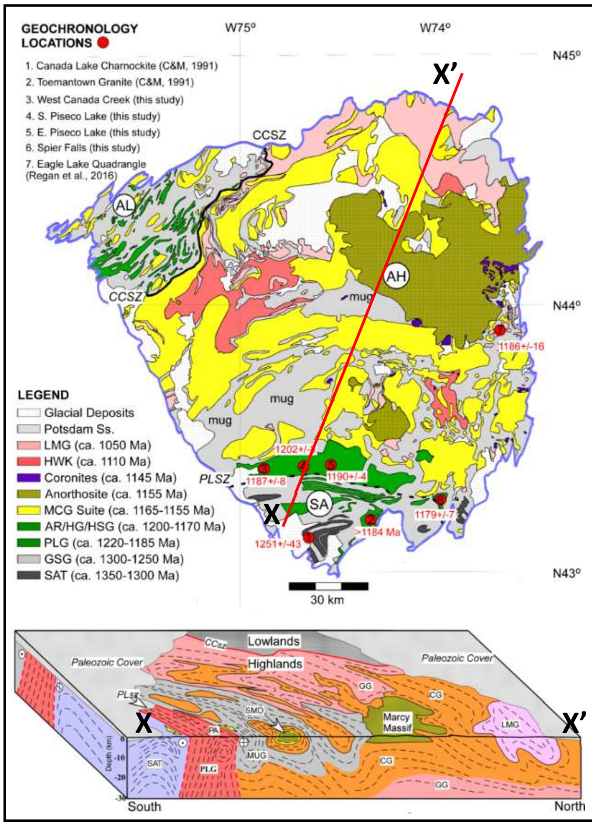
# New York State Geological Association

## 95th Annual Meeting Field Trip Guidebook






**Compiled by David W. Valentino**

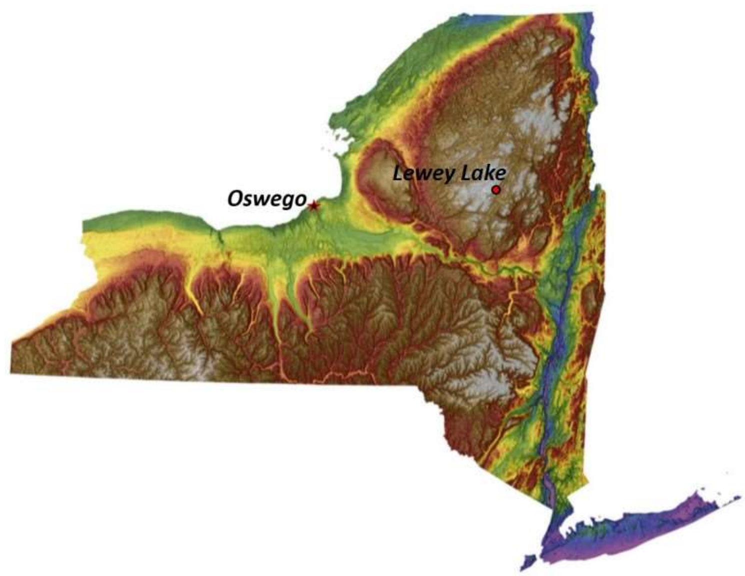
**Hosted by the State University of New York at Oswego at the Lewey Lake Campground, Southern Adirondacks**
**September 13-15, 2024**

# Field Trip Guidebook, 95th Annual Meeting
# New York State Geological Association

## September 13-15, 2024

# Structure, Petrology, Geochemistry and Geochronology of the South-Central Adirondacks

## Guidebook compiled by David W. Valentino




This guidebook was published by the New York State Geological Association.
Additional copies may be obtained from the Executive Secretary of NYSGA, or downloaded at the NYSGA website, www.nysga-online.org.

# Field Trip Leaders


## David Valentino, State University of New York at Oswego
## Matthew Gorring, Montclair State University
## Jeff Chiarenzelli, St. Lawrence University


## ACTIVITIES

**FRIDAY, SEPTEMBER 13, 2024**

Field trip attendees arrive at Lewey Lake Campground.

Group meal (bring cash) and evening social will be hosted by the Oswego Geology Club.

**SATURDAY, SEPTEMBER 14, 2024**

Group will meet at 8AM at the entrance to the Lewey Lake Campground.

First half of the day will include an excursion through the Snowy Mountain AMCG suite and structural dome.

Lunch at Falls Brook.

Second half of the day will include a traverse south across mixed metasedimentary gneisses and into the Piseco shear zone.

Group meail (bring cash) and evening social will be hosted by the Oswego Geology Club at the Lewey Lake Campground - Site location to be determined.

**SUNDAY, SEPTEMBER 15, 2024**

Group will meet at the Charlie John's parking lot in Speculator at 8:30AM.

The traverse through the Piseco shear zone will continue on Powley Road, south of Piseco Lake.

The last stop of the trip will be a short hike to the L-tectonite zone located on the flank of Fort Noble Mountain.

Trip will end at about noon.

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Due to the timing of organization of the 2024 NYSGA field trip, this field guide is a compilation of select field trips run in the southern Adirondacks, by a long list of researchers over the past 20 years. The authors of those trips are included in the field guide, and the current field trip will lean heavily on that earlier work.

## ABSTRACT

This field trip was first run in 2004 for NYSGA and was reorganized for the 2005 meeting, and again 2018 NYSGA-NEIGC joint field conference to show progress in our understanding of the complex geology of the southern Adirondacks. However, in 2018 the trip canceled just prior to the conference due to the sudden tragic loss of Dr. Brian Hough that occurred a few days before the conference. Brian was a colleague of the lead author. The trip was offered in 2022, but canceled due to poor attendance. Two years later the trip is offere again, and it is dedicated to the memory of Brian. Although his tenure at SUNY Oswego was not long, and was tragically cut-short, the impact that he had on many student and colleagues will last a lifetime.

Highly deformed Piseco granitic gneisses occur in an arching east-west transpressional ductile shear zone (Piseco Lake shear zone) that spans the width of the exposed southern Adirondacks. The highly deformed granitic gneisses have restricted silica content, are metaluminous, alkali-calcic to calc-alkalic, continental arc trace element signatures. These granitic rocks intruded supracrustal gneisses resulting in extensive Shawinigan partial melting. The Piseco Lake shear zone (20-30 km wide) formed in this belt of granitic rocks and correlate with a pronounced arcuate-shaped high magnetic anomaly. The magnetic anomaly extends well beyond the exposed Adirondack basement window.

The shear zone is 20-30 km wide and is believed to be the location of a cryptic suture because it occurs between the Adirondack Highlands (underlain primarily by anorthosite and related granitic rocks, AMCG suite) and the Southern Adirondack Terrane (underlain by calc-alkaline tonalitic arc rocks) (Valentino et al., 2019). Within the shear zone, the original megacrystic granite contains lineated quartz and rodded feldspar aggregates up to a meter long in places. Along the axis of the shear zone there are thick (1-2 km), subvertical zones of granitic L-S and L-tectonites. The northern domain of the zone is defined by large foliation domes that are cored by L-tectonite. The southern limbs of the domes steepen toward the south and merge with a wide zone (up to 15 km) of steeply dipping granitic mylonite. Overall, the shear system (domes and steep mylonite zone) forms the core of a region of intense ductile deformation with left-lateral kinematic indicators and subhorizontal E-W ribbon lineations.

The Piseco granitic suite are highly deformed suture-stitching arc plutons that intruded within a sinistral, oblique-convergent, shear system in the deep crust during the Shawinigan orogeny. This is ductile shear zone is the most continuous and largest in the entire Adirondack massif. The shear zone, associated granitic rocks, and the magnetic anomaly abruptly trends toward the south in the eastern Adirondacks. Just beyond this location, the magnetic anomaly appears to be truncated by a branch of the NY-AL magnetic lineament. Following the trace of the magnetic anomaly toward the west, suggests that the shear zone continues for a considerable distance beyond the Adirondack window. It's magnitude, in addition to the magnitude and extend of the associated magnetic anomaly, suggests that the Piseco shear zone penetrates the Moho.

The current field trip is an update on our very long research project, and it's geared toward an undergraduate student audience. All field locations were picked to accommodate large student groups. Sampling in the Adirondack Park is generally prohibited by NYS law, and we encourage future instructors to help preserve the field locations presented herein by showing and discussing, and not removing the spectacular bedrock features. Note that the field guide is a compilation of previously run trips for Friends of the Grenville and New York State Geological Association.

# L- verses S-tectonite fabric variations within the southern Adirondack shear zone system: progressive deformation associated with a sinistral conjugate to a Grenville syntaxis

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## Introduction

This field guide was prepared in tandem with a field guide for the 73th and 75th NYSGA field conferences, and synchronously with an article written for the Memorial Volume to Nicholas Rast, recently published in the Journal of Geodynamics (Gates et al., 2004). Therefore, some parts of this guide are directly related to work presented in the earlier field guides and some parts were prepared for multiple projects; however, the emphasis here is exclusively on new findings in the Adirondacks. We encourage the reader to examine our data presented in the earlier field guides (Gates et al., 2001; Gorring et al., 2003) and summarized in Gates et al. (2004) for further details.

Transpressional strain is found to be related to a variety of tectonic environments. Transcurrent faults with restraining bends, produce structures such as thrusts and conjugate faults (Woodcock, 1986). Oblique motion vectors between two tectonic plates result in oblique collision that produces zones of transpressional strike-slip deformation in the hinterland, and belts of thrusting in the foreland (e.g., Woodcock, 1986; Tappionier and Molnar, 1976). As well, zones of transcurrent strain can develop syntaxes in regions of the crust experiencing horizontal escape as the result of rigid indentors in the colliding lithosphere (Tappionier and Molnar, 1977). These structures have been almost exclusively described for rocks that were exhumed from intermediate to shallow levels of the crust. The distribution of strain and the location of faults can be controlled by the presence of pre-existing structures (Dewey and Burke, 1973), or by the juxtaposition of rock bodies with ductility contrasts such as decoupling of cover rocks over deforming crystalline basement (Gates et al., 1999; Valentino et al., 2004).

Dewey and Burke (1973) and Windley (1986) proposed a model for tectonism recorded in the Grenville Province rocks based upon the deep structure of Himalayas and the intensity of tectonism recorded there. Tapponnier and Molnar (1977) proposed that the rigid indentation of India formed a syntaxis (abrupt bend in the general attitude of the orogen) containing conjugate strike-slip faults in the Eurasian continent during the Himalayan Orogeny. Northeast-striking sinistral, transcurrent shear systems accommodate tectonic escape (Tapponnier et al., 1982) in China and southeast Asia, and these fault systems record hundreds to thousands of kilometers of offset over tens of millions of years. There are also smaller, northwest-striking, dextral systems that have been synchronously active with the sinistral zones that form the conjugate pairs to the larger sinistral zones of tectonic escape within the Himalayan syntaxis.

The Grenville Province forms one of the longest and most deeply exhumed areas of continental crust on Earth, extending from Scandinavia, through eastern Canada and inliers in the Appalachian chain, to Texas and Mexico, and perhaps beyond. Grenvillian basement massifs in the northeastern United States form a series of unconnected inliers along the Appalachian orogen (Figure 1). Because of the great spacing and high degree of tectonism associated with the

Appalachian tectonic events, correlation of Grenvillian rocks among the massifs are difficult. In addition to widespread granulite-facies metamorphic conditions at about 1.0 Ga, these basement massifs all contain vast volumes of 'A-type' granite bodies whose magma had intruded (ca. 1150 Ma) into older supracrustal rocks (ca. 1250 Ma) of varied character prior to Ottawan deformation (ca. 1040 Ma; e.g., McLelland and Isachsen, 1986). The Grenville Province exposes the deep crustal roots of an ancient mountain range of immense portions, and records the assembly of one of the Earth's few recognized supercontinents, Rodinia. Consequently the Ottawan Orogeny (ca. 1070-1000 Ma) is often cited as a classic example of continent-continent collision and compressive thickening of the crust, with invocation of the Himalayas as a modern tectonic reference frame (Dewey and Burke, 1973; Windley, 1986; McLelland et al. 2001). However, refinement and testing of such a model must address many important components of the orogeny. One of the most significant components in the Himalayas, is the massive amount of strike-slip faulting expressed in tectonic escape and the syntaxis (Tapponnier and Molnar, 1977). Whereas compressive tectonics is universally documented in the Grenville orogen, few workers have recognized analogous, large-scale, orogen-parallel deformation (cf. Baer, 1977). Some of the evidence for strike-parallel deformation is described herein, and is much of the basis for the sequence of outcrops listed in this guide.

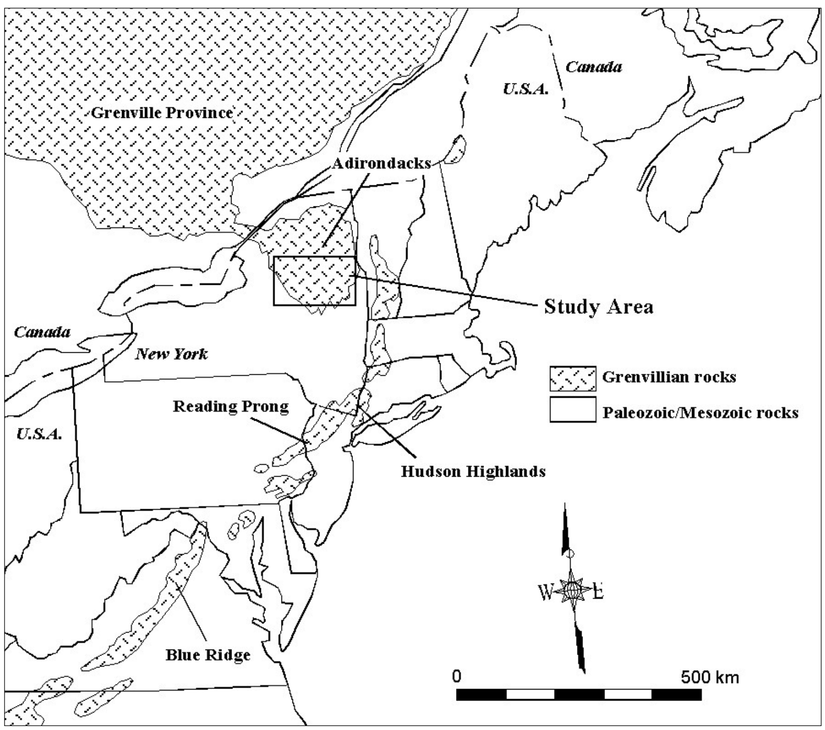


**Figure 1.** General map of the northeast U.S.A. and eastern Canada showing the distribution of Grenvillian basement rocks. The study area for this field guide is shown in the central and southern Adirondack Mountains, New York.

## Sinistral shear recorded in rocks of the Adirondack Highlands

In contrast to the overwhelming northeast trends throughout most of the Grenville Province, the structural grain of the south-central Adirondack Highlands is generally east-west (Figures 1 and 2). This broad zone (>60-km wide) displays general parallelism of geologic contacts, fold axes, compositional layering, foliation, mineral lineations and an anastomosing system of mylonite zones. Several large (>20-km across) structural domes cored by rheologically rigid anorthosite lie within the zone. Kinematic investigations indicate that this zone is dominated by sinistral transpression (Chiarenzelli et al., 2000; Gates et al., 2004). There are a number of large-scale features (drag folds and rotated mega (gigga-) clasts) which are consistent with the abundant meso- and micro-scale kinematic indicators. Kinematic indicators include S-C fabrics, shear bands, and rotated porphyroclasts. The broad zone is bounded by shear zones that traverse portions of the southern Adirondacks. The structure of the south-central Adirondacks has been interpreted as the consequence of transpressional modification of earlier crustal-scale recumbent folds analogous to those exposed in the Adirondack Lowlands (Chiarenzelli et al., 2000). Widespread granulite-facies mineral assemblages within substantial volumes of supracrustal rocks are consistent with compressional tectonics; however, the southernmost bounding shear zone (the Piseco Lake shear zone) has mineral assemblages that indicate deformation outlasted high-grade conditions.

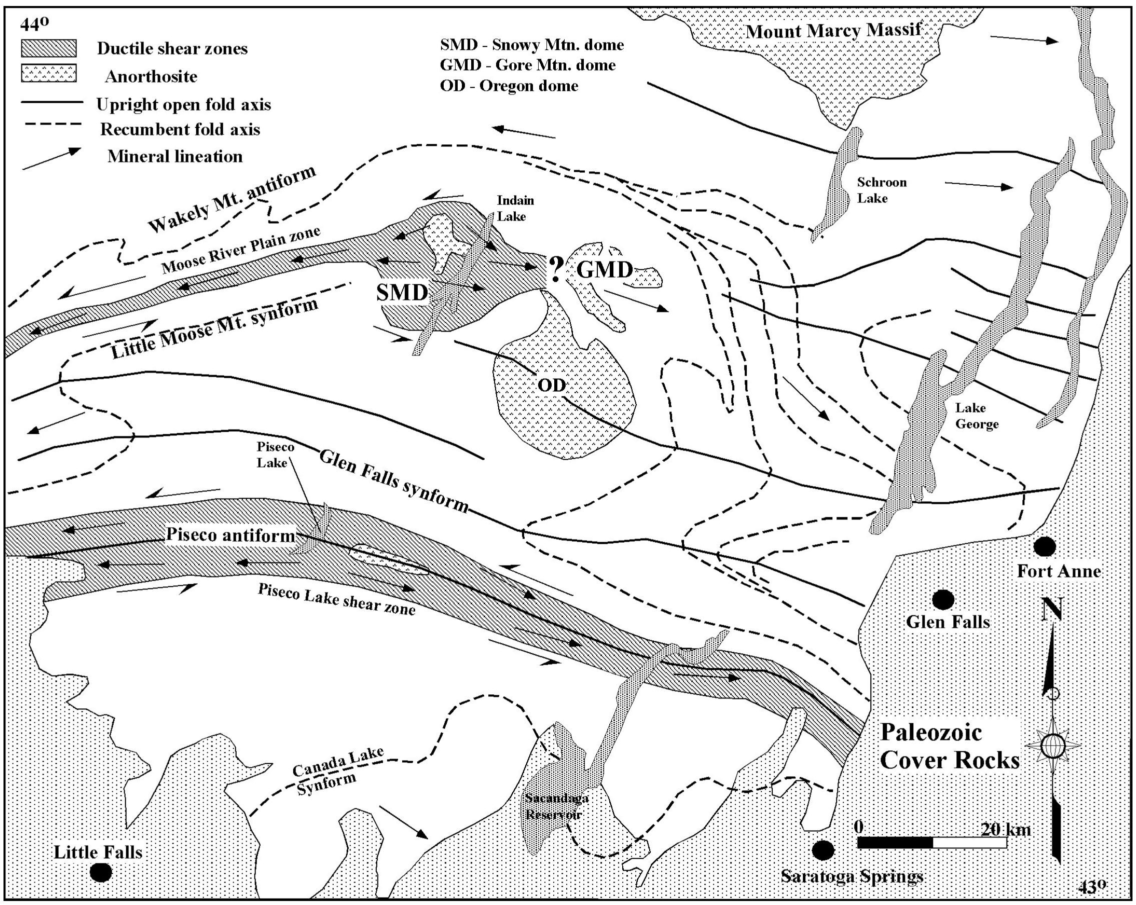


**Figure 2.** General geologic map of the central and southern Adirondacks showing the locations of major structures discussed in this field guide including the Moose River Plain shear zone, the Snowy Mountain dome (SMD) and the Piseco Lake shear zone.

## Moose River Plain Shear Zone and Snowy Mountain Dome

A zone of high-grade intensely sheared rocks extends east-west through the Moose River Plain of the west-central Adirondacks and was thereby named the Moose River Plain shear zone

(MRPSZ; Figures 2 and 3). This shear zone occurs between the Wakely Mountain antiform and Little Moose Mountain synform (Wiener et al., 1984), and it experienced sinistral shearing under granulite-facies conditions. The eastward trace of the MRPSZ intersects and is deflected around the anorthosite-cored Snowy Mountain dome (DeWaard and Romey, 1969). East of the Snowy Mountain dome, the MRPSZ, traces toward the area of Gore Mountain, but the details are not as well documented.

Penetrative foliation occurs along a narrow belt (~2 km wide) that defines the MRPSZ. The foliation generally strikes 270° and dips moderately to steeply north (Figure 5A). It is defined by metamorphic mineral assemblages characteristic of granulite-facies conditions. Sheared charnockitic gneiss contains the assemblage plagioclase-clinopyroxene-hypersthene, pelitic gneiss contains biotite-K-feldspar-sillimanite-garnet, and gabbroic-gneiss contains augite-hypersthene-garnet-plagioclase. Local migmatite in the sheared charnockitic gneiss suggests anatexis during deformation. Within granitic and charnockitic gneisses, foliation is defined by planar aggregates of recrystallized feldspars and quartz. Foliation in pelitic gniess is defined by recrystallized quartz and K-feldspar and parallel alignment of biotite and sillimanite. Mineral-elongation lineations are defined by linear aggregates of feldspar, pyroxene and garnet in charnokitic gneiss, and biotite and sillimanite in pelitic gneiss. The foliation and lineation in the gabbroic gneiss is mostly defined by alternating planar aggregates of plagioclase and pyroxenes. The eastern limit of the MRPSZ is structurally continuous with the penetrative foliation that mantles the Snowy Mountain dome (DeWaard and Romey, 1969).

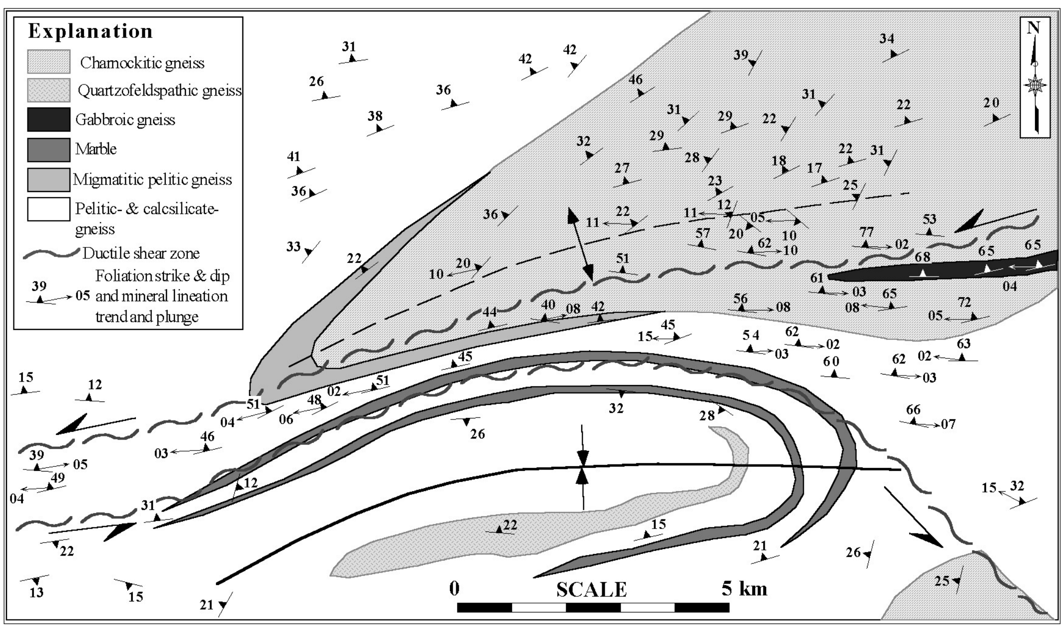


**Figure 3.** Detailed geologic map of the Moose River Plain shear zone in the area between the Wakely Mt. Antiform and Little Moose Mt. Synform.

The zone of deformed rocks in the Moose River Plain region was interpreted as the result of shearing between the lower and upper limb of the Wakely Mountain antiform and Little Moose Mountain synform (Wiener et al., 1984). Consistent subhorizontal mineral lineations throughout the Moose River Plain shear zone are indicative of a subhorizontal transport direction and inconsistent with earlier kinematic models based solely on map-pattern folds. Kinematic indicators throughout the shear zone are consistent with left-lateral shear. Kinematic indicators include σ- and δ-type porphyroclasts (cf. Simpson and Schmid, 1986; Passchier and Simpson, 1986) in pelitic and granitic gneiss, Type-I S-C fabrics (Lister and Snoke, 1984) in charnockitic gneiss, asymmetric foliation boudins often associated with local migmatite, and fish-structures comprised of broken garnet crystals, and small high-strain zones (Figure 5A). Locally the foliation is deflected at the margins of the MRPSZ consistent with map-scale left-lateral drag folds (Figure 3).

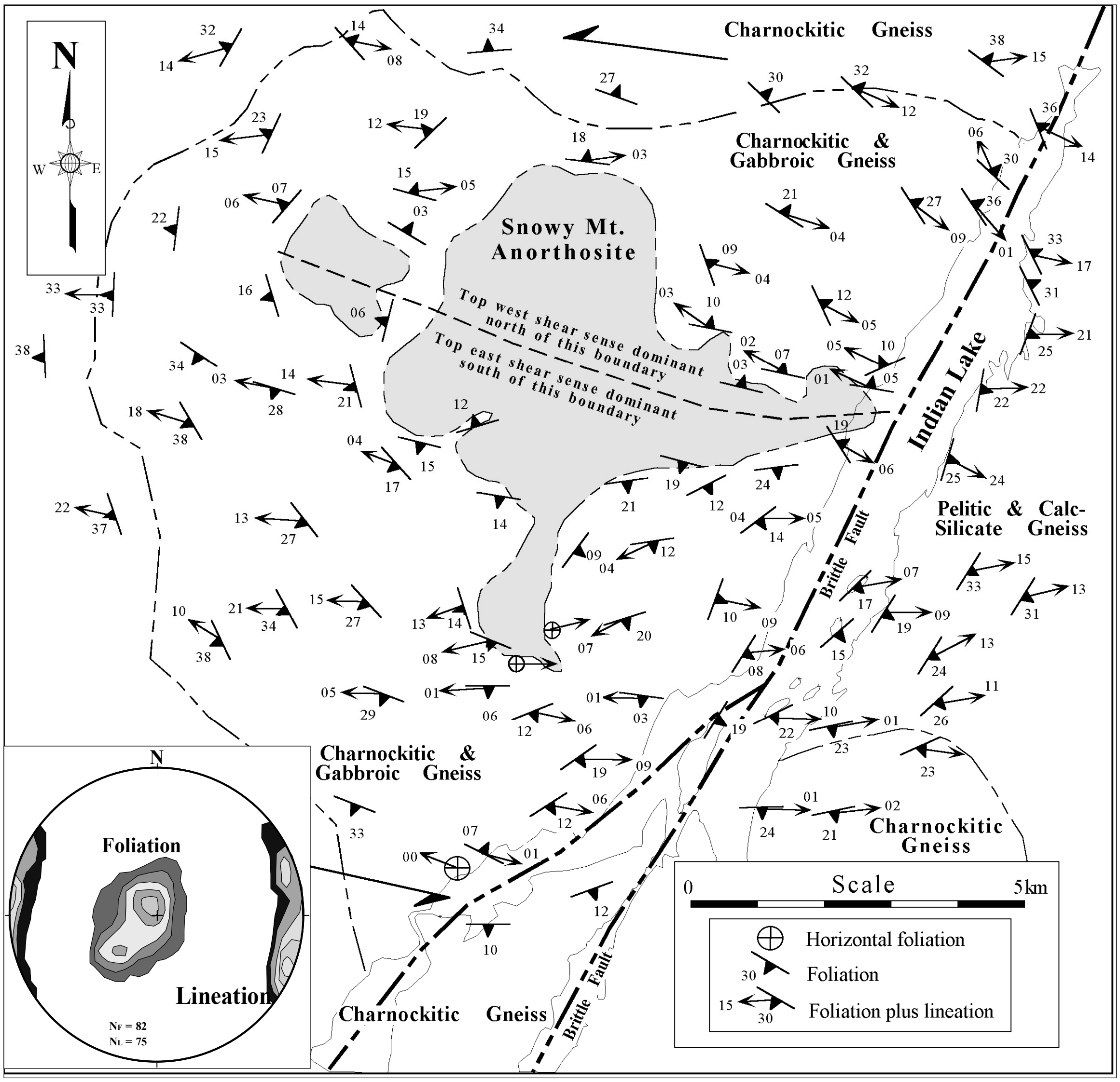


**Figure 4.** Detailed structure map of the Snowy Mountain dome, central Adirondack Mountains. Geologic contacts are modified from DeWaard and Romey (1964). The inset is a stereogram for poles to foliation and lineation for the eastern half of the dome.

Large (15-20-km across) structural domes cored by anorthosite in the Adirondack Highlands are interpreted to have resulted from fold interference (McLelland and Isachsen, 1986) (Figures 2 and 5). The Snowy Mountain dome, located west of Indian Lake, is underlain by AMCG suite rocks with anorthosite in the core (DeWaard and Romey, 1969). The eastern extent of the MRPSZ foliation is structurally continuous with penetrative deformation fabrics that wrap around and define the Snowy Mountain dome. The core of the dome is underlain by megacrystic anorthosite with crystals commonly up to 20 cm. Anorthosite is mantled by gabbroic- and then charnockitic- gneiss forming a semi-concentric compositional zonation (DeWaard and Romey, 1969). Although the central anorthosite is generally not deformed, the margins of the body contain dynamically recrystallized plagioclase that define well-developed foliation and lineation. As first described by DeWaard and Romey (1969), the transition from anorthosite to gabbroic gneiss is marked by more intensely developed deformation fabrics away from the dome core. Farther outward on the dome flanks, the foliation is penetrative in the charnockitic gneiss. The presence of relict plagioclase megacrysts in the charnockitic gneiss suggests a plutonic origin. Most of the unit consists of planar and linear aggregates of recrystallized plagioclase and anhedral, broken grains of clinopyroxene and hypersthene. Poles to foliation reveal that the dome has a dominant northwest-southeast-trending axis (Figure 4). The attitude of lineations vary about 30° around a general east-west trend that is roughly parallel to lineations in the MRPSZ.

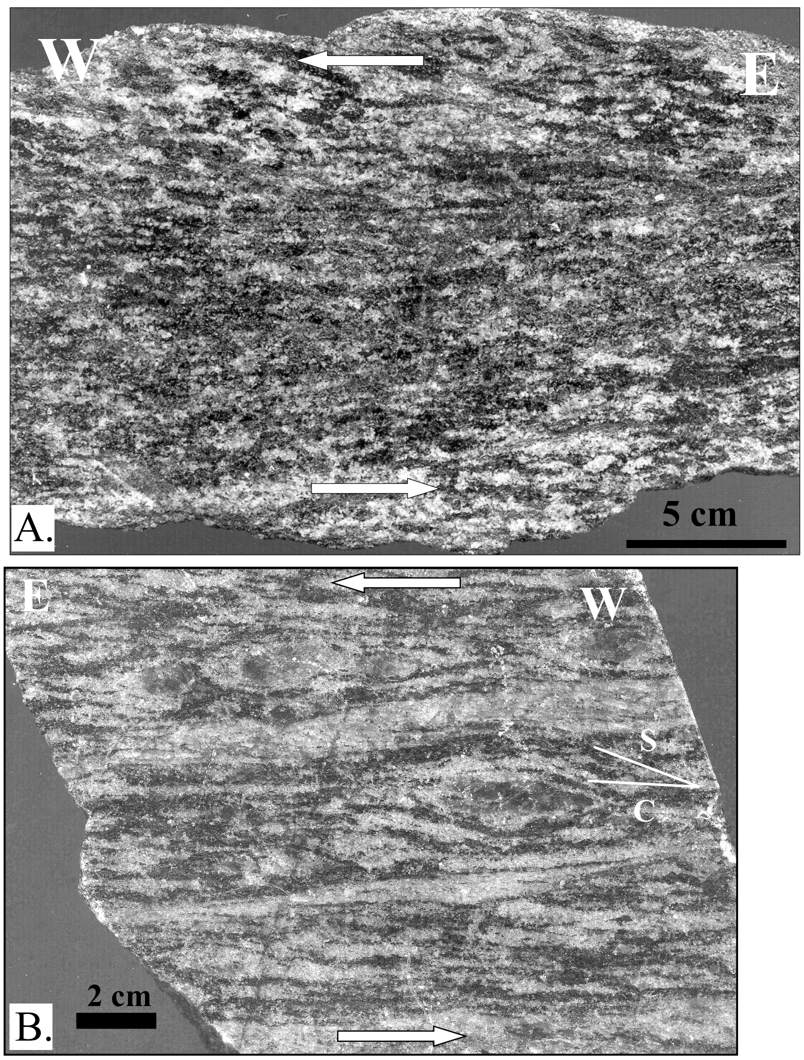


**Figure 5.** Examples of kinematic indicators from the Moose River Plain shear zone and the high strain fabrics that define the Snowy Mountain dome. A] Small high-strain zone from the MRPSZ showing sinistral shear; B] S-C fabric in gabbroic gneiss from the northeastern flank of the SMD.

Shear-sense indicators observed at the Snowy Mountain dome including σ- and δ-porphyroclasts (Passchier and Simpson, 1986), and type-I S-C fabrics (Lister and Snoke, 1984). Shear-sense indicators from the southern flank of the dome reveal top-to-the-east bulk shear,

whereas the northwestern flank reveals top-to-the-west shear (Figure 5B). On the northwest side of the dome, where foliation dips moderately westward (Figure 4), the shear sense is locally dip-slip normal. On this basis, the dome can be divided into two domains as shown on Figure 5.
The axial obliquity of the dome with respect to the general east-west shear along the MRPSZ is consistent with development of the dome by sinistral transpression, and possibly large scale sinistral rotation. The dome does not appear to be a secondary fold defined by folded foliation as suggested in kinematic models for the Adirondacks (Weiner et al., 1984). In contrast, it appears to be a dome-shaped distribution of foliation developed in the less resistant rocks that mantle the more resistant anorthosite that cores the dome. The asymmetry of the dome axis relative to the general shear direction may reflect modification of the original dome geometry in the left-lateral shear couple. We propose here that the Snowy Mountain anorthosite and related rock suite, are part of an asymmetric giga-clast within a sinsitral shear zone (Figure 6).

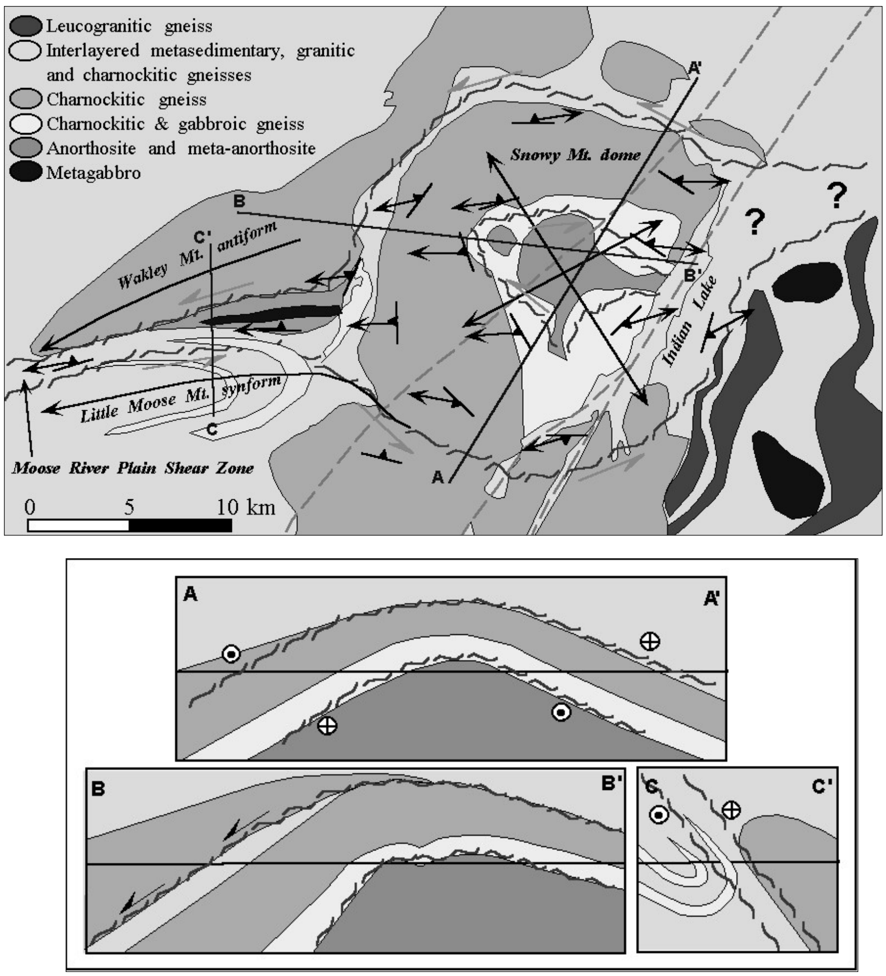


**Figure 6.** Schematic geologic map of the Snowy Mountain dome and the intersection with the Moose River Plain shear zone. The structure sections (A-A'; B-B'; C-C') are the same scale as the map and have no vertical exaggeration.

## Piseco Lake Shear Zone

In the southern Adirondacks, there is a zone (10-20 km wide) of spectacular L-S and L>S tectonite with a general east-west map pattern, that extends across the entire southern Adirondacks (Figure 2). This deformation zone was designated by Gates et al. (2004) the Piseco Lake shear zone (PLSZ) based upon its inclusion of the Piseco dome and antiform of earlier workers (Cannon, 1937; Glennie, 1973; McLelland, 1984; Wiener et al., 1984), but also upon the extent of penetrative fabrics general shear fabrics found well beyond the core of the antiform. It is these fabrics, more than any other structure. Throughout the PLSZ, rocks of mostly granitic composition contain intense foliation and lineation, as described by Cannon (1937) and McLelland (1984) in his paper on the formation of ribbon lineations. Penetrative foliation and lineation are defined by dynamically recrystallized quartz, K-feldspar and plagioclase, and alignment of muscovite, biotite and locally chlorite. Rocks within the zone consist dominantly of fine-grained aggregates of these minerals. Locally there are 2- to 6-cm-wide K-feldspar porphyroclasts supporting a plutonic origin for these rocks.

Foliation within the PLSZ defines an upright antiform (Cannon, 1937; Glennie, 1973; Weiner et al., 1984) with a subhorizontal axis that trends approximately 110° in the east, 090° in the central part, and 080° in the west. Foliation on the antiform limbs dips moderately to steeply both north and south. Lineations are penetrative in these rocks and are defined by dynamically recrystallized ribbons and rods of quartz, K-feldspar, plagioclase and streaks of chlorite, biotite, magnetite and muscovite. The plunges of the lineations are consistently shallow to subhorizontal. Overall the fabric in the antiform limb regions can be classified at L-S with the lineation and foliation both well developed. In the antiform crest, foliation is not well developed and penetrative lineations are defined by mineral rods, rods of mineral aggregates, and mineral ribbons. Lineations in the core area of the antiform are intensely developed, and in many places the linear fabric is dominant over the weak planar fabric (L>>S; Figure 7) with grain-shape aspect ratios upward of 60:1 (in the L-parallel and S-perpendicular plane).

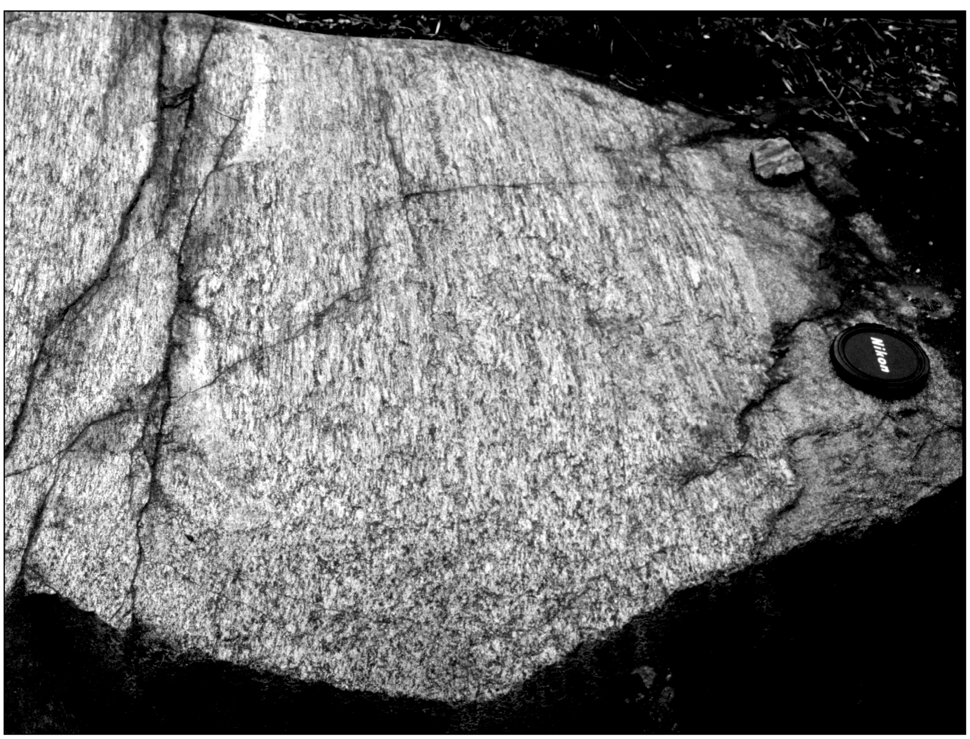


**Figure 7.** Outcrop of L-tectonite from the Piseco Lake shear zone. The view is looking west at an outcrop face that is subvertical in the foreground and subhorizontal in the background, revealing the ends and sides of mineral lineations respectively.

Metamorphic index minerals are not diverse in these rocks due to the overall granitic composition. The penetrative foliation and lineation is associated with diagnostic metamorphic minerals such as biotite, chlorite and muscovite, which are indicative of greenschist-facies conditions (Figure 8). Locally, anhedral grains of augite and hypersthene have overgrowths of hornblende, biotite or chlorite. The presence of hypersthene suggests these rocks experienced granulite facies metamorphism (McLelland, 1984), but the main fabric developed later during intense dynamic retrogression (Chiarenzelli et al., 2000).

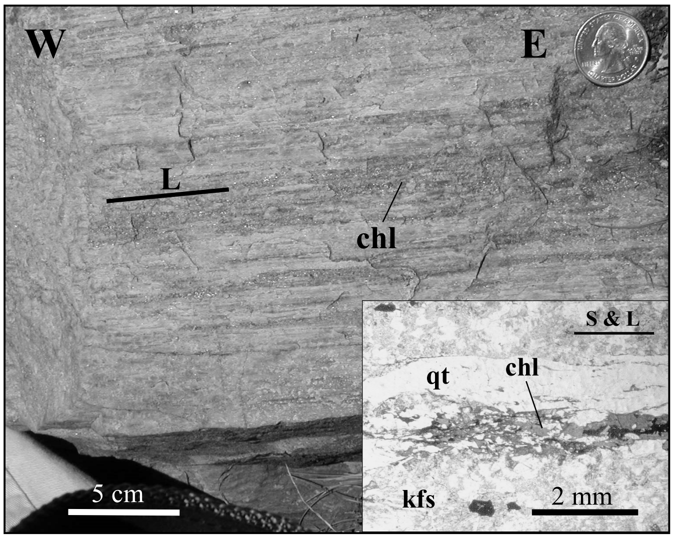


**Figure 8.** Outcrop of L-S fabrics in the PLSZ along Route 8 in the vicinity of Piseco Lake. The darker layers are linear aggregates of chlorite. The inset photomicrograph shows acicular chlorite (blades in three dimensions) oriented sub-parallel to the quartz ribbon.

McLelland (1984) suggested that the Piseco dome developed in the constrictional part of a regional west-directed thrust, but little kinematic data was presented. Shear-sense indicators are abundant in the PLSZ, and include Type I S-C fabrics (Lister and Snoke, 1984), $\sigma$ - and $\delta$-porphyroclasts of K-feldspar (cf. Simpson and Schmid, 1983; Passchier and Simpson, 1986), asymmetric polymineralic tails around porphyroclasts, and biotite- and muscovite-fish (Figure 9). These kinematic indicators reveal a consistent sinistral-shear sense on both the north- and south-dipping domains of the zone.

## Normal Shear Zones

Geologic mapping of the PLSZ in the area of Speculator Mountain (southeast of the field trip area) revealed a cross cutting ductile normal shear zone with west directed displacement (Freyer et al., 2004). The area of Speculator Mountain is underlain by a sequence of granitic-, charnockitic- and gabbroic-gneisses that contain penetrative foliation and ribbon mineral lineations. The foliation texture varies from protomylonite to mylonite in a nearly vertical stack of rocks. Near the base of the mountain, protomylonite occurs in megacrystic granitic-gneiss. Moving structurally upward, the granitic-gneiss contains penetrative mylonitic foliation and lineation. Dynamically recrystallized quartz and K-feldspar, as well as core-mantle structure in K-feldspar are evidence for ductile strain. The mylonitic foliation dips gently to moderately (20-30 degrees) westward, but in some places the foliation is locally folded about a N-S axis. Mineral lineations associated with the mylonitic foliation are defined by ribbon-shaped aggregates of recrystallized quartz, and feldspars. Biotite forms mineral streaks that parallel the ribbon lineations. The lineations trend approximately due west.

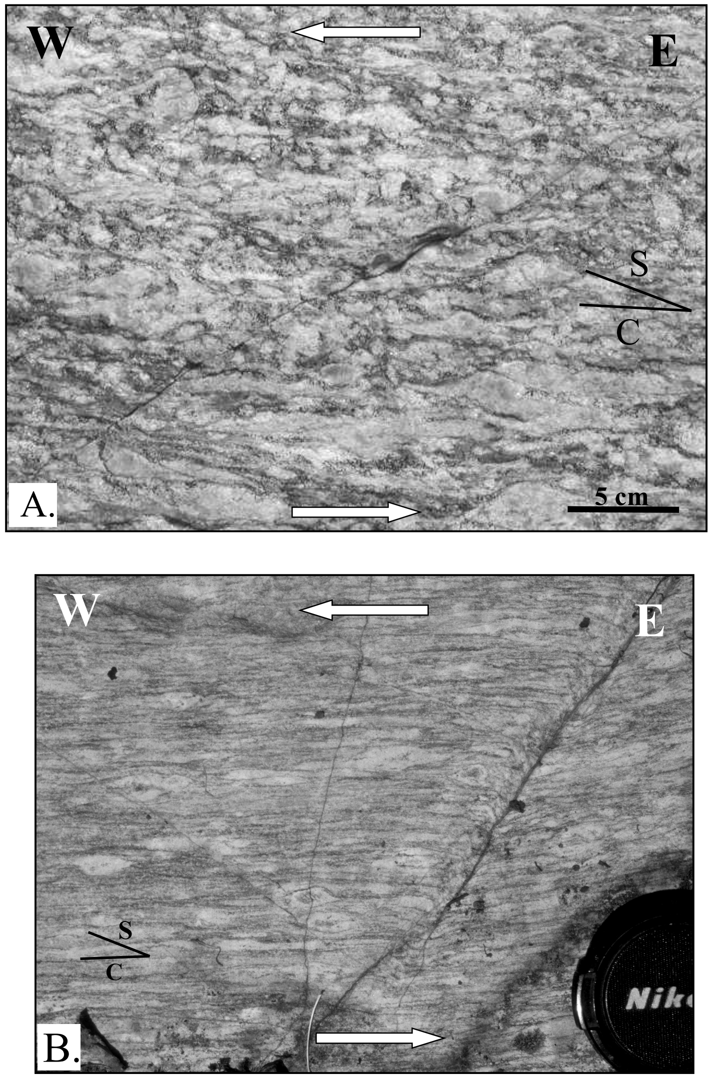


**Figure 9.** Outcrop photographs of kinematic indicators from the PLSZ. A] View is looking perpendicular to moderately north dipping foliation in western end of the Ohio Gorge on West Canada Creek. Type I S-C foliation is well developed in megacrystic granitic gneiss, and the shear sense is sinistral. B] Penetrative foliation developed in granitic gneiss along Route 10 south of the intersection with Route 8 (this is the pavement view on the top of the outcrop at STOP 12). σ-shaped porphyroclasts of K-feldspar and plagioclase indicate sinistral shear. These examples are from the northern and southern parts of the PLSZ respectively, and both show sinistral shear.

In some minor mafic rocks, there are relict hypersthene grains with reaction rims and fringes of hornblende and biotite. The hornblende and biotite define a microscopic foliation and lineation that is parallel to the macroscopic mylonitic foliation and lineation, suggesting these index minerals formed during ductile deformation. These mineral textures also suggest that amphibolite facies metamorphism was associated with ductile deformation, and it was superimposed on rocks that were originally higher grade (presence of relict hypersthene grains). All the rocks are granitic in composition, with differences only in the mafic index minerals. The hanging wall rocks contain hypersthene, augite and hornblende. Within the shear zone, these mafic minerals show evidence of retrogression to biotite and/or chlorite, and there is good correlation between the occurrence of retrograde minerals and the level of fabric development.

Kinematic analysis of granitic mylonite revealed abundant shear sense indicators such as Type I S-C fabrics, δ- and σ-porphyroclasts, asymmetric tails around porphyroclasts, and shear bands. The shear sense indicators show that the direction of displacement was top toward the west, with the charnockitic-gneiss at the top of Speculator Mountain displaced over the megacrystic grantic-gneiss at the base. The presence of a large ductile normal shear zone was not previously documented in this area; however, small normal shear zones occur directly to the west in the PLSZ, and they have the same sense of displacement. These small normal shear zones consistently have hanging wall down toward the west (Figure 10). This is the same relationship observed at Speculator Mountain, but at the map-scale.

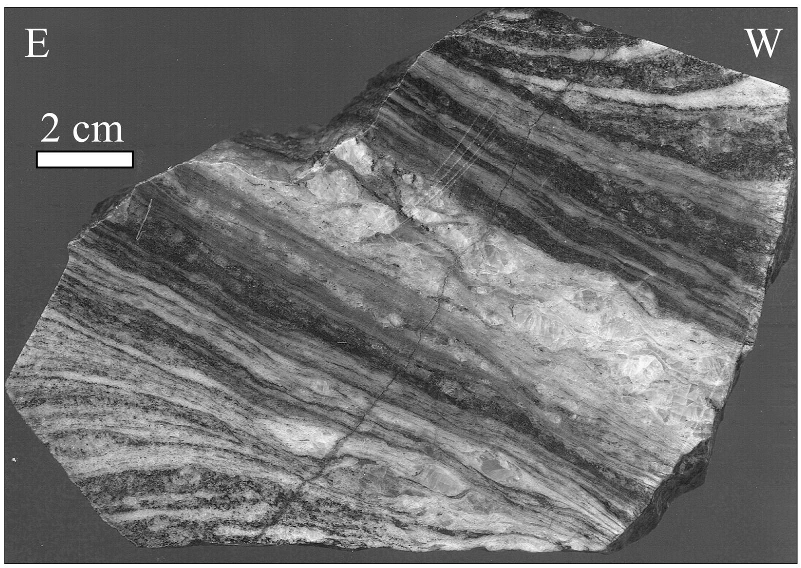


**Figure 10.** Polished rock slab of a small ductile shear zone that cross cuts the PLSZ fabric in the area of West Canada Creek. The view is looking south at a near vertical surface, and the shear sense is top down to the west. These small normal shear zones commonly contain parallel granitic pegmatite that is also plastically deformed.

## Constraints on Timing

Geochronologic studies in the Adirondack Highlands constrain the timing of compressional deformation, peak metamorphic conditions, and late syn- to post-tectonic intrusives to 1090-1030 Ma after the intrusion of vast volumes of AMCG plutonic rocks from 1160-1100 Ma (McLelland et al., 1988; McLelland et al., 1996). Although sinistral shear along the MRPSZ and Snowy Moutain dome may have been active during the time of regional high-grade metamorphism (Ottawan orogeny), sinistral shear in the PLSZ clearly post-dates, and is superimposed on the granulite-facies mineral assemblages. A lower limit can be placed on sinistral deformation in the southern

Adirondacks, at least locally, where an undeformed, 950 Ma, leucogranitic dike swarm intrudes strongly lineated gneiss (McLelland et al., 1996).

Recently published argon data ($^{40}Ar/^{39}Ar$) from biotite in samples collected near the Carthage-Colton shear zone in the Adirondacks suggest extensional movement occurred at 950-920 Ma (Streepey et al., 2000), well after the end of compression at 1030 Ma (McLelland et al., 1996). Given the nearly 100 Ma difference in timing between compression and extension, Streepey et al. (2000) suggested that movement on the Carthage-Colton shear zone was not related to orogenic collapse, but to an undefined, enigmatic extensional event.

Interpretations suggest that the Adirondacks cooled at a rate of 1°-2°C/Ma during a period of at least 100 Ma at this time (Mezger et al., 1993). The significance of extended periods of slow cooling is not yet fully understood; however, strike-slip deformation related to orogen parallel deformation after 1050 Ma provides a plausible mechanism for the slow uplift of the region over an extended timeframe. In the Adirondack Highlands, cooling rates are thought to have increased to 4°C/Ma at ca. 950 Ma (Streepey et al., 2000). The scenario proposed here, late strike-slip modification of Ottawan compressional structures in a large sinistral zone, provides a realistic time frame for Rodinia assembly, a plausible mechanism for extension, and an explanation of otherwise enigmatic P-T-t paths.

**Tectonic model and conclusions**

Gates et al. (2004) proposed that dextral shearing in the Hudson Highlands of southern New York, and sinistral shearing in the southern Adirondacks occurred during the development of a conjugate syntaxis associated with the Ottawan orogeny (Figure 11). Clearly, the limitations on this interpretation are the great distance between these two Grenville terranes that is covered by Paleozoic sedimentary rock and the potential modifications to the geometrical relations as the result of Paleozoic orogenesis. Nonetheless, the similarity in timing and character and evidence of numerous outcrop-scale, conjugate, shear-zone relations with similar orientations in both areas render the model plausible. Although the Adirondacks and Hudson Highlands are only a small portion of the Grenville Province, and thus extrapolation of this model to the orogen scale is speculative, oblique convergence and orogen-parallel transpression accompanying orogenesis of "Ottawan" age has been noted in other areas including the Central Gneiss Belt in Ontario (Gower, 1992), Baltica (Stephens et al., 1996; Park, 1992), and South America (Sadowski and Bettencourt, 1996). Therefore, the model presneted here may have significant tectonic implications for the final assembly of Rodinia over a broader area.

Supporting evidence for the model comes from paleomagnetic polar wander paths for both North America and Baltica. They show a pronounced 90° bend at about ca. 1020 Ma which is consistent with an abrupt change in plate motion, perhaps in response to a shift from convergence to strike-slip motion (Bylund, 1992; Park and Gower, 1996).

Even if plate convergence was purely orthogonal, considerable strike-slip faulting and horizontal-escape tectonism due to plate-margin geometry is possible. The Himalayan stress field is related to the shape of the Indian subcontinent (rigid indenter of Tapponnier and Molnar, 1976) and resulted in the lateral escape of crustal blocks in southeast Asia along major transcurrent zones. In contrast, the Himalayan contractional structures (thrusts and fold nappes) are of limited areal extent. Recent work has shown that the stress field in the crust is reflected in the subcontinental mantle (Holt, 2000). The fast polarization direction of split shear waves beneath the Adirondacks has been shown to be E-W (Barruol et al., 1997), parallel to the east-west structural fabric of the south-central Adirondack Mountains (Dawers and Seeber, 1991). This east-west trend truncates the prevalent northeast-trend of both the Grenville and Appalachian orogen in eastern North America (Barruol et al., 1997). Because the Hudson Highlands are outboard of the Adirondacks, they were positioned near the margin of Laurentia or originated as part of the overriding South American (Dalziel et al., 1994) continent. The recognition of strike-slip faulting and transpression in the Grenville core may record the escape of tectonic elements (Gates, 1995) and enhances analogs drawn with the Himalayas and models based on indentation tectonics (Hoffman, 1992).

Based upon existing age constraints, this conjugate shear system was active in the core of the Ottawan orogen during and subsequent to peak metamorphic conditions and within the range of ca. 1008 to 876 Ma. Relative to modern geographic coordinates, the Grenville strike-slip shear zones yield bulk-extension and bulk-compression directions of west-northwest and east-northeast respectively. These strain axes are consistent with compression directions deduced from en echelon transpressional folds in the Hudson Highlands and the en-echelon domes on the central Adirondacks (Chiarenzelli et al., 2000). This bulk strain analysis assumes that bulk rotation of the Hudson Highlands relative to the Adirondacks during Paleozoic Appalachian tectonic events (Taconic, Acadian, Alleghanian orogenies) and Mesozoic extension was minimal. The assumption is reasonable because there is no post-Precambrian penetrative deformation in the western Hudson Highlands and the major folds and faults in the surrounding Paleozoic strata are essentially parallel to those in the crystalline rocks indicating similar strain axes and minimal rotation.

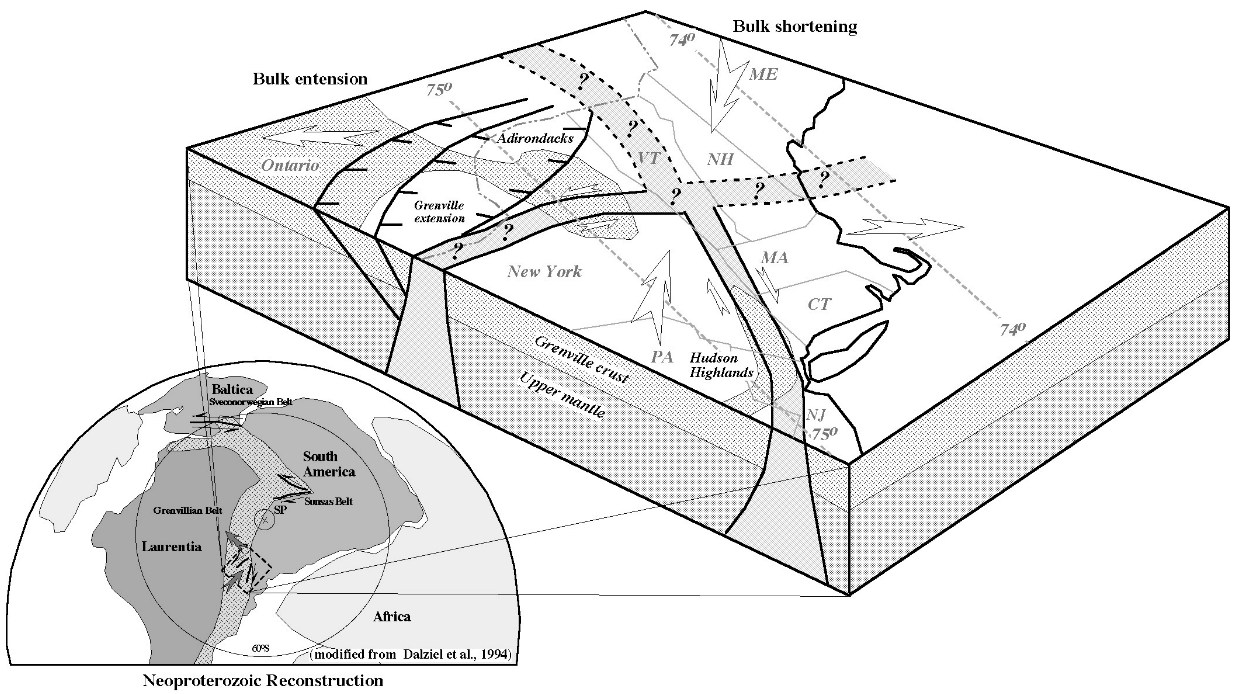


**Figure 11.** Block diagram depicting the crust-scale conjugate ductile shear zones forming a syntaxis. The inset shows the location of the syntaxis in a reconstruction of Rodinia (modified from Dalziel et al., 1994).

The extensional deformation identified in the northwestern Adirondacks can be explained using the conjugate model with the interpreted bulk-strain directions (Figure 11). The Grenville Province north of the Adirondack Lowlands contains numerous Proterozoic normal faults and shear zones with an overall northwest-southeast extension direction (Streepey et al., 2000), and published age data suggest that these normal faults were active as much as 100 Ma after peak metamorphic conditions in the Adirondack Highlands. The conjugate shear model proposed by Gates et al. (2004) is consistent with the orientation, timing, and location of these later extensional faults such as the Carthage-Colton mylonite zone (separating the amphibolite facies Adirondack Lowlands from the Highlands) and extension in the Central Metasedimentary Belt in Ontario (van der Pluijm and Carlson, 1989).

Gates (1995) proposed that eastern Laurentia underwent escape tectonism along major faults as a result of a second Grenville collision somewhere between the present New England and Labrador. This model must be reconsidered in light of the new data. The early Himalayan-type collision that formed the westward-directed fold nappes and granulite-facies metamorphism is present throughout the Grenville orogen. The transcurrent-transpressional deformation post-dates it. This deformation could still have resulted from a second collision, but it could also have been the second phase of a single event like the Himalayas, where the escape tectonic features overprint the earlier contractional features. The extensive sinistral shearing in the southern Adirondacks equals or may even exceed the exposed dextral shearing in the Hudson Highlands. However, strike-slip deformation has yet to be identified in the Blue Ridge Province in the southern Appalachians. Therefore, the marked predominance of one conjugate fault set over the other as in the Himalayas does not appear to be the case in the study area. Instead, the distribution of the conjugate faulting appears relatively balanced. This situation may have resulted from the location of the area directly in front of the “indenter” or the lack of a “free face” (Tapponnier et al., 1982) that characterizes the Himalayan geometry. An uneven, leading, Amazonian margin with promontories that impinged on the equally irregular Laurentian margin could have produced local syntaxes with relatively balanced conjugate transcurrent faulting.

**Acknowledgements**

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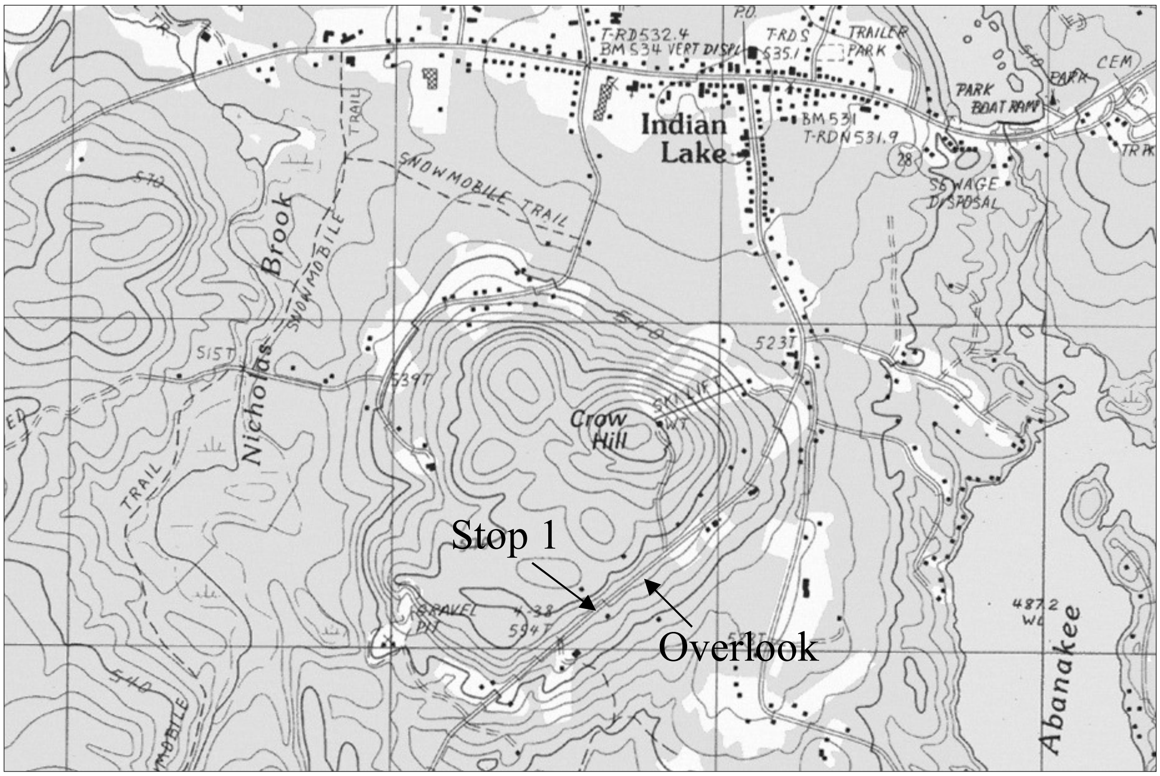
## Field Trip Description and Road Log

**Road Log:**

Mileage:

0.0 The trip begins at the assembly point in the parking lot of the Tops supermarket in the town of Indian Lake, NY, at the eastern intersection of Rts. 28 and 30. Proceed south on Rt. 30.

1.0 Turn left into the overlook parking lot, and walk south on Rt. 30 approximately 0.2 miles to the first roadcut on the west (right) side of the road.




**STOP 1: Calc-silicate gneiss on the north side of the Snowy Mountain Dome (SMD).**

Calc-silicate gneiss with penetrative foliation and folds occurs in outcrops on the west side of Route 30. The foliation is defined by planar aggregates of recrystallized plagioclase, quartz and diopside (Figure 13). Locally the calc-silicate gneiss contains quartzofeldspatic layers that define isoclinal folds, and locally there are recrystallized masses of diopside (some >10 cm in diameter).

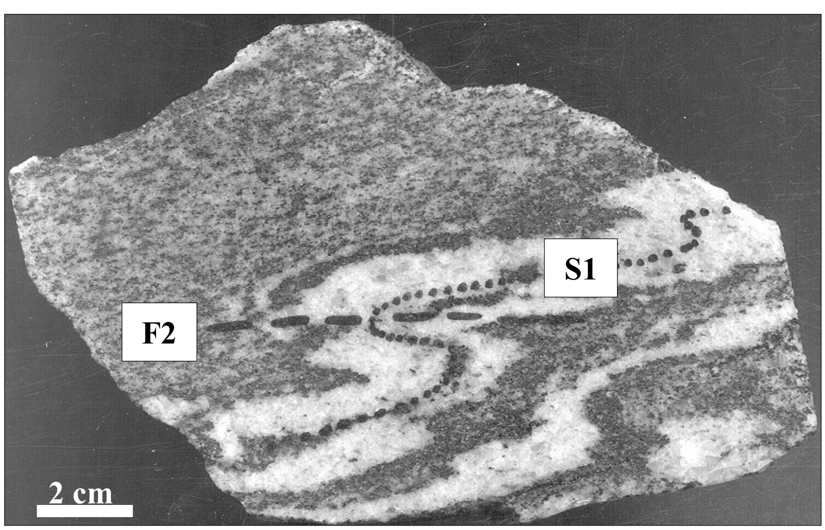
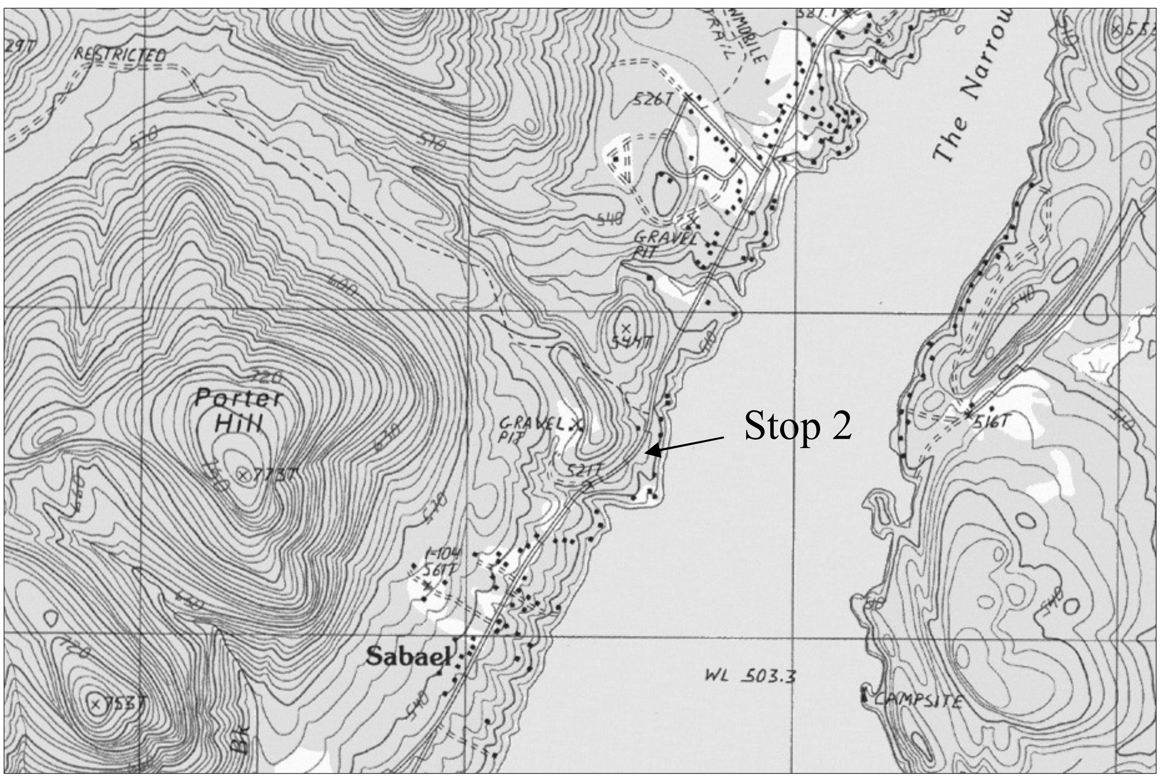


**Figure 12.** Rock slab of calc-silicate gneiss showing the S1 foliation defining F2 isoclinal folds.

The dominant foliation in the outcrop in most places is structurally continuous with penetrative foliation (S2) in the Snowy Mountain dome, and dips moderately northward at this location. Portions of the exposure reveal an earlier foliation (S1) preserved mostly in the hinges of the isoclinal folds (F2) (Figure 13). The S1 foliation does not occur in the rocks of the Snowy Mountain suite, and the S2 foliation dies out away from the Snowy Mountain dome. In a relative sense, the S1 foliation is either predates or is synchronous with the intrusion of the Snowy Mountain suite, and the S2 foliation is superimposed on the suite.

Mileage:

1.0 Continue south on Rt. 30 towards Speculator.
2.1 Point Breeze Hotel
2.6 Roadcuts of charnockitic gneiss.
3.5 Park on the right side of Rt. 30 and cross the road to the roadcut on the east (left) side (at the "Southwinds" sign).




**STOP 2: Charnockitic gneiss on the north side of the SMD.**

The contact between the calc-silicate gneiss of STOP 1 and charnockitic gneiss of the Snowy Mountain suite occurs approximately 1 km northeast of this location, and is concordant with the S2 foliation. Here there is exposure of highly deformed charnockitic gneiss on both sides of the road. The foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite. The foliation dips moderately northeastward and weak mineral lineations trend shallowly toward the east. Many of the outcrop surfaces reveal augen of plagioclase with core-mantle structure. Dynamically recrystallized tails developed on porphyroclasts of plagioclase merge with the penetrative foliation. The plagioclase augen are interpreted to be relict igneous crystals, possibly original megacrysts. When viewed on outcrop surfaces that are parallel to the lineation and perpendicular to the foliation, the augen appear to be asymmetric defining both σ- and δ-porphyroclasts. Additionally, domino structures and Type I S-C fabrics can be viewed on some optimum surfaces. The kinematic indicators are consistent with top toward to the west ductile shearing, or low-angle sinistral considering the shallow plunge of the lineations.

Proceeding south across the Snowy Mountain dome, the penetrative foliation in the charnockitic gneiss progressively dips toward the each and then toward the southeast. There are numerous outcrops along Route 30 that can easily be viewed. Where the southeastern spur of Squaw Mountain intersects Route 30, there is exposure of gabbroic gneiss and megacrystic anorthosite. We will not be stopping at this outcrop during this trip due to time constraints. However, this is a good place to view the transitional compositions and deformation fabrics. The megacrystic anorthosite lacks penetrative deformation at this location, but some parts of the outcrop contain dynamically recrystallized anorthosite with well developed S2 foliation. The gabbroic gneiss contains penetrative foliation and well developed lineations at this location.

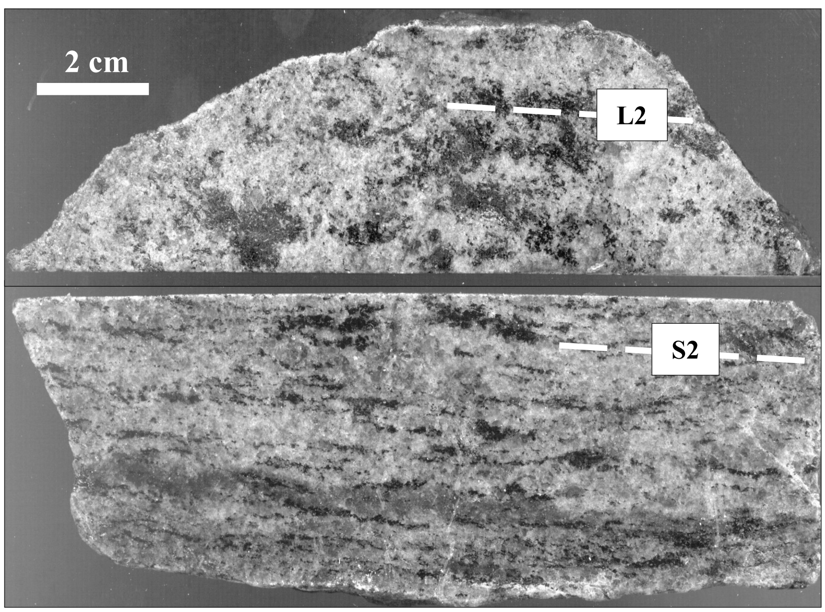



**Figure 13.** Mutually perpendicular rock slabs of charnockitic gneiss from the northeastern flank of the Snowy Mountain dome. The top slab is cut parallel to the S2 foliation revealing weakly developed mineral lineations. The bottom slab is cut perpendicular to the foliation and parallel to the lineation to reveal the penetrative foliation.

The transition from gabbroic- to charnockitic-gneiss occurs approximatley 1000 meters northeast along the Squaw Mountain spur. This transition was documented by DeWaard and Romey (1969). Within the charnockitic gneiss branching high-strain zones can be seen (Figure 14). In places, the high-strain zones merge and have tapered terminations, and close inspection will reveal the penetrative folation. Compositionally, the rocks in the high-strain zones are identical to the bounding charnockitic gneiss, except for the occurrence of minor quartz veins. The high-strain zones have the same general strike as the location foliation, but typically dip steeper northward in this area. Mineral lineations are better developed in the high-strain zones. Shear sense indicators are consistent with the shear sense indicators observed in the charnockitic gneiss with top toward the west ductile flow, or low-angle sinistral. The high-strain zones contain the same metamorphic minerals as the lower-strain charnockitic gneiss.

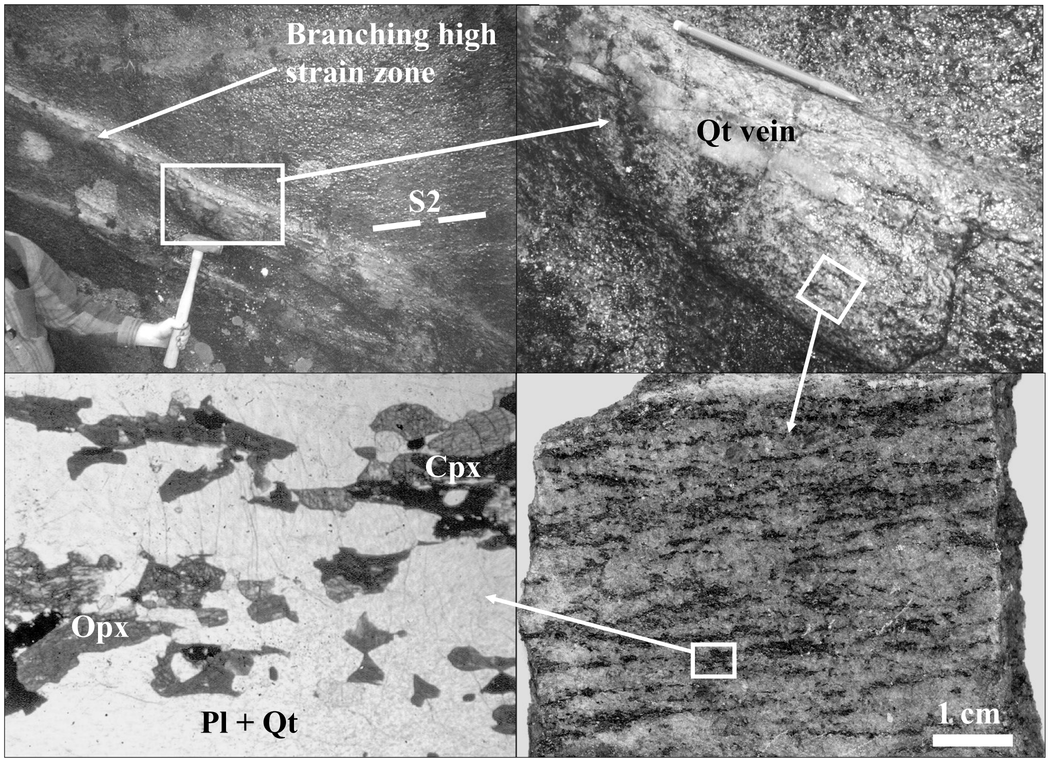
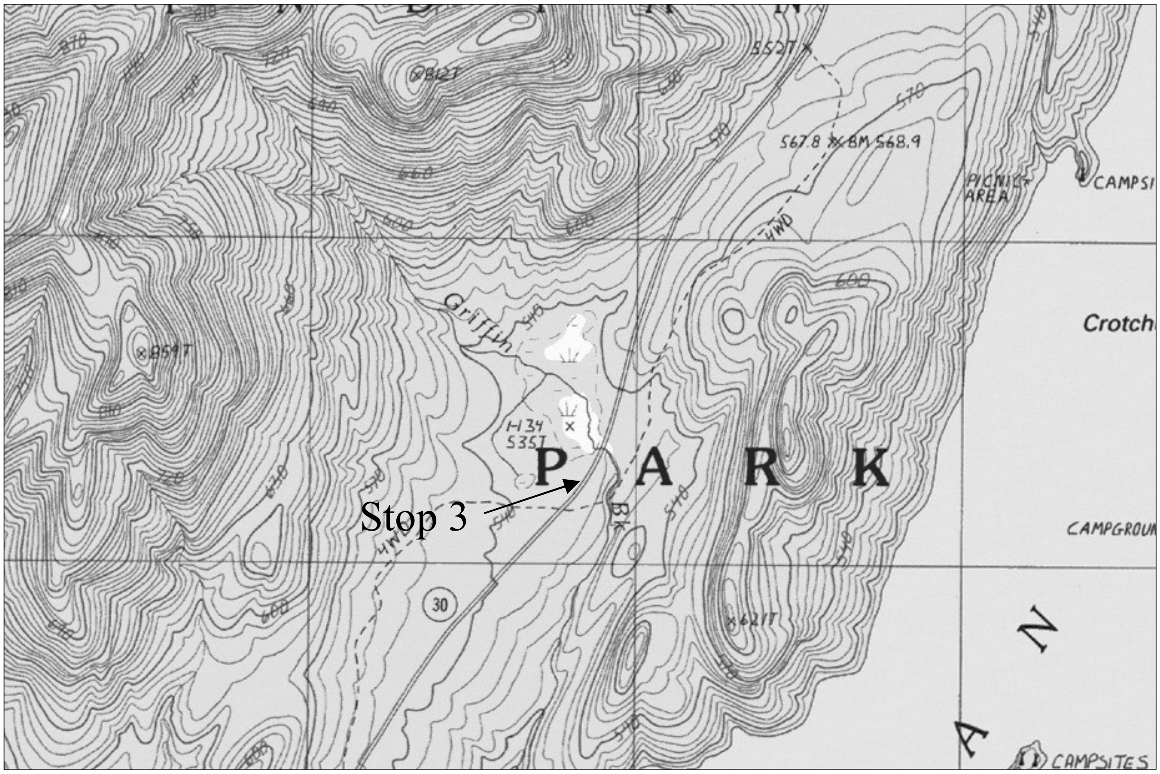



**Figure 14.** Example of a branching high-strain zone in charnockitic gneiss on the eastern flank of the Snowy Mountain dome in the area of Squaw Mountain. See text for details.

Mileage:
3.5 Continue south on Rt. 30 towards Speculator.
5.9 Roadcuts of gabbroic metanorthosite and megacrystic metanorthosite.
7.1 Trailhead to Snowy Mountain. Drive slowly for the next mile or so.
8.0 Just after Griffith Brook, turn right into a turnout and park for Stop 3.

**STOP 3: "Underview" of the Snowy Mountain Dome:**

From this location, the entire structure of the Snowy Mountain dome can be viewed. Numerous slide faces expose the shallowly dipping foliation that occurs at the top of the dome (Figure 15). The exposures at the top of Snowy Mountain can be accessed by a popular hiking trail that occurs about 2 km north of this location. The top of Snowy Mountain is underlain by gabbroic gneiss with penetrative S2 foliation. The foliation dips shallowly toward the north and subhorizontal mineral lineations trend nearly due east. A near vertical outcrop near the top of the mountain reveals abundant shear sense fabrics. Detailed kinematic analysis using porphyroclasts, S-C fabrics and shear bands resulted in dominant shear of top toward the west. However, some domains upward of a few meters thick showed conflicting shear sense of top toward the east. These exposures are the structurally highest part of the dome.



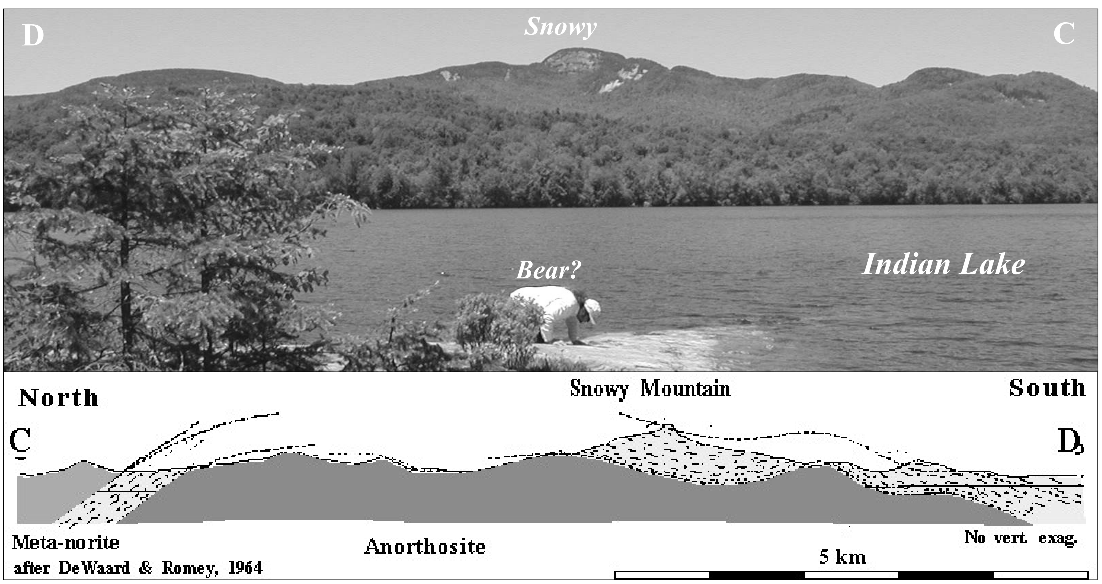



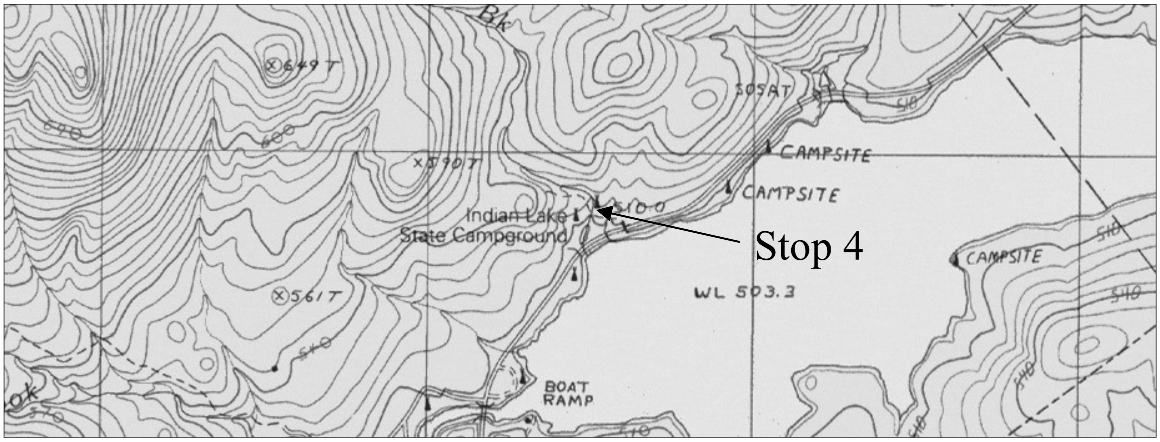

**Figure 15.** Westward view of Snowy Mountain from the east shore of Indian Lake (top) with the cross section of DeWaard and Romey (1964). The cross section an eastern view of the area so "C" and "D" are reversed on the photograph.

Mileage:

8.0 Continue south on Rt. 30 towards Speculator.

9.2 Access road for Timberlock resort on left.

10.5 Sign noting "Entering Camping Area" of Lewey Lake and Indian Lake Campgrounds.
11.3 Turn right onto access road for campsites. Drive this road until just into the woods, and park in the wide flat area just before the bridge over Falls Brook. Walk across the bridge and past the metal gate, then plunge into the woods on the right of the access road about 10 meters to the outcrops in the brook that form the falls.




**STOP 4: Charnockitic gneiss on the southeast side of the Snowy Mountain Dome.**

Stop 4 is of highly deformed charnockitic gneiss, the same lithology as Stop 2. However, the penetrative foliation dips moderately toward the southeast due to the position on the Snowy Mountain dome. At this location, and as before, the foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite, and weak mineral lineations trend shallowly toward the east. Augen of plagioclase have dynamically recrystallized tails often forming asymmetric kinematic indicators. As well, Type I S-C fabrics are well developed in some domains (Figure 16). Unlike Stop 2, the shear sense determined at this location is top toward the east. But, considering the dip is southerly, and mineral lineations trend easterly, the shear sense can be considered low-angle sinistral.

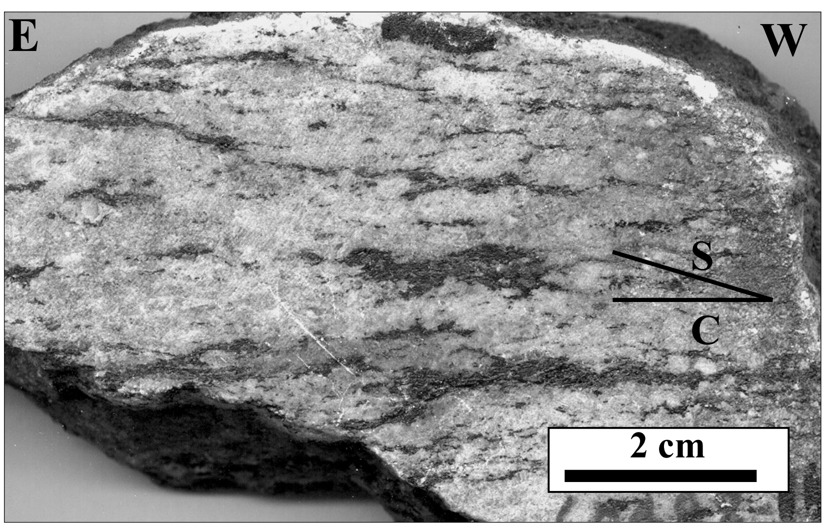
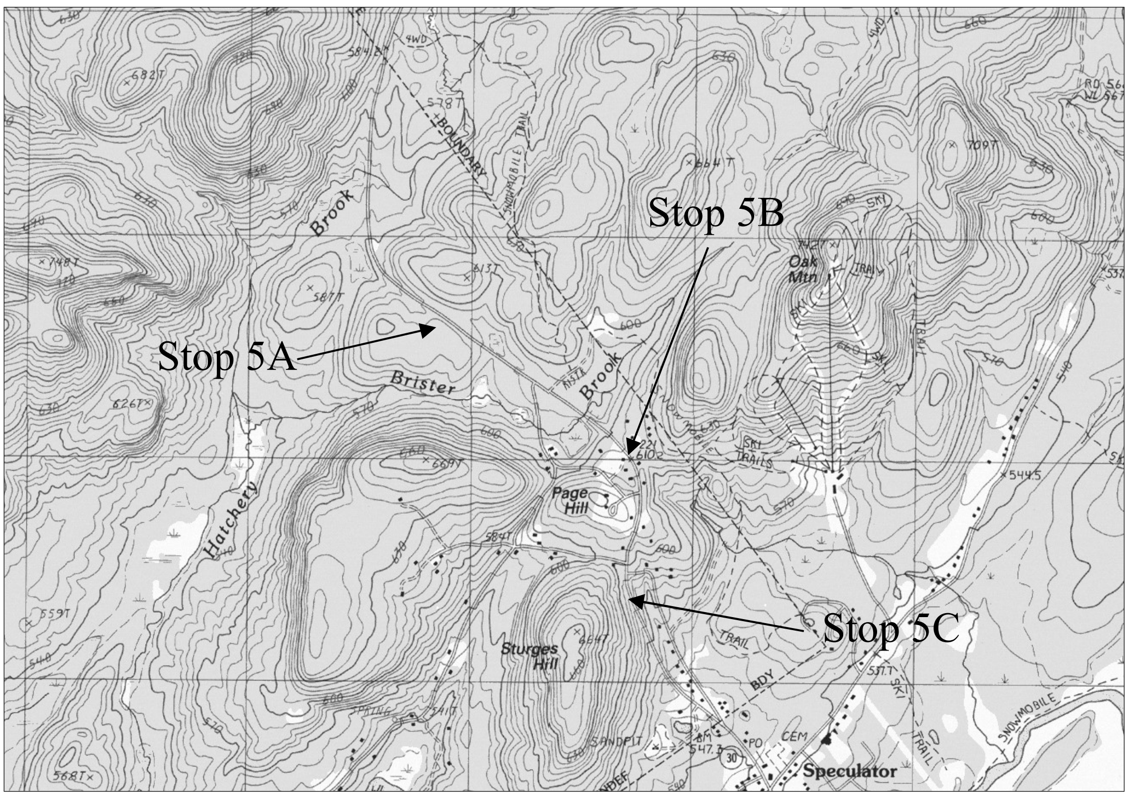



**Figure 16.** Rock slab of charnockitic gneiss from the falls on Falls Brook with Type I S-C fabric. The shear sense is top toward the east or sinistral. The dark minerals are broken grains of hypersthene and augite, while the lighter portions of the rock consist of recrystallized aggregates of plagioclase and quartz.

Mileage:

11.3 Return to Rt. 30, and continue south towards Speculator.
11.9 Lewey Lake on the right.
15.8 Intersection with dirt road on right ("Mountain Bike Trail").
16.2 Mason Lake on the right.
17.6 Jessup River.
18.4 Roadcuts of quartzo-felspathic gneiss with granite dikes on both sides of the road.
19.0 Roadcut of calcite-garnet rock on the right, with a rock painted as a pig on the left.
21.1 Roadcut of steeply-dipping dextrally sheared rocks on the right.
21.3 Intersection with dirt road on right ("Mountain Bike Trail").
22.4 Park on west (right) side of road at the large roadcut for Stop 5A.




**STOP 5: Rocks typical of the intervening zone between the SMD to the north and the PLSZ to the south.**

Rocks of each outcrop for Stop 5 are typical of rocks that occupy the zone between the SMD to the north (STOPS 1 to 4) and the PLSZ to the south (STOPS 6 to 13).

**STOP 5A: Garnet amphibolite, calc-silicate rock and quartzo-felspathic gneiss.** Here, these three rock types and their contacts are seen. The northern ¼ of the outcrop consists of garnet amphibolite, the next ~ ¼ of the outcrop is calc-silicate rock and the southern ½ is fine-grained quartzo-feldspathic gneiss. Complex sheath folds with sub-horizontal tight, isoclinal and sheath folds of foliation and compositional layers dominate the rock, particularly in the gneiss (trend to 110°) (Figure 17). Excellent views of the folds are seen on top of the southern part of the outcrop.

The contacts between the rock types are also folded in similar fashion. Matrix minerals define lineations that are E-W and sub-horiziontal, but are variable in orientation due to folding.

Mileage:

22.4 Continue south on Rt. 30 towards Speculator.

23.0 Park on the right, just after the guard rail, as you ascend the north slope of Burgess Hill (see location map). The outcrop is a roadcut on the east (opposite) side of Rt. 30 just north of the sign for Lake Pleasant.

**STOP 5B: Garnet amphibolite and quartzo-feldspathic gneiss.**

Here the garnet amphibolite and garnet-bearing quartzo-feldspathic rock is in sheared contact. The amphibolite has a distinct foliation and lineation that is folded into shallowly inclined tight folds (N-dipping axial planes) whose axes are shallowly E-W plunging. The lineation in the amphibolite is shallowly plunging to 112°. The fabric in the quartzo-feldspathic rock is distinct in contrast to the amphibolite, showing a penetrative L>>S tectonite fabric whose lineation plunges shallowly to 112°. The L>>S fabric is defined by both rods of quartz and quartz aggregates, and by tails around garnet. The highly fractured nature of the outcrop offers excellent views of this fabric. The contact between the rock types is distinct due to the color difference, but also because the amphibolite is boudinaged (foliation boudinage) due to apparent contact-parallel shear. The interboudin partitions are in-filled by plagioclase and amphibole (Figure 17).


**Figure 17.** Pavement view of top surface of rock at Stop 5B showing the foliation boudinage in the amphibolite (bottom) and the penetratively strong fabric in the quartzo-feldspathic rock (top).

Mileage:

23.0 Continue south on Rt. 30 towards speculator.

23.2 Top of the hill (garnet amphibolite roadcuts on both sides of the road).

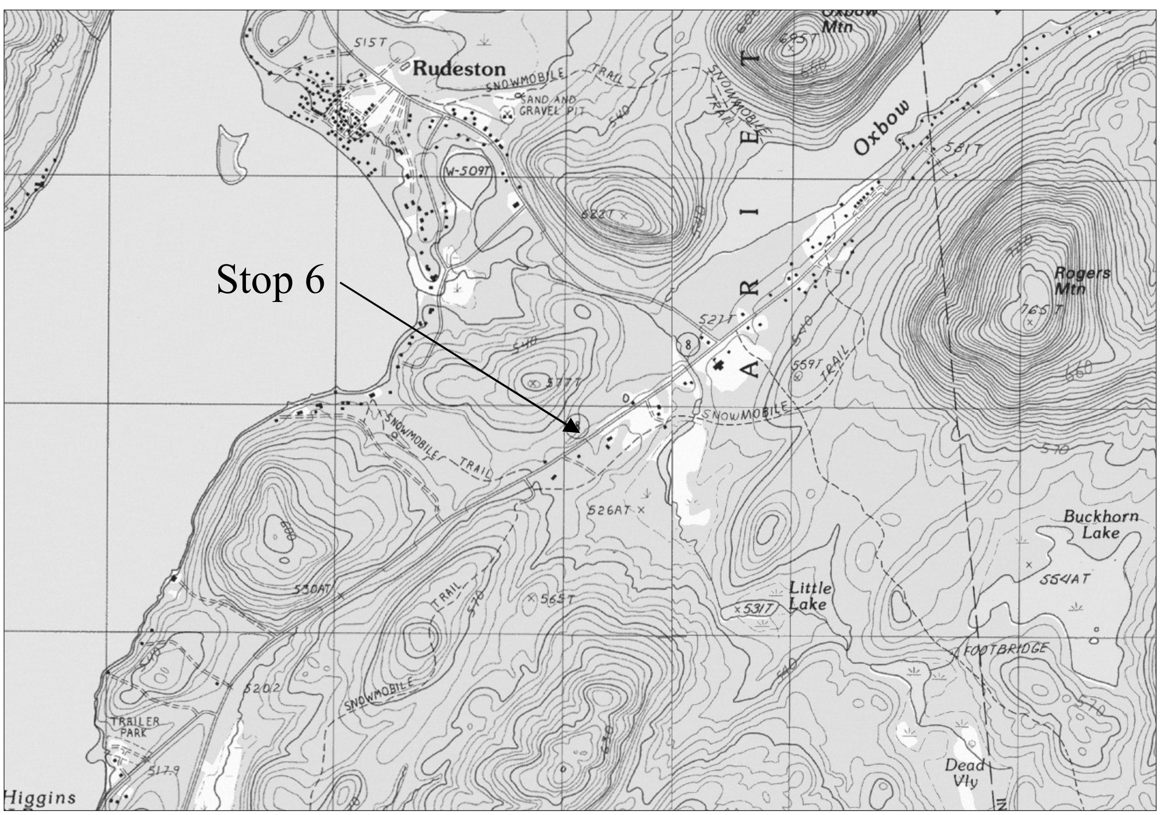
23.4 Park on the right side of the road just south of the intersection, and walk to the top of the large roadcut for southerly views of Lake Pleasant and Speculator Mountain, and the PLSZ.

**STOP 5C: Overlook of Speculator Mountain, and the PLSZ.**

The rock here is sub-horizontally stratified, with the rock at the top of the hill to the north (garnet amphibolite) the lowest stratum, and the base of the outcrop is interlayered amphibolite and granitic gneiss, followed by granitic gneiss with mica ‘mats’ at the top (at the viewing area). Foliation is sub-horizontal here, but, again, the mineral lineation is shallowly E- and W-plunging.

The view to Speculator Mountain illustrates the structure of the late history of the PLSZ. The bench on the east side of the mountain is the top of the hanging wall block of a moderately W-dipping normal fault, and the peak of Speculator Mountain is the hanging wall block. This normal fault is defined by fabric with a distinct top-down fabric trajectory (see Figure 10), and defines the zone to be about 100 m thick. This is one of many normal shear zones that cut the E-W fabric that defines the PLSZ, but this one is perhaps the thickest. Most identified are a few centimeters thick (as in Figure 10).

Mileage:
23.4 Continue south into Speculator.
24.1 Turn right (west) onto Rt. 8.
26.1 Roadcut on right is gneiss in the PLSZ.
27.1 Lake Pleasant
27.5 Lake Pleasant town center.
33.0 Intersection with Old Piseco Road in Piseco, NY.
34.0 Park on right side of the road at the low roadcut for Stop 6.



**STOP 6: L-S and L>S fabrics in the PLSZ.**

The Piseco Lake shear zone is developed in rocks of granitic composition. Dynamically recrystallized feldspars and quartz form spectacular ribbon- and rod-shaped mineral lineations (McLelland, 1984), in addition to mafic phases such as biotite, chlorite and accessory magnetite. In many places, the alignment of ribbons forms the foliation in this outcrop (Figure 18). Individual quartz-ribbons have aspect ratios upward of 60:1. The foliation dips gently southward and the lineations trend about 110°(Figure 18). This location occurs on the southern flank of the map-scale antiform defined by the foliation in the Piseco Lake shear zone. At the western end of the outcrop there are rods of amphibolite (10-30 cm diameter) within the granitic gneiss.

In the granitic gneiss, both biotite and chlorite blades form microscopic lineations and foliation parallel to the macroscopic structure. Rare grains of hypersthene have been found, but they always have well developed overgrowth textures that include biotite and chlorite. The biotite and chlorite are the most abundant index minerals in the granitic gneiss, and suggest the deformation was last active under low-grade metamorphic conditions, although probably began at much higher conditions to account for the relict grains of hypersthene.


**Figure 18.** Pavement exposure of grantic gneiss with penetrative mineral elongation lineations defined by quartz ribbons and aggregates of dynamically recrystallized feldspar. The view is looking toward the west.

Mileage:
34.0 Continue west on Rt. 8.
36.4 Turn south onto Rt. 10.
36.9 Roadcuts for Stop 12 (see below).
37.4 Piseco Outlet.
37.6 Turn right onto Powley Road (becomes dirt road).
45.3 Turn around at a wide and grassy DEC camping area to return north on Powley Road.

46.6 Park as far off the road as possible. The outcrop for Stop 7 is pavement exposures located within the bed and the gutter on the east side of the road.

**STOPS 7 TO 12** are a sequence of outcrops chosen to illustrate the variation and progression of textures and structures associated with the southern PLSZ (Gates et al., 2004). The sequence is in order from outside the PLSZ into central part. The rocks associated with STOPS 7 to 11 are located on or next to Powley Road, a dirt road that runs obliquely across the structure of the PLSZ (Figure 19). In the event that the town paves Powley Road, much or all of this rock will be covered.

All rocks at these Stops are very similar in mineral content, and vary only in detail with regard to mineral percentage and fabric type and intensity. The rock is dominantly quartzo-feldspathic gneiss with intense sub-horizontal to shallowly WSW- and E-plunging mineral elongation lineation and steeply S-dipping foliation. Both fabric elements are defined by ribbons of quartz, and ribbons of aggregate feldspar + quartz (generally 1-5 cm long depending upon grain size). Intensity of the fabric varies across strike at the 50 cm scale, with local layers of significantly coarser-grained fabrics (grains up to 1 cm in diameter).

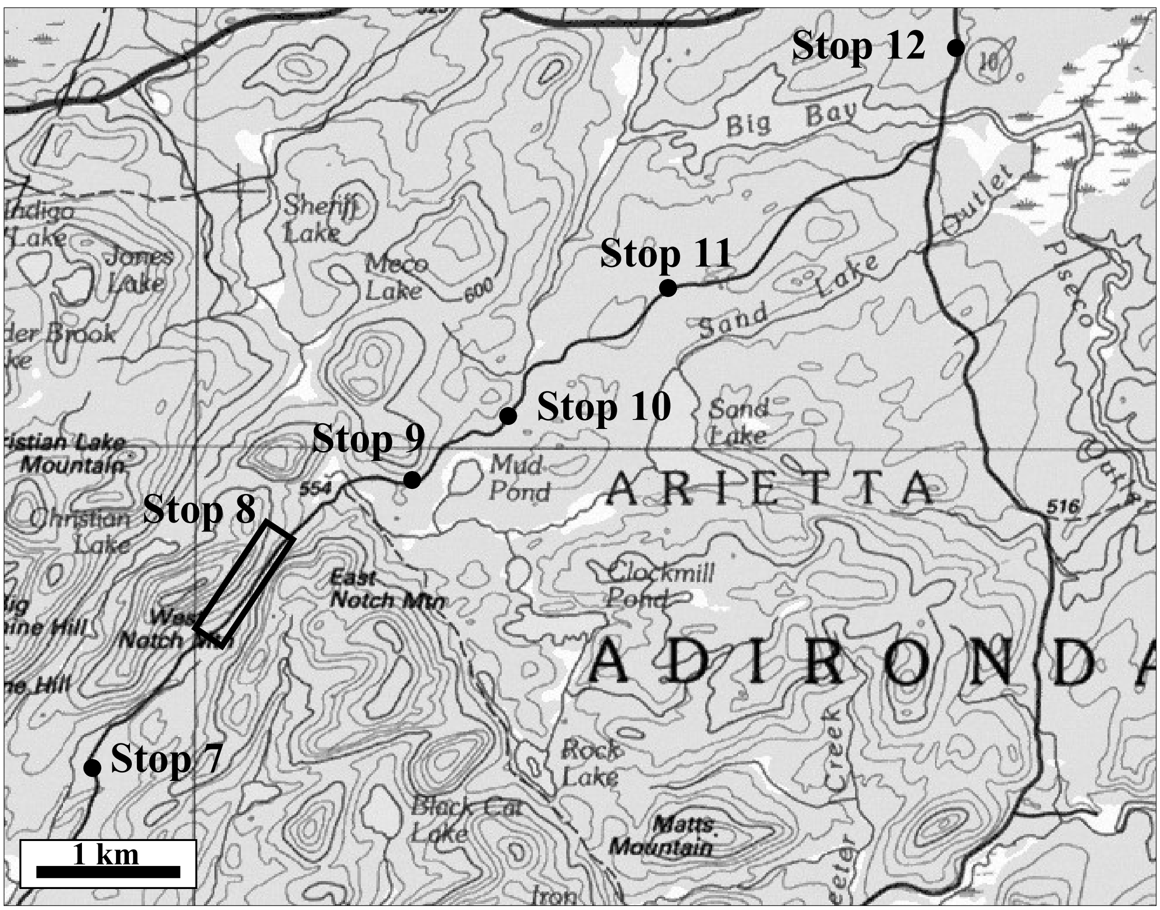



**Figure 19.** Location map of STOPS 7 through 12. STOPS 7 to 11 are on Powley Road, which cuts across the east-west trend of the PLSZ.

**STOP 7: Shear fabrics of the southern PLSZ.**

This stop consists of a sub-continuous series of pavement exposures located in the road bed, and in the gutter on the east (northeast-bound) side of the road. Due to the nature of this location, the extent of the exposed rock at this stop changes daily, so some or all of the rock described here may be viewable depending upon the time of the season in which the stop is visited (best later in the season).

Here, quartzo-feldspathic gneiss has intense shallowly WSW-plunging lineation and steeply S-dipping foliation, both defined by ribbons (generally 1-5 cm long depending upon grain size). Locally, the gneiss has layers (up to 50 cm wide) of coarser-grained fabrics (grains up to 1 cm in diameter). Within the gneiss is lens- to block-shaped, and blunt-ended amphibolite bodies, also with a distinct mineral fabric that is sub-parallel to that of the gneiss. In general, the long dimension of lens-shaped amphibolite bodies are sub-parallel to the host gneiss fabric. The lengths of these bodies are not quantified due to the fact that the outcrop is composed of meter-scale windows through road gravel, but short dimensions are usually exposed showing bodies 10 to 30 cm wide. Fabric in the amphibolite is generally terminated at the boundary of the body, whereas the fabric in the quartzo-feldspathic gneiss drape the amphibolite bodies, showing fabric tails at the blunt ends of the bodies, sub-parallel to the mineral lineation (as porphyroclasts draped by matrix minerals; Figure 19).

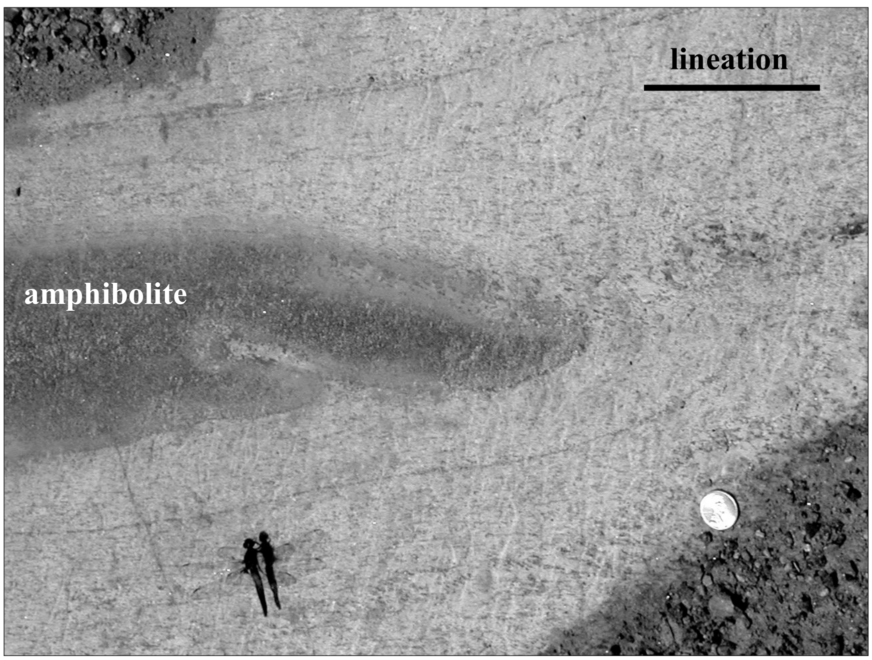



**Figure 19.** Pavement view of exposure at Stop 7 from within the road bed. Top is north. Note the apparent deflection of the fabric and difference in texture of the quartzo-feldspathic gneiss where it forms a ‘tail’ at the ‘nose’ of the ‘shark’-shaped amphibolite lens.

Mileage:

46.6 Continue northeast on Powley Road, back towards Rt. 10.

46.8 Pavement outcrop on right gutter.

48.1 Park along the side of the road in “the notch” between East and West Notch Mountains (see location map). The notch is Stop 8, featuring 0.2 miles of continuous exposure on both sides of Powley Road. The exposure on the northwest side (left) is the subject of the stop.

**STOP 8: Variations of L-S, L>S and L>>S fabrics of the PLSZ.**

Due to the continuous nature of the exposure in an across-strike direction, the fabrics within the quartzo-feldspathic gneiss may be examined for their variations at about the meter scale. In general, the rock fabrics vary between L-S to L>>S tectonite. Foliation intensity is variable, but mostly weak here. Foliation dip varies greatly across strike (moderately to steeply south-dipping), whereas the intensity and orientation of the lineation is consistently sub-horizontally E- and ESE-plunging. Of particular note in this outcrop, in addition to the matrix fabrics, is the pervasive feldspar porphyroclasts. Fabrics drape the porphyroclasts to form tails that are elongate sub-parallel to the matrix mineral lination (sub-horizontal). Perhaps the cleanest views of the fabrics along the lineation may be seen at the very end (northeast end) of the exposure. We suggest that it is best to leave this spot for last in order to best appreciate the nature of the fabric in these rocks.

Mileage:

48.1 Continue northeast on Powley Road towards Rt. 10.

48.8 Swampy area and sign for “snowmobile trail”.

49.2 Park along the side of the road avoiding the blind curve. The outcrops for Stop 9 are along the side and gutter of the northwest side of the road just before and at the left-hand curve in the road.

**STOP 9: Fabric variations in garnet-bearing quartzo-feldspathic gneiss in the PLSZ.**

Here the quartzo-feldspathic gneiss fabrics vary from L>S to L>>S tectonite, whose lineation is shallowly E- to ESE-plunging, and the relatively weak foliation is moderately to steeply S-dipping. Feldspar porphyroclasts are present as at Stop 8. The southwest end of the exposure shows a high density of garnet porphyroclasts within foliation. Locally, garnet is concentrated into 2-3 cm-wide bladed bands, or is apparently flattened. Also locally, garnet occurs in patches or ‘clots’ 3-5 cm wide and up to 20 cm long.

Mileage:

49.2 Continue northeast on Powley Road towards Rt. 10.

49.8 Outcrop on the left at the top of the hill.

50.0 Park on the side of the road for a set of small low pavement exposures on the left (northwest) side of the road as the top of the hill is approached.

**STOP 10: Mylonitic augen gneiss of the PLSZ.**

Best views of the fabrics in the quartzo-feldspathic gneiss are seen in the approximately 1.5 meter-long, beautifully polished pavement at the top of the hill. Here the rock has meter-scale mineralogical layers where the northern part is relatively more leucocratic, dominated by feldspar (up to 1 cm wide) and quartz ribbons (up to 3 mm wide). The fabric is intensely strong L-S tectonite throughout the exposure, with a steeply S-dipping foliation, and a sub-horizontal shallowly E-plunging lineation. The fabric may be considered ‘textbook’ mylonite, with spectacularly grain-size reduced texture in the less leucocratic layer. The mylonitic fabric transects the sharp contact between mineralogical layers at a low angle where is transitions into a more ribbon texture in the leucocratic layer. Of particular note here, besides the intense matrix fabrics, is the penetrative augen (generally 1 to 4 cm long) composed exclusively of aggregates of millimeter-grain-size quartz + feldspar, not single crystals. In every case, augen are draped by the matrix fabric, elongate sub-parallel to the lineation. There are a few much larger of these augen in this rock composed of rounded single feldspar crystals (up to 4 cm long) that are surrounded by aggregate quartz and feldspar (Figure 20).

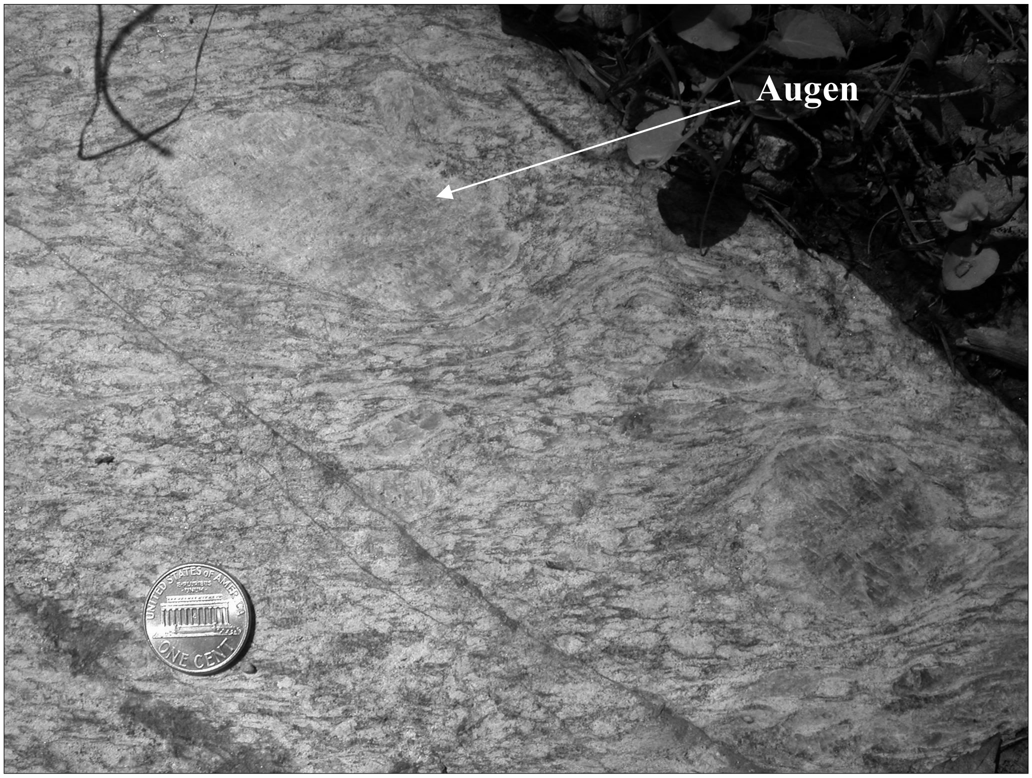



**Figure 20.** View of pavement at Stop 10 showing pervasive augen and two larger augen, all draped by matrix fabrics.

Mileage:
50.0 Continue northeast on Powley Road towards Rt. 10.
51.3 Park on the side of the road to view the two small pavement exposures in the bed of the road for Stop 11.

**STOP 11: Ultramylonite of the PLSZ.**

These outcrops are very small (about 1 m or so long each) and isolated, so whether or not these rocks are viewable depends upon many factors including whether or not the road has been re-graded recently. As with STOP 7, the exposure of these rocks is better later in the season.

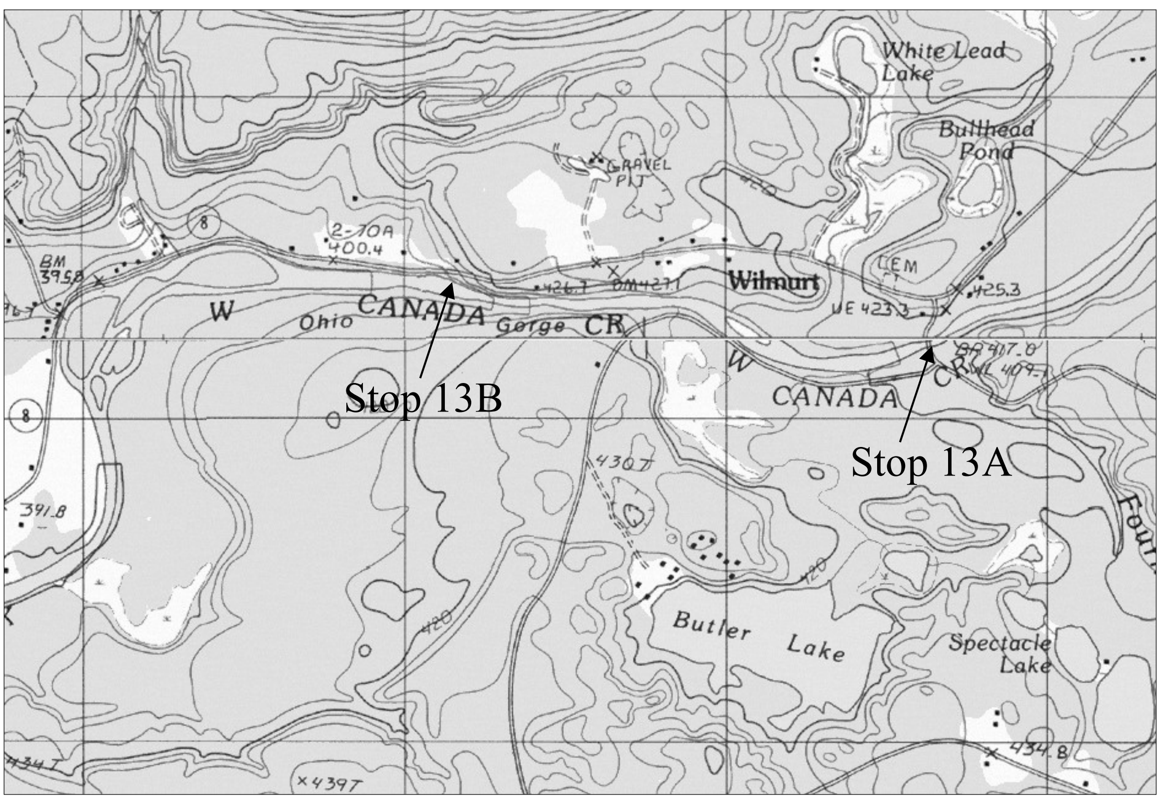
The quartzo-feldspathic gneiss here shows spectacular mylontic fabrics, as at Stop 10, where foliation and lineation are penetratively parallel across the small exposures (E-W fabrics with steep south dips and sub-horizontal E-plunges). Centimeter-scale textural layers are the highlight of this exposure where 1 to 5 cm wide bands of quartz + feldspar aggregate. Relatively thin layers of these aggregates are seen 'pinched and swelled' lenses. Individual augen of the aggregate are in the less leucocratic layers. We envision these textural variations to illustrate a progression of mylonitization where larger bands progressively become augen. Further, we suggest that the augen are seen kinematically combined, and as they interfered, they may form new aggregate bands. In a manner of speaking, one could say that the fabrics in this rock are snapshots of the progression, and that this rock is mylonite that has been multiply reworked as deformation continued.

Mileage:
51.3 Continue northeast on Powley Road towards Rt. 10.
51.5 Mylonite pavement outcrop (similar to the rock at Stop 11).
53.0 Turn left onto Rt. 10 north towards Rt. 8.
53.7 Park on the right side of the road for the roadcuts just over the top of the hill.

**STOP 12: L-S tectonite of the PLSZ.**

The quartzo-feldspathic gneiss here is spectacular L-S tectonite, whose foliation is moderately SSW-dipping, and whose lineation is shallowly W-plunging. As at Stop 10, augens are aggregates of fine-grained feldspar + quartz, and some here have delta tails asymmetric tails that show sinistral offset (see Figure 9B). Pavement outcrop at the top of the western roadcut show excellent three-dimensional views of the fabric.

Mileage:
53.7 Continue north on Rt. 10.
54.2 Turn left onto Rt. 8 west.
73.7 Turn left onto Gray Wilmurt Road just after a sharp right-hand curve in Rt. 8. Cross a bridge over the West Canada Creek and park at the intersection with Jones Road. Walk back toward the bridge over West Canada Creek and down the hill to the outcrop just east (upstream) of the bridge (see location map). The outcrop forms a small water fall on the creek.



**STOP 13: The PLSZ at the Ohio Gorge of West Canada Creek.**

The Piseco Lake shear zone traces westward through the West Canada Creek basin. Some of the best continuous exposures occur in the Ohio Gorge near Wulmurt. The last stops for this field trip are in highly deformed granitic gneiss in the gorge. During periods of high water, the exposures at the eastern and western end of the gorge may be covered or not easily accessed. Permission is needed from the landowner at Stop 13A.

**STOP 13A: East of the gorge.**

The West Canada Creek forms a small waterfall at the upstream part of this outcrop. Pavement exposures reveal the L-S and L>S deformation fabric in granitic gneiss (Figure 21). Foliation is gently dipping and the lineations are subhorizontal. In the region immediately down-stream of the falls, the foliation is defined by planar aggregates of recrystallized K-feldspar and quartz that alternate with dark layers containing abundant chlorite and minor biotite. The dominant fabrics are cross cut by at least three small high-strain zones. Two are steeply dipping and strike about east-west, and the third strikes south and dips moderately westward. One of the steeply dipping high-strain zones occurs in the vertical face at the southern side of the outcrop. Another occurs at the western limit of the outcrop close to the water. The north-south striking zone occurs in the low ledge near the falls. This small shear zone contains deformed pegmatite, and cross cuts the PLSZ foliation and lineation (Figure 10). Shear sense is top down to the west or normal. The other high strain zones both contain evidence for oblique sinistral shear.

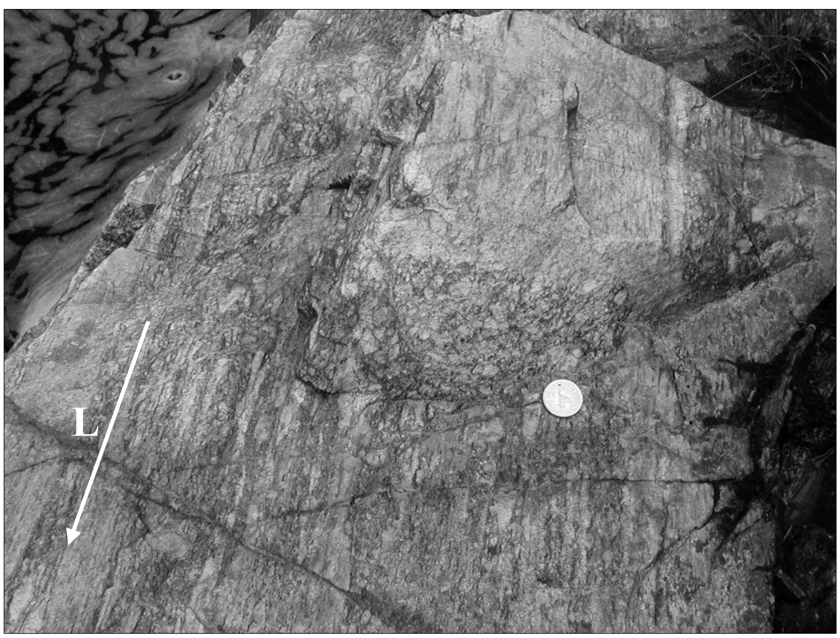



**Figure 21.** Outcrop of granitic gneiss with L>>S fabric. The view is looking west. Note the textural differences in this view. The area above the coin is a subvertical surface with the ends of the mineral lineations exposed. The rest of the outcrop is broken parallel to the lineations.

Mileage:

73.9 From the parking area, turn around and back track to Route 8.

74.1 Turn left onto Route 8.

75.2 Park on the right shoulder just after a steep downhill drive. Walk upstream along West Canada Creek to the first bedrock exposures for the westernmost outcrops in the Ohio Gorge, and Stop 13B.

**STOP 13B: Western limit of the outcrop belt in the Ohio Gorge.**

At this location the north dipping foliation of the Piseco antiform can be viewed in addition to the typical variation in L-S and L>S fabrics at the outcrop scale. Again, the foliation is defined by planar aggregates of dynamically recrystallized feldspars and quartz. Quartz also occurs in greatly attenuated ribbons, as seen at other locations during this field trip. Of particular interest at this location, are abundant kinematic indicators that are easily observed. Outcrop surfaces that are perpendicular to the foliation and parallel to the lineation reveal asymmetric augen of K-feldspar and plagioclase forming both σ- and δ-type shear sense indicators with most showing top toward the west displacement (Figure 9A). Since the mineral lineations are subhorizontal, the shear sense is considered to be low-angle sinistral at this location. The abundant large (cm-size) porphyroclasts of feldspar provide some information about the protolith for the PLSZ rocks in this region. The relict grains are most likely the remains of megacrysts from an original granite.

**End of trip.**

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# VARIATIONS IN L- AND S-TECTONITE ON THE NORTHERN BOUNARY OF THE PISECO LAKE SHEAR ZONE, ADIRONDACK MOUNTAINS, NEW YORK

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## INTRODUCTION

The subject of this field trip is the variation in deformation fabrics along the northern margin of the Piseco Lake shear zone (Gates et al., 2004) with special emphasis on the development of L-tectonite domains at various scales. To some extent, but on a much more regional scale, this was also the emphasis of field guide for the 76th NYSGA field conference (Valentino et al., 2004). This field guide covers a geology field trip that is a continuation of the earlier field trip with overlap of a few field stops.

The Piseco Lake shear zone (Figure 1) is a major Grenvillian structure that is 10 to 20 kilometers wide and strikes east -west in the southern Adirondacks. Kintematic analysis in the zone demonstrated dominately low-angle sinistral shear (Gates et al., 2004). For the current study, an area of 42 square kilometers was mapped across the northern boundary of the Piseco Lake zone in the area of the West Canada Creek basin (Figure 2). The objective of this study was to document the detailed rock fabric variation within the shear zone, the transition zone and the wall rocks to the shear zone. This study was designed to better understand the strain and metamorphic history associated with this major Adirondack structure, and document the geographic distribution of L- and L-S tectonites that were previously reported (McLelland, 1984; Chiarenzelli et al., 2000; Gates et al., 2004).

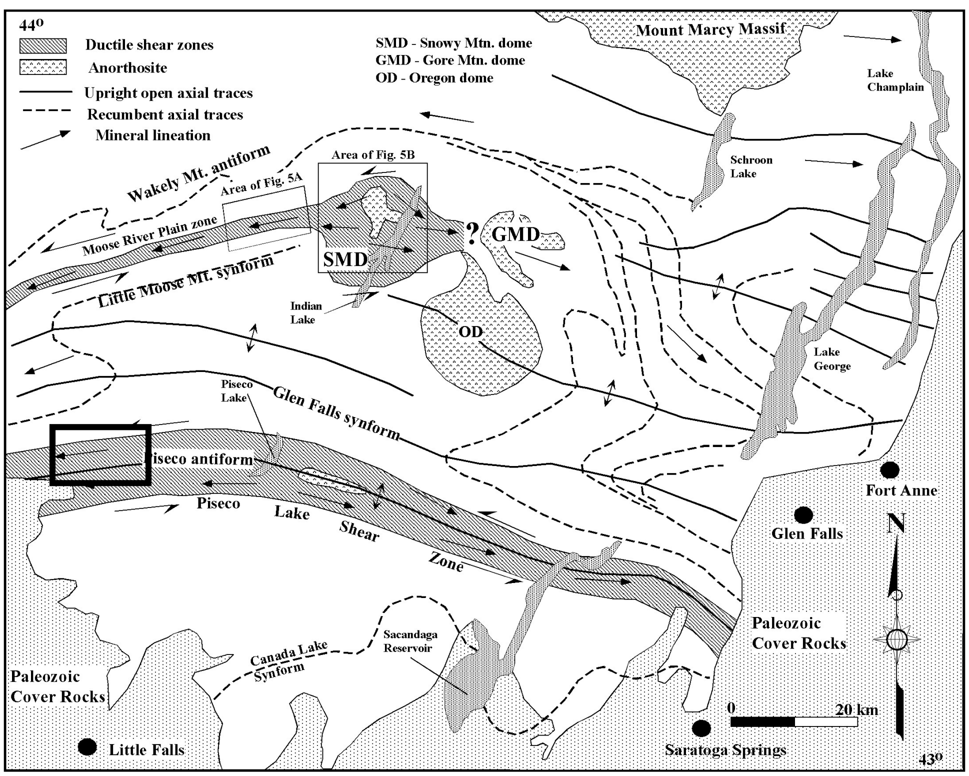



Figure 1 - Schematic structure map of the southern Adirondacks showing the Piseco Lake shear zone and the are for this field trip (after Chiarenzelli, et al., 2000 and Gates et al., 2004). Study area shown with box.

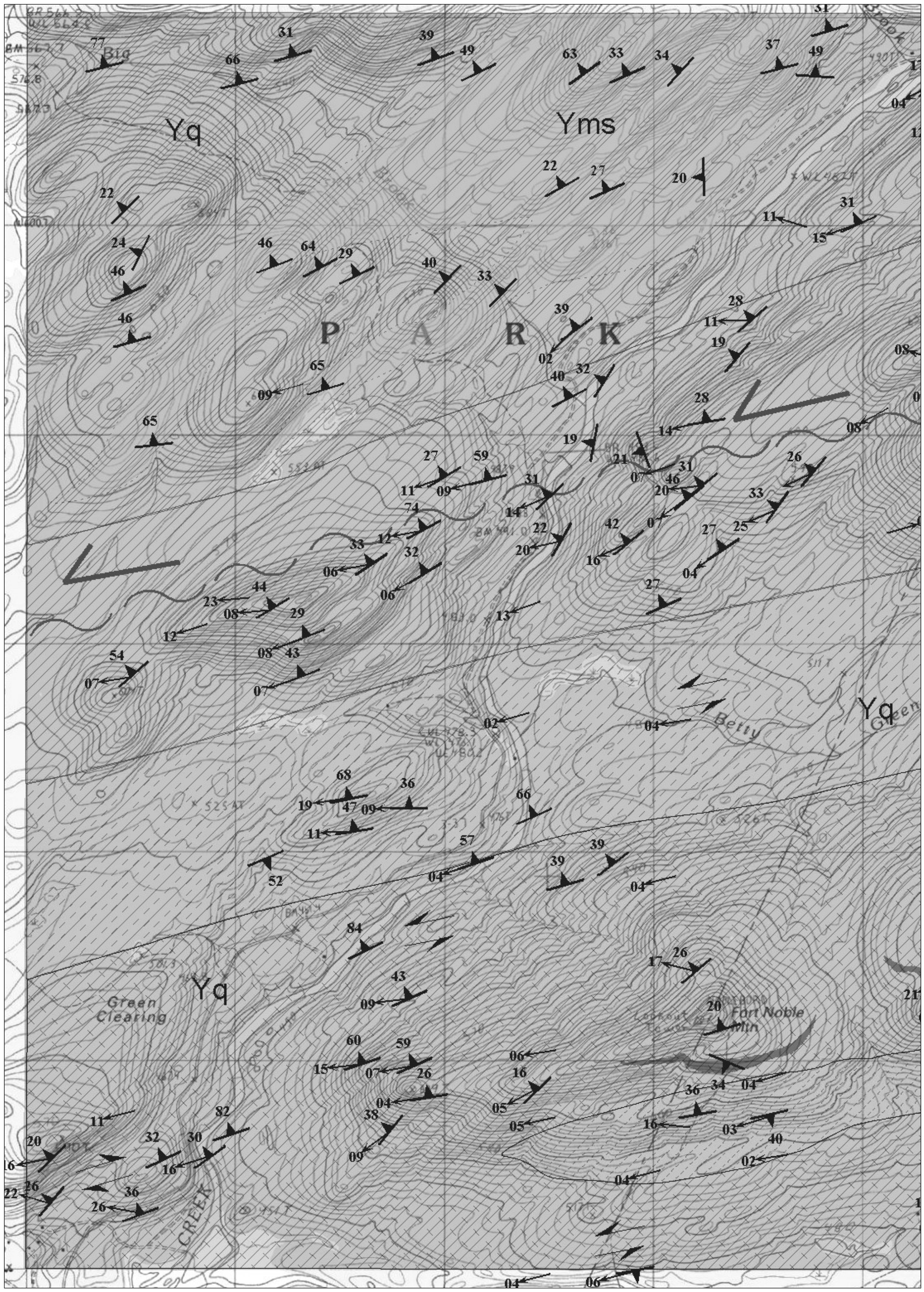



Figure 2 - Bedrock geologic map of the West Canada Creek basin in the southwestern Adirondacks. The map area crosses the northern boundary of the Piseco Lake shear zone. The base map is a provisional USGS metric topographic map with a 1 km grid. The next two pages show the eastern extension of the map area and the map explanation respectively.

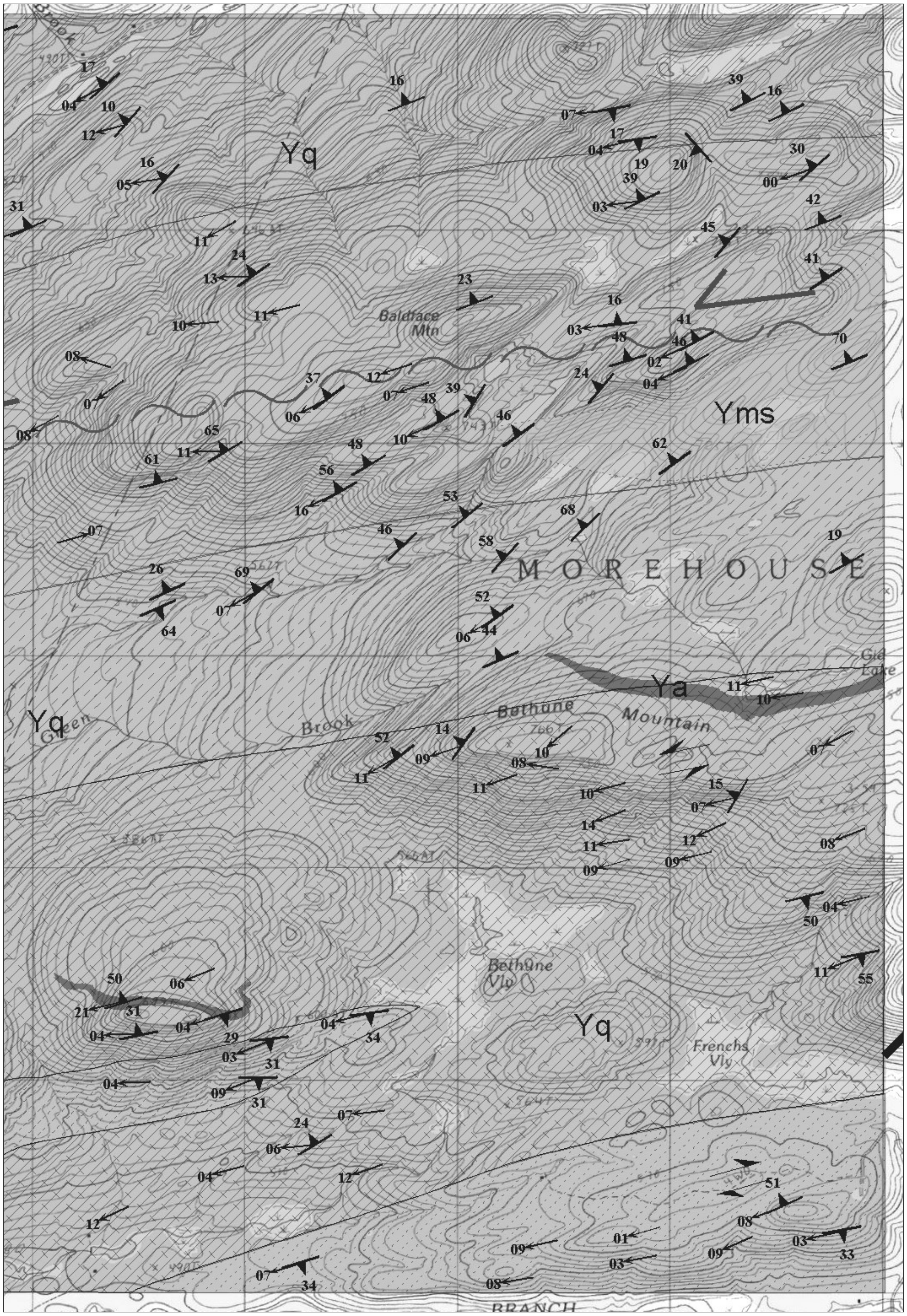



Figure 2 continued - Eastern extent of the geologic map of the West Canada Creek basin. See the next page for the map explanation.

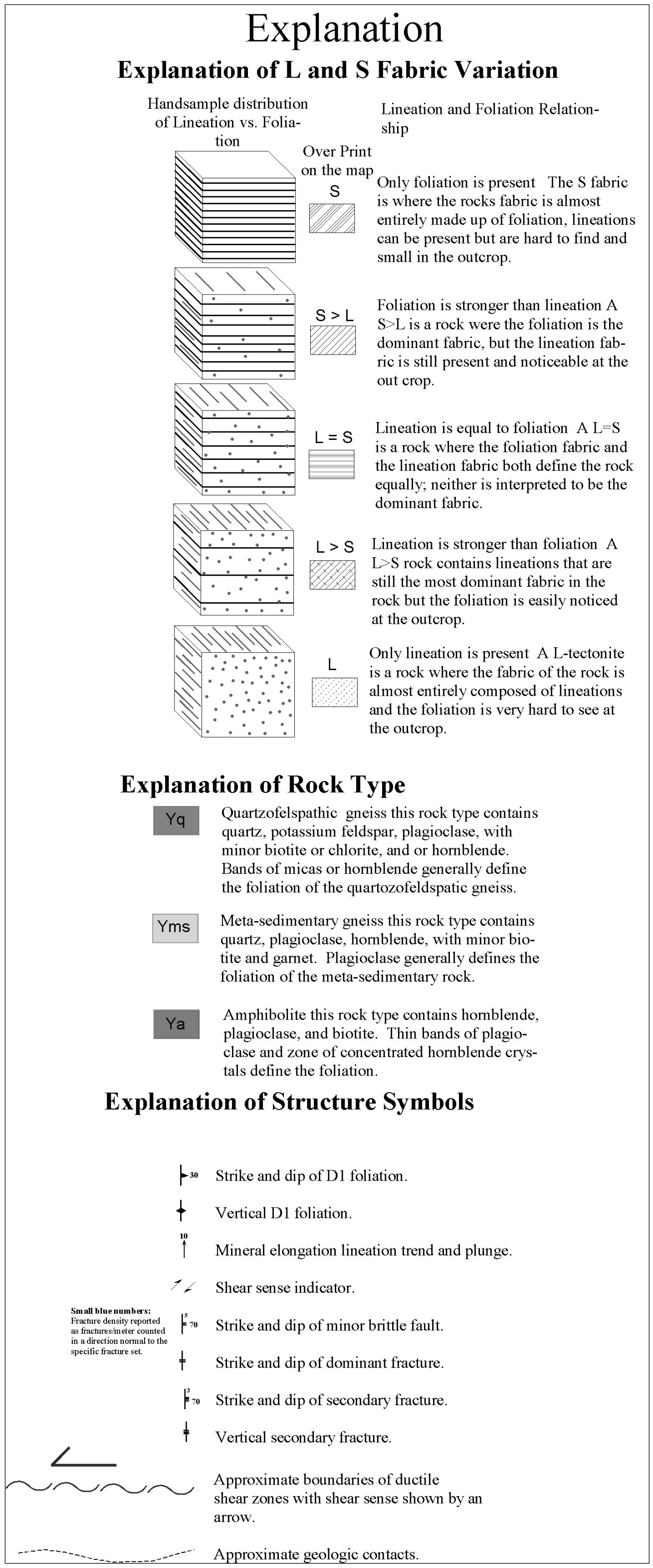



Figure 2 continued - Map explanation for the West Canada Creek basin. Three gray shades were used to represent general rock types and the shades are overlain with patters to represent the five categories of rock fabric.

## FABRIC VARIATION IN THE PISECO LAKE ZONE

Five domains of varying fabric intensities were documented (L>>S, L>S, L-S, S>L, and S) within the Piseco Lake zone and the shear zone transition region with the wall rocks (see Figure 2 on the previous pages). The northern boundary of the Piseco zone is defined by a gradational increase in L-S fabric intensity from north to south. Both the foliation and lineation are defined by dynamically recrystallized aggregates of quartz, K-feldspar, plagioclase and minor mafic phases. This fabric transition corresponds with an increase in grain size reduction of all these minerals. Within the Piseco Lake zone the fabric variation occurs systematically from L-S dominated, to L>S and finally L>>S tectonite (Figure 2). A cigar-shaped map-scale domain of L>>S fabric, 3.5 km by 0.5 km in size, trends parallel to the linear fabric observed at the outcrop. A change in the dominate dip direction between the L>>S and L>S domains supports the presence of a foliation fold over the cigar-shaped domain.

The wall rocks to the shear zone in the study area are mostly granitic gneisses and minor dioritic gneiss containing metamorphic index minerals of hornblende and hypersthene. The granitic gneiss contains a dominant gneissocity that strikes generally east-west with very weak mineral lineations. Quartz and feldspars form course crystalline aggregates that define the gneissocity. The presence of hornblende and hypersthene, and the gneissic fabric suggest these granitic rocks were metamorphosed under granulite facies conditions as reported by earlier researchers (McLelland, 1984).

Within the zones of intense L-S deformation fabrics, the rock is generally granitic gneiss, however, it contains abundant feldspar and quartz grains up to a few cm in diameter. In places, K-feldspar grains appear to be relict igneous metacrysts. As mentioned previously, the L-S fabrics are defined by planar and linear aggregates of dynamically recrystallized quartz and feldspar grains. Additionally, the fabrics are defined by chlorite and minor biotite. This observation was previously noted by Gates et al. (2004) where they demonstrated that the occurrence of chlorite in the Piseco Lake zone to be fabric forming and parallel to the mesoscopic foliation and lineation. These rock textures and index minerals suggest two conclusions: 1. the Piseco Lake zone developed in course grained granite that is not found in the wall rocks, and 2. Cannon (1937) and McLelland (1984) described similar rock fabrics for other parts of the Piseco Lake zone, however, they did not mention the presence of low-grade fabric forming metamorphic index minerals.

### Systematic look at the structural data

The structural data collected during the mapping was divided based on the fabric categories that define the five fabric domains, as shown on the map of Figure 2. These data were used to generate lower hemisphere contour diagrams for the poles to foliation and lineation. Poles to lineations are plotted at or near the perimeter of the diagram and the poles to foliation form the diffuse girdle on the interior of the diagrams. The stereogram representing the data from the L>>S domain (Figure 3E) demonstrates that the foliation is dominantly dipping to the south. But the stereogram showing the data from the L>S domain demonstrates that the foliation is dominantly dipping northward. The L-S, S>L, and S domains show foliation dominantly dipping to the north, however the general strike is consistent throughout all the diagrams.

## OHIO GORGE REGION

The West Canada Creek flows through the east-west trending Ohio gorge a few kilometers south of the geologic map area of Figure 2. Nearly 90% bedrock exposure afforded the opportunity to study the fabric variation in great detail in the heart of the Piseco Lake shear zone. Access to the gorge is restricted due to private property and high water most of the year. During the Summer 2004, a detailed outcrop map was produced for the southern side of the gorge. High-resolution digital photographs were taken and assembled into a mosaic. The photo mosaic was used as the base map, and rock fabric and textural variations were overlain at the sub-meter scale. In general, the bedrock exposed in the gorge is the megacrystic granitic gneiss typical of the Piseco Lake shear zone, and there is little variation in the overall mineral content along the extent of the gorge, but, the outcrop analysis shows variation in deformation fabric at the scale of 10's of meters. Three fabric categories were observed in the gorge, L>>S, L>S and L-S tectonite as described previously. These categories demonstrated gradational and abrupt contacts between one another, and the shape of some fabric domains in the gorge show similar geometric relationships to the map-scale domains.

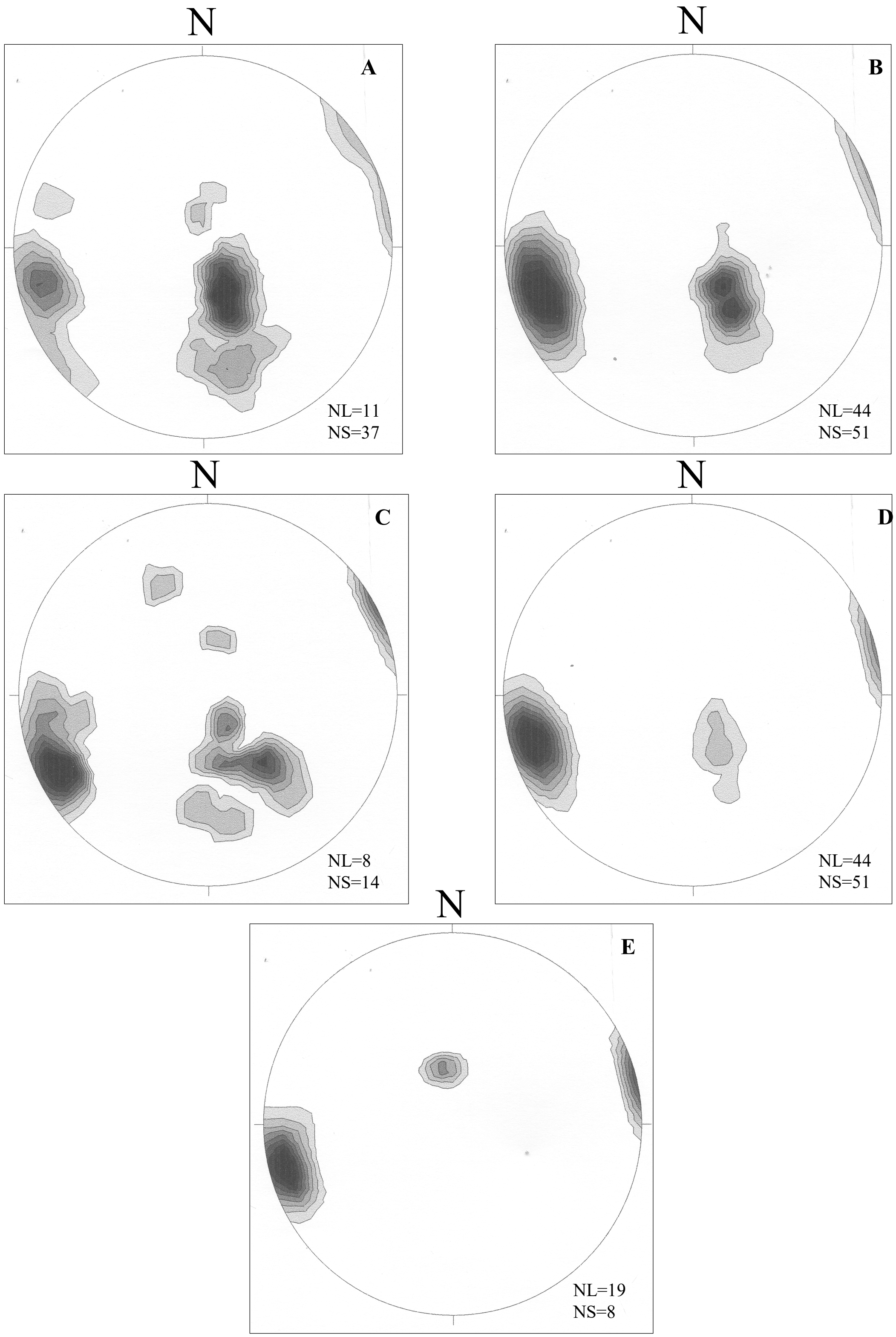



Figure 3 - Lower hemisphere contour stereograms for the L-S domains represented on the geology map of Figure 2. For each diagram above (A-E), the poles to lineations plot near the perimeter of the diagrams and the poles to foliation form the interior domains. Note the increase in the intensity of the cluster of linear data with the decrease in the occurrence of the foliation data.

Throughout the Ohio gorge there are extensive kinematic indicators consistent with sinistral low-angle shear. The L-S domains contain the best preserved porphyroclasts, with the L>>S containing few. The kinematic indicators include S-C fabrics, shear bands, asymetically broken K-feldspar grains, sigma- and delta-porphyroclasts (Lister and Snoke, 1984; Simpson and Schmid, 1983, Passchier and Simpson, 1986).

There are a number of ductile normal faults that crosscut the dominant deformation fabrics. The trace of the dominant outcrop fabric shows “drag” as a primary indicator of normal displacement. Most of these small normal shear zones contain granitic pegmatite, and there are also parallel pegmatite dikes that show no deformation. The ductile normal zone located on the east end of the Ohio gorge exhibits oblique sinistral-normal displacement, while the remaining ductile normal faults exhibit dip slip offset. Figure 4 shows a sterographic plot of the orientation of these ductile normal shear zones and other pegmatite dikes in the Ohio gorge. Both inside the ductile normal zones and within undeformed pegmatite dikes, they are composed of course grained quartz and K-feldspar with minor chlorite. These pegmatites vary in thickness from 0.5 m to 6 cm within one of the normal shear zones. Valentino et al. (2004) noted ductile normal shear zones in the upper reaches of the Ohio gorge and related it to larger-scale displacement at Speculator Mt. farther east.

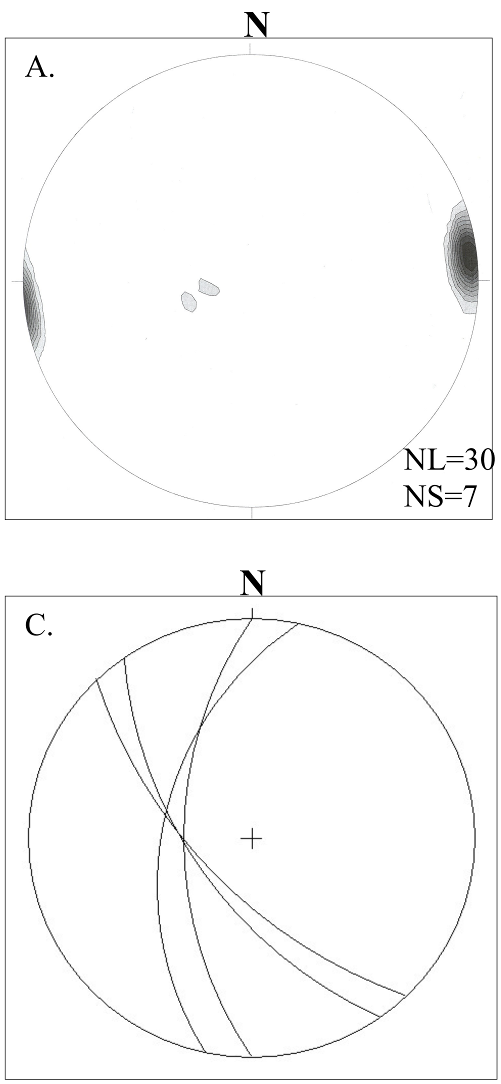



Figure 4 - Lower hemisphere sterograms for structures observed in the Ohio gorge. A. & B. Contour diagram for the poles to lineation and foliation from L>S domain (A) and L-S domain (B) parts of the gorge; C. & D. Great circle plots for ductile normal shear zones (C) and undeformed pegmatite dikes in exposed in the gorge (D).

## DISCUSSION AND CONCLUSIONS

Deformation fabrics vary systematically across the northern boundary of the Piseco Lake shear zone in the West Canada Creek basin. Within the Piseco zone, all rocks contain well-formed mineral elongation lineations, however, the variation in fabric intensity appears to be controlled by the development of foliation. The attitude of mineral elongation lineations vary little, but foliation varies systematically in intensity and orientation. Rocks dominated by L-tectonite occur in a cigar-shaped domain, that occurs in broad open foliation antiform, but the foliation is only weekly developed in these areas (L>>S domain). The deformation within the zone occurs in rocks of granite protolith that are different from the high-grade granitic gneiss that occurs in the northern wall-rock to the shear zone. Geochronologic studies in the Adirondacks constrain the timing of deformation and peak metamorphism to 1090-1030 Ma. This is after the intrusion of the AMCG plutonic rocks from 1160-1100Ma (McLelland and Isachsen, 1986; McLelland et al., 1988; McLelland et al., 1996; McLelland et al., 2001). An AMCG suite age and Ottawan metamorphic age was reported by McLelland et al. (1988) for deformed granite from the core of the Piseco zone. The location of the rock used for this analysis occurs directly along strike about 20 km east of the current study area. Although the AMCG granite within the Piseco zone is highly deformed, there is scant evidence within the study area, that it was subjected to the regional high-grade metamorphism that is preserved in the wall-rocks. It is worth considering that the gneissocity and high-grade metamorphism that occurs in the shear zone wall-rocks pre-dates the intrusion of the granite. However, it is also possible that the low-grade dynamic metamorphism that occurred in the Piseco zone entirely overprinted the high-grade metamorphism of both rock (wall-rocks and granite) units.

## ACKNOWLEDGEMENTS

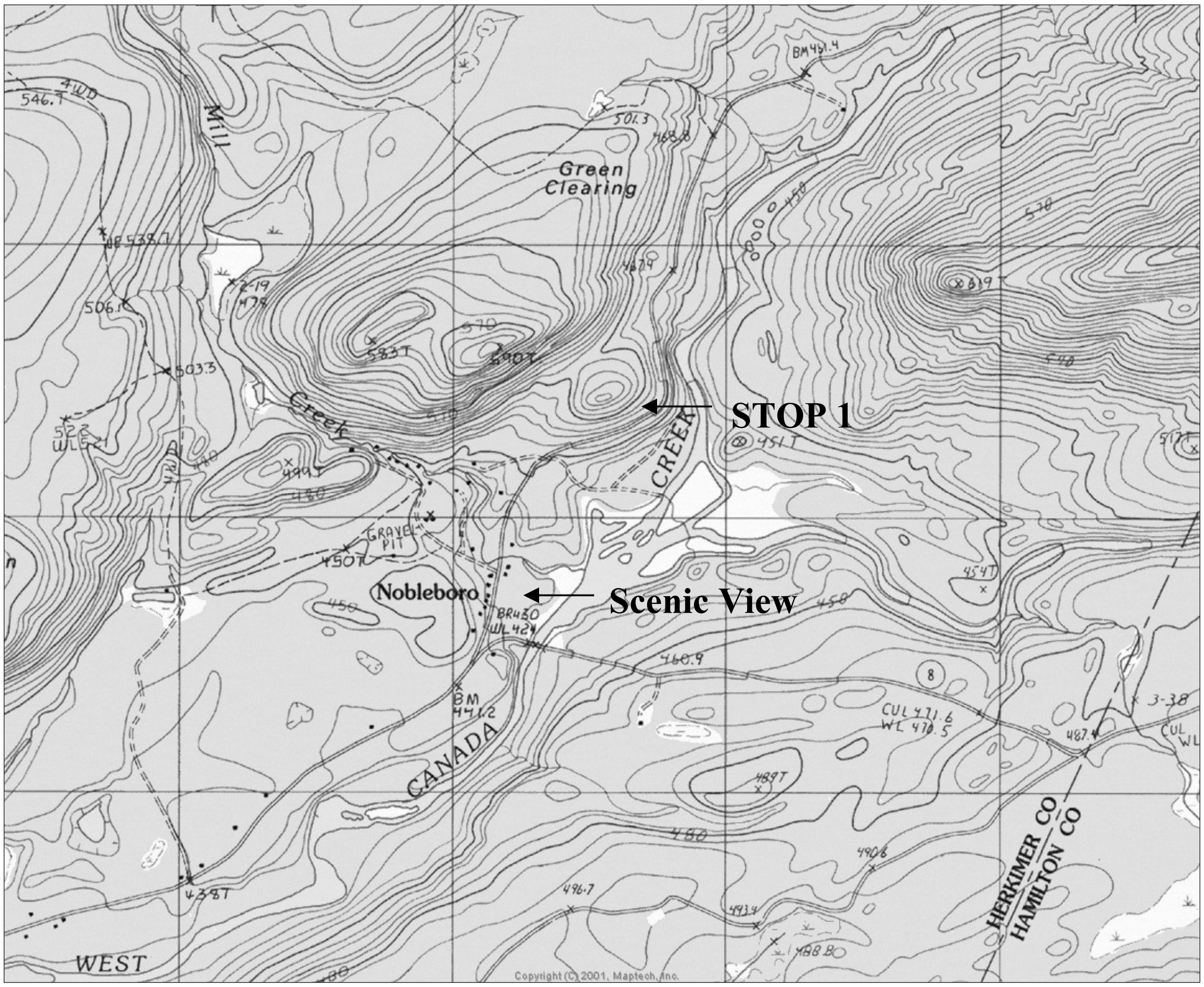
The fieldwork during 2003 was funded through a grant from the Association of American State Geologist. The fieldwork during 2004 was funded by an R.E. McNair scholarship to D. Piaschyk. Lab work was funded by a SUNY Oswego Scholarly and Creative Activity grant.

ROAD LOG AND STOP DESCRIPTIONS

Road Log:
Mileage:

0.0 The trip begins at the assembly point in the parking lot of the scenic overlook on the West Canada Creek. The scenic view is located in Nobleboro off of Route 8, between Poland and Piseco.

0.6 When exiting the driveway to the overlook, turn right on Haskell road, travel about 0.6 miles and park along the side of the dirt road. Caution the banks of the road may not be stable. Cross the dirt road and walk west to what appears to be an old quarry (STOP 1).




STOP 1: S>L Granitic gneiss with strong gneissic texture

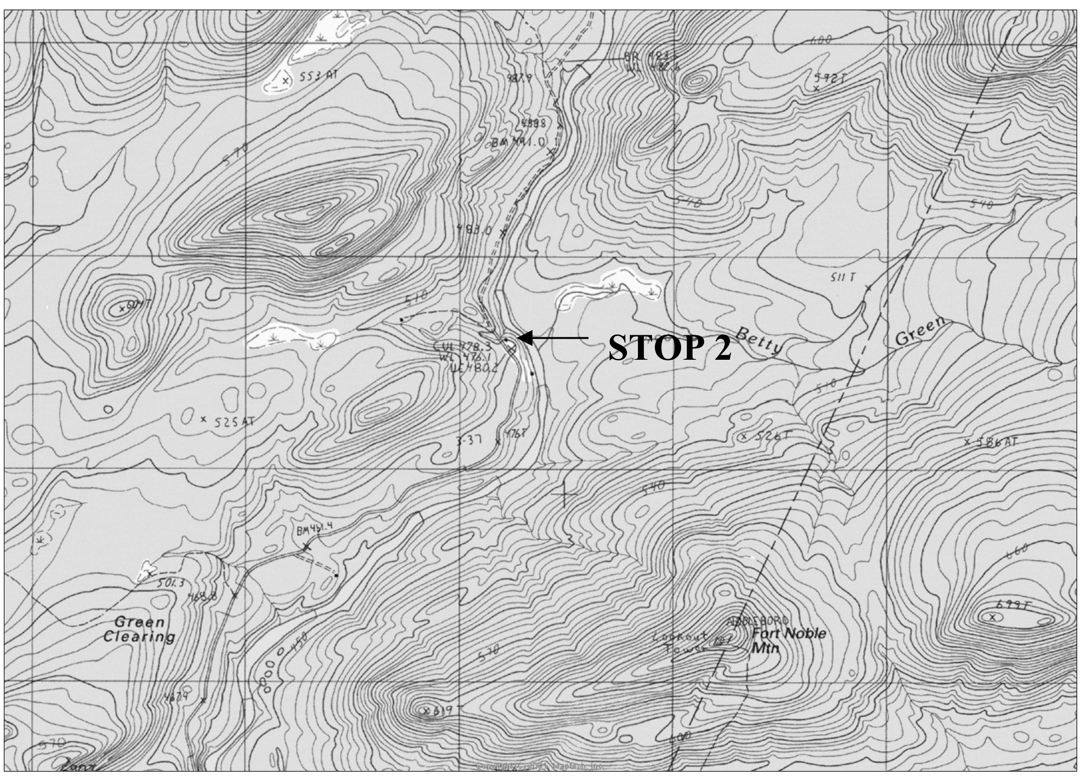
Exposures of course granitic gneiss with well developed gneissocity can be seen in the high-wall of this old quarry. This stop demonstrates S>L fabric, lineation area weakly developed and foliation dominates. (Figure 5). The grain size is uniform and few kinematic indicators are present. The foliation is penetrative and is defined by planes of K-feldspar and biotite and dips to the northwest. The lineations are defined by streaks of biotite and plunge to the southwest.

Figure 5 – Photograph, view is looking north, of granitic gneiss with well developed foliation and gneissocity. K-feldspar bands define the gneissic texture. Lineations can be observed with closer inspection and are parallel to the mechanical pencil in the center of the photograph.

Mileage:

0.6 Continue northeast on Haskell road.

2.7 Arrive at a clearing, before bridge and gate turn right and park in grass. Walk east down a small hill to the West Canada Creek (STOP 2).



STOP 2: L-S and S>L Dioritic Gneiss

The southern most part of the outcrop demonstrates L-S fabric (Figure 6). Lineations are about equal to foliation in intensity. Rods of hornblende define the linear fabric, which plunges to the southwest. Plagioclase and quartz define the foliation. In thin sections of this outcrop a ceased reaction is preserved. The hornblende crystals were breaking down to form biotite in a retrograde reaction. The northern most part of the outcrop demonstrates S>L fabric with gneissic textures, similar to the previous stop. Some small faults with 15cm of displacement and boudins are also preserved at the northern end of the outcrop (Figure 6). Garnets are also visible at the northern end of the outcrop but were not observed at the southern end in hand sample or thin section.

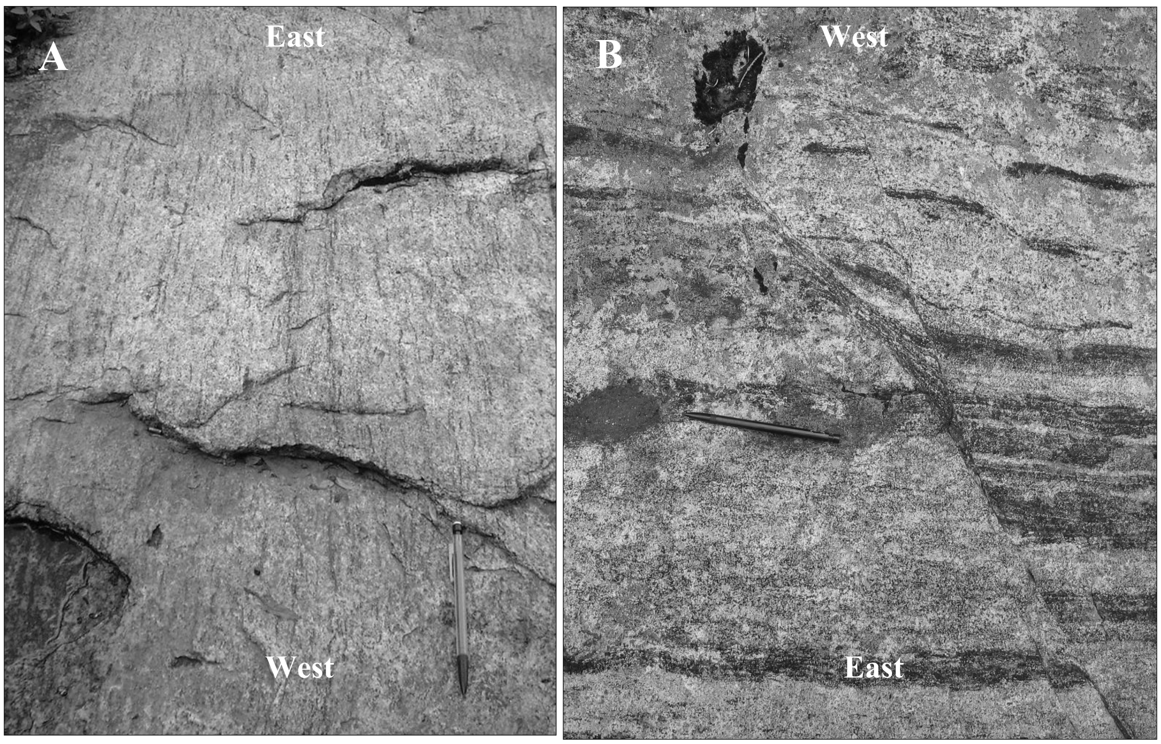


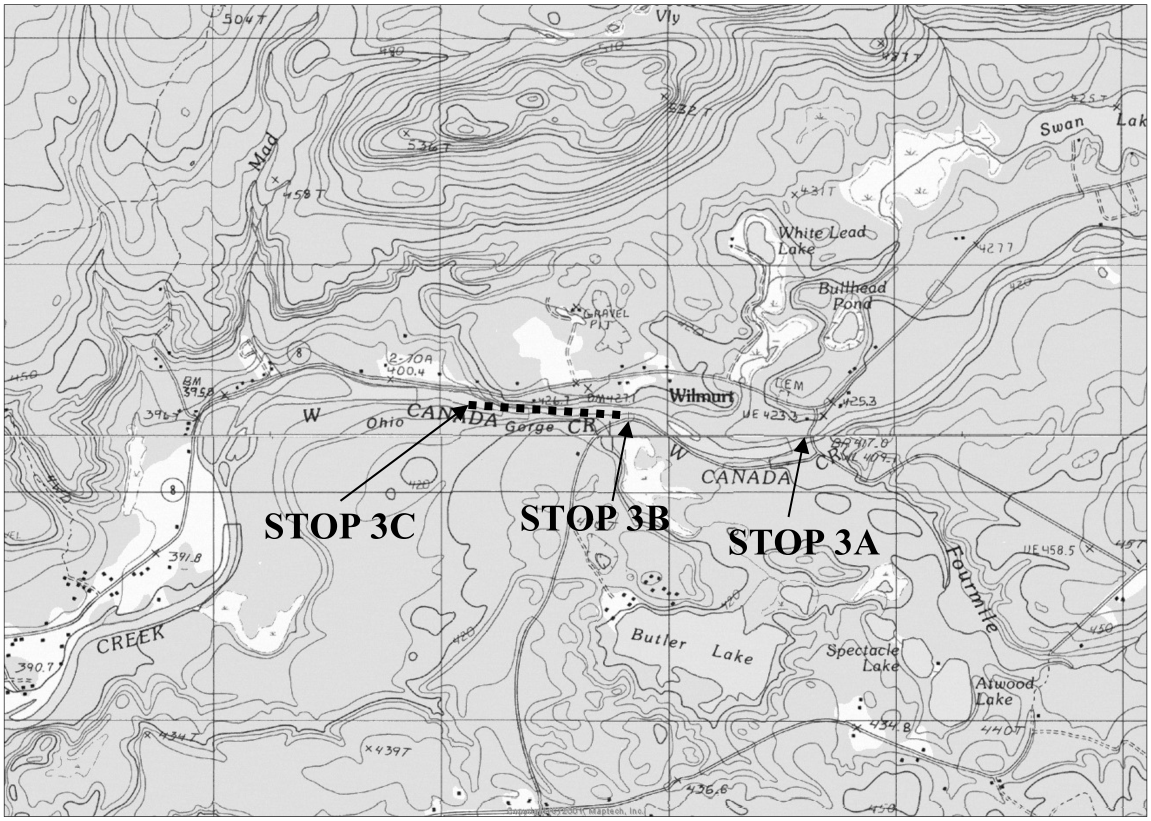

Figure 6 – (A) This is a photo of the L-S fabric at the south end of the outcrop at STOP 15. The black lines are rods of hornblende that define the linear fabric. (B) This is a photo of S>L fabric at the north end of the outcrop. A fault is shown from the top left corner to the bottom right corner. The offset of hornblende bands demonstrates a displacement of about 15cm.

Mileage:

2.7 Turn left out of the parking area heading south on Haskell road.

5.4 Pass the over look and take a right at the stop sign onto Route 8 west.

8.1 Turn left onto Gray Wilmurt Road just after right-hand curve in Rt. 8. Cross a bridge over the West Canada Creek and park at the intersection with Jones Road. Walk back toward the bridge over the West Canada Creek and down the hill to the outcrop just east (upstream) of the bridge (see location map). The outcrop forms a small waterfall on the creek. This is location 13 of Valentino et al. (2004).




STOP 3: The Piseco Lake Shear Zone at the Ohio Gorge of the West Canada Creek

The Piseco Lake shear zone traces westward through the West Canada Creek basin. Some of the best continuous exposures occur in the Ohio Gorge near Wulmurt. This stop contains highly deformed granitic gneiss in the gorge. During periods of high water, the exposures in the gorge may be covered by water. Permission is needed from the landowners at STOP 3A and 3C.

STOP 3A East of the Ohio Gorge. The West Canada Creek forms a small waterfall at the upstream part of this outcrop. Pavement exposures reveal the L-S and L>S deformation fabric in granitic gneiss (Figure 7). Foliation is gently dipping and the lineations are subhorizontal. In the region immediately down-stream of the falls, the foliation is defined by planar aggregates of recrystallized K-feldspar and quartz that alternate with dark layers containing abundant chlorite and minor biotite. The dominant fabrics are cross cut by at least three small high-strain zones. Two are steeply dipping and strike about east-west, and the third strikes south and dips moderately westward. One of the steeply dipping high-strain zones occurs in the vertical face at the southern side of the outcrop. Another occurs at the western limit of the outcrop close to the water. The north-south striking zone occurs in the low ledge near the falls. This small shear zone contains deformed pegmatite, and cross cuts the Piseco Lake shear zone foliation and lineation. Shear sense is top down to the west or normal. The other high-strain zones both contain evidence for oblique sinistral shear.

Mileage:

8.1 From the parking area head west on Wilmurt Road

8.7 Cross over a small bridge and on the first curve before driving up a hill park on the right side of the road. Walk northwest about 20 m, and STOP3B is the first outcrop on the southeast side of the Ohio gorge.


Figure 7 - Outcrop of granitic gneiss with L>>S fabric. The view is looking west. Note the textural differences in this view. The area above the coin is a subvertical surface with the ends of the mineral lineations exposed. The rest of the outcrop is broken parallel to the lineations.

STOP 3B East end of the Ohio Gorge. The east end of the Ohio gorge demonstrates L>S and L-S fabrics. The gorge contains granitic gneiss that varies only in the proportion of quartz, K-feldspar, plagioclase, biotite, and chlorite. The L-S domains have the larges grain size with numerous δ and σ shear sense indicators. The L-S domains also demonstrate lineation about 1 to 5 cm long, .5-2 cm wide, and 1-3 lineations per cm. The L>S domains have a smaller grain size then the L-S domains. The L>S domains demonstrate more lineations and less shear sense indicators, lineations are 1-6 cm long, .5-2 cm wide, and 3-5 lineations per cm. A contact between L>S and L-S can be observed (Figure 8). West of the fabric contact is an oblique left normal fault about 5 cm wide. This fault crosscuts the metamorphic fabrics strikes north south and dips to the east. Farther west is a .5 m wide pegmatite that strikes northwest southeast and dips southwest that also crosscuts metamorphic fabric. The pegmatite is composed of quartz, K-feldspar, and minor chlorite with grains about 1 to 3 cm in size.

STOP 3C requires a .75-kilometer traverse west along the ridge of the Ohio gorge. Please **WATCH YOUR STEP** the walls of the gorge are vertical and a fall would likely be fatal.

STOP 3C West end of the Ohio Gorge. The west end of the Ohio gorge also demonstrates L>S and L-S domains. Another ductile normal fault can also be observed. The ductile normal fault is much larger then the one observed at the east end of the gorge (Figure 9). A high strain zone is also present that strikes east west.

Mileage:

| | |
|---|---|
| 8.7 | Back track to Route 8, and turn right. |
| 12.0 | Pass the scenic view where the trip began and continue east on Route 8. |
| 16.9 | Turn left onto Fayle Road. |
| 18.5 | Cross a one lane wood bridge, drive to an opening in the tree and the end of Fayle Road. Park and hike to the west about 350 meters to STOP 4A. |

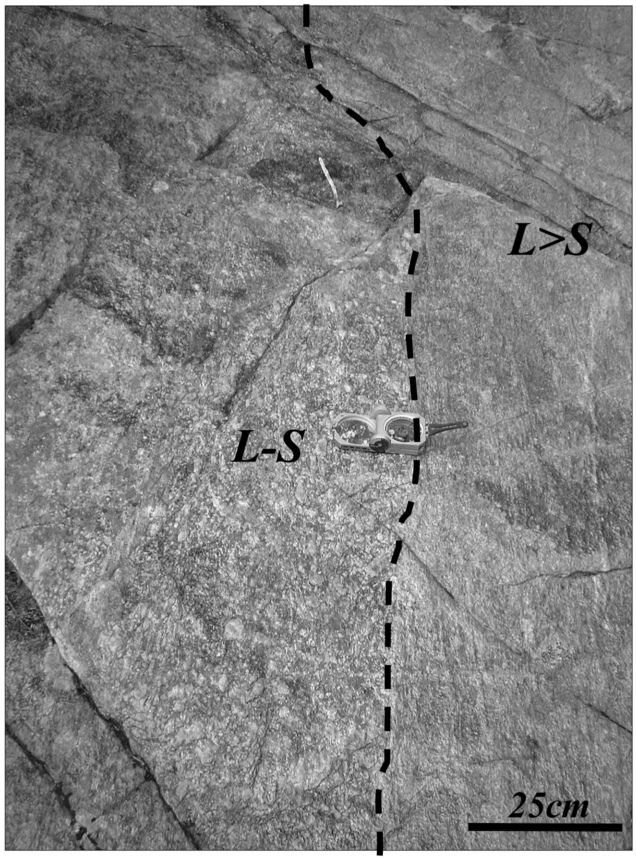
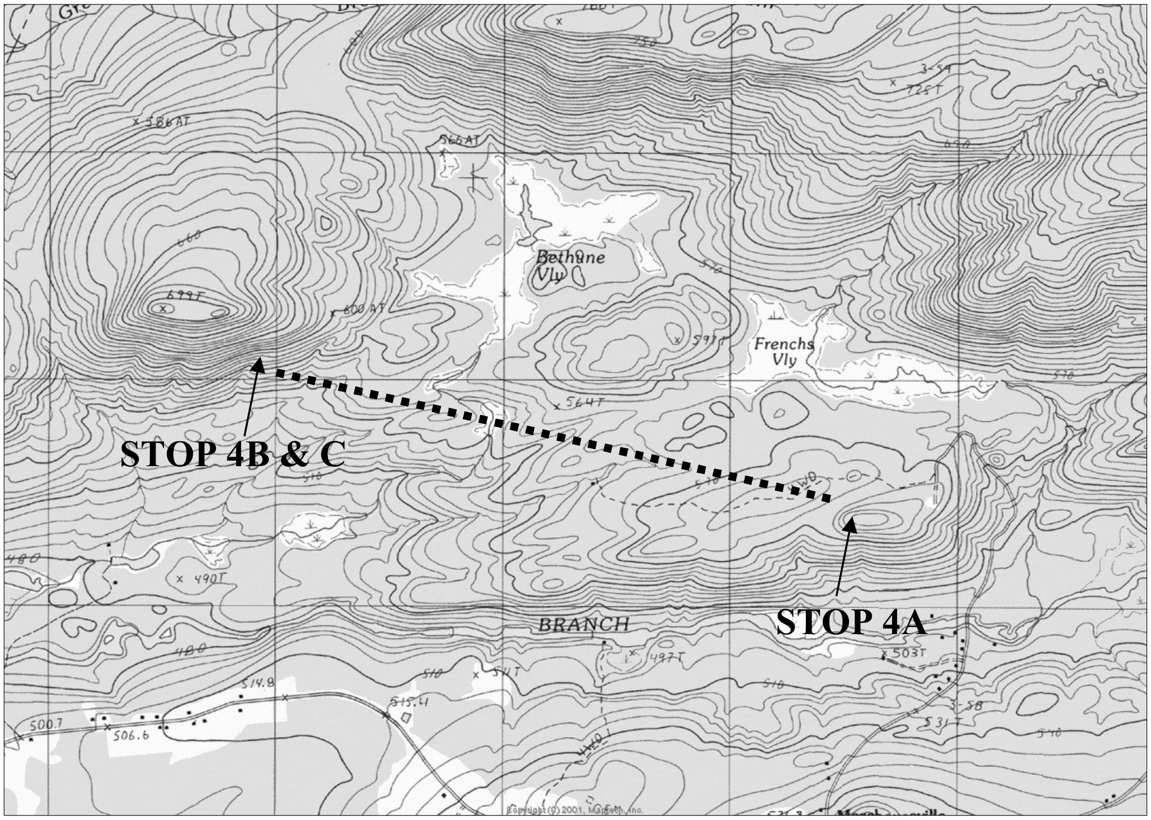



Figure 8 - This is a photo taken at the eastern end of the Ohio gorge, and the view is westward. This photo demonstrates a contact between L-S and L>S rock fabrics. In the L-S domain the grain size is larger and the lineation is less developed, while in the L>S domain the grain size is smaller and the lineations are stronger and easier to see. Note that the boundary between these fabric domains is slightly oblique to the general trend of the rock fabric.

Figure 9 - This photo was taken facing south at STOP 3C. This portion of the ductile normal shear zone will only be visible if the water level is low. The small shear zone crosscuts the metamorphic fabric of the Piseco Lake zone. The footwall displays fabric drag and the hanging wall remains relatively undisturbed. The center of the zone contains deformed pegmatite with dynamically recrystallized quartz and K-feldspar.




STOP 4: L>>S Granitic Gneiss

Excellent outcrops on the northern side of a small hill just east of the parking area. Follow the dirt road to a path through the woods, and then head up hill to the south to the outcrops. This outcrop of granitic gneiss contains domains of L>S and L>>S. The L>S domains contain large and numerous σ-type shear sense indicators, some δ-type are present but are much less frequent. The porphyroclasts are large about 1-3 cm and the recrystallized porphyroclastic material is often wrapped with a quartz ribbons (Figure 10). The interpreted shear sense is low-angle and left lateral. The granitic gneiss is composed of quartz, K-feldspar plagioclase, and minor chlorite and biotite. The foliation strikes east west and dips to the south.

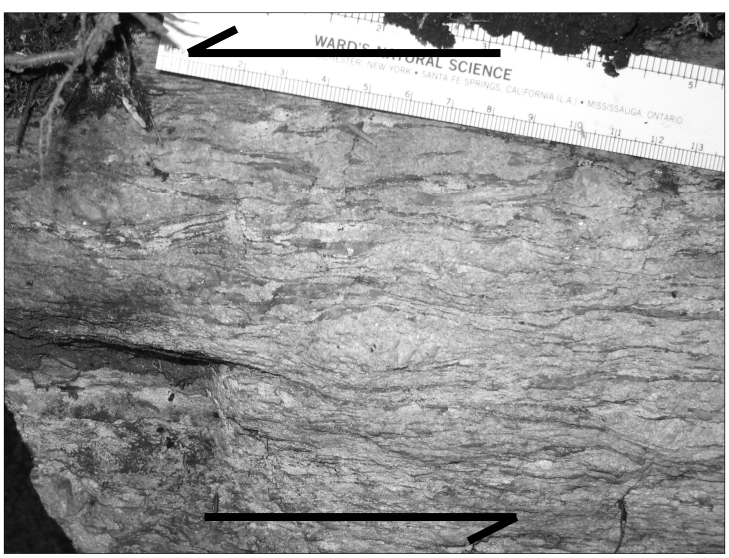


Figure 10. The view is south at STOP 4, and looking at a surface parallel to lineation and perpendicular to foliation. Large porphyroclasts of K-feldspar and have σ-type tails which display left lateral shear sense.

STOPS 4B and 4C require about 2.5 kilometers of traverse at a bearing of about 280º. The traverse will cross a few small streams and under brush can be thick in places. There is no trail to follow, so **PLEASE STAY WITH THE GROUP**.

STOP 4B Mafic Gneiss. This outcrop is a rare mafic gneiss composed of biotite, hypersthene, plagioclase, quartz and ilmenite. The fabric is L>S, lineations are defined by rods of plagioclase and streaks of biotite. The grains size is very small about 0.5mm. This rock unit borders the L>>S domain which can be seen at STOP 4C.

STOP 4C L>>S Cigar Shaped Domain. The final stop is a spectacular L-tectonite (Figure 11). The outcrop is granitic gneiss composed of quartz, K-feldspar, plagioclase, and fabric forming chlorite and biotite. Foliation is hard to see in hand sample but can be seen if stained for plagioclase and K-feldspar.

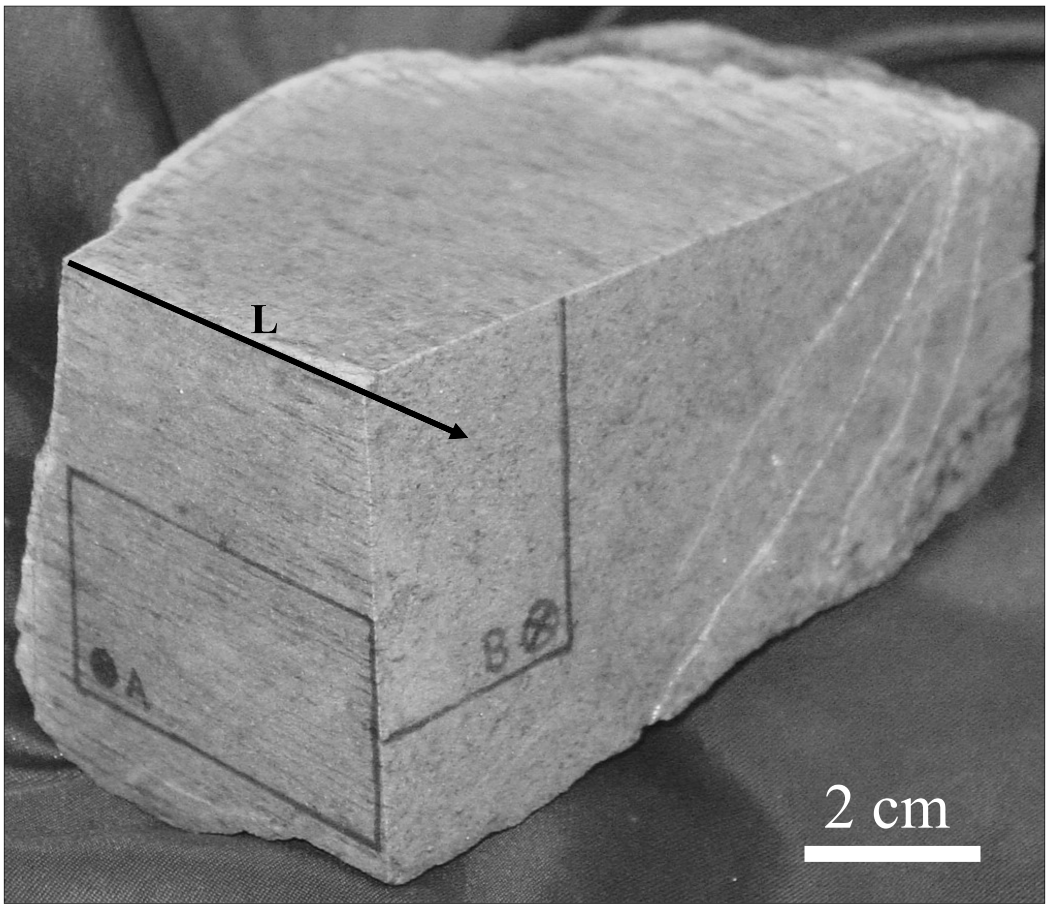



Figure 11. This photo was taken of sample from STOP 4C. Quartz rods and recrystallized aggregates of K-feldspar define the linear fabric. Dark minerals are primarily chlorite and biotite.

END OF TRIP.

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# Friends of the Grenville Field Trip 2008
# Indian Lake, New York

## Day 1, Saturday, September 27th

## The Southern Adirondack Sinistral Transpressive Shear System

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*Dave Valentino and Eric Johnson at Falls Brook, southeast flank of Snowy Mountain dome.*
*Photo by Lyal Harris*

## Abstract

The southern Adirondack mountains of New York are underlain by metaigneous and metasedimentary rocks that were deformed in a system of mostly sinistral shear zones (the southern Adirondack shear system) during the late stage of the Ottawan orogeny. At all scales, the shear system is generally east-west striking and contains generally east-west trending (080º to 120º) subhorizontal mineral elongation lineations and variably developed foliation (shallow to steeply dipping). The shear system is identified by the Snowy Mountain dome-Moose River plain shear system in the north, and the Piseco Lake domes and shear zone (PLsz) in the south.

The Snowy Mountain anorthosite body, and related AMCG rocks, occur within a structural dome (Snowy Mt. dome, SMD) approximately 15 km across. The SMD is defined by a concentric mantle of variably foliated noritic-, gabbroic-, and charnockitic-gneisses. Kinematic analysis was performed on rocks around SMD. The northeast and northwest flanks of the dome yielded a dominant shear sense of top westward, while on the southeast and southwest flanks resulted in a top eastward shear sense. The foliation is penetrative in the dome flanks, but is progressively weaker developed toward the interior anorthosite and in the supracrustal rocks that overly the dome. The foliation that wraps around SMD, narrows into the sinistral Moose River Plain shear zone (MRPz) to the west. Opposing shear sense on opposite flanks of the SMD suggests that sinistral ductile flow occurred around the anorthosite.

The Piseco Lake shear zone (PLsz) is a trans-Adirondack east-west structure, up to 20 km wide, defined by the regional fabric including a penetrative lineation, and foliation attitude and intensity that varies across the zone. The trend of lineations within the zone are subparallel to lithologic contacts and also parallel to subhorizontal regional lineation. The zone is developed primarily within highly deformed coarse-grained granitic rocks whose chemistry suggests an arc affinity. New field results indicate that the structure has two domains including a steeply dipping (5-7 km wide) mylonite zone (southern domain) that merges across strike with a broad open foliation arch (Piseco antiform or domes, northern domain). Sinistral kinematic indicators are common in both the steeply dipping mylonite domain and the flanks of the domes. Locally, the trend of the dome axis is asymmetric to the adjacent mylonite zone, and consistent with sinistral shear. The combination of steeply dipping mylonite with transcurrent strain history and adjacent domes suggests overall sinistral transpression. Metamorphic mineral assemblages from hypersthene to chlorite define the Piseco fabrics, indicating structural development over a wide temperature range (high to low) or reactivation at lower temperature conditions. Small (dm-scale ) north-striking extensional ductile shear zones occur through out the area, crosscutting the fabrics of the Piseco and Snowy Mountain structures.

The entire southern Adirondack shear system spans from a part of the Adirondacks dominated by AMCG suite rocks to a part dominated by granitoids with probable arc affinity. Based on the magnitude of the structures and the special association with rocks of different Adirondack terranes, this shear system may be a tectonic boundary separating the edge of Laurentia and older ca.1350 Ma tonalities and related arc supracrustal rocks exposed to the south. The location of the proposed suture served as a strike-slip escape structure as part of a Himalayan-type syntaxis in the late stage of the Ottawan orogeny.

## Introduction

The Grenville Province forms one of the longest and most deeply exhumed areas of continental crust on Earth. Additionally, the Grenville Province exposes the deep roots of an ancient mountain range of immense portions, and records the assembly of Rodinia, one of the few recognized supercontinents. The Ottawan Orogeny (ca. 1070-1000 Ma) is often cited as a classic example of continent-continent collision and compressive thickening of the crust, with comparison with the Himalayas (Dewey and Burke, 1973; Windley, 1986; McLelland et al. 2001). This is especially true for the Adirondack massif where regional metamorphism ranges up to granulite facies (Figure 1). Oblique motion vectors between regions of the Eurasian and Indian plates has resulted in oblique collision that produced zones of transpressional strike-slip deformation in the hinterland, and belts of thrusting in the foreland (e.g. Tappionier and Molnar, 1976). Tappionier and Molnar (1977) applied a rigid indentor model to the Himalayan orogen, and proposed that zones of transcurrent strain develop syntaxes in regions of the crust

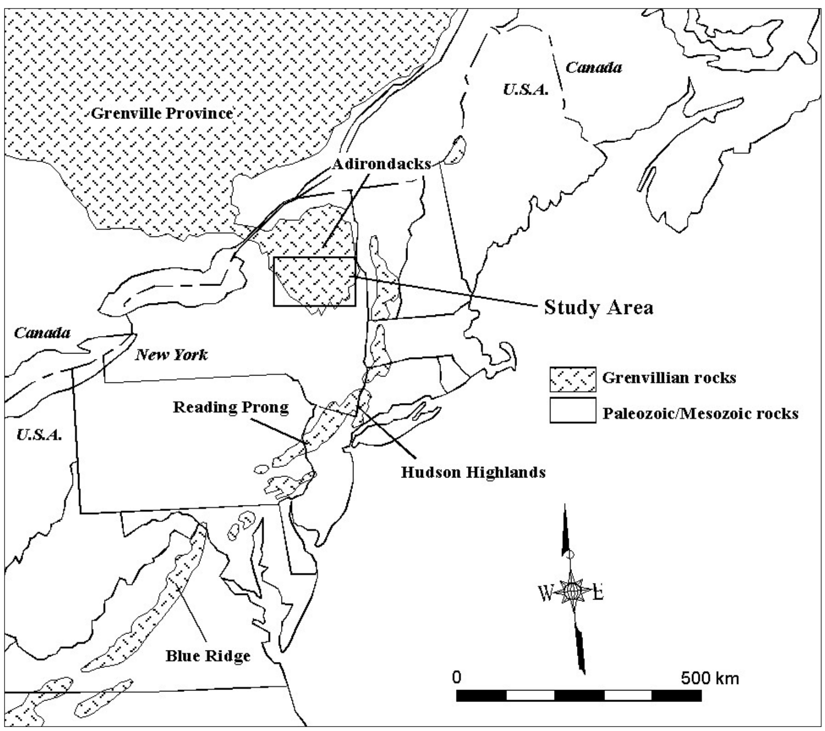


**Figure 1.** General map of the northeast U.S.A. and eastern Canada showing the distribution of Grenvillian basement rocks, and the study area for this field guide located in the central and southern Adirondack Mountains, New York.

undergoing horizontal escape. These structures have been almost exclusively described for rocks that were exhumed from intermediate to shallow levels of the crust. What would be the appearance of these structures deep in the crust? If a Himalayan-type plate collision is to be fully applied to the Grenville, then the presence of deformation zones other than those that exhibit contractional strain histories should be considered. A Himalayan-type tectonic model, if applied completely, should include the complex array of tectonothermal regimes found in association with the Himalayan orogen such as foreland rift basins and major zones of transcurrent and transpressional deformation. Within these complex collision zones, the distribution of strain and the location of faults can be controlled by the presence of pre-existing structures, or by the juxtaposition of rock bodies with ductility contrasts such as decoupling of cover rocks over deforming crystalline basement (Gates et al., 1999; Valentino et al., 2004).

This field trip is based on our field and lab research on rocks of the central and southern Adirondacks over the past decade. During this trip we will present evidence that suggests a comprehensive Himalayan-type model that includes aspects of contractional, transpressional and extensional strain histories over a protracted time span.

## Sinistral shear recorded in rocks of the Adirondack Highlands

In contrast to the overwhelming northeast trends throughout most of the Grenville Province, the structural grain of the south-central Adirondack Highlands is generally east-west (Figures 1 and 2). This broad zone (>60-km wide) displays general parallelism of geologic contacts, fold axes, compositional layering, foliation, mineral lineations and a series of moderate to steeply dipping mylonite zones. Several large (>20-km across) structural domes cored by rheologically rigid anorthosite lie within the zone.

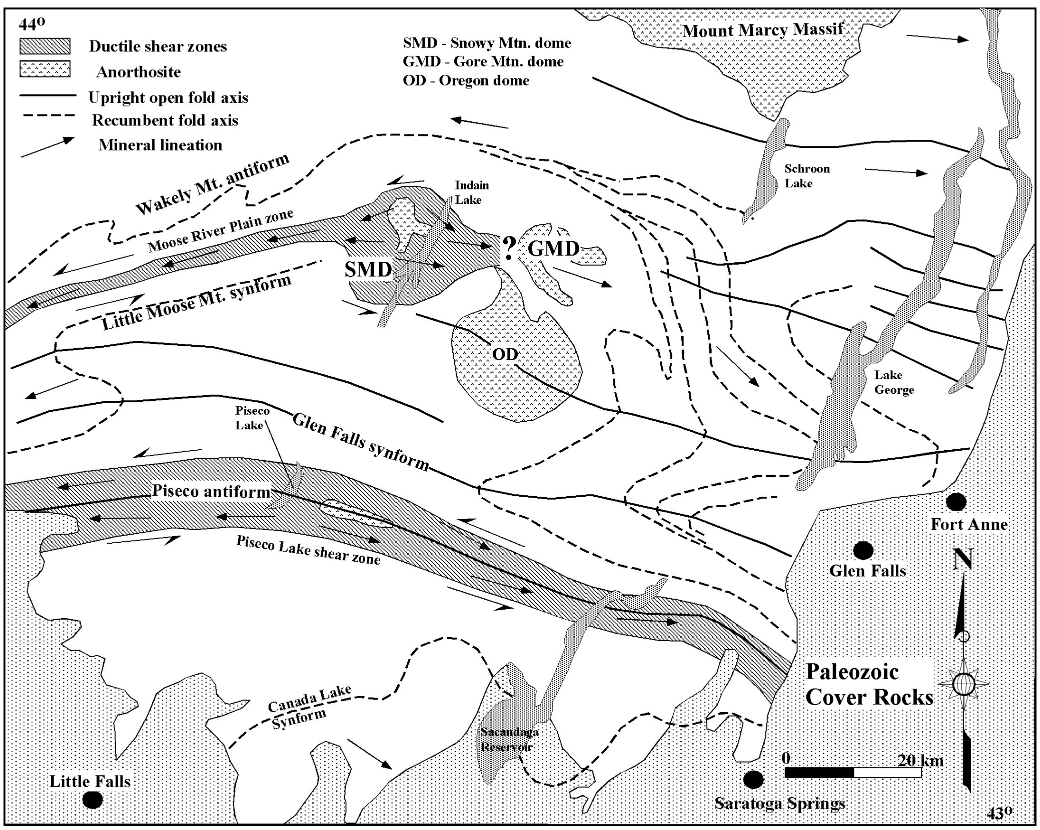


**Figure 2.** General geologic map of the central and southern Adirondacks showing the locations of major structures discussed in this field guide including the Moose River Plain shear zone, the Snowy Mountain dome (SMD) and the Piseco Lake shear zone.

Kinematic investigations indicate that this zone is dominated by sinistral shear strain (Chiarenzelli et al., 2000; Gates et al., 2004). There are a number of large-scale features, such as drag folds and rotated mega (giga-) clasts, which are consistent with the abundant meso- and micro-scale kinematic indicators. Kinematic indicators include S-C fabrics, shear bands, and rotated porphyroclasts (Gates et al., 2004). This east-west, broad zone is bounded by shear zones that traverse portions of the southern Adirondacks. The structure of the south-central Adirondacks has been interpreted as the consequence of transpressional modification of earlier crustal-scale recumbent folds analogous to those exposed in the Adirondack Lowlands (Chiarenzelli et al., 2000). Widespread granulite-facies mineral assemblages within substantial volumes of supracrustal rocks are consistent with compressional tectonics, and there is metamorphic mineral evidence that some shear zones outlasted high-grade conditions.

## Snowy Mountain dome and Moose River Plain shear zone

A zone of high-grade intensely sheared rocks extends east-west through the Moose River Plain of the west-central Adirondacks and was thereby named the Moose River Plain shear zone (MRPSZ; Figures 2 and 3). This shear zone occurs between the Wakely Mountain antiform and Little Moose Mountain synform (Wiener et al., 1984), and it experienced sinistral shearing under granulite-facies conditions. The eastward trace of the MRPSZ intersects and is deflected around the anorthosite-cored Snowy Mountain dome (DeWaard and Romey, 1969). East of the Snowy Mountain dome, the MRPSZ, traces toward the area of Gore Mountain, but the details are not as well documented at this time. This area will be visited the second day of the field conference at Chimney Mountain.

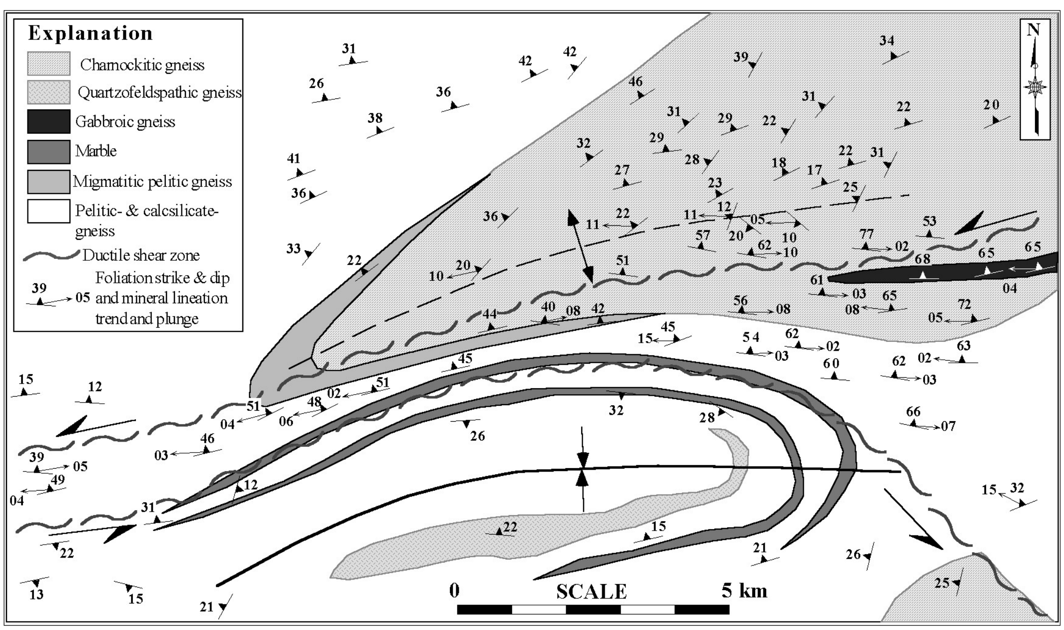


**Figure 3.** Detailed geologic map of the Moose River Plain shear zone in the area between the Wakely Mt. Antiform and Little Moose Mt. Synform.

Penetrative foliation occurs along a narrow belt (~2 km wide) that defines the MRPSZ. The foliation generally strikes 270º and dips moderately to steeply north. It is defined by metamorphic mineral assemblages characteristic of granulite-facies conditions. Sheared charnockitic gneiss contains the assemblage plagioclase-clinopyroxene-hypersthene, pelitic gneiss contains biotite-K-feldspar-sillimanite-garnet, and gabbroic-gneiss contains augite-hypersthene-garnet-plagioclase. Within granitic and charnockitic gneisses, foliation is defined by planar aggregates of recrystallized feldspars and quartz. Foliation in pelitic gniess is defined by recrystallized quartz and K-feldspar and parallel alignment of biotite and sillimanite. Mineral-elongation lineations are defined by linear aggregates of feldspar, pyroxene and garnet in charnokitic gneiss, and biotite and sillimanite in pelitic gneiss. The foliation and lineation in the gabbroic gneiss is mostly defined by alternating planar aggregates of plagioclase and pyroxenes. The eastern limit of the MRPSZ is structurally continuous with the penetrative foliation that mantles the Snowy Mountain dome (DeWaard and Romey, 1969) (Figure 4).

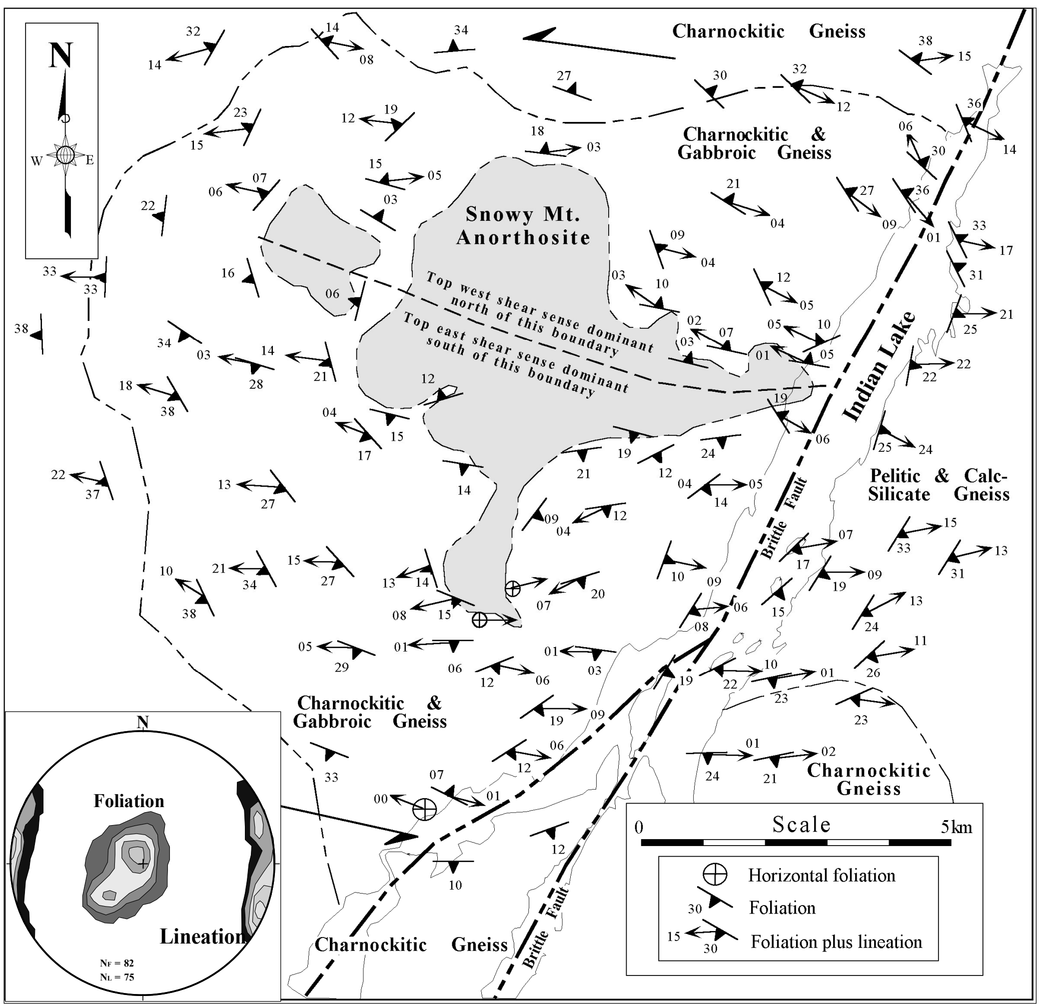


**Figure 4.** Structure map of the Snowy Mountain dome, central Adirondack Mountains. Geologic contacts are modified from DeWaard and Romey (1969). The inset is a stereogram for poles to foliation and lineation for the eastern half of the dome.

The zone of deformed rocks in the Moose River Plain region was interpreted as the result of shearing between the lower and upper limb of the Wakely Mountain antiform and Little Moose Mountain synform (Wiener et al., 1984). Consistent subhorizontal mineral lineations throughout the Moose River Plain shear zone are indicative of a subhorizontal transport direction and inconsistent with earlier kinematic models based solely on map-pattern folds. Kinematic indicators throughout the shear zone are consistent with left-lateral shear. Kinematic indicators include σ- and δ-type porphyroclasts (Simpson and Schmid, 1986; Passchier and Simpson, 1986) in pelitic and granitic gneiss, Type-I S-C fabrics (Lister and Snoke, 1984) in charnockitic gneiss, asymmetric foliation boudins often associated with local migmatite, and fish-structures comprised of broken garnet crystals, and small high-strain zones (Figure 5A). Locally the foliation is deflected at the margins of the MRPSZ consistent with map-scale left-lateral drag folds (Figure 3).

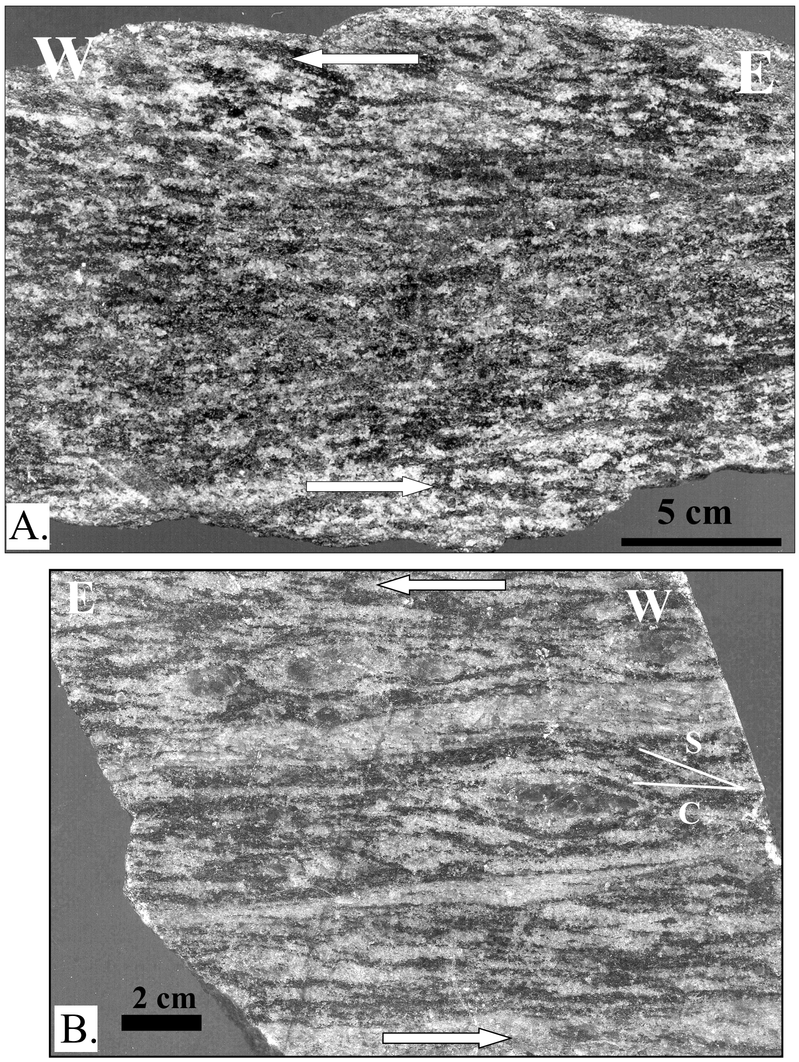


**Figure 5.** Examples of kinematic indicators from the Moose River Plain shear zone and the high strain fabrics that define the Snowy Mountain dome. A] Small high-strain zone from the MRPSZ showing sinistral shear; B] S-C fabric in gabbroic gneiss from the northeastern flank of the SMD.

Large (15-20-km across) structural domes cored by anorthosite in the Adirondack Highlands are interpreted to have resulted from fold interference (McLelland and Isachsen, 1986) (Figures 2). The Snowy Mountain dome (Figures 5 and 6), is underlain by AMCG suite rocks with anorthosite in the core (DeWaard and Romey, 1969). The eastern extent of the MRPSZ foliation is structurally continuous with penetrative deformation fabrics that wrap around and define the Snowy Mountain dome. The core of the dome is underlain by megacrystic anorthosite with crystals commonly up to 20 cm. Anorthosite is mantled by gabbroic- and then charnockitic- gneiss forming a semi-concentric compositional zonation (DeWaard and Romey, 1969). Although the central anorthosite is generally not deformed, the margins of the body contain dynamically recrystallized plagioclase that define well-developed foliation and lineation. As first described by DeWaard and Romey (1969), the transition from anorthosite to gabbroic gneiss is marked by more intensely developed deformation fabrics away from the dome core. Farther outward on the dome flanks, the foliation is penetrative in the charnockitic gneiss. The presence of relict plagioclase megacrysts in the charnockitic gneiss suggests a plutonic origin. Most of the unit consists of planar and linear aggregates of recrystallized plagioclase and anhedral, broken grains of clinopyroxene and hypersthene. Poles to foliation reveal that the dome has a dominant northwest-southeast-trending axis (Figure 4). The attitude of lineations vary about 30° around a general east-west trend that is roughly parallel to lineations in the MRPSZ.

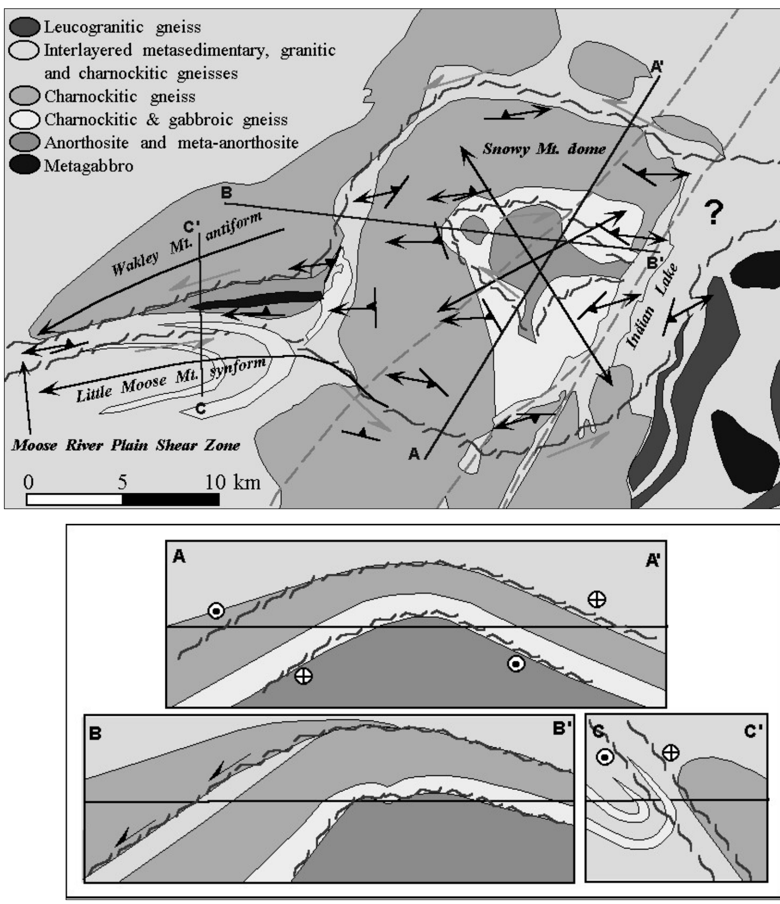


**Figure 6.** Schematic geologic map of the Snowy Mountain dome and the intersection with the Moose River Plain shear zone. The structure sections (A-A'; B-B'; C-C') are the same scale as the map and have no vertical exaggeration.

Shear-sense indicators observed at the Snowy Mountain dome including σ- and δ-porphyroclasts (Passchier and Simpson, 1986), and type-I S-C fabrics (Lister and Snoke, 1984). Shear-sense indicators from the southern flank of the dome reveal top-to-the-east bulk shear, whereas the northwestern flank reveals top-to-the-west shear (Figure 5B). On the northwest side of the dome, where foliation dips moderately westward (Figure 4), the shear sense is locally dip-slip normal. On this basis, the dome can be divided into two domains as shown on Figure 6.

The axial obliquity of the dome with respect to the general east-west shear along the MRPSZ is consistent with development of the dome by sinistral transpression, and possibly large scale sinistral rotation. The dome does not appear to be a secondary fold defined by folded foliation as suggested in kinematic models for the Adirondacks (Weiner et al., 1984). In contrast, it appears to be a dome-shaped distribution of foliation developed in the less resistant rocks that mantle the more resistant anorthosite that cores the dome. The asymmetry of the dome axis relative to the general shear direction may reflect modification of the original dome geometry in the left-lateral shear couple. It is possible that the Snowy Mountain anorthosite and related rock suite, are part of an asymmetric giga-clast within a sinsitral shear zone (Figure 6).

## The Piseco Lake shear zone

In the southern Adirondacks, there is a zone (10-20 km wide) of spectacular L-S and L>S tectonite with a general east-west map pattern (Figure 2). This deformation zone was designated by Gates et al. (2004) the Piseco Lake shear zone (PLSZ) based upon its inclusion of the Piseco dome and antiform of earlier workers (Cannon, 1937; Glennie, 1973; McLelland, 1984; Wiener et al., 1984), but also upon the extent of penetrative fabrics general shear fabrics found well beyond the core of the antiform. Throughout the PLSZ, rocks of mostly granitic composition contain intense foliation and lineation, as described by Cannon (1937) and McLelland (1984). Geochemical analysis of the Piseco zone rocks reveals a calc-alkaline trend for the granitic rocks (Chiarenzelli and Valentino, 2008). Penetrative foliation and lineation are defined by dynamically recrystallized quartz (ribbons), K-feldspar and plagioclase, and alignment of muscovite, biotite and locally chlorite. Rocks within the zone consist dominantly of fine-grained aggregates of these minerals. Locally there are 2- to 6-cm-wide K-feldspar porphyroclasts supporting a plutonic origin for these rocks.

Foliation within the PLSZ defines an upright antiform (Cannon, 1937; Glennie, 1973; Weiner et al., 1984) with a subhorizontal axis that trends approximately 110° in the east, 090° in the central part, and 080° in the west. Foliation on the antiform limbs dips moderately to steeply both north and south. Lineations are penetrative in these rocks and are defined by dynamically recrystallized ribbons and rods of quartz, K-feldspar, plagioclase and streaks of chlorite, biotite, magnetite and muscovite. The plunges of the lineations are consistently shallow to subhorizontal. Overall the fabric in the antiform limb regions can be classified at L-S with the lineation and foliation both well developed. In the antiform crest, foliation is not well developed and penetrative lineations are defined by mineral rods, rods of mineral aggregates, and mineral ribbons. Lineations in the core area of the antiform are intensely developed, and in many places the linear fabric is dominant over the weak planar fabric (L>>S; Figure 7) with grain-shape aspect ratios upward of 60:1 (in the L-parallel and S-perpendicular plane).

Metamorphic index minerals are not diverse in these rocks due to the overall granitic composition. The penetrative foliation and lineation is associated with diagnostic metamorphic minerals such as biotite, chlorite and muscovite, which are indicative of lower-amphibolite to upper-greenschist facies conditions (Figure 8). Locally, anhedral grains of augite and hypersthene have overgrowths of hornblende, biotite or chlorite (Figure 9). The presence of hypersthene suggests these rocks experienced granulite facies metamorphism (McLelland, 1984), but the main fabric developed later during intense dynamic retrogression (Chiarenzelli et al., 2000).

Price et al. (2003) conducted a micro-structural study of the orientation of the chlorite and biotite grains in the L-S and L tectonites from the Piseco zone to see if the orientations are concordant or discordant with the mesoscopic rock fabrics. The inset of Figure 8 shows a domain of chlorite grains aligned parallel to a ribbon-shaped quartz aggregate. Superficially, they are parallel suggesting a genetic tie. Figure 9 shows one example from Price's orientation study of mica grains in an L>S tectonite from the area of West Canada Creek. In all three stereograms, the long axes of the mica grains are plotted relative to the macroscopic lineation in the sample. The magnitude of each plot represents the percentage of grains in specific directions. These orientations were obtained using mutually perpendicular thin sections with a Nikon universal-stage. Overall it was demonstrated that the micas have a preferred grain shape alignment with the elongate aggregates of quartz and feldspar in both the L-S and L-tectonite domains at the microscopic and macroscopic scale.

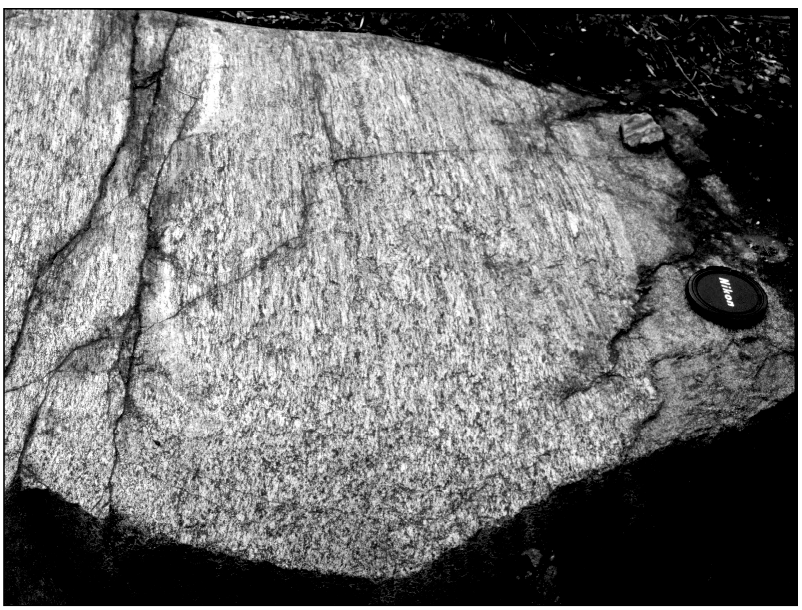

**Figure 7.** Outcrop of L-tectonite from the Piseco Lake shear zone. The view is looking west at an outcrop face that is subvertical in the foreground and subhorizontal in the background, revealing the ends and sides of mineral lineations respectively.

McLelland (1984) suggested that the Piseco dome developed in the constrictional part of a regional west-directed thrust, but little kinematic data was presented. Shear-sense indicators are abundant in the PLSZ, and include Type I S-C fabrics (Lister and Snoke, 1984), σ - and δ-porphyroclasts of K-feldspar (Simpson and Schmid, 1983; Passchier and Simpson, 1986), asymmetric polymineralic tails around porphyroclasts, and biotite- and muscovite-fish (Figure 11). These kinematic indicators reveal a consistent sinistral-shear sense on both the north- and south-dipping domains of the zone.

Figure 11 shows the textural transition across a southern segment of the Piseco zone, from generally moderately deformed megacrystic granite to well developed mylonite and finally domains of ultramylonite (12D).

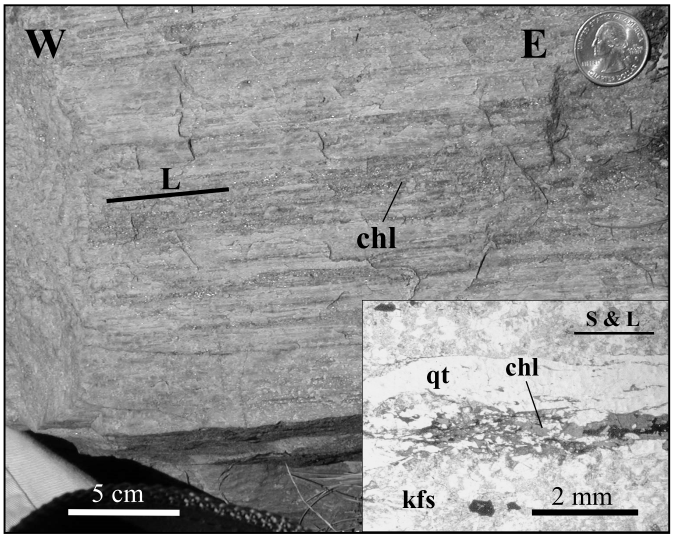


**Figure 8.** Outcrop of L-S fabrics in the PLSZ along Route 8 in the vicinity of Piseco Lake. The darker layers are linear aggregates of chlorite. The inset photomicrograph shows acicular chlorite (blades in three dimensions) oriented sub-parallel to the quartz ribbon.

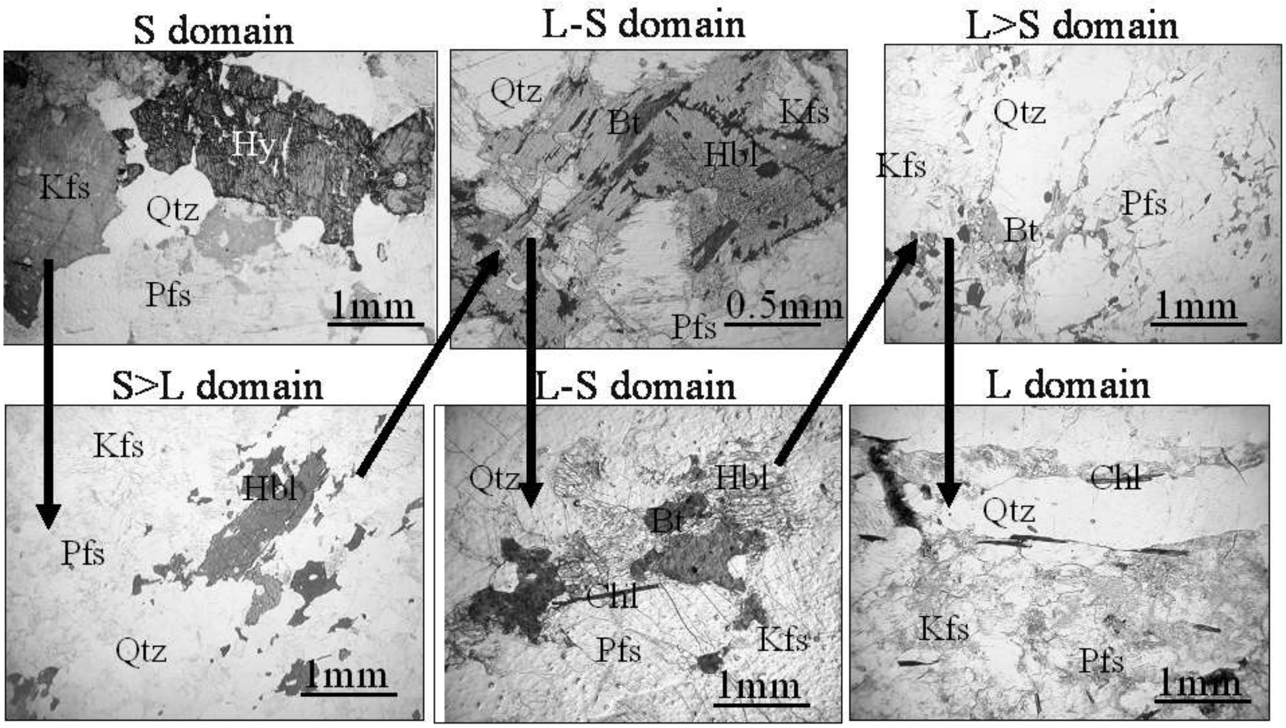


**Figure 9.** Photomicrographs that span various L & S fabric domains on the northern flank of the Piseco antiform. To the north and outside the L-S fabrics of the Piseco structure, the granitic rocks contain hypersthene. Rocks from the L-S, L>S and L domains show clear signs of retrograde overprint with the presence of hornblende (Hbl), biotite (Bt), and chlorite (Chl).

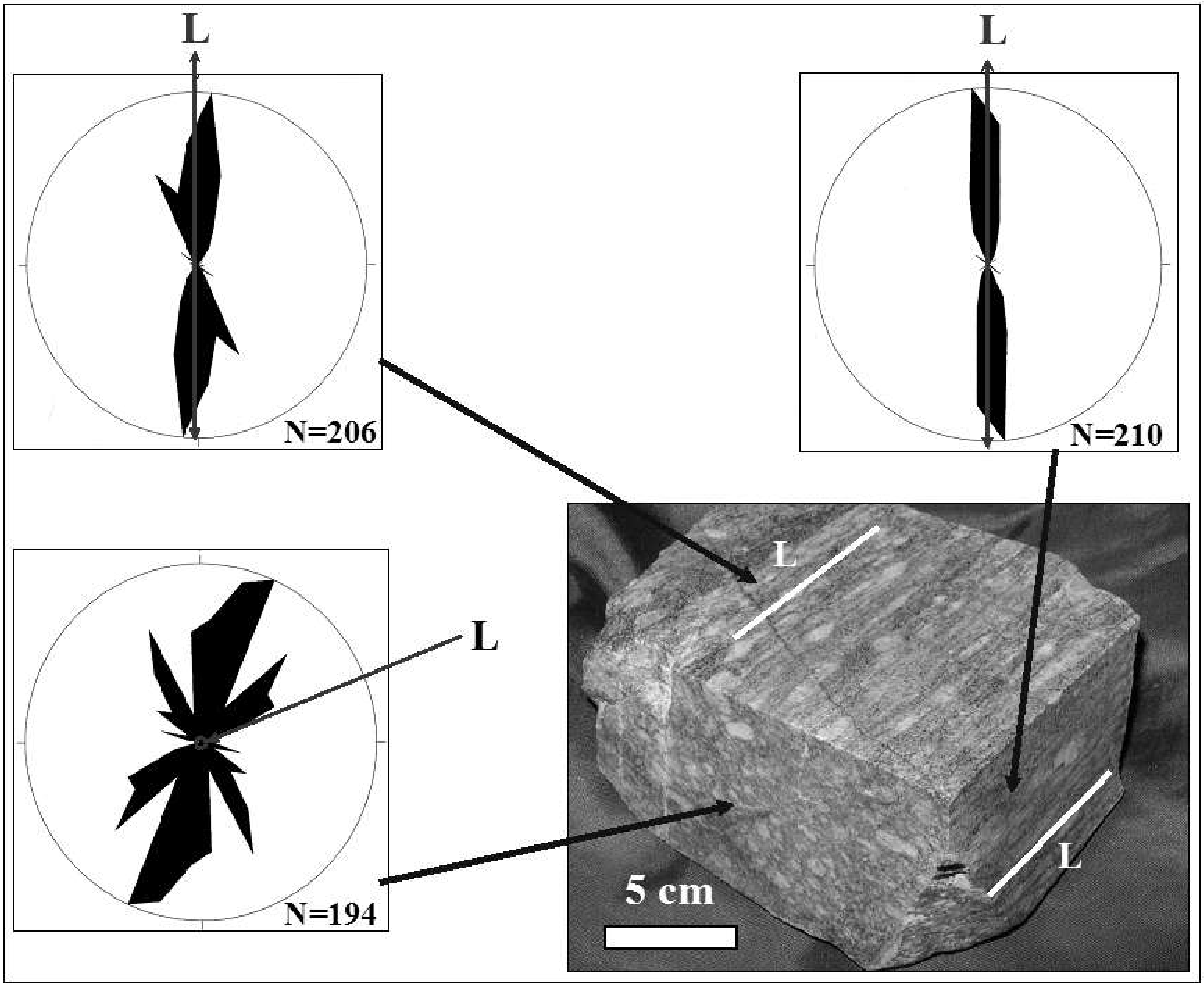


**Figure 10.** Photograph of a sample of L>S tectonite from the West Canada Creek area within the Piseco Lake shear zone. The three rose diagrams show the statistical orientation of the long-axes of chlorite and biotite grains relative to the macroscopic mineral elongation lineation (L) for three mutually perpendicular sections (modified from Price, 2003).

## Variation in the L and S tectonite

There are two structural domains that make up the Piseco Lake shear zone: the northern domain that consists of strongly lineated, foliation domes (Piseco antiform of earlier researchers), and the southern domain that consists of moderately to steeply dipping mylonite defined by penetrative foliation and lineation. There is no apparent break in the foliation of the southern mylonite zone and the foliation in the dome region, and lineations are consistent in orientation and trend. Collectively, these structural domains make up a zone of ductile deformation that is more than 25 kilometers wide, and appears to cross the exposed limit of the southern Adirondacks. Due to the size of this structure, it has been a daunting task to produce detailed geologic maps, however, specific regions were targeted to characterize the variations in the L and S tectonite. As well, detailed field mapping projects were completed in regions of the Piseco zone through the SUNY Oswego Geology Field Program.

Cannon (1937) produced a detailed structure map in the Piseco Lake region that includes both the northern dome and the southern mylonite zone. Figure 12 shows two of Cannon's north-south cross sections through the Piseco antiform near Piseco Lake. It is interesting that that the Cannon defined the antiform by an arch-shaped configuration in the foliation, but based on his map, the pronounced lineation passes through the antiform unhindered by any apparent folding. From the more recent mapping project and consistent with Cannon's work, the foliation within the antiform is not homogeneously developed. In fact, the core of the antiform lacks any macroscopic foliation at many localities, and we argue that Cannon's cross sections are a bit misleading in that regard.

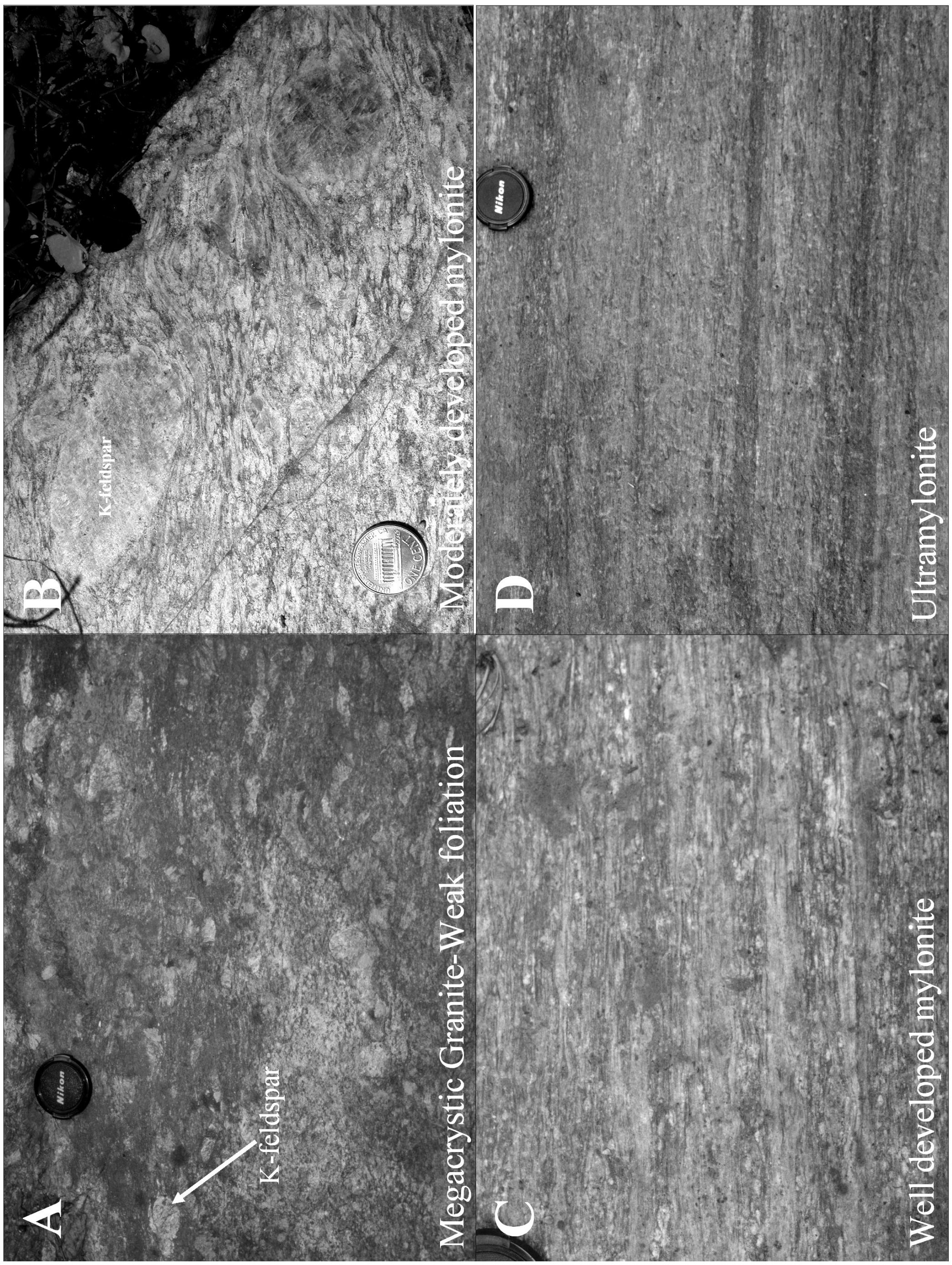

**Figure 11.** Collection of outcrop photographs across the southern region of the Piseco Lake shear zone in general granitic gneisses (A to D). The view for all of these photographs is into the ground with the foliation and lineation aligned left-right. Figure 13B shows large K-feldspar porphyroclasts with sinistral shear sense.

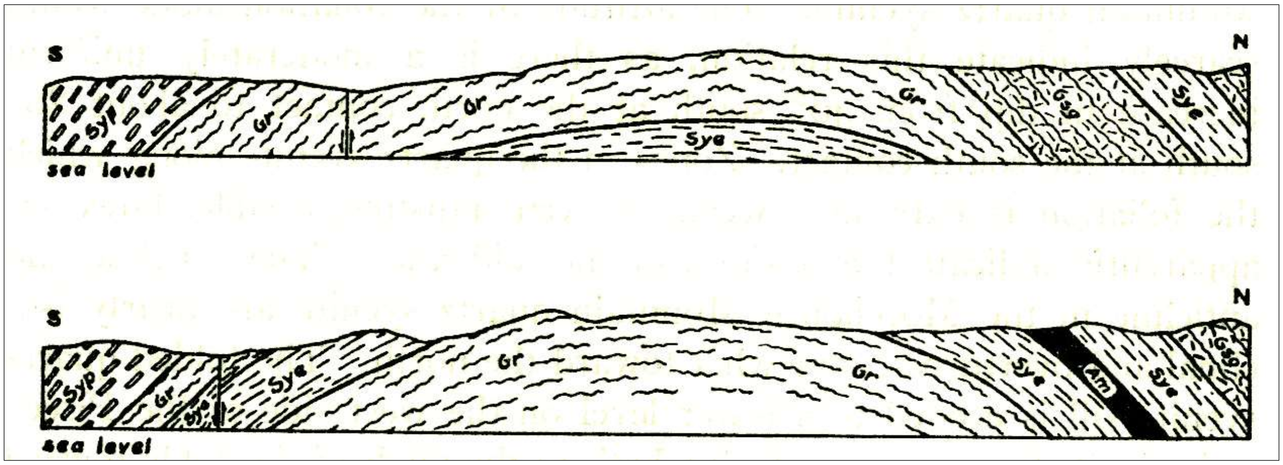


**Figure 12.** Cross-sections through the Piseco dome near Piseco Lake (Cannon, 1937).

A structure map was compiled based on our recent field studies integrated with the earlier work of Cannon (1937) (Figure 12). As mentioned before, most of the Piseco Lake zone resides within granitic rocks. This makes mapping the zone a bit monotonous, but provides an opportunity to discriminate rock fabrics independent of lithologic variation. In general, most of the rocks of the Piseco Lake zone would be considered L-S tectonities with the foliation and lineation well developed as in those shown in Figure 11. In the Piseco Lake area, lineations have a consistent trend of about $095^{o}$, regardless of the dip of the foliation. Isolated domains, on the scale of outcrops to kilometers, contain rocks with a dominant lineation and very weak to non-existent foliation. These rocks would be considered the L>>S category, or in some cases just L-tectonites.

The structure map of Figure 13 does not include lithologic variation because most of the area is granitic gneiss. However, structural patterns defined by the trace of foliation and lineation are represented. Most of the compiled region contains rocks with both foliation and lineation observable in hand sample, but there are map-scale domains of rocks that are dominated by lineations. The L-S domains are divided based on the steepness of the foliation dip: steeply dipping L-S mylonite (dip greater than $70^{o}$), and moderately dipping L-S mylonite. Again, the lineations throughout this region have a very consistent subhorizontal trend of about $095^{o}$ independent of the attitude of the foliation. Form lines for the strike of foliation clearly delineate the geometry of the Piseco dome. The axis of the dome trends about $120^{o}$, plunges less than $5^{o}$ in the area immediately west of Piseco Lake, and the axial trace is displaced by apparent Cenozoic faulting. In the northwestern part of the dome, the trace of the dome axis is more westerly. Finally, there are two domains of L-tectonite that occur near the axis of the dome. The northern flank of the dome merges with the regional shallowly dipping foliation, but the southern flank merges into a domain of moderately to steeply dipping L-S mylonite that continues across strike for approximately 10 kilometers (Figure 14).

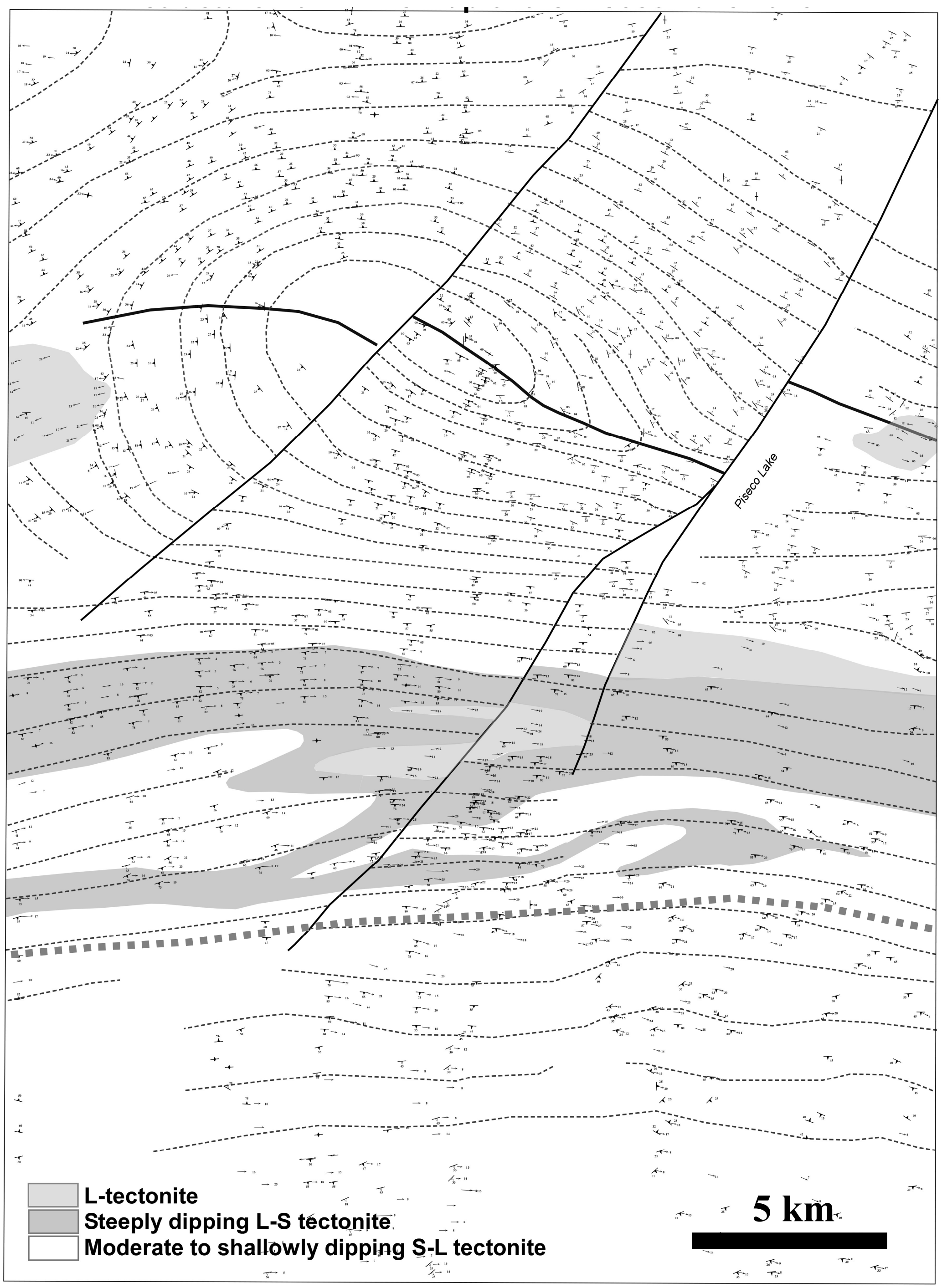


**Figure 13.** Structure map that crosses the Piseco Lake shear zone (type-locality of Piseco Lake) compiled from recent mapping and data from Cannon (1937). Lithologic variation is not represented on this map. The dark gray regions represents rocks dominated by L-S mylonite with a dip greater than 70°. The pale gray region represents rocks dominated by L-tectonite, and the non-shaded regions of the map represent rocks with variable L-S fabrics and shallow to moderate dip. Structure form lines are represented by the dashed lines.

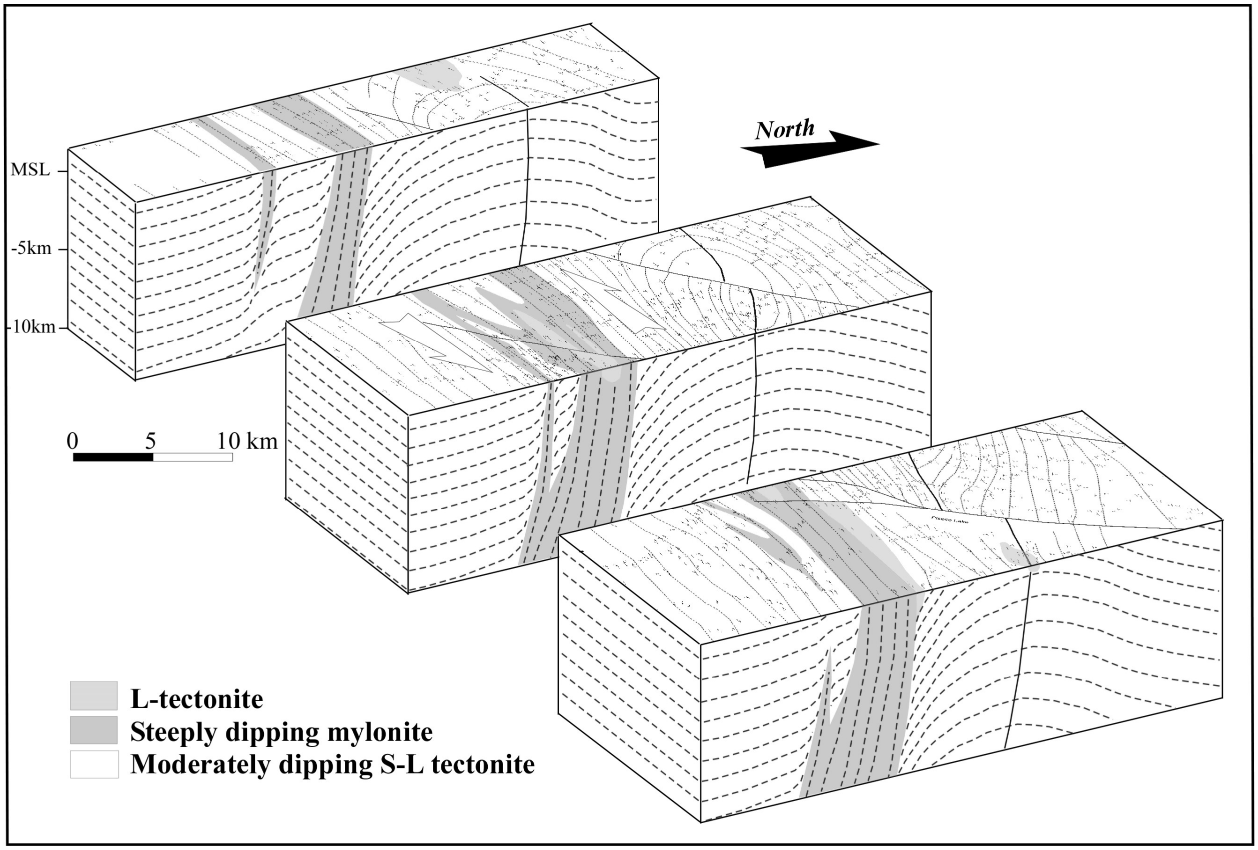


**Figure 14.** Structural block models for the area of Figure 14. These models include the Piseco dome in the area of Piseco Lake and the broad zone of mylonite that occurs on the southern flank of the dome.

### Fabric variation in the West Canada creek basin region

In 2004, Damian Piaschyk (who was an undergraduate geology major at SUNY Oswego at that time) completed detailed mapping of 42 square kilometers area that crosses the northern boundary of the zone in the West Canada Creek basin (Figure 16), and his work was originally presented at the 2005 NYSGA field conference (Piaschyk et al., 2005). The objective of that study was to document the detailed rock fabric variation within the shear zone, the transition zone and the wall rocks to the shear zone. As well, Piaschyk's study was designed to better understand the strain and metamorphic history associated with this major Adirondack structure, and document the geographic distribution of L- and L-S tectonites that were previously reported (McLelland, 1984; Chiarenzelli et al., 2000; Gates et al., 2004). Because of the high-level of detail, Piaschyk's comprehensive field work is again included as part of this field guide for the Friends of the Grenville.

Five domains of varying fabric intensities were documented (L>>S, L>S, L-S, S>L, and S) within the Piseco Lake zone and the shear zone transition region with the wall rocks (Figure 13). The northern boundary of the Piseco zone is defined by a gradational increase in L-S fabric intensity from north to south. Both the foliation and lineation are defined by dynamically recrystallized aggregates of quartz, K-feldspar, plagioclase and minor mafic phases. This fabric transition corresponds with an increase in grain size reduction of all these minerals. Within the Piseco Lake

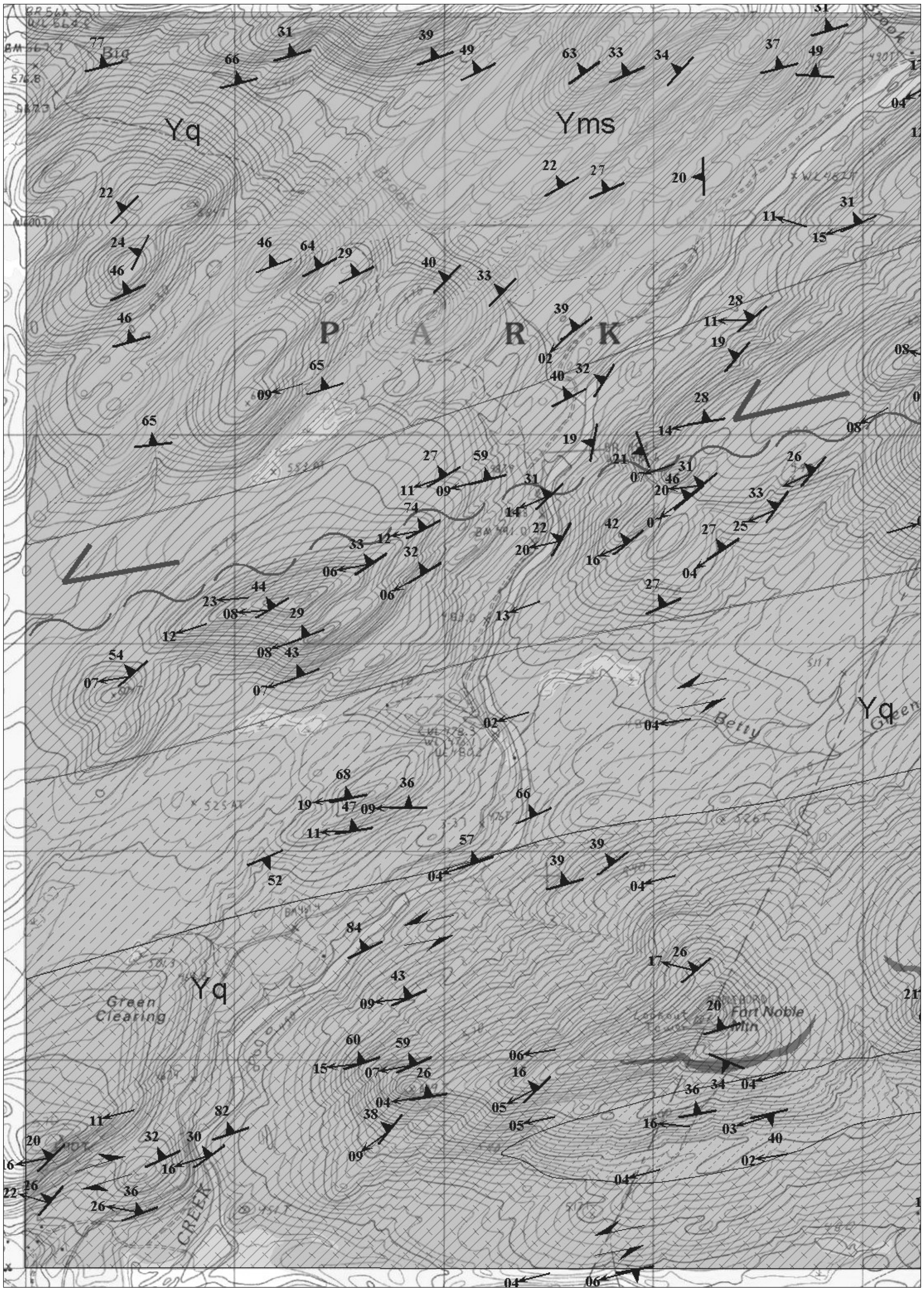


**Figure 15.** Bedrock geologic map of the West Canada Creek basin in the southwestern Adirondacks. The map area crosses the northern boundary of the Piseco Lake shear zone. The base map is a provisional USGS metric topographic map with a 1 km grid. The next two pages show the eastern extension of the map area and the map explanation respectively.

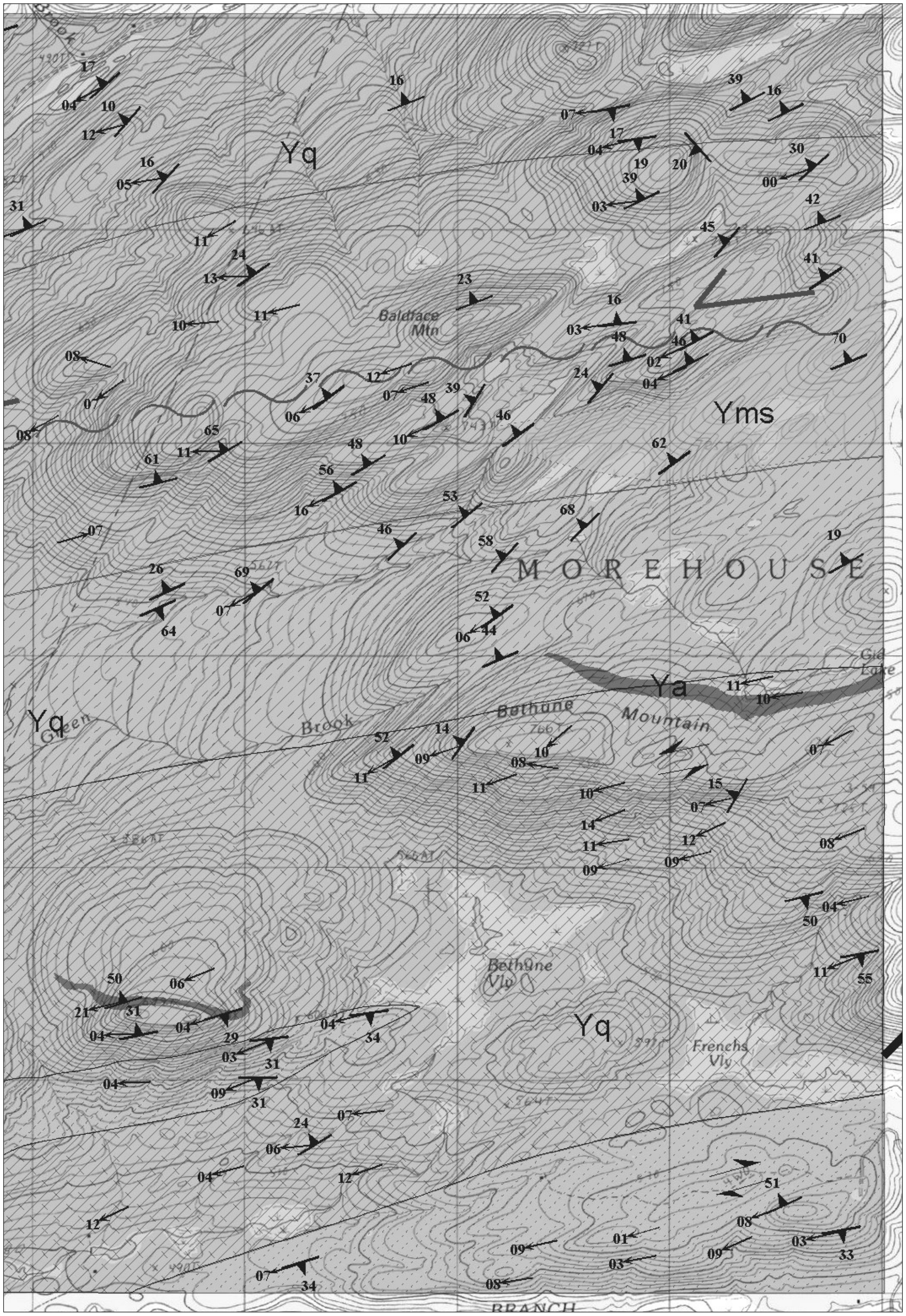


**Figure 15 (continued).** Eastern extent of the geologic map of the West Canada Creek basin. See the next page for the map explanation.

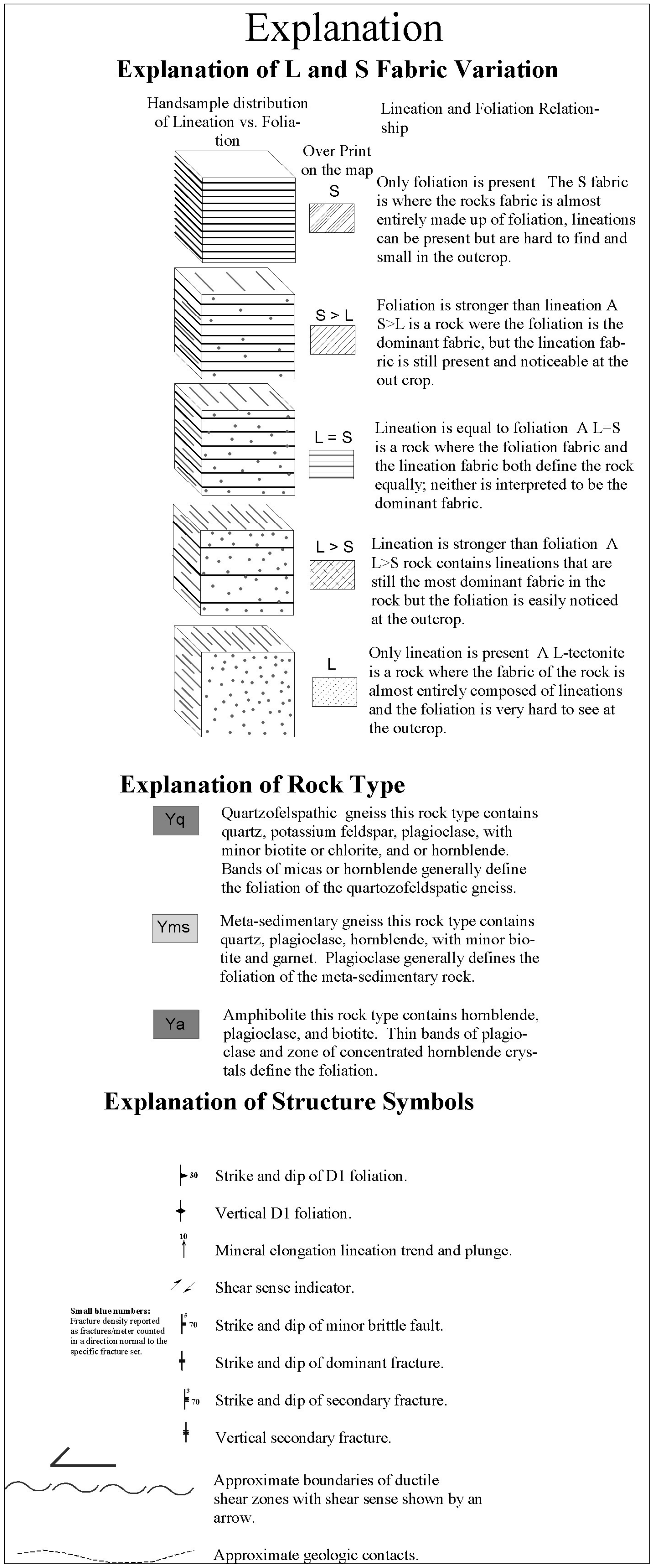


**Figure 15 (continued).** Map explanation for the West Canada Creek basin. Three gray shades were used to represent general rock types and the shades are overlain with patters to represent the five categories of rock fabric.

zone the fabric variation occurs systematically from L-S dominated, to L>S and finally L>>S tectonite. A cigar-shaped map-scale domain of L>>S fabric, 3.5 km by 0.5 km in size, trends parallel to the linear fabric observed at the outcrop. A change in the dominate dip direction between the L>>S and L>S domains supports the presence of a foliation fold over the cigar-shaped domain. The wall rocks to the shear zone in the study area are mostly granitic gneisses and minor dioritic gneiss containing metamorphic index minerals of hornblende and hypersthene (Figure 9). The granitic gneiss contains a dominant gneissocity that strikes generally east-west with very weak mineral lineations. Quartz and feldspars form course crystalline aggregates that define the gneissocity. The presence of hornblende and hypersthene, and the gneissic fabric suggest these granitic rocks were metamorphosed under granulite facies conditions as reported by earlier researchers (McLelland, 1984).

Within the zones of intense L-S deformation fabrics, the rock is generally granitic gneiss, however, it contains abundant feldspar and quartz grains up to a few cm in diameter. In places, K-feldspar grains appear to be relict igneous megacrysts. As mentioned previously, the L-S fabrics are defined by planar and linear aggregates of dynamically recrystallized quartz and feldspar grains. Additionally, the fabrics are defined by chlorite and minor biotite. These rock textures and index minerals suggest two conclusions: the Piseco Lake zone developed in course grained granite that is not found in the wall rocks, and Cannon (1937) and McLelland (1984) described similar rock fabrics for other parts of the Piseco Lake zone, however, they did not mention the presence of low-grade fabric forming metamorphic index minerals.

### Systematic look at the structural data

The structural data collected during the mapping in the West Canada Creek region was divided based on the fabric categories that define the five fabric domains, as shown on the map of Figure 16. These data were used to generate lower hemisphere contour diagrams for the poles to foliation and lineation. Poles to lineations plotted at or near the margin of the diagram and the poles to foliation form the diffuse girdle on the interior of the diagrams. The stereogram representing the data from the L>>S domain (Figure 16) demonstrates that the foliation is dominantly dipping to the south. But the stereogram showing the data from the L>S domain demonstrates that the foliation is dominantly dipping northward. The L-S, S>L, and S domains show foliation dominantly dipping to the north, however the general strike is consistent throughout all the diagrams.

### Ohio gorge region

The West Canada Creek flows through the east-west trending Ohio gorge a few kilometers south of the geologic map area of Figure 16. Nearly 90% bedrock exposure afforded the opportunity to study the fabric variation in great detail in the northern domain of the Piseco Lake zone. Access to the gorge is restricted due to private property and high water most of the year. During the Summer 2004, a detailed outcrop map was produced for the southern side of the gorge. High-resolution digital photographs were taken and assembled into a mosaic. The photo mosaic was used as the base map, and rock fabric and textural variations were overlain at the sub-meter scale. In general, the bedrock exposed in the gorge is the megacrystic granitic gneiss typical of the Piseco Lake zone, and there is little variation in the overall mineral content along the extent of the gorge, but, the outcrop analysis shows variation in deformation fabric at the scale of 10's of meters. Three fabric categories were observed in the gorge, L>>S, L>S and L-S tectonite as described previously. These categories demonstrated gradational and abrupt contacts between one another, and the shape of some fabric domains in the gorge show similar geometric relationships to the map-scale domains.

Throughout the Ohio gorge there are extensive kinematic indicators consistent with sinistral low-angle shear. The L-S domains contain the best preserved porphyroclasts, with the L>>S containing few. The kinematic indicators include S-C fabrics, shear bands, asymetically broken K-feldspar grains, σ- and δ-porphyroclasts (Lister and Snoke, 1984; Simpson and Schmid, 1983, Passchier and Simpson, 1986).

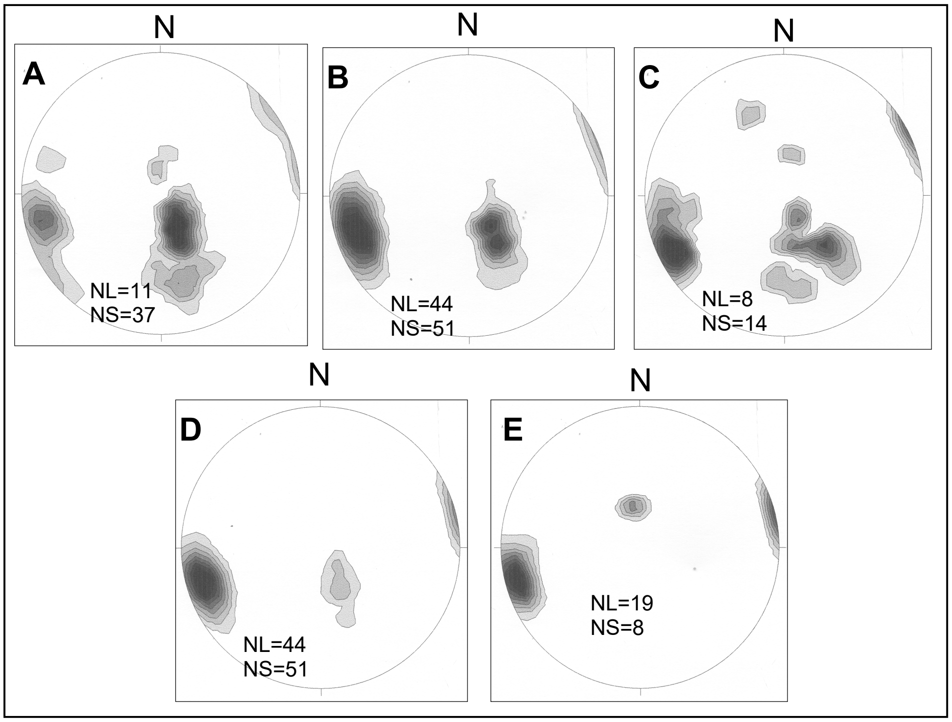


**Figure 16.** Lower hemisphere contour stereograms for the L-S domains represented on the geology map of Figure 2. For each diagram above (A-E), the poles to lineations plot near the perimeter of the diagrams and the poles to foliation form the interior domains. Note the increase in the intensity of the cluster of linear data with the decrease in the occurrence of the foliation data.

## Cross-cutting normal shear zones

There are a number of ductile shear zones with normal shear sense that crosscut the dominant deformation fabrics of the Piseco Lake zone. Most of these shear zones are small (<30 cm thick), contain granitic pegmatite, and some parallel pegmatite dikes that show no deformation. The ductile normal zone located on the east end of the Ohio gorge exhibits oblique sinistral-normal displacement, while the remaining ductile normal faults exhibit dip slip offset. Figure 17 shows a sterographic plot of the orientation of these ductile normal shear zones (Figure 18) and other pegmatite dikes in the Ohio gorge. Both inside the ductile normal zones and within undeformed pegmatite dikes, they are composed of course grained quartz and K-feldspar with minor chlorite. These pegmatites vary in thickness from 0.5 m to 6 cm within one of the normal shear zones.

Geologic mapping in the area of Speculator Mountain (excellent profile view of the mountain from Stop 5C) revealed a cross cutting ductile normal shear zone with west directed displacement (Freyer et al., 2004). The area of Speculator Mountain is underlain by a sequence of granitic-, charnockitic- and gabbroic-gneisses that contain penetrative foliation and ribbon mineral lineations. The foliation texture varies from protomylonite to mylonite in a nearly vertical stack of rocks. Near the base of the mountain, protomylonite occurs in megacrystic granitic-gneiss. Moving structurally upward, the granitic-gneiss contains penetrative mylonitic foliation and lineation. Dynamically recrystallized quartz and K-feldspar, as well as core-mantle structure in K-feldspar are evidence for ductile strain. The mylonitic foliation dips gently to moderately (20-30 degrees) westward, but in some places the foliation is locally folded about a N-S axis. Mineral lineations associated with the mylonitic foliation are defined by ribbon-shaped aggregates of recrystallized quartz, and feldspars. Biotite forms mineral streaks that parallel the ribbon lineations. The lineations trend approximately due west.

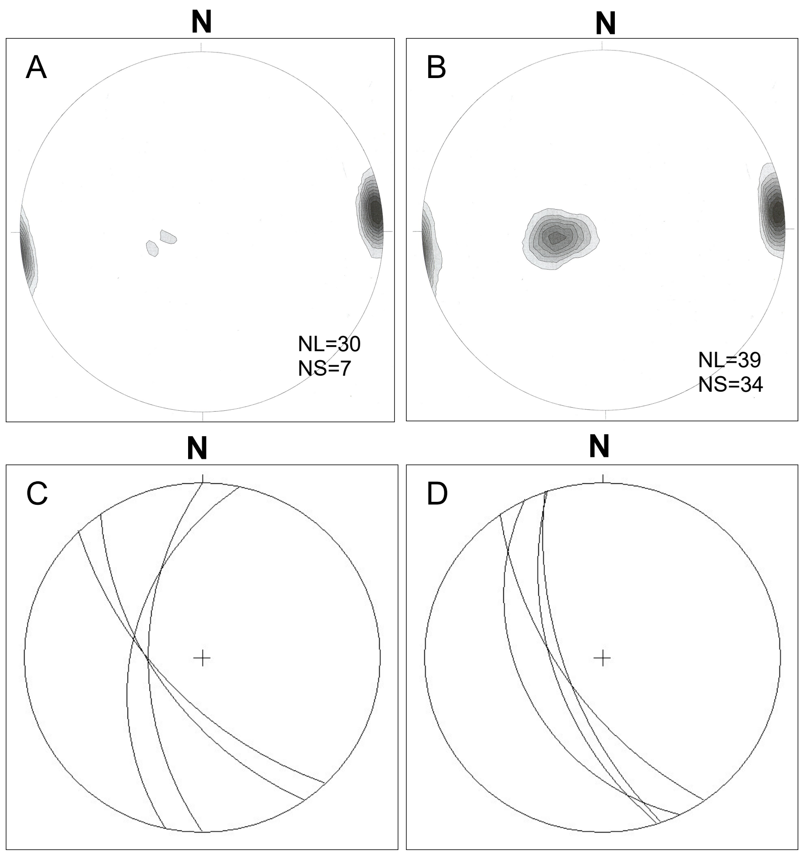


**Figure 17.** Lower hemisphere sterograms for structures observed in the Ohio gorge. Contour diagrams for the poles to lineation and foliation from L>S domain (A) and L-S domain (B) parts of the gorge; Great circle plots for ductile normal shear zones (C) and pegmatite dikes in exposed in the gorge (D) that are not deformed.

Kinematic analysis of granitic mylonite revealed abundant shear sense indicators such as Type I S-C fabrics, δ- and σ-porphyroclasts, asymmetric tails around porphyroclasts, and shear bands. The shear sense indicators show that the direction of displacement was top toward the west, with the charnockitic-gneiss at the top of Speculator Mountain displaced over the megacrystic grantic-gneiss at the base. The presence of a large ductile normal shear zone was not previously documented in this area, but is consistent with displacement and relative timing of the small normal shear zones observed in the West Canada Creek area.

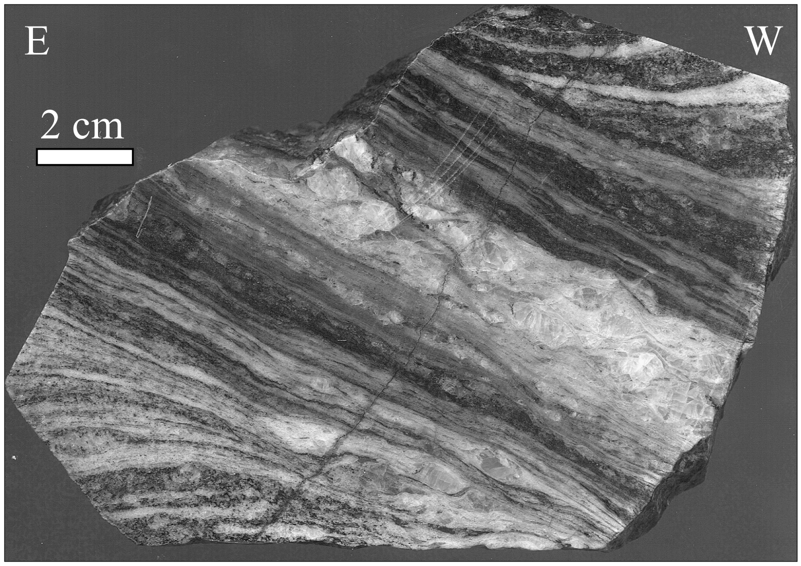


**Figure 18.** Polished rock slab of a small ductile shear zone that cross cuts the PLSZ fabric in the area of West Canada Creek. The view is looking south at a near vertical surface, and the shear sense is top down to the west. These small normal shear zones commonly contain parallel granitic pegmatite that is also plastically deformed.

## The geochemistry and geochronology of Piseco core rocks

The Piseco core rocks, consisting primarily of strongly deformed and lineated granitic (McLelland, 1984) and charnockitic gneisses, previously described, were once thought to be part of a possible basement complex to the Grenville supracrustal sequence in the Adirondacks Highlands. However, zircons separated from a lineated granitic rock at the intersection of Routes 8 and 10 near Piseco Lake (Figure 13) yielded a three-point isochron of 1150+/-5 Ma (McLelland et al. 1988; Chiarenzelli and McLelland 1991) placing the age firmly within that defined by numerous samples for the AMCG suite. In addition, an age of 1157+/-8 Ma was also obtained from a three point isochron from zircons separated from the megacrystic Rooster Hill granitic gneiss (Chiarenzelli and McLelland, 1991). The Rooster Hill gneiss is exposed in an E-W-trending band about 15 km south of Piseco Lake along Route 10, but is considerably less deformed in some locations than other megacrystic rocks further to the north. A plutonic origin can be inferred with some confidence. A recent investigation of the geochemistry of the Piseco suite and revaluation of the zircon data has called these conclusions into question (Chiarenzelli and Valentino, 2008). Here we present some of this new data but caution the reader as to its preliminary nature.

### Geochemical trends

Chiarenzelli and Valentino (2008) undertook a geochemical study of the Piseco core rocks and compared them to other granitic rocks of the Adirondack Lowlands and Highlands including the A-type granitoids of the western Adirondack Highlands (Whitney, 1992) and the megacrystic Hermon granite of the Lowlands (Carl and DeLorraine, 1997). Twelve granitoid samples, along and across strike, from the Piseco Lake shear zone one near Piseco Lake were collected and analyzed for major, trace and Rare Earth elements (Tables 1, 2 and 3). This data was pooled with twelve additional samples collected by Rachel Price (Price, 2004) who studied the Piseco core rocks to the west in the Ohio Gorge area.

Examination of geochemical data from the Piseco core rocks indicates that the rocks from both areas are very similar in composition. The dominant rock type, despite obvious textural differences, has a granitic composition (~70% $SiO_2$; Figure 20). In addition, the rocks are per- to metaluminous and range from subalkaline to calc-alkaline (Figure 21). Among the suite, rare earth element patterns normalized to chondritic values are similar and show enrichment in the LREE a small negative europium anomaly, and relatively flat HREE concentrations (Figure 22). A single sample shows a positive europium anomaly and appears to have a distinct geochemical signature. It also has the least amount of SiO2 (55.76%) and may well represent a xenolithic layer within the Piseco core rocks.

On the Nb vs. Y tectonic discrimination diagram the Piseco core rocks appear to form a linear trend which extends from within volcanic arc/syn-collisional granite field to the center of the diagram (Figure 23A). Similarly, on Rb vs. Y+Nb diagram most of the rocks plot in the volcanic arc granite field; with a few samples plotting in the within plate granite and syn-collisional fields. On the AFM diagram the rock define a calc-alkaline trend (Figure 23B).

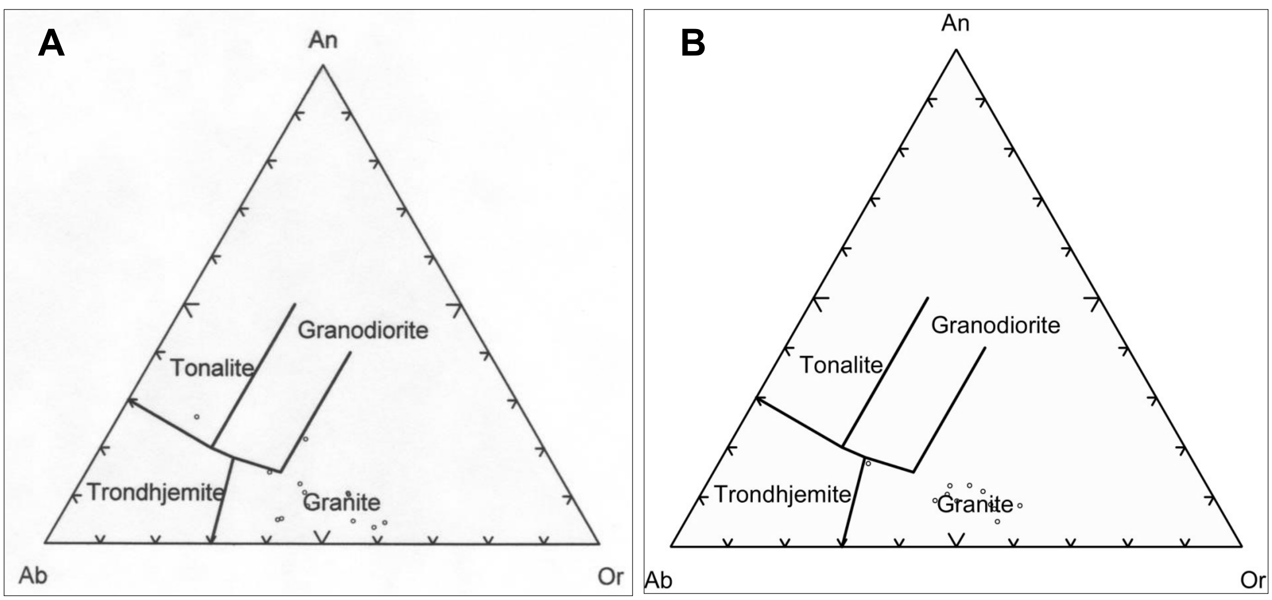


**Figure 19.** Ab-An-Or diagram used to classify plutonic rocks from the Piseco Lake Shear Zone near Piseco Lake (A) and Ab-An-Or diagram used to classify plutonic rocks from the Ohio Gorge, West Canada Creek (B).

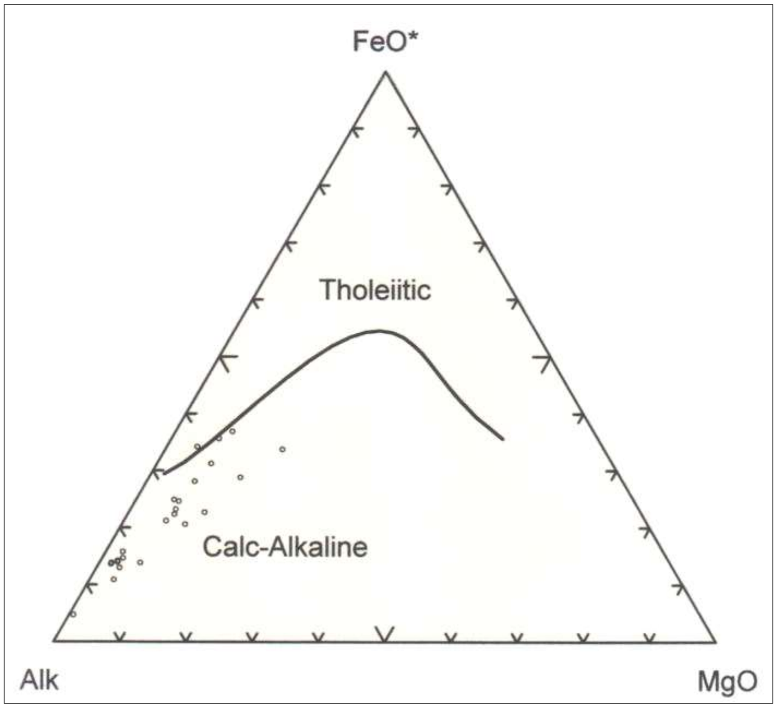


**Figure 20.** AFM diagram for rocks of the Piseco Lake Shear Zone.

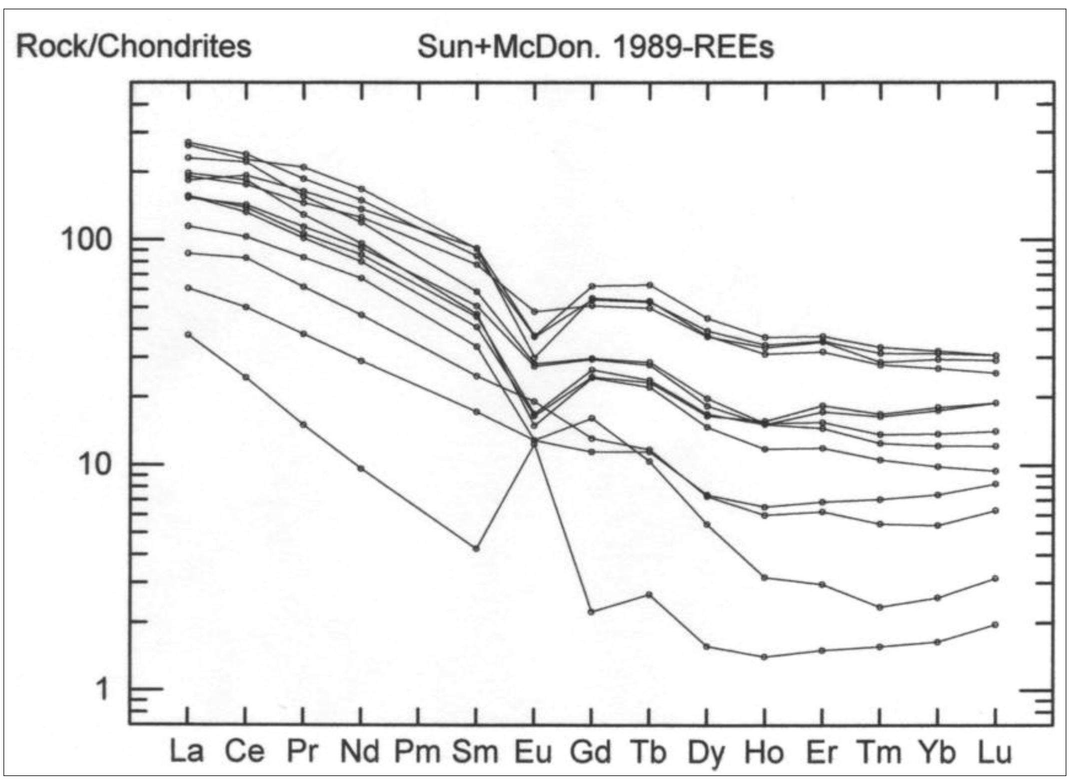


**Figure 21.** Rare earth element diagram for rocks of the Piseco Lake shear zone.

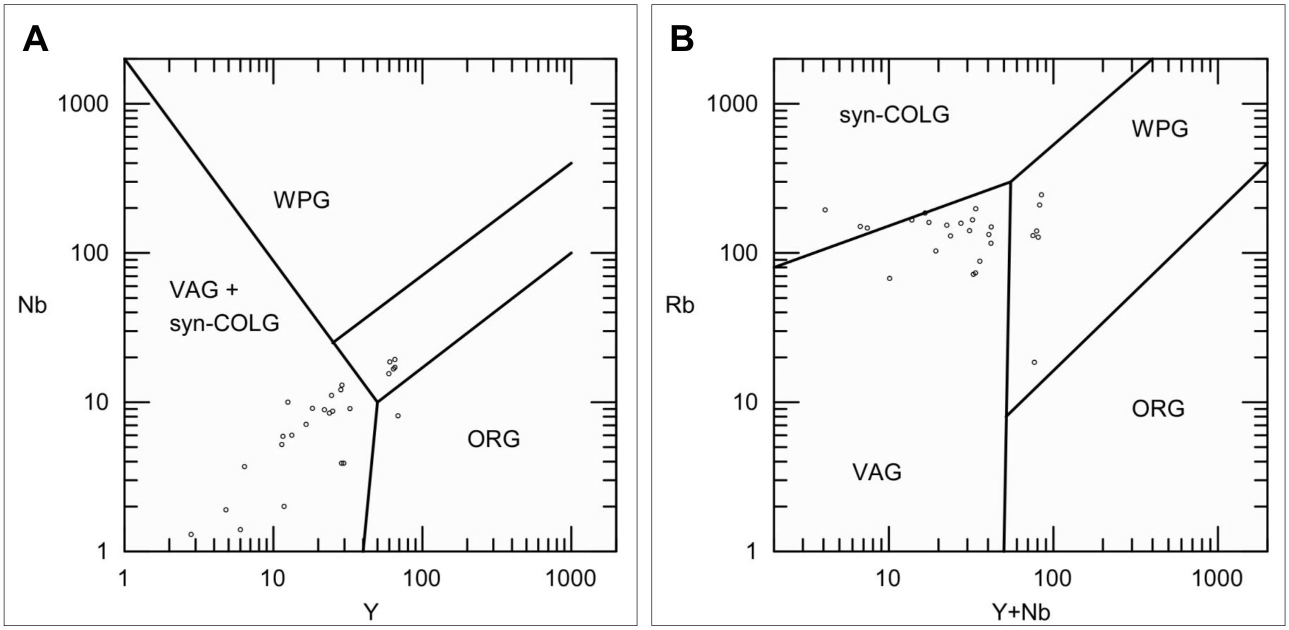


**Figure 22.** Nb vs. Y tectonic discrimination diagram (A) and Rb vs. Y+Nb tectonic discrimination diagram (B) for rocks of the Piseco Lake shear zone.

Plutonic rocks of the western Adirondack Highlands AMCG suite and those of the Hermon granite were utilized for comparison purposes. Whitney (1992) undertook a detailed (115 samples) geochemical study of rocks in the Western Adirondack Highlands. His work indicated that the rocks are metaluminous to mildly peraluminous and display an A-type geochemical signature. Compared I- and S-type granites he noted an enrichment in Fe, K, Ce, Y, Nb, Zr, and Ga, and a depletion in Ca, Mg, and Sr. Rare earth element patterns displayed moderate LREE enrichment and a negative Eu anomaly throughout the suite. Carl and deLorraine (1997) provided major and trace element analyses for the Hermon granite in the Lowlands. They concluded that the Hermon granite is calc-alkali to alkali and enriched in alkalis but strongly depleted in Cr and Ni. Where present, they note that the large (several centimeters) k-spar megacrysts are a distinctive. Compared to Piseco core rocks, the Hermon granite shows many geochemical similarities, whereas the western Adirondack Highland AMCG rocks are significantly different from both. On the AFM diagram (Figure 24) the Piseco core rocks and Hermon granite show calc-alkaline trends, whereas the AMCG rocks display an iron enrichment trend. In terms of the REE pattern the AMCG plutonic rocks of the western Adirondack Highlands show greater enrichment in all rare earth elements. Rocks of the Hermon granite fall within a narrow band within the field defined by the Piseco core rocks (Figure 25).

On both the Rb vs. Y+Nb and Nb vs. Y tectonic discrimination diagrams AMCG plutonic rocks of the Western Adirondack Highlands fall in small clusters within the within plate granite field or the unlabeled strip between within plate granites and orogenic granites. Conversely the Hermon granite and Piseco core rocks form linear trends that extend from well within the volcanic arc granite and syn-collisonal granite field with a few samples extending into the within-plate field (Figures 26 and 27).

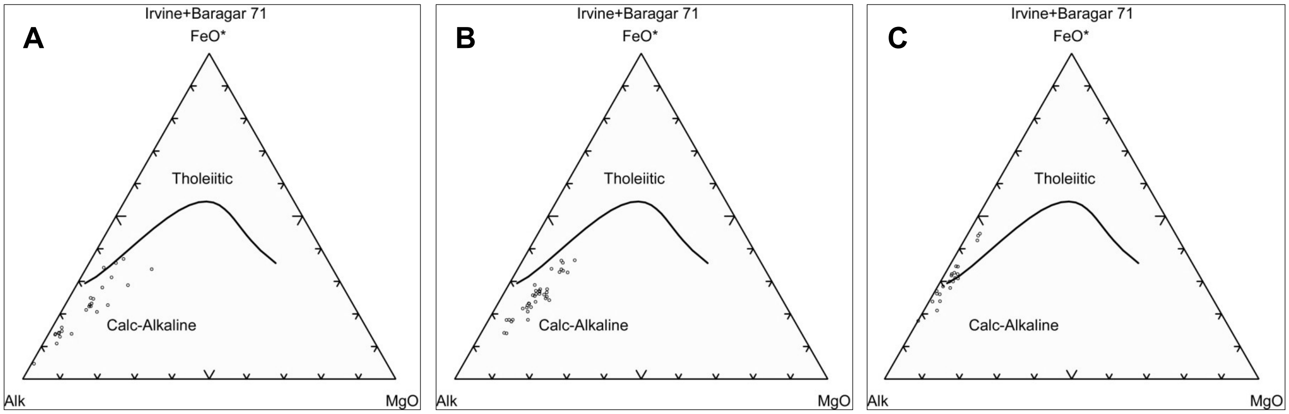


**Figure 23.** AFM diagram for the Hermon granite (A), Piseco core rocks (B), and AMCG granitoids of the western Adirondack Highlands (C).

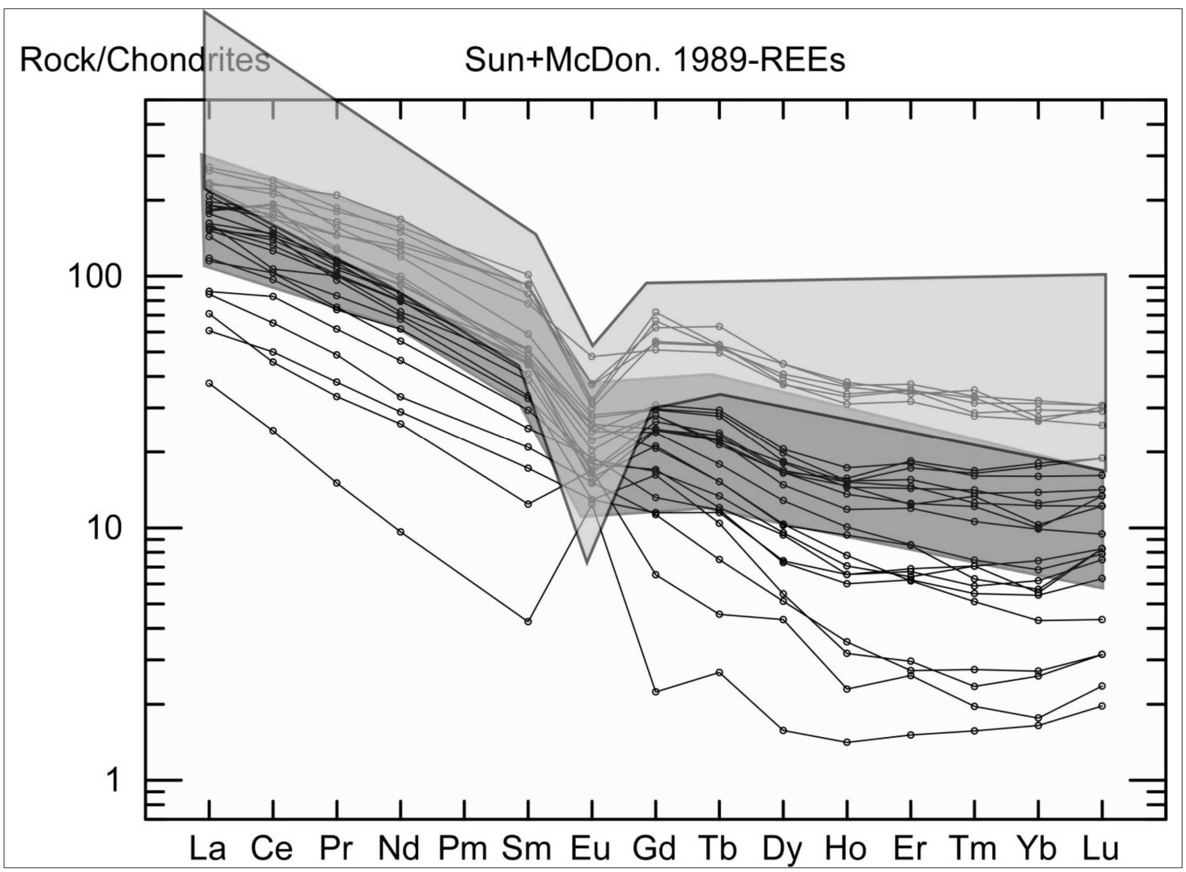


**Figure 24.** Rare earth element patterns for the AMCG plutonic rocks of the Western Adirondack Highlands (light gray field), Hermon granite (dark gray field), and the Piseco core rocks (individual lines).

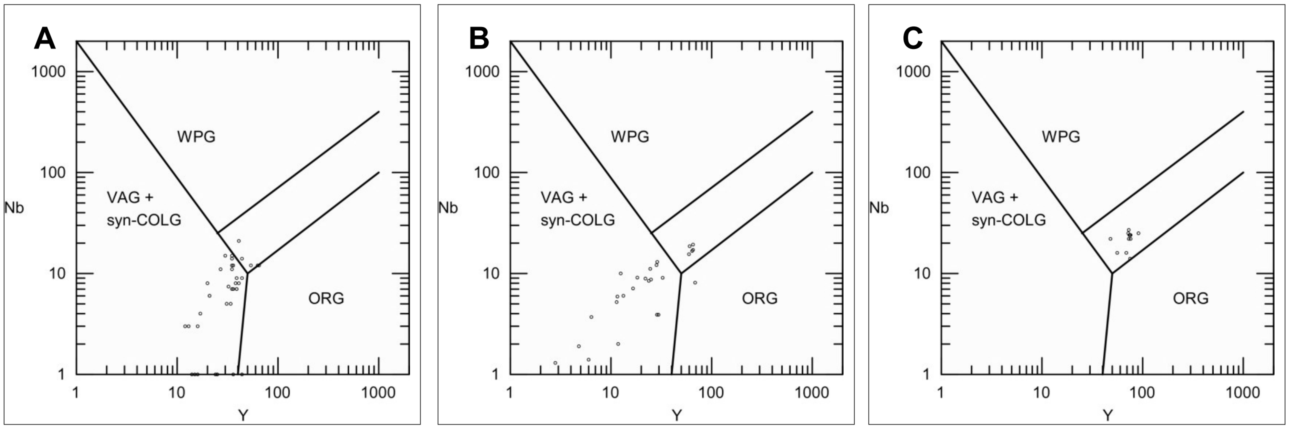


**Figure 25.** Nb vs. Y trace element discrimination diagram (Pearce et al., 1984) for the Hermon Granite (A), Piseco core rocks (B), and AMCG granitoids of the Adirondack Highlands (C).

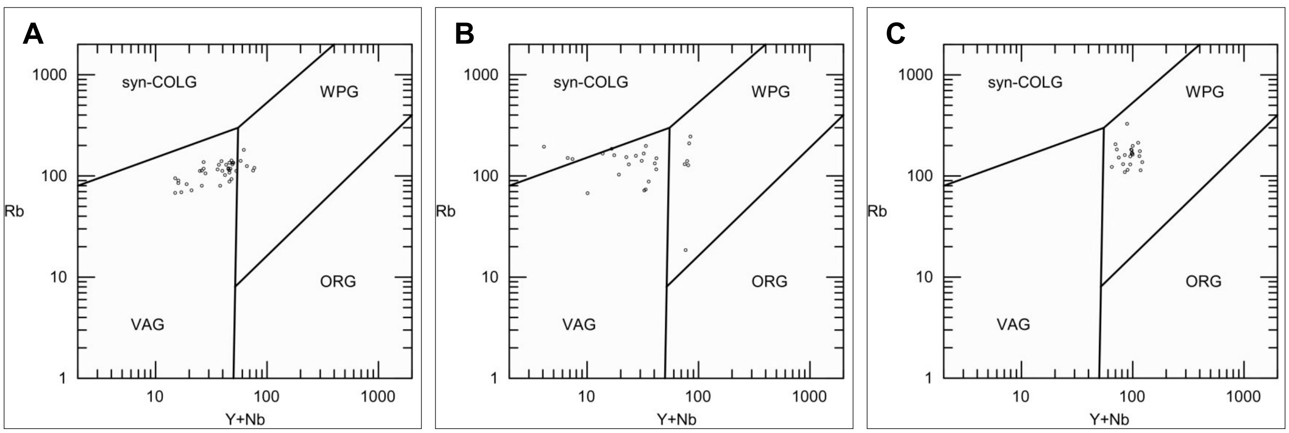


**Figure 26.** Rb vs. Y+Nb trace element discrimination diagram (Pearce et al., 1984) for the Hermon Granite (A), Piseco core rocks (B), and AMCG granitoids of the Adirondack Highlands (C).

**Table 1.** Major (ICP-OES) element concentrations for granitic rocks of the Piseco Lake shear zone.

| | Units | PL-07-1 | PL-07-2 | PL-07-3 | PL-07-4 | PL-07-5 | PL-07-6 | PL-07-7 | PL-07-8 | PL-07-9 | PL-07-10* | PL-07-10* | PL-07-11 | PL-07-12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SiO2 | % | 67.9 | 72.88 | 74.08 | 68.34 | 66.57 | 72.63 | 66.62 | 65.59 | 55.76 | 76.12 | 76.59 | 73.63 | 74.18 |
| Al2O3 | % | 13.5 | 14.25 | 13.63 | 15.75 | 15.99 | 14.71 | 14.78 | 13.49 | 19.42 | 12.97 | 12.88 | 12.24 | 12.33 |
| Fe2O3 | % | 5.33 | 1.32 | 0.53 | 2.9 | 3.34 | 1.6 | 5.34 | 3.68 | 5.92 | 1.49 | 1.46 | 1.71 | 2.47 |
| MgO | % | 0.65 | 0.4 | 0.07 | 0.79 | 1.52 | 0.64 | 1.12 | 0.86 | 2.8 | 0.18 | 0.18 | 0.25 | 0.6 |
| CaO | % | 1.84 | 0.56 | 0.62 | 1.75 | 1.72 | 1.12 | 3.32 | 1.85 | 5.57 | 0.68 | 0.68 | 0.6 | 1.73 |
| Na2O | % | 3.09 | 2.98 | 2.89 | 3.97 | 3.15 | 3.64 | 3.19 | 3.47 | 5.72 | 3.97 | 4.03 | 2.82 | 3.25 |
| K2O | % | 5.49 | 6.33 | 6.72 | 4.94 | 5.57 | 4.66 | 3.92 | 4.14 | 1.95 | 4.17 | 4.11 | 5.12 | 2.96 |
| TiO2 | % | 0.95 | 0.26 | 0.04 | 0.52 | 0.61 | 0.21 | 0.78 | 0.73 | 0.59 | 0.11 | 0.11 | 0.23 | 0.35 |
| P2O5 | % | 0.28 | 0.08 | 0.01 | 0.17 | 0.22 | 0.08 | 0.37 | 0.22 | 0.39 | 0.02 | 0.04 | 0.04 | 0.1 |
| MnO | % | 0.09 | 0.02 | 0.01 | 0.04 | 0.03 | 0.02 | 0.08 | 0.06 | 0.06 | 0.01 | 0.01 | 0.02 | 0.01 |
| Cr2O3 | % | 0.002 | 0.003 | 0.003 | 0.005 | 0.005 | <.001 | 0.003 | 0.008 | 0.014 | 0.009 | 0.005 | 0.006 | 0.003 |
| Ni | ppm | 10 | 47 | 11 | 44 | <5 | <5 | 7 | 20 | 21 | 33 | 9 | 14 | 7 |
| Sc | ppm | 9 | 3 | <1 | 5 | 11 | 4 | 10 | 5 | 24 | 5 | 5 | 2 | 5 |
| LOI | % | 0.7 | 0.8 | 1.4 | 0.7 | 1 | 0.7 | 0.2 | 5.8 | 1.7 | 0.2 | 0.3 | 3.3 | 2 |
| TOT/C | % | 0.04 | 0.01 | 0.01 | 0.02 | 0.01 | 0.03 | 0.04 | 0.02 | 0.15 | 0.01 | 0.02 | 0.02 | 0.03 |
| TOT/S | % | 0.03 | <.01 | <.01 | 0.01 | 0.01 | 0.01 | 0.04 | 0.01 | 0.03 | 0.01 | 0.01 | 0.02 | 0.01 |
| SUM | % | 99.82 | 99.9 | 100 | 99.88 | 99.73 | 100 | 99.73 | 99.9 | 99.9 | 99.94 | 99.8 | 99.96 | 99.98 |

**Table 2.** Trace element (ICP-MS) concentrations for granitic rocks of the Piseco Lake shear zone.

| | Units | PL-07-1 | PL-07-2 | PL-07-3 | PL-07-4 | PL-07-5 | PL-07-6 | PL-07-7 | PL-07-8 | PL-07-9 | PL-07-10* | PL-07-10* | PL-07-11 | PL-07-12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ag | ppm | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 |
| As | ppm | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| Au | ppb | 0.8 | 0.9 | 0.7 | <.5 | 0.9 | 0.6 | 0.5 | 0.7 | <.5 | <.5 | 0.6 | <.5 | <.5 |
| Ba | ppm | 933.2 | 937.3 | 312.7 | 718.8 | 970.3 | 393.4 | 639.5 | 569.7 | 355 | 698.2 | 674.9 | 285 | 244.2 |
| Be | ppm | 2 | 1 | 1 | 3 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 2 | 1 |
| Bi | ppm | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 |
| Cd | ppm | 0.1 | <.1 | <.1 | 0.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 |
| Co | ppm | 5.1 | 1.6 | <.5 | 4.1 | 7 | 2.1 | 9.8 | 4.6 | 13.8 | 0.9 | 0.7 | 1.3 | 3.2 |
| Cs | ppm | 0.4 | 0.9 | 0.9 | 0.7 | 2.3 | 0.8 | 0.4 | 1.2 | 0.2 | 0.1 | 0.1 | 1.1 | 0.1 |
| Cu | ppm | 7.5 | 8.7 | 1.7 | 2.3 | 3 | 0.6 | 24.4 | 14 | 4 | 1.5 | 1.5 | 19.2 | 1 |
| Ga | ppm | 21.3 | 16.2 | 17.9 | 21.2 | 20.9 | 21.2 | 19.6 | 20 | 27.1 | 15.3 | 16 | 15.9 | 18.4 |
| Hf | ppm | 17.5 | 5.2 | 1 | 7.5 | 6.9 | 2.4 | 11.1 | 9.5 | 3.4 | 6.1 | 6.5 | 6.8 | 4.2 |
| Hg | ppm | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 | <.01 |
| Mo | ppm | 1.8 | 0.4 | 0.3 | 0.8 | 0.6 | 0.3 | 0.7 | 0.8 | 0.4 | 0.8 | 0.8 | 0.7 | 0.4 |
| Nb | ppm | 15.5 | 5.9 | 1.3 | 13 | 12.1 | 6 | 16.7 | 18.6 | 8.1 | 3.9 | 3.9 | 8.9 | 3.7 |
| Ni | ppm | 1.5 | 2.5 | 1.7 | 4.6 | 8 | 2.3 | 4.9 | 3 | 16.8 | 3.5 | 3.2 | 2 | 3.8 |
| Pb | ppm | 4.7 | 1.5 | 2.6 | 2.1 | 1.7 | 1 | 1.6 | 1.5 | 0.8 | 1.7 | 1.7 | 2.4 | 1 |
| Rb | ppm | 130.6 | 160.3 | 194.3 | 149.4 | 132.9 | 103 | 127.6 | 140.3 | 18.5 | 73.4 | 71.9 | 140.8 | 67.5 |
| Sb | ppm | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 |
| Se | ppm | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 | <.5 |
| Sn | ppm | 2 | 2 | 1 | 3 | 4 | 2 | 3 | 3 | 2 | 1 | 1 | 2 | 1 |
| Sr | ppm | 212.8 | 369.4 | 176.2 | 383.9 | 418.6 | 183.9 | 266.8 | 254.6 | 729.1 | 65.7 | 63.5 | 110.9 | 186.3 |
| Ta | ppm | 0.7 | 0.7 | 0.1 | 0.7 | 0.9 | 0.3 | 1.1 | 1.3 | 0.4 | 0.1 | 0.1 | 0.5 | <.1 |
| Th | ppm | 1.6 | 12 | 2.4 | 12.1 | 8.1 | 4.1 | 11.1 | 8.2 | 1 | 11.2 | 11.7 | 13 | 11 |
| Tl | ppm | <.1 | <.1 | <.1 | 0.2 | 0.3 | 0.1 | 0.2 | 0.2 | <.1 | <.1 | <.1 | <.1 | 0.1 |
| U | ppm | 0.7 | 1.9 | 1.7 | 1.8 | 1.6 | 2.1 | 0.9 | 1.9 | 0.3 | 1.1 | 1.2 | 1.8 | 0.9 |
| V | ppm | 28 | 19 | 7 | 41 | 62 | 18 | 65 | 39 | 137 | <5 | <5 | 7 | 27 |
| W | ppm | 0.3 | 0.1 | <.1 | <.1 | 0.7 | 0.1 | <.1 | 0.1 | <.1 | <.1 | <.1 | <.1 | <.1 |
| Zn | ppm | 107 | 19 | 4 | 50 | 47 | 14 | 68 | 46 | 57 | 11 | 12 | 19 | 16 |
| Zr | ppm | 757.6 | 177.8 | 23.9 | 286 | 283.7 | 80.1 | 426.8 | 357 | 122.1 | 176.5 | 184.3 | 242.4 | 135.7 |

**Table 3.** Rare Earth element concentrations for granitic rocks of the Piseco Lake shear zone.

| | Units | PL-07-1 | PL-07-2 | PL-07-3 | PL-07-4 | PL-07-5 | PL-07-6 | PL-07-7 | PL-07-8 | PL-07-9 | PL-07-10* | PL-07-10* | PL-07-11 | PL-07-12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Y | ppm | 59.6 | 11.6 | 2.8 | 28.9 | 28.4 | 13.3 | 64.1 | 60.6 | 68.6 | 29.7 | 28.7 | 22 | 6.4 |
| La | ppm | 45.4 | 20.6 | 8.9 | 54.6 | 36.4 | 14.4 | 63.9 | 62.1 | 43.6 | 37.1 | 37.1 | 46.8 | 27.2 |
| Ce | ppm | 107.6 | 50.8 | 14.9 | 135.5 | 87.4 | 30.6 | 146.8 | 139 | 118.2 | 81 | 85 | 112.6 | 63.1 |
| Pr | ppm | 13.86 | 5.86 | 1.43 | 14.82 | 10.85 | 3.61 | 17.71 | 19.9 | 15.6 | 9.67 | 10.1 | 12.27 | 7.94 |
| Nd | ppm | 58.8 | 21.6 | 4.5 | 55.8 | 43 | 13.5 | 69.9 | 78.4 | 63.9 | 37.4 | 40.1 | 45 | 31.5 |
| Sm | ppm | 11.9 | 3.8 | 0.65 | 9 | 7.78 | 2.64 | 12.98 | 13.99 | 14.08 | 6.26 | 6.96 | 7.15 | 5.13 |
| Eu | ppm | 2.78 | 1.11 | 0.72 | 1.63 | 1.59 | 0.75 | 2.15 | 1.74 | 2.17 | 0.96 | 0.98 | 0.87 | 0.75 |
| Gd | ppm | 10.48 | 2.71 | 0.46 | 6.11 | 6.06 | 2.36 | 11.14 | 11.32 | 12.83 | 5.06 | 5.44 | 5.01 | 3.33 |
| Tb | ppm | 1.86 | 0.44 | 0.1 | 1.07 | 1.04 | 0.43 | 1.98 | 2 | 2.36 | 0.87 | 0.89 | 0.83 | 0.39 |
| Dy | ppm | 9.43 | 1.85 | 0.4 | 5.03 | 4.66 | 1.88 | 10.01 | 9.51 | 11.38 | 4.21 | 4.29 | 3.76 | 1.39 |
| Ho | ppm | 1.88 | 0.34 | 0.08 | 0.87 | 0.86 | 0.37 | 1.93 | 1.76 | 2.09 | 0.89 | 0.86 | 0.67 | 0.18 |
| Er | ppm | 5.82 | 1.03 | 0.25 | 2.57 | 2.42 | 1.14 | 5.87 | 5.27 | 6.17 | 3.05 | 2.86 | 1.98 | 0.49 |
| Tm | ppm | 0.73 | 0.14 | 0.04 | 0.35 | 0.32 | 0.18 | 0.8 | 0.71 | 0.85 | 0.43 | 0.42 | 0.27 | 0.06 |
| Yb | ppm | 5.01 | 0.92 | 0.28 | 2.35 | 2.08 | 1.26 | 5.32 | 4.56 | 5.45 | 3.07 | 2.98 | 1.68 | 0.44 |
| Lu | ppm | 0.74 | 0.16 | 0.05 | 0.36 | 0.31 | 0.21 | 0.78 | 0.65 | 0.78 | 0.48 | 0.48 | 0.24 | 0.08 |

## Geochronology

As mentioned above the age, and correlation with AMCG rocks elsewhere in the Adirondack Highlands, of the Piseco Lake core rocks has been inferred from a three-point U-Pb zircon isochron as 1150+/-5 Ma. This has been tentatively verified by an age (1157+/-8 Ma) on the Rooster Hill gneiss that may represent a less deformed megacrystic variant of the Piseco core rocks (Chiarenzelli and McLelland, 1991). Both samples where completed at a time (mid-1980s) when relatively large amounts of zircon were required to provide sufficient amounts of lead for analysis and to overcome the ubiquitous lead blank from the large-scale combustion of leaded gasoline. As a consequence zircon fractions where often subdivided on the basis of magnetic susceptibility and/or size. Air abrasion was routinely used to improve the concordancy of zircon fractions. SEM investigation of zircon populations was carried out, and often displayed core-rim relations, but dating of small volumes of zircon and combining visual observations and analyses was not routinely possible.

Given the constraints of the time, it is entirely possible, and in fact likely, that the zircon ages obtained from high-grade Adirondack rocks represent mixed ages influenced by zircon grown both during igneous crystallization and metamorphism events. Currently techniques such as Sensitive High-Resolution Ion Microprobe (SHRIMP) analsyis is capable of focusing on individual spots as small as a few microns for analysis. Reinvestigation of Adirondack zircon suites has refined the ages determined by the original analyses by several tens of millions of years (McLelland et al., 2001). Given the state of deformation of the Piseco core rocks we began to wonder what a modern geochronological study of the original zircon suite would tell us. For this reason we obtained the original zircon fractions reported in McLelland et al. (1988) and Chiarenzelli and McLelland (1991) for the sample of the Piseco core rocks from the outcrops at the intersection of Routes 8 and 10, just south of Piseco Lake. The actual rock sampled is a strongly lineated (L-tectonite), granitic mylonite with prominent quartz ribbons formed by intense deformation (AM-86-9).

An abundant population of lavender zircons were originally separated from the Piseco core rock sample. They are several hundred microns in length and consisted of rounded to subhedral prisms with rounded terminations. They average about 500 ppm Uranium but varied from 101-1109 ppm. Uranium to Thorium ratios varied from 1.6 to 36.7 and fell into two distinct groups; >10 and <5. Zircons ranged from 2:1 to 3:1 in aspect ratio (length to width). The zircons, from the least magnetic fraction (NM 0°) were mounted in epoxy, observed under cathodoluminscence via the scanning electron microscope, and analyzed by laser ablation multi-collector inductively coupled mass spectrometry (LA-MC-ICP-MS). This work was completed at the Laserchron Laboratory at the University of Arizona. Both 25 micron and 35 micron spot-size data was collected. Scanning electron microscope observation revealed cores and rims in most grains, suggesting, at least, a two-stage growth history. Consequently ablation pits were located in an attempt to analyze either cores or rims. Figure 27 shows some of the ablation pits on the sectioned zircon grains.

Unfortunately the results are somewhat equivocal and difficult to interpret because of the large spot size used and relatively large two-sigma errors (Table 4, Figure 28). Based on core-rim relations it appears that there may be two or, possibly, three distinct populations of zircons as some older cores are mantled by both ~1150 Ma and ~1080 Ma rims (Figure 27). In addition the bimodal distribution of the U/Th ratios shows that the older zircon core material was consistently low (<5 and generally less <3), whereas younger rims had considerable higher ratios.

### Summary of geochemical and geochronological results

The preliminary nature of this work limits the interpretations that can be drawn from the available data. However, it appears that the chemistry of the Piseco core rocks is not typical of other A-type granitoids in the Adirondacks, particularly those of the western Adirondacks just north of the Piseco Lake shear zone. The visual similarity of the Piseco core rocks to the Hermon granite of the Lowlands, including the abundant population of coarse, potassium feldspar megacrysts, is also generally reflected in their major and trace element chemistry. The chemistry of the Piseco core rocks, like the Hermon granite, is also suggestive of an arc origin, likely a continental arc because of the predominance of granites.

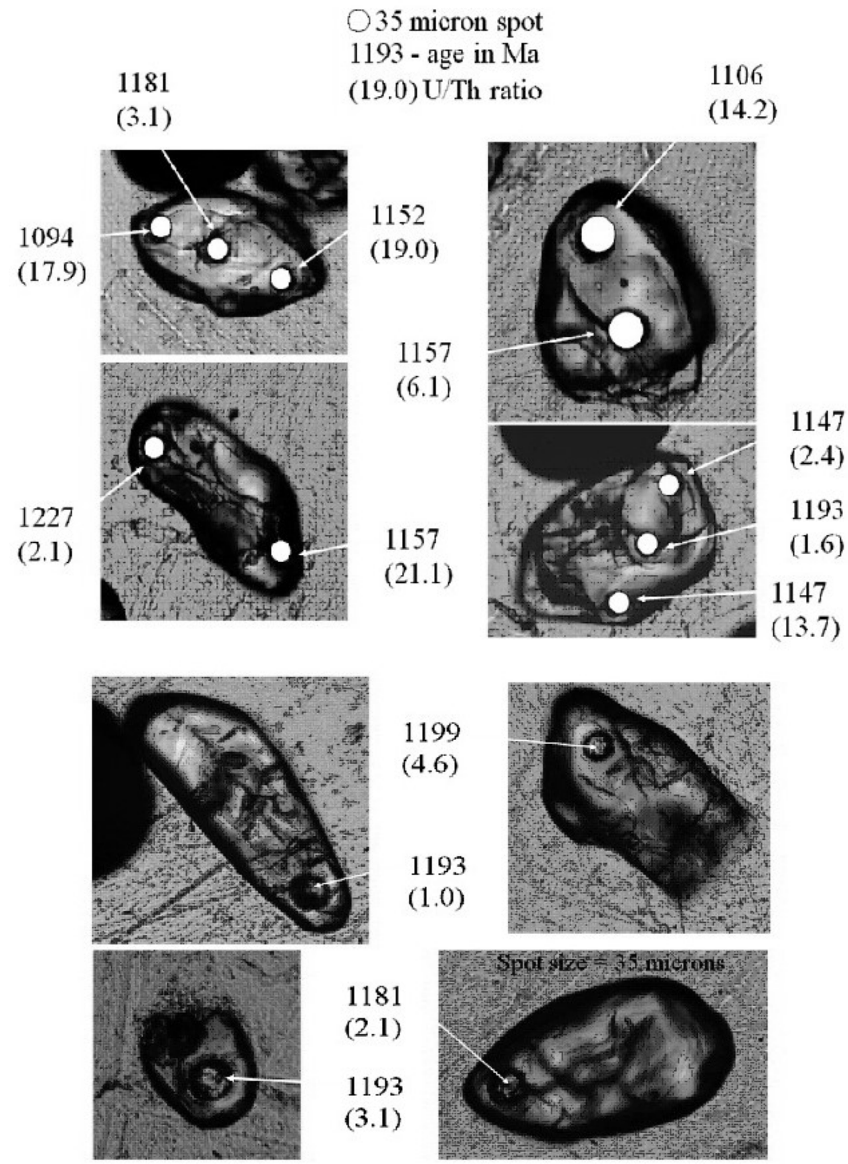


**Figure 27.** Photomicrographs of zircons analyzed by LA-MC-ICP-MS frm the Piseco core rocks.

At this time, it is unfortunate that the geochronological results are equivocal. However, they serve to demonstrate the complexity of the zircon suite and the possibility of multiple populations. Distinct core rim relations are intriguing because the rimming material corresponds to recognized events in the Adirondack Highlands, both late Shawinigan and Ottawan metamorphism. In addition, the large difference in U/Th ratios warrants future investigation and may prove useful in distinguishing metamorphic from igneous or xenocrystic zircons. The data suggests that the oldest zircons in the Piseco core rock have typical igneous signatures (low U/Th ratios), while those of rimming material, both ~1080 and 1150 Ma, are much higher. At this point in time we believe 1169+/-7 Ma is a minimum age for the Piseco core rock that appears to have experienced metamorphic zircon overgrown at ca. 1150 and 1080 Ma.

Future work will involve extending geochemical and geochronological studies along the length of the Piseco antiform and the intriguing possibility that they are related to the Hermon granite of the Lowlands. As a working model, Valentino et al. (2008) have proposed that the Piseco core rocks represent a continental arc developed during subduction preceding the Shawinigan Orogen. Such an origin may explain their chemistry, spatial relationship to highly migmatized pelitic gneisses (a characteristic also shown by the Hermon Granite), and the intensity of later deformation in an orogen parallel kinematic regime (Gates et al., 2004).

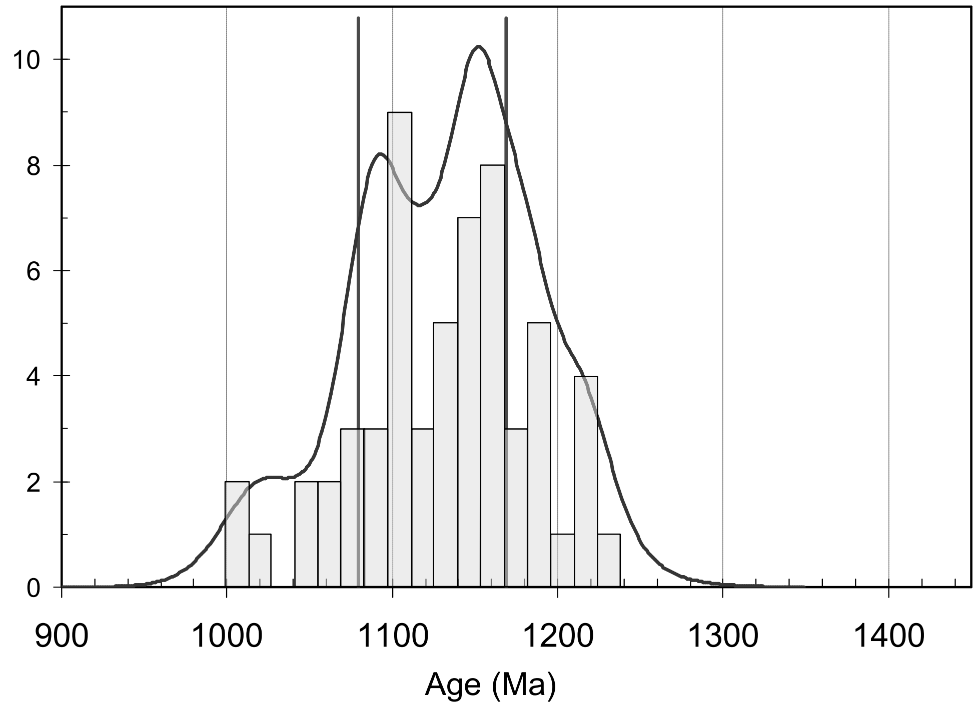


**Figure 28.** Histogram showing all data (56 points) from the Piseco core rock zircons. Vertical dark lines represent ages of 1079+/-8.1 and 1169+/-7 Ma.

## Tectonic Model

Gates et al. (2004) proposed that dextral shearing in the Hudson Highlands of southern New York, and sinistral shearing in the southern Adirondacks occurred during the development of a conjugate Himalayan-type syntaxis associated with the Ottawan orogeny (Figure 29). One potential problem with this tectonic model is the distance between the southern Adirondacks and the Hudson Highlands (located in southern New York and northern New Jersey). The Proterozoic basement is covered by various Paleozoic rocks that were impacted by Appalachian deformation events, and the current geometry of the apparent Proterozoic conjugate system may have been modified. The projected intersection between the conjugate sinistral and dextral zones would occur under the area of the Taconic Highlands of eastern New York and southern Vermont. The trace of the Piseco antiform, including the highly deformed granitic rocks, varies from generally east-west to nearly north-south in the eastern Adirondacks (McLelland-personal communication 2008). The pronounced lineation that trends between 090 and 110 across most of the southern Adirondacks takes a clock-wise bend in the region of the Great Sacandaga Lake northeastern arm, and then trends generally north-south near the Hudson River. This substantial difference in the trace of the Piseco Lake zone structures may reflect clock-wise (dextral) transposition. It is interesting that this change in trend occurs near the conjugate intersection region that was proposed by Gates et al. (2004). In effect, the Piseco Lake zone may have been deformed by dextral shearing on the north-east striking arm of the conjugate system. So, the similarity in timing and orientation of these

**Table 4.** LA-MC-ICP-MS U-Pb zircon data for the Piseco core rocks.

| Analysis | U | 206Pb | U/Th | 206Pb* | ± | 207Pb* | ± | 206Pb* | ± | error | 206Pb* | ± | 207Pb* | ± | 206Pb* | ± | Best age | ± |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (ppm) | 204Pb | | 207Pb* | (%) | 235U* | (%) | 238U | (%) | corr. | 238U* | (Ma) | 235U | (Ma) | 207Pb* | (Ma) | (Ma) | (Ma) |
| 25 microns | | | | | | | | | | | | | | | | | | |
| AM-86-9-5 | 738 | 45172 | 17.9 | 13.1623 | 1.5 | 1.8456 | 3.9 | 0.1762 | 3.6 | 0.92 | 1046.1 | 34.3 | 1061.9 | 25.5 | 1094.4 | 30.6 | 1094.4 | 30.6 |
| AM-86-9-6 | 399 | 26832 | 3.1 | 12.5983 | 1.4 | 2.0714 | 4.6 | 0.1893 | 4.4 | 0.95 | 1117.4 | 45.2 | 1139.4 | 31.7 | 1181.5 | 27.3 | 1181.5 | 27.3 |
| AM-86-9-7 | 601 | 35926 | 19.0 | 12.7875 | 1.4 | 2.0264 | 2.8 | 0.1879 | 2.4 | 0.86 | 1110.2 | 24.2 | 1124.4 | 18.8 | 1152.0 | 28.4 | 1152.0 | 28.4 |
| AM-86-9-8 | 547 | 31880 | 14.0 | 12.9141 | 2.5 | 1.9725 | 2.7 | 0.1847 | 1.0 | 0.37 | 1092.9 | 10.1 | 1106.2 | 18.1 | 1132.4 | 49.6 | 1132.4 | 49.6 |
| AM-86-9-9 | 465 | 29778 | 3.8 | 12.8375 | 2.1 | 1.9507 | 2.9 | 0.1816 | 2.0 | 0.68 | 1075.8 | 19.4 | 1098.7 | 19.4 | 1144.2 | 42.1 | 1144.2 | 42.1 |
| AM-86-9-10 | 480 | 34766 | 12.6 | 12.6631 | 1.3 | 2.1062 | 2.7 | 0.1934 | 2.4 | 0.88 | 1140.0 | 24.8 | 1150.8 | 18.6 | 1171.4 | 25.9 | 1171.4 | 25.9 |
| AM-86-9-11 | 681 | 46940 | 7.0 | 12.6688 | 1.4 | 2.1652 | 2.2 | 0.1989 | 1.7 | 0.78 | 1169.6 | 18.3 | 1169.9 | 15.1 | 1170.5 | 26.7 | 1170.5 | 26.7 |
| AM-86-9-12 | 316 | 19752 | 6.2 | 12.6218 | 1.5 | 2.1401 | 1.9 | 0.1959 | 1.2 | 0.62 | 1153.3 | 12.7 | 1161.9 | 13.4 | 1177.8 | 29.9 | 1177.8 | 29.9 |
| AM-86-9-13 | 846 | 60304 | 33.4 | 13.0400 | 1.7 | 1.9203 | 2.1 | 0.1816 | 1.3 | 0.61 | 1075.8 | 12.7 | 1088.2 | 13.9 | 1113.0 | 33.0 | 1113.0 | 33.0 |
| AM-86-9-14 | 648 | 41186 | 36.7 | 13.0513 | 1.6 | 1.9401 | 2.0 | 0.1836 | 1.1 | 0.58 | 1086.9 | 11.3 | 1095.0 | 13.1 | 1111.3 | 32.0 | 1111.3 | 32.0 |
| AM-86-9-15 | 500 | 31118 | 17.6 | 13.0670 | 2.9 | 1.9746 | 3.9 | 0.1871 | 2.6 | 0.66 | 1105.8 | 26.0 | 1106.9 | 26.0 | 1108.9 | 57.8 | 1108.9 | 57.8 |
| AM-86-9-16 | 408 | 23172 | 3.1 | 12.5231 | 1.9 | 2.1964 | 2.8 | 0.1995 | 2.1 | 0.73 | 1172.6 | 22.0 | 1179.9 | 19.7 | 1193.3 | 38.1 | 1193.3 | 38.1 |
| AM-86-9-17 | 243 | 15498 | 2.9 | 12.7922 | 1.7 | 2.0025 | 2.6 | 0.1858 | 2.0 | 0.76 | 1098.5 | 19.7 | 1116.3 | 17.3 | 1151.2 | 32.8 | 1151.2 | 32.8 |
| AM-86-9-18 | 437 | 25816 | 4.6 | 12.4875 | 1.7 | 2.0988 | 2.9 | 0.1901 | 2.3 | 0.80 | 1121.8 | 23.6 | 1148.4 | 19.7 | 1198.9 | 33.9 | 1198.9 | 33.9 |
| AM-86-9-19 | 483 | 34544 | 6.9 | 12.7869 | 2.1 | 2.0187 | 2.8 | 0.1872 | 1.9 | 0.67 | 1106.2 | 19.3 | 1121.8 | 19.2 | 1152.1 | 41.7 | 1152.1 | 41.7 |
| AM-86-9-20 | 724 | 48670 | 2.4 | 12.7250 | 1.9 | 2.0917 | 3.5 | 0.1930 | 3.0 | 0.85 | 1137.8 | 31.0 | 1146.1 | 24.1 | 1161.7 | 36.9 | 1161.7 | 36.9 |
| AM-86-9-21 | 420 | 24068 | 1.8 | 12.7251 | 3.8 | 2.1053 | 4.1 | 0.1943 | 1.4 | 0.34 | 1144.6 | 14.5 | 1150.5 | 28.0 | 1161.7 | 76.0 | 1161.7 | 76.0 |
| AM-86-9-22 | 318 | 21354 | 2.1 | 12.5992 | 3.1 | 2.1432 | 4.3 | 0.1958 | 3.0 | 0.69 | 1152.9 | 31.2 | 1162.9 | 29.6 | 1181.4 | 61.1 | 1181.4 | 61.1 |
| AM-86-9-23 | 247 | 14528 | 1.4 | 12.3272 | 3.4 | 2.2200 | 3.6 | 0.1985 | 1.2 | 0.34 | 1167.1 | 12.9 | 1187.4 | 25.1 | 1224.4 | 66.5 | 1224.4 | 66.5 |
| AM-86-9-24 | 270 | 22194 | 2.2 | 12.6331 | 3.5 | 2.1175 | 3.9 | 0.1940 | 1.8 | 0.46 | 1143.1 | 18.8 | 1154.5 | 26.9 | 1176.1 | 68.5 | 1176.1 | 68.5 |
| AM-86-9-25 | 501 | 23092 | 7.9 | 12.7299 | 2.2 | 2.1289 | 2.7 | 0.1966 | 1.5 | 0.57 | 1156.8 | 16.1 | 1158.2 | 18.4 | 1160.9 | 43.4 | 1160.9 | 43.4 |
| AM-86-9-26 | 1109 | 48708 | 1.4 | 12.6904 | 5.2 | 2.2120 | 6.6 | 0.2036 | 4.1 | 0.62 | 1194.6 | 44.7 | 1184.9 | 46.5 | 1167.1 | 103.7 | 1167.1 | 103.7 |
| AM-86-9-27 | 632 | 45106 | 14.4 | 12.6038 | 4.6 | 2.2222 | 4.9 | 0.2031 | 1.6 | 0.34 | 1192.1 | 17.7 | 1188.1 | 34.0 | 1180.6 | 90.4 | 1180.6 | 90.4 |
| AM-86-9-28 | 714 | 43448 | 21.1 | 12.7519 | 2.9 | 2.1389 | 4.3 | 0.1978 | 3.1 | 0.73 | 1163.6 | 33.2 | 1161.5 | 29.7 | 1157.5 | 58.3 | 1157.5 | 58.3 |
| AM-86-9-29 | 333 | 23294 | 2.1 | 12.3102 | 1.4 | 2.3248 | 1.9 | 0.2076 | 1.3 | 0.67 | 1215.8 | 14.4 | 1219.9 | 13.7 | 1227.1 | 28.1 | 1227.1 | 28.1 |
| AM-86-9-30 | 322 | 20734 | 1.8 | 12.4839 | 1.5 | 2.2957 | 3.6 | 0.2079 | 3.3 | 0.91 | 1217.4 | 36.3 | 1211.0 | 25.5 | 1199.5 | 30.0 | 1199.5 | 30.0 |
| AM-86-9-31 | 559 | 32420 | 13.1 | 13.2284 | 3.8 | 1.9386 | 4.2 | 0.1860 | 1.9 | 0.44 | 1099.6 | 18.7 | 1094.5 | 28.3 | 1084.3 | 76.2 | 1084.3 | 76.2 |
| AM-86-9-33 | 259 | 17068 | 2.0 | 12.8911 | 3.3 | 2.1109 | 6.3 | 0.1974 | 5.4 | 0.85 | 1161.1 | 57.3 | 1152.4 | 43.6 | 1135.9 | 65.6 | 1135.9 | 65.6 |
| AM-86-9-34 | 543 | 22932 | 1.0 | 12.5275 | 1.8 | 2.3006 | 2.6 | 0.2090 | 1.9 | 0.72 | 1223.6 | 20.8 | 1212.5 | 18.3 | 1192.6 | 35.2 | 1192.6 | 35.2 |
| AM-86-9-35 | 593 | 39630 | 16.5 | 12.6967 | 1.8 | 2.0419 | 3.1 | 0.1880 | 2.5 | 0.82 | 1110.7 | 25.8 | 1129.6 | 21.1 | 1166.1 | 35.5 | 1166.1 | 35.5 |
| AM-86-9-36 | 306 | 21784 | 2.6 | 12.5839 | 2.4 | 2.1591 | 2.8 | 0.1971 | 1.4 | 0.50 | 1159.5 | 15.0 | 1168.0 | 19.4 | 1183.8 | 47.7 | 1183.8 | 47.7 |
| AM-86-9-37 | 767 | 48310 | 19.4 | 13.5254 | 1.1 | 1.7168 | 2.9 | 0.1684 | 2.7 | 0.93 | 1003.3 | 24.9 | 1014.8 | 18.6 | 1039.7 | 22.0 | 1039.7 | 22.0 |
| AM-86-9-38 | 818 | 55020 | 24.8 | 13.3425 | 1.2 | 1.7544 | 2.3 | 0.1698 | 1.9 | 0.85 | 1010.9 | 18.2 | 1028.8 | 14.7 | 1067.1 | 23.9 | 1067.1 | 23.9 |
| AM-86-9-39 | 692 | 44216 | 19.3 | 12.7910 | 1.0 | 2.0064 | 2.1 | 0.1861 | 1.8 | 0.88 | 1100.4 | 18.3 | 1117.7 | 14.0 | 1151.4 | 19.9 | 1151.4 | 19.9 |
| AM-86-9-40 | 635 | 55224 | 23.7 | 13.2333 | 9.1 | 1.9462 | 9.5 | 0.1868 | 2.9 | 0.31 | 1104.0 | 29.5 | 1097.1 | 64.0 | 1083.6 | 182.3 | 1083.6 | 182.3 |
| AM-86-9-41 | 657 | 38796 | 13.0 | 13.2185 | 2.0 | 1.8335 | 2.8 | 0.1758 | 1.9 | 0.68 | 1043.9 | 17.9 | 1057.5 | 18.1 | 1085.8 | 40.7 | 1085.8 | 40.7 |
| AM-86-9-42 | 324 | 28590 | 2.8 | 13.2103 | 1.6 | 1.8991 | 2.0 | 0.1819 | 1.2 | 0.62 | 1077.6 | 12.2 | 1080.8 | 13.2 | 1087.1 | 31.3 | 1087.1 | 31.3 |
| AM-86-9-43 | 251 | 18258 | 3.0 | 12.7315 | 1.7 | 2.1836 | 2.0 | 0.2016 | 1.0 | 0.50 | 1184.1 | 10.8 | 1175.8 | 14.0 | 1160.7 | 34.6 | 1160.7 | 34.6 |
| AM-86-9-44 | 567 | 36520 | 15.9 | 13.2347 | 2.1 | 1.8733 | 4.9 | 0.1798 | 4.4 | 0.90 | 1066.0 | 43.4 | 1071.7 | 32.4 | 1083.4 | 42.3 | 1083.4 | 42.3 |
| AM-86-9-45 | 215 | 13324 | 2.2 | 12.6922 | 2.4 | 2.1791 | 2.7 | 0.2006 | 1.3 | 0.47 | 1178.5 | 13.8 | 1174.4 | 19.0 | 1166.8 | 47.8 | 1166.8 | 47.8 |
| AM-86-9-46 | 524 | 34122 | 10.9 | 12.8953 | 1.9 | 2.0539 | 3.5 | 0.1921 | 3.0 | 0.85 | 1132.7 | 30.6 | 1133.6 | 23.8 | 1135.3 | 37.0 | 1135.3 | 37.0 |
| AM-86-9-47 | 510 | 34730 | 10.1 | 12.7826 | 1.6 | 2.0455 | 3.6 | 0.1896 | 3.2 | 0.90 | 1119.4 | 33.0 | 1130.8 | 24.3 | 1152.7 | 31.0 | 1152.7 | 31.0 |
| AM-86-9-48 | 604 | 35066 | 13.1 | 12.7553 | 2.2 | 2.0723 | 3.3 | 0.1917 | 2.4 | 0.73 | 1130.7 | 25.1 | 1139.7 | 22.6 | 1157.0 | 44.4 | 1157.0 | 44.4 |
| AM-86-9-49 | 545 | 33488 | 14.2 | 13.0840 | 1.4 | 1.9591 | 2.6 | 0.1859 | 2.2 | 0.85 | 1099.2 | 22.6 | 1101.6 | 17.8 | 1106.3 | 28.2 | 1106.3 | 28.2 |
| AM-86-9-50 | 490 | 34910 | 6.1 | 12.7533 | 3.6 | 2.1082 | 3.8 | 0.1950 | 1.0 | 0.27 | 1148.4 | 10.5 | 1151.5 | 25.9 | 1157.3 | 72.0 | 1157.3 | 72.0 |
| AM-86-9-51 | 1065 | 71116 | 14.2 | 12.7059 | 1.5 | 1.9489 | 3.0 | 0.1796 | 2.6 | 0.87 | 1064.7 | 25.8 | 1098.1 | 20.2 | 1164.7 | 28.9 | 1164.7 | 28.9 |
| AM-86-9-52 | 668 | 64200 | 10.8 | 12.6332 | 2.5 | 2.1327 | 3.0 | 0.1954 | 1.7 | 0.56 | 1150.6 | 17.7 | 1159.4 | 20.7 | 1176.0 | 49.1 | 1176.0 | 49.1 |
| AM-86-9-53 | 116 | 8756 | 4.9 | 12.1012 | 4.5 | 2.1994 | 7.4 | 0.1930 | 5.9 | 0.79 | 1137.8 | 61.3 | 1180.8 | 51.8 | 1260.6 | 88.4 | 1260.6 | 88.4 |
| AM-86-9-54 | 101 | 6918 | 2.0 | 12.2708 | 2.0 | 2.2161 | 3.0 | 0.1972 | 2.2 | 0.75 | 1160.4 | 23.8 | 1186.1 | 21.0 | 1233.4 | 39.3 | 1233.4 | 39.3 |
| AM-86-9-55 | 232 | 15482 | 2.6 | 12.8966 | 2.4 | 2.1514 | 3.3 | 0.2012 | 2.2 | 0.67 | 1181.9 | 24.1 | 1165.5 | 23.0 | 1135.1 | 48.7 | 1135.1 | 48.7 |
| AM-86-9-56 | 566 | 38354 | 11.6 | 12.6944 | 1.9 | 2.0922 | 2.8 | 0.1926 | 2.0 | 0.72 | 1135.6 | 21.0 | 1146.3 | 19.1 | 1166.5 | 38.0 | 1166.5 | 38.0 |
| AM-86-9-57 | 340 | 24492 | 2.4 | 12.8152 | 1.7 | 2.0888 | 2.9 | 0.1941 | 2.4 | 0.81 | 1143.8 | 24.7 | 1145.1 | 20.1 | 1147.7 | 34.2 | 1147.7 | 34.2 |
| AM-86-9-58 | 638 | 40950 | 13.7 | 12.8150 | 2.0 | 1.9949 | 3.4 | 0.1854 | 2.7 | 0.80 | 1096.5 | 27.4 | 1113.8 | 22.9 | 1147.7 | 39.9 | 1147.7 | 39.9 |
| AM-86-9-59 | 169 | 12056 | 1.6 | 12.5242 | 3.0 | 2.2217 | 4.7 | 0.2018 | 3.6 | 0.77 | 1185.0 | 39.4 | 1187.9 | 33.1 | 1193.2 | 59.7 | 1193.2 | 59.7 |
| AM-86-9-60 | 824 | 61036 | 14.7 | 12.6719 | 3.3 | 2.1577 | 3.8 | 0.1983 | 1.9 | 0.51 | 1166.2 | 20.6 | 1167.5 | 26.4 | 1170.0 | 64.8 | 1170.0 | 64.8 |
| 35 microns | | | | | | | | | | | | | | | | | | |
| AM-86-9-1 | 585 | 28878 | 10.3 | 13.4922 | 2.8 | 1.7522 | 3.3 | 0.1715 | 1.7 | 0.52 | 1020.2 | 16.0 | 1028.0 | 21.3 | 1044.6 | 56.9 | 1044.6 | 56.9 |
| AM-86-9-2 | 620 | 53724 | 14.4 | 12.5355 | 1.9 | 2.2573 | 2.5 | 0.2052 | 1.6 | 0.64 | 1203.3 | 17.3 | 1199.1 | 17.4 | 1191.4 | 37.5 | 1191.4 | 37.5 |
| AM-86-9-3 | 555 | 51766 | 16.1 | 12.4381 | 1.9 | 2.2988 | 2.6 | 0.2074 | 1.8 | 0.69 | 1214.8 | 20.2 | 1211.9 | 18.7 | 1206.8 | 37.8 | 1206.8 | 37.8 |
| AM-86-9-4 | 647 | 51884 | 12.5 | 12.6230 | 2.7 | 2.2688 | 3.1 | 0.2077 | 1.6 | 0.51 | 1216.6 | 17.4 | 1202.7 | 21.7 | 1177.6 | 52.4 | 1177.6 | 52.4 |

major shear zone systems in the Hudson Highlands and Adirondacks, and possible transposition of the sinistral zone by the dextral zone, strongly supports the Himalayan-type syntaxis model.

Based upon existing age constraints, this conjugate shear system was active in the core of the Ottawan orogen during and subsequent to peak metamorphic conditions. Relative to modern geographic coordinates, this conjugate system yields bulk-extension and bulk-compression directions of west-northwest and east-northeast respectively (Figure 29). These strain axes are consistent with compression directions deduced from en echelon transpressional folds in the Hudson Highlands and the en-echelon domes on the central Adirondacks (Chiarenzelli et al., 2000). This bulk strain analysis assumes that bulk rotation of the Hudson Highlands relative to the Adirondacks during Paleozoic Appalachian tectonic events (Taconic, Acadian, Alleghanian orogenies) and Mesozoic extension was minimal. The assumption is reasonable because there is no post-Precambrian penetrative deformation in the western Hudson Highlands and the major folds and faults in the surrounding Paleozoic strata are essentially parallel to those in the crystalline rocks indicating similar strain axes and minimal rotation. The Grenville Province north of the Adirondack Lowlands contains numerous Proterozoic normal faults and shear zones with an overall northwest-southeast extension direction (Streepey et al., 2000), and published age data suggest that these normal faults were active as much as 100 Ma after peak metamorphic conditions in the Adirondack Highlands. Finally, this late extensional deformation can be explained by applying the bulk-strain directions inferred from the conjugate syntaxis model (Figure 29).

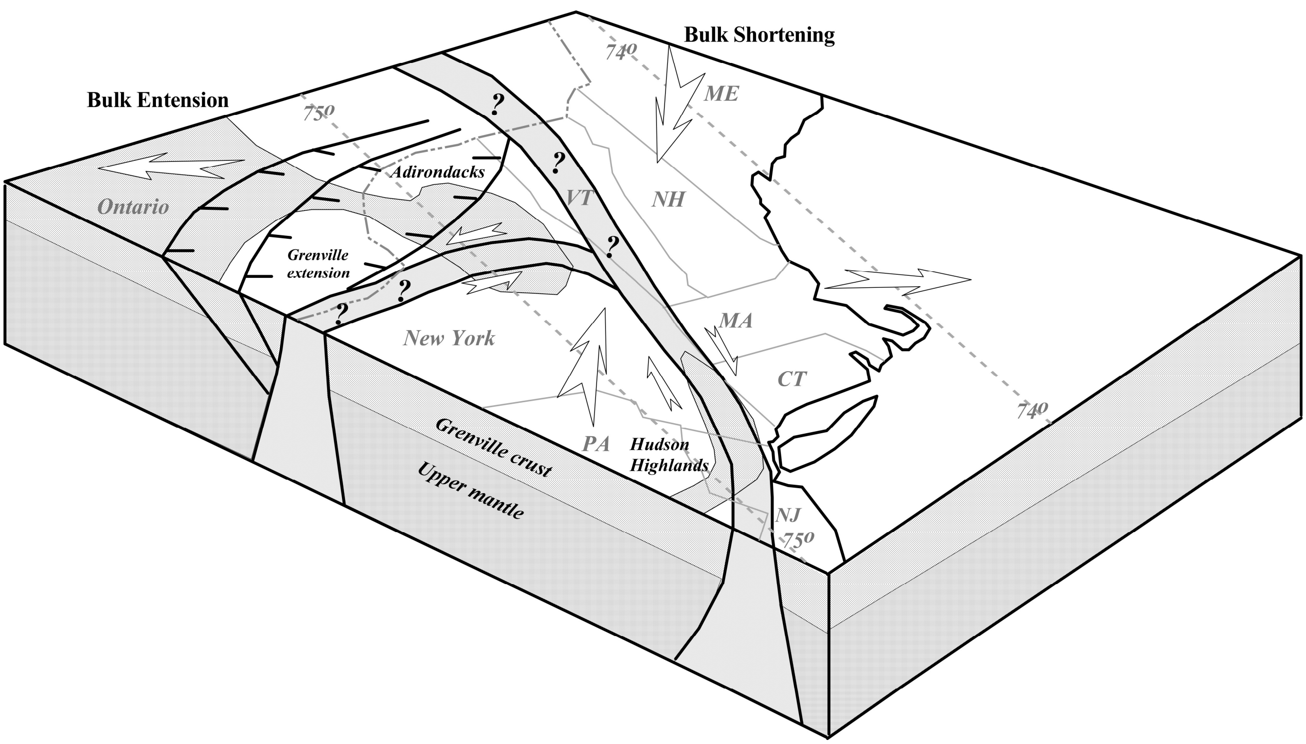


**Figure 29.** Block diagram depicting the crust-scale conjugate ductile shear zones forming a syntaxis. The inset shows the location of the syntaxis in a reconstruction of Rodinia (modified from Gates et al., 2004).

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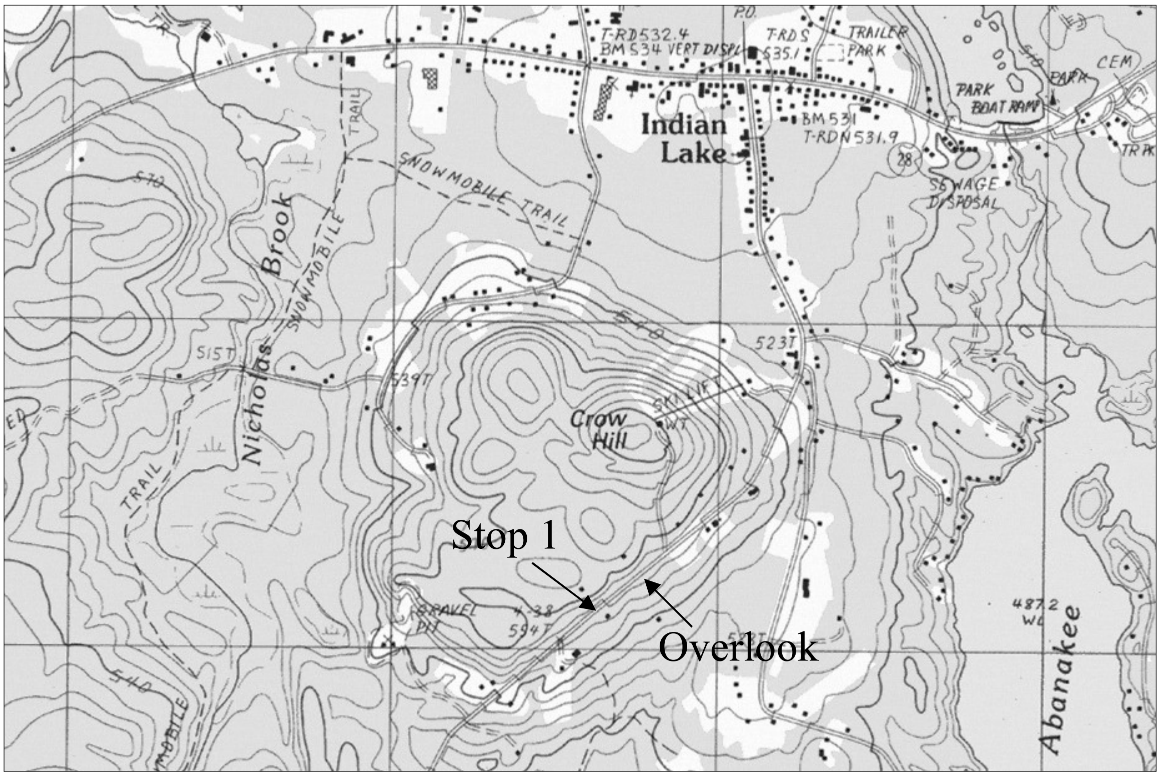
## Field Trip Description and Road Log

**Road Log:**

Mileage:

0.0 The trip begins at the assembly point in the parking lot of the super-market in the town of Indian Lake, NY, at the eastern intersection of Rts. 28 and 30. Proceed south on Rt. 30.

1.0 Turn left into the overlook parking lot, and walk south on Rt. 30 approximately 0.2 miles to the first roadcut on the west (right) side of the road.




**STOP 1: Calc-silicate gneiss on the north side of the Snowy Mountain Dome (SMD)**

Calc-silicate gneiss with penetrative foliation and folds occurs in outcrops on the west side of Route 30. The foliation is defined by planar aggregates of recrystallized plagioclase, quartz and diopside (Figure 30). Locally the calc-silicate gneiss contains quartzofeldspatic layers that define isoclinal folds, and locally there are recrystallized masses of diopside (some >10 cm in diameter).

The dominant foliation in the outcrop in most places is structurally continuous with penetrative foliation (S2) in the Snowy Mountain dome, and dips moderately northward at this location. Portions of the exposure reveal an earlier foliation (S1) preserved mostly in the hinges of the isoclinal folds (F2) (Figure 30). The S1 foliation does not occur in the rocks of the Snowy Mountain suite, and the S2 foliation dies out away from the Snowy Mountain dome. In a relative sense, the S1 foliation is either predates or is synchronous with the intrusion of the Snowy Mountain suite, and the S2 foliation is superimposed on the suite.

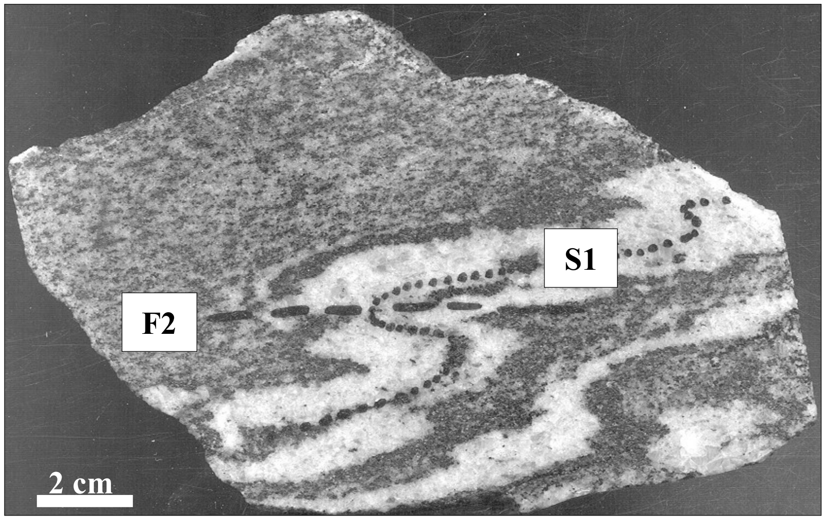
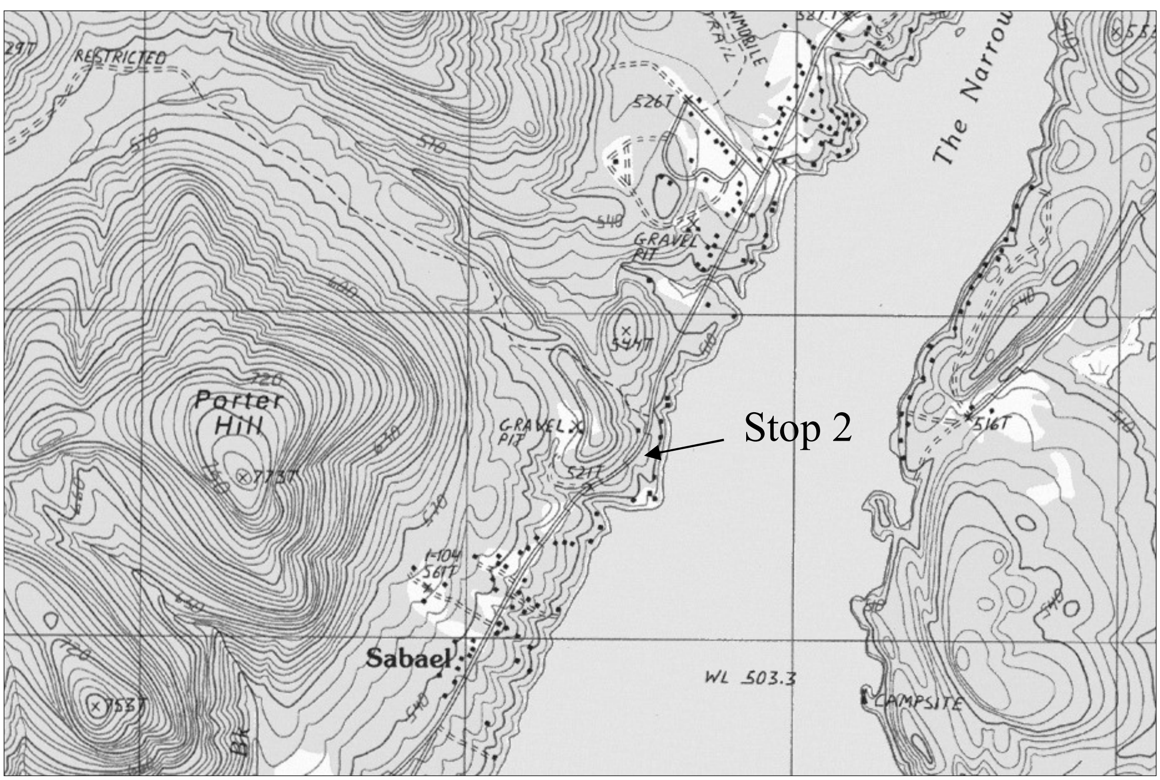



**Figure 30.** Rock slab of calc-silicate gneiss showing the S1 foliation defining F2 isoclinal folds.

Mileage:
1.0 Continue south on Rt. 30 towards Speculator.
2.1 Point Breeze Hotel
2.6 Roadcuts of charnockitic gneiss.
3.5 Park on the right side of Rt. 30 and cross the road to the roadcut on the east (left) side (at the "Southwinds" sign).



**STOP 2: Charnockitic gneiss on the north side of the SMD**

The contact between the calc-silicate gneiss of STOP 1 and charnockitic gneiss of the Snowy Mountain suite occurs approximately 1 km northeast of this location, and is concordant with the S2 foliation. Here there is exposure of highly deformed charnockitic gneiss on both sides of the road. The foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite (Figure 31). The foliation dips moderately northeastward and weak mineral lineations trend shallowly toward the east. Many of the outcrop surfaces reveal augen of plagioclase with core-mantle structure. Dynamically recrystallized tails developed on porphyroclasts of plagioclase merge with the penetrative foliation. The plagioclase augen are interpreted to be relict igneous crystals, possibly original megacrysts. When viewed on outcrop surfaces that are parallel to the lineation and perpendicular to the foliation, the augen appear to be asymmetric. Domino structures and Type I S-C fabrics can be viewed on some optimum surfaces. The kinematic indicators are consistent with top toward to the west, low-angle sinistral shear.

Proceeding south across the Snowy Mountain dome, the penetrative foliation in the charnockitic gneiss progressively dips toward the each and then toward the southeast. There are numerous outcrops along Route 30 that can easily be viewed. Where the southeastern spur of Squaw Mountain intersects Route 30, there is exposure of gabbroic gneiss and megacrystic anorthosite. We will not be stopping at this outcrop during this trip due to time constraints. However, this is a good place to view the transitional compositions and deformation fabrics. The megacrystic anorthosite lacks penetrative deformation at this location, but some parts of the outcrop contain dynamically recrystallized anorthosite with well developed S2 foliation. The gabbroic gneiss contains penetrative foliation and well developed lineations at this location.

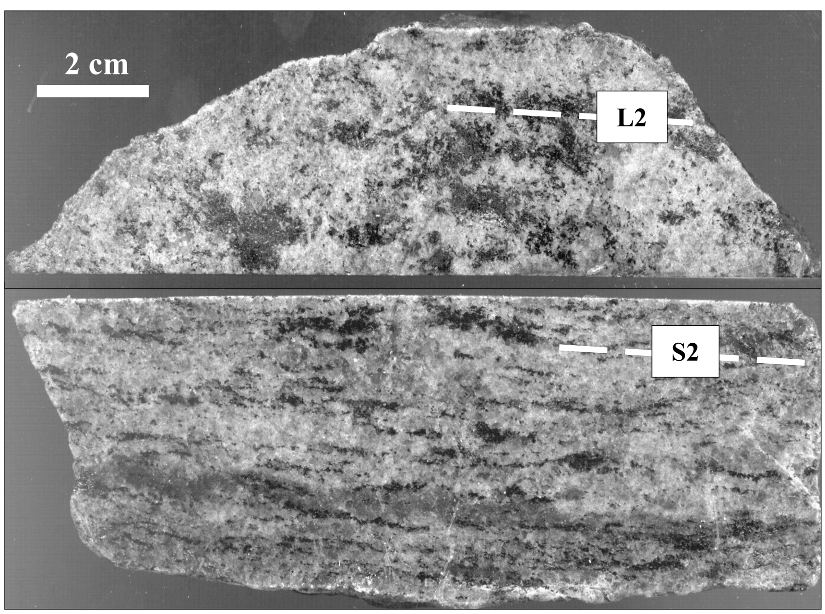



**Figure 31.** Mutually perpendicular rock slabs of charnockitic gneiss from the northeastern flank of the Snowy Mountain dome. The top slab is cut parallel to the S2 foliation revealing weakly developed mineral lineations. The bottom slab is cut perpendicular to the foliation and parallel to the lineation to reveal the penetrative foliation.

The transition from gabbroic- to charnockitic-gneiss occurs approximatley 1000 meters northeast along the Squaw Mountain spur. This transition was documented by DeWaard and Romey (1969). Within the charnockitic gneiss branching high-strain zones can be seen (Figure 32). In places, the high-strain zones merge and have tapered terminations, and close inspection will reveal the penetrative folation. Compositionally, the rocks in the high-strain zones are identical to the bounding charnockitic gneiss, except for the occurrence of minor quartz veins. The high-strain zones have the same general strike as the location foliation, but typically dip steeper northward in this area. Mineral lineations are better developed in the high-strain zones. Shear sense indicators are consistent with the shear sense indicators observed in the charnockitic gneiss with top toward the west ductile flow, or low-angle sinistral. The high-strain zones contain the same metamorphic minerals as the lower-strain charnockitic gneiss.

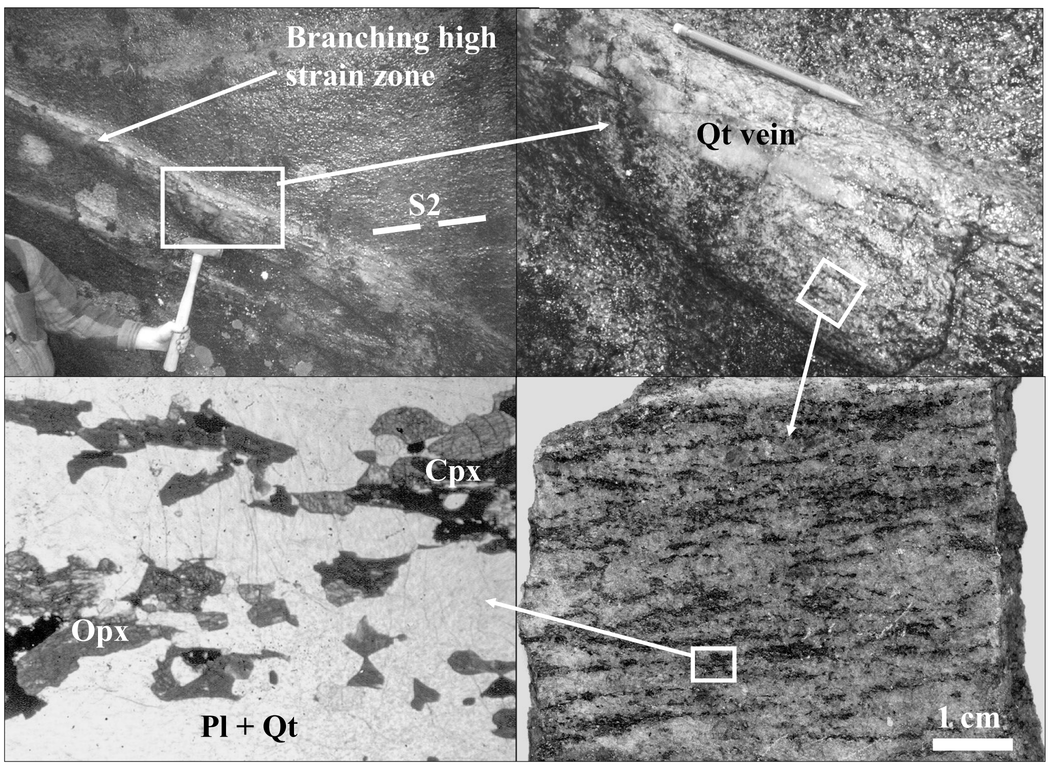


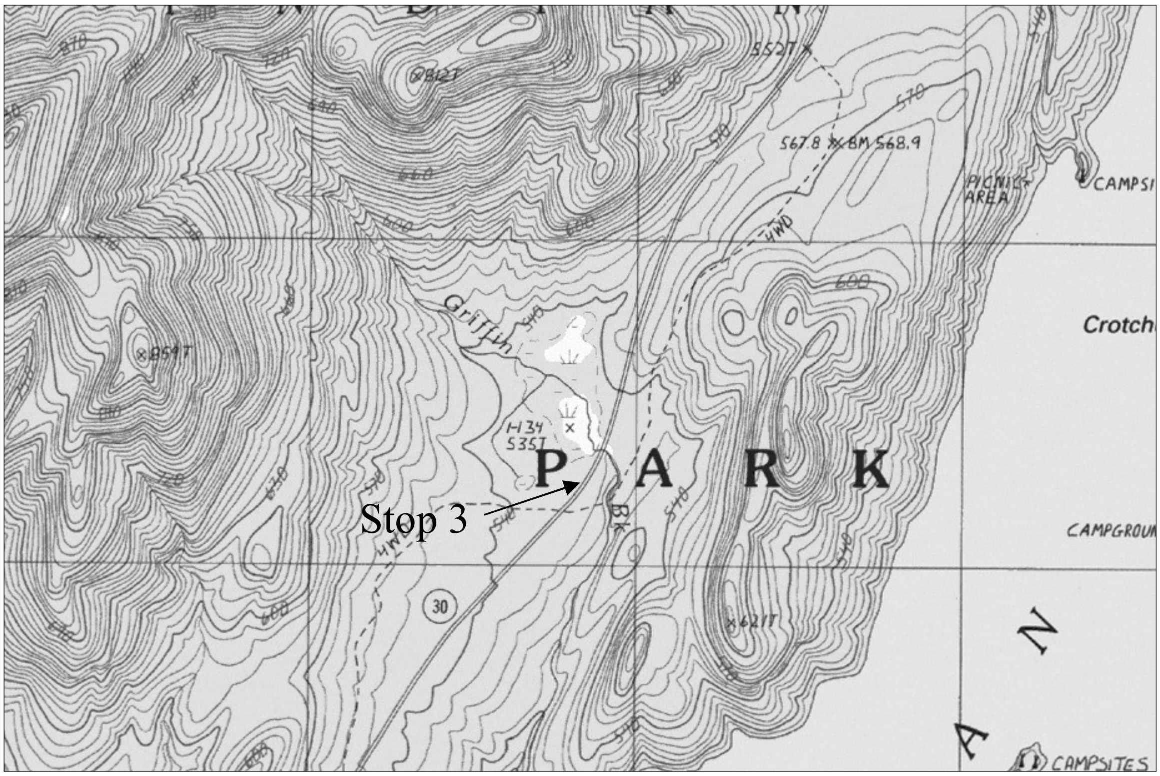

**Figure 32.** Example of a branching high-strain zone in charnockitic gneiss on the eastern flank of the Snowy Mountain dome in the area of Squaw Mountain.

Mileage:

3.5 Continue south on Rt. 30 towards Speculator.
5.9 Roadcuts of gabbroic metanorthosite and megacrystic metanorthosite.
7.1 Trailhead to Snowy Mountain. Drive slowly for the next mile or so.
8.0 Just after Griffith Brook, turn right into a turnout and park for Stop 3.

**STOP 3: “Underview” of the Snowy Mountain Dome**

From this location the crest of the Snowy Mountain dome can be viewed. Numerous slide faces expose the shallowly dipping foliation that occurs at the top of the dome (Figure 33). The exposures at the top of Snowy Mountain can be accessed by a hiking trail that occurs about 2 km north of this location. The top of Snowy Mountain is underlain by gabbroic gneiss with penetrative S2 foliation. The foliation dips shallowly toward the north and subhorizontal mineral lineations trend nearly due east. A near vertical outcrop near the top of the mountain reveals abundant shear sense fabrics. Detailed kinematic analysis using porphyroclasts, S-C fabrics and shear bands resulted in dominant shear of top toward the west. However, some domains upward of a few meters thick showed conflicting shear sense of top toward the east. These exposures are the structurally highest part of the dome available.



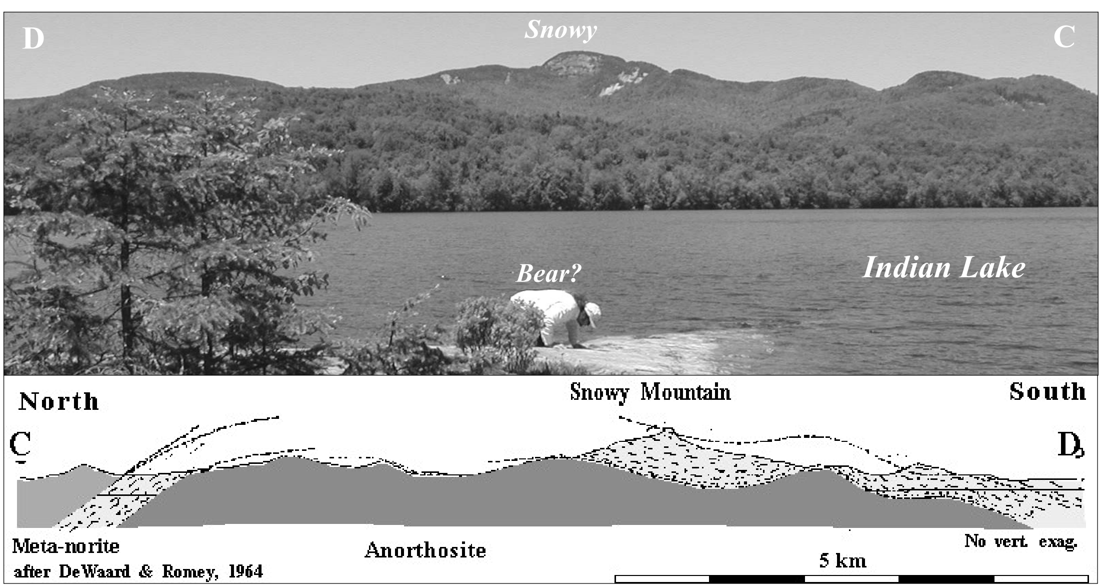
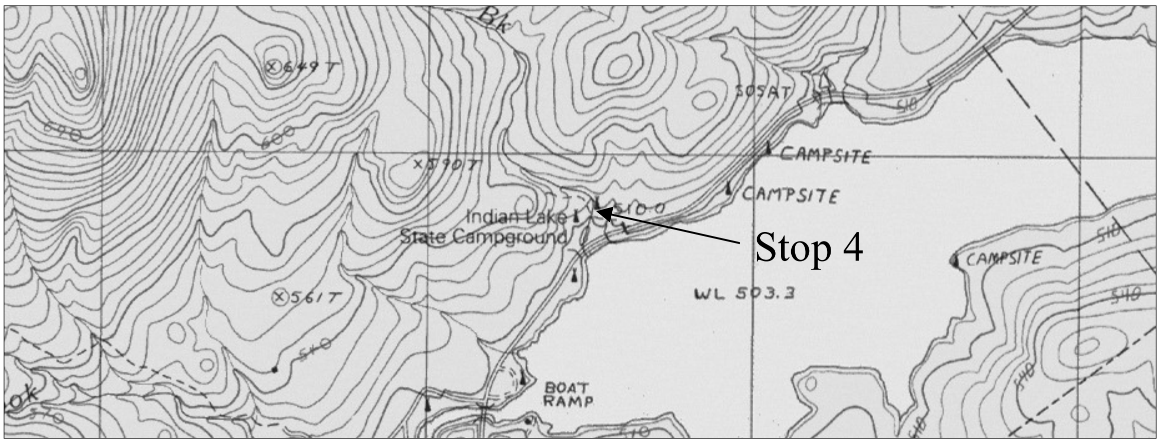



**Figure 33.** Westward view of Snowy Mountain from the east shore of Indian Lake (top) with the cross section of DeWaard and Romey (1964). The cross section is an eastern view of the area so "C" and "D" are reversed on the photograph. Note that Gary Solar is pretending to be a bear.

Mileage:

8.0 Continue south on Rt. 30 towards Speculator.
9.2 Access road for Timberlock resort on left.
10.5 Sign noting "Entering Camping Area" of Lewey Lake and Indian Lake Campgrounds.
11.3 Turn right onto access road for campsites. Drive this road until just into the woods, and park in the wide flat area just before the bridge over Falls Brook. Walk across the bridge and past the metal gate, then plunge into the woods on the right of the access road about 10 meters to the outcrops in the brook that form the falls.




## STOP 4: Charnockitic gneiss on the southeast side of the Snowy Mountain Dome

Stop 4 is of highly deformed charnockitic gneiss, the same lithology as Stop 2. However, the penetrative foliation dips moderately toward the southeast due to the position on the Snowy Mountain dome. At this location, and as before, the foliation (S2) is defined by planar aggregates of dynamically recrystallized plagioclase and broken grains of hypersthene and augite, and weak mineral lineations trend shallowly toward the east. Augen of plagioclase have dynamically recrystallized tails often forming asymmetric kinematic indicators. As well, Type I S-C fabrics are well developed in some domains (Figure 34). Unlike Stop 2, the shear sense determined at this location is top toward the east. But, considering the dip is southerly, and mineral lineations trend easterly, the shear sense can be considered low-angle sinistral.

Mileage:

11.3 Return to Rt. 30, and continue south towards Speculator.
11.9 Lewey Lake on the right.
15.8 Intersection with dirt road on right ("Mountain Bike Trail").
16.2 Mason Lake on the right.
17.6 Jessup River.
18.4 Roadcuts of quartzo-felspathic gneiss with granite dikes on both sides of the road.
19.0 Roadcut of calcite-garnet rock on the right, with a rock painted as a pig on the left.
21.1 Roadcut of steeply-dipping dextrally sheared rocks on the right.

21.3 Intersection with dirt road on right ("Mountain Bike Trail").
22.4 Park on west (right) side of road at the large roadcut for Stop 5A.

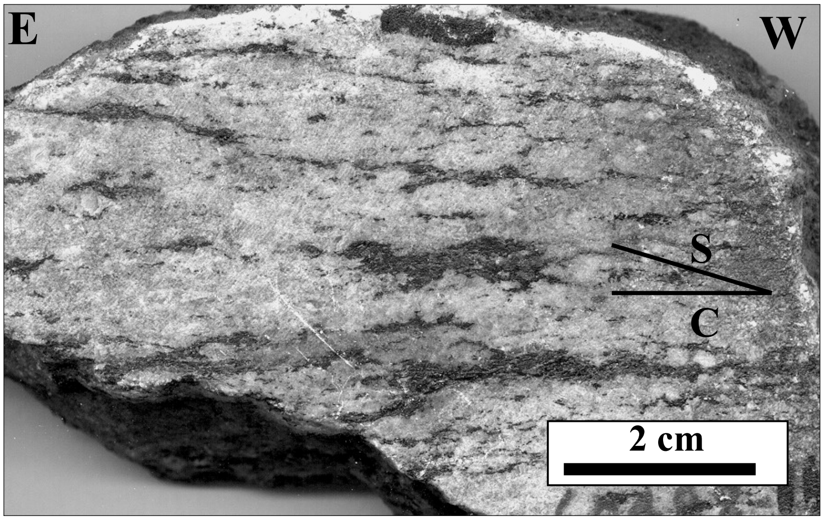
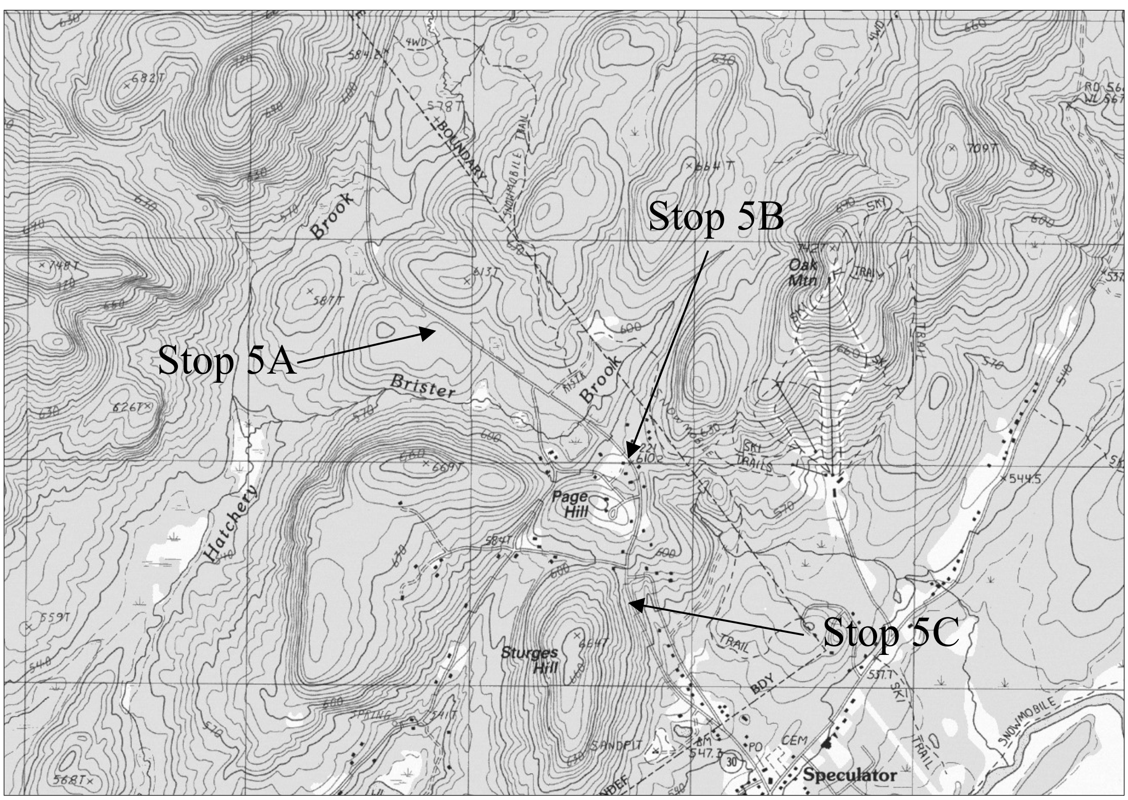



**Figure 34.** Rock slab of charnockitic gneiss from the falls on Falls Brook with Type I S-C fabric. The shear sense is top toward the east or sinistral. The dark minerals are broken grains of hypersthene and augite, while the lighter portions of the rock consist of recrystallized aggregates of plagioclase and quartz.



## STOP 5: Rocks typical of the intervening zone between the SMD to the north and the PLSZ to the south

Rocks of each outcrop for Stop 5 are typical of rocks that occupy the zone between the SMD to the north (STOPS 1 to 4) and the Piseco Lake shear zone to the south (STOPS 6 to 13).

### STOP 5A: Garnet amphibolite, calc-silicate rock and quartzo-felspathic gneiss

Here, these three rock types and their contacts are seen. The northern ¼ of the outcrop consists of garnet amphibolite, the next ~ ¼ of the outcrop is calc-silicate rock and the southern ½ is fine-grained quartzo-feldspathic gneiss. Complex sheath folds with sub-horizontal tight, isoclinal and sheath folds of foliation and compositional layers dominate the rock, particularly in the gneiss (trend to 110$^o$) (Figure 17). Excellent views of the folds are seen on top of the southern part of the outcrop. The contacts between the rock types are also folded in similar fashion. Matrix minerals define lineations that are E-W and subhorizontal, but are variable in orientation due to folding.

Mileage:
22.4 Continue south on Rt. 30 towards Speculator.
23.0 Park on the right, just after the guard rail, as you ascend the north slope of Burgess Hill (see location map). The outcrop is a roadcut on the east (opposite) side of Rt. 30 just north of the sign for Lake Pleasant.

### STOP 5B: Garnet amphibolite and quartzo-feldspathic gneiss

Here the garnet amphibolite and garnet-bearing quartzo-feldspathic rock is in sheared contact. The amphibolite has a distinct foliation and lineation that is folded into shallowly inclined tight folds (N-dipping axial planes) whose axes are shallowly E-W plunging. The lineation in the amphibolite is shallowly plunging to 112$^o$. The fabric in the quartzo-feldspathic rock is distinct in contrast to the amphibolite, showing a penetrative L>>S tectonite fabric whose lineation plunges shallowly to 112$^o$. The L>>S fabric is defined by both rods of quartz and quartz aggregates, and by tails around garnet. The highly fractured nature of the outcrop offers excellent views of this fabric. The contact between the rock types is distinct due to the color difference, but also because the amphibolite is boudinaged (foliation boudinage) due to apparent contact-parallel shear. The inter-boudin partitions are in-filled by plagioclase and amphibole (Figure 35).

Mileage:
23.0 Continue south on Rt. 30 towards speculator.
23.2 Top of the hill (garnet amphibolite roadcuts on both sides of the road).
23.4 Park on the right side of the road just south of the intersection, and walk to the top of the large roadcut for southerly views of Lake Pleasant and Speculator Mountain, and the PLSZ.

### STOP 5C: Overlook of Speculator Mountain, and the PLSZ

The rock here is sub-horizontally stratified, with the rock at the top of the hill to the north (garnet amphibolite) the lowest stratum, and the base of the outcrop is interlayered amphibolite and granitic gneiss, followed by granitic gneiss with mica ‘mats’ at the top (at the viewing area). Foliation is sub-horizontal here, but, again, the mineral lineation is shallowly E- and W-plunging.

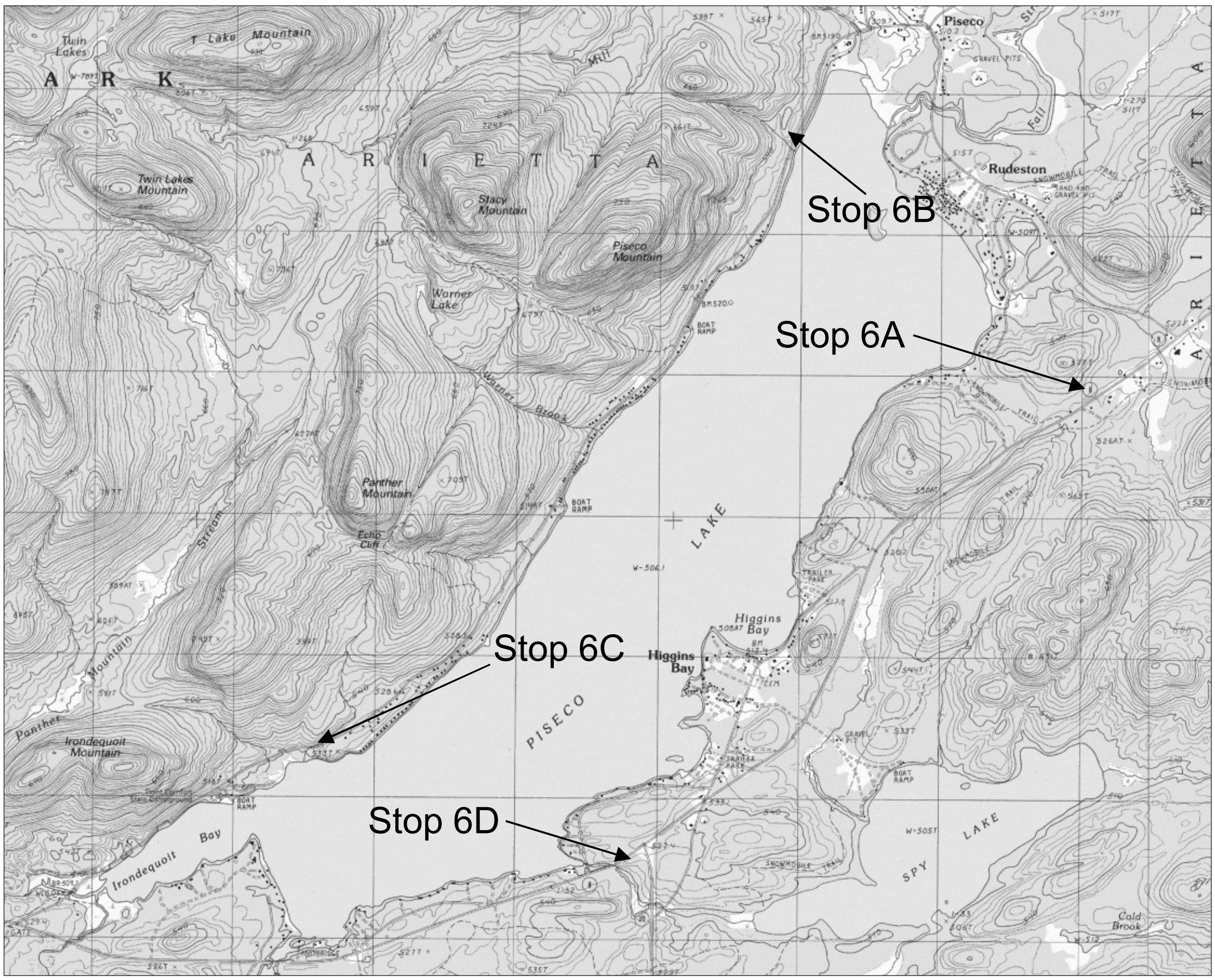
The view to Speculator Mountain illustrates the structure of the late history of the PLSZ. The bench on the east side of the mountain is the top of the hanging wall block of a moderately W-dipping normal fault, and the peak of Speculator Mountain is the hanging wall block. This normal fault is defined by fabric with a distinct top-down fabric trajectory, and defines the zone to be about 100 m thick. This is one of many normal shear zones that cut the E-W fabric that defines the PLSZ, but this one is perhaps the thickest. Most identified are a few centimeters thick (as in Figure 18).


**Figure 35.** Pavement view of top surface of rock at Stop 5B showing the foliation boudinage in the amphibolite (bottom) and the penetratively strong fabric in the quartzo-feldspathic rock (top).

Mileage:
23.4 Continue south into Speculator.
24.1 Turn right (west) onto Rt. 8.
26.1 First roadcut on right is highly lineated gneiss in the margin of the PLsz.
27.1 Lake Pleasant
27.5 Lake Pleasant town center.
33.0 Intersection with Old Piseco Road in Piseco, NY.
34.0 Park on right side of the road at the low roadcut for Stop 6.

**STOP 6A-D: L-S and L>S fabrics in the Piseco dome.**

The Piseco Lake zone consists of the northern dome that merges with a steeply dipping shear zones to the south. This series of field stops shows variations in the attitude and type of fabrics that occur in the core of the dome. Stops 6A to 6D are a driving traverse around Piseco Lake, the type location of the Piseco antiform. At all of these localities, dynamically recrystallized feldspars and quartz form spectacular ribbon- and rod-shaped mineral lineations (McLelland, 1984), in addition to mafic phases such as biotite, chlorite and accessory magnetite. In many places, the alignment of ribbons forms the foliation in this outcrop. Individual quartz-ribbons have aspect ratios upward of 60:1. At Stop 6A, the foliation is weakly to moderately developed, and dips shallowly southward at the eastern part of the outcrop (Figure 36), but is steeply dipping at the western end of the outcrop. The transition between these different foliation attitudes is difficult to determine because the intensity of the foliation is variable. Lineations are penetrative on all scales, and consistent in attitude (Trend: 110$^{o}$; Plunge: 05$^{o}$). Stop 6A occurs on the southern flank of the map-scale dome portion of the Piseco antiform. At the western end of the outcrop there are rods of amphibolite (10-30 cm diameter) within the granitic gneiss.




There is an apparent Cenozoic fault that traces down the western side of Piseco Lake and has locally displaced parts of the Piseco dome (Figures 13 and 14). At Stop 6B, again the foliation is weakly developed with a penetrative shallowly plunging lineation. However, the foliation, where it can be observed, dips northerly. As you drive southwest along the western side of Piseco Lake, note that the foliation gradually shallows and then dips southerly. There are several outcrops that can be observed where this transition in foliation attitude occurs. The rock fabrics at Stop 6C are similar to those at Stops 6A and 6B, but again the variably developed foliation dips toward the south. Stop 6D is located at the intersection of Rts. 8 and 10, and the folation and lineation is penetrative.

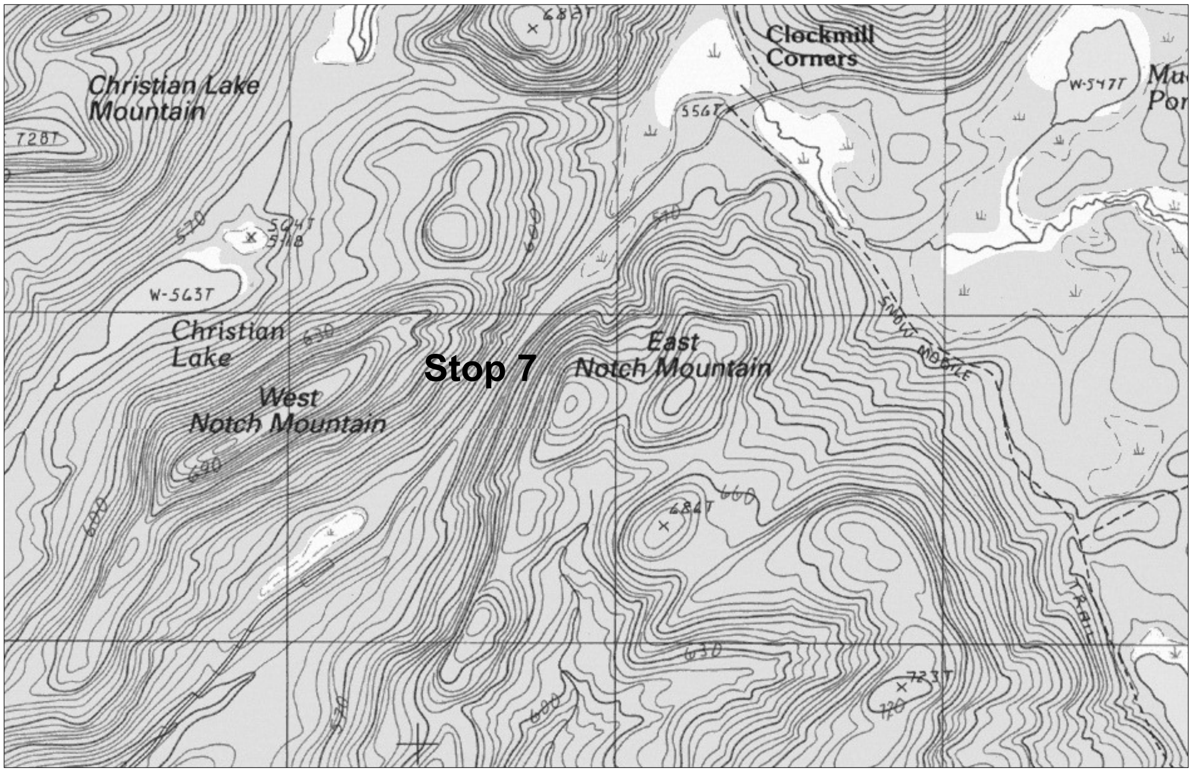
Common to all of these field stops is that both biotite and chlorite blades form microscopic lineations and foliation parallel to the macroscopic structure. Rare grains of hypersthene have been found, but they always have well developed overgrowth textures that include biotite and chlorite. The biotite and chlorite are the most abundant index minerals in the granitic gneiss, and suggest the deformation was last active under low- to moderate- metamorphic conditions, although probably began at much higher conditions to account for the relict grains of hypersthene.


**Figure 36.** Pavement exposure of grantic gneiss with penetrative mineral elongation lineations defined by quartz ribbons and aggregates of dynamically recrystallized feldspar. The view is looking toward the west.

Mileage:
34.0 Turn around and proceed east on Rt. 8 about 0.5 mile. west on Rt. 8.
34.5 Turn north and follow the road around Piseco Lake to Stops 6B and 6C.
42.4 At the intersection with Rt. 8, turn east and proceed about 2.9 miles.
45.3 Turn south onto Rt. 10 and park for Stop 6D. Proceed south on Rt. 10 about 1.2 miles.
46.5 Turn west onto Powley Road (becomes a gravel road) and continue 4.9 miles.
51.4 Park where Powley Road traverses through the Notch.

**STOPS 7: Steeply dipping mylonite zone of the southern PLsz**

Along Powley Road, there are a sub-continuous series of pavement exposures located in the road bed, and in the gutter on the east (northeast-bound) side of the road. Due to the nature of this location, the extent of the exposed rock at this stop changes daily, so some or all of the rock described here may be viewable depending upon the time of the season in which the stop is visited (best later in the season). The best exposures occur along the road between West and East Notch Mountains.




All rocks in this region are very similar in mineral content, and vary only in detail with regard to mineral percentage and fabric type and intensity. The rock is dominantly granitic gneiss with intense subhorizontal to shallowly plunging mineral elongation lineation that trends on average about 095 $^{o}$, with steeply dipping generally east-west striking foliation. Both fabric elements are defined by ribbons of quartz, and ribbons of aggregate feldspar and quartz (generally 1-5 cm long depending upon grain size). Intensity of the fabric varies across strike at the 50 cm scale, with local layers of significantly coarser-grained fabrics (grains up to 1 cm in diameter). There are also places where the foliation intensity varies as seen at the field stops around Piseco Lake. Rare amphibolite bodies that are 10's of cm thick occur within the granitic gneiss (Figure 37). Shear sense indicators are abundant in the granitic rocks and consistently show sinistral shear sense (Figure 11).

Mileage:
57.4 Continue south on Powley Road about 6 miles and park.

**STOP 8: Southern extent of steeply dipping mylonite**

Here the granitic gneiss fabrics contain both a penetrative foliation and lineation. The foliation is steeply dipping and strikes about east-west. Mineral elongation lineation defined by linear aggregates of quartz and feldspar are subhorizontal. The extent of readily available bedrock exposure diminishes south of this location, so this may be the southern-most exposure of the Piseco Lake shear zone. Note that this location is about 21 kilometers across strike from the northern side of the Piseco dome where the pronounced lineation occurs.

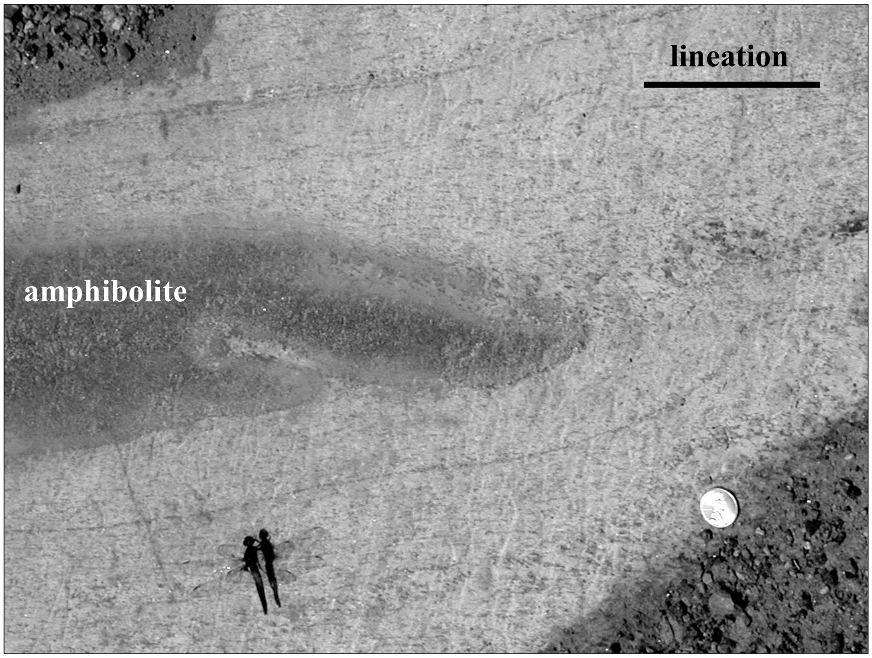
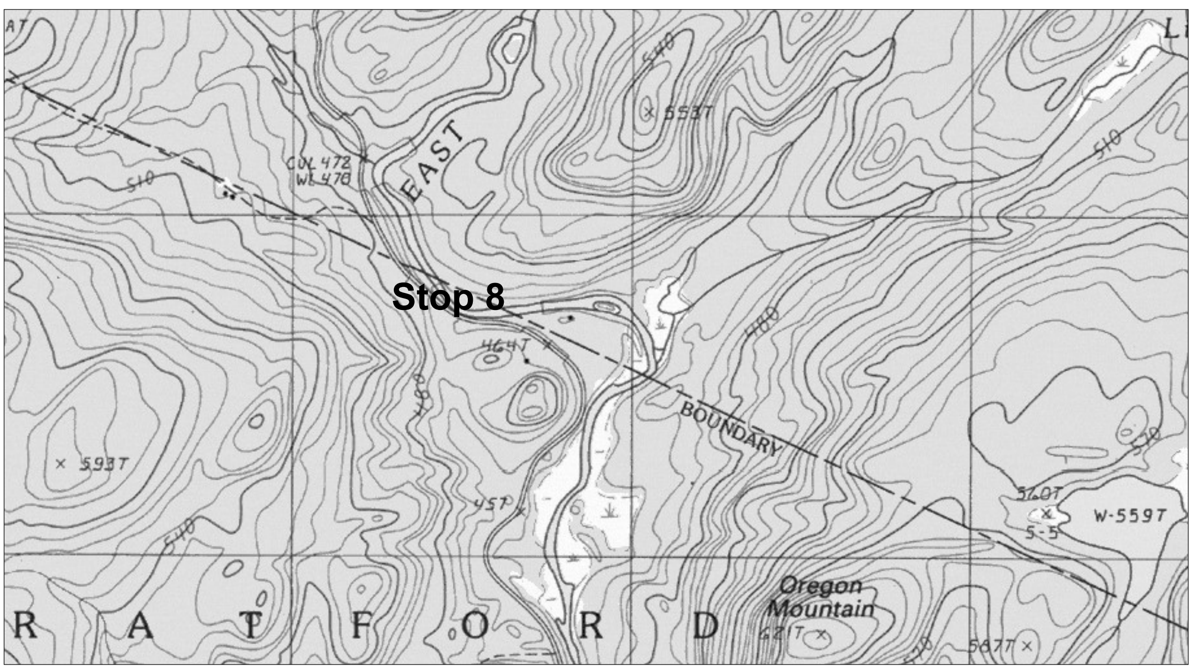
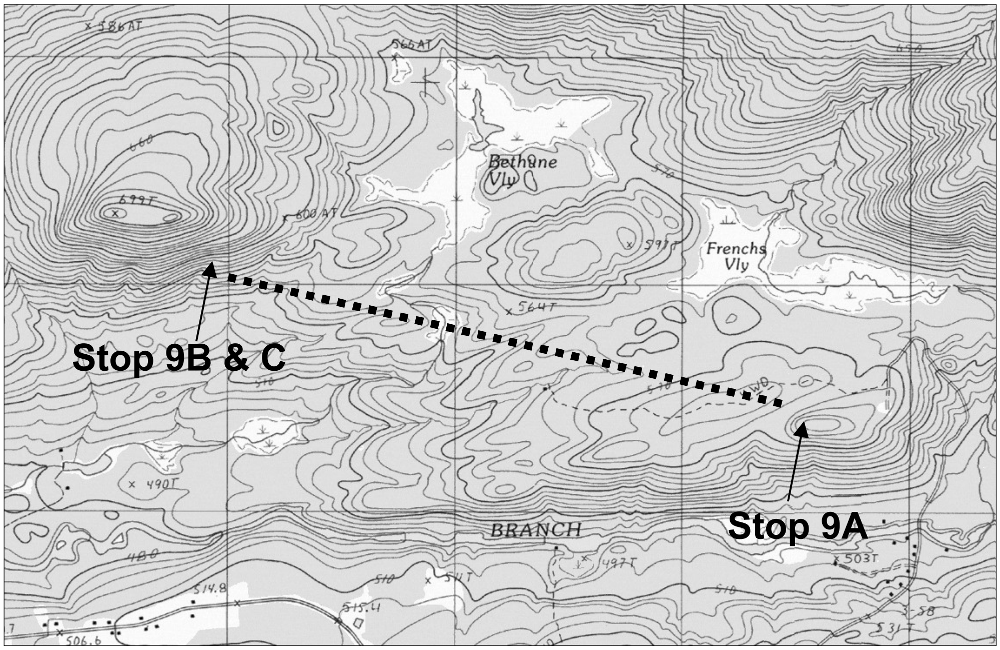



**Figure 37.** Pavement outcrop from the bed of Powley Road. Top is north. Note the apparent deflection of the fabric and difference in texture of the quartzo-feldspathic gneiss where it forms a 'tail' at the 'nose' of the 'shark'-shaped amphibolite lens.




Mileage:
68.3 Turn around and proceed back to the intersection of Powley Road and Rt. 10, and park.
69.5 Continue north on Rt. 10 about 1.2 miles to the intersection with Rt. 8.
81.6 Turn west onto Rt. 8 and drive 12.1 miles to Moorehouseville.

83.2 Turn north onto Fayle Road, proceed north. Cross a one lane wood bridge and drive to an opening in the trees at the end of Fayle Road. Park and hike to the west about 350 meters.




**STOP 9: L>>S and L-tectonite in the core of the Piseco antiform**

Excellent outcrops on the northern side of a small hill just west of the parking area. Follow the dirt road to a path through the woods, and then head up hill to the south to the outcrops. This outcrop of granitic gneiss contains domains of L>S and L>>S. The L>S domains contain large and numerous σ-type shear sense indicators, some δ-type are present but are much less frequent. The porphyroclasts are large about 1-3 cm and the recrystallized porphyroclastic material is often wrapped with a quartz ribbons (Figure 38). The interpreted shear sense is low-angle and left lateral. The granitic gneiss is composed of quartz, K-feldspar plagioclase, and minor chlorite and biotite. The foliation strikes east west and dips to the south.

Stops 9B and 9C require about 2.5 kilometers of traverse at a bearing of about 280º. The traverse will cross a few small streams and under brush can be thick in places. There is no trail to follow, so PLEASE STAY WITH YOUR GROUP.

Stop 9B there is an outcrop of a rare mafic gneiss composed of biotite, hypersthene, plagioclase, quartz and ilmenite. The fabric is L>S, lineations are defined by rods of plagioclase and streaks of biotite. The grains size is very small about 0.5mm. This rock unit borders the L>>S domain which can be seen at Stop 9C.

Stop 9C is a spectacular L-tectonite (Figure 39) that occurs in a cigar-shaped domain that appears on the geology map of Figure 15. The outcrop is granitic gneiss composed of quartz, K-feldspar, plagioclase, and fabric forming chlorite and biotite. Foliation is hard to see in hand sample but can be seen if stained for plagioclase and K-feldspar.

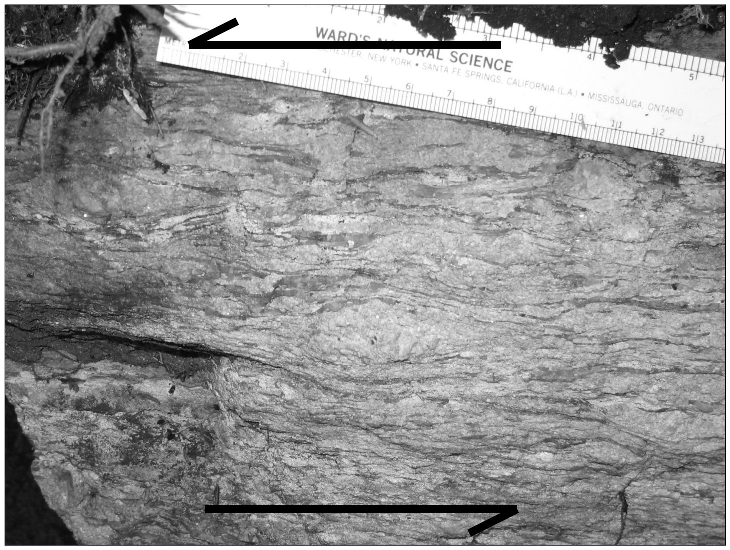


**Figure 38.** The view is south at Stop 9, and looking at a surface parallel to lineation and perpendicular to foliation. Large porphyroclasts of K-feldspar and have σ-type tails which display left lateral shear sense.

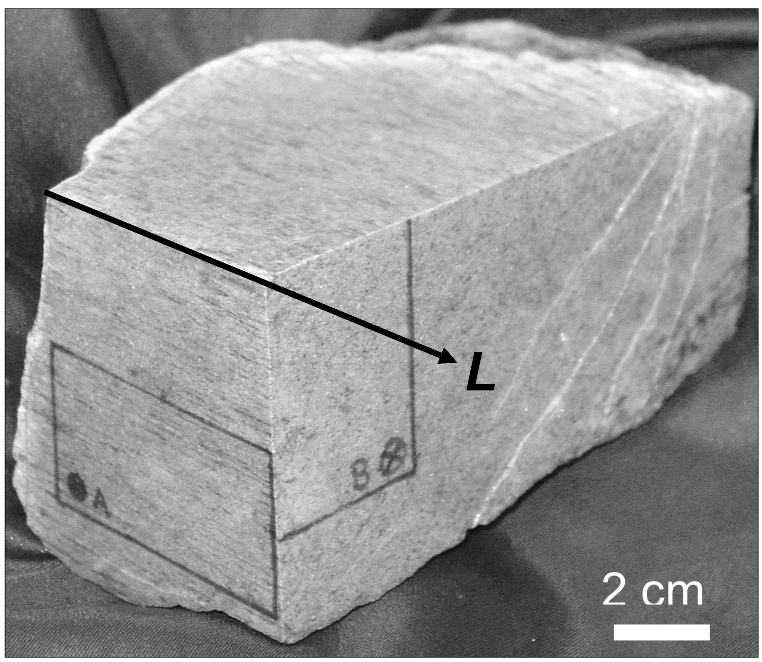
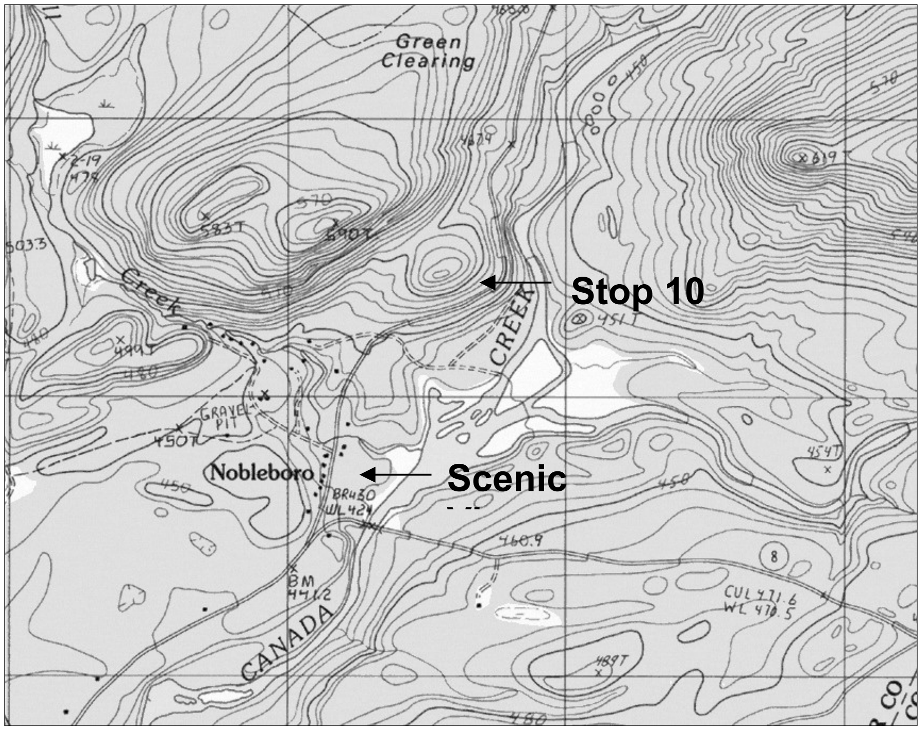



**Figure 39.** This photo was taken of sample from Stop 9C. Quartz rods and recrystallized aggregates of K-feldspar define the linear fabric. Dark minerals are primarily chlorite and biotite.

Mileage:
84.8 Return to Rt. 8 on Fayle Road.
89.8 Turn west on Rt. 8 and drive about 4.9 miles to Haskel Road on the right.
90.4 Proceed north on Haskel Road about 0.6 miles to an abandoned quarry on the left.




**STOP 10. Northern limit of Piseco zone fabrics: granitic gneiss with well developed gneissocity**

Exposures of course granitic gneiss with well developed gneissocity can be seen in the high-wall of this old quarry. This stop demonstrates S>L fabric, lineation area weakly developed and foliation dominates. (Figure 40). The grain size is uniform and few kinematic indicators are present. The foliation is penetrative and is defined by planes of K-feldspar and biotite and dips to the northwest. The lineations are defined by streaks of biotite and plunge to the southwest.

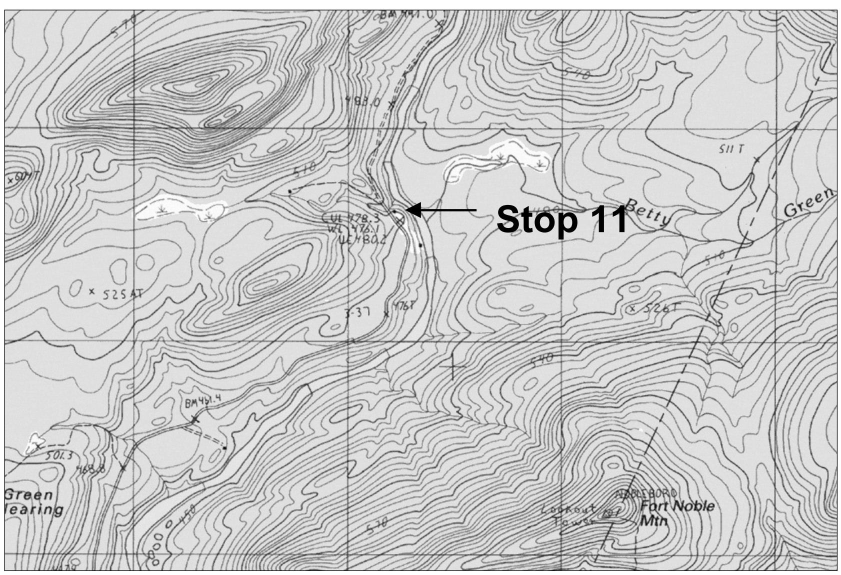
Mileage:

93.3 Proceed north on Haskel Road.
Arrive at a clearing, before bridge and gate turn right and park in grass. Walk east down a small hill to the West Canada Creek.

**STOP 11. L-S and S>L Dioritic Gneiss**

The southern most part of the outcrop demonstrates L-S fabric. Lineations are about equal to foliation in intensity. Rods of hornblende define the linear fabric, which plunges to the southwest. Plagioclase and quartz define the foliation. In thin sections of this outcrop a ceased reaction is preserved. The hornblende crystals were breaking down to form biotite in a retrograde reaction. The northern most part of the outcrop demonstrates S>L fabric with gneissic textures, similar to the previous stop. Some small faults with 15 cm of displacement and boudins are also preserved at the northern end of the outcrop. Garnets are also visible at the northern end of the outcrop but were not observed at the southern end in hand sample or thin section.

**Figure 40.** Photograph, view is looking north, of granitic gneiss with well developed foliation and gneissocity. K-feldspar bands define the gneissic texture. Lineations can be observed with closer inspection and are parallel to the mechanical pencil in the center of the photograph.




Mileage:

96.6 Proceed south on Haskel Road to the intersection with Rt. 8.

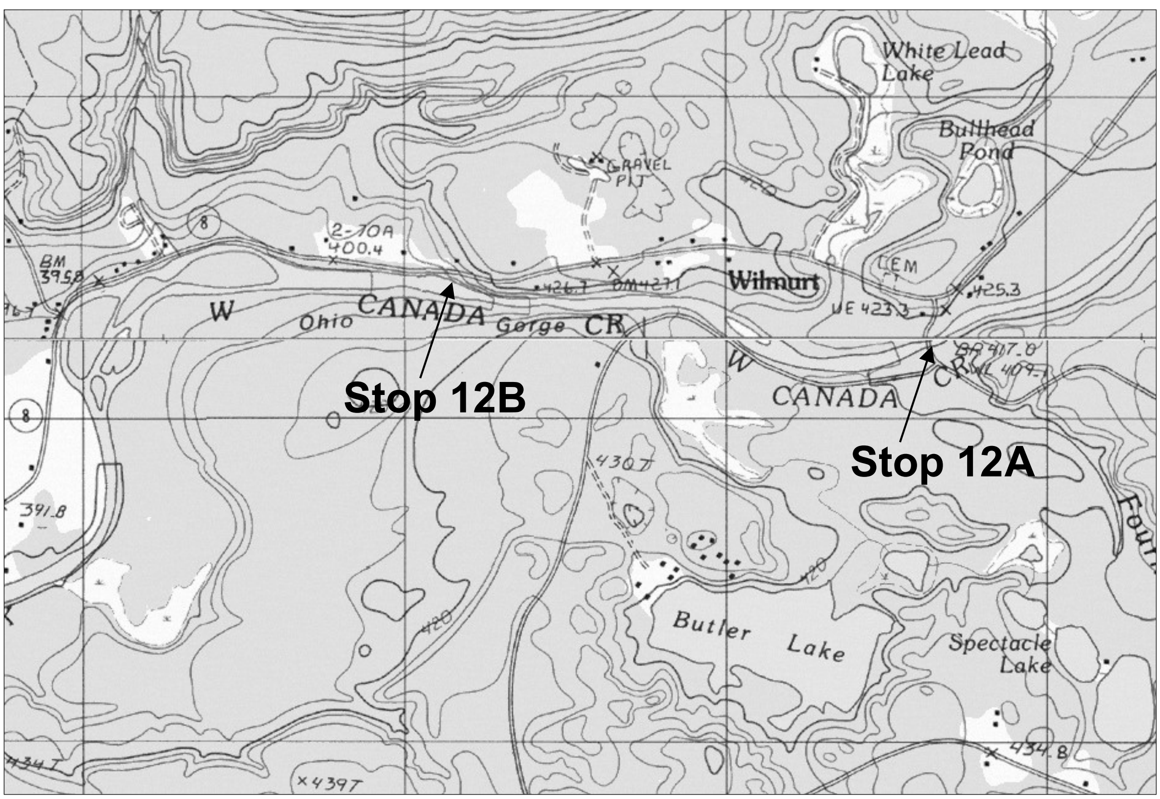
99.2 Turn west on Rt. 8 and proceed to the intersection with Gray Wilmurt Road on the left. Turn south onto Gray Wilmurt Road just after a sharp right-hand curve in Rt. 8. Cross a bridge over the West Canada Creek and park at the intersection with Jones Road. Walk back toward the bridge over West Canada Creek and down the hill to the outcrop just east (upstream) of the bridge (see location map). The outcrop forms a small water fall on the creek. This is private property, so make sure to get permission from the land owner.

**STOP 12: The PLSZ at the Ohio Gorge of West Canada Creek**

The Piseco Lake shear zone traces westward through the West Canada Creek basin. Some of the best continuous exposures occur in the Ohio Gorge near Wilmurt. The last stops for this field trip are in highly deformed granitic gneiss in the gorge. During periods of high water, the exposures at the eastern and western end of the gorge may be covered or not easily accessed. Permission is needed from the landowner at Stops 12A and 12B.

**STOP 12A: East of the gorge**

The West Canada Creek forms a small waterfall at the upstream part of this outcrop. Pavement exposures reveal the L-S and L>S deformation fabric in granitic gneiss (Figure 21). Foliation is gently dipping and the lineations are subhorizontal. In the region immediately down-stream of the falls, the foliation is defined by planar aggregates of recrystallized K-feldspar and quartz that alternate with dark layers containing abundant chlorite and minor biotite. The dominant fabrics are cross cut by at least three small high-strain zones. Two are steeply dipping and strike about east-west, and the third strikes south and dips moderately westward. One of the steeply dipping high-strain zones occurs in the vertical face at the southern side of the outcrop. Another occurs at the western limit of the outcrop close to the water. The north-south striking zone occurs in the low ledge near the falls. This small shear zone contains deformed pegmatite, and cross cuts the PLsz foliation and lineation (Figure 18). Shear sense is top down to the west or normal. The other high strain zones both contain evidence for oblique sinistral shear.



Mileage:
99.4 From the parking area, turn around and back track to Rt. 8 and turn west.
100.6 Park on the right shoulder just after a steep downhill drive. Walk upstream along West Canada Creek to the first bedrock exposures for the westernmost outcrops in the Ohio Gorge. If the water level is high, it may not be possible to view this outcrop.

**STOP 12B: Western limit of the outcrop belt in the Ohio Gorge**

At this location the north dipping foliation of the Piseco antiform can be viewed in addition to the typical variation in L-S and L>S fabrics at the outcrop scale. Again, the foliation is defined by planar aggregates of dynamically recrystallized feldspars and quartz. Quartz also occurs in greatly attenuated ribbons, as seen at other locations during this field trip. Of particular interest at this location, are abundant kinematic indicators that are easily observed. Outcrop surfaces that are perpendicular to the foliation and parallel to the lineation reveal asymmetric augen of K-feldspar and plagioclase forming both σ- and δ-type shear sense indicators (Figure 41) with most showing top toward the west displacement. Since the mineral lineations are subhorizontal, the shear sense is considered to be low-angle sinistral at this location. The abundant large (cm-size) porphyroclasts of feldspar provide some information about the protolith for the PLsz rocks in this region. The relict grains are most likely the remains of megacrysts from an original granite.

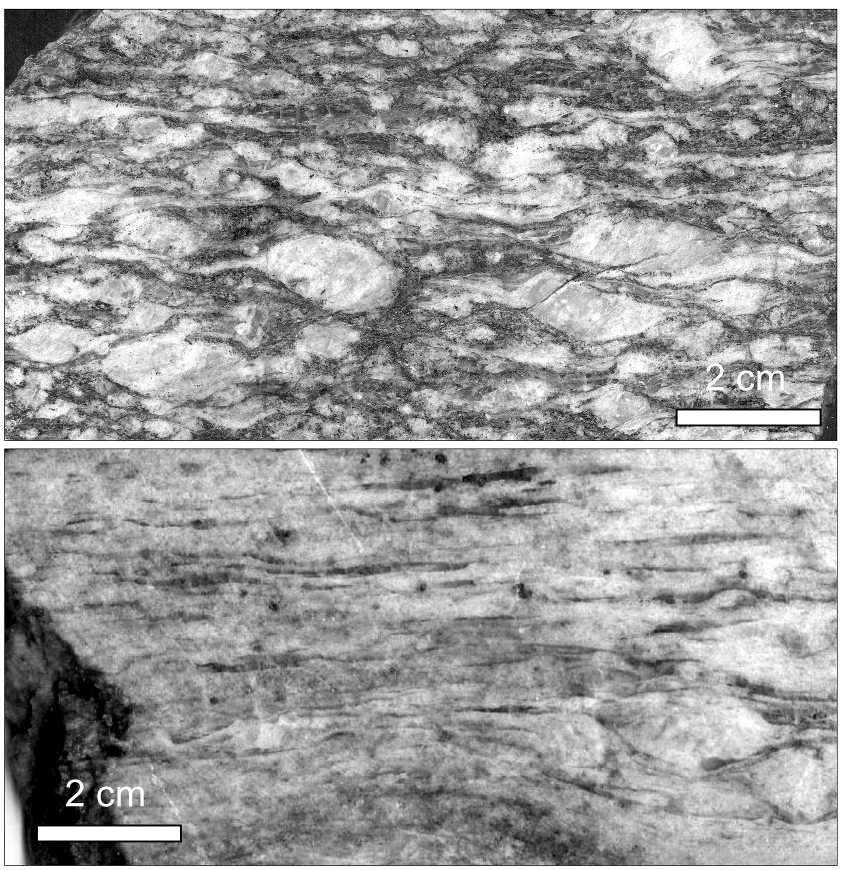



**Figure 41.** Rock slabs of granitic mylonite from the Piseco Lake zone The view is into the ground at surfaces cut perpendicular to the foliation and parallel to the lineation. Note the abundant sinistral shear sense indicators developed on the feldspar grains.

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## Trip A-3

# THE PISECO LAKE SHEAR ZONE: A SHAWINIGAN CRYPTIC SUTURE IN THE SOUTHERN ADIRONDACK MOUNTAINS, NEW YORK

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## ABSTRACT

This field trip was first run in 2005 for NYSGA and was reorganized for the 2018 NYSGA-NEIGC joint field conference to show progress in our understanding of the complex geology of the southern Adirondacks. However, in 2018 the trip canceled just prior to the conference due to the sudden tragic loss of Dr. Brian Hough that occurred a few days before the conference. Brian was a colleague of the lead author. Four years later the trip is finally being run again, and it is dedicated to the memory of Brian. Although his tenure at SUNY Oswego was not long, and was tragically cut-short, the impact that he had on many student and colleagues will last a lifetime.

Highly deformed Piseco granitic gneisses occur in an arching east-west transpressional ductile shear zone (Piseco Lake shear zone) that spans the width of the exposed southern Adirondacks. The highly deformed granitic gneisses have restricted silica content, are metaluminous, alkali-calcic to calc-alkalic, continental arc trace element signatures. These granitic rocks intruded supracrustal gneisses resulting in extensive Shawinigan partial melting. The Piseco Lake shear zone (20-30 km wide) formed in this belt of granitic rocks and correlate with a pronounced arcuate-shaped high magnetic anomaly. The magnetic anomaly extends well beyond the exposed Adirondack basement window.

The shear zone is 20-30 km wide and is believed to be the location of a cryptic suture because it occurs between the Adirondack Highlands (underlain primarily by anorthosite and related granitic rocks, AMCG suite) and the Southern Adirondack Terrane (underlain by calc-alkaline tonalitic arc rocks) (Valentino et al., in press). Within the shear zone, the original megacrystic granite contains lineated quartz and rodded feldspar aggregates up to a meter long in places. Along the axis of the shear zone there are thick (1-2 km), subvertical zones of granitic L-S and L-tectonites. The northern domain of the zone is defined by large foliation domes that are cored by L-tectonite. The southern limbs of the domes steepen toward the south and merge with a wide zone (up to 15 km) of steeply dipping granitic mylonite. Overall, the shear system (domes and steep mylonite zone) forms the core of a region of intense ductile deformation with left-lateral kinematic indicators and subhorizontal E-W ribbon lineations.

The Piseco granitic suite are highly deformed suture-stitching arc plutons that intruded within a sinistral, oblique-convergent, shear system in the deep crust during the Shawinigan orogeny. This is ductile shear zone is the most continuous and largest in the entire Adirondack massif. The shear zone, associated granitic rocks, and the magnetic anomaly abruptly trends toward the south in the eastern Adirondacks. Just beyond this location, the magnetic anomaly appears to be truncated by a branch of the NY-AL magnetic lineament.

Following the trace of the magnetic anomaly toward the west, suggests that the shear zone continues for a considerable distance beyond the Adirondack window. It's magnitude, in addition to the magnitude and extend of the associated magnetic anomaly, suggests that the Piseco shear zone penetrates the Moho.

The current field trip is an update on our very long research project, and it's geared toward an undergraduate student audience. All field locations were picked to accommodate large student groups. Sampling in the Adirondack Park is generally prohibited by NYS law, and we encourage future instructors to help preserve the field locations presented herein by showing and discussing, and not removing the spectacular bedrock features. Note that the field guide included here in was pirated and modified from the Friends of the Grenville field conference run by D. Valentino, J. Chairenzelli, D. Piaschyk, L. Williams and R. Peterson in 2008.

## INTRODUCTION

The Adirondack Mountains are a relatively recently uplifted (Roden-Tice and Tice, 2005), domal exposure of Mesoproterozoic high-grade gneisses that are part of the contiguous Grenville Province (Figure 1). Sharing many similarities to nearby rocks in Ontario and Quebec, and Grenville basement inliers in the Appalachians (McLelland et al., 2010), the rocks exposed in the Adirondacks record processes in the deep crust related to a series of orogenic events collectively known as the Grenville Orogenic Cycle (McLelland et al., 1988). Undergoing deformation spanning a period of over 250 million years (ca. 1250-1000 Ma), the Grenville Province of Laurentia is a small part of a world-wide system of orogenic belts whose assembly led to the eventual formation of the supercontinent Rodinia.

The Adirondacks have been subdivided into the Lowlands and Highlands based on difference in metamorphic grade, predominance of supracustal verses metaigneous rocks, and topography. The Carthage-Colton shear zone in the northwestern Adirondacks (Geraghty et al., 1981; Wiener, 1983), is the boundary between these terranes. The shear zone displays evidence of one or more ductile, high-grade events, as well as, later brittle remobilization and intrusion by leucogranites (Selleck et al., 2005). It has been interpreted as a late, brittle, normal fault accommodating orogenic collapse and, although the earlier ductile history is obscured, thrust and strike-slip kinematics have been noted (Baird and MacDonald, 2004; Wiener, 1983). Traditionally, lithologic similarities with the Central Metasedimentary Belt in Canada has led to inclusion of the Adirondack Lowlands as part of this terrane; whereas, the Adirondack Highlands has been equated to the Central Granulite Terrane of Quebec, again based on lithologic similarities and metamorphic grade. More recently Rivers (2008) has proposed orogen-wide subdivisions based on geochronology, and metamorphic and structural data. He suggested that the Adirondacks were part of a terrane accreted during the Shawinigan Orogeny (ca. 1140-1200 Ma) and subsequently were part of the orogenic lid; part of a medium to low pressure belt of allochthonous rocks that lack the widespread deformation that occurred elsewhere during the Ottawan Orogeny (ca. 1020-1080).

Tectonic models in the South-Central Grenville Province suggest that southeastern margin of Laurentia (present coordinates) has been the site of subduction and accretionary processes for much of the period between 1200-1500 Ma (Carr et al., 2000; Hanmer et al, 2000; Rivers and Corrigan, 2000). Part of this pre-orogenic history includes a period of back-arc, failed rift spreading in the Central Metasedimentary Belt (Dickin and McNutt, 2007) and the opening of a marginal sea within the current location of the Trans-Adirondack Back-arc Basin (Chiarenzelli et al., 2012). This began ca. 1300 Ma and was terminated by the Elzevirian Orogeny at ca. 1240 Ma. The continental arc developed along the leading edge of Laurentia (ca.1300-1350 Ma) was dismembered and dispersed by this subsequent rifting. Fragments of this arc are now found in Ontario, Quebec, the Green Mountains of Vermont, and in the Southern and Eastern Adirondacks, and were accreted to Laurentia during the Shawinigan Orogeny (Figure 1). Collectively these

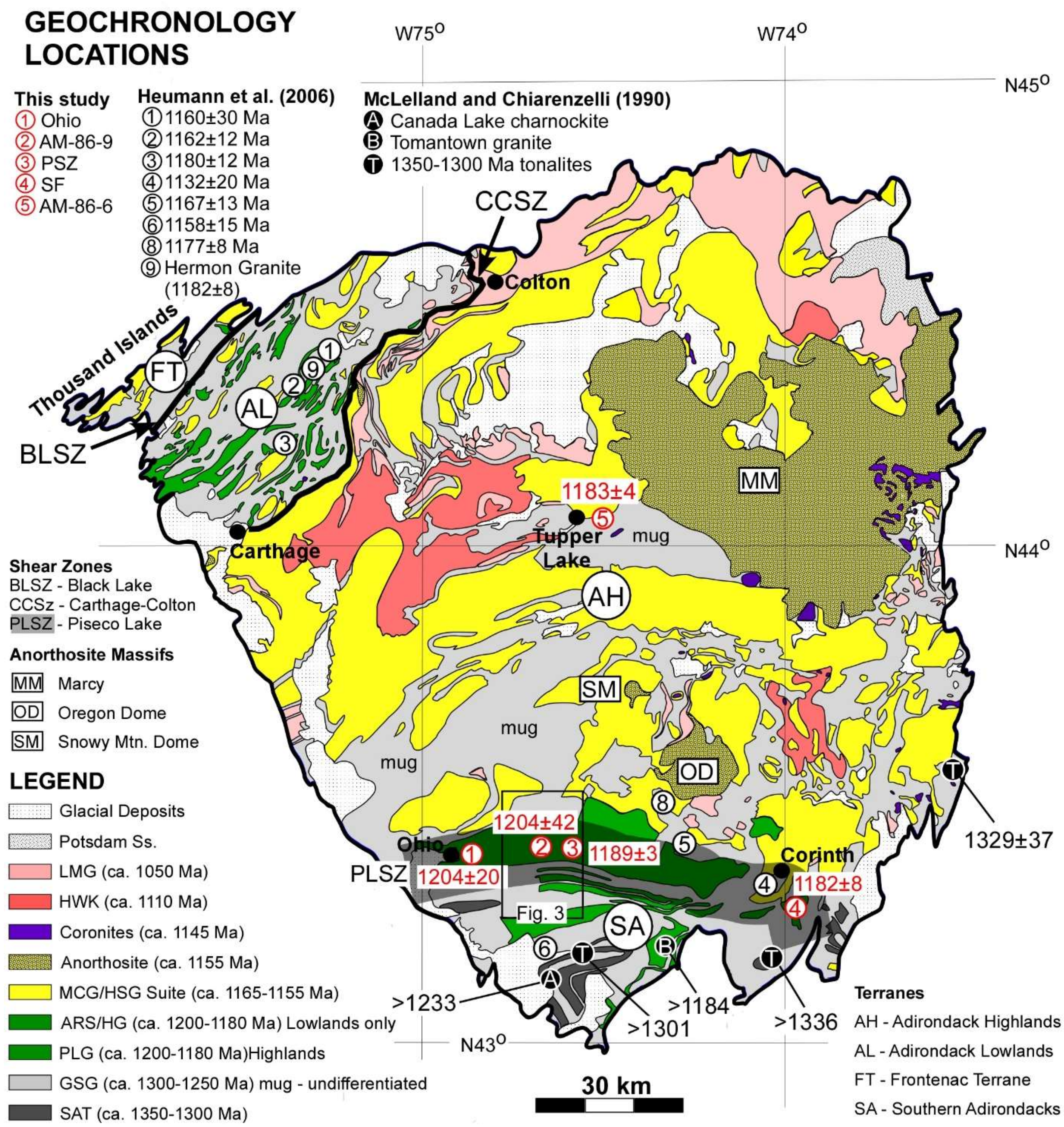



***Figure 1.*** *Simplified geological map showing rock suites (from Valentino et al. – in press): ARS – Antwerp-Rossie suite; GSG – metasedimentary rocks of the Grenville Supergroup; HG – Hermon granitic gneiss; HSG – Hyde School gneiss; HWK – Hawkeye granite; LMG – Lyon Mountain granite; MCG – Mangerite-charnockite-granite suite (granitoid part of AMCG suite); mug- mixed metasedimentary and metaigneous rocks that are most likely correlative with GSG; PLG – Piseco Lake gneisses; SAT – Southern Adirondack tonalite suite. U-Pb zircon analysis results (red circles – this study; white circles – Heumann et al., 2006; black circles – McLelland and Chiarenzelli, 1990). Numbered red circles (1-5) are geochronology locations for this study. Location of Figure 3 show as thin black rectangle.*

rocks have been called the Dysart-Mt. Holly Complex (Hanmer et al., 2000) after locations in Ontario and Vermont, respectively. The ca. 1300-1350 Ma tonalitic rocks in the Southern Adirondacks (McLelland and Chiarenzelli, 1990) and the Green Mountains of Vermont (Ratcliffe et al., 1991) are considered part of this arc or arcs.

## THE PISECO GRANITOID AND SHEAR SYSTEM

The Piseco granitoid suite (Figure 2), located in the southern Adirondacks, was originally thought be part of a basement complex to the Adirondack supracrustal sequence (McLelland and Isachsen, 1986), and were later characterized as granitic members of the AMCG suite (McLelland et al., 1988; 2004; Hamilton et al., 2004). Most recently, evidence supports an independent origin, and slightly older age for these rocks, which are exclusively found within, and along strike, of the highly tectonized Piseco shear zone (Valentino et al., in press). Their ubiquitous high strain prohibits detailed characterization of primary textures at most locations. However, the bulk mineralogy and detailed geochemistry, in addition to very large recrystallized mineral aggregates suggest that these rocks were predominantly igneous, megacrystic, and associated with arc Shawinigan plutononism (Valentino et al., in press).

In contrast to the dominant northeast structural trends throughout most of the Grenville Province, the south-central Adirondack Highlands structural grain is predominantly east-west (Figure 2), including the belt of Piseco granitoids. Across strike, where the overlying Paleozoic cover rocks have been stripped away, this region is greater than ~150 km wide and displays general parallelism of geologic contacts, fold axes, compositional layering, strike of foliation, the trend of mineral elongation lineations and substantial (~5-10 km wide) zones of mylonite. Several large (>20 km across) structural domes, cored by rheologically rigid anorthosite, lie within the zone (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2004; Valentino et al., 2008), and kinematic investigations indicate that this zone is dominated by left-lateral transpressive shear (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008). There are a number of large-scale features, such as drag folds and rotated giga-scale clasts (i.e. Snowy Mountain anorthosite body), which are consistent with the abundant meso- and micro-scale kinematic indicators including S-C fabrics, shear bands, and rotated porphyroclasts of various minerals (Gates et al., 2004). Here we designate this east-west striking, broad zone of gneisses as the Central Adirondack Shear System (CASS), and the crust-scale structures of the CASS are interpreted as the consequence of transpressional modification of earlier recumbent folds, analogous to those exposed in the Adirondack Lowlands (Chiarenzelli et al., 2000). The CASS is superimposed on rocks that contain widespread granulite-facies mineral assemblages, deformed migmatitic gneisses, and substantial volumes of supracrustal rocks, all supporting earlier history of compressional tectonism as described above. However, discrete mylonite zones within the CASS were shown to contain retrograde deformation fabrics, with some containing fabric forming greenschist facies minerals, such as biotite, chlorite and muscovite (Price et al., 2003; Valentino et al., 2008). These relationships suggest that structural activity within the CASS outlasted high-grade conditions and continued through denudation, uplift and cooling of the central Adirondacks. It was previously proposed that the locus of deformation within the CCAS, the Piseco Lake shear zone, marks the boundary of oblique-slip convergence between the southeastern margin of Laurentia and the Southern Adirondack arc terrane (Gates et al. 2004; Valentino et al., 2008).

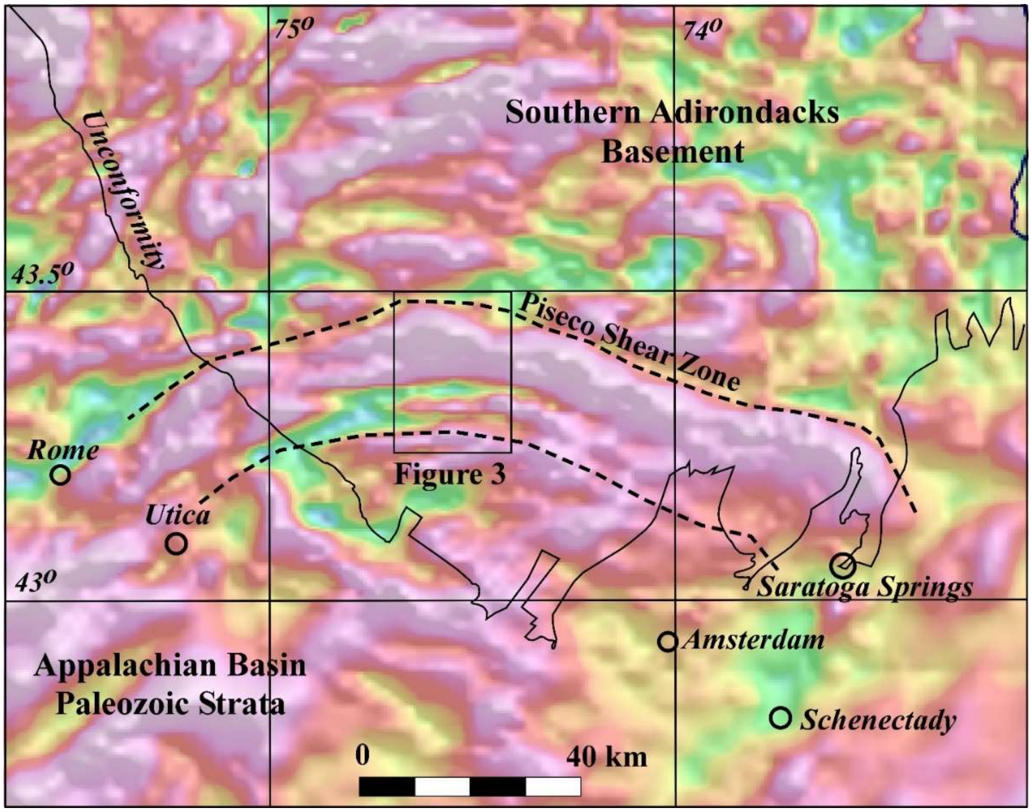



***Figure 2.*** *Magnetic anomaly map of the southern Adirondack region. Location is shown on Figure 1.*

## THE PISECO LAKE SHEAR ZONE

Several discrete ductile shear zones occur within the CASS (Gates et al., 2004; Valentino et al., 2008; Weimer et al., 2001), with the Piseco shear zone as the most continuous and largest spanning the entire 120 km width of the Adirondack massif and upward of 30 km wide (Figures 2 and 3). A prominent magnetic anomaly correlates with the Piseco Lake shear zone (PLz) and it appears that the zone extends well beyond the exposed limits of the Adirondack massif (Figure 2). Strong deformation in the area surrounding Piseco Lake was first noted by Cannon (1937). Fakundiny (1996) and Fakundiny et al. (1994) proposed a fundamental structural discontinuity in this area based largely on geomorphological criteria and the trace of the Prospect Fault (Valentino et al., 2012). In addition, fundamental lithologic differences have been noted across the boundary as AMCG rocks are rare or absent to the south, whereas tonalitic rocks (ca.1300-1350 Ma) of the Southern Adirondack arc terrane have not been recognized north of it. The PLz is developed in a suite of granitoids (Piseco Lake Granitoids – PLG) that span the width of the Adirondack massif outcrop belt, but more importantly the belt strongly correlates with the pronounced linear magnetic anomaly.

The PLz is defined by spectacular L-S, L>S and L-tectonites developed in the Piseco granitoids, with an east-west arching trend. This trend continues smoothly to the eastern margin of the Adirondack Dome, where before plunging beneath Paleozoic cover rocks to the east at Spier Falls on the Hudson River, where the lineation and foliation gradually transitions to a north-south orientation defining a broad (10’s of km) open vertical fold. The PLz comprises parallel structural domains that developed contemporaneously: 1) a broad (10-15 km wide) tabular steeply dipping zone of granitic mylonite (southern domain); 2) a series of flanking upright (5-10 km wide) foliation domes (northern domain) (Cannon, 1937; Glennie, 1973; McLelland, 1984; Wiener et al., 1984). There is no apparent structural discontinuity between the foliation of the southern mylonite zone and the foliation in the dome region. As well, lineations are consistent in orientation and defined by the same minerals within both domains. Collectively, these structural domains make up a zone of ductile deformation that is upward of 30 kilometers wide, crossing the exposed width of the boundary between the Central and Southern Adirondacks.

## The Southern Domain – Shear Zone

There is a well-defined textural transition that occurs in variably deformed granitoids in the southern limit of the PLz. From south to north, the granitic rocks exhibit moderately deformed megacrysts of K-feldspar, well developed mylonite with remnant K-feldspar grains (~5-10 mm in diameter) and finally domains of ultramylonite (Valentino et al., 2008). Penetrative foliation is defined by dynamically recrystallized quartz, K-feldspar and plagioclase, and alignment of micas. Rocks within the zone are made of fine-grained aggregates of these minerals in strong alignment. Locally there are 2-6 cm long K-feldspar megacrysts and/or porphyroclasts preserved which are consistent with a plutonic origin. Pegmatitic and aplitic layers provide evidence of strong transposition of primary contacts (Piaschyk et al., 2005; Valentino et al., 2008). Rocks with steeply dipping penetrative mylonitic fabric persist over an across strike distance of more than 10 km, eventually merging with the highly deformed granitoids in the northern domes. Lineations in this zone are subhorizontal and defined by dynamically recrystallized quartz, K-feldspar, plagioclase, and accessory mafic minerals such as hornblende, biotite or chlorite. Shear sense indicators are abundant and occur at the meso- and microscopic scale. K-feldspar megacrysts form Type I S-C fabrics,□□- and □- porphyroclasts and domino-structures (Figure 4). Where the L-S fabrics are well developed, consistently the shear sense indicators are sinistral across the entire 10 km wide zone of the southern domain.

## Northern Domain – Dome

Penetrative foliation and lineations define several upright antiformal domes (Cannon, 1937; Glennie, 1973; Weiner et al., 1984; Valentino et al., 2012) that flank the north side of the steeply dipping mylonite zone (southern domain). These domes have subhorizontal arching axes that trend approximately 110° in the east, 090° in the central region, and 080° in the west. The largest of these domes occurs in the vicinity of Piseco Lake. The foliation on the dome limbs dips moderately with mineral elongation lineations that trend at 110° and plunge about 10° eastward. In the crest of the domes, foliation is not well developed and penetrative lineations are defined by mineral rods, rods of mineral aggregates, and mineral ribbons. Lineations in the domes are intensely developed, and in many places the linear fabric is dominant over the weak foliation (L>>S) with grain aggregate aspect ratios upward of 60:1, in the L-parallel and S-perpendicular plane, as originally noted by McLelland (1984). Some rocks, of considerable thickness ~1-2 km, in the core of the domes lack foliation altogether and are true L-tectonites. Microscopic examination showed that the lineations are defined by dynamically recrystallized ribbons and rods of quartz, K-feldspar, plagioclase, in addition to streaks of magnetite, biotite, chlorite and occasionally muscovite (Valentino et al., 2008).

Like the rocks in the southern domain, shear-sense indicators are abundant in the dome rocks that are not dominated by L-tectonite. They include Type I S-C mylonite, σ - and δ -porphyroclasts of K-feldspar, and asymmetric polymineralic tails around porphyroclasts (Figure 4). These kinematic indicators reveal a consistent sinistral-shear sense on both the north- and south-dipping L-S tectonite domains of the domes.

## Magnetic Anomalies

The magnetic anomaly map of North America (U.S.G.S. – Mineral Resources Online Spatial Data) has an interesting distribution of high and low anomalies in the Adirondack region that roughly correlate with major metaigneous and metasedimentary rock bodies (Figure 2). The corresponding magnetic anomaly for the anorthosite bodies is low, while vast regions underlain by charnockitic gneiss express high anomalies. Regions of the Adirondacks with substantially thick sequences of supracrustal rocks generally have low magnetic anomaly signatures, similar to the anorthostie bodies. Magnetic anomaly patterns in the Adirondack lowlands are parallel to the overall northeastern striking geologic structures that control the geographic distribution of various metaigneous and metasedimentary rock bodies. Within the Adirondack Highlands, the northern region can be characterized as having magnetic anomalies with a nebulous, or unorganized, structural pattern, most likely the result of the vast anorthosite bodies that make up the Mount Marcy massif.

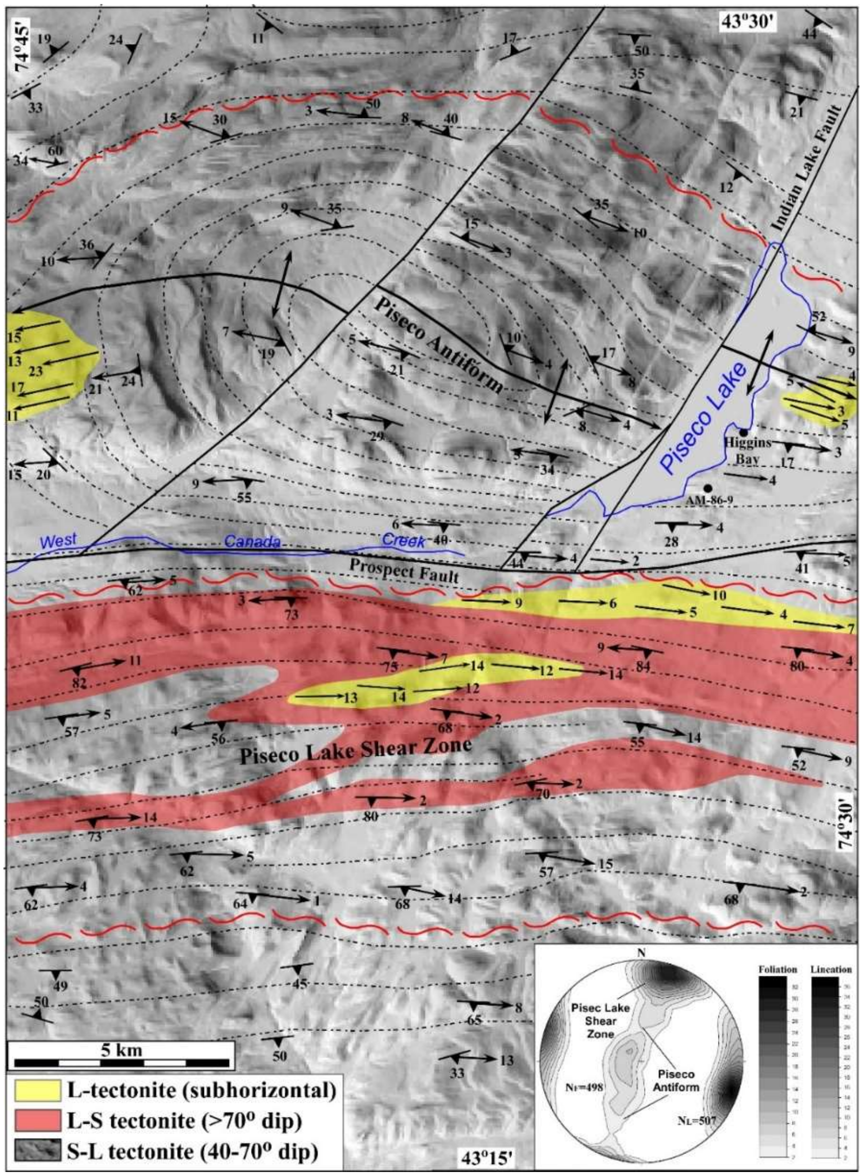



***Figure 3.*** *Simplified structural geology map for the Piseco Lake shear zone and dome plotted on a gray-scale digital elevation model. Location is shown on Figure 2. Inset shows lower hemisphere contour stereogram for poles to foliation and lineation data collected in the mapped region. Note that the lineation data is a composite plot for both the antiform and shear zone domains; foliation is designated separately. The sinuous dashes show the approximate boundaries of the Piseco Lake shear zone in this area. The axis of the Piseco antiform is shown in addition to Mesozoic faults (heavy black lines) that offset the antiform axis near Piseco Lake (Valentino et al., 2012).*

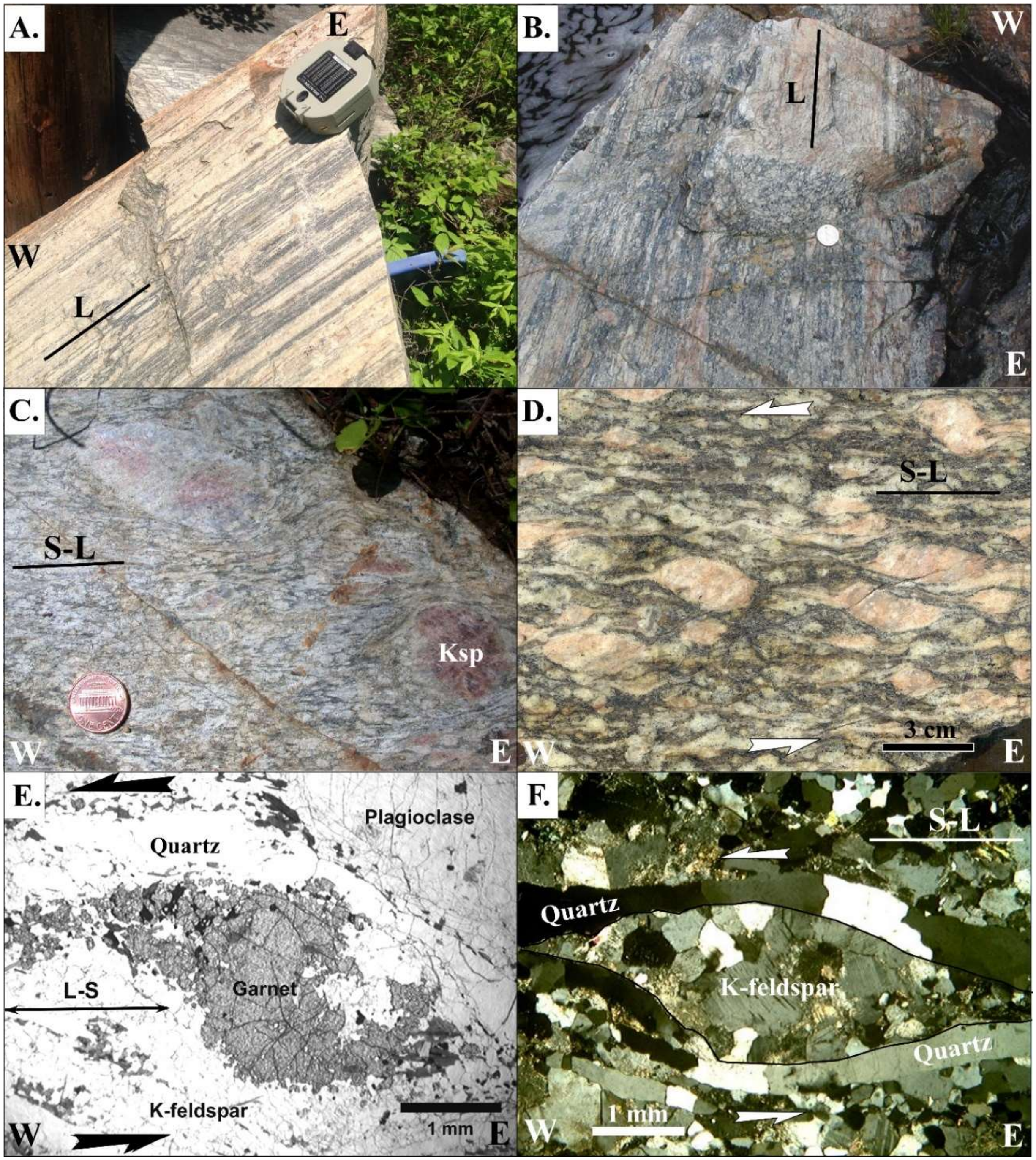



***Figure 4.*** *Examples of deformation fabrics in the Piseco shear zone. A. Strongly lineated granitic mylonite from the southern flank of the structural dome near Piseco Lake. B. Tectonite dominated by mineral aggregate elongation lineations from the core of the dome. C. Well developed granitic mylonite from the southern steeply dipping shear zone. D. Augen mylonite with relict K-feldspar megacrysts forming asymmetric σ-porphyroclasts on the northern flank of the dome. E. Photomicrograph of asymmetric garnet enveloped in quartz ribbons, and recrystallized K-feldspar and plagioclase (ppl). F. Photomicrograph of highly deformed granitic gneiss from the Piseco shear zone (xpl) displaying polygonal grains of dynamically recrystallized K-feldspar and quartz ribbons. The aggregate of K-feldspar (center) is surrounded by quartz ribbons and the overall shape forms a recrystallized asymmetric sigma-porphyroclast.*

With the exception of small anorthosite bodies with ovoid low magnetic anomalies, the structural pattern of anomalies in the central and southern Adirondacks is strikingly regular and trends roughly east-west parallel to the structures of the Central Adirondack Shear System (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008). One of the most pronounced high magnetic anomalies extends unbroken across the entire exposed width of the southern Adirondacks, forming a broad open arch that curves to a north-south trend in the east and appears to be sharply truncated near Saratoga Spring, NY. This anomaly extends west of the Adirondacks where it bifurcates and continues beneath the Appalachian basin of central NY. This high magnetic anomaly has the most structural continuity for any anomaly associated with the exposed basement geology, and it directly correlates with the highly deformed Piseco granitoid suite and related shear system (McLelland and Isachsen, 1986; McLelland et al., 1988; 2004; Gates et al., 2004; Hamilton et al., 2004; Valentino and Chiarenzelli, 2008).

## ORIGIN OF THE PISECO LAKE GRANITOIDS

The limited compositional range, megacrystic texture, coarse grain-size, and large volume of the Piseco Lake granitoids suggest they are an intensely deformed and deep-seated suite of granitic plutons. The occurrence of deformed and transposed cross-cutting aplites and pegmatites is in concert with this interpretation (Piaschyk et al., 2005; Price et al., 2003). Previous U-Pb zircon studies (McLelland et al., 1988; Valentino et al., in press) confirm that the granitic precursors were intruded into the region by at least 1155 Ma and likely earlier (ca. 1200 Ma). The work of Heumann et al. (2006) has suggested that highly deformed paragneisses in contact with the Piseco Lake granitoids underwent anatexis and zircon and monazite growth from 1160-1180 Ma. If the Piseco Lake granitoids provided some, or all, of the heat that facilitated the melting, a significant volume of melt/heat must have been present by 1180 Ma. This is consistent with our preliminary zircon studies previously published (Valentino et al., in press), indicating intrusion prior to AMCG plutonism at ca. 1155-1165 Ma and likely at ca. 1200 Ma.

The fabric in the Piseco Lake granitoids and surrounding mylonitic pssamitic/pelitic gneisses, and hence the gross structure of the shear zone itself, can be tied to zircon and monazite growth during high-grade ductile deformation and melting during the waning phase of the Shawinigan Orogeny (Heumann et al, 2006). This is emphasized by the lack of younger “Ottawan” zircons in many of the paragneiss localities in the northwestern, central, and southern Adirondacks studied by Heumann et al. (2006) and in mylonitic gneiss analyzed for this study. Zircons younger than 1080 Ma are nearly absent, indicating minimal, if any, zircon growth during the Ottawan Orogeny along the Piseco Lake Shear Zone; but volumetrically significant metamorphic zircon growth occurred throughout the Shawinigan Orogeny. This in turn provides further evidence that the gross crustal architecture of the Central and Southern Adirondack Region and Central Adirondack Shear System was developed during the Shawinigan Orogeny. The Piseco Lake granitoids provide direct evidence of the processes at work in the deep crust and likely, upper mantle, just prior to and during, the Shawinigan Orogeny. In essence they, and their intense deformation, set the stage for the voluminous AMCG intrusions that followed (Valentino et al., in press).

The kinematic studies on all scales from microscopic to megascopic (Chiarenzelli et al., 2000; Gates et al. 2004; Valentino et al., 2008) indicate left-lateral motion focused along the shear zone and domes developed in the Piseco Lake granitoids. The focus of this intensive deformation, between two distinct terranes, has led to the conclusion that it demarcates a cryptic suture (Chiarenzelli et al., 2011; 2010a; Valentino et al., in press. Antiformal domes and the counterclockwise rotation of rigid anorthosite bodies (Chiarenzelli et al., 2000; Gates et al., 2004) suggest bulk crustal flow throughout the CASS region, as do vertical zones of L-tectonite and rocks with pronounced linear fabrics. Taken together these observations are consistent with the intrusion of a voluminous suite of suture-stitching plutons of arc affinity within a sinistral, oblique-convergent, ductile shear system during the Shawinigan orogeny.

## TECTONIC MODEL

Any tectonic model proposed to explain the origin and deformation of the Piseco Lake granitoids must take into consideration their field relations, age, geochemical and isotopic trends, intense deformation, kinematics, geophysical signature, and the geologic context of the region. Various lines of evidence presented in Valentino et al. (in press) and summarized herein, suggest that the granitoids are the deformed roots of a continental batholith which developed just prior to, and during, the Shawinigan Orogeny and preceded voluminous AMCG plutonism.

Paleogeographically, the plutonic protoliths of the gneisses appear to represent the product of northward subduction of oceanic crust beneath the Southern Adirondack arc, Trans-Adirondack Back-Arc basin, and the southeast edge of Laurentia, believed to be coincident with the Black Lake Shear Zone at this time (Chiarenzelli et al., 2010b; Wong et al., 2012; and Peck et al. 2004; 2013). Telescoping of this basin during closure led to massive shortening and collapse of the basin and attendant SW-directed thrusting and nappe formation. However, the dominant fabric, which overprints early events, was left-lateral plastic deformation related to oblique collision. The imprint of this late Shawinigan event is recorded at all scales from microscopic kinematic features to “mega” porphyroclasts and elongate structural domes (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008) to a regional subhorizontal lineation.

AMCG plutonism began during the waning stages of Shawinigan orogenesis (Valentino et al., in press). This can be seen in the Marcy anorthosite massif where large, relative intact bodies of meta-anorthosite are cut by thin (1-2 cm) garnet-pyroxene shear zones, many with an E-W orientation (Hecklau et al., 2014). Intrusive boundaries, along coarse-gabbroic pegmatites and fine-grained granitic sheets, are often zones of intense strain. This suggests the meta-anorthosite body, although rigid and resistant to ductile deformation in general, underwent ductile deformation along heterogeneities. Coronitic metagabbros, thought to be the parental magmas from which anorthosite was derived via fractional crystallization (Regan et al., 2011), may provide a lower limit on regional ductile deformation associated with the Shawinigan Orogeny. Coronites display a wide range of deformational and metamorphic features ranging from equant bodies with pristine coronitic textures to elongate, curvilinear belts of garnetiferous amphibolite. In many instances garnetiferous amphibolites retain a small core of coronitic metagabbro that survived deformation (Lagor et al., 2013). Dating of one coronitic metagabbro from Dresden Station yielded an age of 1144+/-7 Ma via U-Pb zircon methods (McLelland and Chiarenzelli, 1989) and extends the range of ages generally attributed to the AMCG suite (ca. 1155-1165 Ma) to at least 1144 Ma. This age overlaps the age of 1151+/-9 Ma for monazite growth in the pelitic gneisses intruded by the Dresden coronitic metagabbro (Grover et al., 2013), indicating the growth of high-grade minerals in compositionally appropriate rocks during intrusion of the coronites.

The transition from arc magmatism represented by the Piseco Lake granitoids to intrusion by anorthosite massifs and cogenetic granitic rocks (AMCG suite) occurred within a relative short period of time; at most several tens of millions of years (Figure 5). This spatial and temporal link suggests that intense deformation associated with the Piseco Lake granitoids was the kinematic trigger for AMCG magmatism. Most models for AMCG rocks invoke for slab detachment or delamination, but few details are known. One possible explanation presented by Valentino et al. (in press) and favored here is that highly oblique subduction and orogeny-parallel deformation may have contributed to detachment and delamination. Shear stress may have reactivated old crustal weaknesses (transform-faults) and/or created tears that propagated into the descending slab and lower plate, resulting in splitting and fragmentation of the rigid lithosphere. Catastrophic failure of this type would allow rapid ascent of asthenospheric mantle, decompressional partial melting of the asthenosphere, and subsequent melting of underlying crustal rocks. Given left-lateral kinematics documented, the progressive closure of the ocean basin the foci of asthenospheric rise and production of AMCG magmatic rocks would propagate from west to east.

An analog for this model would incorporate aspects of the Andean margin where subducting slabs of different age and density behave as independent lithospheric "tiles". These tiles are separated by oceanic fracture zones, subducting at different rates and angles beneath South America, and control the distance between the magmatic arc and trench. In combination with highly oblique convergence, the oceanic fracture zones between these "tiles" would serve as inherent zones of weakness ultimately causing catastrophic tears in the subducting lithospheric plate. A similar scenario involving tearing and propagation of a subducting slab undergoing buckling is currently occurring along the Puerto Rican trench (Meighan and Pulliam, 2013; Meighan et al., 2013).

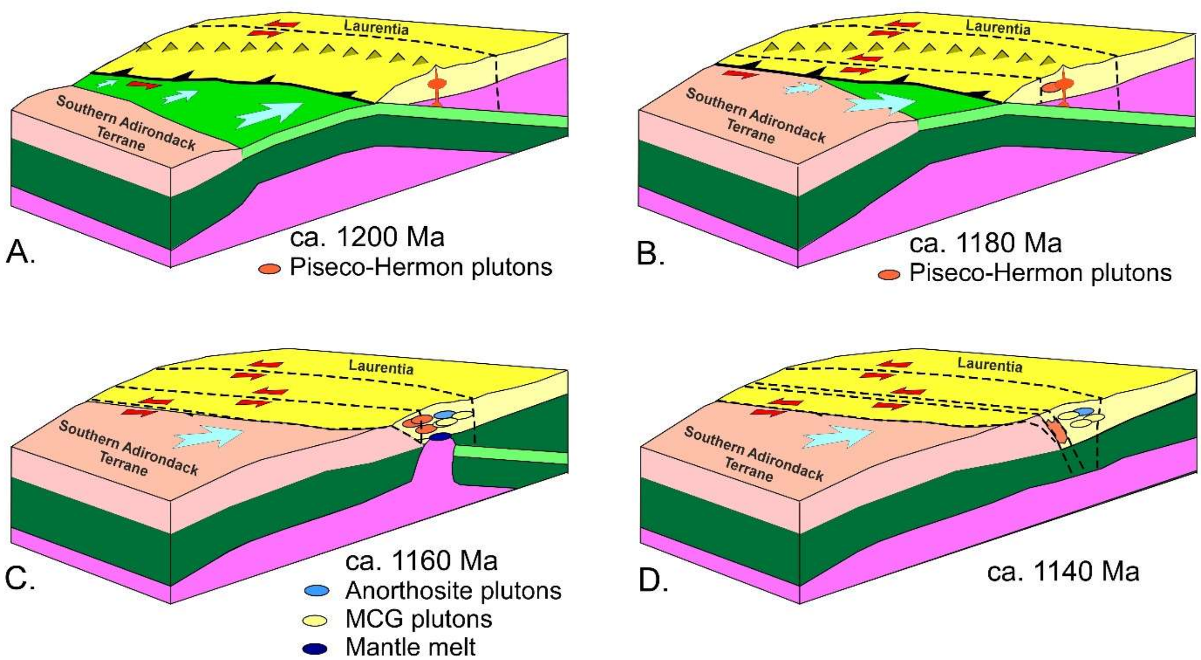
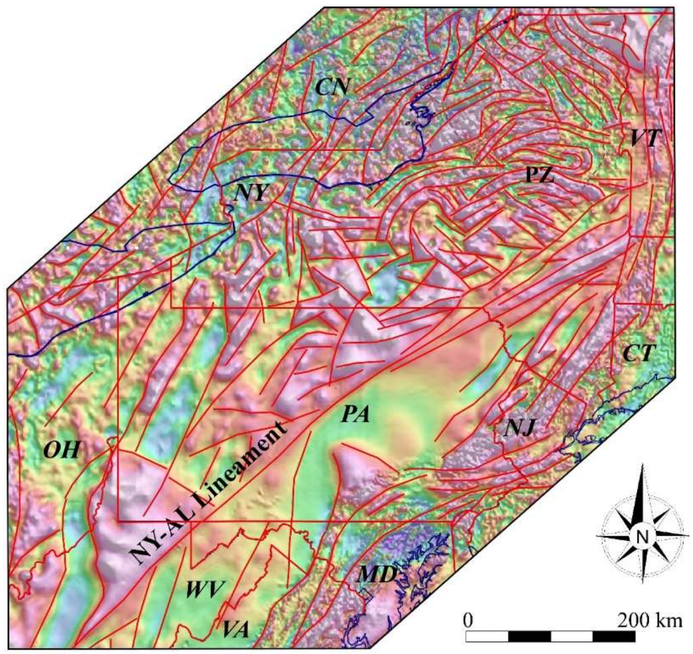


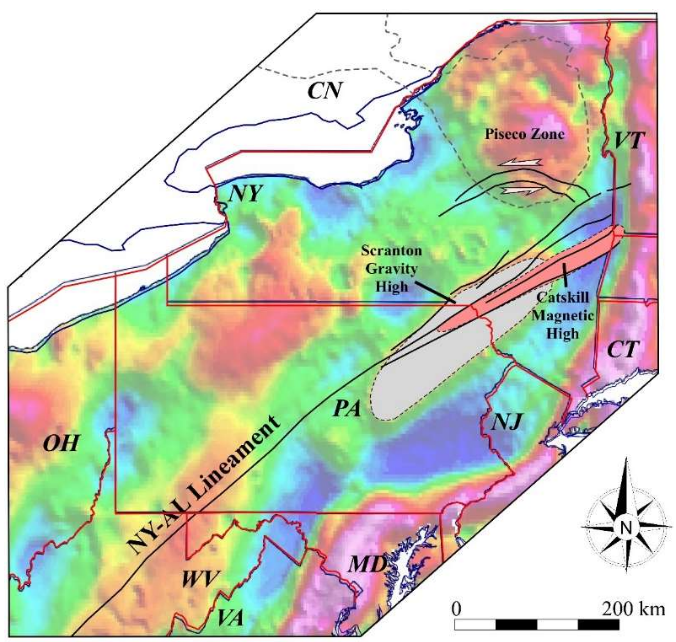

***Figure 5.*** *Tectonic model depicting the oblique subduction, subsequent oblique collision and sinistral transform boundary that forms on the granite-stitched suture between the Southern Adirondack Terrane and the Adirondack Highlands (Laurnetia). Refer above for details.*

This tectonic model would not be complete without discussing the proximity of the Piseco shear zone to the New York-Alabama magnetic anomaly lineament (NY-AL), an anomaly that defines a major basement boundary that crosses eastern Laurentia (Steltenpohl et al., 2010). The origin of the anomaly is not definitively known, however, recent researchers have suggested that the linear nature of the anomaly is associated with an intracrustal transcurrent shear system with either dextral or sinistral displacement.

Between northwestern Georgia and northeastern Pennsylvania, the NY-AL lineament trends without deviating about 046°, a distance greater than 1000 km (Figure 5). With an easterly change in trend of 15-20°, the lineament is shown to continue northeast and include the Catskill magnetic high extending from northeastern Pennsylvania to the Vermont-Massachusetts border region (Figure 6A). This trend crosses the Scranton gravity high, proposed to be a Neoproterozoic rift basin (Rankin, 1976; Hawman and Phinney, 1992). However, if the 046° trend of the >1000 km long NY-AL lineament is projected into southern New York, it would correspond to the western margin of the Scranton gravity high (Figure 6B), in addition to the apparent truncations of a series of magnetic high anomalies, including the Piseco anomaly, and by association the granitoids and shear zone. Based on the transcurrent deformation associated with the PLz, we propose the zone to be a splay off of the major crustal boundary that is manifest as the NY-AL magnetic lineament (Steltenpohl et al., 2010).




A.

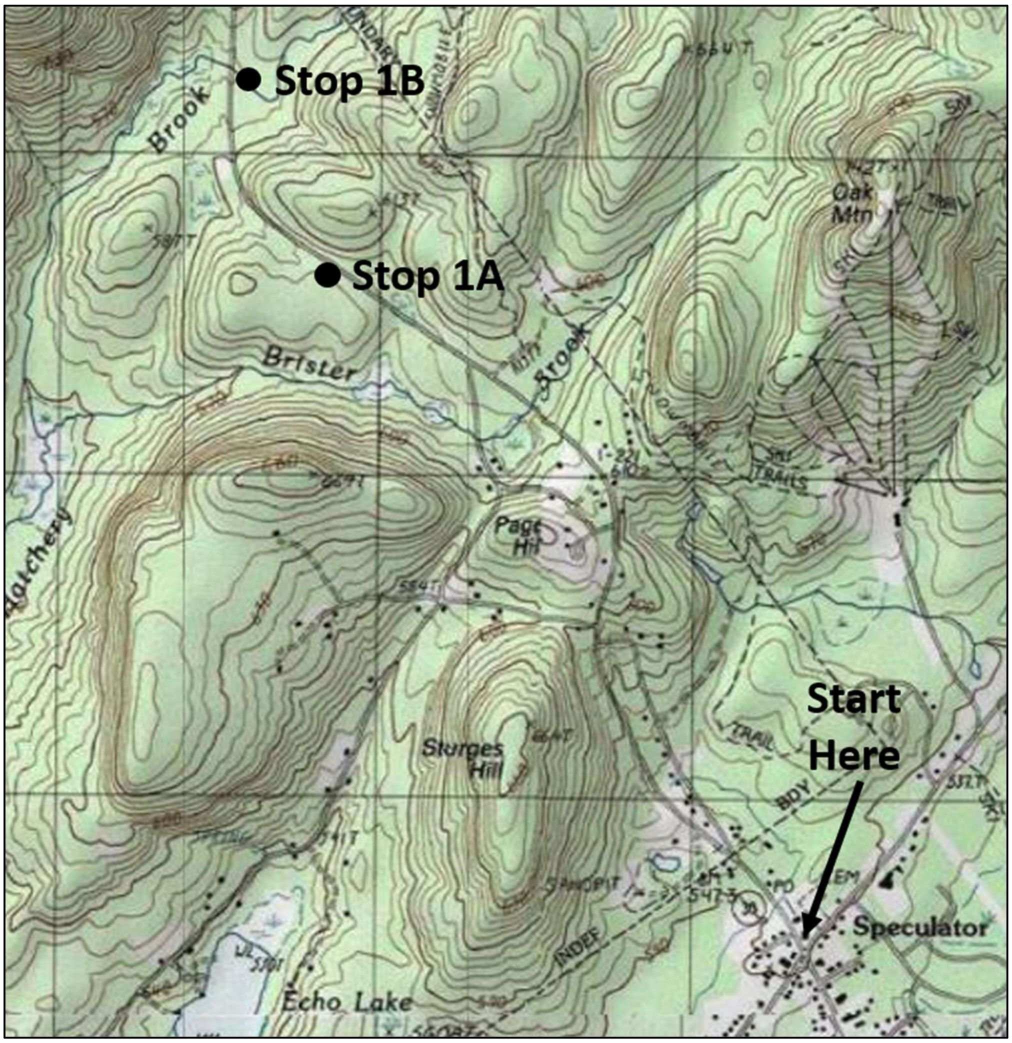



B.

***Figure 6.*** *(A) Magnetic and (B) gravity anomaly maps with interpreted lineaments. The New York-Alabama lineament (NY-AL) is labeled along with the Scranton gravity high and the Catskill magnetic high. Outline of the Adirondacks is represented by the dashed line and the Piseco Lake shear zones (PZ) is shown with shear sense arrows (Maps from USGS respository online).*

## FIELD GUIDE AND ROAD LOG

Assemble in the parking lot at the Charlie John's market located the intersection of Route 8 and Route 30 in the village of Speculator, New York (Starting Point on map below). From this point the trip heads north on Route 30 to the first stop.




Mileage:
0.0 Assembly point
1.7 Stop 1: Park on the wide shoulder on the east side of Route 30. The outcrop is on the west side of the road, the traffic is light but fast, so be very careful crossing the road.

STOP 1A: Supracrustal rocks of the Adirondack Highlands, just north of the Piseco Lake shear zone (18T 549883 m E, 4818851 m N)

There are several rock types that can be observed at this outcrop, along with the contacts and primary compositional layering. The northern ¼ of the outcrop consists of garnet amphibolite, the next ~ ¼ of the outcrop is calc-silicate gneiss and the southern ½ is fine-grained quartzo-feldspathic gneiss locally interlayered with highly folded marble (Figure 7). Complex sheath folds with sub-horizontal tight, isoclinal and sheath folds of foliation and compositional layers dominate the rock, particularly in the gneiss (trend to 110$^o$). Excellent views of the folds are seen on top of the southern part of the outcrop. The contacts between the rock types are also folded in similar fashion. Matrix minerals define lineations that are E-W and subhoriziontal, but are variable in orientation due to folding. Overall, the diverse lithologies and style of deformation are typical for the supracrustal rocks located north of the Piseco Lake grantioids. At this point, note that primary compositional layering is preserved at this outcrop.

***Figure 7.*** *Photograph of folded quartzo-feldspathic gneiss and marble (recessed part of outcrop). Note the stalk of grass for scale.*

STOP 1B: Piseco Lake granitoid (18T 549600 m E, 4819452 m N)

From Stop 1A, walk north along Route 30 approximately 400 meters to Hatchery Brook crossing, and then follow the foot path on the east side of Rt 30 to the small waterfall. The water falls over a small ledge of Piseco Lake granitoid, and observable outcrops occur to the right. At this location, the megacrystic granitoid is mildy deformed (Figure 8). There is a weak alignment of deformed feldspar and quarts forming shallowly dipping foliation and mineral lineation that trends approximately east-west. Note that the mineral elongation lineation is parallel to the axes of small folds and mineral lineations at Stop 1A. Also note that this occurrence of Piseco Lake granioid is north of the main igneous body that will be observed later on this trip, and that this location will be the only place where you will see Piseco Lake granitoid in a state of low strain. Walk back to vehicles and follow trip directions.

From Stop 1, proceed north to a safe place to turn around, and return to the intersection of Route 30 and Route 8 in the village of Speculator.

Mileage:

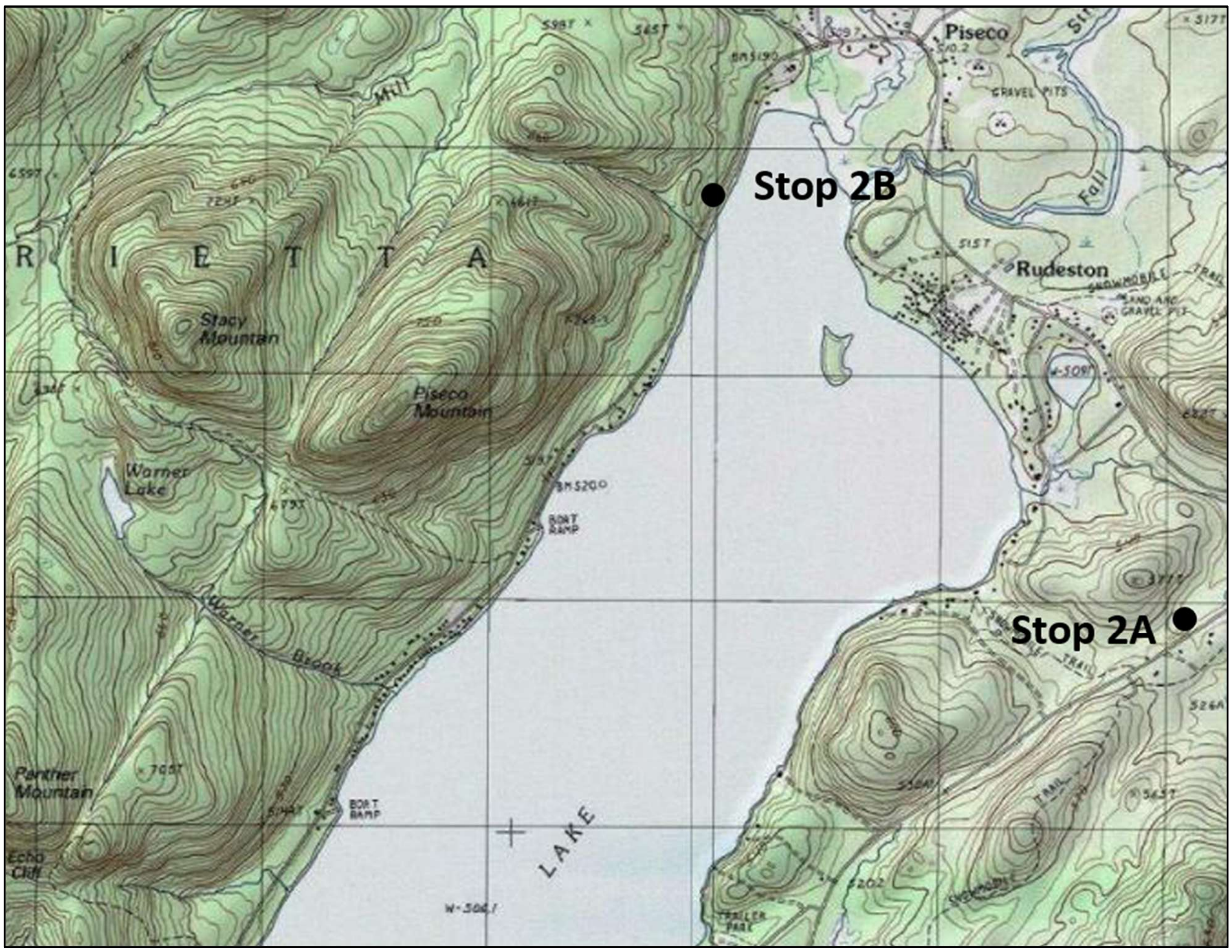
| | |
|---|---|
| 3.4 | Turn west on Route 8 in the Village of Speculator. |
| 5.4 | First roadcut on right is highly lineated granitic gneiss in the margin of the PLsz. |
| 12.2 | Intersection with Old Piseco Road in Piseco, NY. |
| 13.3 | Park on north side of Route 8 at the low roadcut for Stop 2. |

***Figure 8.*** *Piseco Lake graniotid at Hatchery Brook.*

STOP 2A-D: L-S and L>S fabrics in the Piseco dome – driving traverse

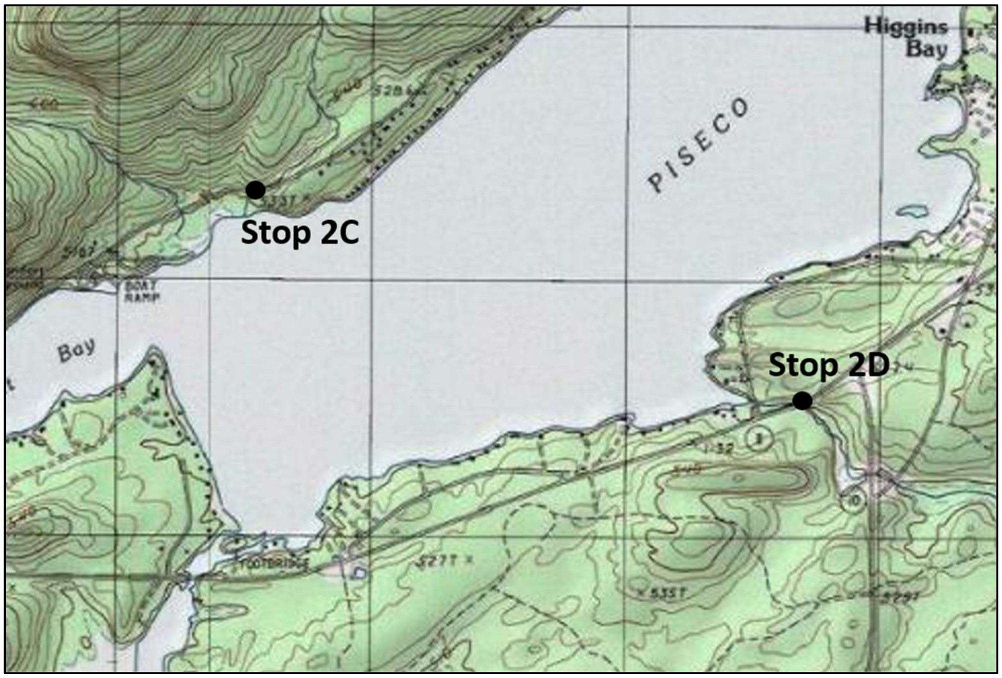
Stop 2A: 18T 540256 m E, 4808187 m N
Stop 2B: 18T 537957 m E, 4809931 m N
Stop 2C: 18T 534370 m E, 4805562 m N
Stop 2D: 18T 536919 m E, 4804838 m N

The Piseco Lake shear zone includes the northern foliation domes that merge with the steeply dipping shear zones to the south. This series of field stops shows variations in the attitude and type of fabrics that occur in the core of the dome at Piseco Lake. Stops 2A to 2D are a driving traverse around Piseco Lake, the type location of the Piseco antiform. At all of these localities, dynamically recrystallized feldspars and quartz form spectacular ribbon- and rod-shaped mineral lineations (McLelland, 1984), in addition to accessory biotite and magnetite. In many places, the alignment of ribbons forms the foliation in this outcrop. Individual quartz-ribbons have aspect ratios upward of 60:1. At Stop 2A, the foliation is weakly to moderately developed, and dips shallowly southward at the eastern part of the outcrop, but is steeply dipping at the western end of the outcrop. The transition between these different foliation attitudes is difficult to determine because the intensity of the foliation is variable. Lineations are penetrative on all scales, and consistent in attitude (Trend: 110°; Plunge: 05°). Stop 6A occurs on the southern flank of the map-scale dome portion of the Piseco antiform. At the western end of the outcrop there are rods of amphibolite (10-30 cm diameter) within the granitic gneiss.

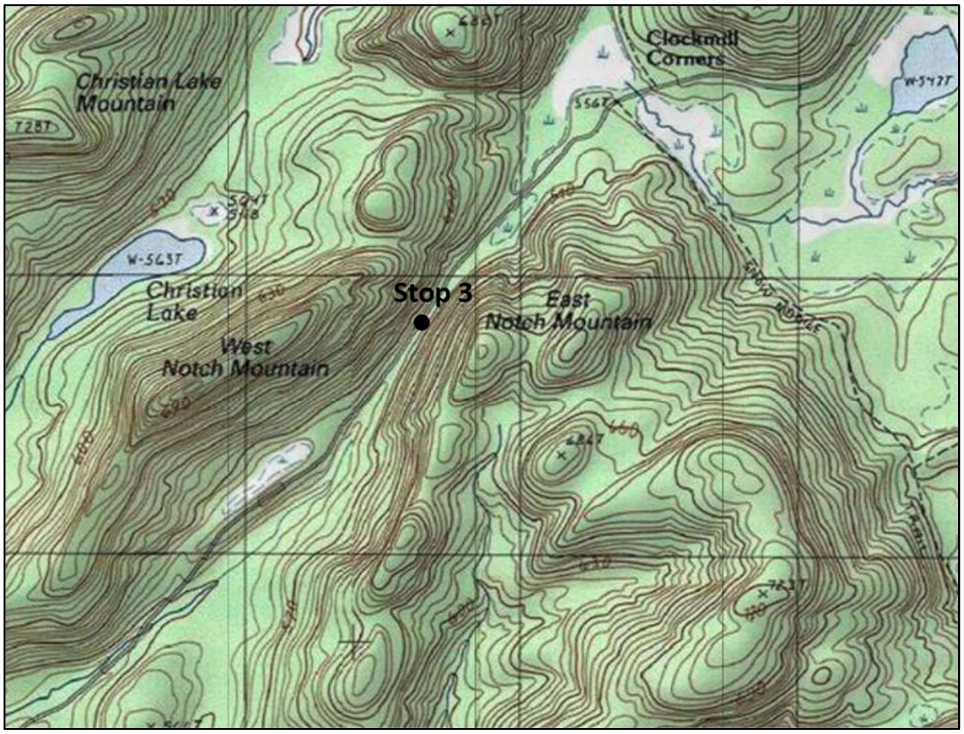



There is an apparent Mesozoic fault that traces down the western side of Piseco Lake and has locally displaced parts of the Piseco dome (Figure 3). At Stop 2B, again the foliation is weakly developed with a penetrative shallowly plunging lineation. However, the foliation, where it can be observed, dips northerly. As you drive southwest along the western side of Piseco Lake, note that the foliation gradually shallows and then dips southerly. There are several outcrops that can be observed where this transition in foliation attitude occurs. The rock fabrics at Stop 2C are similar to those at Stops 2A and 2B, but again the variably developed foliation dips toward the south. Stop 2D is located at the intersection of Rts. 8 and 10, and the folation and lineation is penetrative.

Common to all of these field stops is that biotite and sometimes chlorite blades form microscopic lineations and foliation parallel to the macroscopic structure. Rare grains of hypersthene have been found, but they always have well developed overgrowth textures that include biotite and chlorite. The biotite and chlorite are the most abundant index minerals in the granitic gneiss, and suggest the deformation was last active under low- to moderate- metamorphic conditions, although probably began at much higher conditions to account for the relict grains of hypersthene.




Mileage:
13.3 Turn around and proceed east on Rt. 8 about 0.5 mile. west on Rt. 8.
13.8 Turn north and follow the road around Piseco Lake to Stops 2B and 2C.
22.7 At the intersection with Rt. 8, turn east and proceed about 2.9 miles.
23.6 Turn south onto Rt. 10 and park for Stop 2D. Proceed south on Rt. 10 about 1.2 miles.
24.8 Turn west onto Powley Road (becomes a gravel road) and continue 4.9 miles.
29.7 Park where Powley Road traverses through the Notch.




STOP 3: Steeply dipping mylonite zone of the southern PLsz (18T 530638 m E, 4799018 m N)

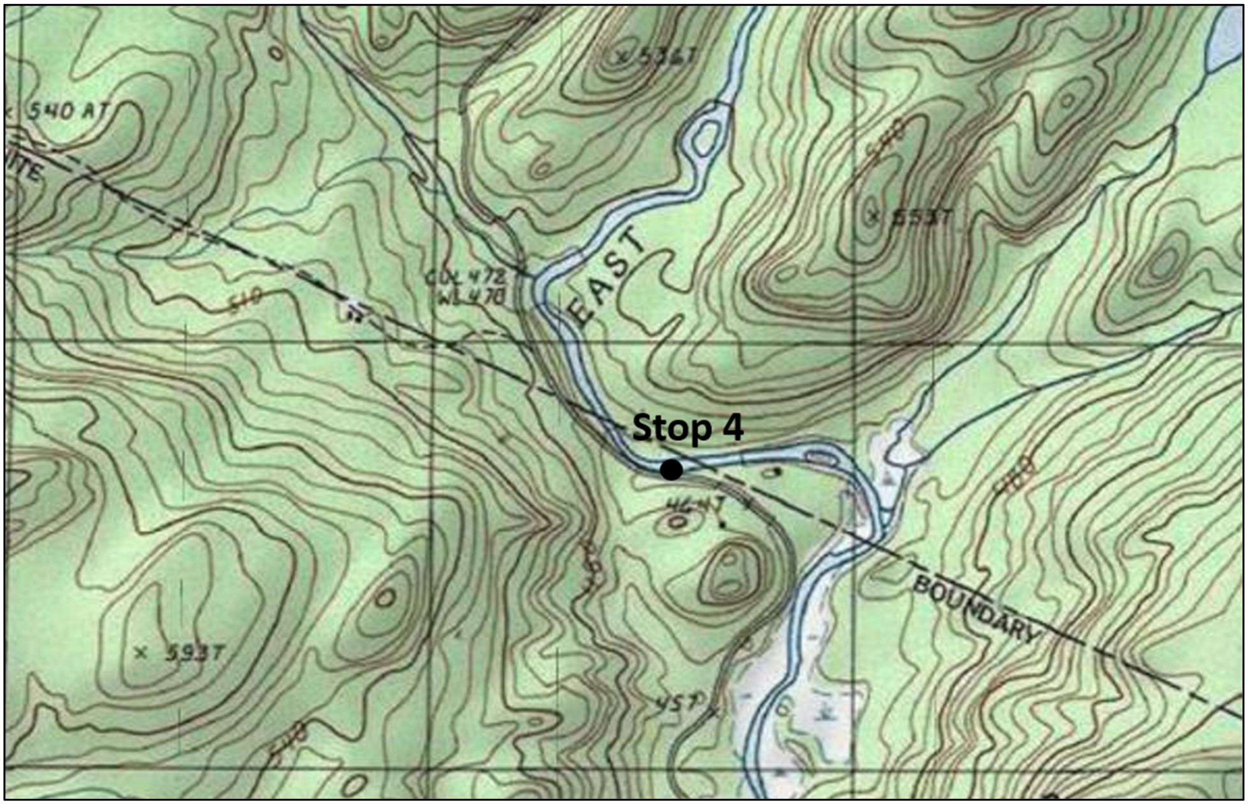
Along Powley Road, depending on the time of year and the amount of road maintenance, there are a sub-continuous series of pavement exposures located in the road bed, as well as in the gutter on the east (northeast-bound) side of the road. Due to the nature of this location, the extent of the exposed rock at this stop changes yearly, so some or all of the rock described here may be viewable depending upon the time of the season in which the stop is visited (best later in the summer). The best exposures occur along the road between West and East Notch Mountains.

All rocks in this region are very similar in mineral content, and vary only in detail with regard to mineral percentage and fabric type and intensity. The rock is dominantly granitic gneiss with intense subhorizontal to shallowly plunging mineral elongation lineation that trends on average about 095 $^{o}$, with steeply dipping generally east-west striking foliation. Both fabric elements are defined by ribbons of quartz, and ribbons of aggregate feldspar and quartz (generally 1-5 cm long depending upon grain size). Intensity of the fabric varies across strike at the 50 cm scale, with local layers of significantly coarser-grained fabrics (grains up to 1 cm in diameter). There are also places where the foliation intensity varies as seen at the field stops around Piseco Lake. Rare amphibolite bodies that are 10's of cm thick occur within the granitic gneiss. Shear sense indicators are abundant in the granitic rocks and consistently show sinistral shear sense.

Mileage:

35.7 Continue south on Powley Road about 6 miles and park. Outcrops are located along the bank of East Canada Creek.

STOP 4: Southern extent of steeply dipping mylonite (18T 527500 m E, 4790961 m N)

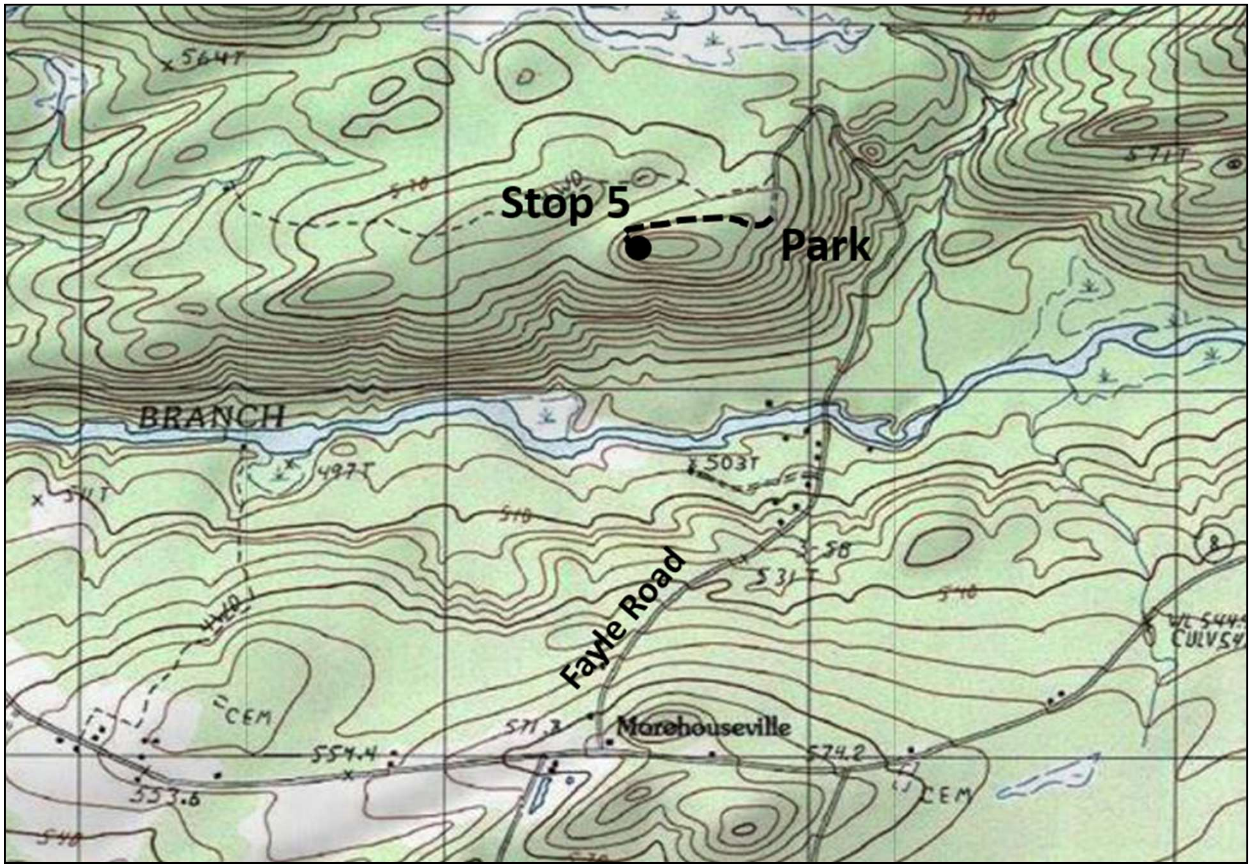



Here the granitic gneiss fabrics contain both a penetrative foliation and lineation.  The foliation is steeply dipping and strikes about east-west.  Mineral elongation lineation defined by linear aggregates of quartz and feldspar are subhorizontal.  The extent of readily available bedrock exposure diminishes south of this location, so this may be the southern-most exposure of the Piseco Lake shear zone.  Note that this location is about 21 kilometers across strike from the northern side of the Piseco dome where the pronounced lineation occurs.

Mileage:

46.6 Turn around and proceed back to the intersection of Powley Road and Rt. 10, about 10.9 miles.
47.8 Continue north on Rt. 10 about 1.2 miles to the intersection with Rt. 8.
59.9 Turn west onto Rt. 8 and drive 12.1 miles to Moorehouseville.
61.5 Turn north onto Fayle Road, proceed north.  Cross a one lane wood bridge and drive to an opening in the trees at the end of Fayle Road.  Park and hike to the west about 350 meters to the west end of the small linear hill.

STOP 5: L>>S and L-tectonite in the core of the Piseco antiform (18T 518563 m E, 4805631 m N)




Excellent outcrops on the northwestern side of a small hill just west of the parking area. Follow the dirt road to a path through the woods, and then head up hill to the south to the outcrops. This outcrop of granitic gneiss contains domains of L>S and L>>S. The L>S domains contain large and numerous σ-type shear sense indicators, some δ-type are present but are much less frequent. The porphyroclasts are large about 1-3 cm and the recrystallized porphyroclastic material is often wrapped with a quartz ribbons. The interpreted shear sense is low-angle and left lateral. The foliation strikes east-west and dips gently to the south. Return to the vehicles by following the path. At this point the trip is over. Retrace your trip to Route 8. If you are headed back to Lake George, then follow Route 8 back to Speculator, NY, then turn south on Route 30.

End of trip.

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