Trip A-5

THE NATURE AND TECTONIC SIGNIFICANCE OF THE CARTHAGE COLTON SHEAR ZONE: ADIRONDACK MOUNTAINS, NEW YORK STATE.

Eric Lee Johnson
Hartwick College
Department of Geology and Environmental Science
Oneonta, NY 13820
Johnsone@hartwick.edu

ABSTRACT

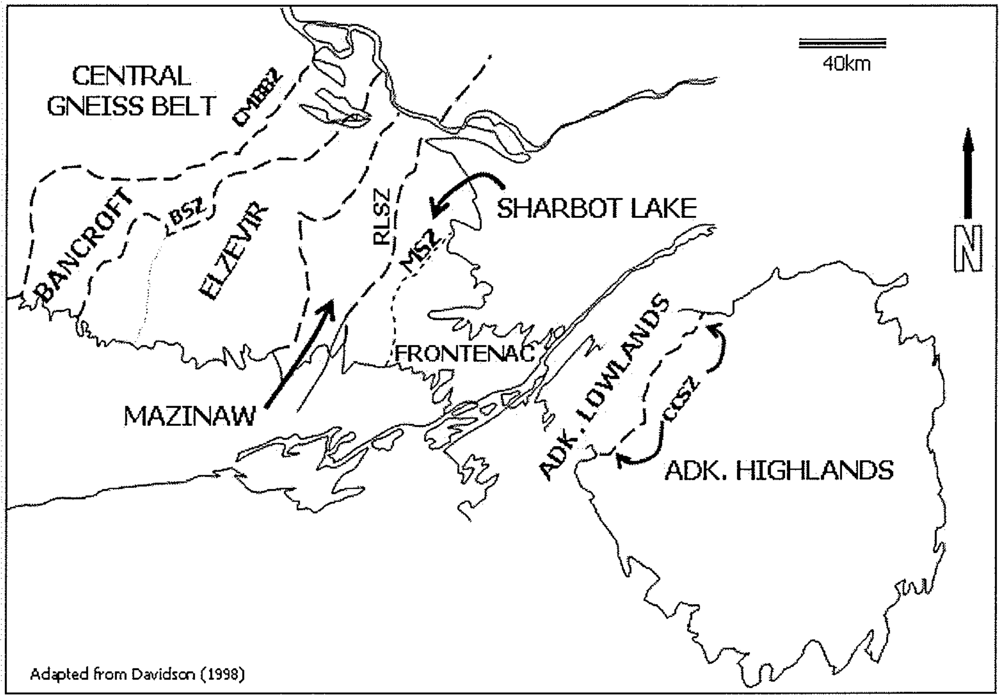
This trip will examine the nature and geologic significance of the Carthage-Colton Shear Zone (CCSZ) and late to post-Ottawan intrusive activity along this zone. The CCSZ marks the boundary between the Central Metasedimentary Belt and the Central Granulite Terrane (Frontenac-Adirondack Belt). The significance of this shear zone and the bounding terranes has been a matter of continued debate. This trip will analyze field, geothermometric, and geochronologic relationsips along several transects across the CCSZ with the goal of better elucidating the nature and timing of this complex and enigmatic structure.

INTRODUCTION

Grenville-aged rocks to the south and east of the Grenville Front Tectonic Zone (GFTZ) are subdivided into a number of terranes with differing tectonothermal histories that are separated from one another by shear zones (Davidson, 1986: Rivers et al., 1989: see figure 1). Using the terminology of Wynne-Edwards (1972) and Davidson (1986; 1998), from west to east these terranes are the Central Granulite Belt (CGB), the Central Metasedimentary Belt (CMB) consisting of the Bancroft, Elzevir, Mazinaw, Frontenac and Adirondack Lowlands Terranes and the Adirondack Highlands which belongs to the Central Granulite Terrane (CGT) (see figure 1). Conversely, Carr et al (2000) breaks the NE Canadian/US Grenville Province into three belts: the pre-Grenvillian Laurentian margin, The Composite Arc Terrane, and the Frontenac-Adirondack Belt. For the purpose of this discussion, we will utilize the Wynne-Edwards (1972)/ Davidson (1998) terminology.

Ductile shear zones ranging from greenschist through granulite grade separate the various terranes and are the critical link to understanding the overall tectonic development of this region. On this trip we will examine the nature and timing of activity along the Carthage-Colton Shear Zone which separates rocks belonging to the Central Granulite Terrane (CGT: Adirondack Highlands) and the Central Metasedimentary Belt Terrane (CMB: Adirondack Lowlands).

Geologic/tectonic relationships between the CMB and CGT and the role of the CCSZ have been a matter of some debate. Geraghty et al. (1981) and Isachsen and Geraghty (1986) interpret the CCSZ to represent a through-crustal shear zone along which the CMB terrane was thrust over the CGT terrane during the 1.1 billion year old Grenville Orogeny. Wiener (1983) interprets the CCSZ to represent the lower limb of a large fold-thrust nappe and does not view the CCSZ as a boundary between separate (or once separate) terranes. Isotope data (U/Pb; $^{40}Ar/^{39}Ar$), however, support the assertion that the CCSZ does indeed separate two terranes with differing thermal histories (McLelland, et al.1993a: Mezger et al. 1991: Mezger et al., 1993). Isotopic evidence clearly show the Adirondack Highlands Terrane (CGT) reached granulite facies conditions during the 1030-1070 Ma Ottawan Orogeny (McLelland and Chiarenzelli, 1990) while isotopic data from the Adirondack Lowlands Terrane suggest that maximum temperatures in never exceeded 400°C at this time (Mezger et. al, 1993: McLelland et al. 1993a). Both terranes, however, contain 1155 Ma AMCG suite magmas leading to an unusual history in which the CGT and CMB are together prior to and during the ~1155 Ma event, separate during the 1050-1070 Ma Ottawan event and then reunited at some later time. Mezger et al. (1992) identify the CCSZ as a major crustal collapse structure that juxtapose the CMB and CGT rocks syn- to-post-Ottawan Orogeny. Mezger et.al. (1992) propose that the CMB and CGT terranes where separated by the opening of a small ocean basin (post 1150Ma) allowing these two terranes to follow different P-T-t paths during the Ottawan Orogeny. An alternative view is that the CMB and CGT rocks were united since the 1160 Ma event but that the CMB rocks during the Ottawan Orogeny were at too high of a structural level in the crust to undergo significant thermal heating. In this model, late to syn-Ottawan collapse along the CCSZ juxtapose the two terranes at their current structural level (Mezger et al., 1992: McLelland et al. 1993b). Zones of ductile deformation in the Diana Complex, a CMB lithology, record retrograde conditions of 400-550°C at pressures of 3 to 5 kbar which Lamb (1993) attributes to late activity along the CCSZ during slow uplift and cooling. Zhao et al. (1997) and Martignole and Reyonlds (1997) report granulite-grade strike-slip movement along the Labelle and Morin Shear Zones in Quebec, Hanmer et. al (2000) report 1.09-1.06Ga oblique sinistral movements along the Tawachiche Shear Zone, and Streepey et al. (2001) and Johnson et al. (2004) report oblique dextral movements along the CCSZ introducing the possibility that lateral displacements may be important during the Ottawan phase of the Grenville Orogeny. In all of these models, the precise role of the CCSZ (and Labelle Shear Zone/Tawachiche Shear Zone) is the critical link to understanding the tectonic relationship(s) between the CMB and CGT.



Adapted from Davidson (1998)

FIGURE 1 Map of the Grenville Province showing the various terranes and their bounding shear zones. CCSZ=Carthage Colton Shear Zone: RLSZ= Robertson Lake Shear Zone: MSZ = Mazinaw Shear Zone: BSZ=Bancroft Shear Zone: CMBBTZ = Central Metasedimentary Belt Boundary Zone.

Excellent exposures of highly-deformed and variably metamorphosed rocks belonging to the CMB, and CGT along the CCSZ form the basis for this field trip and we will cross the CCSZ at several locations in the Harrisville, Fine, South Edwards, and Hermon 7.5 minute quadrangles. Detailed descriptions are presented in the road log. The Carthage Colton Shear Zone is not a simple boundary between adjacent terranes as it has been partially dissected and offset by later (post Ottawan) ductile and brittle events. We will examine several of these on this trip and discuss their relationship to zones of economic mineralization in the region. The overall goal of this field guide is to examine the existing models which attempt to relate the tectonic development of the Adirondack Highlands and Lowlands Terranes and the role of the Carthage Colton Shear Zone in this history.

This trip will focus on the wealth of geochronologic data that has recently been collected in and along the CCSZ. In addition, this guide presents new and previously unpublished U/Pb and $^{39}Ar/^{40}Ar$ cooling dates collected across the CCSZ. The complexity of the CCSZ in terms of deformation and mineralization events is well documented and we will focus on differences in deformation extent and style as we cross the CCSZ. These observations and data pose interesting challenges to existing models for the role of the CCSZ and relationships between the Adirondack Highlands and Lowlands Terranes. One major area of controversy is the exact timing of juxtaposition of the Adirondack Highlands and Lowlands Terranes. Critical to this discussion is the nature and timing of widespread metasomatic alteration of rocks in both the Lowlands Terrane (hanging wall) and Highlands Terrane (footwall) near to the CCSZ detachment surface. This event is marked by widespread scapolite replacement of plagioclase feldspars, and the emplacement of hornblende + scapolite and scapolite veins in both the footwall (Highlands) and hanging wall (lowlands) of the CCSZ. This metasomatism is critical to understanding the relationship between the Highlands and Lowlands Terranes during late Ottawan time because it marks a common event for both terranes. In the Dana Hill Metagabbro (Highlands), scapolite growth corresponds with the injection of thousands of hornblende veins into the gabbro which is constrained by U/Pb dating to occur prior to 1020 Ma. In the Diana Syenite Complex (Lowlands), scapolite growth occurs in shear zones dated to 1040-1052 Ma. These data and observations argue that the Adirondack Highlands and Lowlands Terranes were near to a common structural level as early as 1050Ma. At this time, these two terranes would be at very different temperatures requiring a pronounced thermal gradient (100°C) exist across the CCSZ at least until 1000 Ma.

At several locations, we will examine late syn-orogenic granitic intrusions that decorate the footwall (Highlands) along the CCSZ. These granite bodies are variably deformed and belong to the 1050 Ma Lyon Mountain Suite (McLelland et al., 2001). The abundance of these granite bodies near to and along the CCSZ suggests a causal relationship may exist between CCSZ movements and granite emplacement.

A NEW TECTONIC MODEL

Field, isotopic, and petrologic data from the CCSZ are tantalizingly similar to those reported from recent studies of rapidly exhumed granulite cores in the modern day Himalayan Mountains (Wobus et al., 2003). Zeitler et al. (2001) describe these rapidly exhumed granulites (Nanga Parbat) as tectonic aneurisms triggered by orogenic compression coupled with rapid surface denudation. Pronounced (100°C+) thermal gradients exist across the bounding shear

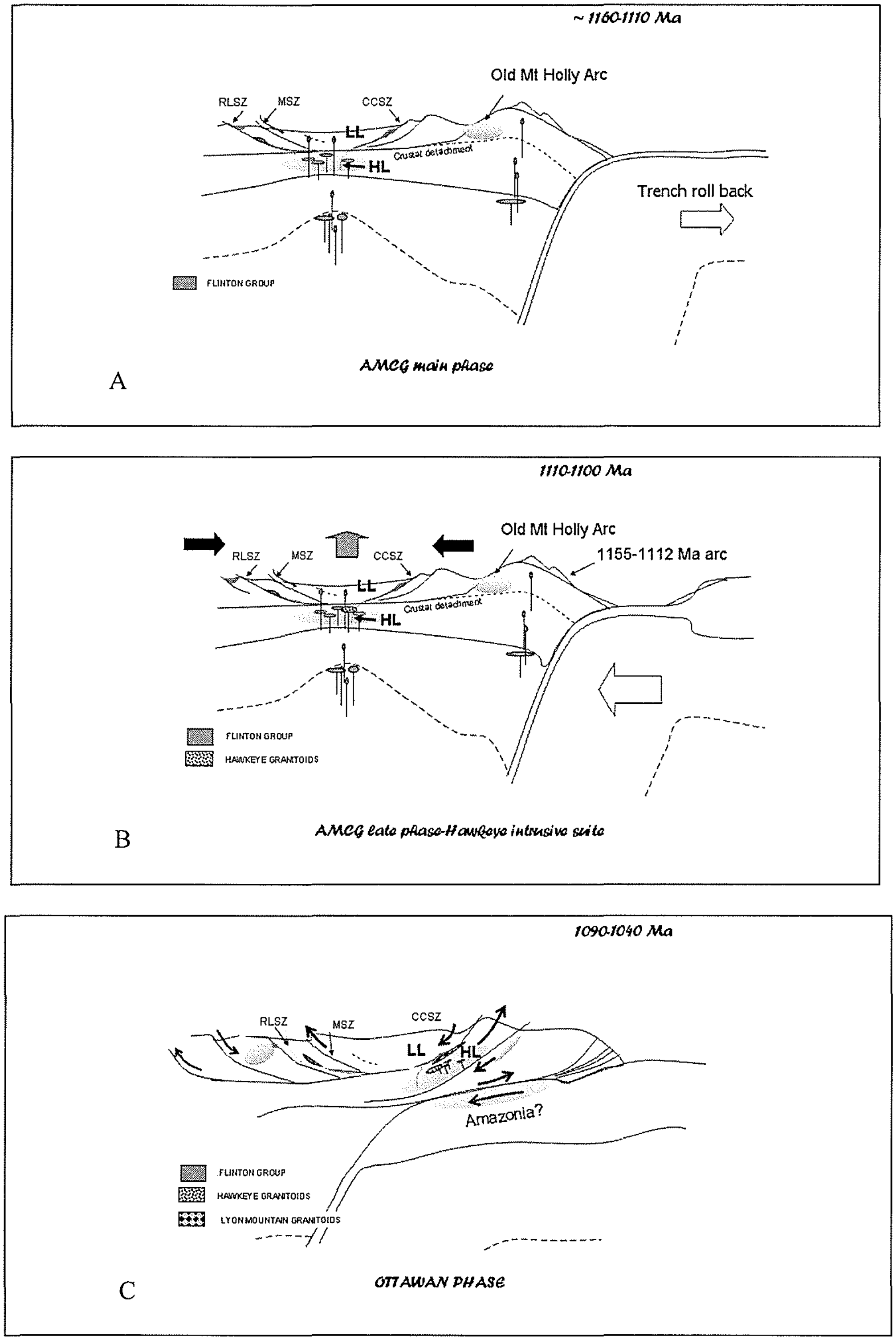


Figure 2. Tectonic cross-sections showing the development of a crustal channel. LL=Adirondack Lowlands Terrane: HL = Adirondack Highlands Terrane. All other abbreviations as in Figure 1.

zones, and the exhuming granulite core undergoes pressure release melting forming A-type granites. These granites intrude along the bounding shear zones (Zietler et al., 2001). Because of the rapid exhumation, rocks across the bounding shear zones record very different thermal histories. This is a very similar scenario to what we will observe along the CCSZ on this trip and I propose that we may be looking at the top of a crustal channel that developed during peak to post peak Ottawan time. Tectonic cross-sections (figure 2a-c) show the basic elements of how the crustal channel model is applied to the tectonic development of this portion of the Grenville.

RELEVANT REFERENCES

Bohlen, S.R., Valley, J.R., and Essene, E.J., 1985, Metamorphism in the Adirondacks: I. pressure and temperature: Journal of Petrology, v. 26, p.971-992.

Buddington, A.F., 1939, Adirondack igneous rocks and their metamorphism, Geological Society of America Memoir 7, 354p.

Carr, S.D., Easton, R.M., Jamieson, R.A., and Culshaw, N.G., 2000, Geologic transect across the Grenville orogen of Ontario and New York: Canadian Journal of Earth Science, v. 37, p. 193-213.

Dahl, P., Foland K., Pomfrey M., 2001, ^{40}Ar/^{39}Ar Thermochronology of hornblende and biotite, Adirondack Lowalands (New York), with implications for evolution of a major shear zone: Geological Society of America Abstracts with Programs, v.33, n. 6, p A292.

Davidson A., 1986. New Interpretations in the southwestern Grenville Province, Ontario. In: Moore JM, Davidson A, Baer AJ, eds: The Grenville Province. Geological Society of Canada Special Paper 31, pp. 61-74.

Davidson A. 1998. An overview of Grenville Porvince geology. Canadian Shield: in Lucas S.B., and St-Onge, M.R., eds., Geology of the Precambrian Superior Province andPrecambrian fossils in North America, Geology of North AMerica Series (DNAG), v.7, p. 207-270.

Davis, M.E., 1981, Petrology and geochemistry of a portion of the Carthage-Colton Mylonite Zone, South Edwards 7.5 minute Quadrangle, NW Adirondacks, New York [M.A. thesis]: State University of New York at Binghamton.124 p.

Ellis, D. M., 1978, Stability and phase equilibria of chloride- and carbonate-bearing scapolites at 750°C and 4000bar: Geochemica et Cosmochimica Acta, v. 42, p. 1271-1281.

Geraghty, E.P,. Isachsen, Y., and Wright, S.F., 1981, Extent and character of the Carthage-Colton Mylonite Zone, Northwest Adirondacks, New York: New York State Geological Survey Report to the U.S. Nuclear Regulatory Commission, 83p.

Hall, P. C.,1984, Some aspects of deformation fabrics along the highland/lowland boundary, Northeast Adirondacks, New York State: [M.S. thesis], State University of New York, Albany, NY, 86p.

Hanmer, S., Corrigan, D., Pehrsson, S., and Nadeau, L., 2000, SW Grenville Province, Canada: the case against post-1.4 Ga accretionary tectonics: Tectonophysics, v. 319, p. 33-51.

Harrison, T.,1981 Diffusion of ^{40}Ar in hornblende: Contributions to Mineralogy and Petrology, v. 78, p. 324-331.

Heyn, T.,1990, Tectonites of the northwest Adirondack Mountains, New York: Structural and metamorphic evolution[PhD.thesis]: Cornell University, 216p.

Holland, T., and Blundy, J., 1994, Non-ideal interactions in calcic amphiboles and their bearing on amphibole-plagioclase thermometry: Contributions to Mineralogy and Petrology, v. 116, p. 443-447.

Indares, A., Martignole, J., 1990, Metamorphic constrains on the tectonic evolution of the allochthonous monocyclic belt of the Grenville Province, western Quebec: Canadian Journal of Earth Sciences, v. 27: p. 371-386.

Isachsen, Y., and Geraghty, E.P., 1986, The Carathage-Colton Mylonite Zone: a major ductile fault in the Grenville Province: International Basement Tectonics Association Proceedings, v. 6, p.199-200.

Johnson E.L., Fruchey B.L. and Goergen E.T, 2004, Right lateral oblique slip movements followed by post-Ottawan (1050-1020Ma) orogenic collapse along the Carthage-Colton shear zone: Data from the Dana Hill metagabbro body, Adirondack Mountains, New York: in: Tollo R.P. COrriveau,L., McLelland J. and Bartholomew M.J., eds., Proterozoic tectonic evolution of the Grenville Orogen in North America: Boulder, Colorado, Geological Society of America Memoir 197, pp. 357-378.

Johnson, E.L. and Bryan, K., 2002, Sillimanite + quartz replacement of K-feldspar in late to post Ottawan granite bodies in and adjacent to the Carthage Colton Shear Zone, NW Adirondack Mtns. New York State: A case of fluid driven auto-metamorphism?:Geological Society of America Abstracts with Programs, v. 34 ,no. 1, p. A6.

Lamb, W.M.,1993, Retrograde deformation within the Carthage-Colton mylonite zone as recorded by fluid inclusions and feldspar compositions: Tectonic implications for the southern Grenville Province: Contributions to Mineralogy and Petrology, v. 14, p. 379-394.

Martignole, J., Reynolds, P., 1997, ^{40}Ar/^{39}Ar thermochronology along a western Quebec transect of the Grenville Province: Canada: Canadian Journal of Earth Science, v. 15, p. 283-296.

McLelland, J.M., Chiarenzelli, J., Whitney, P,. and Isachsen, Y., 1988, U-Pb zircon geochronology of the Adirondack Mountains and implications for their tectonic evolution: Geology, v. 16, p.920-924.

McLelland, J. M., Chiarenzelli, J., 1990, Isotopic constraints on emplacement age of anorthositic rocks of the Marcy massif, Adirondack Mountains, New York: Journal of Geology, v. 98, p. 19-41.

McLelland, J.M., Isachsen, Y., Whitney, P., Chiarenzelli, J., and Hall L., 1993a, Geology of the Adirondack Massif, New York, in Rankin, D., ed., The Geology of North America: Precambrian Conterminous, U.S.: The Geological Society of America, v. C-2, p. 338-353.

McLelland, J.M., Daly, J.S., Chiarenzelli, J.,1993b, Sm-Nd and U-Pb isotopic evidence of juvenile crust in the Adirondack Lowlands and implications for the evolution of the Adirondack Mountains: Journal of Geology, v. 101, p. 97-105.

McLelland, J.M., McLelland J, Walker, D., Orrell, S., Hamilton, M., and Selleck, B. 2001, Zircon U-Pb geochronology of the Ottawan Orogeny, Adirondack Highlands, New York, Regional and tectonic implications: Precambrian Research, v. 109, no. 1-2, p. 39-72.

McLelland, J.M., Olson, C., Orrell, S., Goldstein A, and Cunningham, B., 2002, Structural evolution of a quartz sillimanite vein and nodule complex in a late to post tectonic leucogranite, Western Adirondack Highlands, NY, Journal of Structural Geology, v. 24, no 6-7, p. 1157-1170.

Mezger, K., Essene, E.J, van der Pluijm, B.A., and Halliday, A.N.,1993, U-Pb geochronology of the Grenville Orogen of Ontario and New York: constraints on ancient crustal tectonics: Contributions to Mineralogy and Petrology, v. 114, p. 13-26.

Mezger, K., van der Pluijm, B.A., Essene, E.J., and Halliday, A.N.,1992, The Carthage Colton Mylonite Zone (Adirondack Mountains, New York): The site of a cryptic suture in the Grenville Orogen?: The Journal of Geology, v. 100, p. 630-638.

Mezger, K., Rawnsley, C.M., Bohlen, S.R., and Hanson, G.N., 1991, U-Pb garnet, sphene, monazite, and rutile ages: Implications for the duration of high-grade metamorphism and cooling histories, Adirondack Mts. New York: Journal of Geology, v. 99, p. 415-428.

Mora, C.I., and Valley, J., 1989, Halogen-rich scapolite and biotite: Implications for metamorphic fluid-rock interactions: American Mineralogist, v. 74, p. 721-737.

Parodi, M.R., 1979, Petrology, structure, and geochemistry of the Dana Hill Metagabbro, Russell, New York [M.A. thesis]: State University of New York at Binghamton, Binghamton, NY, 120p.

Rebbert, C., Rice, J., 1997, Scapolite-plagioclase exchange: Cl-CO_3 scapolite solution chemistry and implications for peristerite plagioclase: Geochimica et Cosmochimica Acta, v. 61, no. 3, p. 555-567.

Rivers, T., Martignole, J., Grower, C., Davidson, A., 1989, New Tectonic Divisions of the Grenville Province: Tectonics, v. 8, p. 63-84.

Streepey, M., Johnson, E. L., Mezger, K., van der Pluijm, B., and Essene, E.J., 2001, Early history of the Carthage-Colton shear zone, Grenville Province, Northwest Adirondacks, New York (U.S.A.) , New York: Journal of Geology v. 109, p. 479-492.

Tyler, R.D., 1980, Chloride metasomatism in the southern part of the Pierrepont Quadrangle, Adirondack Mountains, New York [Ph.D. thesis]: State University of New York at Binghamton, Binghamton, New York, 527p.

Wiener, R.W., 1983, Adirondack Highlands-Lowlands 'boundary': a multiply folded intrusive contact with fold-associated mylonitization:. Geological Society of America Bulletin, v. 94, p. 1081-1108.

Wiener, R.W., McLelland, J.M., Isachsen, Y., and Hall, L. M., 1984, Stratigraphy and structural geology of the Adirondack Mountains, New York: review and synthesis, in Bartholomew, M.J., ed., The Grenville Event in the Appalachians and related topics: Geological Society of America Special Paper194, p. 1-55.

Wobus C. Hodges K.V. and Whipple K.X.(2003) Has focused denudation sustained active thrusting at the Himalayan topographic front? Geology, v. 31 no. 10, pp 861-864.

Wynne-Edwards, H.R., 1972, The Grenville Province, in Price, R.A., and Douglas, R.J.W., eds., Variations in tectonic styles in Canada: Geological Association of Canada Special Paper 11, p. 263-334.

Zeitler, P.K, Meltzer A.S., Koons, P.O., Craw, D., Hallet, B., Chamberlain, C.P. Kidd, W.S.F., Park,S.K., Seeber, L., Bishop M.,and Shroder J. (2001) Erosion, Himalayan Geodynamics, and the Geomorphology of Metamorphism: GSA Today, January (2001) pp. 4-8.

Zhao, X., Ji S., Martignole, J., 1997, Quartz microstructures and c-axis preferred orientations in high-grade gneisses and mylonites around the Morin anorthosite (Grenville Province): Canadian Journal of Earth Sciences, v. 34, p. 819-832.

ROAD LOG

Downtown Harrisville: Field trip members assemble at the public parking lot adjacent to the old Scanlon's Bakery.
Travel south on NY route 3 to the intersection of Rt. 3 and Hermitage Road.

3.9 miles
STOP 1 Valentine Wollastonite Mine: Discuss field relationships between the Diana Syenite Body and lowland marbles. Basic goal here is to demonstrate that the Diana Syenite intrudes into lowlands marbles and contact metamorphism drove formation of the Wollastonite.

Note that much of the wollastonite body is at best weakly deformed and so lacks Ottawan deformation.

Return to the vehicles and travel north on NY route 3

4.6 Miles
STOP 2 Big Crop Diana Syenite: Look at pegmatites and shear zones that cut the body. These shear zones vary to greenshcist facies formed during the end of CCSZ deformation.

OPTIONAL
STOP 3 Contact Metamorphism of marble at the Diana Contact (route 813). Once again show a lack of a strong Ottawan deformation. Note that this type of grain coarsened marble can be found in many locations at or near to Diana Syenite contacts.

9.6 Miles At the north end of the town of Pitcairn turn east on Jayville Road.
STOP 4 Jayville Road: Here we will cross into the Adirondack Highlands for the first time. Variations in the orientation of stretching lineation will mark our passage across the CCSZ. In the Lowlands, stretching lineations are more steeply dipping and oriented to the NW, but once we cross the CCSZ, stretching lineations rotate to near strike parallel orientation (NNW).

13.3 Miles

STOP 4A Fault Zone in Diana Syenite. This zone shows both strong ductile and brittle deformational fabrics. The Diana Syenite Body is vertically stacked by several small thrust faults. (Lowlands)

STOP 4B Contact between Diana Syenite and the Border Granite (Lyon Mountain?) Along RR tracks near Topa-da-Hill Road. Is this the Highlands-Lowlands Boundary?

STOP 4C Long Lake Fault Zone (look up the lake at this major lineament). This structure is a brittle normal fault that offsets the CCSZ detachment (SEE FIGURE 1). We will encounter this fault once again at STOP 10. At this location, the Long Lake Fault vertically truncates the CCSZ detachment.

STOP 4D Road south of Jayville Road (ROD and TODD outcrop); note that while to the North of Jayville Road we have passed into the Granite, but here to the south and east, we are still in the Diana Syenite Body. A small east-west trending (strike-slip?) fault offsets the CCSZ (Highlands-lowlands boundary) at this location. This fault passes directly through the Jayville Mine (STOP 4E) and continues (at least in topographic expression) to the east passing through the Benson Mine.

STOP 4E Jayville Mine (stop to look for vonsenite ore) Here we can visit the mine shaft and discuss the amphibolite matrix for the vonsenite ($Fe^{2+}Fe^{3+}{}_2BO_5$) ore and the origin of the boron. Discuss the Lyon Mountain Granite at this local and the presence of felsic quartz-albite facies dikes.. Examine the location of the mine in terms of known brittle and ductile features.

Reset odometer to 0.0 miles Travel NORTH on NY route 3 for 4.5 Miles

STOP 5 Faulting in the Diana Syenite Body. Classic mixture of rock types that characterize the faulted contact between the Diana Syenite Body and lowlands paragneisses including the feldspathic quartzite, marble and diopsidite. Note the strong ductile fabric of these rocks that is overprinted by later brittle faulting.

5 .1 miles
STOP 6 Outcrop of diopsidite skarn. Contact skarn between the Diana Syenite Body and the Balmat Edwards (?) marble. This friable green colored rock is primarily made up of green diopside and grey calcite. (mapped as Tia)

6.1 miles
LUNCH Greenwood Falls Picnic Area. Look at the Diana Syenite Body.

8.4 miles
STOP 7 Diopsidite contact rock (Dia/Tia). Note on the map that these diopsidie contact skarns are found in the middle of the Diana Syenite Body and along its eastern edge, at the CCSZ detachment. This unit is associated with the contact between the Diana Syenite and the Balmat Edwards Marble.

9.6 miles
STOP 8 Once we pass the last outcrop of green diopsidite, we have left the Adirondack Lowlands and entered the Adirondack Highlands Terrane. Pink leucogranite and hornblende granite outcrops underpin the ridge. Our stop is near the intersection of Route 3 and Sykes Road. The contact between the Leucogranitic gneiss and the Irish Hill Gneiss is well exposed in this outcrop. The Irish Hill Gneiss (Whippoorwill Corners Gneiss of Hall ,1981) consists of calc-silicate gneiss (containing calcite + diopside+/- tourmaline) and quartzite with abundant concordant and cross-cutting pegmatites.

10.9 miles
STOP 9 Hornblende granite. This stranded small body of granite differs from those that we have seen on Jayville road. Larger exposures of a similar granite can be found to the north in the South Edwards Quadrangle (Eastern Granite Gneiss of Hall 1981). The granite is moderately deformed at this location.

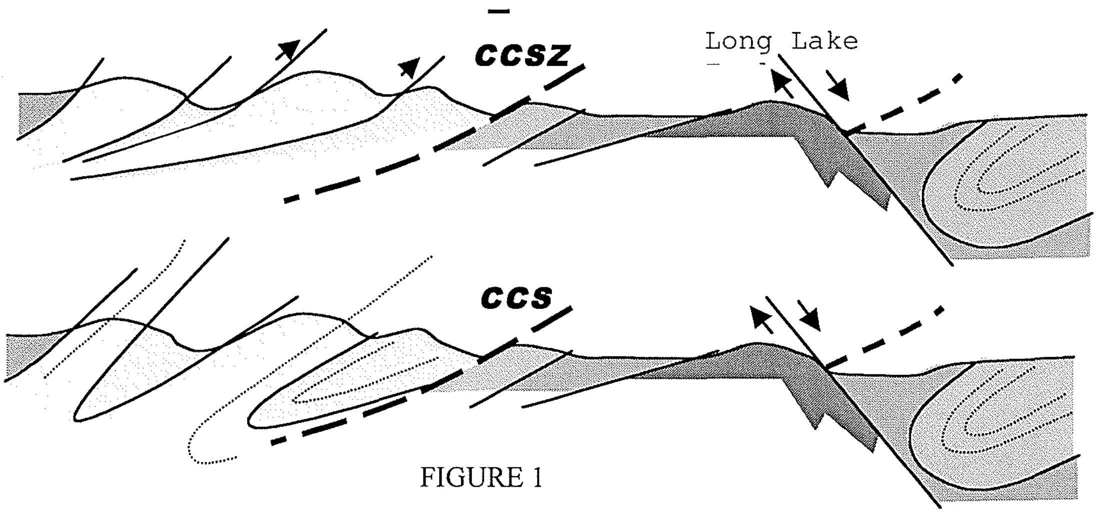


FIGURE 1

11.2 miles

STOP 10 A Faulted Block of the Lowlands: Intersection of NY Routes 58 and 3. Park in the small lot at the intersection of Routes 58 and 3. Directly to the north of the parking lot is a small mine adit. We will start by heading north to the old bridge over the Oswegatchie River. Outcrops to the west (down the slope) are of green Irish Hill Gneiss. The outcrops along the road show a strong brittle deformation and a mixture of rock types. This outcrop contains marble (looks very much like Balmat Edwards Type), bleached syenite-granite, and even some diopsidite. Fluorite crystals have been found in vugs and tension gashes in the marble. This outcrop lies on the trace of the Long Lake Lineament (Fault) and movements on this lineament are the logical cause for the strong brittle overprint observed in these rocks. The intriguing thing about this series of outcrops is that the rock types are more like those of the Lowlands Terrane even though we have crossed the CCSZ and are well into the Highlands at this location. Just 100m west one can find outcrops of Irish Hill Gneiss (Highlands) and to the east (on Route 3) we find pink granite (Highlands Rock) with a strong brittle overprint. This outcrop may represent a block belonging to the Adirondack Lowlands that has been down faulted along the Long Lake Fault (see figure 2).

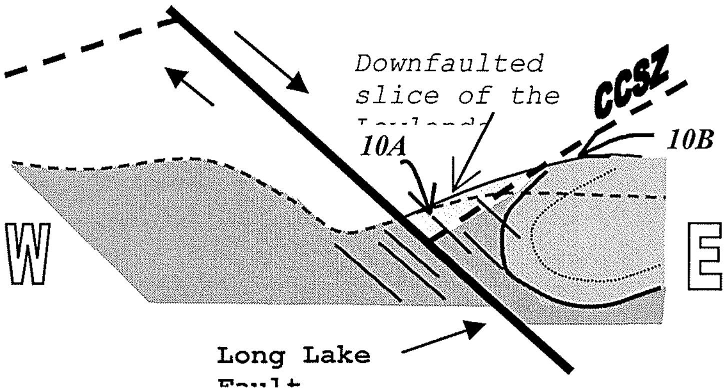


FIGURE 2

STOP 10 B Route 3 Granite gneiss and breccia (Long Lake Fault): Calcite filled breccia in highlands granite gneiss and Irish Hill Gneiss. Both sides of the road.

Return to the vehicles and proceed WEST on Route 58. We will pass several large outcrops of Irish Hill Gneiss and of pink leuco-granitic gneiss. The leuco-granitic gneisses are highly deformed. As we proceed west on Route 58, we will pass through outcrops of hornblende granite gneiss (Eastern Granite Gneiss of Hall, 1981). The Highlands/ Lowlands boundary is constrained between the last outcrop of Eastern Mountain Granite Gneiss and the first outcrop of Diana Syenite (which along Route 58, is also a pink granitic gneiss). The Diana Syenite can be identified by the presence of abundant rounded augens of grey plagioclase feldspar.

13.3-13.4 miles
STOP 11 Two large road cuts expose (or nearly expose) the contact between the pink leuco-granitic gniess and the calc-silicate Irish Hill Gneiss. Here the Irish Hill Gneiss is cut by many coarse pegmatite bodies. Stop 11a: Irish Hill Gneiss. Stop 11b: Leuco-granitic gneiss. We are now nearly due north of STOP 8 (IHG/Lg contact on Route 3).

14.7 miles
STOP 12 Outcrops of strongly deformed leuco-granitic gneiss (Highlands).

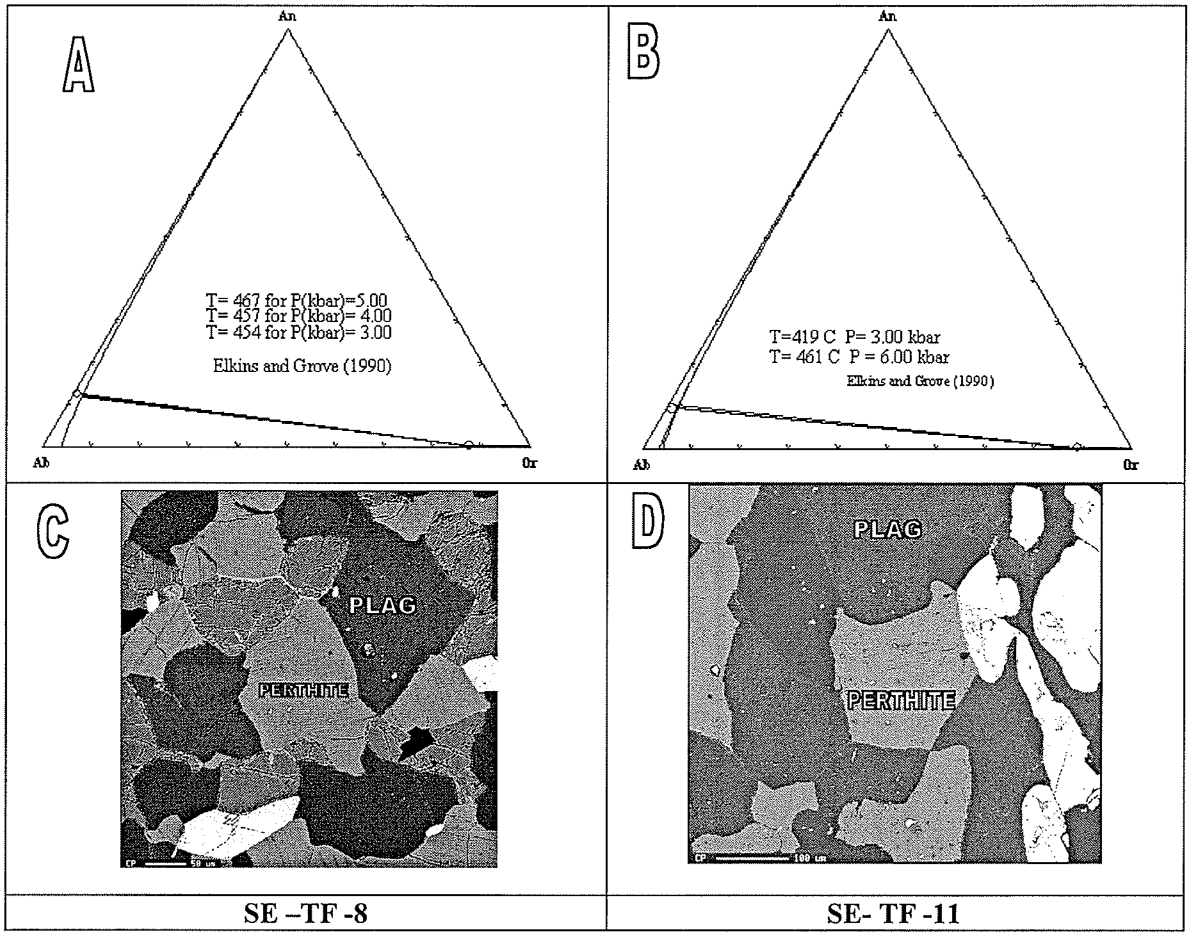
16.2 miles
STOP 13 Roadcut into Diana Syenite. The Diana Syenite (granitic phase) shows strong ductile deformation with well developed c/s fabric. Note also the strong brittle overprint as marked by the abundant and closely spaced joints sets. We have once again crossed the Highlands/Lowlands boundary. Here we will look for kinematic indicators.

18.3 miles Turn right onto Harmon Road.
Continue west on Route 58 to the intersection with Harmon Road (to the right). Turn right on Harmon road and continue east until the road crosses the creek. Park the vehicles off to the right at the junction of Harmon Road and Stammerville Road. Proceed to the small outcrops on either side of the roadway.

19.0 miles
STOP14 Shear Zones in the Diana Syenite Complex: The outcrop on the north side of the road show numerous anastomosing shear zones. Sheared Diana contains Hornblende (Cl-rich) + biotite + plagioclase (An) + perthite + quartz + titanite +/- Fe-Ti oxide minerals. Relict clinopyroxene rimmed by amphibole and amphibole + chlorite is common as is scapolite replacement of some plagioclase crystals.

Samples SE-TF-8 and SE TF-11 have been dated by the author using U/Pb titanite and ^{39}Ar/^{40}Ar for hornblende. The intrusion age for the Diana Syenite Complex has been dated to 1155 +/- 4 Ma (Grant et. al. 1986).

In shear zones, titanite replaces Fe-Ti oxides probably via a reaction involving plagioclase feldspar, and calcic amphibole. Titanite is also found in the syenite outside of these shear zones but it is rare. Away from the shear zones, Fe-Ti oxides are common while they are nearly absent in the shear zones. These observations suggest that sphene growth accompanied recrystallization during shearing, and since the recrystallization conditions during shear zone formation range only to the lower amphibolite facies and probably well below the 600-650°C closure temperature for lead in titanite, U/Pb ages are interpreted to represent growth ages and hence the time of shearing.



SE –TF -8

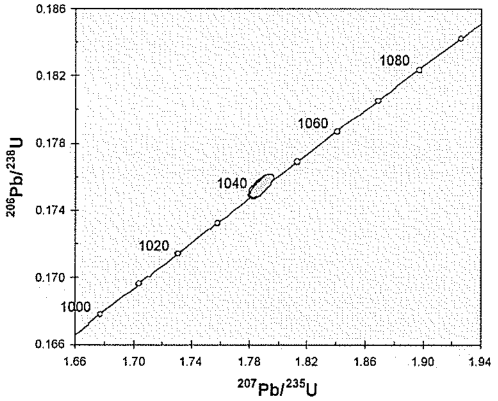
SE- TF -11

FIGURE 4

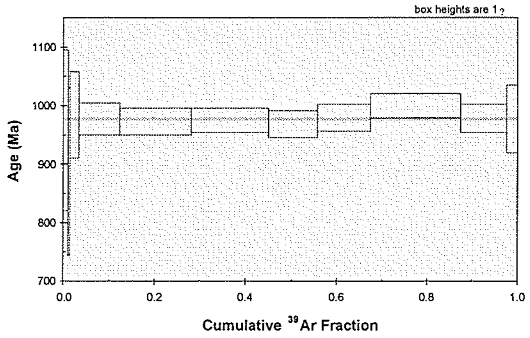
Figure 4c and 4d show backscatter electron images of feldspar pairs used for two feldspar geothermometry. Both samples (SE-TF-8 SE TF-11) were collected from the cores of shear zones in these outcrops. Re-integration of the perthite was accomplished using electron microprobe analyses using a 5 micron (SE-TF-8) and 10 micron (SE-TF-11) beam size over an analyses grid. The 150 analyses (grid points) were used to reintegrate the composition for SE-TF-11 and 45 analyses (grid points) were used for SE-TF-8 (note scale differences, figures 4c and 4d). Temperatures were calculated using SOLVCALC and the thermodynamic model of Elkins and Grove (1990). Temperatures calculated for reintegrated feldspar compositions are 454-467°C for sample SE-TF-8 and 419-461°C for sample SE TF 11 (for pressures of 3-6kbar). These results are similar to those reported by Lamb (1993) for shear zones in the Diana Syenite Complex to the south near Harrisville, New York. Two feldspar geothermometry is plagued by resetting and so these temperatures are considered to represent minimums. The presence of biotite and chlorite which is not retrograde to the deformation in these shear zones indicates that shearing took place at upper greenschist to lower amphibolite facies.

The U/Pb age for titanite are concordant and constrain the time of titanite growth during shearing to ~1041 Ma (see figure 5). ^{39}Ar/^{40}Ar data for amphibole from this sample yield a flat spectrum with a plateau age of 979.8 +/- 8.6 Ma. The closure temperature for hornblende (Ar) is 500-550°C, and these ages are interpreted to represent cooling ages.

U/Pb titanite(sphene)



^{39}Ar/^{40}Ar Hornblende

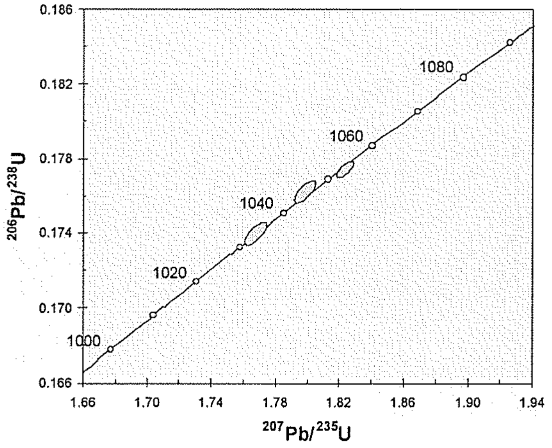


Weighted Mean
207Pb/235U age 1041.3+/-1.7Ma
206Pb/238U age 1042.1+/-1.8Ma

Plateau age = 979.6 ± 8.6 Ma (1s)
MSWD = 0.16, probability=0.998
Includes 100% of the 39Ar

SE TF 8
FIGURE 5

U/Pb titanite(sphene) *SE-TF-11*



Fractions	**1**	**2**	**3**
207Pb/235U ages	1054.0+/-2.5Ma	1034.1+/-3.2Ma	1045.1+/-3.2Ma
206Pb/238U ages	1053.2+/-2.2Ma	1034.3+/-3.0Ma	1046.6+/-2.9Ma

FIGURE 6

Sample SE-TF 11: (Same outcrop as SE-TF-8) Geochronology data for the SETF-11 is shown in figure 6. Three fractions prepared from this sample all yield concordant ages that range from 1054 to 1034 Ma. These ages are interpreted to represent multiple generations of titanite (sphene) growth in the shear zone.

Return to the vehicles and drive east on Harmon Road. The road turns sharply to the south and ends at a gate. Park in the turn around at the end of the road and walk back up the road (30m) to the outcrops.

STOP 15 Ultramylonite zone in the Diana Complex. The small shear zone exposed here shows extremely sharp strain gradients. The core of this shear zone is ultramylonitic and yet within 2-3 meters, the host Diana Syenite retains some igneous texture. It is interesting to note that strain recorded throughout the Diana Syenite Body is highly variable. The DSC is everywhere deformed ranging from coarse-grained augen gneisses with distinct igneous textures preserved (most common) to ultramlyonite. Against this deformational backdrop, the Diana Syenite is cut by sub-meter width shear zones that record low recrystallization temperatures (greenschist-amphibolite facies). In many locations, a strong brittle deformational event is also evident.

Return to Route 58 and continue West

20.6 miles
STOP 16 Famous Green Diopside skarn outcrop. This skarn body marks the contact between the granitic gneiss, which exhibits a strong lineation, and the marble. It is interesting to note that the skarn does not show a deformational overprint.

Continue on Rt. 58 west for 0.1 mile and turn right onto Maple Avenue. Follow Maple Avenue into the town of Edwards. At the intersection in town, turn north on NY Route and follow this route to Dana Hill Road.

21.0 miles
Leucogranitic Gneiss (Lowlands)

26.0 miles
Turn right onto Dana Hill Road.

26.3 miles
STOP 17 Freshly blasted small outcrop of leucogranitic gniess. This granite gneiss body outcrops along the eastern margin of the Diana Syenite Body. This granite body is, therefore, a part of the Adirondack Lowlands. Just around the next corner, we will encounter the Diana Syenite.

DANA HILL METAGABBRO

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 STOP 18 we will examine EVENT 4 shearing. Events 1 through 6 will be examined at stop 20.

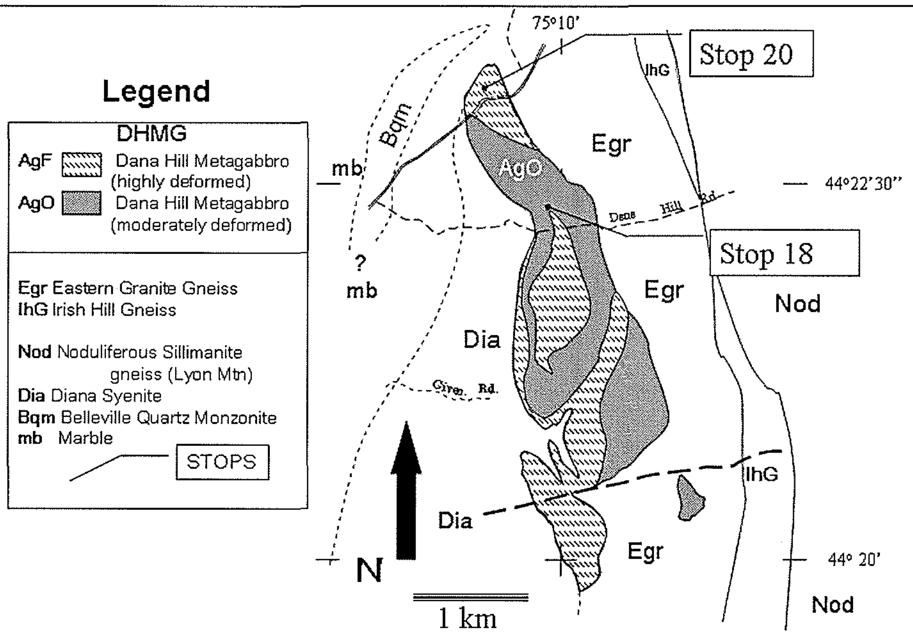


FIGURE 7

Geologic map of the Dana Hill Metagabbro showing the locations of field trip sites.

27.3 miles

STOP 18 The "Zebra" rock outcrop of Dana Hill Metagabbro (Adirondack Highlands). The gabbro is cut by multiple cm to sub meter wide EVENT 4 (see appendix) shear zones. The zones typically dip steeply and shear sense, which varies from shear to shear, can be determined by rotation of a preexisting foliation into the zone (see appendix and figure 8).

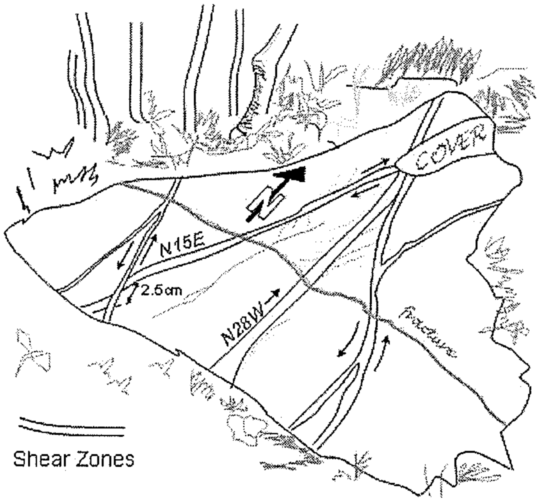
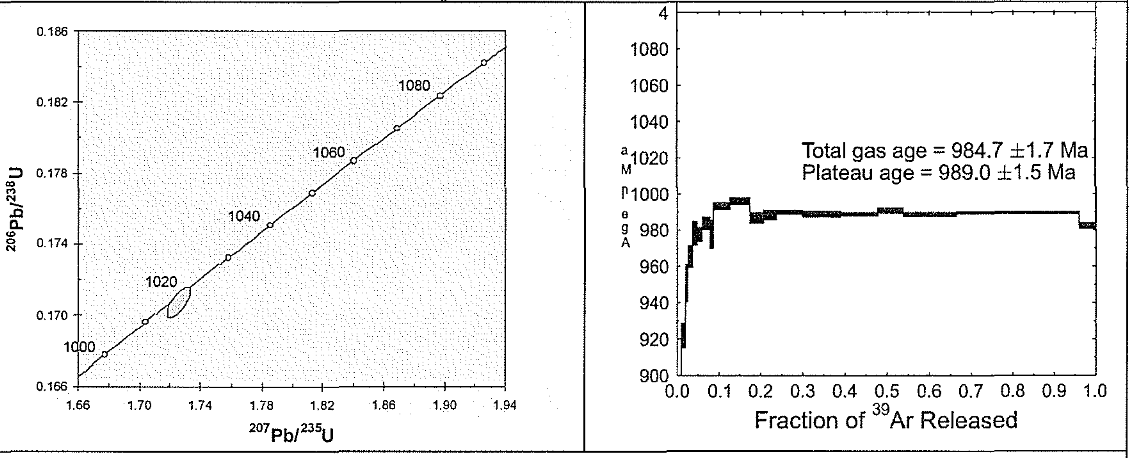


FIGURE 8

Sketch of a portion of the Dana Hill "Zebra Rock" outcrop showing multiple generations of small (cm-wide scale) EVENT 4 shear zones. Note that shear zones show both dextral and sinestral shear sets and that shear zones cut and offset one another.

The typical assemblage consists of amphibole +/- clinopyroxene + scapolite + plagioclase + Fe-Ti oxides. Plagioclase compositions are consistent within individual shear zones but range from An_{05} to An_{32} between shear zones. Polygonal scapolite forms distinct halos about amphibole and original ilmenite is replaced by titanite in the shear zones. Geochronologic data for this outcrop are presented in Figure 9.

U/Pb data Sphene/^{39}Ar/^{40}Ar Hornblende



207Pb/235U age 1019.0+/-1.7Ma
206Pb/238U age 1017.7+/-1.8Ma

Dana Hill 2-7

FIGURE 9

Sphene (titanite) growth is constrained to occur during shearing and U/Pb ages are considered to be cooling ages off of peak Ottawan temperatures of 680-720°C (Streepey et al., 2001). These shear zones are similar in size and type with those found in the Diana Syenite Body (STOP 14) but shearing in these zones takes place at considerably higher temperatures. Sphene (titanite) U/Pb ages for shear zones in the Diana Syenite are considered to be growth ages marking the time of shear zone formation at ~1054-1034 Ma. Shear zones in the Dana Hill Metagabbro at this location record cooling temperatures at 1020 Ma so it is not unreasonable to suggest that the shear zones found in Dana Hill Metagabbro were active at the same time but at very different temperatures. ^{39}Ar/^{40}Ar cooling ages for these shear zones and similar style shear zones in the Dianan Syenite Body overlap indicating that both units cooled through 550°C closure temperature for hornblende at the same time.

Continue east on Dana Hill Road. The ridge that we are passing over is cored by the Dana Hill Metagabbro. We will encounter hornblende granite, Irish Hill Gneiss (NoD) and Lyon Mountain Granite Gniess (with sillimanite nodules) to the east of the Gabbro Body. Outcrops, however, are far and few between unless we track off into the woods. Excellent exposures of these rocks can be found along County Road 17 and along Plumb Brook (at the NY State Fishing access site). Next we will examine a small outcrop of Lyon Mountain Granite on Silver Hill Road.

29.1 Miles End of Dana Hill Road. Turn right (south) along County Road 17.
30.6 Miles Turn right (west) onto Silver Hill Road.
31.5 Miles Bear right at the Y intersection and continue down the dirt road (Cook Road).

32.2 Miles

STOP 19 Sillimanite + quartz + magnetite shear zones in the Lyon Mountian Granite Gneiss. Sillimanite + quartz + magnetite is a common assemblage in the Lyon Mountain Gniess (McLelland et al., 2001). At this location, one can see the formation of this assemblage as a consequence of deformation and post deformational fluid flow through the shear zones. In the shear zones, sillimanite needles are both aligned along the developing folia and as radial splays that clearly cross-cut the foliation. In the shear zones, plagioclase feldspar is only present as albite lamellae in exsolved perthite. Bulk and trace element chemistries of this rock both in and outside of the shear zones show some interesting variations (see table 1 RL).

Bulk and Trace element chemistries for Lyon Mountian Granite Gneiss

Oxide	***SRCH1***	***SRCH2***	FRED	DH	AM-86-11	AM 86-4	AM 86 10
SiO2	71.83	71.96	68.86	68.3	69.98	70.1	69.8
TiO2	0.27	0.287	0.63	0.56	0.46	0.69	0.62
Al2O3	13.46	13.34	14.36	14.61	12.37	12.63	12.3
FeO	na	na	na	na	5.13	1.76	2.0
Fe2O3	3.45	3.61	4.35	4.31	1.11	3.77	3.0
MnO	0.01	0.01	0.03	0.03	0.01	0.02	0.0
MgO	0.26	0.27	0.66	0.74	0.08	0.01	0.4
CaO	**0.01**	**0.04**	1.03	0.96	1.25	0.94	0.71
Na2O	**0.81**	**0.73**	3.68	3.32	3.99	2.05	2.1
K2O	**9.19**	**9.16**	5.08	5.92	4.91	7.56	6.8
P2O5	0.03	0.03	0.16	0.12	0.04	0.17	0.1
Total	99.32	99.437	98.84	98.87	99.33	99.7	98.1
Rb	**320**	**305**	155	167	190	315	210
Sr	257	268	183	203	20	73	60
Zr	499	505	471	448	1230	414	620
Nb	9	10	35	21	30	18	20
Y	13	15	73	65	120	66	80
Ba	**1294**	**1216**	616	863	nd	840	600
Eu	nd	nd	nd	3			

Table 1 RL. Bulk and selected trace element chemistry for Lyon Mountain Granite Gneiss samples. Data for the shaded fields are from McLelland et al. (2001) and are presented here for comparison. Samples in bold italic are from sillimanite-bearing shear zones.

Samples from sheared sillimanite-bearing Lyon Mountain samples (SRCH1 and SRCH2) show marked depletions in Ca, Na, and enrichments in K, Rb, and Ba. The proposed mechanism for quartz-sillimanite formation is via the incongruent dissolution of plagioclase feldspar via the reaction:

$$CaAl_2Si_2O_8 + H_2O = Al_2SiO_5 + SiO_2 + Ca(OH)_{2aq}$$

$$2NaAlSi_3O_8 + H_2O = Al_2SiO_5 + 5SiO_2 + 2Na(OH)_{aq}$$

REACTIONS 1 AND 2

Slight enrichments in SiO_2 Al_2O_3 can be accommodated by these reactions and the simple removal of Na_2O and CaO , but K_2O enrichments cannot be caused in this fashion. It appears that potassium was indeed introduced to these samples during and after shearing.

The timing of this fluid infiltration event is constrained to post date emplacement of the granite during syn to late-Ottawan time (~1050 Ma).

Turn around and retrace the route back to the intersection of Dana Hill Road.

36.9 Miles
Turnoff for the DEC Plumb Brook Fishing Access Site.

37.5 Miles Whippoorwill Corners. **(Jct. County Routes 17 and 24)** Note the large outcrop of Irish Hill (Whippoorwill Corners) Gneiss.

Follow County Route 24 South to STOP 20.

38.4 Miles Roadcut of pink granitic gneiss

39.3 Miles Roadcut into pink granitic gneiss (hornblende granite protolith)

39.4 Miles **DANA HILL METAGABBRO** 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.

STOP 20 We return to the Dana Hill Metagabbro to examine the complex deformation of the body. This outcrop along with the outcrops at the top of the hill across the road, exhibit all 6 deformational events (see appendix and fig.10). We will start at the far 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 Body (Lowlands Terraine), sub meter 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. It therefore marks a common event for both terranes.

The goal of this stop is to deomstrate 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 others the gabbro ranges to 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 entire 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 greenshist to sub greenschist facies conditions. We will examine these events and the available geochronologic data for this complex outcrop.

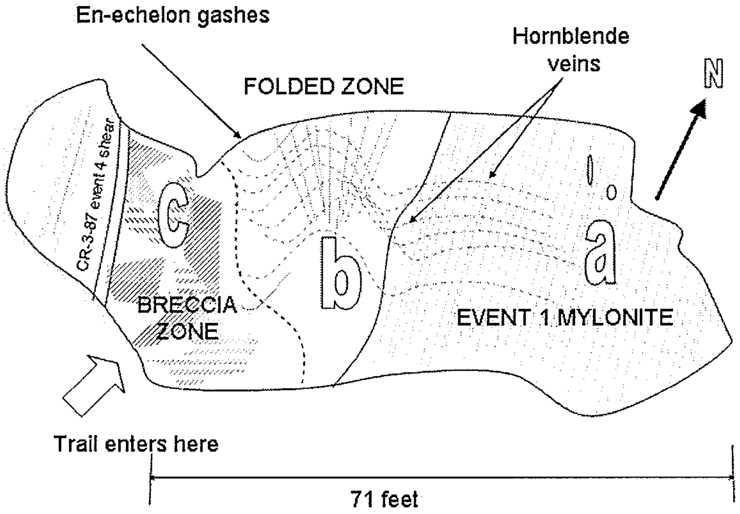


Figure 10. Map view of the outcrop at stop 20. We will begin at the western edge of exposure in zone a. The small oval shapes in zone a represent feldspar (albite)+quartz veins and tension gash fills that are undeformed internally.

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 (An_{45-51}) 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 microns for polygonal plagioclase. Re-crystallization temperatures for event 1 samples using the quartz-free geothermometer of Holland and Blundy (1994) range from 744 to 770°C (for 6kbar). 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 where scapolite replaces plagioclase feldspar in the host metagabbro. These halos can extend several mm into the surrounding metagabbro. In zone b (see figure 10), 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).

THE BRECCIA ZONE (EVENT 6)

Brecciation 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 20.

Figure 11 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 sphene (titanite), these dates represent cooling ages for the body. The consistency of U/Pb titantie ages for samples throughout the body indicates that all (Events 1-5) shearing and veining occurred prior to 1020 Ma.

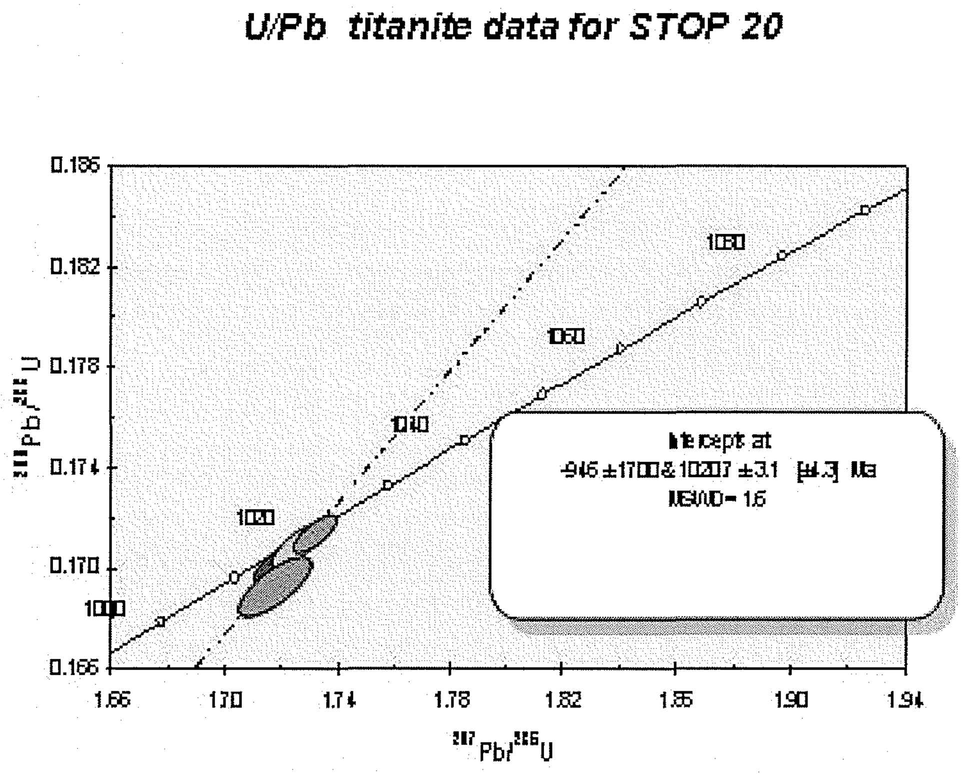
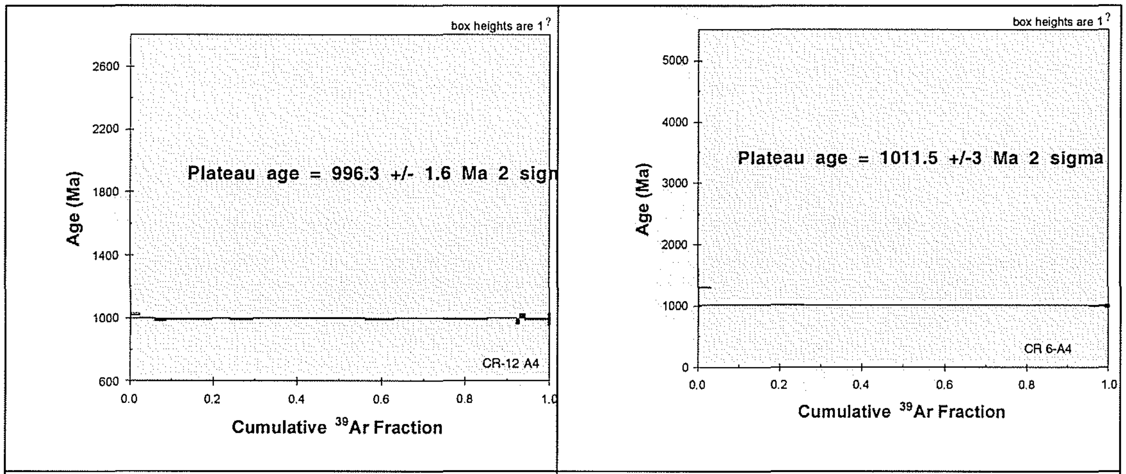


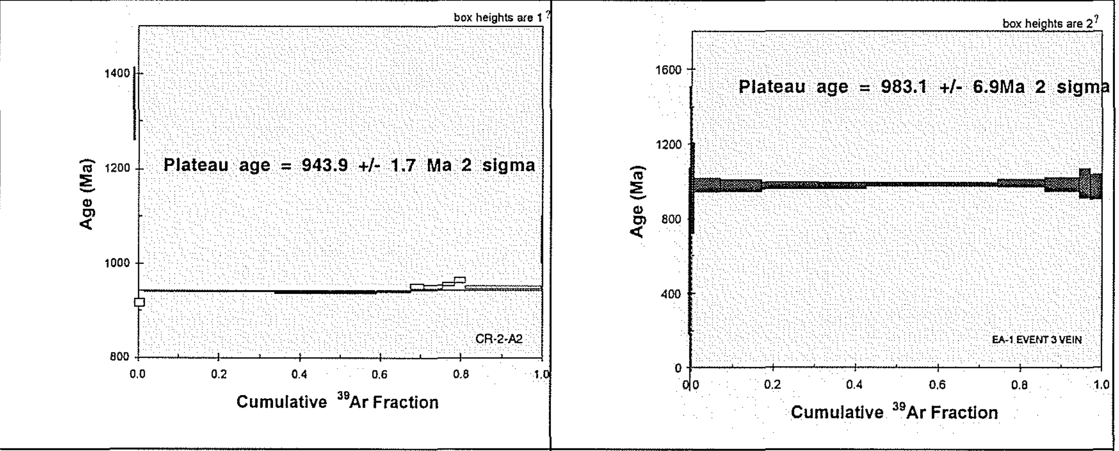
FIGURE 11

The ^{39}Ar/^{40}Ar results for hornblende in these samples is presented in figure 12. 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 985-1010Ma. The generally flat spectra for ^{39}Ar/^{40}Ar data indicate rapid cooling with little to no post-closure disturbance.



EVENT 1 MEGA-SHEAR CR-12

EVENT 2 SHEAR CR6-A4



EVENT 4 SHEAR CR-2 A2

EVENT 5 HORNBLENDE TOURMALINE VEIN

FIGURE 12

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 side), 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, the Dana Hill Body did not completely overprint pre-existing deformational fabrics, 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-forming reactions. The origin(s) of these fluids (CO_2 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, 1981; Selleck , pers. comm.)

SUMMARY

The CCSZ is a west to northwest dipping and complex zone of strong ductile deformation. The style of deformation and the width of the deformed zones differ between the Highlands (east) and the Lowlands Terranes. In the Fine Quadrangle to the south, a marked change in the orientation of stretching lineation from NW trending down dip to NNW trending along strike coincides with crossing the detachment of the CCSZ. I believe that the nearly ubiquitous CCSZ deformation recorded in the Lowlands (Diana Syenite) coincides with early movements on the CCSZ. This earlier deformation fabric records both reverse and normal movement sense with reverse movement sense being most common. The later movement history is recorded in thousands of low temperature sub-meter width shear zones. These shear zones were active at upper greenschist to lower amphibolite facies conditions during Ottawan to late Ottawan time (1060-1030 Ma) and mark minor offsets in the bodies that they cut. These zones record primarily oblique normal movement sense. The Lowlands (Hanging Wall) rocks near to the CCSZ detachment cool to 500-550°C by ~980 +/- 9 Ma. In the Highlands Terrane, the CCSZ deformation extends several kilometers into the footwall and takes place at considerably higher temperatures. On the Highlands side, the shear zone is intruded during Ottawan to late Ottawan time by a series of granite bodies belonging to the Lyon Mountain Suite. Deformation in these granite bodies is variable reflecting their late injection into this evolving shear zone. The deformational history for the Highlands Terrane is well preserved in the Dana Hill Metagabbro Body which preserves granulite –amphibolite ductile shearing through greenschist facies brittle faulting and brecciation. Early high-temperature (700°C+) shearing produced broad mylonitic to ultramylonitc shear zones that were subsequently invaded by hornblende veins which, in turn, are cut by sub-meter width shear zones. Deformation terminates with folding and brecciation of the body. Shear sense is primarily dextral and oblique with stretching lineations plunging gently to the NNW. Early mega-shear zones dip steeply to the WNW and displacement sense is oblique normal.

All generations of ductile shearing and hornblende veining cooled together through the 600-650°C closure temperature for sphene (titanite) by 1020 Ma and the bulk of the shear zones and veins cool through the closure temperature for argon in hornblende by ~500-550°C. Scapolitization of original plagioclase feldspar is common in both the Highlands and Lowlands Terranes and marks a common event for both. In the Dana Hill Metagabbro, scapolite formation is directly tied to event 3 hornblende veining. With the exception of brecciation, all subsequent veining and shearing involve scapolite formation. Sub-meter width scapolite-bearing shear zones in the Diana Syenite are dated to have formed over the interval of 1054-1034 Ma and scapolite bearing sub meter width shear zones in the Dana Hill record U/Pb cooling temperatures of 1020 Ma (off 680-720°C peak temperatures). Based on these dates and the fact that both terranes are recording the same fluid driven scapolitization event, juxtaposition of Adirondack Highlands and Lowlands Terranes at or near a common structural level is constrained to have occurred between 1054-1020 Ma.

At 1020 Ma, the Dana Hill Metagabbro Body is cooling through 600-650°C, which is at least 100°C hotter than the Lowlands Diana Syenite Body, requiring a thermal discontinuity across the CCSZ that survives to as late as 1010-985 Ma. Since thermal discontinuities typically cannot survive in the crust for more than 14 Ma, additional heat source(s) are required. This heat may be supplied by continued adjustments along the CCSZ or the intrusion of late quartz+albite pegmatites into the region.

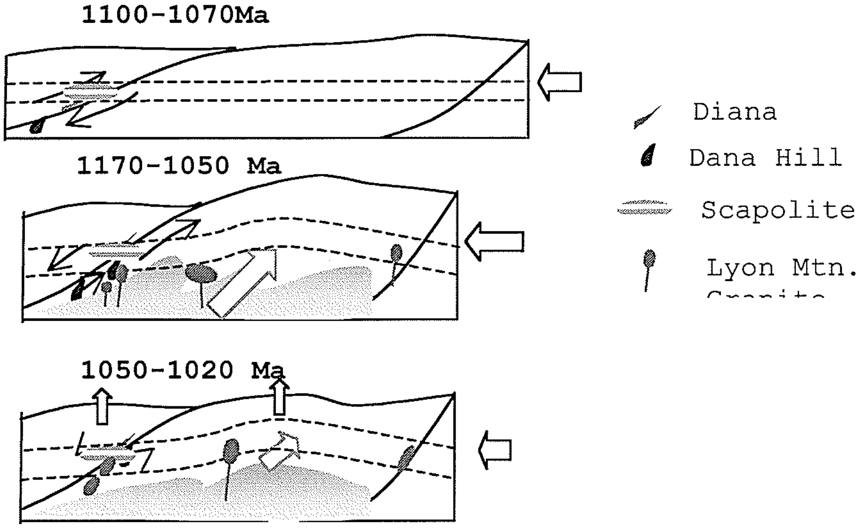


FIGURE 13 The proposed sequence of events for the CCSZ through the Ottawan Orogeny. 1100-1070 Ma: Initial Ottawan compression leading to shortening and activation of the CCSZ as a reverse fault. 1170-1050 Ma: higher temperatures in the core of the Highlands Terrane lead to lower crustal viscosity and the extrusion of a crustal channel. The CCSZ acts as the roof of this developing channel and movement sense is normal. Decompression of the extruding Highlands leads to granitic melt generation forming Lyon mountain magmas. Along the CCSZ, deformation in the Dana Hill Metagabbro transitions from mega shears to sub-meter shear zones as temperatures fall due to exhumation. Highlands and Lowlands Terranes are juxtaposed by 1040 Ma and both share a common fluid driven scapolitization event. 1020-980 Ma: both terranes cool through 550-500°C. Post 980 Ma: transition from ductile to brittle deformation, formation of the Long Lake Fault?

Recent models of crustal channel formation in the Himalayas (see Hodges et al., 2003, and references therein) fit well with the observed movement history along the CCSZ. In the Himalayan case, crustal channels form in response to mobilization of a low viscosity granulite core that, driven by compression and surface denudation, undergoes syntectonic (syn-compression) exhumation. In the Himalaya, this exhumation is accommodated along a basal (thrust) shear zone. The roof of the exhuming crustal channel is marked by large ductile to brittle normal shears. In the Himalayan case, these bounding shear zones support long-lived thermal gradients due to the rapid exhumation of the still hot granulite core of the channel. Although both the roof and channel rocks are involved in the same orogenic episode, they record very different thermal histories. This is exactly the case for the rocks on either side of the Cartage Colton Shear Zone. Crustal channels and their bounding shear zones in the Himalaya are decorated with A-type Granite Bodies that form as pressure release melts in the exhuming granulite core. The A-type Lyon Mountain Granite Bodies that run the length of the CCSZ provide an excellent analog. In this model, the Adirondack Highlands Terrane is transported up and to the east against the "cover rocks" of the Adirondack Lowland Terrane (figure 13).

END OF TRIP

APPENDIX Deformational and veining events for the Dana Hill Metagabbro Body.

Outcrop event	**Sample #**	Orientation	Mineral assemblage	**^{40}Ar/^{39}Ar date***	**U/Pb date** (see Streepey et.al., 2001)	**T(°C) (6kbar)**
Undeformed metagabbro	Cr-9 A4	na	Plag + Cpx + Fe-Ti Oxides (amph rims on cpx)	Amph rim: 943.8+/-1.7	NA	NA
1. 30+m shear zone	Cr-7,Cr12 Cr-6 A4 CR-11A4 H-1A	FOL: N51W 59W LIN: 05 N54W	Cr-7, Cr6,Cr 11* and Cr-12* cpx+ amph+titanite+plag H-1A Cpx + plag + amph + titanite * scapolite replaces plag near amph. veins.	Cr-6A4 1005 +/- 1.9 Ma	1021 -1023Ma	718-744
2. 3m shear zone	Cr-5,4,3,2	**FOL: N47W 76W** LIN: 29N55W	**Cr-5 amph+plag+titanite+qtz**		NA	NA
3 Parallel amph veins.	Cr-12	Vein orientation: N09E 67W	Cr-12 vein: amph + cpx + scapolite Matrix: well defined halo of scapolite replacing plag near to the vein walls. Vein is .3cm wide.	Cr12-A4 Matrix cpx mylonite: 996.3 +/- 2 Ma No date from vein	1021 Ma	NA
4. cm wide shear zones	Cr-3 87; Cr2-A2 Cr 10A4	Cr3: FOL: N44W 74W LIN: 47 N61W Cr-2 FOL: N35E 57W LIN: 57 N55W	Cr-3 87: plag + amphibole + cpx +Fe-Ti oxides* Cr 2 A2 amph + plag+ scap+ titanite + biotite +qtz+ Fe-Ti oxides (replacing titanite)	Cr-2-A2 944+/- 1.9 Ma Cr-3-87 940.9 +/- 3Ma	NA	715°C
5. Folded mylonitic gabbro	NA	na	Folded mylonite with CR-7 assemblage (addition of scapolite near amph. veins)	NA	NA	NA
6. Brecciated gabbro	H-6A H-87 5B	Na	Matrix: albite + chlorite + actinolite + calcite epidote	NA	NA	NA

Outcrop event	**Sample #**	Orient-ation	Mineral assemblage	**^{40}Ar/^{39}Ar date /Pb date see Streepey et.al, 2000)**	**T (C)**
1. 30+m shear zone	RW-H1	FOL N09W 82 W LIN 30 346	Amphibole + plagioclase + scapolite	976+/- 2Ma	771°C
Amph-Tourm vein parallel to RW-H1 Foliation	EA-1	Foliated amph-tourm vein FOL N30W 90	Amphibole + tourmaline +quartz+titanite	983+/- 2 Ma	
2. 3m shear zone	RW-S3 (A,B,C)	FOL N60W 90 LIN:	**Plagioclase (granular) + amphibole +scapolite (as corona on amphibole)**	1009 +/-3Ma	
3. Amphibole Vein	RW-AVS3	Trend N65E 85S			
4. cm wide shear zones	RW-S1 RWS-2 CR-1DH1 CR-7DH1 CR-6DH1	Dextral shears S1 :FOL: N01W 87E LIN: NA S2: FOL N09E 70E LIN:NA CR-1: FOL N80W 90 CR-7 FOL: N53W 44NE	RW-S1 amphibole + scapolite +plagioclase (polygonal) + titanite (minor) RW S-2: CR6-DH1: Scapolite + plag + amphibole+biotite+Fe/Ti oxides CR-7 DH1: Scapolite + amphibole + biotite + plag CR-1 DH1: amphibole + scapolite +plag +Fe-Ti oxides	RW S1 1000+/-2Ma CR-1 DH1 989 +/-1 Ma CR-7DH1 985 +/- 2Ma	718°C
5. Veining event	LHV-1	late amph vein	amph + tourmaline		
6. Brecciated vein	MV-1	ductile to brittle shear.	Highly altered: amph to chlorite.		