GEOLOGY AND GEOCHRONOLOGY OF THE EASTERN ADIRONDACKS

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INTRODUCTION

The eastern Adirondacks contain a wide variety of rock types, and this trip aims to visit representatives of the major lithologies. Stops include units recently dated by U-Pb geochronology including multi- and single-grain TIMS and SHRIMP II analyses.

The Adirondack Mountains represent a southwestern extension of the Grenville Province via the Thousand Islands – Frontenac Arch region of the St. Lawrence River (Fig. 1). The region is topographically divided into the Adirondack Highlands and Lowlands separated by the Carthage-Colton Mylonite Zone (CCMZ, Fig. 2). The former is underlain largely by orthogneisses metamorphosed to granulite facies and the latter by upper-amphibolite grade metasediments, notably marbles. Both sectors have experienced multiple deformations resulting in refolded major isoclines. The tectonic history consists of a tripartite division, as summarized below and in figure 3. Broadly, the various lithologies fall into the following groups: 1300-1350 Ma tonalites and granodiorites; 1160-1150 Ma anorthosites, mangerites, charnockites, and granites (AMCG suite); 11000-1090 Hawkeye granite; and 1050-1040 Ma Lyon Mt Granite (LMG). The three major orogenic events associated with these are the Elzevirian (ca1350-1220), the Shawinigan (1215-1160 Ma) and the Ottawan Orogenies (1090-1045 Ma). The Elzevirian involves protracted outboard arc magmatism and accretion and was followed by the collisional Shawinigan Orogeny between Laurentia and the Adirondack Highlands – Green Mountain Terrane. The Ottawan was a Himalayan-type collision of Laurentia with Amazonia (?). Most of the metamorphic and structural effects present in the Adirondacks are the result of the Ottawan Orogeny, but Shawinigan and Elzevirian features can be recognized locally. Both the AMCG suite and the LMG are thought to be late- to post-tectonic manifestations of delamination of overthickened orogens.

Structurally, the eastern Adirondacks are dominated by the same large, recumbent fold-nappe structures (F_2) as found in the southern Adirondacks (Figs. 2, 4, 5), and with fold axes oriented dominantly ~E-W parallel to lineation. As in the southern Adirondacks, the fold-nappes are thought to have sheared-out lower limbs, but this has yet to be demonstrated on a map scale. At least two distinguishable upright fold events are superimposed on the nappes: F_3 with shallow plunging ~E-W axes and F_4 with shallow-plunging NNE axes. All of three fold sets affect Hawkeye and older units, and thus must be of Ottawan age. This also the case with the strongly penetrative rock fabric, including strong ribbon lineations, that are present in these rocks and are associated with the large fold-nappes. Intense fabric and nappe structure are largely absent from the Lyon Mt Granite and this is interpreted to reflect its intrusion in late, post-nappe stages of the Ottawan. In the northern portion of the eastern Adirondacks the NNE, F4, folds become quite tight and have a strong lineation associated with them. This may be the result of rock sequences being squeezed between large, domical prongs of anorthosite. Finally, we note that there exists abundant local evidence of small isoclinal F_1 folds that pre-date F_2. These, and their associated fabrics, are thought to be pre-Ottawan in origin, and in a few cases this can be shown to be the case.

A dominant feature of the eastern Adirondacks is the great Marcy anorthosite massif that underlies almost all the High Peaks (Fig. 2). Over two-dozen zircon age determinations demonstrate that the anorthosite was emplaced at 1155 $\pm$ 8 and that associated granitoids and coronitic metagabbros are coeval with it (Fig. 6). These relationships make it clear that thermal energy from the anorthosite had nothing to do with the regional granulite facies (ca 1050 Ma) that characterize the Adirondack Highlands and post-dates the AMCG suite by 60-100 million years. It is likely that most of the region experienced peak temperatures on the order of ~750-800^{o}C and pressures of ~8 Kbar. Based upon extensive isotope work by John Valley and his students, it appears most likely that this metamorphism proceeded under fluid-absent conditions (Valley *et al.*, 1983). Note, however, that this does not exclude the presence of late, post-peak fluids associated with the emplacement of Lyon Mt Granite.

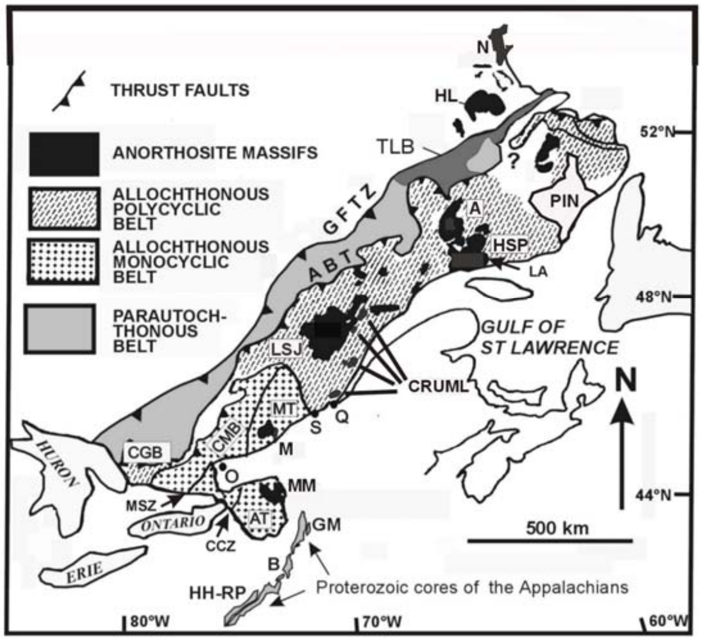

Fig. 1. Generalized location map of the Adirondacks as a southwestern extension of the Canadian Grenville Province whose three major tectonic divisions (Rivers, 1997) are shown. ABT-Allochthonous Boundary Thrust; GFTZ- Grenville Front Tectonic Zone; TLB (dark gray) - Trans-Labrador Batholith, GM – Green Mountains, H – Housatonic Mountains, HH-RP – Hudson Highlands and Reading Prong. The major anorthosite massifs (with ages) of the region are: MM- Marcy (ca 1150 Ma), M) Morin (ca 1160 Ma), LSJ) Lac St. Jean (ca 1150 Ma), HSP) Havre St-Pierre, A) Atikonak (ca 1130 Ma), ME), HL) Harp Lake (ca 1450 Ma), N) Nain-Kiglapait (ca 1300 Ma),; P) Pentecote (ca 1350 Ma).

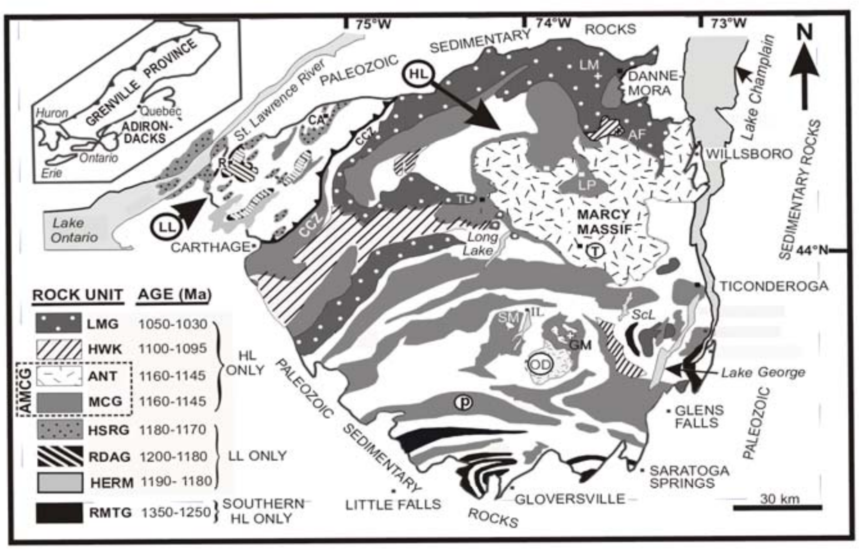

Fig. 2. Generalized geological/geochronological map of the Adirondacks showing locations of dated AMCG samples. Units designated by patterns and initials consist of igneous rocks dated by U-Pb zircon geochronology with ages indicated. Units present only in the Highlands (HL) are: RMTG – Royal Mountain tonalite and granodiorite (southern HL only), HWK -Hawkeye granite, LMG – Lyon Mountain Granite and ANT - anorthosite. Units present in the Lowlands (LL) only are: HSRG – Hyde School and Rockport granites (Hyde School also contains tonalite), RDAG – Rossie diorite and Antwerp granodiorite. Granitoid members of the AMCG suite (MCG) are present in both the Highlands and Lowlands. Unpatterned areas consist of metasediments, glacial cover, or undivided units.

Recent investigations in the Adirondacks have demonstrated that emplacement of Lyon Mt. Granite accompanied extensional collapse of the Ottawan orogen and exhumation of the high-grade granulite core. The most complete study of this sort is that of Selleck et al. (2005) that utilized zircon geochronology to document that down-to-the-west displacement along the northwest dipping Carthage-Colton shear zone (CCZ, Fig. 2) was coeval with intrusion of Lyon Mt. Granite (Fig. 2) into the fault complex at ca 1045 Ma. It is thought that at peak Ottawan contraction the overthickened lithosphere experienced delamination by foundering, convective thermal erosion, or both. Following delamination of the dense lithospheric keel, the orogen rebounded and hot new asthenosphere moved to the crust-mantle interface and caused melting of deep crust to yield Lyon Mt. Granite, As the granite ascended into the crust it both lubricated and enhanced low-angle normal faults formed in response to increased topographic elevations and leading to orogen collapse. In such situations, it is not uncommon to find that collapse is quasi-symmetrical around the orogen core thus giving rise to a mega-gneiss dome or double-sided core complex such as the Shuswap complex. Given this, we have undertaken research aimed at establishing whether, or not, low-angle down-to-the-east normal faulting took place in the Adirondacks at ca 1045 Ma. Geological evidence is consistent with this proposition, and kinematic indicators related to the issue are described in Stop 9 of the Road Log where the authors present evidence supporting topside down-to-the-east displacement. Some of the more regional geological evidence is discussed below.

The Canada Lake isocline is a prominent feature of the southwestern Adirondacks (Fig. 7). The lithologies comprising it reappear to the east of Great Sacandaga Reservoir in the southeastern Adirondacks, but given the pattern of strikes and dips, there are only two ways of achieving the repetition: either by thrust faulting or normal faulting. Although there is remaining uncertainty, kinematic indicators tend to support the normal fault alternative. The fault trace consists of a distinctive belt of pegmatites and quartz veins that are locally mylonitic and stained by hydrothermal fluids. We propose that this belt represents the trace of a low angle (~45º) normal fault whose projection is shown on figure 7. Coarse synkinematic pegmatites are common in, and near, the belt, and secondary muscovite occurs locally. To the east of the fault trace metapelites and ca 1300 Ma tonalites are common, whereas east of it they are not encountered. These issues are discussed in greater detail at stop 9.

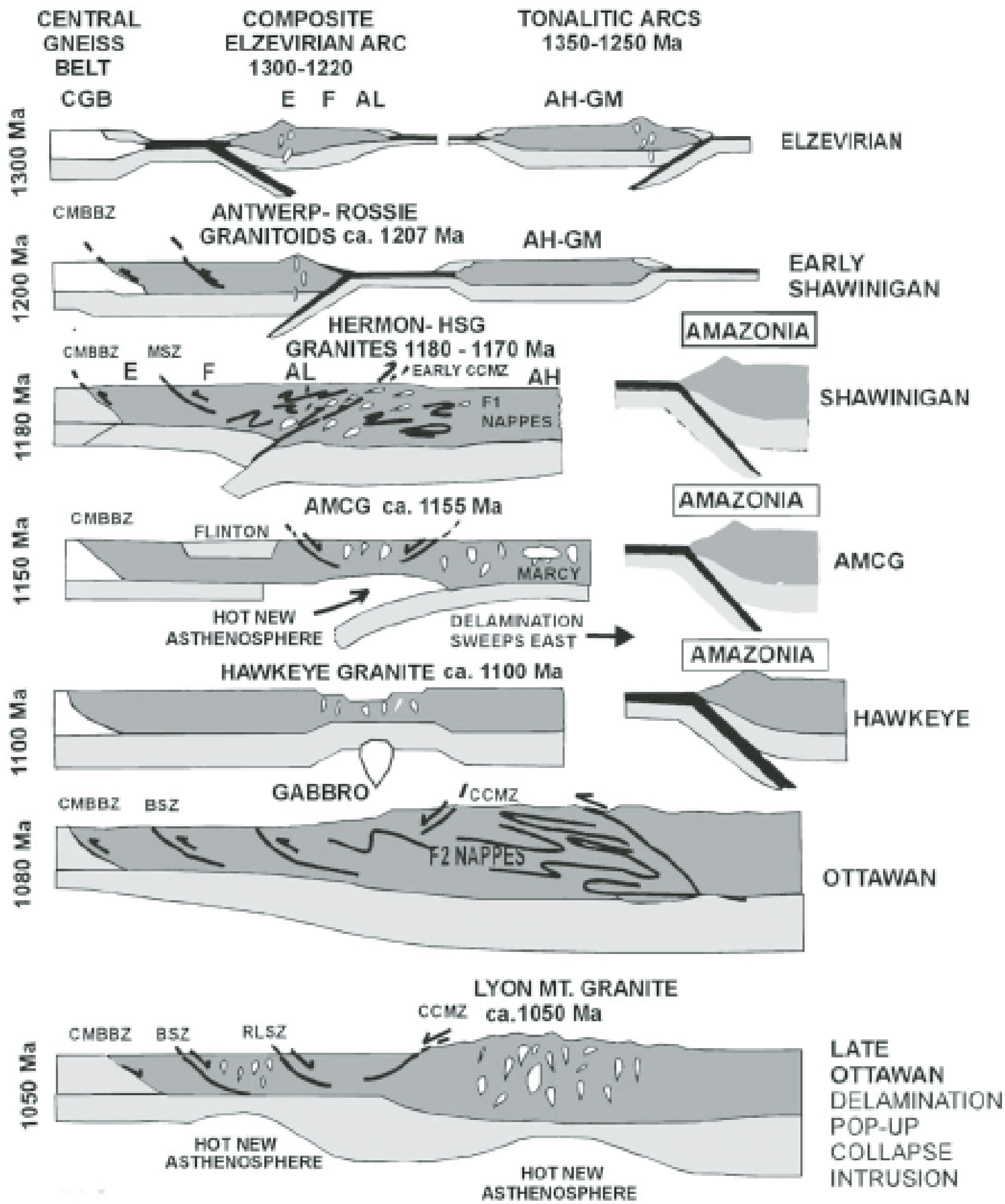

Figure 3. Generalized tectonic evolution of the Adirondack region.

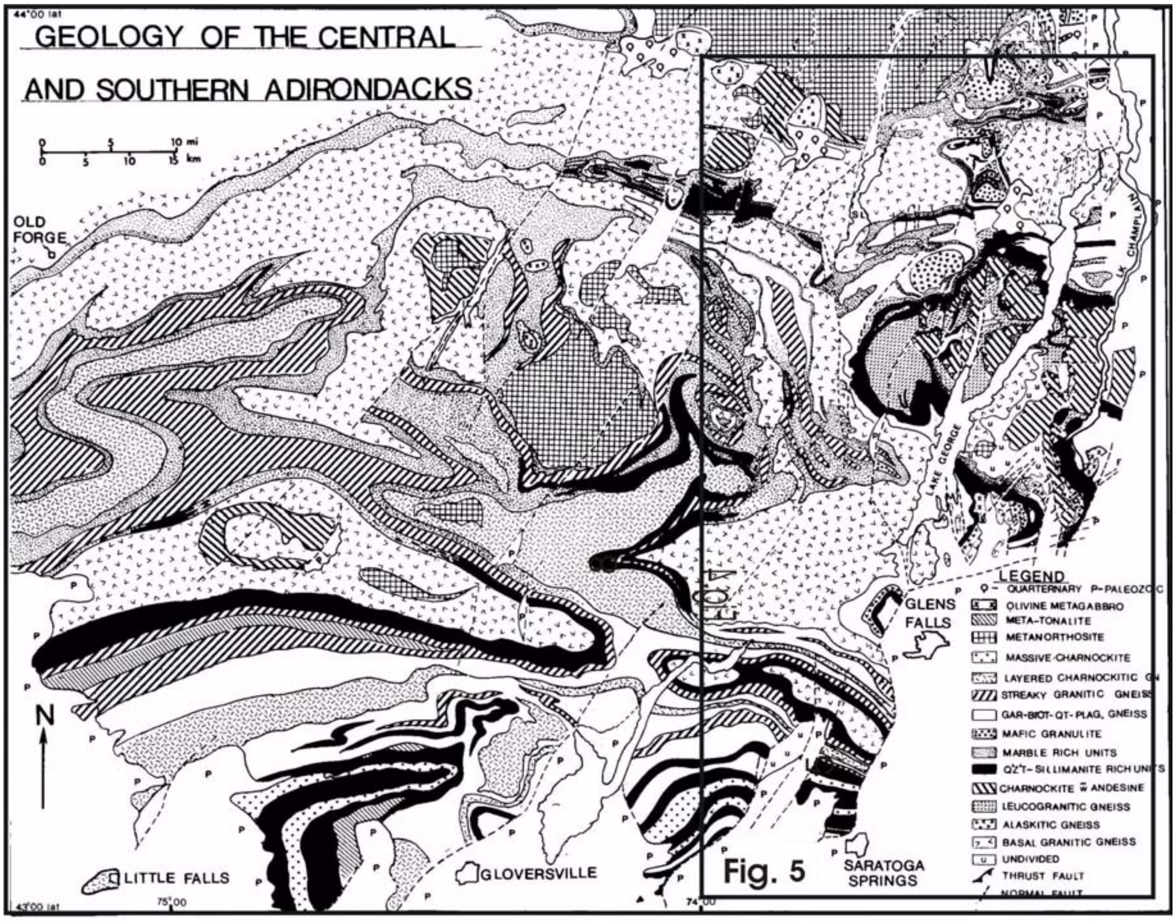

Figure 4. Generalized geology of the southern Adirondacks. Region of Fig. 5 shown.

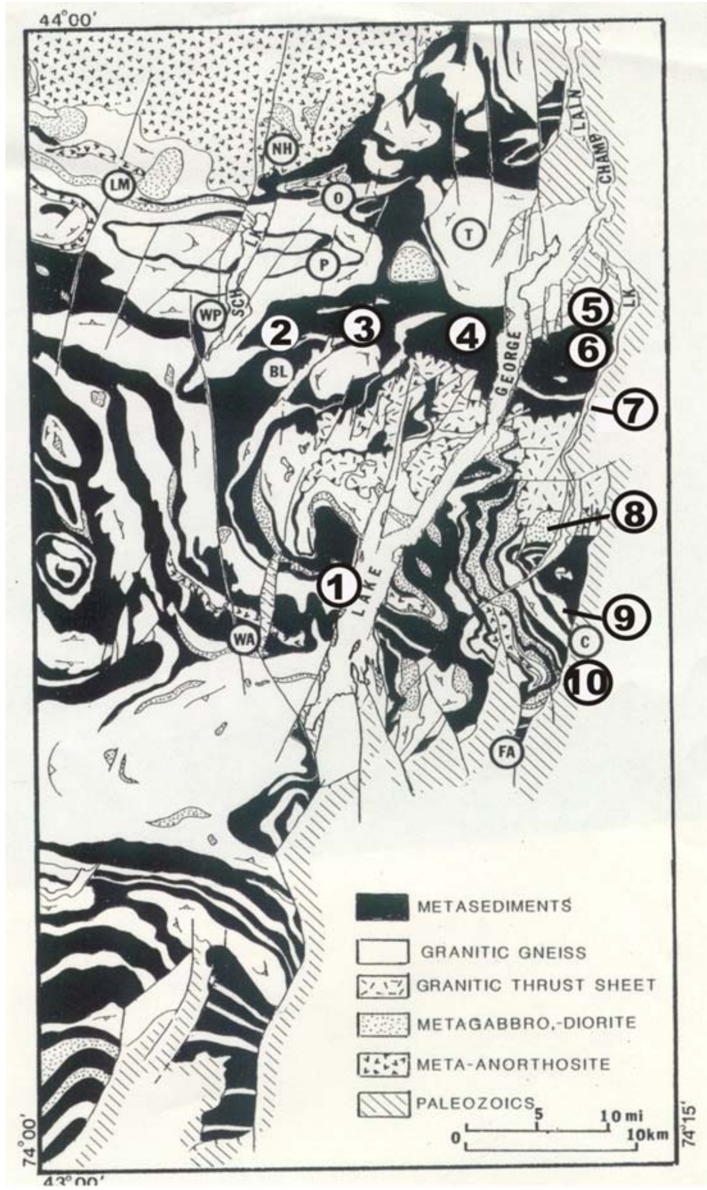

Figure 5. Generalized geologic map of the eastern Adirondacks with stop locations shown. BL – Brandt Lake; C – Comstock; FA – Fort Ann; LGV – Lake George Village; LM – Loch Mueller; NH – North Hudson; O – Owl's Head Mt.; P – Pharoah Mt.; T – Ticonderoga; Wa – Warrensburg; WP – Whitney Point.

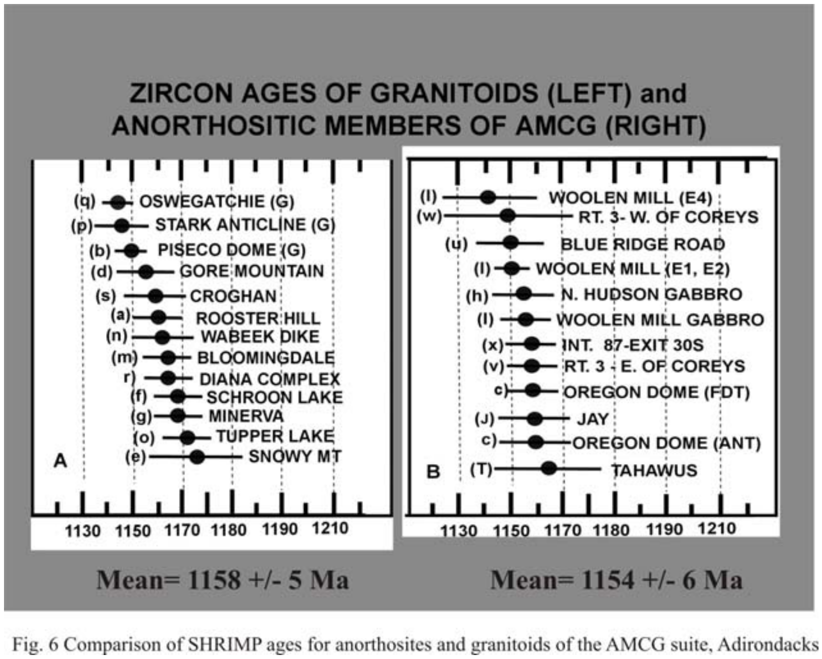

Figure 6. Comparison of SHRIMP ages for anorthosites and granitoids of the AMCG suite, Adirondacks.

ROAD LOG

Mileage

0.0 From parking lot of the Fort William Henry Conference Center turn left (south) on Rt. 9.
0.5 Pass Prospect Mt entrance on right.
1.0 Junction with 9N. Turn right at light.
1.2 Turn right (north) on Northway (Rt 87). Note exposures of pink granite along Northway.
4.0 Sulfidic staining on NNE fault in granite.
5.5 Exposure of hornblende granite on left.
5.9 Pegmatite on right.
6.0 Pass metagabbro
6.7 Hornblende granite on both sides.
7.0 Hornblende granite
7.2 Hornblende granite with metagabbro
7.4 Metagabbro, pegmatite, and metasediments on right.
7.5 Take Exit 23 off of Northway
8.0 Turn right at stop sign
8.4 Turn left (north) onto Schroon River Road.
8.8 Junction with Wall St on right. PARK

STOP 1. The Poor Man's Gore Mt. (30 min)

These exceptionally good roadcuts provide instructive observations regarding the origin of the famous mega-garnets of Gore Mt. and dated at ~1050 Ma. Although these garnets are smaller than the classic examples at Barton Mines, they occur in the same sort of coarse grained, almandine amphibolite and have the same sort of relationships as the former. Moreover, they are similar to 6-7 other occurrences scattered around the Adirondacks. Importantly, each of these, including Barton Mines, is characterized by its location along a fault zone characterized by pegmatites, quartz veins, and various other hydrothermal manifestations. We shall return to this key observation.

The protolith of the garnetiferous amphibolite is demonstrably a coronitic olivine gabbro of the type associated with the coeva1 ca. 1155 Ma massif anorthosites of the Adirondacks (Fig. 6). These anhydrous, silica undersaturated protoliths are commonly well preserved in pluton interiors. The timing of garnet corona formation has been dated at ~1050 Ma, when the Adirondack Highlands were at upper amphibolite to granulite facies conditions (Basu, pers. comm., Connelly, 2005). Note that many garnets appear to be localized in trains that suggest that they formed along fractures.

Rims of coarse, black hornblendes that resemble reaction rims surround the large garnets. However, these are best accounted for as reaction “behinds”, i.e., as the original gabbroic composition reacted to form garnet at a given nucleation site, there was an excess of hornblende-forming components that accumulated into the rims. In gabbroic anorthosites the more feldspathic bulk composition results in lag deposits of white, plagioclase rims.

The northern contact of the amphibolite is defined by a very coarse, white pegmatite consisting of striated oligoclase, K-spar, quartz and hornblende is one many oligoclase-bearing pegmatites of the eastern Adirondacks that have been dated at ca, 1042 Ma and are related to ~1050 Ma Lyon Mt. Granite. A narrow offshoot of the pegmatite crosscuts within the main body of the amphibolite. A highly deformed, ~1155 Ma hornblende granite lies north of the pegmatite and is crosscut by quartz veins. Both the pegmatite and quartz veins manifest a locally abundant hydrothermal phase present at ~1050 Ma. Just prior to this time the olivine metagabbros were at ~ 700C and 10-20 km AND DRY. Fine-grained coronas may have been in the process of forming between olivine and plagioclase. At this point, a high angle fault developed and provided access for hydrothermal, pegmatitic differentiates of Lyon Mt Granite. As these fluid-rich materials encountered the olivine gabbro, hydrous solutions moved along fracture-related pathways and resulted in greatly enhanced mobility of chemical species at ~700C. The result was the almandine amphibolite that we see today. The reason that such grain size is anomalous is that hydrous fluids are rarely present at these temperatures and depths. The model also explains the association of over a dozen other similar deposits, including Gore Mt, along pegmatite-bearing faults.

The final chapter in this story concerns the presence of light colored clots of calcic plagioclase and orthopyroxene in the rock. These are associated with garnets and commonly develop as rims between hornblende and garnet or within pressure shadows associated with garnet. This assemblage is due to the reaction:

$$\text{Garnet + Hornblende} \rightarrow \text{Ca-Plagioclase + Orthopyroxene.}$$

The entry of orthopyroxene marks passage into granulite facies conditions and cannot merely be due to “loss of water” since breaking down the reactant assemblage requires that its stability curve be exceeded to the high temperature side. Note that the plagioclase-orthopyroxene assemblage also occurs in what appear to be pressure shadows on the garnets and have an igneous appearance. Anatexis could have been promoted by dehydration reactions upon entering the granulite facies.

Return to vehicles and turn around.

9.6 Enter Rt I87N
31.3 Exit Northway at Pottersville.
31.6 Stop sign. Turn right (north) at junction with Rt 9.
31.7 Continue north on Rt 9.
32.3 Turn right (east) on Glendale Road by Word of Life Bible Camp.
32.8 Cross Schroon Lake outlet.
34.0 Quartz-sillimanite nodules in Lyon Mt Granite.
34.2 Roadcut of Lyon Mt Granite on left (north) side of Road. Park on right next to Smith Pond.

STOP 2. Ca 1050 Ma Lyon Mountain Leucogranite (30 Minutes).

The medium grained, pink leucogranite is characteristic of the main quartz-microperthite unit of Lyon Mt Granite that occurs in broad tracts along the perimeter of the Adirondack Highlands. The classic low-Ti Kiruna-type magnetite deposits of the Adirondacks are closely associated with the granite, either occurring within it or in rocks (commonly metacarbonates) immediately adjacent to it. Magnetite mineralization is accompanied by sodic alteration manifested by checkerboard albite and by quartz-albite (Ab_{98}) replacements of the original quartz-microperthite rocks (McLelland et al., 2002). A total of 12 occurrences of Lyon Mt Granite from across the Adirondacks have been dated by U/Pb techniques including single and multigrain TIMS and SHRIMP II (Fig. 2). All of these fall into the interval 1050 $\pm$ 10 Ma (McLelland et al., 2001). The present roadcut was dated by single grain TIMS methods and yields an age of 1049 $\pm$ 2 Ma (Fig. 3). Staining of the roadcut reveals that it contains several sheets and layers of quartz-albite rock one of which is associated with a irregular veinlet of magnetite. Locally, quartz-sillimanite nodules are present in these rocks and are attributed to leaching by high temperature hydrothermal fluids (McLelland et al., 2002). Pegmatites and quartz veins are common. Oxygen isotope studies indicate that sodic alteration and magnetite deposition took place at relatively high temperatures of ca 650°C. The granite exhibits some deformation and grain-shape fabric, but it is very much less intense than that present in older rocks (cf. the ca 1155 Ma Hornblende granite at Stop 1).

Evidence from the Carthage-Colton Zone along the Highlands-Lowlands boundary demonstrates that the detachment normal faulting along that zone overlapped emplacement of the Lyon Mt. Granite in the zone. As discussed in Selleck et al (2005) the granite enhanced the faulting by providing lubrication and elevated fluid pressures.

34.9 Turn left (north) on Short Street
35.4 Turn left (north) on Adirondack Road.
37.3 Turn right (northeast) on Pease Hill Road.
38.2 Stay left at intersection
40.9 Turn left (north) at intersection with Palisades Road.
41.6 Quartz-sillimanite nodules in Lyon Mt Granite
43.0 Junction with Rt 8. Turn left (northeast) at stop sign.
43.7 Metapelites assigned by Walton and deWaard to their “Older Paragneiss”.
44.3 Marble, calcsilicate of Walton’s “Paradox Lake Formation in near continuous outcrop for 2.6 miles.
46.9 Long roadcut of migmatitic metapelite assigned by Walton to the “Treadway Mt Formation”. Park.

STOP 3. Deformed Migmatitic Metapelites (> 1300 Ma). (30 Minutes).

The southern and eastern Adirondack Highlands, as well as the Northwest Lowlands, contain significant thicknesses of dark garnet-biotite-quartz-oligoclase + sillimanite metapelite accompanied by white garnet-bearing quartz-feldspar leucosome. McLelland and Husain (1986) interpreted the leucosomes as *in situ* anatectic products of the original rock and the dark fraction as restite. The presence of armored spinel, and rarely corundum, in the restite is consistent with this interpretation. In regions of low strain the leucosomes occur as crosscutting, anastamosing, irregular sheets, dikes, and veins of clearly coarse-grained pegmatitic material. As strain increases, the pegmatitic material gets pulled into psuedoconformity, disrupted, and grain size reduced so as to yield porcellaneous layers that are commonly parallel but locally retain their original crosscutting configurations. In short, the apparent layering in these rocks is almost wholly tectonic and has nothing to do with original stratigraphic superposition. They are, in fact, mylonitized migmatites, of the variety referred to as “straight gneiss”. These metapelites are crosscut by the ca 1300 Ma tonalitic suite, and therefore pre-date or are penecontemporaneous with these rocks. Our interpretation is that their current reintegrated compositions are best accounted for by a greywacke-shale precursor, and that these were arc-related, flysch-type sediments approximately coeval with the Elzevirian tonalites. This would also help to explain the relative proximity between these lithologies.

The age of anatexis within the metapelites has been ascertained by SHRIMP II studies on zircons from leucosomes and restites in both the Highlands and Lowlands (Heumann et al, 2004, Bickford et al, 2008) and reveals cores of age ca 1340-1240 Ma and narrow metamorphic overgrowths of 1010-1040 Ma. Sandwiched between these are mantles with oscillatory zoning and ages of 1170-1180 Ma. We interpret these mantles as zircon grown during anatexis thus dating this event as Shawinigan. Within the southwestern Highlands, the absence of further significant anatexis during the granulite facies Ottawan Orogeny (1090-1030 Ma) is thought to be a consequence of earlier dehydration. Within the Lowlands, the absence of any Ottawan zircon is interpreted as a reflection that this terrane did not experience granulite facies conditions at ca 1090-1030 Ma. Significantly, east of the present locality, zircons exhibit both Shawinigan and Ottawan (ca 1050-1040 Ma) overgrowths, and the latter can be quite robust. We interpret this observation to reflect the introduction of fluids into the eastern Adirondacks late in the Ottawan Orogeny. Within the outcrop at this stop, the thick vein of coarse pegmatite shows excellent Ottawan overgrowths exhibiting excellent oscillatory zoning.

A second, highly deformed leucosome was also dated and yielded the same results. An important difference is that oxygen isotope values for zircons from the large, coarse vein suggest that it was not formed in situ whereas those in the highly deformed vein are consistent with an in situ origin, as is the case in all other metapelitic migmatites studied.

Both mafic and granitic sheets can be traced across the roadcut face and reveal the presence of fault offsets. Note that the name "Treadway Mt Formation" assigned to this unit by Walton suggests that it has stratigraphic characteristics and continuity. This assumption is no longer considered to be correct and is, at best, is a lithotectonic assignation.

47.2 Granite and gabbro.
47.9 Large isoclinal fold in quartzites and metapelitic rocks.
48.1 Undeformed gabbro.
48.4 Marble. Park in parking area.

STOP 4. Swede Mt Sequence (60 Minutes, Including Lunch).

The metasediments exposed along the Rt 8 at Swede Mt provide an exceptional opportunity to closely examine both the rocks and structure. At the southwestern end of the sequence (mile 47.9) a well-exposed isoclinal fold can be seen in the large roadcut on the south side of Rt 8. Folded units include marble, quartzite, sillimanite-garnet-quartz-feldspar (khondalite) gneiss, and rusty sulfidic Dixon Schist. The latter is thought to represent a sheared, altered, and graphitic variety of the khondalite. The fold axis trends ~E-W at a low angle of plunge about the horizontal, and its axial plane, which dips from ~50 degrees SW to horizontal, has been folded about upright E-W axial planes. The fold is typical of refolded isoclines in the Adirondacks. Similar rocks at Dresden Station, on the east side of Lake George, are intruded by a metagabbro dated at 1106 $\pm$ 7 Ma. At this locality the metagabbro truncates foliation and even individual garnet grains in the khondalite. These relations indicate that the khondalite was deposited and first metamorphosed in Elzevirian times. Early workers considered the khondalite to be a stratigraphic unit (Hague Gneiss or Spring Hill Pond Formation), but regional mapping suggests that individual units are continuous over distances of miles only. Both Dixon schist and the khondalite were mined for flake graphite during the early part of the century. The region around Swede Mt is known as the Dixon National Forest and the former mining hamlet of Graphite is located at mile 49.8.As Rt 8 is followed eastward, an undeformed dolerite dike is encountered. The dike strikes parallel to the highway and has caused brecciation and alteration of the country rock that consists principally of marble at this locality. At the top of the hill, and across from Swede Pond, a long roadcut exposes typical Adirondack marbles. At the eastern end of these exposures, a thick bed of quartzite is wrapped around the nose of an isoclinal fold. Note the linear features along its axis. Xenoliths of the quartzite occur in the metagabbro across the road.

49.7 Elephant rock. Consists of leucocratic sillimanite-garnet-quartz-feldspar gneiss (khondalite).
49.8 Khondalite, Dixon Schist and graphite. Trail on right side of road leads to old graphite mines.
54.2 Stop sign. Turn left (north) at junction with Rt 9N.
61.2 Charnockite of the Ticonderoga Dome.
63.7 Rotary. Bear left (north) on Rt 9N.

64.4 Stop light. Junction with Rt 74. Turn right (east).
67.1 Ticonderoga Railroad Station and Fort View Inn.

72.1 Park on right side of road

STOP 5. Classic Great Unconformity (10 Min)

This roadcut provides a classic exposure of flat-lying Potsdam sandstone (~550 Ma) in profound angular unconformity with steeply dipping Proterozoic gneisses (ca. 1300-1050 Ma). A conglomeratic layer is developed at the base of the Potsdam, and zone of alteration is present along the unconformity.

72.7 Turn left into large parking area

STOP 6. Isoclinal Folds And Intrusion Breccia (30 Min)

Roadcuts on the west side of the highway expose excellent examples of Adirondack isoclinal folds developed in granitic gneiss of uncertain, but possibly ~1150 Ma (AMCG) age. The fold axes are oriented almost E-W and plunge gently around the horizontal, which is common in the Adirondacks. However, the axial planes are vertical which is very unusual for Adirondack isoclinal folds, which are commonly recumbent. The upright axial planes appear to be the result of a late, upright anticlinal fold that has rotated recumbent isoclines to their present upright positions. In places the folded units appear to be crosscut by other granitic material. Towards the north end of the roadcut a deformed pegmatite fills a small reverse fault.

South from the folded outcrop a large roadcut exposes a series of intrusion breccias in which granites have disrupted amphibolites and other rocks. A number of crosscutting relationships can be seen. Many of the granitic rocks display minimal deformational fabric and are thought be Lyon Mt. Granite (see Table 1 for whole rock geochemical data). In any case, the intrusion breccia is one of the very few recognized outside of the anorthosite massifs. Its proximity to the upright isoclinal folds is considered to be significant but is not yet clearly understood.

Table 1. Whole rock XRF analyses of the Lyon Mt. Granite at Stop 6

	White LMG	Pink LMG
SiO_2	74.49	75.29
TiO_2	0.06	0.07
Al_2O_3	13.42	13.25
Fe_2O_3	0.70	1.11
MgO	0.01	0.03
CaO	0.76	0.45
Na_2O	2.22	3.28
K_2O	7.45	5.77
P_2O_5	0.10	0.079
Sum	99.30	99.44

78.1 Parking area with potable spring water
79.1 Park along right side of road

STOP 7. Dresden Station Roadcut (30 Min)

Large roadcuts on either side of the highway contain some of the best exposures seen anywhere in the Adirondacks. Lithologies include strongly foliated ferrodiorite at the south end of the western roadcut and an olivine metagabbro at the south end of the eastern roadcut. Also present are marbles, calcsilicates, garnet-sillimanite metasediments, and graphitic schist. Dips are everywhere steep to the south, and a strong subhorizontal E-W lineation is widely developed. Well-exposed isoclinal folds are present at several localities in the roadcuts. These features are described below.

a) The ferrodiorite belongs to a much larger mass of this rock that can be seen a few hundred feet south in the next roadcut. It is typical of late liquid fractionates of anorthosite, which it grades into to the west and uphill. The contact with quartzite at the south end of the roadcut is highly foliated and may represent a detachment surface. Elsewhere this structural horizon is associated with intense mylonitization.

b) A few tens of feet to the north an isoclinal fold is clearly visible and is cored by marbles.

c) The south end of the eastern roadcut passes through a dark metagabbro with a U-Pb zircon age of 1106 $\pm$ 7 Ma indicative of AMCG suite affinities (McLelland and Chiarenzelli, 1989, Aleinikoff, 2006 pers. comm.). The rock contains olivine and two pyroxenes with clinopyroxene exceeding orthopyroxene. The olivines are rimmed by orthopyroxene-clinopyroxene-garnet coronas and small grains of spinel clouded plagioclase. McLelland and Whitney (1980) have extensively described coronas of this type, and relevant reactions are given in their publications. The coronas are thought to have formed during granulite facies conditions characteristic of the Ottawan Orogeny. The northern contact of the metagabbro exhibits a good chill margin and adjacent garnet-sillimanite metapelite has undergone microscopically visible anatexis along the contact. Within the metagabbro good ophitic texture is well preserved and randomly oriented plagioclase laths are undeformed despite the fact that these rocks experienced the Ottawan Orogeny (1090-1030 Ma). Preservation of original, delicate igneous textures in the metagabbros is thought to be the result of their strength, low ductility, and anhydrous nature. The pristine nature of the chilled contact margin may reflect the fact that the local country rock had already been dehydrated. This possibility is manifested by relationships plainly displayed on the top surface of the roadcut where the metagabbro truncates strong linear (~N-S) and planar fabrics in a garnet-sillimanite xenolith (?). It follows that the fabric is older than ca 1106 Ma and most likely represents Shawinigan (ca 1210-1160 Ma) penetrative deformation. This is one of the few examples of unequivocal pre-Ottawan fabrics in the Adirondack Highlands. Within the metagabbro, and exposed near the truncated contact, are planar surfaces that exhibit strong E-W lineation defined by elongate mineral grains. This lineation parallels Ottawan fabrics and is interpreted as due that that event. Across the highway, the metagabbro thins and is exposed at the top of the roadcut as a narrow (~0.5 m) body hydrothermally altered mylonite surrounded by metasediments. This exposure may represent a fold nose or a neck resulting from attenuation. Whatever structure is involved is somewhat immaterial compared to the fact that at this locality the metagabbro exhibits mylonitic foliation and lineation parallel to regional and local Ottawan trends thus substantiating that the Ottawan Orogeny was strongly felt in the eastern Adirondack Highlands.

d) As one proceeds north at road level from the metagabbro contact, a series of metasediments are encountered. The first of these is the garnet-sillimanite (+ feldspar, quartz, and graphite) with a fabric orientation that now parallels E-W regional Ottawan structures. Presumably the fabric was originally formed in the Shawinigan but was rotated into parallelism by intense Ottawan tectonism. Note the manner in which the marbles have torn through other lithologies that now sit within them as tectonic "fish". Beyond the marble unit, a schistose unit shows a sulfidic stain. Close inspection shows that these rocks represent highly fractured equivalents of the garnet-sillimanite unit with which it is commonly associated. It is also the horizon that was mined for graphite in the late 1800's and into the 20th century. The unit is known as the Dixon Schist; hence Dixon-Ticonderoga pencils. Presumably the fracturing provided pathways for fluids that deposited sulfides and perhaps graphite. Given the ductile nature of the Ottawan Orogeny, this fracturing must have been a late event in the geologic history of the area.

e) At the north end of the roadcut there are excellent exposures of the garnet-sillimanite unit with its distinctive, pea-size garnets. Although these garnets exhibit the pale-lavender color commonly associated with spessartine, there is very little of this molecule present and the garnets are dominantly almandine. Many garnets have spiral arms and almost all are zoned with clear rims and ilmenite-rich cores. This difference may be the result of Shawinigan vs. Ottawan growth.

85.8 Park along right of highway near intersection with Blue Goose Road

STOP 8. Ca 1350 Ma Tonalite (15 Min.)

Within the Adirondacks, the ca 1350-1250 Ma suite of tonalitic to granodioritic rocks is restricted to the southern and easternmost regions (Fig.5). Identical lithologies and ages are found in the Green Mts., Vermont and in the western Central Metasedimentary Belt. Together this group is known as the Adirondack-Dysart-Green Mt suite. Its strongly calcalkaline signatures attest to its origin in within a group of composite, outboard arcs. The rocks themselves tend to be compositionally homogeneous and consist of approximately 25% quartz, 80% intermediate plagioclase (~AN_{35}), and 10% mafics. They are characterized by their gray color and the presence of disrupted amphibolite layers thought to be disrupted synemplacement gabbroic dikes.

89.1 Junction Rts. 4 & 22 in Whitehall
96.2 Turn left into parking area

STOP 9. Kinematic Indicators & Straight Gneiss (30 Mins)

This long outcrop provides some of the best exposures of mylonitic rocks and kinematic indicators in the Adirondacks. At its north end it exposes mylonitic metapelitic migmatites that are folded around E-W recumbent isoclinal axes that are visible only in minor folds. Upright, relatively open folds that are approximately coaxial with the E-W isoclines refold them. Down-dip ribbon lineations are readily apparent on foliation surfaces and trend ~E-W. Zircons from leucosomes in these rocks have been dated at this locality and show Elzevirian cores, Shawinigan mantles, and Ottawan overgrowths, and are consistent with the fluxing of Ottawan anatexis by Ottawan fluids.
Towards the south end of the roadcut the mylonitic migmatites are intruded by pink megacrystic granite thought to be of AMCG (ca 1155 Ma) age. The granite is variably deformed into a L-S tectonite gneiss defined by elongate feldspar and quartz grains. Foliation in the gneiss generally dips gently SE (Figure 8), although in some areas, the foliation wraps around weakly deformed mafic boudins. Lineations trend SE, typically down-dip of the foliation. The fabric in this granite is similar to those in the surrounding metapelite units.
This granitic gneiss unit is important for understanding the late stage deformation of this region because it is younger than the surrounding metapelites and presumably did not experienced as complex a deformational history. Measurements of strained porphyroclasts in the granitic gneiss at this location generally indicate near plane strain (2D) deformation of the granite, although some samples fall into the constrictional field (Figure 9). We note that in some samples it was difficult to accurately measure strain because of high strain (S_1:S_3 ratios as high as 50:1), large grain sizes, and complex deformation. However, the best-constrained samples indicate plane strain. As such, we interpret this deformed zone as one that has experienced bulk plane strain after the intrusion of the megacrystic granite.
Strained feldspar porphyroclasts in this granitic gneiss also allow an excellent opportunity to assess the kinematics of this zone. An analysis of >100 tailed feldspar porphyroclasts indicates that ~45% indicate a top-SE sense of shear (normal sense offset in current orientation) based on the asymmetry of sigma-type porphyroclasts (Figure 10), while 25% indicate a top-NW sense of shear (Kowalkoski et al., 2008). The remaining 30% of porphyroclasts with clear tails were symmetrical. When ranked for the confidence of the

kinematic indicator, the top-SE sense of shear is even more dominant. These data could be interpreted in several ways. Given the predominance of top-SE kinematic indicators, this zone could be interpreted as a region of normal ductile shear that post-dates the emplacement of the granite (post 1155 Ma?). This extension may have overprinted early thrust displacement, which would explain the presence of top NW sense indicators, although it may be unlikely that early kinematic indicators would be preserved. Alternatively, the presence of both top–SE and NW as well as porphyroclasts with symmetrical tails could also be interpreted as a zone of pure shear that produced thinning and extension of the lower to middle crust.

Based on these preliminary studies, we hypothesize that the last stage of ductile deformation within this zone of the eastern Adirondacks involved extensional deformation, possibly along a SE-dipping normal detachment fault. It is possible that this extension was coeval with the NW-dipping ca 1045 Ma Carthage-Colton Zone that dropped the Lowlands down to the northwest and into juxtaposition with the Highlands. Ongoing geochronologic studies will provide new information of the timing of deformation in this zone. We also suggest that this eastern zone of extension may be an along-strike continuation of the Tawachiche Shear Zone in Quebec (Fig. 11) that dropped the Montauban-La Bostonaiss arc down to the east and into juxtaposition with the Morin Terrane (Nadeau et al, 1992, Corrigan and van Breemen, 1999, Bickford et al, 2008). The picture that emerges is one of late-stage orogen collapse affecting the Adirondack-Morin Terranes at the end of the Ottawan Orogeny. The collapse, which was accompanied by emplacement of Lyon Mt Granite, gave rise to a symmetrical core complex or gneiss dome on the scale and style of the Shuswap Complex.

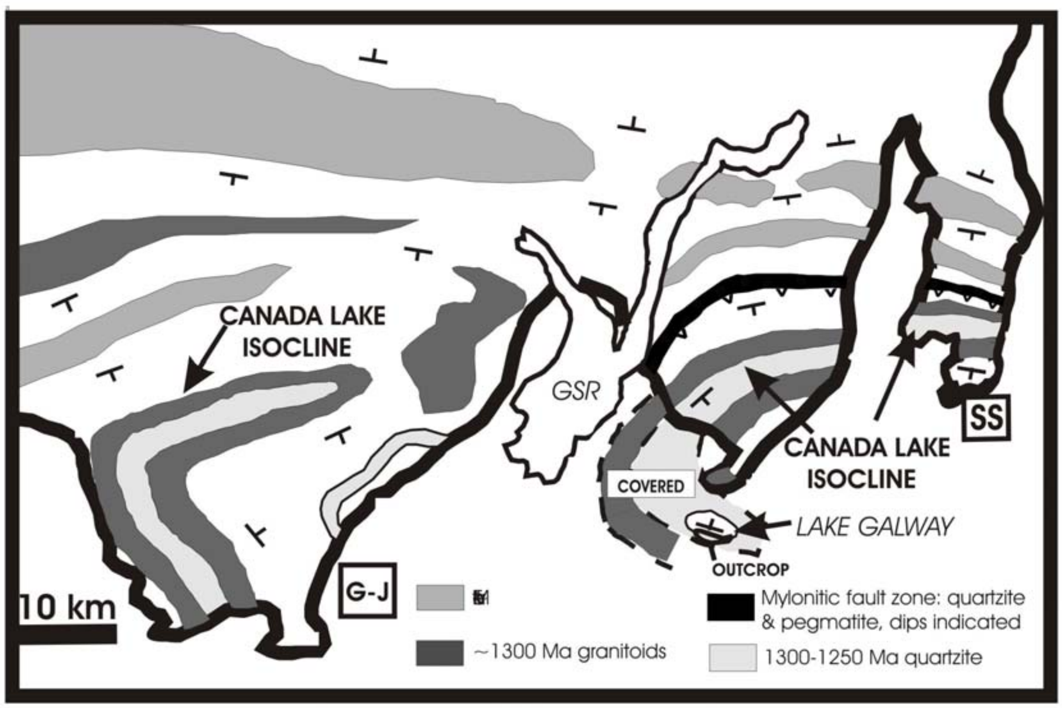

Fig. 7. Schematic structure of the southern Adirondacks showing Canada Lake isocline and eastern repetition

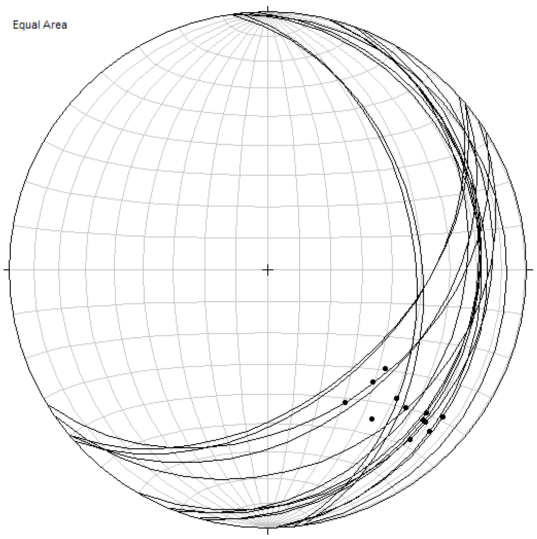

Figure 8. Stereographic projection of foliations and lineations at stop 9. Foliations typically dip gently southeast or east. Lineations plunge down dip.

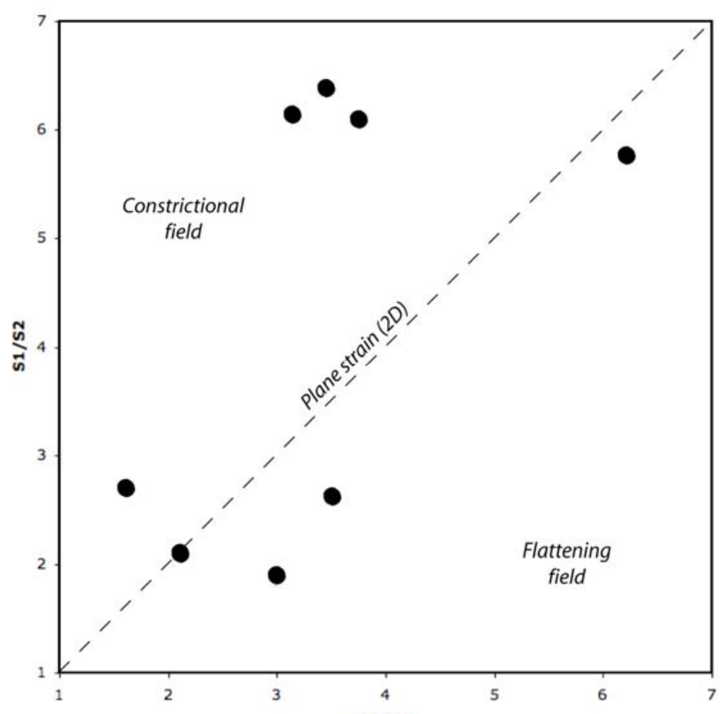

Figure 9. Flinn diagram of samples from the granitic gneiss unit at stop 9. Strain in the granitic gneiss is largely apparent plane strain (2D) although some samples fall in the constrictional field.

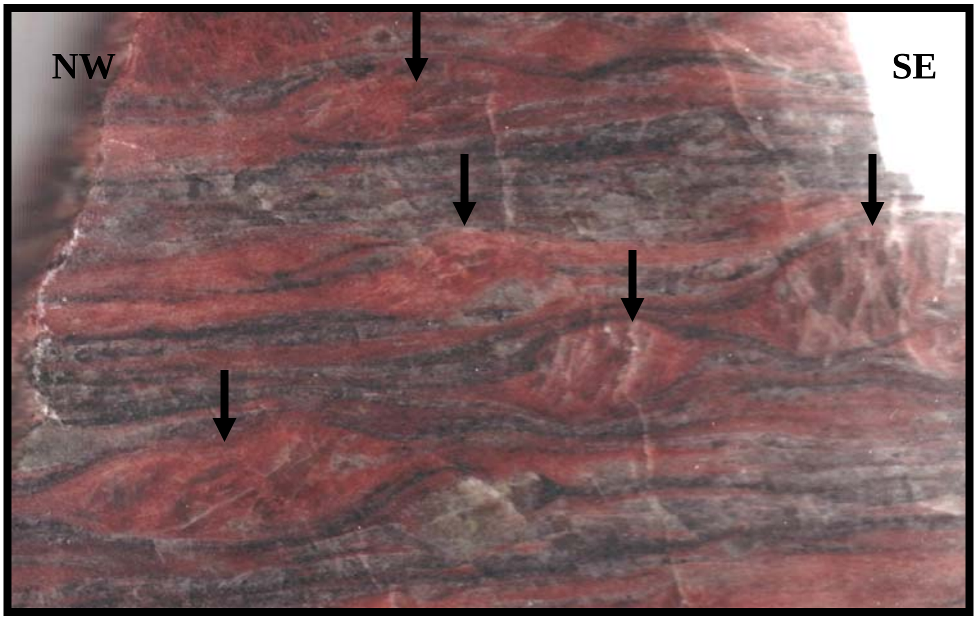

Figure 10. Photograph of slab of granitic gneiss from sample 9 cut perpendicular to foliation and parallel to the lineation. The slab shows a number of K-feldspar porphyroclasts with asymmetric tails that predominantly indicate a top-SE sense of shear (arrows). Image is ~10 cm across.

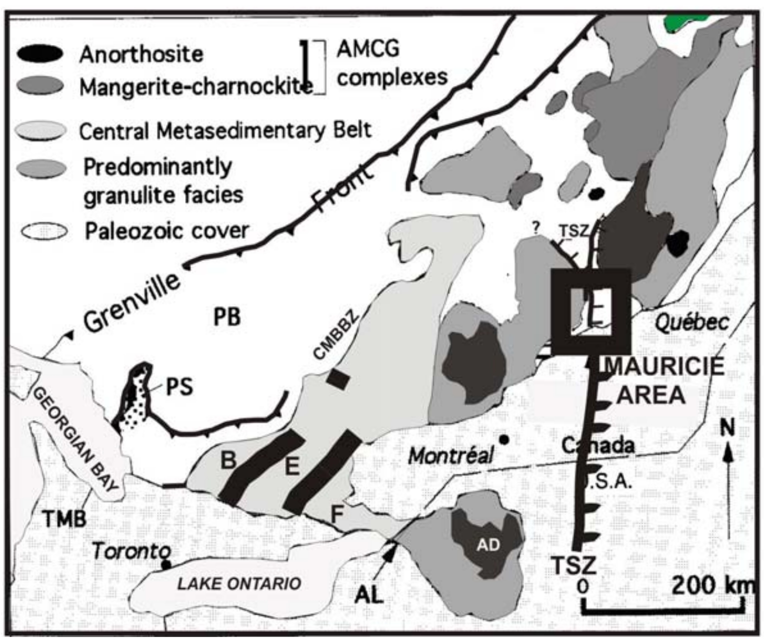

Figure 11. Schematic map of the regional setting of the Adirondacks Highlands (AD) and Lowlands (AL). PS – Parry Sound; B – Bankcroft Terrane; E – Elzevir Terrane; F – Frontenac Terrane; CMBBZ – Central Metasedimentary Boundary Zone; TSZ – Tawachiche Shear Zone and its along-strike projection to the south. Black box encloses the Mauricie are in which lies the town of Shawinigan.

96.6 Stop light at junction of Rts. 4 & 22 at Comstock
97.1 Park along right shoulder of road

STOP 10. Mylonitic Straight Gneiss (20 Min)

This roadcut contains excellent straight gneisses of several lithologies as well as some unusual rock types. Near its SE end are superb mylonitic straight gneisses of sillimanitic migmatitic metapelites. Pegmatites are in various stages of disruption. To the north these become interlayered with garnetiferous gabbroic anorthosite that closely resembles the metapelite leoucosomes except for the presence of hornblende and coarser and more abundant garnets. Gabbroic layers are also present as well as a peculiar aluminous ultramafic that contains diaspore. A whole rock analysis yields SiO_2 = 33%, Al_2O_3 = 17.5 %, Fe_2O_3 = 85 MgO = 24.32%, and CaO = 3%. Calcsilicates are found on both sides of the highway, but on the west side contain pods and layers of orange grossularite-diopside-wollastonite skarn. Nearby these is a discontinuous layer consisting of ~80% red garnet. These types of lithologies are indicative the presence of fluids at high temperature.

99.1 Intersection with Flat Rock Road. Unconformity with Potsdam sandstone expos
100.1 Junction Rt. 149 and Rt. 4 in Ft. Ann. Turn right (west) at traffic light; proceed 20 miles to Lake George Village.

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