GEOLOGY OF THE CARTHAGE-COLTON SHEAR ZONE AND LYON MOUNTAIN GRANITE AN ADIRONDACK FIELD TRIP IN HONOR OF BRUCE SELLECK

William H. Peck[1], Department of Geology, Colgate University, Hamilton, New York 13346
Eric L. Johnson[2], Department of Geology, Hartwick College, Oneonta, New York 13820
Martin S. Wong[3], Department of Geology, Colgate University, Hamilton, New York 13346
Email addresses: [1]wpeck@colgate.edu, [2]johnsone@hartwick.edu, [3]mswong@colgate.edu

INTRODUCTION

This field trip is in honor of Bruce Selleck, Thomas A. Bartlett Chair and Professor of Geology at Colgate University, who passed away unexpectedly on Monday, July 31 2017. Bruce had deep ties to the upstate New York region, growing up on a farm on the western edge of the Adirondack Park. Bruce received his AB in Geology in 1971 from Colgate University, and returned to his alma mater as a faculty member in 1974, after taking MA and PhD degrees at the University of Rochester. His scholarship initially focused on the Paleozoic sedimentology of New York, but as his career progressed Bruce later expanded the scope of his research to include study of the tectonic development of the Adirondack Mountains, with longtime colleague and friend Jim McLelland.

This field trip revisits some of the key localities first described by Bruce and his collaborators in the Carthage-Colton shear zone, a major structure in the southern Grenville Province that separates the Adirondack Highlands from the Adirondack Lowlands and underlies the crossroads of Selleck's Corners, and the farm where Bruce grew up. This guide draws heavily on the Friends of the Grenville field trip to look at these rocks led by Eric Johnson and Bruce in 2005, Bruce's papers on the Carthage-Colton shear zone and the syntectonic Lyon Mountain granite, and subsequent research by Bruce, the field trip leaders, and our colleagues.

GEOLOGIC SETTING

The area of the Carthage-Colton shear zone has long been recognized as a major geologic discontinuity in the Mesoproterozoic crust of the Adirondack mountains, dividing the Adirondack Highlands from the Adirondack Lowlands (Fig. 1). The Lowlands are for the most part dominated by upper amphibolite facies metasedimentary rocks, while the Adirondack Highlands are made up of granulite facies metaplutonic rocks with only a minor metasedimentary component. When U-Pb age determinations became available for the Adirondacks in the late 1980s and early 1990s it became clear that magmatic suites of the Lowlands and Highlands have different age groupings (McLelland and Chiarenzelli 1988), and that the Highlands and Lowlands have different metamorphic ages. In the Adirondack Lowlands U-Pb ages of metamorphic minerals and partial melting reflect the 1190-1140 Ma accretionary Shawinigan orogeny, while in the Highlands both the Shawinigan and the 1090-1020 Ma Himalayan-style Ottawan orogeny are represented (Mezger et al. 1991; Heumann et al. 2006).

Mezger et al. (1992) framed the newly-available geochronology and overall tectonic setting of the Carthage-Colton shear zone in the terms of orogenic collapse, where the Lowlands was down-dropped during the waning Ottawan orogeny and juxtaposed the terranes at ca. 1030 Ma. In one of their tectonic scenarios the Lowlands was at a higher, and cooler (<400°C) crustal level above the Highlands during the Ottawan Orogeny. This basic tectonic interpretation has been extended to elsewhere in the southern Grenville Province to explain discontinuities in metamorphic grade, age of metamorphism, and tectonic style across several terrane-bounding shear zones. In this model regions such as the Adirondack Lowlands lacking Ottawan resetting of metamorphic chronometers are part of the orogenic lid during the Ottawan orogeny, making up the suprastructure of the orogen. The Adirondack Highlands make up part of the Ottawan orogenic infrastructure, which underwent mid-crustal channel flow and eventually collapse (see Rivers, 2011).

The west-dipping Carthage-Colton shear zone is structurally complex and records several kinematic regimes. Ottawan granulite-facies transpression is recorded in some fabrics, and is followed by rapid cooling during extensional collapse (Streepey et al. 2001; Johnson et al., 2004; Bonamici et al. 2015). Much of the Carthage-Colton shear zone deforms the 1164±11 Ma Diana complex (Hamilton et al., 2004), the westernmost major pluton of the Highlands Anorthosite- Mangerite- Charnockite- Granite (AMCG) suite. The Diana complex is for the most part made up of pyroxene syenite and related rocks, but also includes hornblende granite and associated small bodies of anorthosite (Hargraves, 1969). Rocks of the Diana complex are often penetratively deformed, mylonitized, and metasomatized in the Carthage-Colton shear zone (Johnson and Selleck, 2005; Bonamici et al. 2015).

For this field trip we will revisit several locations where intrusions related to the Lyon Mountain granite suite intrude the footwall of the Carthage-Colton shear zone (ie. the Adirondacks Highlands). Selleck et al. (2005) recognized that these synkinematic intrusions were emplaced at ca. 1050 Ma, similar in age to other ferroan & potassic granites elsewhere in the Adirondack Highlands (Chiarenzelli et al. 2018). The Lyon Mountain granite is regionally associated with hydrothermal alteration and iron oxide mineralization, and is interpreted to be the product of crustal melting caused by gravitational collapse of the Ottawan orogen (Selleck et al. 2005; Chiarenzelli et al. 2018).

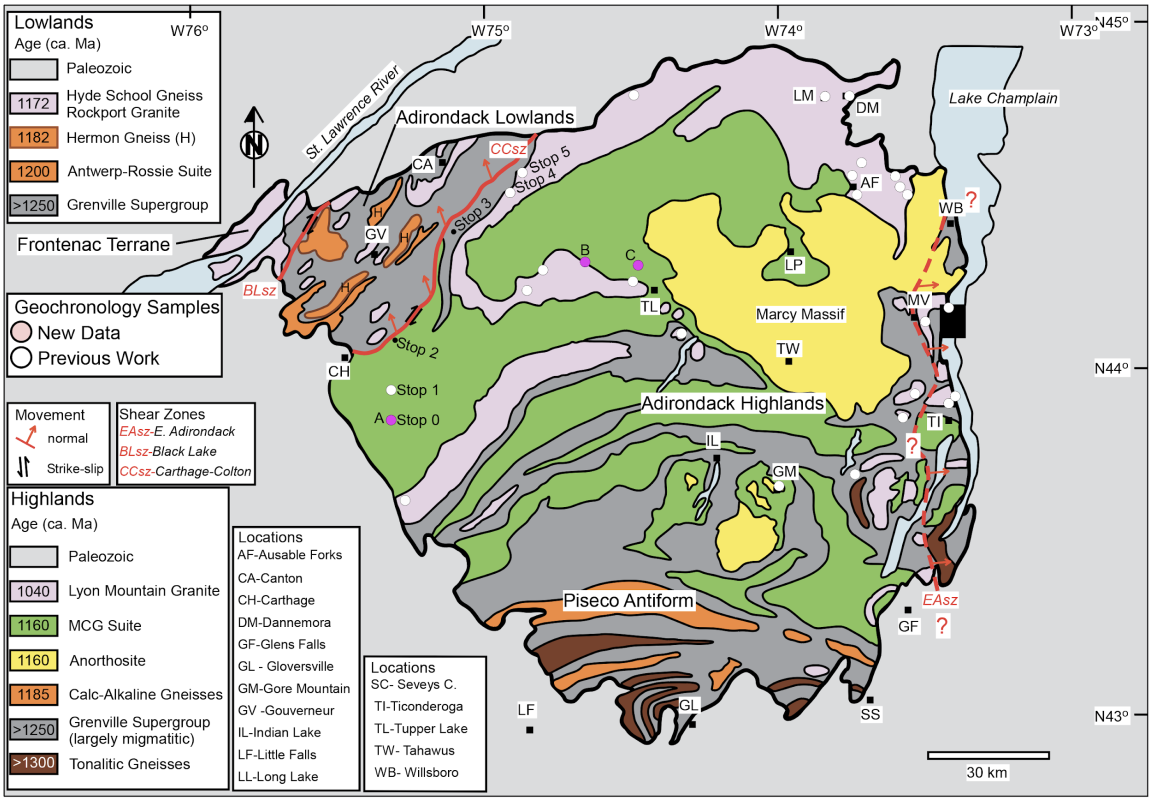


Figure 1. Geological map of the Adirondack region (from Chiarenzelli et al. 2018). Colored units are igneous rocks dated by U-Pb zircon geochronology, with ages indicated in the legend. Separate legends are given for the Adirondack Highlands and Adirondack Lowlands terranes. Small white circles note sampling locations for U-Pb zircon analyses of the Lyon Mountain granite tabulated by Chiarenzelli et al. (2018). Pink circles are new U-Pb zircon age localities: (A) Croghan, (2) Seveys Corners West, (C) Long Lake. Field trip stops are numbered.

PRE-TRIP STOP

STOP 0: DEFORMED AMCG GRANITOIDS SOUTH OF CROGHAN
Extensive outcrops on both sides of NY-812 (LAT-LONG 43.87477 -75.38969)

This stop, 1.2 miles south of the Citgo gas station, is included for field trip participants traveling from the south to the meeting place in Croghan as a 'guide your own' stop. Extensive outcrops of penetratively deformed and folded rocks are exposed on both sides of NY-812, showing a variety of granites, syenites, and amphibolites (Fig. 2). Lithologically these exposures are similar to the Diana syenite and other AMCG-suite granitoids elsewhere in the Adirondacks. These rocks are mapped as hornblende and biotite granites on the state geologic map.

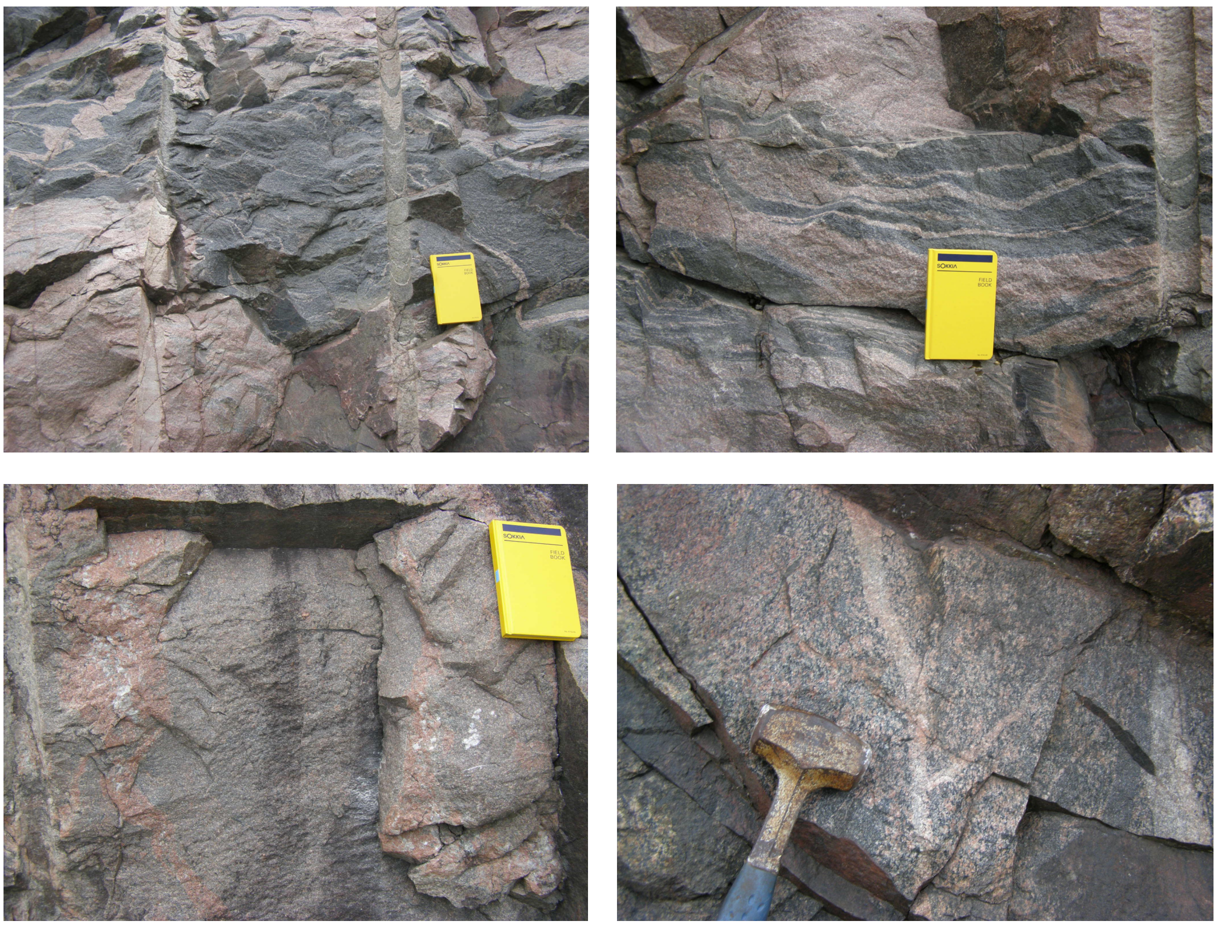


Figure 2. Deformed anorthosite-suite syenite and amphibolite (above) intruded by granite pegmatite (lower left) and granitic dikes (lower right), south of Croghan, NY.

In 2017 Bruce Selleck dated several rocks thought to be part of the Lyon Mountain granite suite to test the relationship with mineralogically similar, but deformed AMCG suite granitoids, including two rocks from this site (Fig. 3). The sample CRO-16-H is a deformed granitoid from this outcrop, and 29/31 analyzed euhedral zircon with oscillatory zoning yields a $^{207}Pb/^{206}Pb$ weighted mean age of 1176±10 Ma (MSWD=2.1), similar to other members of the AMCG suite. The sample CRO-16-PEG is coarse pegmatite dike that cuts fabric in the host syenite. Fourteen analyses of zircon with broad zoning in BSE from this sample have a $^{207}Pb/^{206}Pb$ weighted mean age of 1047±10 Ma (MSWD=1.7), which is identical to typical igneous ages determined in the Lyon Mountain granite elsewhere. Three older analyses overlap those of the host gneiss, and are likely inherited. Bruce Selleck (personal communication 2017) thought that this sample (lower left, Figure 2) might represent in-situ melting of AMCG suite granitoids to produce Lyon Mountain granite pegmatite.

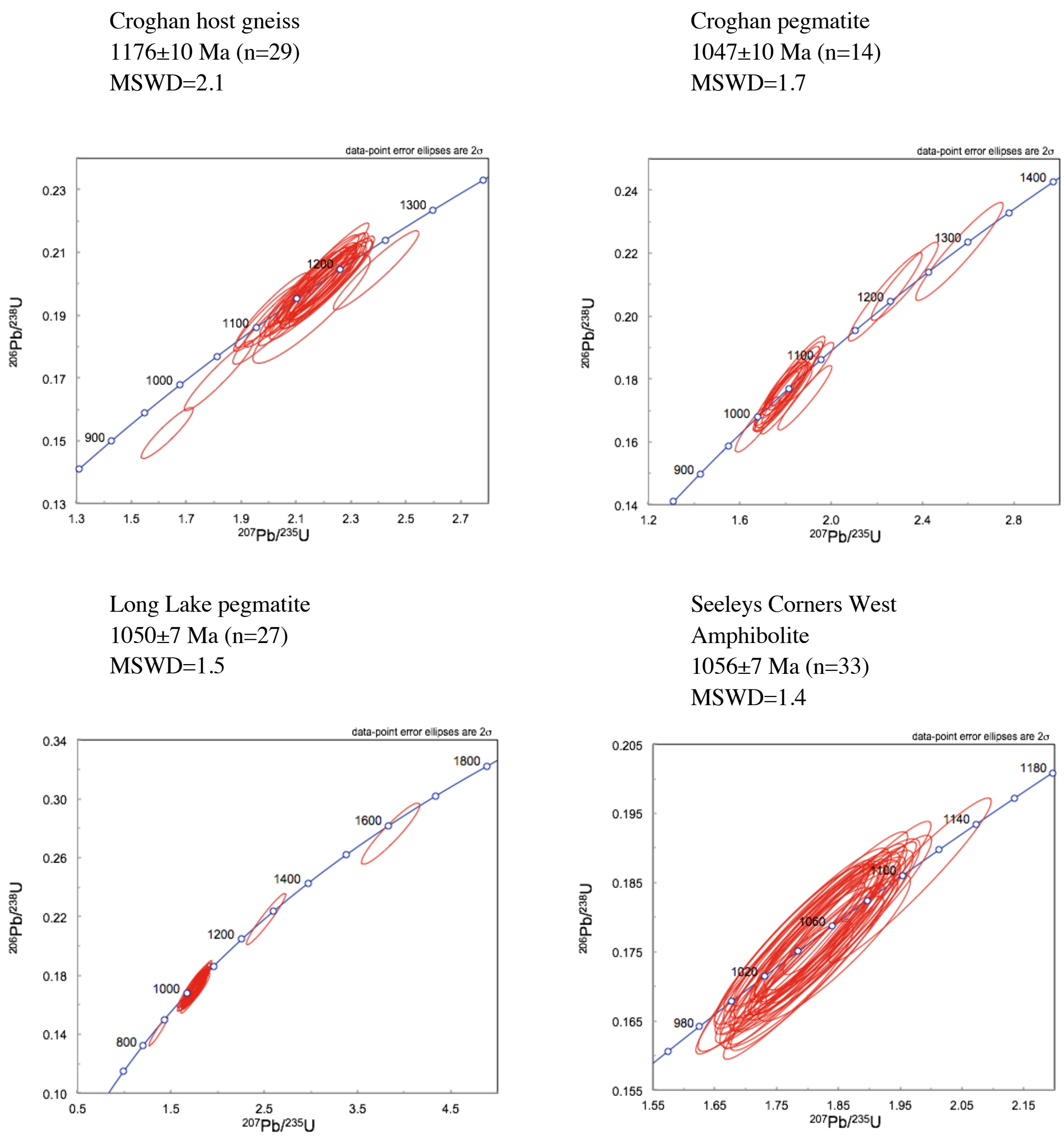


Figure 3. New laser ablation ICP-MS age determinations of Lyon Mountain granite and host rocks. $^{207}Pb/^{206}Pb$ weighted mean ages are given for zircon analyses interpreted to date igneous growth.

ROAD LOG

This field trip begins at the Citgo Gas Station in Croghan, NY, street address 9741 NY Route 812. The geology caravan will depart at 9 AM on Friday Morning, October 12, 2018. LAT-LONG 43.89162, -75.39191

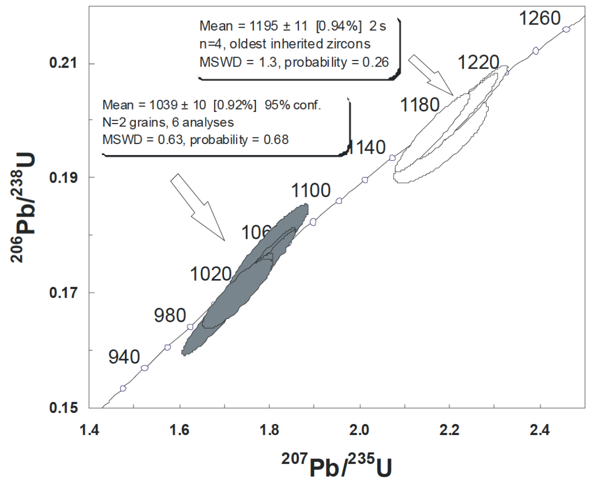
Mileage

0.0 Citgo Gas Station in Croghan, NY
4.4 Proceed north on NY-812 (Indian River Road). Park next to prominent outcrops east side of road.

STOP 1: INTRUSIVE RELATIONSHIPS ON INDIAN RIVER ROAD
Indian River Road near Croghan, NY (LAT-LONG 43.95181 -75.38115)

This roadcut exposes dikes of leucogranite intruding mafic syenite. The location is south of the mapped extent of the Carthage-Colton shear zone and thus within the Adirondack Highlands. This outcrop and nearby exposures represent a zone of extension within the lower plate (Adirondack Highlands) of the CCSZ that accommodated granite emplacement. The undeformed quartz mesoperthite leucogranite dikes crosscut foliation in the syenite and contain xenoliths of the mafic country rock. The outcrop is also crosscut by later hematite-stained quartz-feldspar-calcite veins that resemble the late mineralized veins associated with the Lyon Mountain granite elsewhere in the Adirondack Highlands (Johnson and Selleck, 2005).

Figure 4. Ca. 1039 Ma leucogranite intruding foliated mafic syenite at Stop 1. Note xenolith of foliated mafic rock in leucogranite



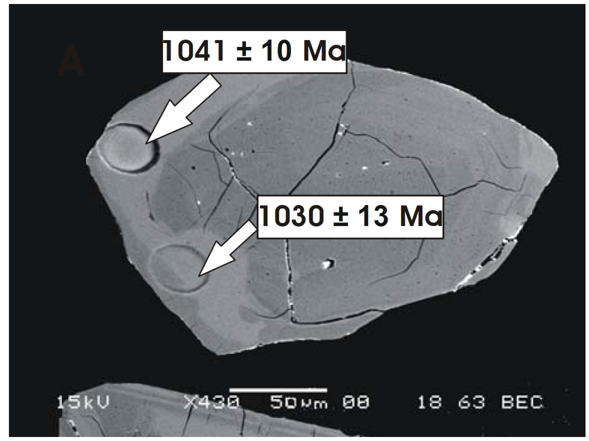


Figure 5a. Concordia plot of U-Pb SHRIMP data from leucogranite at Stop 1.
Figure 5b. BSE image of zircon from leucogranite. The finely zoned overgrowth is interpreted as igneous. Darker (lower U content) cores from this suite are older and represent xenocrysts.

Zircon from the leucogranite are subequant to elongate with faintly zoned cores and finely-zoned rims (Selleck, et al, 2005). Four reliable core analyses yield an upper intercept age of 1195 ± 11 Ma (Fig. 5, MSDW = 1.3). Six analyses of zoned rims on yielded 1039 ± 10 Ma with MSDW of 0.63. The core ages are older than zircons dating intrusion of the Diana Complex (1164 ± 11 Ma) but overlap the ages of some older cores (1180–1190 Ma) in the Diana reported by Hamilton et al. (2004). The rims represent igneous overgrowths on xenocrysts, as observed in other studies of the Lyon Mountain Granite suite in the Adirondack Highlands (Chiarenzelli et al. 2018), and fixes the minimum age of penetrative deformation in this part of the Adirondack Highlands.

16.7 Continue north on NY-812 N, turn left onto NY-3 West
17.0 Turn right onto Hermitage Road, park on right shoulder of Hermitage Road

STOP 2: THE VALENTINE WOLLASTONITE DEPOSIT
Hermitage Road near the intersection with NY-3 (LAT-LONG 44.12217 -75.3775)

The Gouverneur Talc Company No. 4 Quarry is at the northern contact between the 1164 Ma Diana Syenite and marble country rocks, which exposes the spectacular blue calcite marble and coarse wollastonite of the Valentine deposit. This relatively quick visit to the deposit will examine representative lithologies dumped by the mine operators next to the entry gate, which is a working site.

Mining of wollastonite in the Valentine deposit began in 1977, and the deposit is well-known as a mineral collecting locality (Chamberlain et al. 1999). Calcite marbles (containing blue or white calcite) contain high-grade mineral assemblages including diopside, spectacular euhedral graphite, and other accessory minerals such as phlogopite, titanite, and chondrodite (Gerdes and Valley 1994). Secondary minerals include talc, prehnite, quartz, secondary vein wollastonite, and a host of other alteration minerals (Chamberlain et al. 1999). Visible in the dump next to the entry gate are also cemented crushed ore from the mine. This phenomenon was first noticed by Bruce Selleck in 2017 at the Lewis deposit, and now that we know what to look for, cementation of wollastonite mine wastes seems to be a common process. Crushed wollastonite rock is cemented by calcite and silica, probably by the carbon sequestration reaction wollastonite + CO_2 = calcite + quartz occuring passively in wollastonite mine waste rock and old stockpiles. Current research on wollastonite weathering and carbon sequestration is ongoing.

Wollastonite is relatively common in marbles and calc-silicates of the Adirondacks, and often forms during closed-system metamorphism of protolith sediments via the reaction calcite + quartz = wollastonite + CO_2. Large wollastonite ore deposits are found associated with 1155 Ma AMCG-suite rocks: around the Westport anorthosite dome in the eastern Adirondack Highlands (Fig. 1) and adjacent to the Diana Syenite at the boundary of the Adirondack Highlands and Adirondack Lowlands. Large wollastonite deposits require the infiltration of large volumes of water-rich fluids into the contact aureole, producing wollastonite via reaction with calcite country rocks, where fluids bring in dissolved silica and remove evolved CO_2 (Gerdes and Valley, 1994).

The Willsboro-Lewis wollastonite district around the Westport dome has low oxygen isotope ratios (as low as -1.3‰ SMOW), which is indicative of interaction with large volumes of heated meteoric water, and places important constraints on the depth of emplacement of the Marcy anorthosite in the Adirondack High Peaks. (Valley and O'Neil 1982; Clechenko and Valley 2003). Large volumes of surface water during contact metamorphism is strong evidence of shallow (<10 km) anorthosite emplacement (Valley and O'Neil 1982). Interestingly, the main wollastonite ore of the Valentine deposit does not share the low oxygen isotope ratios of the Willsboro-Lewis wollastonite district (Gerdes and Valley 1994), nor does wollastonite at the contact of the the contemporaneous Morin or Lac St. Jean anorthosites of Quebec (Peck 1996; Higgins et al. 2001; Peck et al. 2005). This may indicate deeper emplacement in the crust or differences in hydrothermal flow for these other AMCG plutons.

The Valentine deposit shows steep gradients in oxygen isotopes ratios across skarn/hostrock boundaries, revealing that fluid infiltration was channelized and not pervasive (Gerdes and Valley 1994). Carbon isotope fractionations between co-existing calcite and graphite are consistent with equilibration at 675°C during overprinting Ottawan metamorphism (Gerdes and Valley 1994), although for the most part the rocks are not very deformed by this event.

17.1 Turn around on Hermitage Road, heading back to NY-3 E. Turn left onto NY-3 East
27.6 Drive on NY-3 East to the junction with Co Rd 23A, turn left on Co Rd 23A
33.5 Take Co Rd 23A to NY-58 N. Turn left on NY-58 N
37.6 Follow NY-58 N to Co Rd 24. Turn right on Co Rd 24
43.1 Proceed on Co Rd 24 5.5 miles to park on broad shoulder, right side of road.

STOP 3: DANA HILL METAGABBRO

Co. Rt. 24 near Edwards, NY (LAT-LONG 44.3838, -75.1781). This stop involves a short hike uphill.

Park the vans and climb the hill on the north side of the road. On the trail up the hill we will pass several sub-meter width EVENT 4 shear zones.

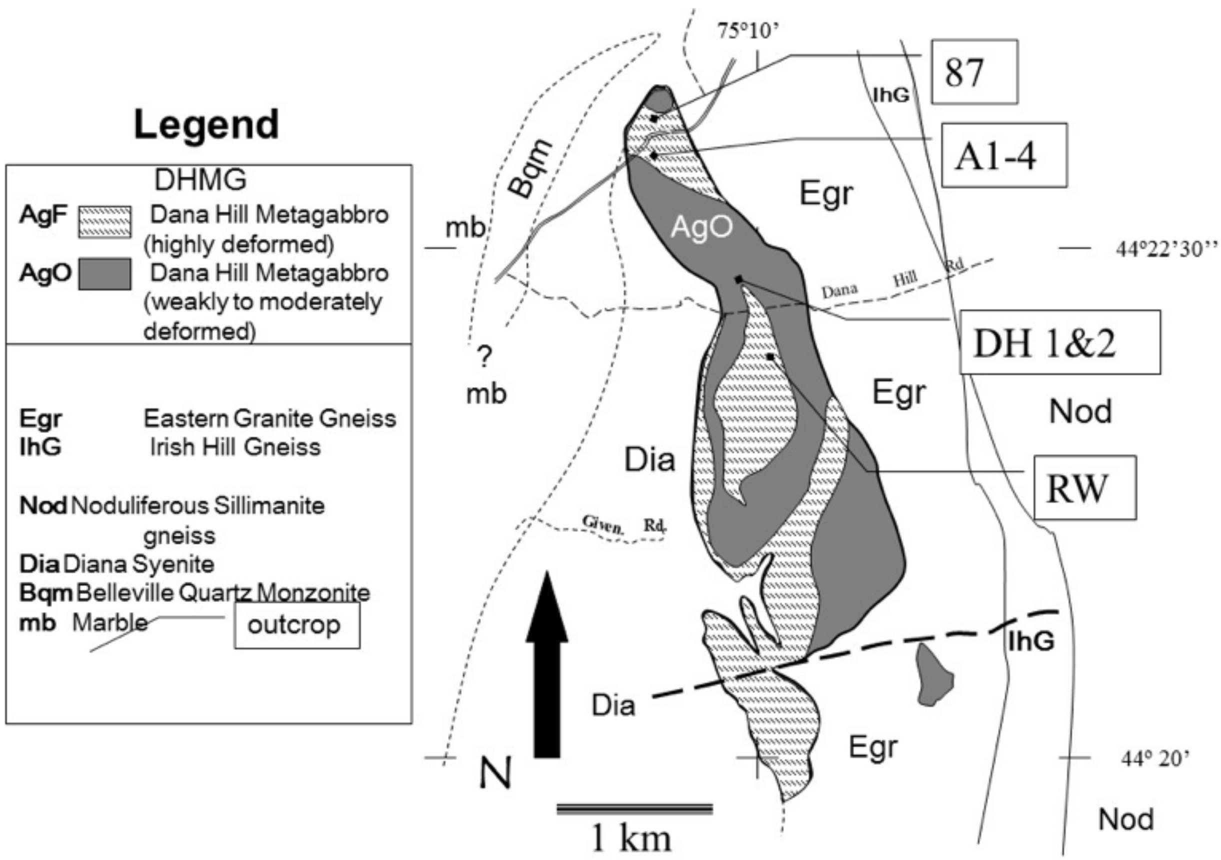


Figure 6. Map of the Dana Hill Metagabbro Body.

The Dana Hill Metagabbro preserves multiple deformation and veining events ranging from granulite facies ductile to sub-greenschist facies brittle events (see appendix). In many cases, cross-cutting relationships allow for the determination of a sequence of events. To date, six major deformational/veining events have been identified (Johnson et al. 2004; Streepey et al. 2001). At this stop we will examine the complex deformational events recorded in the body. This outcrop along with the outcrops at the top of the hill across the road, exhibit all 6 deformational events. We will start at the far southern end of the outcrop and examine the deformational sequence of events recorded. From the oldest to the youngest, this outcrop preserves EVENT 1 mega-shearing, EVENT 3 hornblende veining, EVENT 4 sub-meter shearing, and EVENT 6 folding and brecciation. EVENTS 2 and 4 can be observed at the top of the hill across the road. Events 3 through 5 take place in the presence of a fluid or fluids that drive scapolite replacement of original plagioclase feldspar in the host metagabbro. In the Diana Syenite, cm to dm-wide shear zones (dated to 1052-1034 Ma) also exhibit scapolite replacement of plagioclase feldspar. This scapolitization event is widespread in and around the CCSZ from just north of Harrisville to Colton and is present in both the Highlands and Lowlands terranes, therefore, marks a common event for both terranes. Continuing north to the far end of the outcrop lone finds a weakly to un-deformed pod of cumulate gabbro.

The goal of this stop is to demonstrate that the Dana Hill Metagabbro body acted as a rigid block during deformation. In some instances, cumulate igneous textures have been completely preserved while in other exposures the gabbro is ultramylonitic in texture. The resistance to deformation in the Dana Hill Metagabbro resulted in an episodic response to the applied stress leading to discrete pulses of deformation. This body preserves individual and distinct events that record the much of deformational history of the region. The earliest shear zones are massive (30m wide) and mylonitic to ultramylonitic. These shear zones record recrystallization temperatures in excess of 700°C. Subsequent shearing events are dramatically different forming sub-meter wide anastomosing shear zones at recrystallization temperatures at or below 700°C. The last deformation events to affect the Dana Hill Metagabbro transition to brittle failure at low to sub greenschist facies conditions. The deformational history is one of an exhuming footwall with deformation beginning in the granulite facies and eventually passing through the brittle-ductile transition at greenschist to sub greenschist facies conditions. We will examine these events and the available geochronologic data for this complex outcrop.

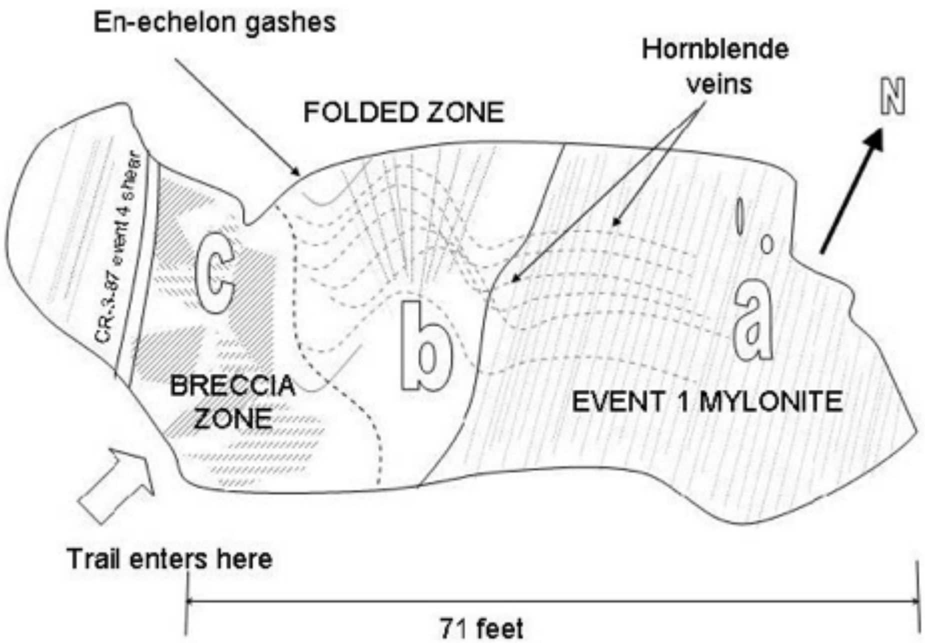


Figure 7. Map view of the outcrop at stop 3. We will begin at the western edge of exposure in zone a. The small oval shapes in zone a represent feldspar (albite)+quartz veins and tension gash fills that are undeformed internally.

EVENT 1 shearing accounts for the mylonitic character of the outcrop as a whole. The foliation here dips steeply yet transport lineation orientations plunge shallowly to the north-northwest. Kinematic indicators yield dextral shear sense. These mylonites contain recrystallized clinopyroxene + amphibole + sphene+ plagioclase (An45-51) along with accessory minerals (apatite, zircon, +/-quartz). Amphibole compositions for these samples range from Ferroan Pargasite to Magnesian Hastingsite. Chlorine contents are high for all amphiboles studied ranging from 2 to 18% hydroxyl site occupation. Amphibole and plagioclase chemistries are presented in Johnson et al. (2004). All samples exhibit a well-annealed polygonal fabric with perfect 120° triple junctions between grains. Grain sizes show a narrow range of variation for these samples averaging in the range of 100-300 μm for polygonal plagioclase. Re-crystallization temperatures for event 1 samples using the quartz-free geothermometer Holland and Blundy (1994) range from 744 to 770°C (for 6 kbar). Scapolite replacement of plagioclase is not present in EVENT 1 shears at this location.

Hornblende veins cut the foliation at high angles in zone a. Hornblende veining belongs to EVENT 3 (we do not see EVENT 2 shear zones in this outcrop.). The hornblende veins are surrounded by reaction halos were scapolite replaces plagioclase feldspar in the host metagabbro. These halos can extend several mm into the surrounding metagabbro. In zone b (see Fig. 7), the metagabbro is folded and the open to nearly chevron folds are marked by EVENT 3 hornblende veins. What looks like a rotated cleavage fanning across the folds are in fact the old EVENT 1 mylonitic foliation surfaces. This zone transitions into the chaotic breccia zone (EVENT 6; zone c). Brecciation (EVENT 6) was accompanied by the growth of actinolite, biotite and chlorite after hornblende, and the breakdown of scapolite to a mixture of albite, epidote, and calcite Breccia sample H-6A preserves rafts and clots of scapolite-rich mylonitic metagabbro with an invasive matrix of fibrous mats of chlorite, epidote, and actinolite. Hornblende (ferroan pargasite) that has not suffered alteration to actinolite is fluorine-rich (average F = .75 wt %; average Cl = .57 wt %).

At the eastern margin of the breccia zone, an EVENT 4 sub-meter scale shear zone is exposed. This shear (sample CR-3-87 Johnson et al. 2004; Streepey et al. 2001) preserves deformation textures (little annealing) and contains the assemblage hornblende + recrystallized clinopyroxene + plagioclase An 32 + Fe-Ti oxides + scapolite (minor). Plagioclase-amphibole equilibrium pairs where present yield re-crystallization temperatures for event 4 shearing in the range of 730°C to 680°C ±50°C for a pressure of 6 kbar.

GEOCHRONOLOGY OF STOP 3

Figure 8 shows the U/Pb isochron data for shear-zone grown sphene (titantite) for this outcrop. U/Pb data presented represent EVENTS 1, and 4 and yield a tightly constrained age of 1020.7 +/- 3.1 Ma. Since recrystallization temperatures for events 1 through 4 occur at temperatures above the closure temperature for U/Pb in titanite, these dates represent cooling ages for the body. The consistency of U/Pb titanite ages for samples throughout the body indicate that all (Events 1-5) shearing and veining occurred prior to 1020 Ma.

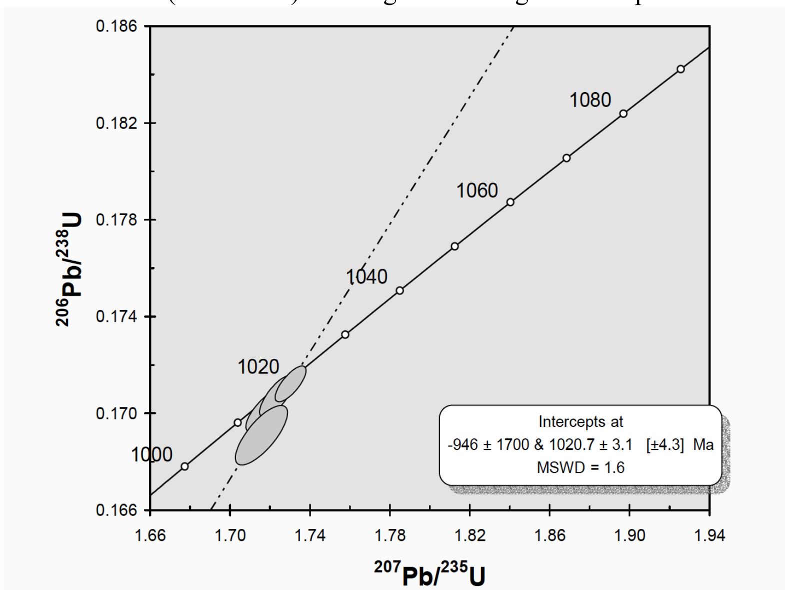


Figure 8. U/Pb isochron plots for samples from the Dana Hill Metagabbro

The $^{39}Ar/^{40}Ar$ results for hornblende in these samples is presented in figure 9. These data mark the date at which these samples cooled through the 500-550°C closure temperature for hornblende. The data from this and outcrop A-4 (opposite side of the road) are quite interesting. The results yield two cooling ages: one at ~985-1000 Ma and a second (recorded in two shear zones) of ~935-940 Ma. The latter and younger ages were determined from two samples at this outcrop. The 945 Ma age was used by Streepey et al. (2001) to constrain the timing of the last stage of movement along the CCSZ. Only one of these samples (CR-2A2) yields a statistically clear plateau. Both shear zones are overprinted by the later brecciation event and, therefore, may have suffered some Ar loss during this event. Conversely, hornblende overgrowths on undeformed cumulate textured Dana Hill Metagabbro sample from the outcrop across the road also yield a 945 Ma age indicating hornblende growth at this time. Whether or not the 945 Ma age represents renewed deformation remains a point of controversy. The bulk of the shear zones and veins studied in the Dana Hill Metagabbro (and surrounding Diana Syenite body) record $^{39}Ar/^{40}Ar$ hornblende cooling ages of 985-1010 Ma. The generally flat spectra for $^{39}Ar/^{40}Ar$ data indicate rapid cooling with little to no post-closure disturbance.

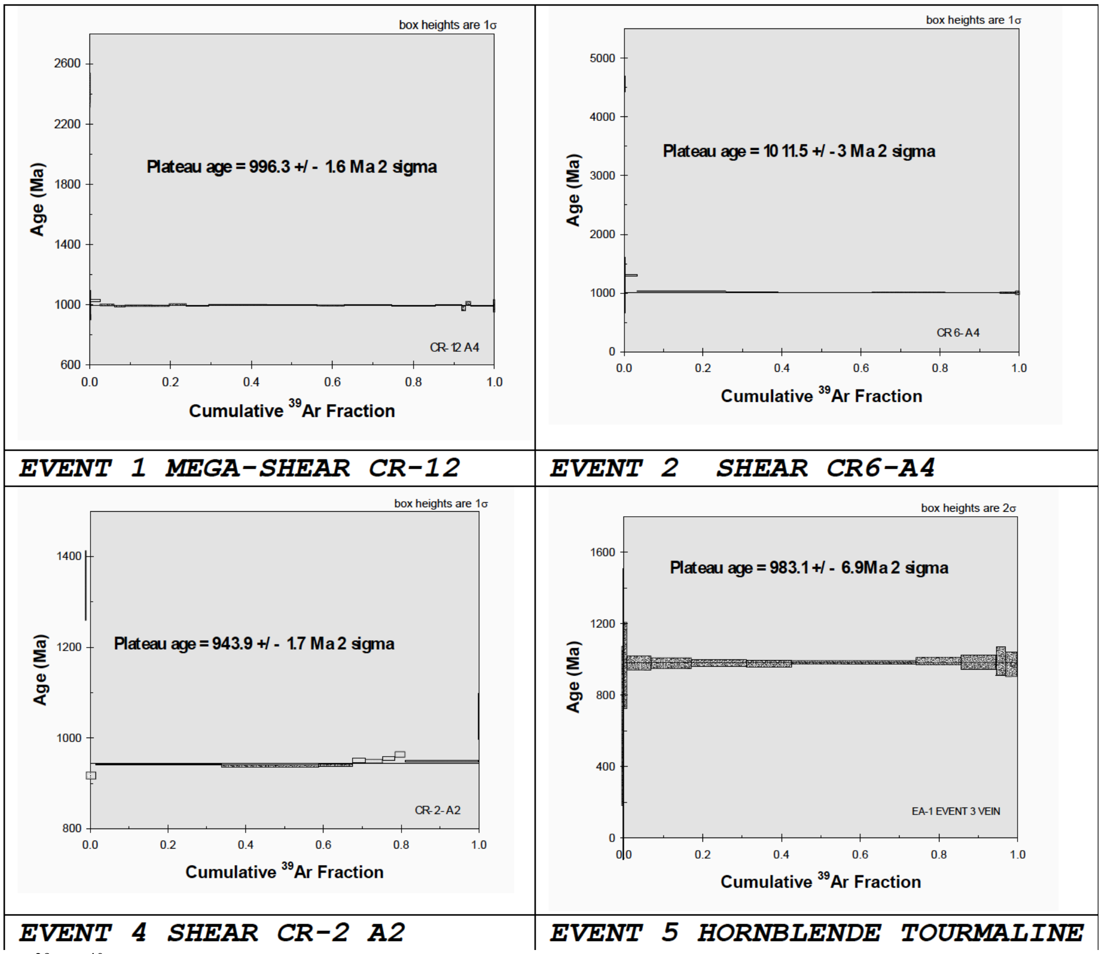


Figure 9. $^{39}Ar/^{40}Ar$ data from samples of Dana Hill Metagabbro.

The Dana Hill Metagabbro outcrops visited today provide an overview of the deformational and thermal history associated with movement along the CCSZ. Since this body is located at the CCSZ detachment, it records the entire deformational history. During exhumation of the footwall (Highlands), the width of the deformation zone narrows with falling temperature and confining pressure and eventually, deformation is confined to regions directly adjacent to the detachment surface. Due to its the resistance to strain, preexisting deformational fabrics in the Dana Hill body were not completely overprinted, leading to the complexly deformed body that we see today. Deformation in the Dana Hill can be broken down into three distinct regimes with falling temperature and pressure: 1. mega-shearing, 2. sub-meter width shearing, 3. brittle failure. Early veining episodes may have been driven by fluid infiltration into the body (driving scapolite and high Cl hornblende-forming reactions). The origin(s) of these fluids (CO2 and HCl/NaCl rich) is unknown, but a likely source is from exhalation/mobilization of evaporite deposits in the adjacent lowlands hanging wall block. This origin for the metasomatic fluids fits well with the observed and widespread scapolite veining and scapolite replacement of original plagioclase feldspar in the lowlands near Pierrepont (Tyler, 1980; Selleck , pers. comm.).

44.9 Continue east on Co Rd 24 for 1.8 mi. Turn right on on Co Rd 24

Note, this is different from the 2005 FOG guidebook; the bridge in Russell was closed earlier in the summer

49.9 Continue on Co Rd 17, turns into Clare Rd/Fine-Canton-Lisbon Rd heading north from Degrasse.

52.7 Continue north on Fine-Canton-Lisbon Rd (Co Rd 27) to the intersection with Donnerville Road, across from large roadcuts. Pull over.

STOP 4: LYON MOUNTAIN LEUCOGRANITE, MYLONITE, AND ULTRAMYLONITE AT BROUSES CORNERS
Brouces Corners (LAT-LONG 44.44050 -75.06017)

Dark mylonitic gneiss and coarse calcsilicate granulite are intruded by coarse, pink leucogranite pegmatite at this locality (Figure 10). Strong foliation in the mylonitic gneiss and local bands of ultramylonite dip gently northwest with a prominent NW-trending lineation. The pegmatite contains xenoliths of mylonitized wall rock and pegmatite veins invade and crosscut mylonitic foliation. However, the pegmatite shows mylonitic deformation along portions of its intrusive margins. One m-scale mass of pegmatite forms a large strain sigmoid indicating deformation consistent with a top-NW sense of shear. These field relationships suggest that the pegmatite was intruded during the waning phases of mylonitization and provides a key age constraint on deformation. Pseudotachylite veins crosscut mylonitic foliation but do not apparently crosscut granite pegmatite. Note the quartz veins within the tabular pegmatite masses; the veins appear to have formed as extension fractures within the pegmatite. Some quartz veins are strongly mylonitic.

Zircons from sample BC-PEG, a coarse, undeformed pink granite pegmatite, are equant, and faintly zoned in CL and BSE images (Figure 11). These analyses (based on 9 spot ages) yield a mean age of 1044 ± 7 Ma (Selleck, et al. 2005), which overlaps within error the ages of leucogranite at Indian River Road and Selleck's Corners. This age fixes the timing of mylonitic strain, as the pegmatite intrudes mylonitic rock but is itself mylonitized along its margins. The pegmatite does not contain pseudotachylite veins, suggesting that these veins developed prior to pegmatite intrusion, although no unequivocal crosscutting relationships have been observed.

Petrographic and electron backscatter diffraction (EBSD) analyses provide further insight into the kinematics of this late Ottawan deformation. Kinematic indicators in the mylonites and ultramylonites include sigma-type porphyroclasts and a strong oblique grain shape fabric that is well developed in quartz-rich mylonites (Figures 12 and 13). These kinematic indicators consistently indicate a top-NW sense of shear. Petrographic observations suggest that quartz largely was dynamically recrystallized by sub-grain rotation (SBR) recrystallization, which typically occurs between 400-500°C (Stipp et al., 2002). EBSD analyses of these mylonites yield strong lattice preferred orientations (LPO), with c-axes showing patterns that are a combination of single girdle and y-strain axis maxima (Fig. 13). This pattern suggests quartz deformation via a combination of rhomb and prism <a> slip, which is also consistent with deformation temperatures of 400-500°C (e.g. Law, 2014), matching the petrographic data. A-axes patterns also illustrate a sense of rotation consistent with a top-NW sense of shear consistent with other kinematic indicators. Taken together, these data are consistent with the interpretation of extensional motion on the CCSZ during late Ottawan time and that deformation continued through cooling to upper greenschist-facies temperatures following peak metamorphism.

Figure 10. Interlayered pegmatitic leucogranite and mylonite/ultramylonite at Brouses Corners. Note contact relationships between pegmatite and mylonite and possible mylonitic xenoliths in pegmatite. Scale in cm.

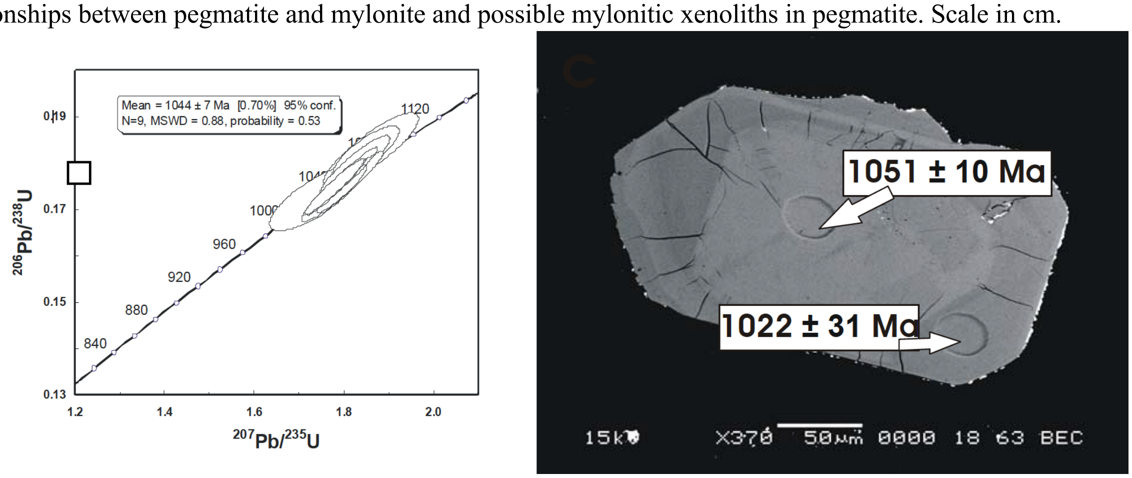


Figure 11. Left - Concordia diagram of SHRIMP results from Brouses Corners pegmatite yielding a mean age of 1044 ± 7 Ma. Right - Typical pegmatite zircon from Brouses Corners pegmatite showing SHRIMP analysis spots. BSE image.

Figure 12. Left - σ−type grain-tail complex around pyrite spheroid in ultramylonite, Brouses Corners; shear sense indicates top down to the northwest transport. Dark bands are magnetite-rich. Width of field is ~12 mm. Right - Pseudotachylite in mylonitic gneiss, Brouses Corners. Note crosscutting relationship with mylonitic foliation. Dark, microlitic-textured areas are ksp+qtz+mag. Width of field is ~ 10 mm.

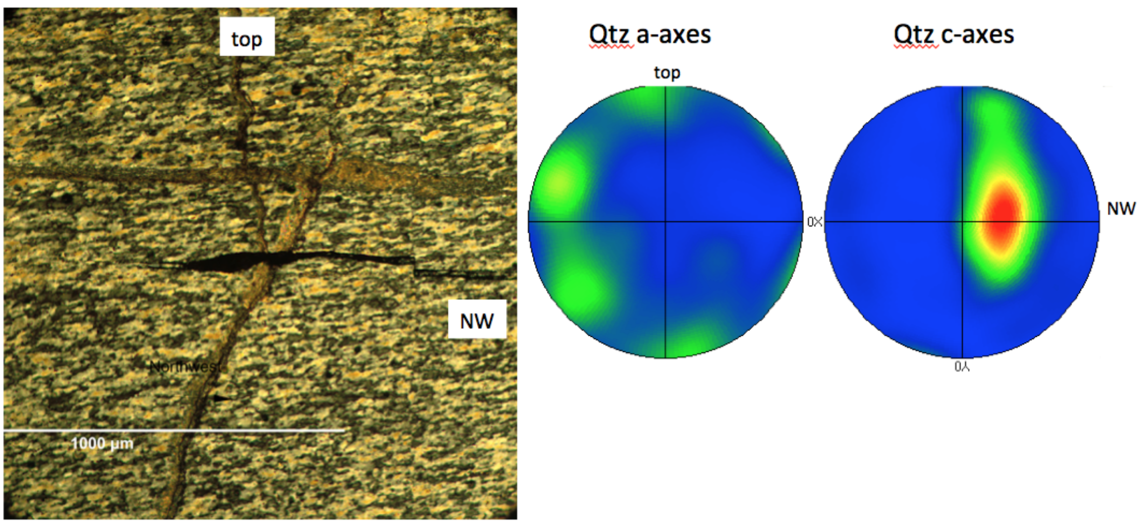


Figure 13. Left - Photomicrograph of mylonitic quartz vein at Brouses Corners showing clear top-NW sense of shear indicators such as the sigma-porphyroclast of hematite and a strong oblique grain shape foliation in quartz. Quartz dynamic recrystallization is dominated by sub-grain rotation (SBR) recrystallization. Field of view is ~1.4 mm. Right - Orientations of a and c-axes in quartz from this sample showing the development of a strong lattice preferred orientation (LPO). C-axes show a combination of single girdle and Y-axis maximum patterns indicating a combination of rhomb and prism <a> slip during deformation.

55.7 Continue north on Co Rd 27 (becomes Stone School- Waterman Hill Rd). Turn right onto Clare Town Line-Pierrepont Center Rd (Co Rd 24).
56.9 Turn right on Selleck Road.
57.9 On the right is the turnoff to the world-class Selleck Road mineral collecting locality, where spectacular tremolite, diopside, tourmaline, and other minerals can be collected from high grade marble on state land (Chamberlain et al., 2016).
60.7 On the left is the farm where Bruce Selleck grew up, and the one-room school-house where he attended Elementary School.
60.8 Turn right onto *Buck Pond Rd.*
62.0 Park on the right next to small outcrops.

STOP 5: SYNTECTONIC LYON MOUNTAIN GRANITE WITH QUARTZ-SILLIMANITE SEGREGATIONS
Buck Hill Road near Sellecks Corners (LAT-LONG 44.47166 -74.98360)

Numerous natural outcrops and small road cuts along Buck Pond Road expose quartz-microcline and quartz-mesoperthite leucogranite with common centimeter- to meter-scale quartz-sillimanite segregations, veins, and nodules. The leucogranite is locally gneissic with northwest-dipping banding. Quartz-sillimanite segregations (Figure 14) are commonly drawn out into elongate, cm-scale rods surrounded by equigranular quartz- mesoperthite granite. Sillimanite crystals form a mineral lineation in deformed segregations, but these oriented segregations are also crosscut by slightly later granitic veins that contain sillimanite. Sillimanite is often partially replaced by muscovite. Networks of quartz-sillimanite veins, quartz-sillimanite ribbons, and smaller quartz-sillimanite segregations and nodules are interpreted as representing progressively dismembered magmatic-hydrothermal features, forming via leaching of granite and granitic magma by Cl-rich, acidic fluids during granite pluton emplacement (McLelland et al. 2002). Equigranular, coarse, pegmatitic quartz-microperthite granite surrounds some quartz-sillimanite in strain sigmoids that indicate a top-down to the northwest transport. Outcrops of leucogranite south of Buck Pond Road are more massive and contain diffuse pegmatitic zones and quartz veins typical of the Lyon Mountain granite of the Adirondack Highlands. This quartz-sillimanite nodular granite is mappable for ~ 12 km along strike to the southwest as a 1-2 km wide belt immediately southeast of the mapped extent of the CCSZ.

This outcrop was sampled for U-Pb SHRIMP zircon geochronology (Selleck et al. 2005). Zircons were separated from coarse-textured quartz-microperthite granite that forms a 10-cm-thick band irregularly intrusive into quartz-sillimanite nodule–bearing quartz-microcline gneiss. Nine age determinations on well-developed, oscillatory-zoned rims (Figure 15) give a weighted mean age of 1046 ± 7 Ma. We interpret this result as documenting intrusion of 1046 Ma granite during active extension on the Carthage Colton shear zone at this site.

Figure 14. Left - σ–type strain marker formed by quartz-sillimanite segregation surrounded by equigranular leucogranite. View looking northeast; tectonic transport is top down to the northwest. Right - Quartz-sillimanite segregations in leucogranite. Q-S segregations are elongate nodules; long axes plunge NW. Note equigranular texture of granite between q-s segregations. Knife is ~12 cm long.

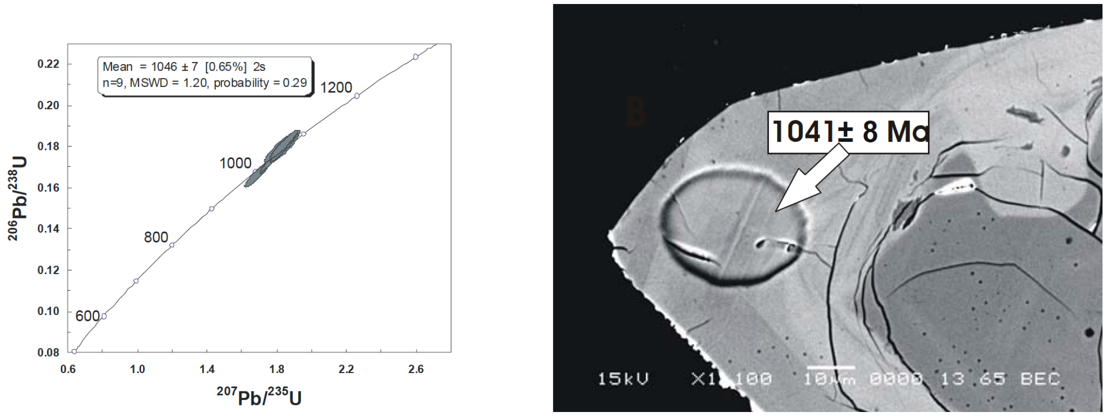


Figure 15. Left - Concordia plot of SHRIMP data from oscillatory-zoned igneous rims on zircons from leucogranite at Buck Pond Road. Right - BSE image of zircon showing SHRIMP analysis pit. Note the fine-scale zoning that is accentuated by ion beam milling.

Figure 16. Polished slab of quartz-sillimanite granite from Buck Pond Road locality showing relationships between quartz-sillimanite segregations, equigranular leucogranite, gneissic ‘country rock’ and quartz veins. Note magnetite within quartz-sillimanite nodule at right-center. Slab is approximately 25 cm wide.

Thank you for joining us on this field trip in honor of the memory of Bruce Selleck.
Mileage to Lake George via Tupper Lake is 132 miles, two and a half to three hours drive.
The Welcoming Reception in Lake George is from 5:30 to 8:00 PM.

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