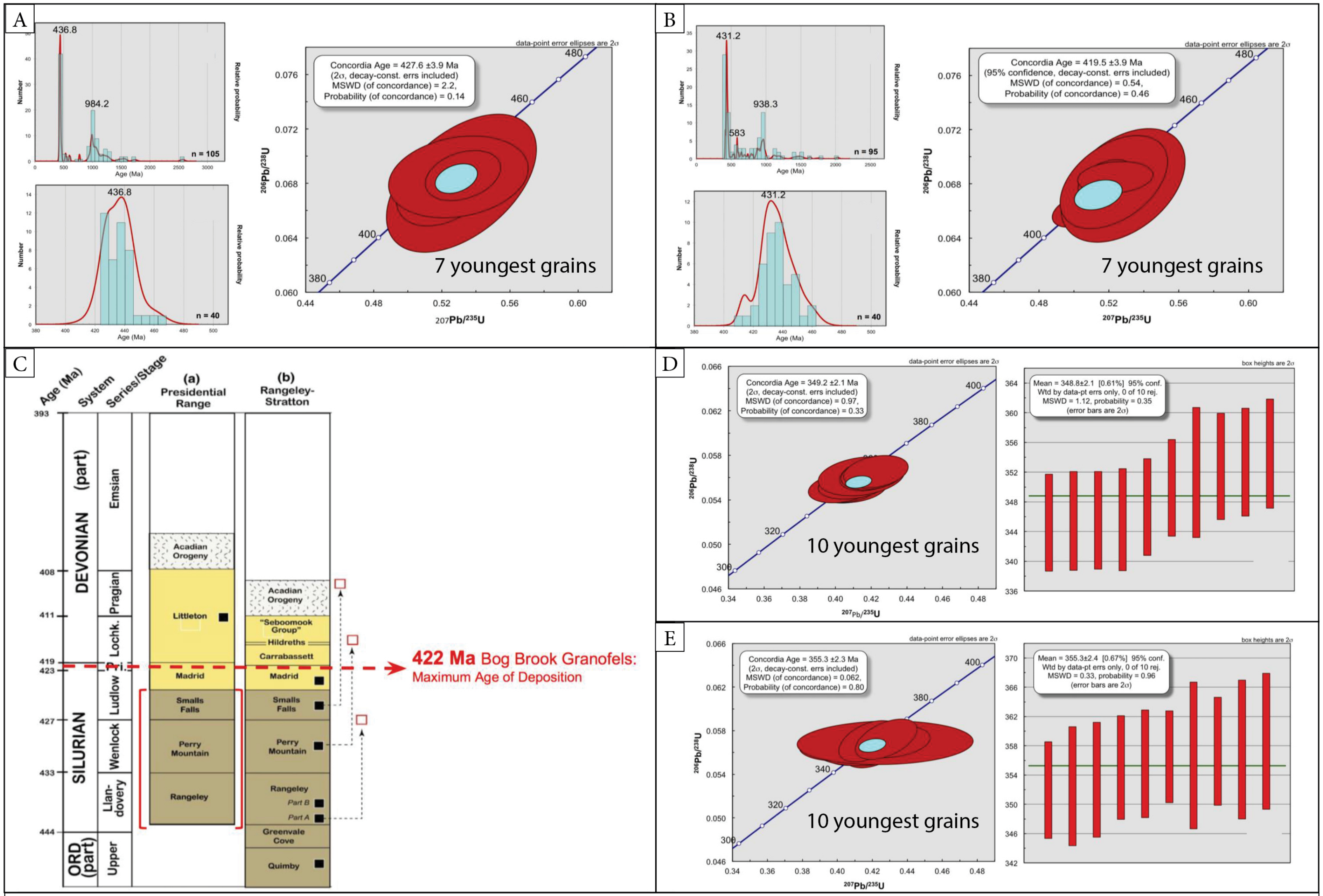

Figure 3. Detrital zircon ages for Bog Brook Granofels at (A) Bog Brook (427.6 Ma) and (B) Wheeler Mine (419.5 Ma). C: Bog Brook Granofels interpreted depositional age (422 Ma) compared to other detrital ages from Bradley and O'Sullivan (2016) all showing younger than expected ages. D and E: Crystallization ages for two mica granite plutons (349 and 355 ma) from the Wheeler Mine region. Credit: Audrey Wheatcroft.

## RANDOLPH VALLEY, NH: OLIVERIAN-AMMONOOSUC CONTACT

### Previous Work

The tectonic setting of the Randolph Valley region is along the very east edge of the Bronson Hill Belt where it is in contact with the Central Maine Belt and where local dips are to the E-SE. The Presidential Range bedrock geology was first mapped in any detail by the Billings in the late 1930's and early 1940's. Their efforts culminated in several papers and the 1979 Geology of the Mount Washington Quadrangle report published by the New Hampshire Department of Resources and Economic Development (Billings et al., 1979). Hatch et al. (1983) made many important contributions to the region, most notably the extension and correlation of the Rangeley, Maine, stratigraphy across the border into New Hampshire, through the Presidential Range, and beyond to the south. The New Hampshire bedrock geologic map (Lyons et al., 1997) updated these previous efforts and more or less retained the contacts shown by the Billings' and the stratigraphic assignments of Hatch and Moench (1984).

Our decades-long bedrock mapping campaign in the Presidential Range culminated in our finished bedrock geologic map (Figure 4) and report (Eusden, 2010). Other publications by our group include Eusden et al. (1996, 2000) and Roden-Tice et al. (2012). Eusden et al. (1996) has maps of several structural fabrics but the bedrock map does not include the lower wooded elevations. Roden-Tice et al. (2012) focuses on the apatite fission track exhumation history of the Presidential Range. In 2013 we published a layperson's book, "The Geology of New Hampshire's White Mountains", which covers many aspects of the geologic history in the Presidential Range (Eusden et al., 2013). The outcrops visited in the Randolph valley for this trip were also visited on two earlier NEIGC's (Eusden et al., 2006 and 2009).

### Current Work

The unusual aspect of the Bronson Hill Anticlinorium in the Randolph Valley is that the region between it and the Central Maine Belt lacks the mantling shelf facies of the Silurian Clough and Fitch Formations. Instead, there is an abrupt boundary with shear fabrics separating migmatized Rangeley Formation from the Ammonoosuc Volcanics, which we have interpreted as the Mahoosuc Fault. Internal to the Bronson Hill Belt, there is another discontinuity separating the Ammonoosuc Volcanics from the Oliverian Jefferson Dome again with ductile shear fabrics that we have interpreted as the Moose River Fault.

The most significant result of our mapping has been to better define the contact between the Ammonoosuc and Oliverian Jefferson Dome. Over the years, the nature of the Ammonoosuc-Oliverian contact has been debated with some researchers supporting an intrusive contact (Billings et al., 1979; Moench and Aleinikoff, 2003) and others a fault contact (Hollocher, 1993; Kohn and Spear, 1999). In the Randolph valley, Billings et al. (1979) show the contact to be delineated by silicified pods that line up to form a late (presumably Mesozoic) brittle fault. Dupee et al. (2002) and Foley and Eusden (2009) were able to subdivide the Ammonoosuc Volcanics into a variety of different lithologic units including amphibolite, rusty gneiss and gray gneiss. They have not been able to easily correlate this new subdivision to the upper and lower Ammonoosuc designations on the state map (Lyons et al., 1997). The maps produced by Dupee et al. (2002) and Foley and Eusden (2009) show that the Ammonoosuc stratigraphy is cut off against the main contact with the Jefferson Oliverian Dome by the Moose River fault. Foley and Eusden (2009) have also mapped meter-scale intercalations, presumably fault slivers or horses, of Ammonoosuc Volcanics and Jefferson Dome rocks. In addition, several exposures of S-C mylonites that exhibit variable intensity have been mapped within the Ammonoosuc and Jefferson Dome rocks adjacent to the main contact (Dupee et al., 2002; Foley and Eusden, 2009). Shear sense for the mylonites is complex with both normal and reverse motions found in the Ammonoosuc Volcanics and reverse motion only in the Jefferson Dome rocks. The foliations and lineations in the mylonites eventually die out away from the main Ammonoosuc-Jefferson Dome contact. It is tempting to interpret the normal motions as doming-related, having developed as simple shear dominated along the flanks of the rising dome. The principal boundary between the Ammonoosuc and Jefferson Dome is probably a structure of this type and thus we interpret the Moose River fault as a late Acadian, normal sense, shear zone. The reverse motion indicators in the both the Ammonoosuc Volcanics and Jefferson Dome are not what one would expect during doming, and since doming is likely the last phase of Acadian deformation in the area, it is possible that the reverse motion indicators represent a pre-doming shear history. However, there are no age constraints on the different mylonites.

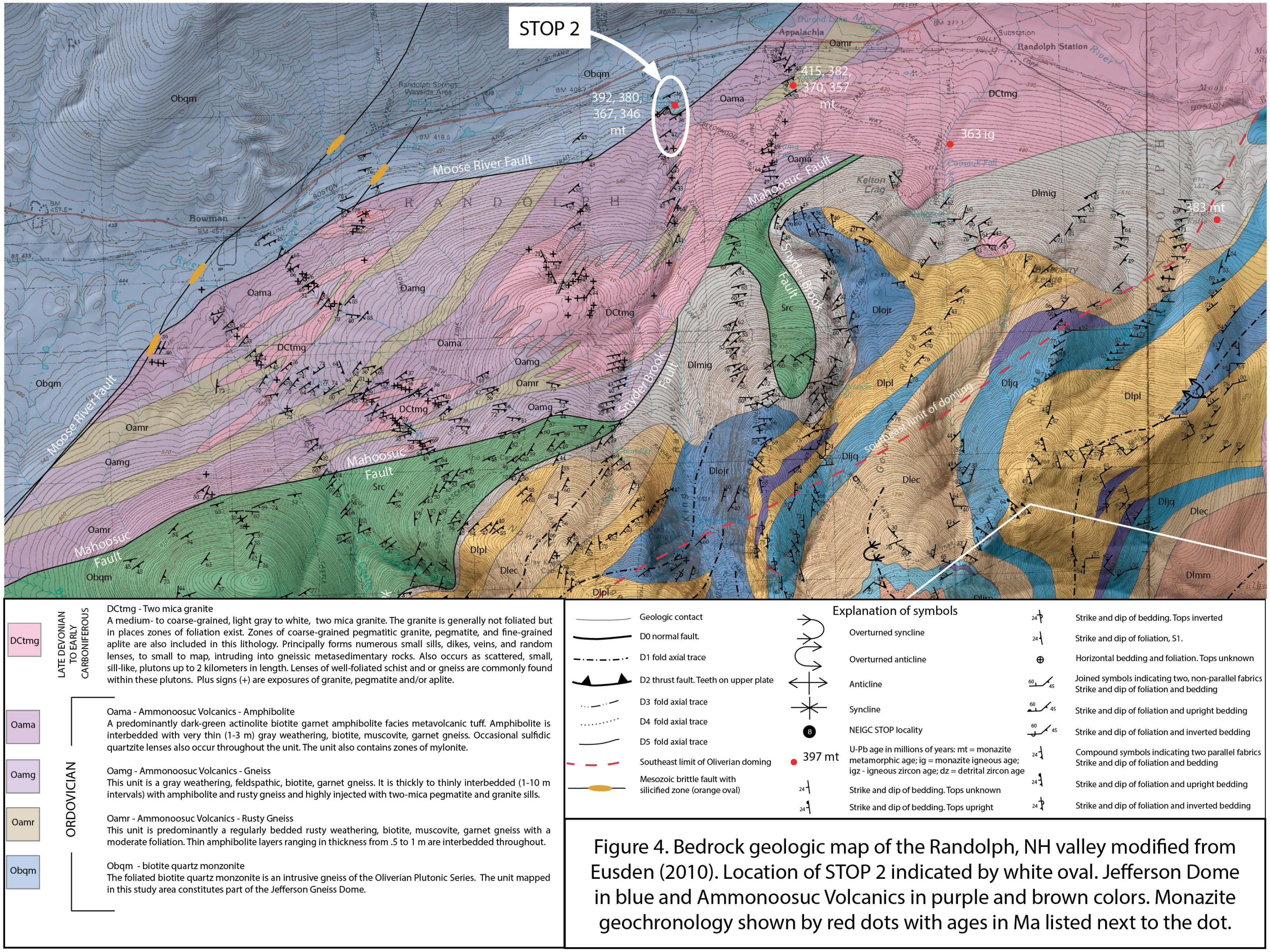

Figure 4. Bedrock geologic map of the Randolph, NH valley modified from Eusden (2010). Location of STOP 2 indicated by white oval. Jefferson Dome in blue and Ammonoosuc Volcanics in purple and brown colors. Monazite geochronology shown by red dots with ages in Ma listed next to the dot.

Foley and Eusden (2009) performed monazite microprobe age determinations on two samples, one from a Jefferson Dome mylonitized sample in Cold Brook (sample MFC02, Stop 2a on this trip) and the other from an Ammonoosuc Volcanics mylonitized rusty gneiss (sample MFS01) in Snyder Brook, just above the main contact with the Jefferson Dome. The oldest monazite age population gives a late Silurian date of 415 +/- 7.2 Ma in MFS01 from the Ammonoosuc Volcanics. Both samples contain ages in the early to middle Devonian with MFC02 showing ages of 392 +/- 3 and 380 +/- 3 Ma and sample MFS01 giving an age of 382 +/- 4.4 Ma. The samples also show middle to late Devonian ages in the 370 Ma range with MFC02 yielding an age of 367 +/- 3.2 Ma and MFS01 an age of 370 +/- 6.2 Ma. Finally both samples show Late Devonian to Early Carboniferous ages with MFC02 yielding an age of 346 +/- 3.6 Ma and MFS01 an age of 357 +/- 6.4 Ma. The Silurian age may be an early, pre-Acadian, shearing event when the Ammonoosuc and Jefferson Dome initially came into contact with each other. The early Devonian ages are consistent with other ages we have determined for the peak of Acadian metamorphism in the Presidential Range (circa 400-380 Ma). The middle Devonian 370 ages may represent the age of doming. The Devonian-Carboniferous ages are probably related to the intrusion of the local Bickford Granite that has been dated to 363 Ma.

## LANCASTER, NH: ALBEE FORMATION AND LOST NATION PLUTON

### Previous Work

The tectonic setting of the Lancaster region is on the west dipping edge of the Bronson Hill and west flank of the Jefferson Oliverian Dome. The earliest detailed mapping was done by Chapman (1942) and later compiled and republished as part of the Mt Washington, NH 15' quadrangle bedrock map and bulletin by Billings et al. (1979). These pioneering geologists established the stratigraphic framework for the region identifying the classic New Hampshire units of the Cambrian Albee Formation and the Ordovician Ammonoosuc Volcanics, Oliverian Jefferson Dome, and Lost Nation Pluton. The Ammonoosuc Volcanics are found mantling the surrounding flanks of the Oliverian domes (Leo, 1991). The emplacement of the Ammonoosuc Volcanics (461± 8 Ma) over the Oliverian plutons (Jefferson Dome: 454±5 Ma) (Moench and Aleinikoff, 2003) is still debated. Dorais et al. (2008) identified continental arc signatures in the Oliverian, Highlandcroft, and Lost Nation suites and suggested that these are all part of the same arc complex. Dorais et al. (2012) further identified the Ammonoosuc Volcanics as having a peri-Gondwanan isotopic signature while the Oliverian, Highlandcroft and Lost Nation rocks have Laurentian signature. Dorais et al. (2012) proposed that obduction of the Ammonoosuc Volcanics along a west directed thrust onto composite Laurentia emplaced it above the Oliverian rocks. Presumably this assembly occurred at the end of the Taconic Orogeny (Macdonald et al. 2014; Taconic III of van Staal et al., 2009). Working just west of the Jefferson, NH 7.5' Quadrangle, Rankin et al. (2013) established that the Albee Formation was separated from the Ammonoosuc Volcanics by the Penobscottian unconformity caused by the Cambrian to Early Ordovician Penobscot Orogeny. Rankin et al. (2013) also endorsed the correlation of the Albee Formation with the Dead River Formation in Maine and subdivided the Albee Formation into several members. Karabinos et al. (2017) recently proposed that the Bronson Hill arc formed on the newly baptized Moretown Terrane and that the western edge of Ganderia is buried somewhere east of the Bronson Hill. Our recent work has culminated in new bedrock maps of the Mt Dartmouth and Jefferson, NH 7.5' quadrangles, is the subject of this part of the trip, and discussed below (Eusden et al., 2015 and 2017b).

### Current Work

New mapping and detrital zircon geochronology in the northern part of the Jefferson 7.5' Quadrangle has revealed a previously unknown region of Cambrian Albee Formation along with the previously recognized Ordovician Ammonoosuc Volcanics, intrusive rocks of the Ordovician Oliverian Dome and Lost Nation-Highlandcroft Pluton, and Jurassic igneous cone sheets of the Pliny Caldera Complex (Figure 5) (Hillenbrand, 2017).

Detrital zircon geochronology was conducted on a total of four samples of thinly bedded to pin-stripped quartz-rich rock all but one previously thought to be the Albee Formation (Figure 6) (Hillenbrand, 2017; Hillenbrand et al., 2017). Two samples came from lower elevations near Tug Mtn. with one previously mapped as Albee and the other as Ammonoosuc Volcanics (Lyons et al., 1997). The other two samples are roof pendants in Jurassic granite from the higher peaks of Terrace Mtn. and both previously mapped as Albee Formation xenoliths (Chapman, 1942).

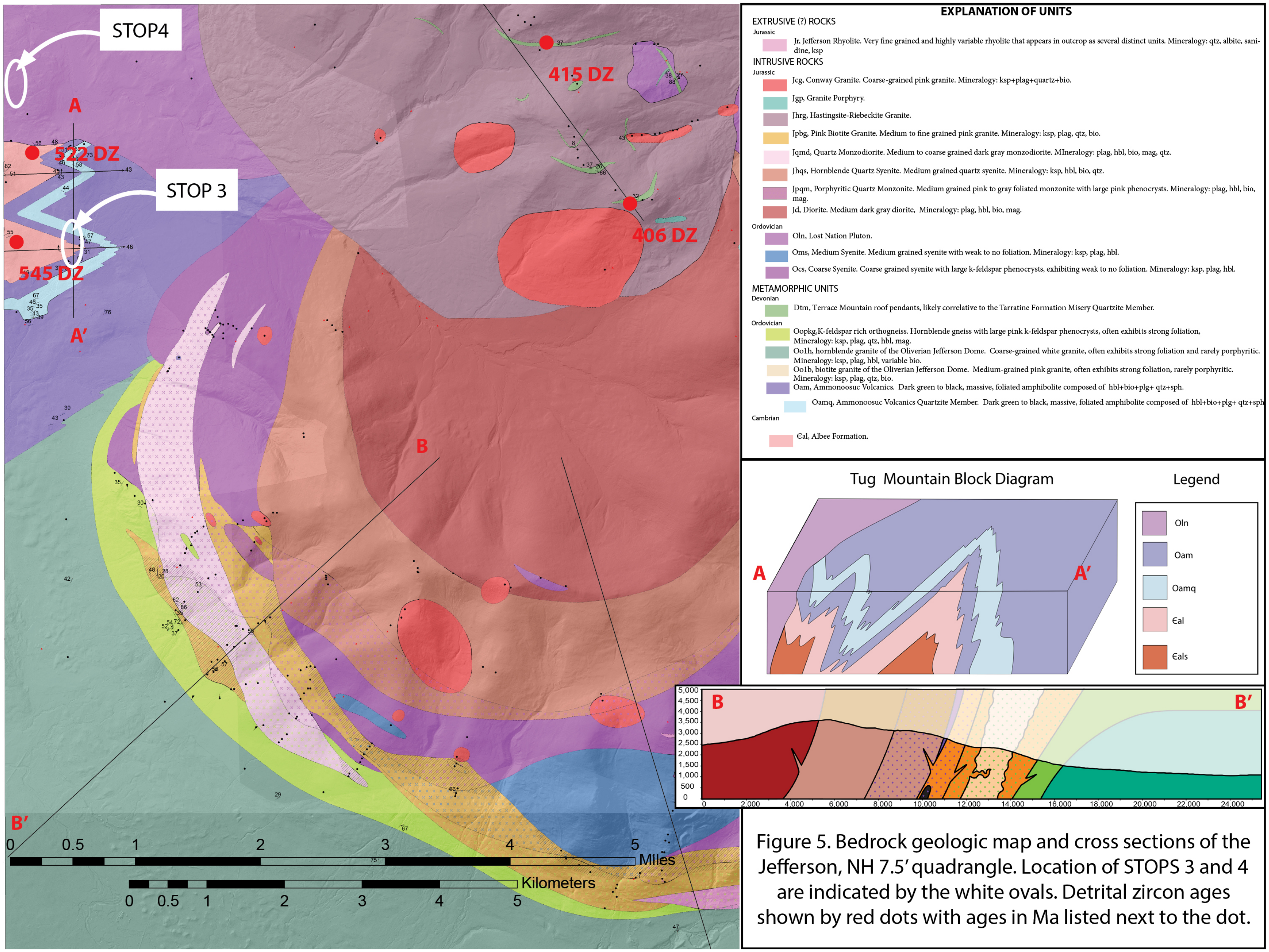

Figure 5. Bedrock geologic map and cross sections of the Jefferson, NH 7.5′ quadrangle. Location of STOPS 3 and 4 are indicated by the white ovals. Detrital zircon ages shown by red dots with ages in Ma listed next to the dot.

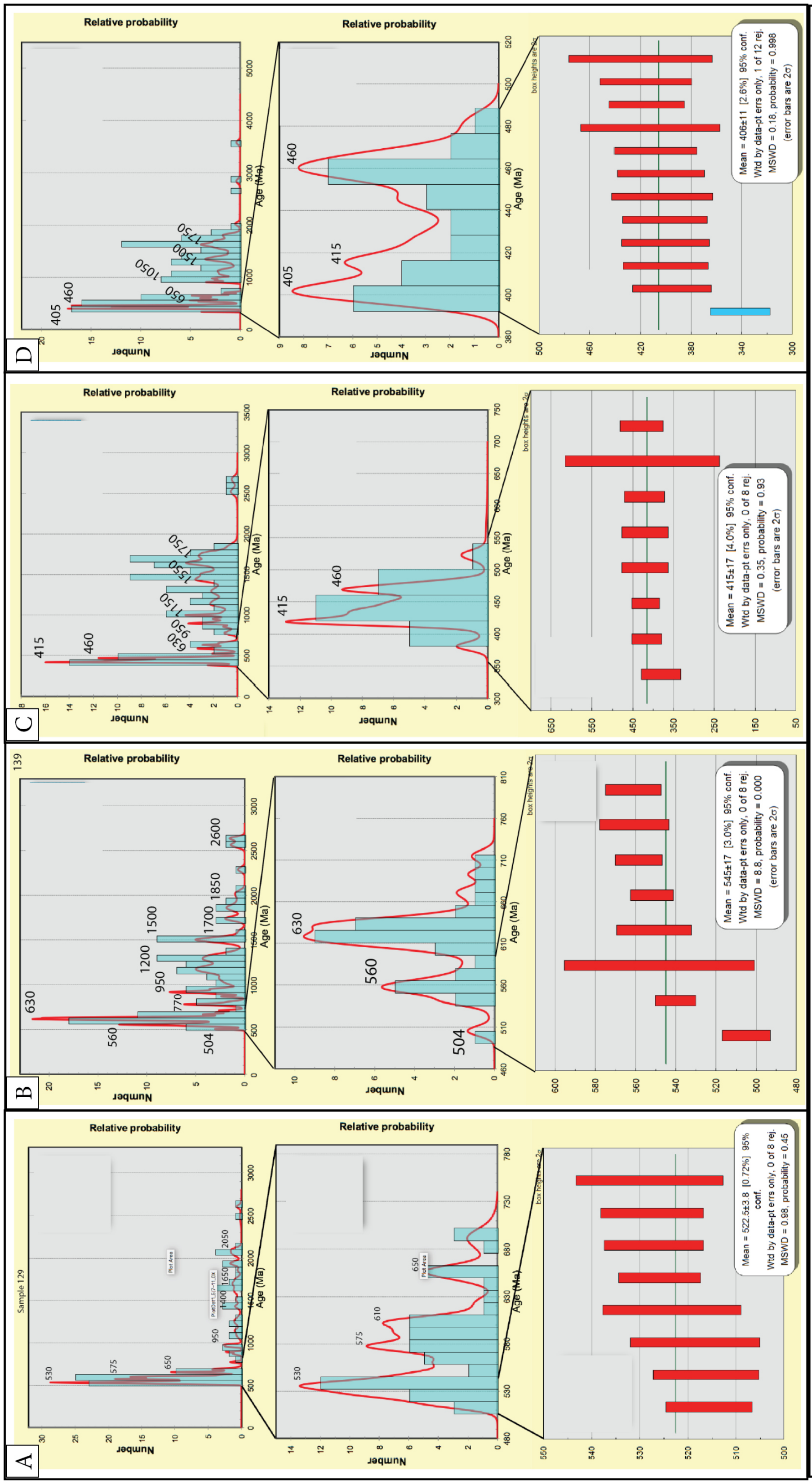

Figure 6. Detrital zircon ages from the Jefferson quadrangle, NH. Cambrian Albee Formation samples (A and B) yielding ages of 522 and 545 Ma. Devonian Tarratine Formation (?) samples (C and D) yielding ages of 415 and 406 Ma.

The two lower elevation samples on Tug Mtn. yielded youngest detrital zircon age peaks of 522 ± 3.8 Ma and 545 ± 17 Ma respectively, supporting their designation as Cambrian and part of the Albee Formation. Therefore, the mapped region of the Albee Formation in the Lancaster region has expanded considerably. Population density plots of detrital zircon ages for both samples show excellent similarities to other Cambrian Ganderian units (e.g. Dead River, Ellsworth, and Moretown Formations).

By contrast, the roof pendants on Terrace Mtn. yielded youngest zircon ages of 406 ± 11 Ma and 415 ± 17 Ma suggesting a Devonian age. Population density plots of zircon detrital ages and very similar to that of the Tarratine Formation in Western Maine and may correlate to the 3rd Acadian, outboard-derived, detrital zircon cycle of Bradley and O'Sullivan (2016). Therefore, these rocks are certainly not Albee Formation and represent instead Devonian sedimentary rocks that are stoped blocks from a higher structural level not typically seen on the current erosional surface.

Though the contact between the Albee Formation and overlying Ammonoosuc Volcanics is not exposed, we speculate, based on their age difference of at least 50 million years and stark contrast in deformation style, that these rocks are in unconformable contact with each other. This unconformity is likely the Early Ordovician (?) Penobscot unconformity. The Albee Formation is multiply deformed showing classic pin-striping, transposition, injection of quartz veins, and a multitude of micro-, macro-, and macro-scale folds. Conversely, the Ammonoosuc Volcanics shows primary features in the form of lapilli and interbedded mafic and felsic units and only a single phase of folding at just the macro-scale. This latter deformation defines a series of NE plunging, map-scale, reclined folds of Acadian or Taconian age. The diapiric doming of the Oliverian Jefferson Dome in the Neoacadian in turn deformed these fabrics.

In the Lancaster area, Chapman (1942), Billings et al. (1979) and most recently Lyons et al. (1997) all show the Ammonoosuc Fault juxtaposing the Lost Nation pluton and a sliver of Albee Formation to the north against the Ammonoosuc Volcanics to the south. These maps show the fault extending east through the Pliny Caldera Complex and back into the Ordovician section east of the Pliny Range. We do not support the existence of the Ammonoosuc Fault in this part of the Lancaster area. This is based on the new extensions of the Albee Formation across the proposed fault, the lack of any evidence of a fault (such as silicified zones or zones of crenulation) in both the Ordovician and Jurassic rocks, and the existence of a chilled intrusive contact, without fault disruption, between the complex mafic intrusive rocks of the Lost Nation Pluton and older rocks.

## ROAD LOG

### Time, Place, Logistics

Sunday October 1st, 8:00 AM meet at the first STOP parking location which is the junction of Fleming and Mine Roads in West Bethel, Maine (350813.44 m E, 4917688.46 m N). To get to the meeting place from the Maine Mineral and Gem Museum in Bethel drive west on U.S. Rte. 2 about 5 miles and turn left (S) on to Fleming Road proceed for .2 miles and park at the junction with Mine Road. Bring your lunch and water. We will have a quick pit stop at the Subway sandwich shop in Gorham, NH. Ticks are really bad in the region so get those socks up over your pant cuffs!

### Mileage

| | |
|---|---|
| **0.0** | Junction of Fleming and Mine Roads in West Bethel. |

**STOP 1** Hike up the well maintained mine access road that approaches from the north and leads in about .5 miles to Wheeler Mine. Along the road up we pass swirly migmatized outcrops, probably a good candidate for diatexite, of the gray schists and quartzites of the Bog Brook unit and many two-mica granite intrusions and cross cutting pegmatites. Two of these granites were dated to be 349.2 ± 2.1 Ma and 355.3 ± 2.3 Ma. Up at the main entrance to the mine there is abundant outcrop of the Bog Brook Granofels, which is where our detrital zircon age sample was taken that yielded a maximum age of 419.5 ± 3.9 Ma. For safety reasons, we've been asked to NOT enter the mine so only look from a distance. Inside the mine are excellent 3-D exposures of granofels, cross cutting two mica granites, and even younger cross cutting pegmatite. The fine-grained granofels and fine-grained varieties of the two

mica granite can be difficult to tell apart! The cross cutting pegmatites have some very long (circa 1 m) biotite crystals in them.

Return to the vehicles and proceed back to U.S. Rte. 2 heading west. Follow Rte. U.S. 2 17 miles to Gorham, NH.

**17** Brief pit stop at the Subway Sandwich shop (66 Maine Street).

Continue on U.S. Rte. 2 west for 1.3 miles.

**18.3** Turn left at the stoplight to continue on Rte. U.S. 2 while Rte. NH 16 continues straight to Berlin.

Proceed 4.5 miles to Durand Rd.

**22.8** At bottom of big hill, turn right onto Durand Rd and proceed west for 1.2 miles to Coldbrook Rd. (private).

**24** Turn left on to Coldbrook Rd., immediately cross the bridge over the Moose River, and park near Dwight and Lauren Bradley's farm. Say "Hi" to their one-eyed corgi Moxie.

**Begin hiking mileage for stop 2**

0.0 Go up the dirt road toward U.S. Rte. 2.
0.1 Pass by the Billings cabin where Marland Billings and Katherine Fowler-Billings stayed while they mapped the Presidentials in the ‘30’s and 40’s. Continue across Rte. 2, crossing the old railroad bed, now a recreation path, to the power lines.
0.2 At power lines, bear right and follow trail into the woods in about 100 yards.
0.3 Woods road merges with Randolph Mountain Club Pine Link Trail.
0.35 Junction with the Beechwood Trail, bear right on the Pine Link Trail.
0.5 Memorial Bridge. This bridge was built in 1924 as a “Memorial to J.R. Edmands and E.B. Cook and those other pioneer pathmakers” in Randolph. The monument at the east end of the bridge is made of mylonitized Oama, the Ammonoosuc Volcanics Amphibolite member. This is a good rock in which to see the foliation and lineation so that you can determine the shear sense plane.

**STOP 2a**. Jefferson Dome. Just under and downstream of the bridge is an outcrop of Obqm, the foliated pinkish biotite quartz monzonite of the Oliverian Plutonic Series, part of the Jefferson Gneiss Dome of the Bronson Hill. The foliation formed during either the doming stage in the Neoacadian or during faulting along the Moose River Fault. The lineation is harder to see and trends moderately southeast. Also seen is a green, probably pre-Acadian, metamorphosed basalt dike and some pegmatite of the 363 Ma. Bickford granite. Maura Foley (Foley and Eusden, 2009) examined the shear sense in thin sections from this outcrop and found S-C fabrics with tops to the northwest (reverse slip). Shear sense for all of the mylonites in the Jefferson Dome rocks shows reverse motion. She also collected some monazite microprobe ages here with the following age populations: early to middle Devonian ages of 392 +/- 3 and 380 +/- 3 Ma (peak Acadian metamorphism); middle to late Devonian ages of 367 +/- 3.2 Ma (doming?); and Carboniferous ages of 346 +/- 3.6 Ma (intrusion of local granites).

From the bridge continue up the west side of Cold Brook on the Sylvan Way trail to Cold Brook Falls.

.55 Cold Brook Fall (very slippery rocks here).

**STOP 2b**. Moose River fault, Ammonoosuc Volcanics, and mylonites. At the falls are exposed Oama, the Ammonoosuc Volcanics Amphibolite member, and a few intercalated layers of Oamg and Obqm. The regional strike and dip (70°, 48 SE) is seen well in outcrop on both sides of the falls. The lineation (125°, 38°) is defined by fine-grained biotite and can be seen in good light. This dip is a result of doming by the Obqm when it diapirically rose up through the more dense cover rocks in the Neoacadian. Mylonitic fabrics are seen throughout the outcrops and particularly well in the amphibolite and gneiss horizons. Oriented thin sections from this locality show tops to the northwest sense (reverse slip) (Dupee et al., 2002). Based on the lineation orientation, there is some minor strike slip motion that is dextral, but the dominant motion appears to be dip slip. Collectively these mylonites make up the Moose River fault separating the Oliverian Jefferson Dome from the Ammonoosuc Volcanics. Farther upstream Foley and Eusden (2009) have found normal shear sense indicators in mylonites. With both normal and reverse motions found in the Ammonoosuc Volcanics it is difficult to determine the overall motion of the Moose River fault. Are there two generations of faulting with early reverse followed by later normal motion? More work is needed. Regardless, the evidence shown by the mylonitic fabrics along the Moose River Fault and truncation of Ammonoosuc sub units strongly suggest that the contact between the Ammonoosuc Volcanics and Oliverian Jefferson Dome is a fault and the intrusive contact, if there ever was one, is obscured.

Continue upstream on the east side of Cold Brook along an old abandoned trail.

.67 Outcrops above Cold Brook fall.

**STOP 2c**. Ammonoosuc Volcanics and sill of Bickford granite. Exposed in the river are a few more outcrops of less mylonitized amphibolite and interbedded gneiss. One amphibolite horizon that has an abundance of sub-centimeter size plagioclase grains in a dark matrix suggests it was once a crystal lapilli mafic tuff. Above these rocks is a sill of medium to fine-grained 363 Ma. Bickford Granite. Sills of medium to fine grained two mica and biotite granite and coarse pegmatite continue upstream for a couple of miles. The granite is not deformed by doming or shearing, and appears to mark the end of Neoacadian tectonism sometime at the end of the Devonian or the earliest Carboniferous. The age of the Bickford is coincident with the timing of the Neoacadian to the south (Mass.) but here no deformation or extensive metamorphism of that age is seen here. There is also no evidence of any Alleghenian tectonism in this part of the Appalachians.

Proceed back to the vehicles and drive west on Rte. 2.

**Continue Road mileage**

Drive uphill on the dirt road past the Bradley's Farm and carefully turn right on to U.S. Rte. 2 and proceed west 15 miles to Jefferson, NH and turn right on the North Rd.

**39** Turn right on the North Rd and proceed 2.5 miles on the North Rd to just after crossing Garland Brook and turn right on Brook Rd.

**41.5** Proceed .6 miles on Brook Rd.

**42.1** Park at 63 Brook Rd.

Walk NE in the field along the NW bank of Garland Brook for .25 miles to prominent outcrops of Albee Formation in the brook.

**STOP 3** On both sides of Garland Brook are outcrops of what we've interpreted as Cambrian Albee Formation. The two detrital zircon samples came from about .5 and 1 miles to the west and northwest in the woods. The maximum depositional ages of these samples are 522 ± 3.8 Ma and 545 ± 17 Ma. The Albee Formation here has the classic pin stripping with dark schist and quartzite layers and lighter veins of quartz. The outcrop is complexly folded and shows some evidence for transposition. We attribute the intensity of meso-scale folding to this outcrop's position on the hinge of a macro-scale reclined overturned, anticline. That fold has a hinge line plunging north at about 45°, an axial surface striking west and dipping north also at about 45°, and an interlimb angle of about 60°. This region had previously been mapped as Ordovician Ammonoosuc Volcanics (Chapman, 1942; Billings et al., 1979). Our new mapping extends the Albee across what used to be the Ammonoosuc Fault. Based on the lack of fault rocks and structural evidence and the continuous extent of the Albee and Ammonoosucs across the previously mapped fault, we now believe the fault doesn't exist in this region and dies out somewhere to the southwest.

Walk back to vehicles

Retrace the drive .6 miles on Brook Rd. to North Rd.

**42.7** Turn right on North Rd and proceed west for 2.5 miles to Grange Rd.

**45.2** Turn right on Grange Rd. and follow it for 2 miles to Pleasant Valley Rd.

**47.2** Continue straight on Pleasant Valley Rd. while Grange Rd. veers off to the left. There is a large outcrop of the Lost Nation pluton on the left side of the road at the intersection.

Proceed on Pleasant Valley Rd. for .2 miles to 23 Paradise Valley Road.

**47.4** Park at the bottom of the driveway to 23 Paradise Valley Road.

Walk up the driveway to examine the washed outcrop next to the house.

**STOP 4** Exposed in this awesome washed outcrop in the yard of the house is the Ordovician Lost Nation pluton. This is a fairly obscure pluton in Appalachian lore and linked temporally and magmatically to the Highlandcroft Plutonic Series (Lyons et al., 1997; Dorais et al., 2008). Complicating the story of the Lost Nation is its 442 ± 4 Ma age by Moench and Aleinikoff (2003), which makes it roughly coeval with the Oliverian Jefferson Dome. Dorais et al. (2008) summarizes much of the geochemical and petrologic work done on the Lost Nation and suggest the Highlandcroft and Oliverian Plutonic Suites are magmatically related arc magmas derived from a Laurentian source.

The basic characteristics in the field for the Lost Nation are lack of a well-developed foliation, typically a more mafic lithology ranging from metagabbro to metagranodiorite, and an irregular discordant pluton shape which is west of the neatly domed pattern of the Oliverian Jefferson Dome.

Exposed here is a greenish-black, salt and pepper texture, metadiorite to metagabbro. The massive rock has little foliation in it, shows a few streaks of schileren of older metasedimentary units (Ammonoosucs?), and is cross cut by numerous thin, white to pink veins of granite that are presumably offshoots from the Jurassic Pliny Complex to the east.

**End of trip. Safe journeys back to your destination!**

## REFERENCES

Billings, M. P., Fowler-Billings, K., Chapman, C. A., Chapman, R. W. & Goldthwait, R.P., 1979. The Geology of the Mount Washington Quadrangle, New Hampshire, Concord: State of New Hampshire Department of Resources and Economic Development.

Brady, James J., 1991, The bedrock geology of the Bethel, Maine area: M.S. thesis, University of Maine, Orono, Maine, 150 p.

Bradley, D. C. & Tucker, R., 2002, Emsian Synorogenic Paleogeography of the Maine Appalachians: Journal of Geology, 110, 10/8/2013-483-492.

Bradley, D. C., Tucker, R. D., Lux, D. R., Harris, A. G., and McGregor, C. C., 2000, Migration of the Acadian Orogen and Foreland Basin across the Northern Appalachians: U.S. Geological Survey, Professional paper 1624, 49 p.

Bradley, Dwight C., Shea, Erin, Buchwaldt, Robert, Bowring, Sam, Benowitz, Jeff, O'Sullivan, Paul B., and Mccauley, Andrew, 2016, Geochronology and Tectonic Context of Lithium-Cesium-Tantalum Pegmatites in the Appalachians: The Canadian Mineralogist, Vol. 54, pp. 945-969.

Bradley, D. C, O'Sullivan, P., 2016, Detrital zircon geochronology of pre- and syncollisional strata, Acadian Orogen, Maine Appalachians. Basin Research, p. 1-20.

Chapman, R.W. (1942) Ring structures of the Pliny region, New Hampshire. Geological Society of America Bulletin, 53(10), 1533-1568.

Divan, Erik J., Wheatcroft, Audrey and Eusden Jr., J. Dykstra, 2017, Salinic To Neoacadian Deformation In The Migmatized Central Maine Belt Of Western Maine: Geological Society of America Abstracts with Programs, Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - 2017. Vol. 49, No. 2, doi: 10.1130/abs/2017NE-290862

Dorais, M.J., Atkinson, M., Kim, J., West, D.P., and Kirby, G.A., 2012, Where is the Iapetus suture in northern New England? A study of the Ammonoosuc Volcanics, Bronson Hill terrane, New Hampshire. Canadian Journal of Earth Sciences 49: 189-205.

Dorais, M.J., Workman, J., and Aggarwal, J., 2008, The petrogenesis of the Highlandcroft and Oliverian Plutonic Suites, New Hampshire: Implications for the structure of the Bronson Hill terrane. American Journal of Science, 308(1), 73-99.

Dupee, Matt., Minor, Jesse, Eusden, J. Dykstra, 2002, Continued Bedrock Geologic Mapping in the Presidential Range, N.H.: A progress report for EDMAP 2001: Geological Society of America Abstracts with Programs, v. 34, number 1, p. A-68.

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. D., Jr., Anderson, K, Beaudry, E, Dupee, M, Larkin, R , Minor, J. and Welling, D. 2006, Domes, volcanics, refolded folds and granites: A transect from the Bronson Hill arc into the Central Maine cover, Northern Presidential Range, New Hampshire: in Gibson, D., Daly, J and Reusch, D, eds., New England Intercollegiate Geological Conference, 98th Annual Meeting, University of Maine Farmington, ME, p. 167-180, Trip C-1.

Eusden, J.D., Jr, Foley, M, and Roden-Tice, M., 2009, The Ordovician to Carboniferous Bedrock Geology and Cooling History of the Bronson Hill and Central Maine Belts, Presidential Range, New Hampshire: *in* Westerman, D.S., and Lathrop, A.S., eds., Guidebook for field trips in the Northeast Kingdom of Vermont and Adjacent Regions: Lyndon State College, Lyndonville, VT, guidebook for 101st annual New England Intercollegiate Geological Conference, Trip A3 p. 1-17.

Eusden, J.D., Thompson, W.B., Fowler, B.K., Davis, P.T., Bothner, W.A., Boisvert, W.A., and Creasy, J.W., 2013, The Geology of New Hampshire's White Mountains: Durand Press, Lyme, NH, 184 p.

Eusden, Dykstra, Devoe, Michelle, Oxman, Graham, and Xiao, Sarah, 2015, Bedrock Geologic map of the Mount Dartmouth 7.5' Quadrangle, New Hampshire: New Hampshire Geological, Open File Report, Department of Environmental Services, 29 Hazen Drive, Concord, New Hampshire 03302-0095.

Eusden, J., Dykstra, Choe, S., Divan, E., Eusden, R., Watermulder, S., and Wheatcroft, A., 2017a, Bedrock Geology of the Gilead Quadrangle, Maine: Maine Geological Survey, Open-File No. 17-10, 2017.

Eusden, Dykstra, Hillenbrand, Ian, Baker, Sarah, and Cargill, Jordan, 2017b, Bedrock Geologic map of the Jefferson 7.5' Quadrangle, New Hampshire: New Hampshire Geological, Open File Report, Department of Environmental Services, 29 Hazen Drive, Concord, New Hampshire 03302-0095.

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

Foley, M. B. and Eusden, J. D. Jr,, 2009, Contact Relations Between The Ammonoosuc Volcancs And Jefferson Dome, Northern NH: Geological Society of America Abstracts with Programs, Vol. 41, p. 79.

Gibson, D., Barr, S., Van Rooyen, D., and White, C., 2017, Geochronology and Geochemistry of Granitoid Plutons, Western Maine: Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - 2017. Vol. 49, No. 2, doi: 10.1130/abs/2017NE-291355

Hatch, N. L., Moench, R. H., and Lyons, J. B., 1983, Silurian-Lower Devonian Stratigraphy of Eastern and South-Central New Hampshire: Extensions from Western Maine: American Journal of Science, 283, 739-761.

Hatch, N.L., Jr., and Moench, R.H., 1984, Bedrock geologic map of the wilderness and roadless areas of the White Mountain National Forest, Coos, Carroll, and Grafton Counties, New Hampshire: U.S. Geological Survey Miscellaneous Field Studies Map.

Hibbard, J. P., van Staal, C. R., Rankin, D. W., and Williams, H., 2006, Lithotectonic map of the Appalachian orogen, Canada – United States of America: Geological Survey of Canada Map 02096A, 2 sheets, scale 1:500,000.

Hillenbrand, Ian W., 2017, "Newly Discovered Albee Formation in the Northern Half of the Jefferson, NH 7.5' Quadrangle: Detrital Zircons, Structure, and Tectonics": *Honors Theses*. 209. http://scarab.bates.edu/honorstheses/209

Hillenbrand, Ian W., Eusden Jr., J. Dykstra, O'Sullivan, Paul B. and Bradley, Dwight C., 2017, Newly Discovered Albee Formation In Northern NH: Detrital Zircons, Structure, And Tectonics: Geological Society of America Abstracts with Programs, Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - 2017. Vol. 49, No. 2, doi: 10.1130/abs/2017NE-290861

Hollocher, K., 1993, Geochemistry and origin of volcanics in the Ordovician Partridge Formation, Bronson Hill Anticlinorium, West-central Massachusetts: American Journal of Science, v. 293, p. 671-721.

Karabinos, P., Macdonald, F., And Crowley, J., 2017, Bridging The Gap Between The Foreland And Hinterland I: Geochronology and Plate Tectonic Geometry of Ordovician Magmatism and Terrane Accretion on the Laurentian Margin of New England: American Journal of Science, Vol. 317, May, 2017, P. 515–554.

Kohn, M.J. and Spear, F., 1999, Probing the depths of Oliverian magmas: Implications for Paleozoic tectonics in the northeastern United States: Geology v. 27, p. 803-806.

Leo, G.W., 1991, Oliverian domes, related plutonic rocks, and mantling Ammonoosuc Volcanics of the Bronson Hill Anticlinorium, New England Appalachians: U.S. Geological Survey Professional Paper 1516, 92 p.

Lyons, J.B., Bothner, W.A., Moench, R.H., and J.B. Thompson Jr., 1997, Bedrock Geologic Map of New Hampshire: U.S. Geological Survey, scale 1:250,000, 2 sheets.

Macdonald, F.A., Ryan-Davis, J., Coish, R.A., Crowley, J.L., and Karabinos, P., 2014, A newly identified Gondwanan terrane in the northern Appalachian Mountains: Implications for the Taconic orogeny and closure of the Iapetus Ocean: Geology, v. 42.6, p. 539-542.

Moench R.H. and Boudette, E L., 1987, Stratigraphy of the Rangeley area, western Maine, in Roy, D. C., ed., Northeast Section of the Geological Society of America, Centennial Field Guide, v. 5, p. 273-278.

Moench, Robert H., Boudette, Eugene L., and Bothner, Wallace 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, I-1898-E, 114 p., 3 sheets.

Moench, R.H., and Aleinikoff, J.N. (2003) Stratigraphy, geochronology, and accretionary terrane settings of two Bronson Hill arc sequences, northern New England. Physics and Chemistry of the Earth, Parts A/B/C, 27(1), 47-95.

Osberg, Philip H., Hussey, Arthur M., II, and Boone, Gary M. (editors), 1985, Bedrock Geologic Map of Maine: Maine Geological Survey, 1 plate, correlation chart, tectonic inset map, metamorphic inset map, color geologic map, cross sections, scale 1:500,000.

Rankin, D. W., Tucker, R. D., and Amelin, Y. , 2013, Reevaluation of the Piermont-Frontenac allochthon in the Upper Connecticut Valley. Geological Society of America Bulletin, 125 (5), 998-1024.

Roden-Tice, M., Eusden, J. D., Wintsch, R. D., 2012, Apatite fission-track evidence for cretaceous development of kilometer-scale relief and steady-state tertiary topography in New England: *Geomorphology,* vol. 141–142, pp. 114–120

Solar, G.S., Tomascak, P.B., 2016, The Migmatite-Granite Complex of southern Maine: Its Structure, petrology, geochemistry, geochronology, and relation to the Sebago Pluton: In Berry, H. N., IV, and West, D. P. Jr., editors, Guidebook for field trips along the Maine coast from Maquoit Bay to Muscongus Bay: New England Intercollegiate Geological Conference, p. 19-42.

van Staal, C.R., Whalen, J.B., Valverde-Vaquero, P., Zagorevski, A., and Rogers, N., 2009, Pre-Carboniferous, episodic accretion-related, orogenesis along the Laurentian margin of the northern Appalachians: Geological Society, London, Special Publications, v. 327, p. 271-316.

Wheatcroft, Audrey, 2017, "Bedrock Geology, Stratigraphy and Geochronology in the Migmatite Terrain of the Southern Gilead 7.5' Quadrangle, Western Maine": *Honors Theses*. 196. http://scarab.bates.edu/honorstheses/196

Wheatcroft, Audrey, Divan, Erik J., Eusden Jr., J. Dykstra and O'Sullivan, Paul B., 2017, Silurian Stratigraphy And Geochronology In The Migmatite Terrain Of Western Maine: Geological Society of America Abstracts with Programs, Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - 2017. Vol. 49, No. 2, doi: 10.1130/abs/2017NE-290863