Trip B-1

L- VERSES S-TECTONITE FABRIC VARIATIONS WITHIN THE SOUTHERN ADIRONDACK SHEAR ZONE SYSTEM: PROGRESSIVE DEFORMATION ASSOCIATED WITH A SINISTRAL CONJUGATE TO A GRENVILLE SYNTAXIS

David W. Valentino, Dept. of Earth Sciences, SUNY Oswego, Oswego, NY 13126
Gary S. Solar, Dept. of Earth Sciences, SUNY Buffalo, Buffalo, NY 14222
Jeffrey R. Chiarenzelli, Dept. of Geology, SUNY Potsdam, Potsdam, NY 13676
Alexander E. Gates, Dept. of Geological Sciences, Rutgers University, Newark, NJ 07102
Paul Freyer, Dept. of Earth Sciences, SUNY Oswego, Oswego, NY 13126
Rachel E. Price, Dept. of Geological Sciences, Rutgers University, Newark, NJ 07102

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.

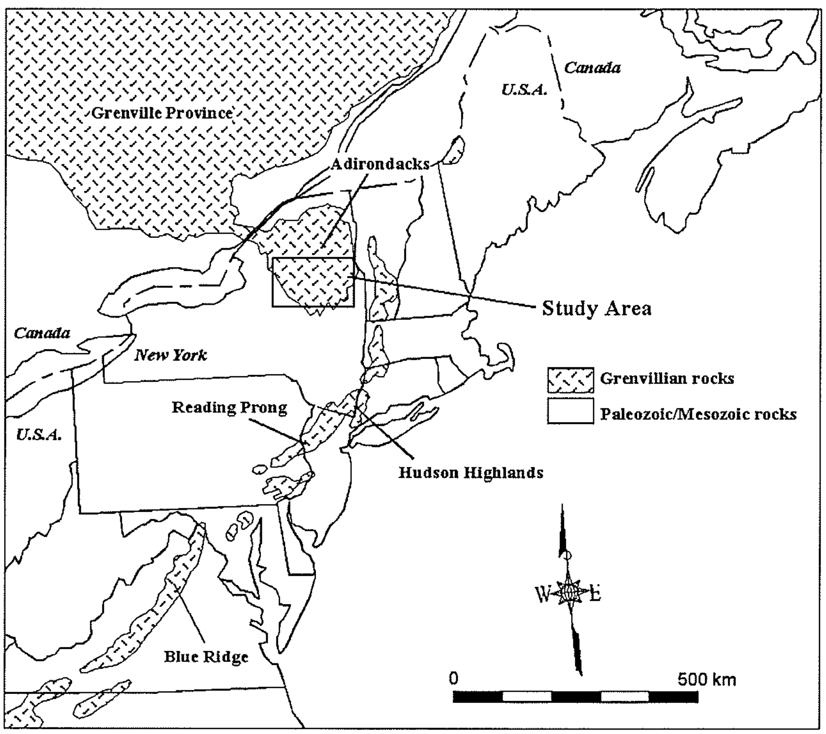


Figure 1. General map of the northeast U.S.A. and eastern Canada showing the distribution of Grenvillian basement rocks. The study area for this field guide is shown in the central and southern Adirondack Mountains, New York.

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 (Figure 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.

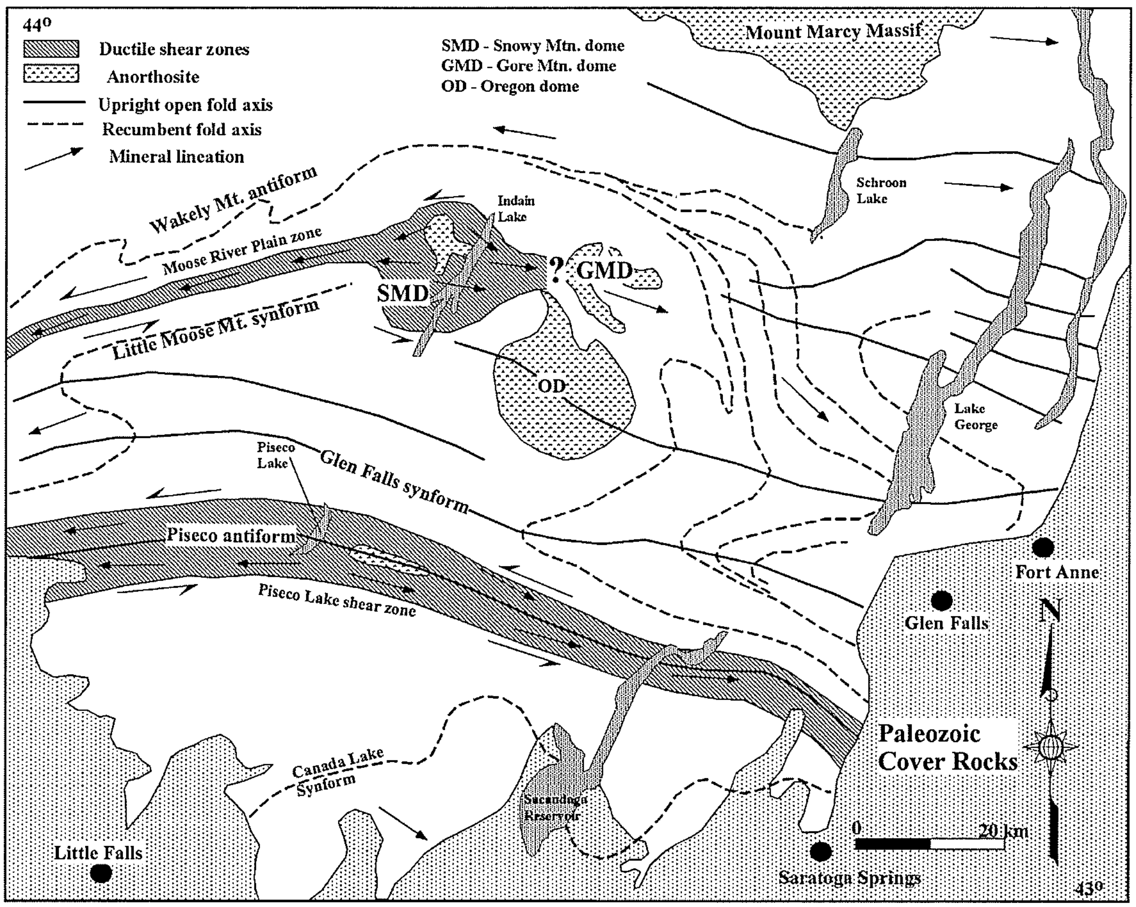


Figure 2. General geologic map of the central and southern Adirondacks showing the locations of major structures discussed in this field guide including the Moose River Plain shear zone, the Snowy Mountain dome (SMD) and the Piseco Lake shear zone.

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 charnockitic 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).

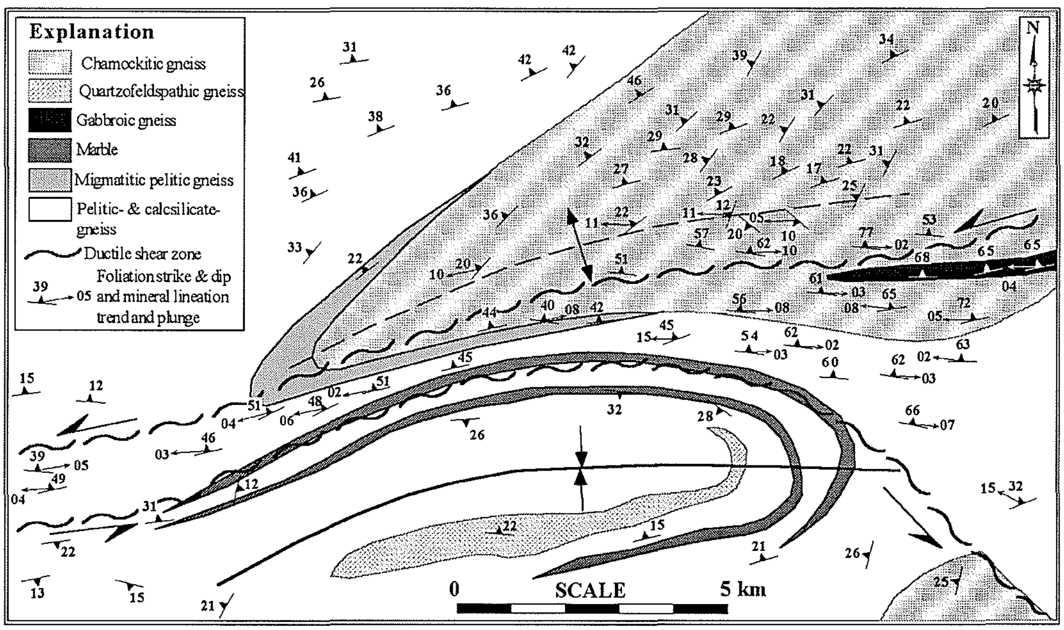


Figure 3. Detailed geologic map of the Moose River Plain shear zone in the area between the Wakely Mt. Antiform and Little Moose Mt. Synform.

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).

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

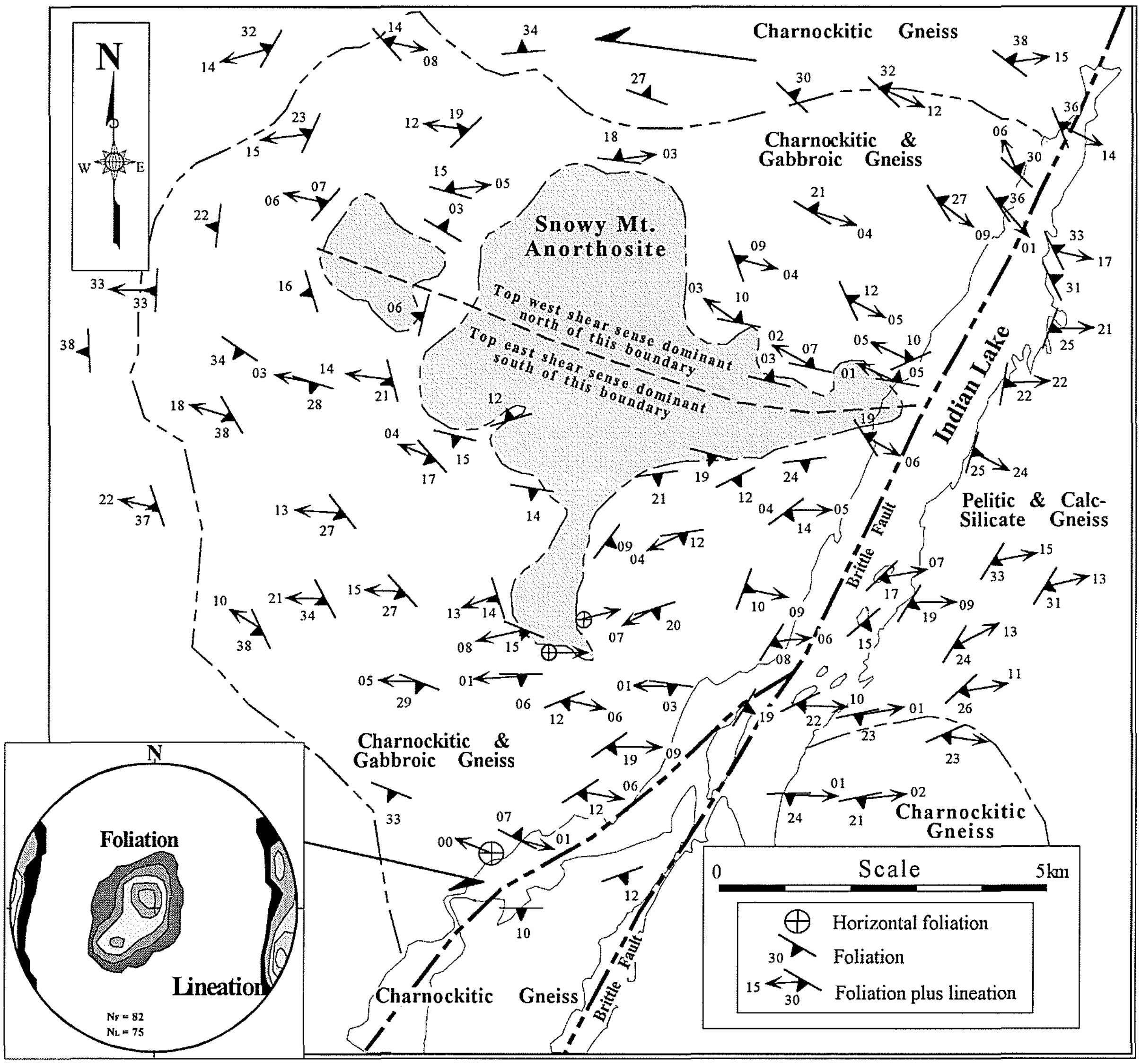


Figure 4. Detailed structure map of the Snowy Mountain dome, central Adirondack Mountains. Geologic contacts are modified from DeWaard and Romey (1964). The inset is a stereogram for poles to foliation and lineation for the eastern half of the dome.

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.

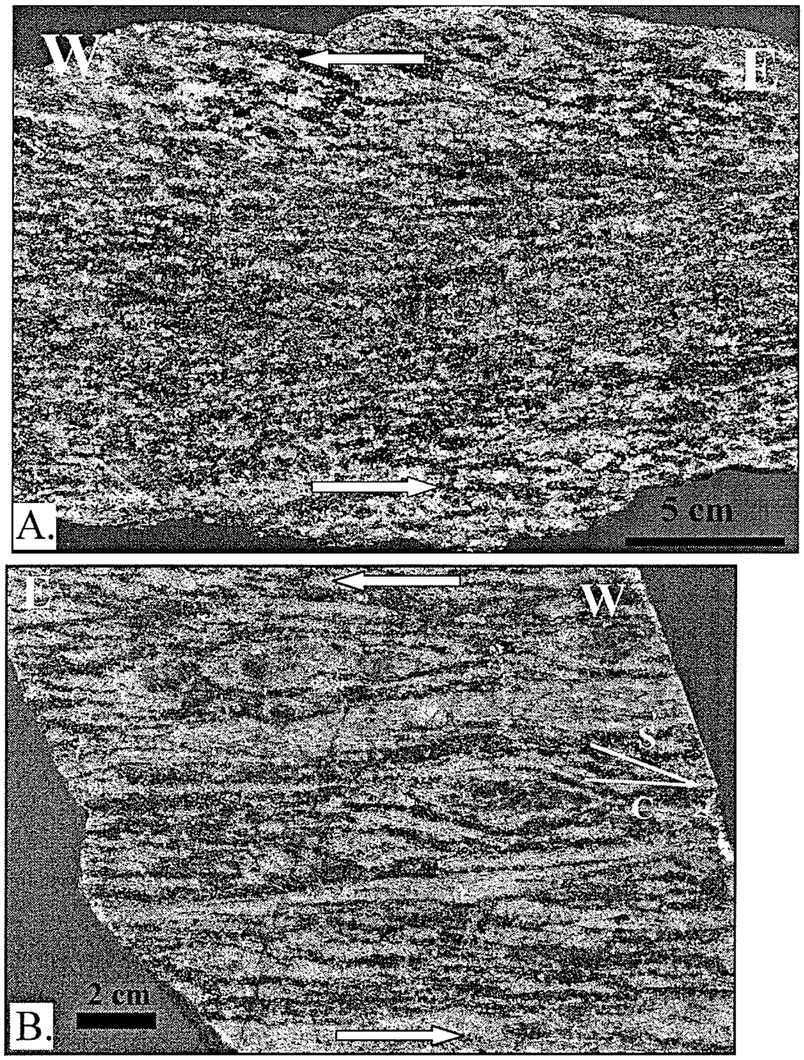


Figure 5. Examples of kinematic indicators from the Moose River Plain shear zone and the high strain fabrics that define the Snowy Mountain dome. A] Small high-strain zone from the MRPSZ showing sinistral shear; B] S-C fabric in gabbroic gneiss from the northeastern flank of the SMD.

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).

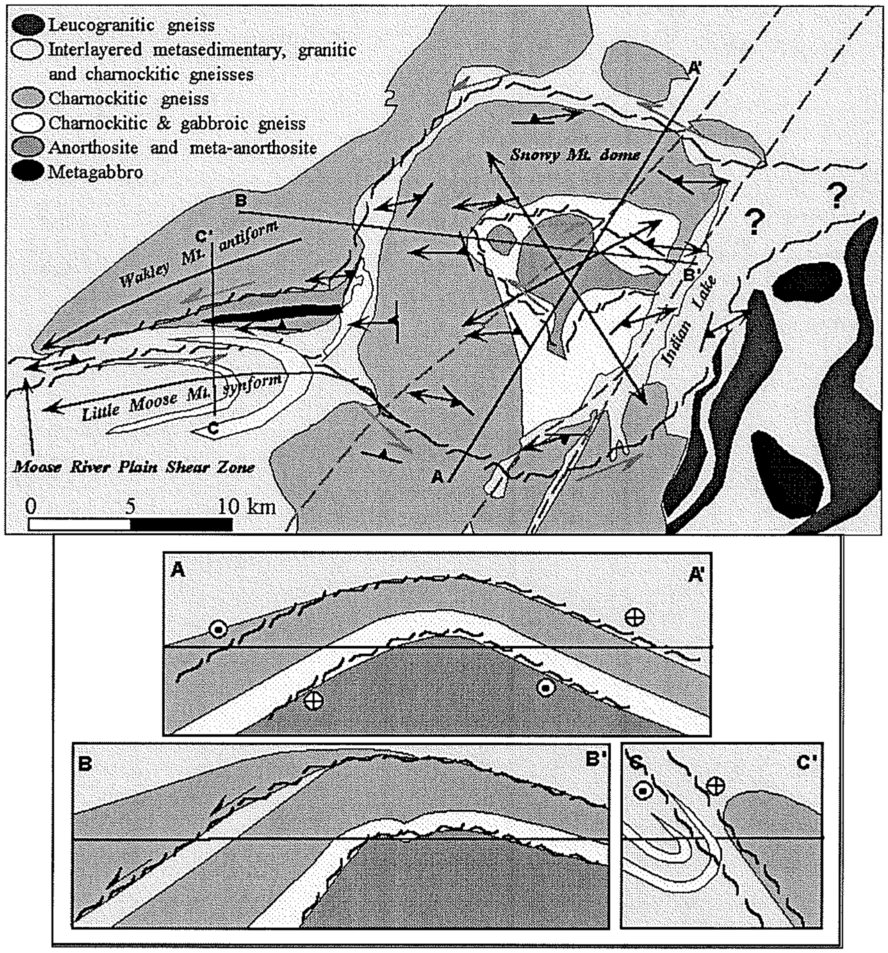


Figure 6. Schematic geologic map of the Snowy Mountain dome and the intersection with the Moose River Plain shear zone. The structure sections (A-A'; B-B'; C-C') are the same scale as the map and have no vertical exaggeration.

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 as 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).

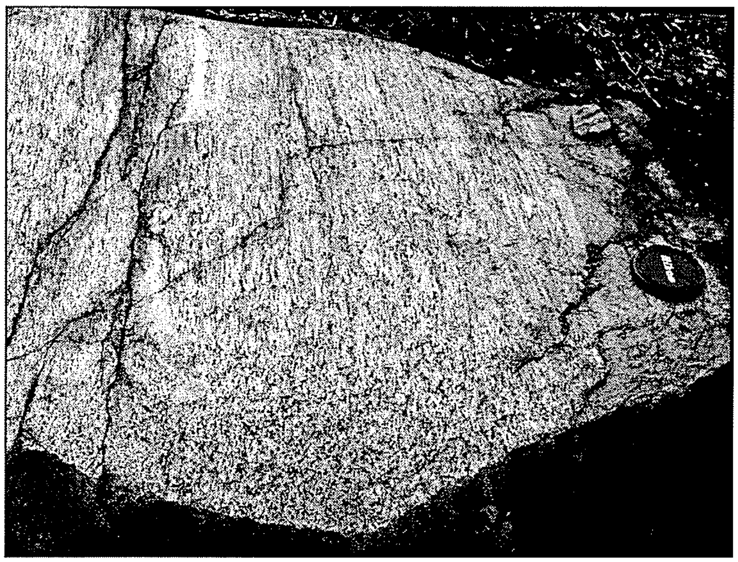


Figure 7. Outcrop of L-tectonite from the Piseco Lake shear zone. The view is looking west at an outcrop face that is subvertical in the foreground and subhorizontal in the background, revealing the ends and sides of mineral lineations respectively.

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).

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 (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.

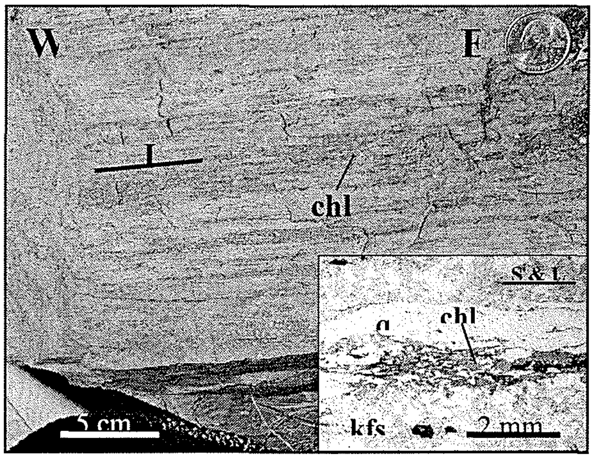


Figure 8. Outcrop of L-S fabrics in the PLSZ along Route 8 in the vicinity of Piseco Lake. The darker layers are linear aggregates of chlorite. The inset photomicrograph shows acicular chlorite (blades in three dimensions) oriented sub-parallel to the quartz ribbon.

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.

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 granitic-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.

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.

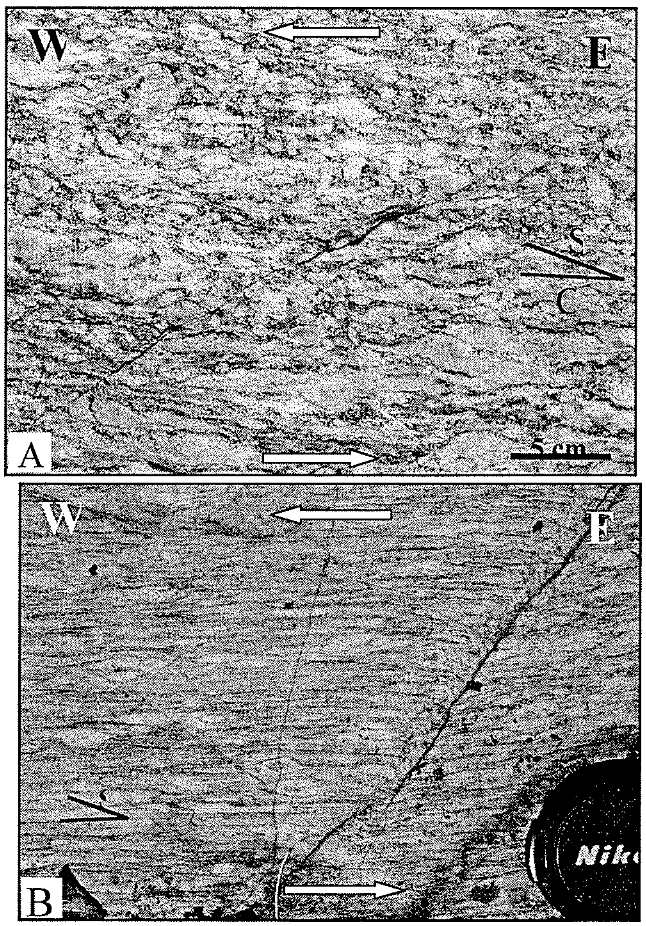


Figure 9. Outcrop photographs of kinematic indicators from the PLSZ. A] View is looking perpendicular to moderately north dipping foliation in western end of the Ohio Gorge on West Canada Creek. Type I S-C foliation is well developed in megacrystic granitic gneiss, and the shear sense is sinistral. B] 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.

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.

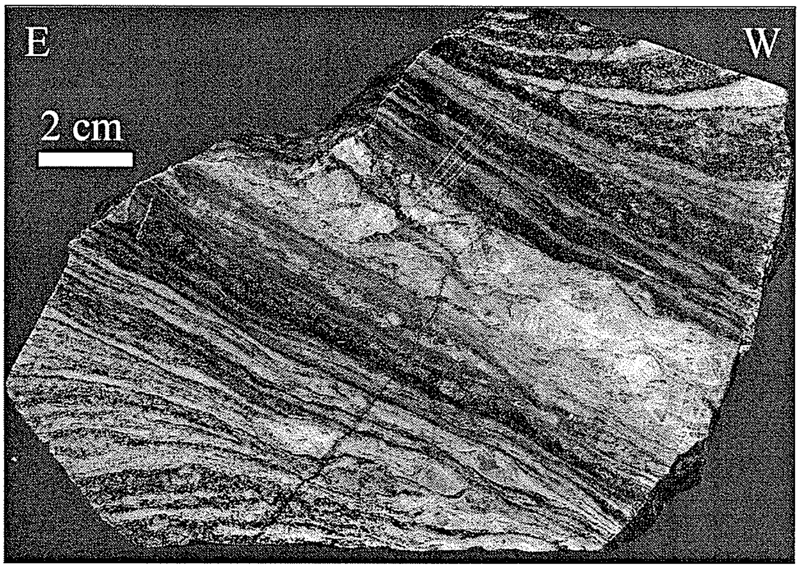


Figure 10. Polished rock slab of a small ductile shear zone that cross cuts the PLSZ fabric in the area of West Canada Creek. The view is looking south at a near vertical surface, and the shear sense is top down to the west. These small normal shear zones commonly contain parallel granitic pegmatite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

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 presented 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 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.

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.

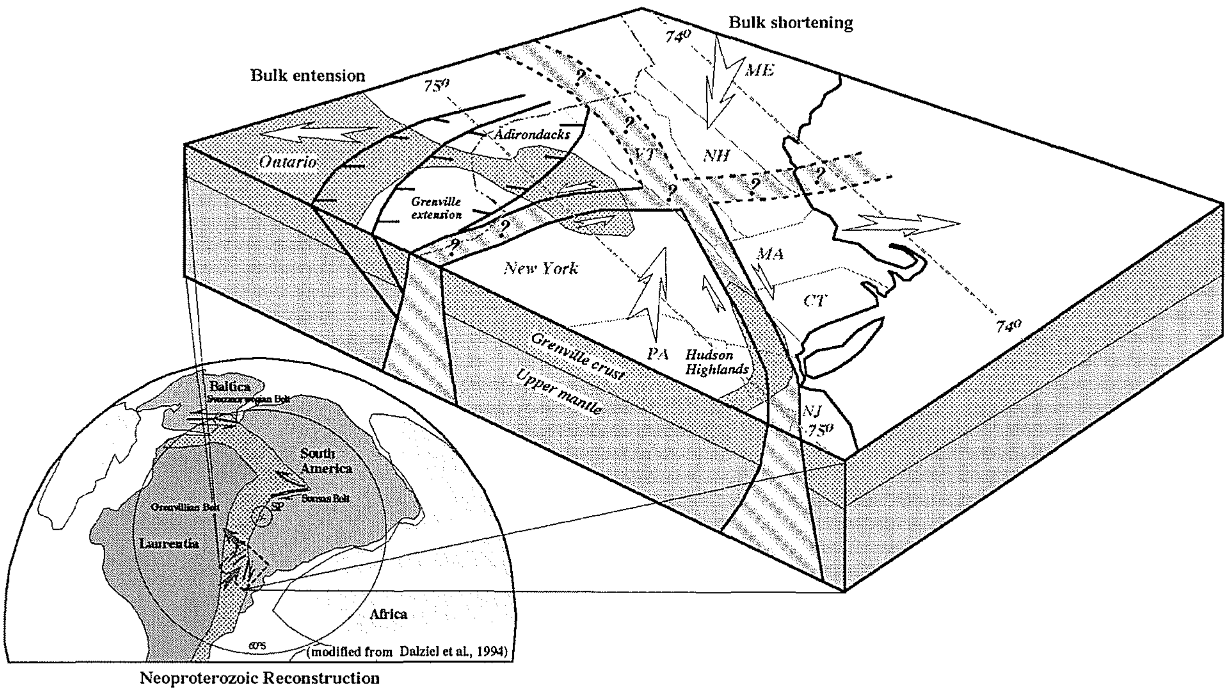


Figure 11. Block diagram depicting the crust-scale conjugate ductile shear zones forming a syntaxis. The inset shows the location of the syntaxis in a reconstruction of Rodinia (modified from Dalziel et al., 1994).

ACKNOWLEDGEMENTS

Funding for the work presented here was through Faculty Development and UUP Grants from the State University of New York at Oswego to Valentino. We also acknowledge the Division of Continuing Education (Yvonne Petrella, Tom Ingram and Jean Dufore) at the State University of New York at Oswego for support through the Summer Field Geology Research Program. We thank P. Whitney for introducing us to the geology of the Moose River area, and would also like to thank J. McLelland and R. Facundiny for suggesting these areas for structure research.

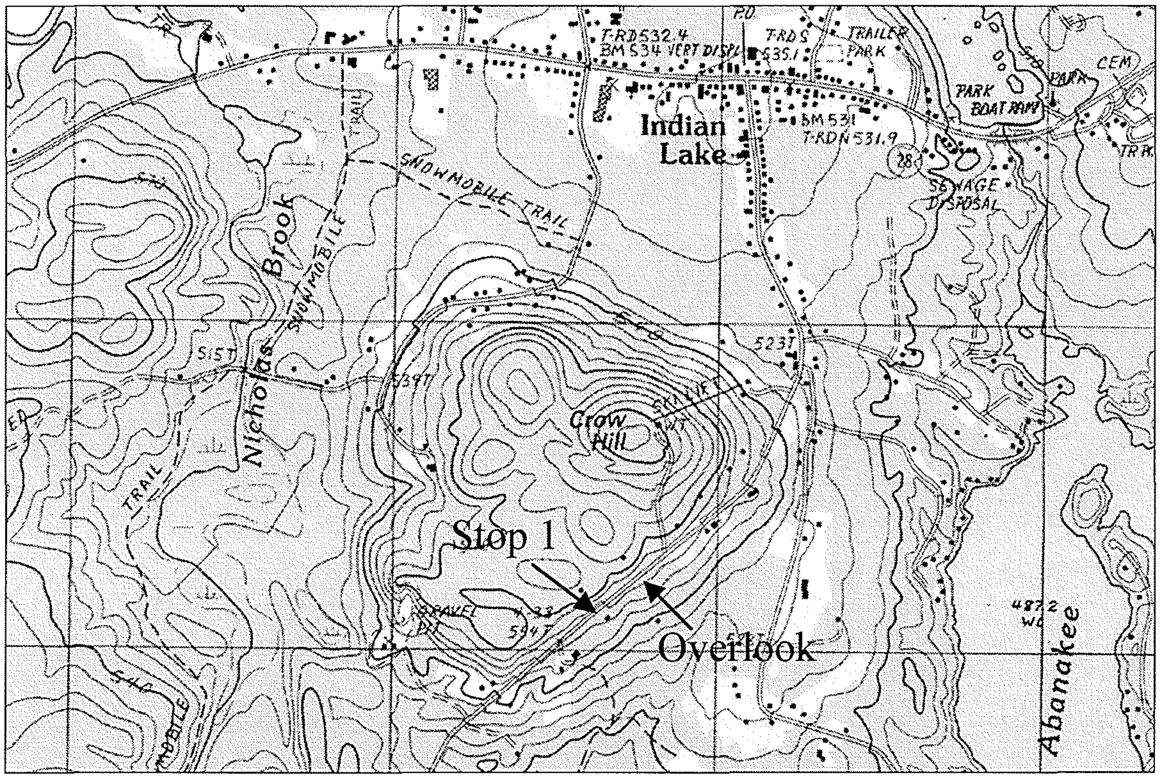
FIELD TRIP DESCRIPTION AND ROAD LOG

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).

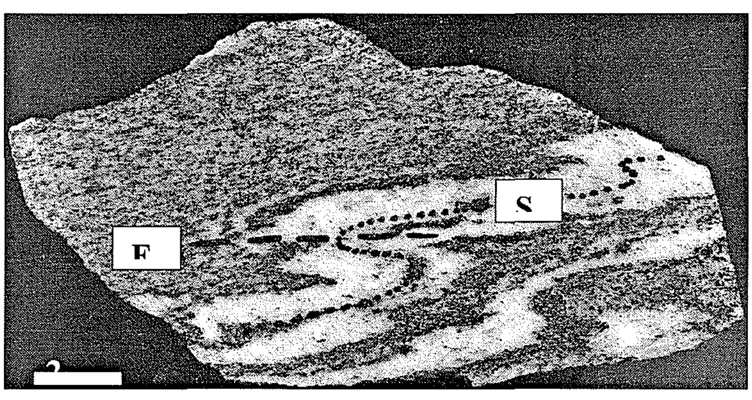
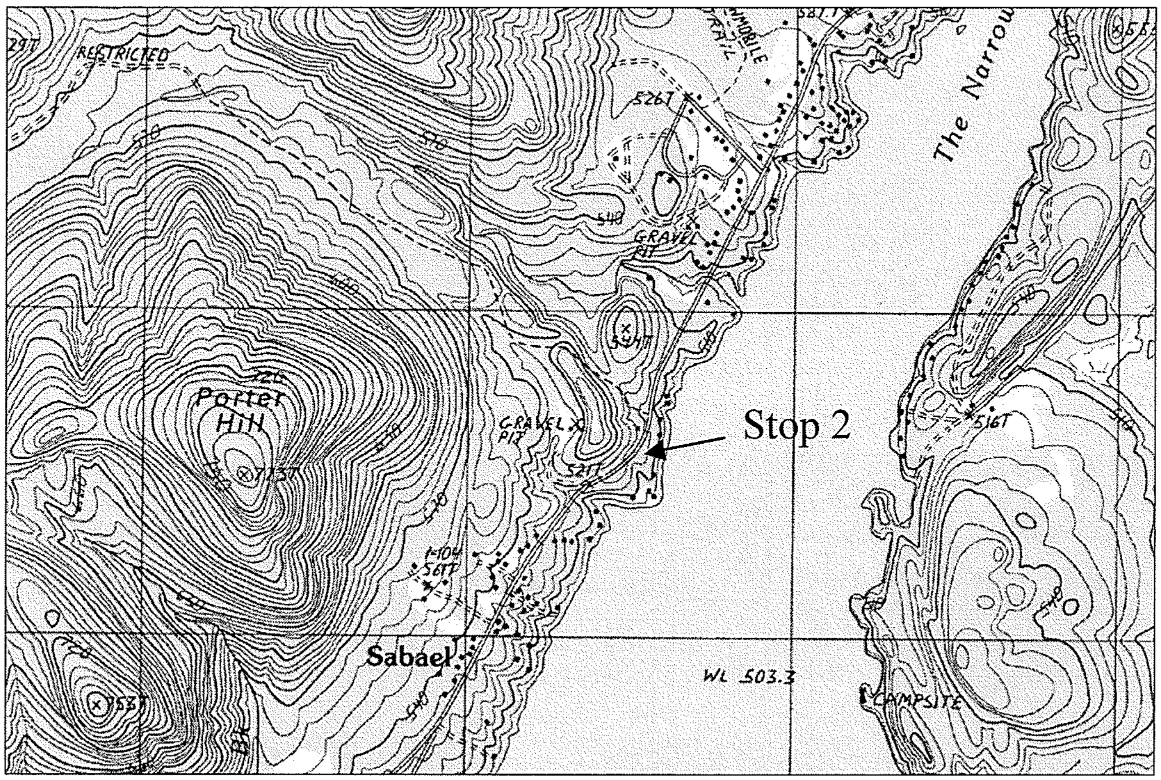


Figure 12. Rock slab of calc-silicate gneiss showing the S1 foliation defining F2 isoclinal folds.

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 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 east 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.

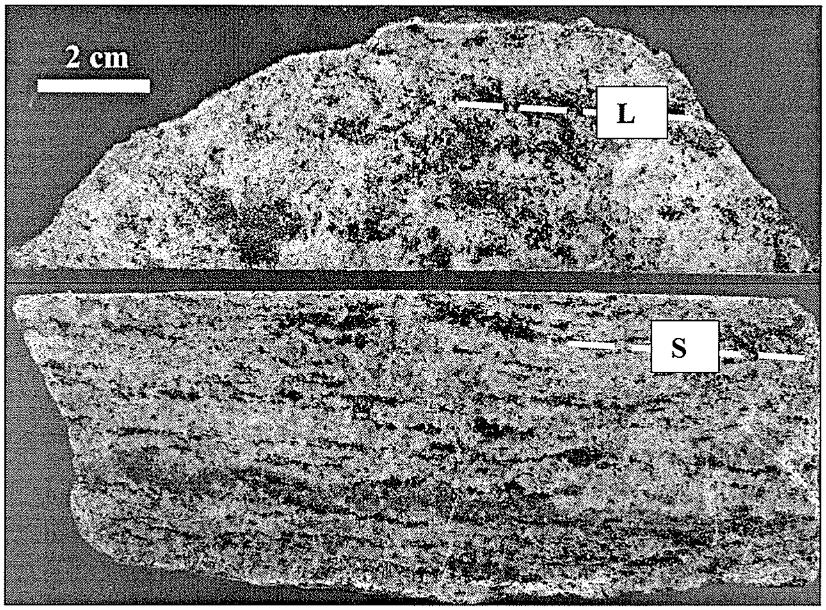


Figure 13. Mutually perpendicular rock slabs of charnockitic gneiss from the northeastern flank of the Snowy Mountain dome. The top slab is cut parallel to the S2 foliation revealing weakly developed mineral lineations. The bottom slab is cut perpendicular to the foliation and parallel to the lineation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

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.

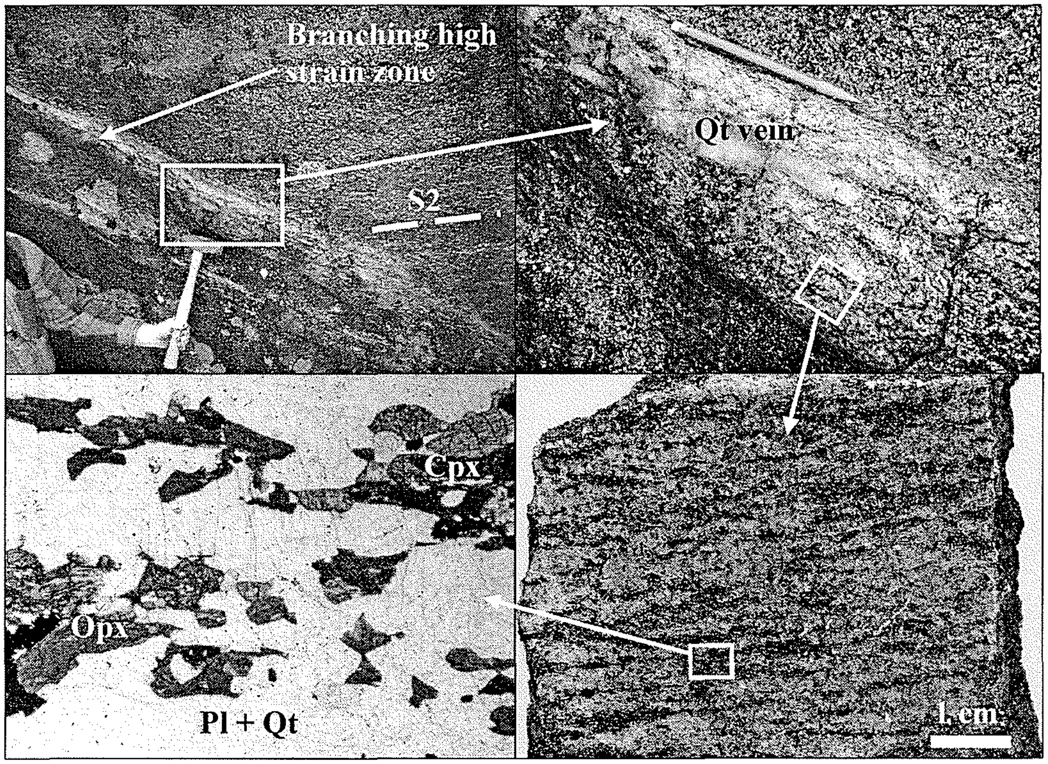
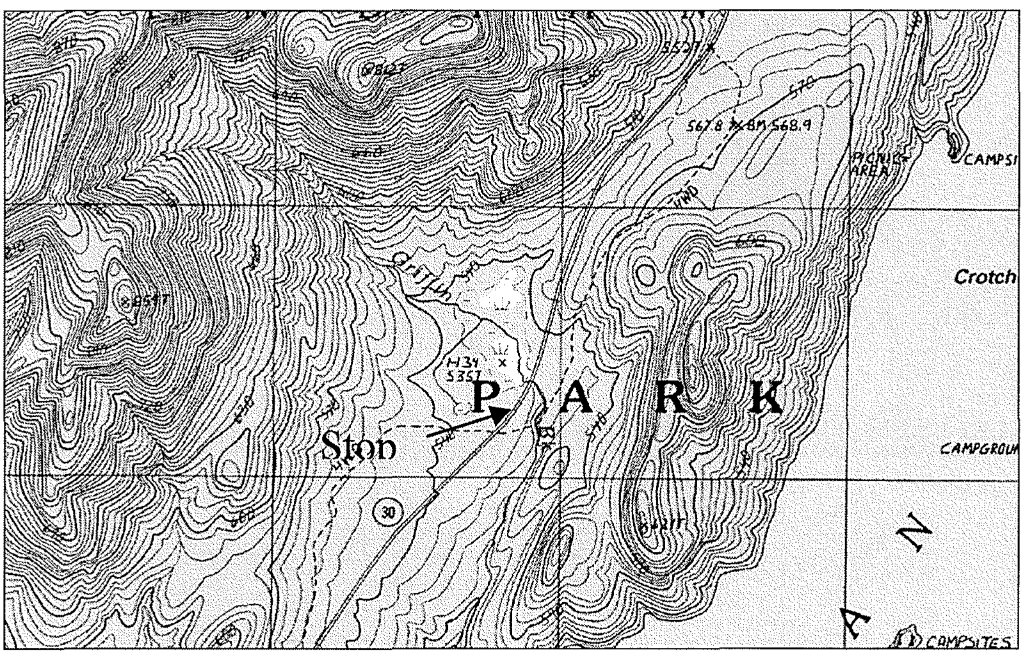


Figure 14. Example of a branching high-strain zone in charnockitic gneiss on the eastern flank of the Snowy Mountain dome in the area of Squaw Mountain. See text for details.



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.

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.

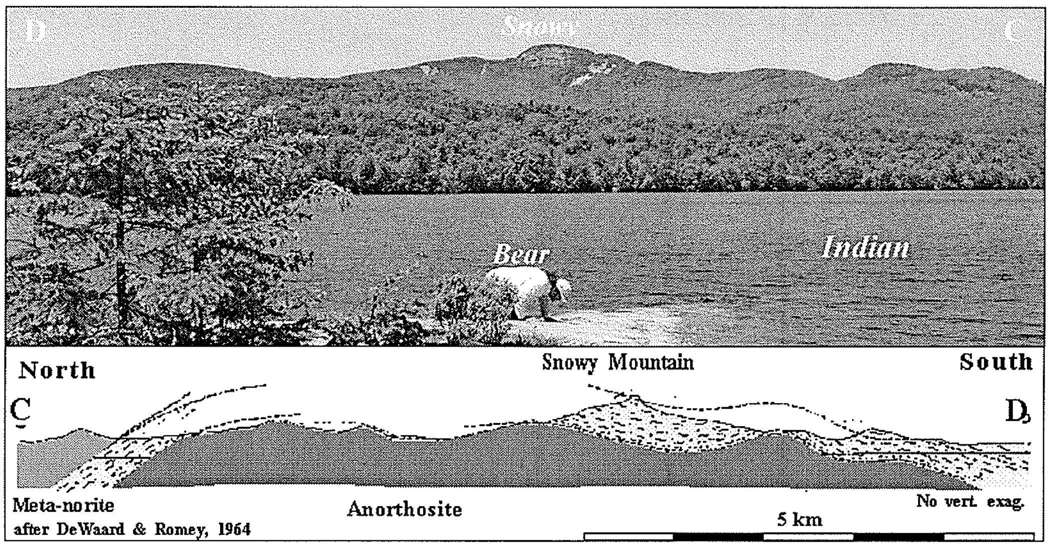
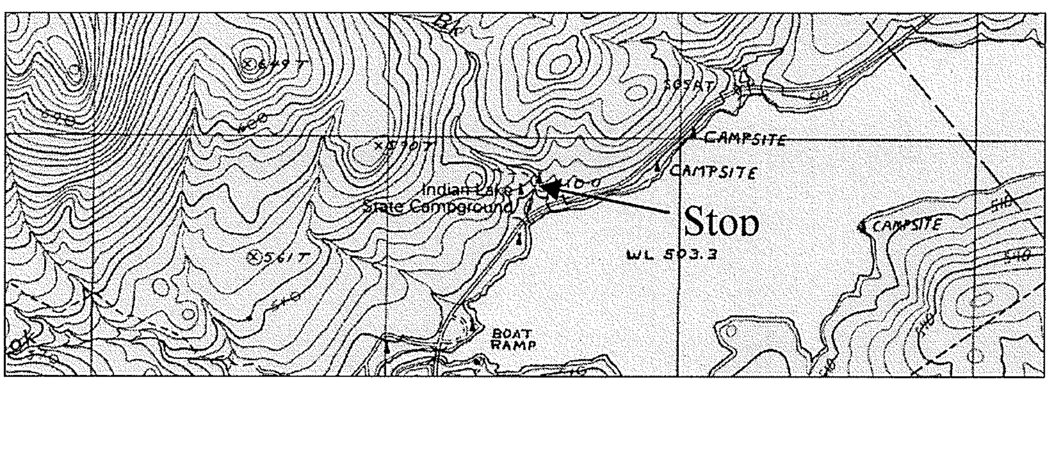


Figure 15. Westward view of Snowy Mountain from the east shore of Indian Lake (top) with the cross section of DeWaard and Romey (1964). The cross section is an eastern view of the area so "C" and "D" are reversed on the photograph.



STOP 4: Charnockitic gneiss on the southeast sie 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.

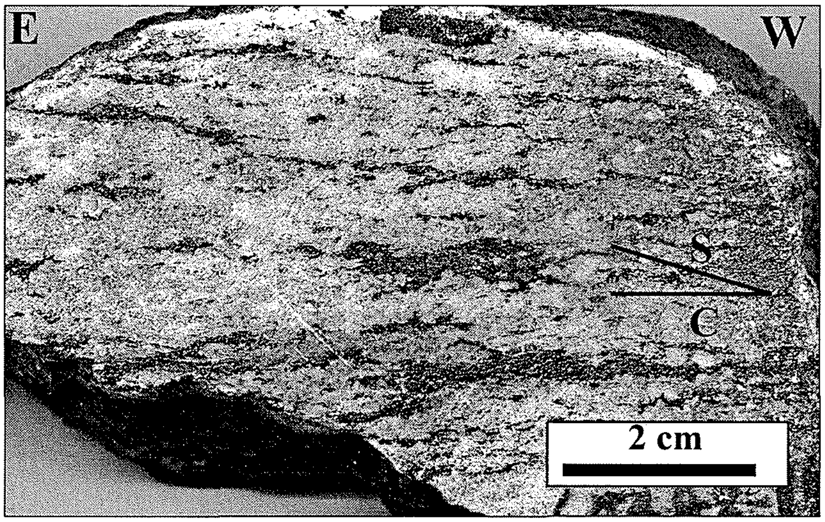


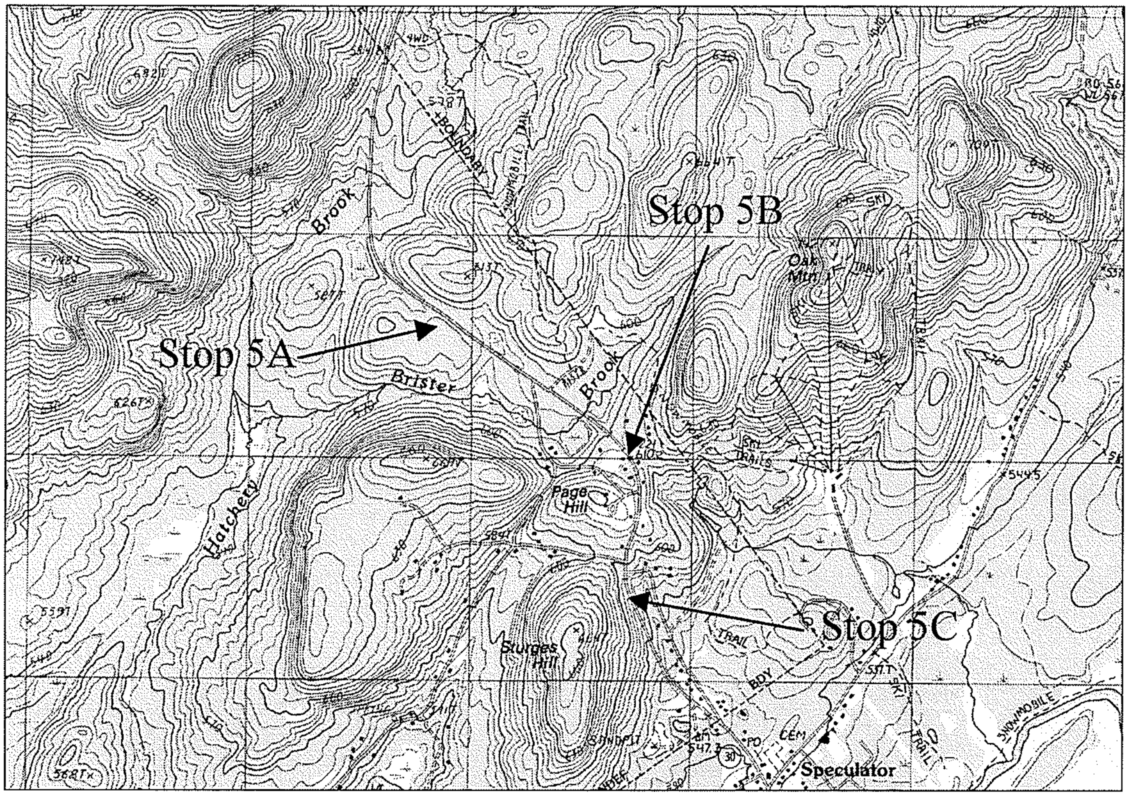
Figure 16. Rock slab of charnockitic gneiss from the falls on Falls Brook with Type I S-C fabric. The shear sense is top toward the east or sinistral. The dark minerals are broken grains of hypersthene and augite, while the lighter portions of the rock consist of recrystallized aggregates of plagioclase 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 portion of the outcrop consists of garnet amphibolite, the next section of the outcrop is calc-silicate rock and the southern portion 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 are 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.

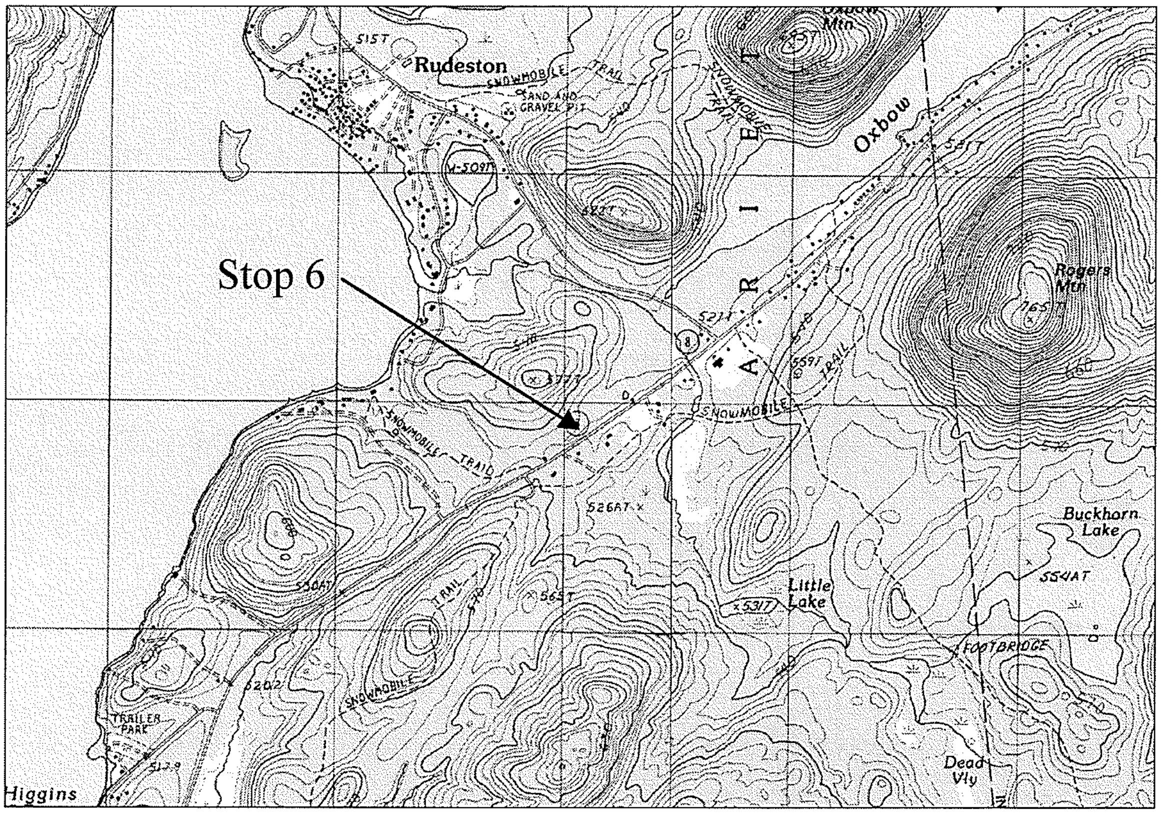
The rock here is sub-horizontally stratified, with the rock at the top of the hill to the north (garnet amphibolite) the lowest stratum, and the base of the outcrop is interlayered amphibolite and granitic gneiss, followed by granitic gneiss with mica 'mats' at the top (at the viewing area). Foliation 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.

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.

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.

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).

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).

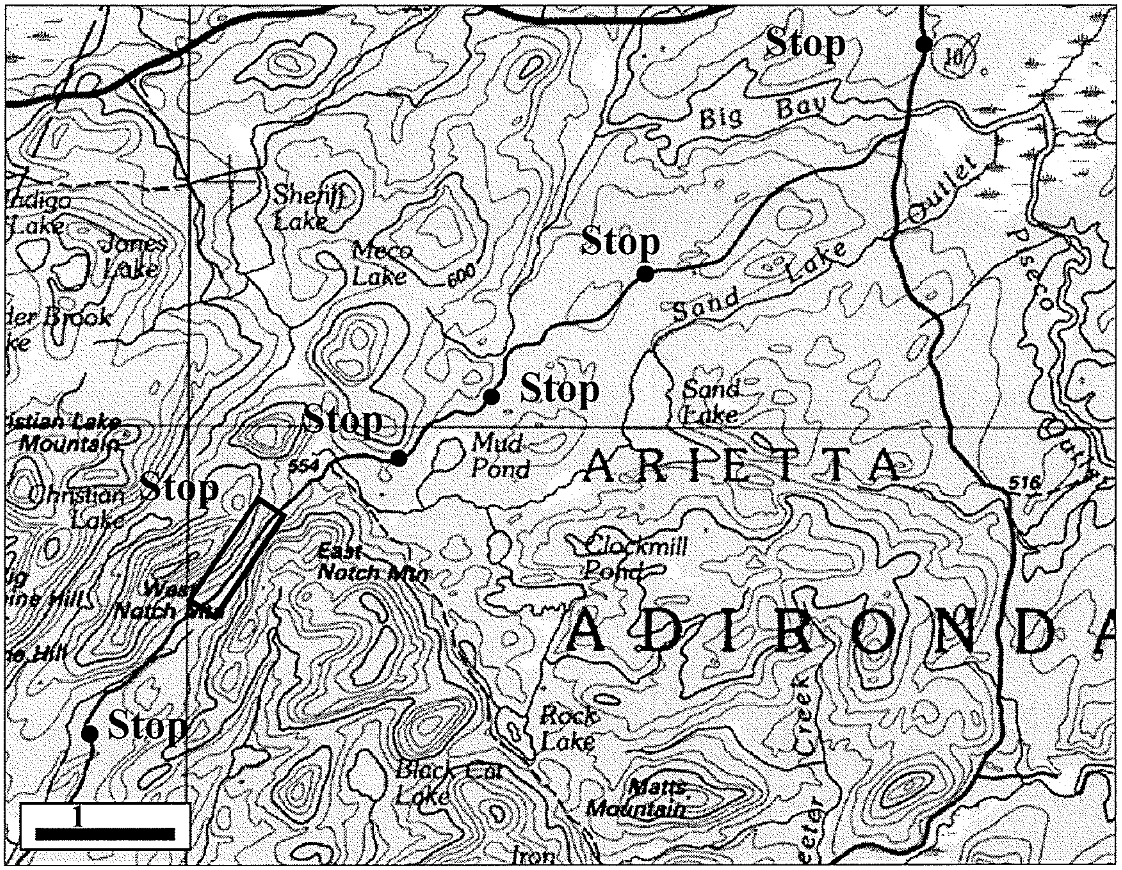


Figure 19. Location map of STOPS 7 through 12. STOPS 7 to 11 are on Powley Road, which cuts across the east-west trend of the PLSZ.

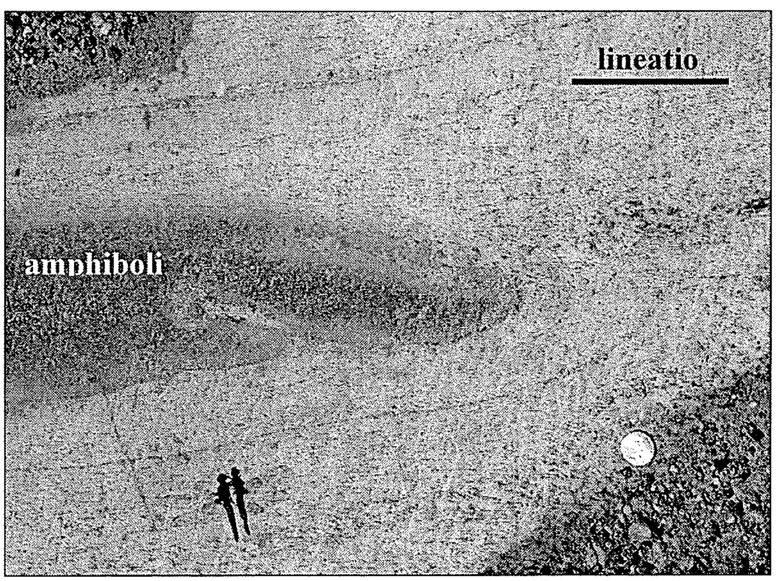


Figure 19. Pavement view of exposure at Stop 7 from within the road bed. Top is north. Note the apparent deflection of the fabric and difference in texture of the quartzo-feldspathic gneiss where it forms a 'tail' at the 'nose' of the 'shark'-shaped amphibolite lens.

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 it 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).

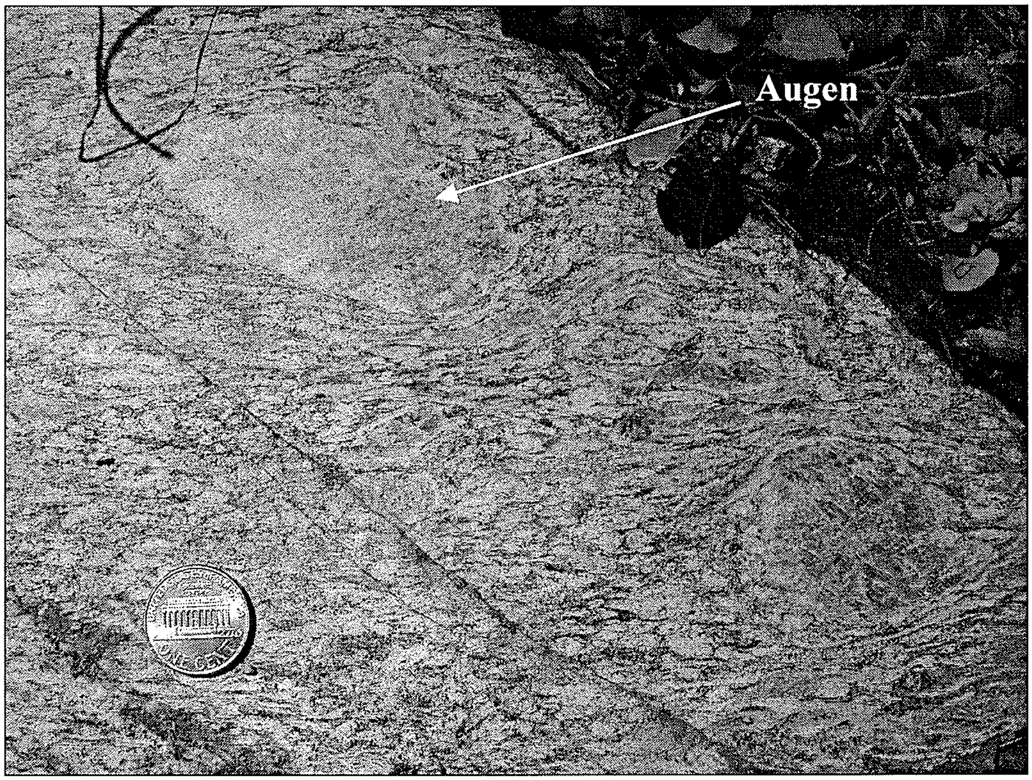


Figure 20. View of pavement at Stop 10 showing pervasive augen and two larger augen, all draped by matrix fabrics.

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:

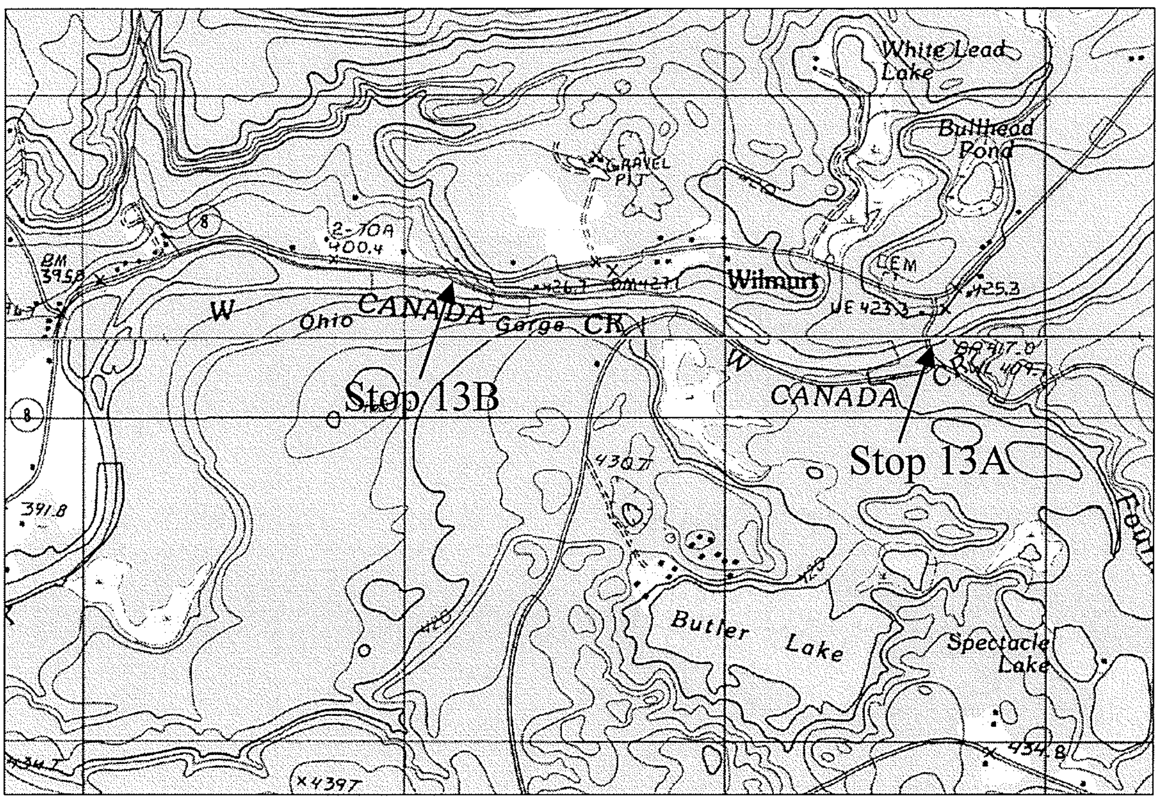
51.3 Continue northeast on Powley Road towards Rt. 10.

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 asymmetric delta 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.

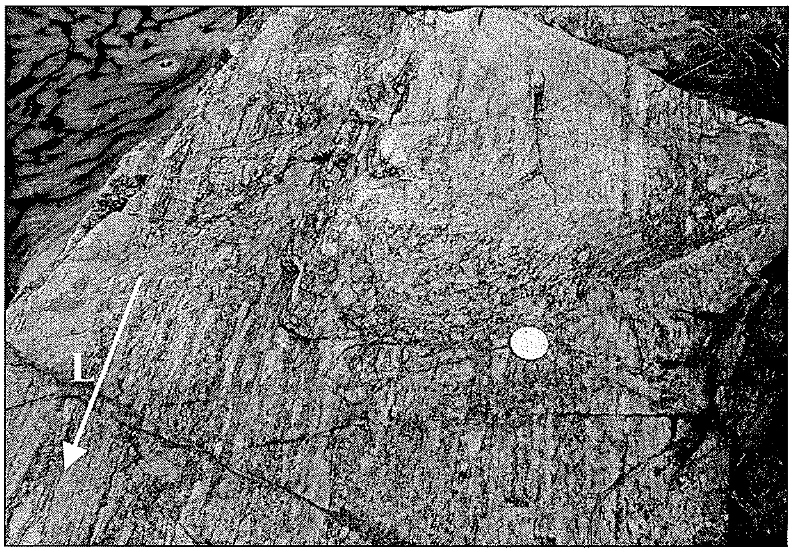


Figure 21. Outcrop of granitic gneiss with L>>S fabric. The view is looking west. Note the textural differences in this view. The area above the coin is a subvertical surface with the ends of the mineral lineations exposed. The rest of the outcrop is broken parallel to the lineations.

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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