Geology of the Black River Valley and the western Adirondack Highlands.

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INTRODUCTION

The Black River, in northern New York State, flows along a course that mostly follows the unconformity between Ordovician sedimentary rocks (to the west) and Proterozoic gneisses of the Adirondack Highlands (to the east; Figure 1). Consequently, the region has attracted sedimentologists, stratigraphers, paleontologists, mineralogists, and metamorphic & igneous petrologists. Our trip, however, will focus almost entirely on the Proterozoic meta-igneous and meta-sedimentary rocks.

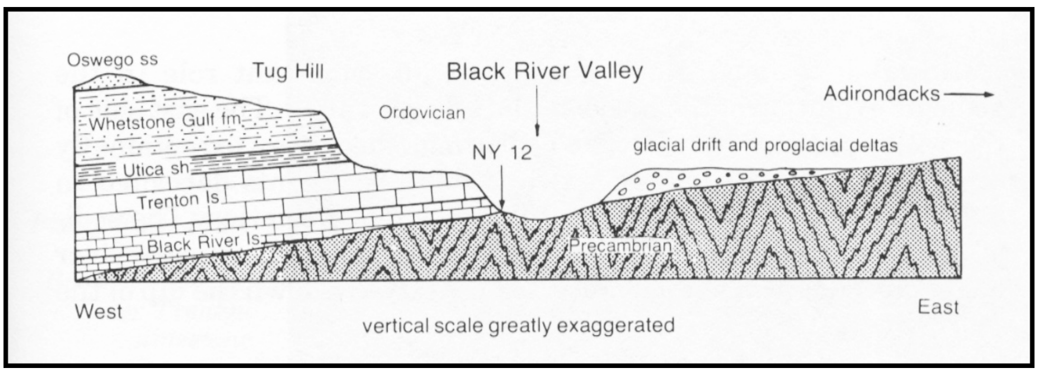

Figure 1. – Simplified west-east cross section across the Black River Valley showing relationship of Ordovician sedimentary rocks of the Tug Hill Plateau to Proterozoic metamorphic rocks of the Adirondack Highlands. From Van Diver (1985).

The Adirondack region of northern New York State is a roughly circular dome of high-grade metamorphic and igneous rocks that form a southeast extension of the Grenville Province in Canada (inset of Figure 2). The Adirondack Highlands comprise mostly meta-igneous rocks (anorthosites, charnockites, mangerites, gabbros, and granites) whereas the Adirondack Lowlands comprise mostly meta-sedimentary rocks (calc-silicates, marbles, metapelites). The Lowlands are separated from the Highlands by the Carthage-Colton mylonite zone (CCMZ), which shows extensive down-to-the-northwest relative motion from the collapse of the Ottawan phase of the Grenville Orogenic cycle (Rivers, 2008). The CCMZ is a metamorphic facies boundary as well, with upper amphibolite facies metamorphic rocks in the Lowlands and granulite facies metamorphic rocks in the Highlands.

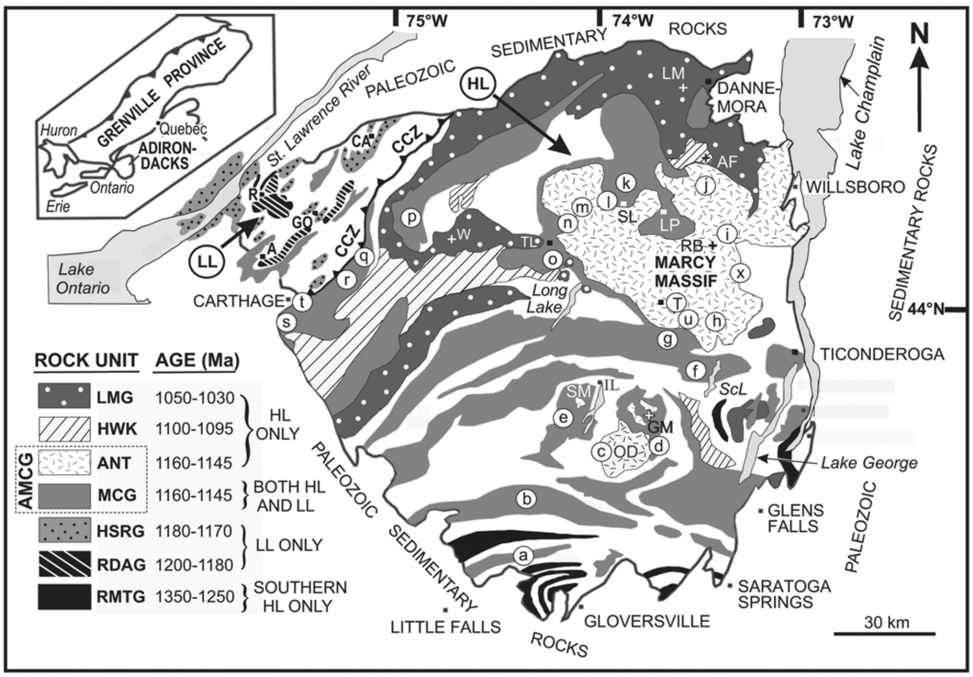

Figure 2. -- Generalized geologic and geochronological map of the Adirondacks from McLelland et al. (2004). Ages of meta-igneous rocks shown in legend. Refer to McLelland et al. (2004) for sample locations and unit descriptions.

As shown in Figure 2, Proterozoic rocks in the western Adirondacks are characterized by mostly charnockites and granites, with lesser amounts of amphibolite and meta-sedimentary rocks (metapelites and calcsilicates). Radiometric dating in the area has largely concentrated on the Lyon Mtn granite (McLelland et al., 2001, 2002b) and surrounding metapelites (Florence et al., 1995). The radiometric dates of zircon fall into two general categories, those associated with the Ottawan phase of the Grenville Orogeny (ca. 1050-1090 Ma) and those associated with earlier anorthosite-mangerite-charnockite-granite (AMCG) magmatism (1145-1160 Ma).

The metapelitic rocks have been the focus of two metamorphic studies (Florence et al., 1995; Darling et al., 2004) and pressure-temperature (PT) conditions of 700-770^{o}C, 4.0-6.4 kb near Port Leyden, NY, and 830-870^{o}C and 6.0-7.2 kb near Moose River, NY, have been determined, respectively. These PT conditions are well into the granulite-facies, but the lower than average pressures reported by Florence et al. (1995) suggest mid-crustal burial depths with an elevated geotherm. The metamorphic temperatures determined in the aforementioned studies are considerably higher than those projected by Bohlen et al. (1985) for the western Adirondacks.

On this trip, we will visit a number of unusual meta-igneous and meta-sedimentary rock types. The basic itinerary is as follows:

Stop 1.— Calc-silicate and sillimanite bearing gneisses on Rt. 12.
Stop 2.— Port Leyden nelsonite.
Stop 3.— Ordovician-age spheroidal weathering at the Knox unconformity.
------------ Lunch --
Stop 4.— Two-pyroxene amphibolite at Lyons Falls, NY
Stop 5.— Hydrothermal quartz + sillimanite veins and pegmatite at Lyonsdale, NY
Stop 6.— Prismatine locality at Moose River, NY
----------- Head back to Hamilton College ---------------------

More detailed rock descriptions and interpretations are included under each of the six stops.

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ROAD LOG

The road log for this field trip begins at the New York State Historical Marker describing the four preserved locks of the former Black River Canal on State Route 12, about 4 miles north of Boonville, NY. Boonville is located about 31 miles north of Utica, NY on State Route 12.

From the exit of the four locks pull-over, proceed north on Rt. 12.

Miles from last point	Cumulative mileage	Route description
0.0	0.0	At the exit for the four locks historical marker, continue on Rt. 12 north
1.2	1.2	Pull over to the exposures on the right side of the road.

STOP 1. -- Calc-silicate- and sillimanite-bearing gneisses.
(43°33'30.73"N; 75°19'47.92"W).

The large roadcut here comprises strongly foliated, northwest dipping, augite + K-feldspar + quartz + biotite gneiss. This rock occurs in a narrow but traceable band extending to the northeast under the Pleistocene deltaic sands and reappearing along the Moose River (Florence et al., 1995). The unconformity with Middle Ordovician sedimentary rocks is directly across the highway from this exposure, although it is not well exposed.

Other minerals occurring here include grandite garnet, titanite, wollastonite, calcite and scapolite. Florence and Darling (1997) report that the garnet is mostly grossular and the scapolite is mostly meionitic. The wollastonite contains thin rims of retrograde garnet similar to that described by Valley et al. (1983) from drill cores just 3 km northeast of this location. Interestingly, the garnet described by Valley et al. (1983) contains up to 0.76 wt. % stoichiometric fluorine. Wollastonite is also in contact with calcite and quartz.

As noted in some other Adirondack marbles, the presence of regional metamorphic wollastonite suggests a locally H_2O-rich fluid composition (Valley and Essene, 1977; 1980). At PT conditions in this region (700-750^oC, 4-6 kbar; Florence et al., 1995) a fluid composition of X_{H2O} = 0.8 to 0.9 is necessary to stabilize wollastonite, quartz and calcite (Jacobs and Kerrick, 1981). The margins of some quartz + pink K-feldspar veins are characterized by epidote + specular hematite suggesting a higher fluid O_2 fugacity than in the country rock interior. Very small and uncommon grains of amethyst have been observed in veins here, consistent with high O_2 fugacities.

A few meters to the north is a small exposure of leucocratic feldspar + quartz + sillimanite gneiss. Small amounts of biotite, magnetite and almandine garnet occur as well. The sillimanite does not occur in quartz veins like at Stop 5, but instead as small, sometimes radiating clusters. The rock's proximity to the calc-silicates suggests a metasedimentary origin. Also, note the convoluted reddish-pink color patterns in the gneiss. Note that the reddish-pink color is absent from rocks close to small fractures in the gneiss. This suggests that reducing fluids at one time penetrated these reddish-pink rocks, and either dissolved or replaced the earthy hematite inclusions that occupied fractures and cleavages in the K-feldspar. It is conceivable that the reddish-pink color of felsic gneiss here and elsewhere in proximity to the Knox unconformity throughout the Black River Valley is the result of Ordovician-age chemical weathering, an argument supported by spheroidal weathering at Stop 3.

Miles from last point	**Cumulative mileage**	**Route description**
1.9	3.1	Continue on Rt. 12 north to the village of Port Leyden. At traffic light, turn right onto E Main St.
0.1	3.2	After about 1 city block, turn left onto Lincoln St.
0.2	3.4	After passing by some houses, turn right onto North St. (dirt).
0.1	3.5	Proceed about 400 feet and park in the open field on the left.
		Look for a large rounded exposure of gneiss on the south side of the road near a power pole and walk over the top of it. Continue down and to the left about 40 meters until a water-filled mine shaft comes into view. Nelsonite specimens can be found south of the mine shaft, but watch for poison ivy!

STOP 2. -- Port Leyden nelsonite
(43°35'4.93"N; 75°20'27.46"W)

This is one of two occurrences of nelsonite in New York State (Darling and Florence, 1995). The other occurs near Cheney Pond, 110 km to the northeast, in the High Peaks region of the Adirondacks (Kolker, 1980; 1982). At Port Leyden, the nelsonite occurs as a dike about 3 to 4 meters wide and is traceable for about 30 meters to the north. The host rock is metapelitic gneiss comprising K-feldspar, quartz, garnet, biotite, sillimanite and spinel.

Nelsonites are igneous rocks comprising apatite and Fe-Ti oxides such as ilmenite, or magnetite and rutile. The Port Leyden nelsonite has 32-50% magnetite, 8-15% ilmenite, 30-45% apatite, and 5-11% pyrite (Darling and Florence, 1995). Chlorite and garnet occur as well, and zircon and monazite are observed in thin section. A characteristic feature is its overall fine-grain texture, a common attribute of nelsonites (A. Philpotts, personal communication). See Figure 3.

Nelsonites are normally associated with anorthosite-suite rocks (like at Cheney Pond) and there are two competing theories on their origin. They are believed to form by either magmatic immiscibility (Philpotts, 1967; 1981) or by cumulate processes (Dymek and Owens, 2001), but in both cases the source rocks are either anorthosites or oxide-apatite gabbro norites. Neither of these two rocks occurs within the vicinity of Port Leyden and so the parent rock of the Port Leyden nelsonite is unknown. It is possible that the parent rocks once existed in the Port Leyden area and were eroded away. This is plausible because Philpotts (1981) suggests that nelsonites actually intrude downward in the crust due to their high liquid density (~4.0 gms/cm^3). It is also possible that anorthosite-suite rocks currently located near Carthage, NY (~50 km to the north-northwest) could be a potential source rock as the Adirondack Lowlands once existed structurally on top of the Adirondack Highlands and slid in a NW direction along the CCMZ late in the history of the Grenville Orogeny (Rivers, 2008). This would require greater that 50 km of horizontal displacement along the CCMZ, however.

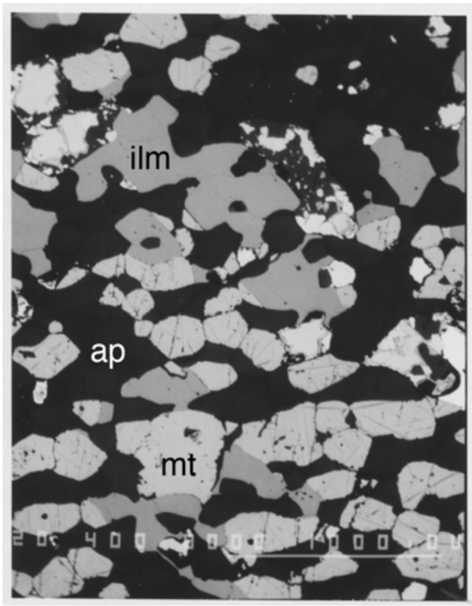

Figure 3. – Backscattered electron image of the Port Leyden nelsonite. Bar scale at bottom is 1 mm. Note distinctive fine-grained texture. ap = apatite; mt = magnetite; ilm = ilmenite. Brightest grains are pyrite (unlabeled).

Radiometric dates have not been published for the Port Leyden nelsonite but it is believed to coincide with intrusion of the AMCG suite, which McLelland et al. (2004) state occurred ca. 1155 Ma. This is interesting because the nelsonite dike cross-cuts the foliation in the metapelite, which would suggest that deformation and metamorphism of the host rocks predates the AMCG igneous event. This is not the case, however, because the nelsonite shows evidence of a weak foliation (mostly in form of oriented pyrite grains). It is interpreted that both the nelsonite and surrounding country rocks experienced regional metamorphism and deformation after the nelsonite intruded, but both deformation and metamorphism were much less pronounced in the nelsonite.

Small lenses (2 cm width) of nelsonite are locally observed in the surrounding metapelitic gneiss. One such lens occurring in rock excavated from the small hydroelectric plant on the Black River at the end of North St. was found to contain small (1 mm), highly fractured sapphires (Darling and Crysler, 2012). Their rich blue color is attributed to the presence of high amounts (up to 0.22 wt.%) of TiO_2, which is not surprising given the composition of the host lens. Although these sapphires are not gem quality, their presence here demonstrates that conditions necessary to form sapphire did exist in the Adirondacks and that gem grade material may exist elsewhere.

Miles from last point	**Cumulative mileage**	**Route description**

0.0	3.5	Turn around and head back along North St.
0.1	3.6	Continue straight (don't turn left onto Lincoln St.)
0.3	3.8	Turn right onto State Route 12, and continue for 12.0 miles
12.0	15.8	Turn right onto Cannan Rd.
0.2	16.0	Pull off to left side of road at the first sight of Roaring Brook.

STOP 3. -- Ordovician spheroidal weathering in Proterozoic gneiss
(43°44'32.78"N; 75°25'30.40"W)

Walk down to the exposures of pink feldspathic gneiss along Roaring Brook. Here fractured bedrock contains very good examples of spheroidal weathering preserving between the fractures sets (Figure 4). The spheroidal weathering is characterized by closely spaced (3-4 mm) bands of iron hydroxide, the bands extending a few centimeters into the gneiss (from the fracture sets). Microscopically, the bands are characterized by fine-grained iron-hydroxide, calcite, chlorite, and possibly serpentine. Locally, the bands are filled with medium-grained calcite, suggesting open fracture deposition.

Figure 4. – Vertical view onto surface of Ordovician–age, spheroidal weathering preserved in middle Proterozoic felsic gneiss just below the Knox unconformity at Roaring Brook (Stop 3). Hammer for scale.

From this location, walk upstream about 30 meters and observe the lowermost strata of the Pamelia Formation (Middle Ordovician) resting directly on top of Proterozoic gneiss.

This is the widely known Knox unconformity and is very well preserved in the stream bed. Spheroidal weathering also occurs directly below the nonconformable contact, but is observed only during low water levels (normally late summer). The spheroidal weathering directly below the nonconformity and ~30 meters downstream (location of Fig. 4) are the only locations where it has been observed. Both are located within one vertical meter of the nonconformity. Exposures of felsic gneiss farther downstream, which are a few meters below the projection of the unconformity, show little or no evidence of spheroidal weathering. The proximal relationship between the nonconformity and the spheroidal weathering is interpreted as evidence of Ordovician-age chemical weathering. Middle Ordovician time, therefore, was likely tropical or sub-tropical, which is consistent with paleomagnetic studies (Niocaill, et al., 1997).

Because the closely spaced bands of iron hydroxide (in the spheroidal weathered portion of the gneiss) contain chlorite, the rocks must have been buried to “chlorite-grade” depths following middle Ordovician deposition. This is interpreted to have occurred during the late Paleozoic Alleghanian Orogeny (Isachsen et al., 1991). Consequently, the chlorite cannot be associated with any retrograde metamorphism that occurred during exhumation of Proterozoic rocks following the Grenville Orogeny.

Miles from last point	**Cumulative mileage**	**Route description**
0.0	16.0	Turn around and head back toward State Rt. 12
0.2	16.2	Turn left onto State Rt. 12 and continue south to the Stewart’s Shop in Lyons Falls (9.4 miles).
9.4	25.6	Turn left into Stewart’s (restrooms and lunch stop).
0.0	25.6	LUNCH and RESTROOM STOP

Miles from last point	**Cumulative mileage**	**Route description**
0.0	25.7	Exit out of the east side of Stewart’s and turn left (Cherry St.)
0.2	25.9	Turn right onto McAlpine St.
0.2	26.1	Turn right onto Center St and proceed through the village of Lyons Falls
0.3	26.4	Former Lyons Falls Pulp & Paper Co. on left; Gould Mansion on right. The road here is now Franklin St.
0.2	26.6	Turn left onto Laura St. immediately after Jim’s Used Book Store, and cross the Black River.
0.2	26.8	Turn left onto Lyons Falls Rd. (County highway 39) and cross the Moose River. This is the site of the former “three-way bridge” of Lyons Falls
0.3	27.1	After crossing the Moose River, turn left into the dirt parking lot and walk down to the falls.

STOP 4. -- Two-pyroxene amphibolite at Lyons Falls
(43°37'7.02"N; 75°21'25.81"W)

Lyons Falls drops about 63 feet here and has been harnessed as a power source since the mid-1800's. The base of the falls served as an initial settlement for French explorers of the "Castorland Company," in June of 1794 (Hough, 1860).

Lyons Falls occurs here because of a ~100 meter wide band of highly resistant amphibolite gneiss that strikes SW-NE, normal to the course of the Black River. The amphibolite here is strongly lineated with discontinuous, thin, plagioclase-rich bands. Foliation is poorly developed. The unit has a sharp contact with quartz-feldspar gneiss to the south (observed at the foot of the upstream board dam) but the north contact is not exposed.

Petrologically, the unit is best described as a medium-grained, two-pyroxene amphibolite. Hornblende and plagioclase are the dominant mineral phases. A red-brown (presumably Ti-rich) biotite and opaque magnetite occurs as well (Figure 5). Unlike the central and eastern Adirondacks, the amphibolite at Lyons Falls contains no garnet, despite the fact they are compositionally similar.

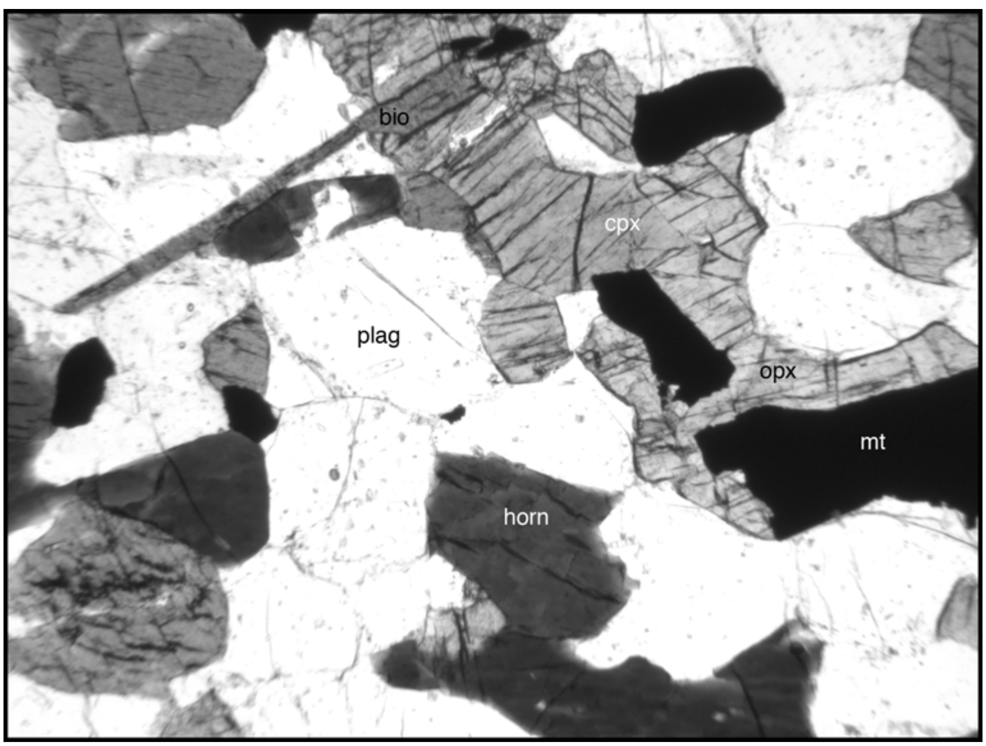

Figure 5. – Photomicrograph of amphibolite at Lyons Falls. Note granoblastic texture and medium grain size. Plag = plagioclase, horn = hornblende, cpx = clinopyroxene, opx = orthopyroxene, bio = biotite, mt = magnetite. Note absence of garnet (see text for discussion). Field of view = 2.5 millimeters width.

The absence of garnet in amphibolites from the western Adirondacks has been known for a long time (Buddington, 1939; de Waard, 1967 and references therein). Its absence is due to lower metamorphic pressures in this region of the Adirondacks as compared to the central and eastern Adirondack Highlands. Figure 6 shows that the amphibolite of Lyons Falls is located to the west of the garnet + clinopyroxene isograd. In mafic rock compositions, this isograd is based on the reaction:

$$\text{orthopyroxene} + \text{anorthite} = \text{clinopyroxene} + \text{garnet} + \text{quartz} \quad (1),$$

where garnet is present on the higher pressure side of the reaction. The famous garnet amphibolites (e.g. Gore Mtn.), so common in the central and eastern Adirondacks could not form in the western Adirondacks simply because the rocks were not buried deep enough.

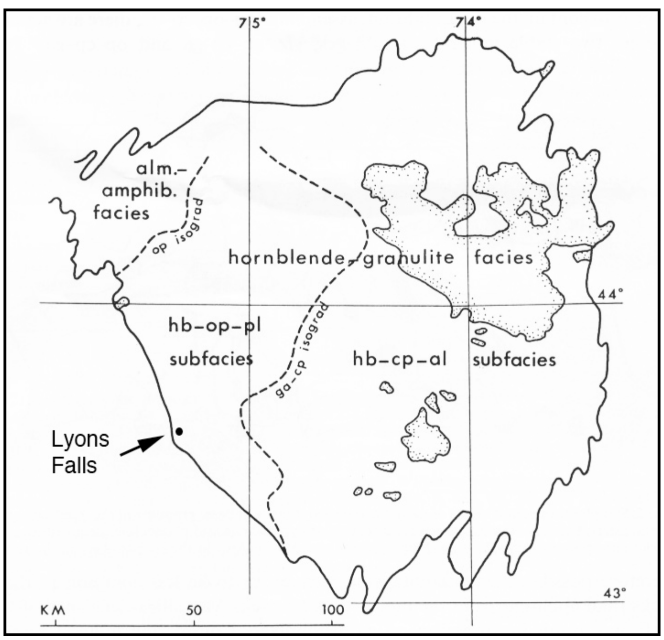

Figure 6. – Simplified metamorphic isograd map for the Adirondacks modified from de Waard (1967). Note the amphibolite at Lyons Falls is located west of the garnet + clinopyroxene isograd.

Also occurring at Lyons Falls are some meter-scale potholes carved into the amphibolite. These are best observed during low-water levels and closer to the water fall.

Miles from last point	Cumulative mileage	Route description
0.0	27.1	Turn around and head back across the Moose River toward Laura St.
0.3	27.4	Turn left (east) onto Laura St.
0.6	28.0	Bear left onto Lyonsdale Rd.
2.4	30.4	Once in Lyonsdale, turn left onto Lowdale Rd. at the Burroughs Mill and cross the Moose River again (caution, the bridges are narrow!)
0.2	30.6	After the second bridge, pull off in the sandy area to the right or left.
		First, walk out onto the last bridge crossed and look north (downstream). Then, walk down the path on the west side of the road for about 100 meters and walk out to exposures in the bed of the Moose River.

STOP 5. – Undeformed pegmatite and hydrothermal sillimanite + quartz veins in Lyon Mtn. granite. (43°37'10.63"N; 75°18'12.84"W)

This stop demonstrates important igneous and hydrothermal features of Lyon Mtn. granite along the Moose River. These exposures were studied extensively by McLelland et al. (2001, 2002a, 2002b) and Selleck et al. (2004). Their overall interpretation is that Lyon Mtn. granite experienced contemporaneous intrusion and hydrothermal alteration at about 1035 Ma. The hydrothermal activity leached large cations (K^+, Na^+) from the granite but left behind Al^{3+} and Si^{4+} to form quartz-sillimanite veins. Early vein sets were ductily deformed (due to magmatic flow or tectonic shear) and younger veins sets formed afterward.

These rocks were included in a large unit of mapped metapelites in Figure 1 of Florence et al. (1995) but the composition and textural features are more consistent with igneous rocks. Some of the country rocks into which the Lyon Mtn. granite intruded are indeed metapelites, and numerous exposures of sillimanite + garnet + hercynite + quartz + K-feldspar gneiss occur in the area.

Looking west from the bridge on the northern side of the Moose River, one can observe an undeformed pegmatite cutting hydrothermally altered Lyon Mtn. granite. The pegmatite is shown in Figure 7 and is compositionally zoned with an uncommon magnetite-rich core. McLelland et al. (2001) dated well-zoned igneous zircons from this pegmatite at 1034 ± 10 Ma. Because the pegmatite is undeformed, the 1034 Ma zircon age has been interpreted as the terminus of Ottawan deformation in the Adirondacks (Orrell and McLelland, 1996).

Figure 7. – Undeformed pegmatite just west of Lyonsdale bridge. Taken from Figure 4a of McLelland et al. (2001). See text for discussion.

The bedrock exposed farther downstream show excellent examples of quartz + sillimanite veins hosted by Lyon Mtn. granite (see Figure 8). These veins occur in two prominent orientations, N20E and N50E (McLelland et al., 2002a). At other locations in the area (e.g. Ager's Falls), the quartz-sillimanite veins are nodular in shape and strongly deformed (McLelland et al., 2002a,b).

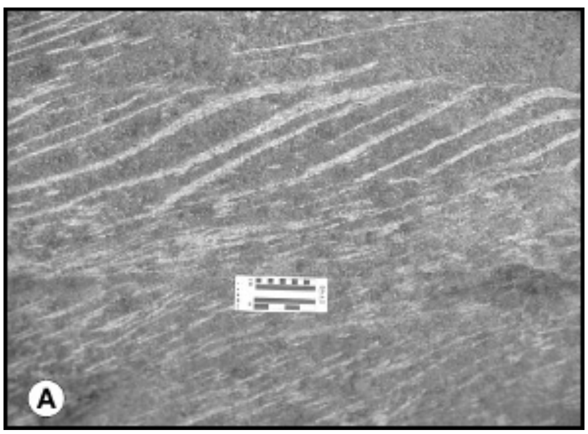

Figure 8. – Hydrothermal quartz + sillimanite veins in Lyon Mtn. granite at Stop 5. Taken from Figure 2a of Selleck et al. (2004).

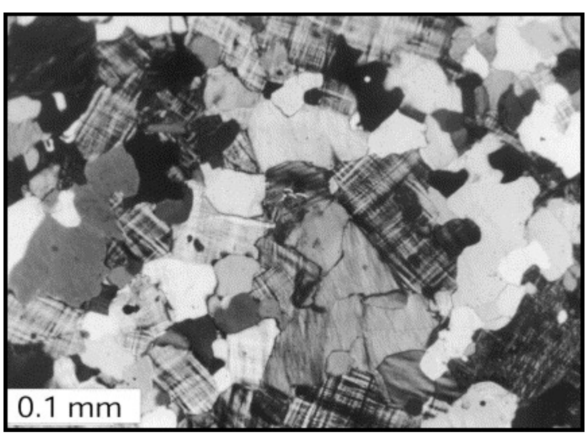

Figure 9. – Photomicrograph of Lyon Mtn. granite. Note little or no grain shape fabric of quartz and microcline. From Figure 11 of McLelland et al. (2002b).

Miles from last point	Cumulative mileage	Route description
0.0	30.6	Turn back and cross the Moose River again on the Lowdale Rd. Again, watch the bridges!
0.2	30.8	Turn left (east) onto Marmon Road.
0.3	31.1	Make a slight left onto Hunkins Rd.
1.1	32.2	Turn right (south) onto Fowlersville Rd.
0.3	32.5	Turn left onto Penney Settlement Rd.
0.5	33.0	Turn left onto North-South Rd.
2.0	35.0	Turn right onto Moose River Rd and head east.
6.9	41.9	1876 red school house on right.
0.2	42.1	Turn left into sandy parking area at first siting of the Moose River.

STOP 6. -- Moose River Prismatine locality

Follow the all-terrain vehicle path downstream for about 200 meters. The path passes through the stone foundations of the former Moose River tannery and then follows rapids as the Moose River flows southwest. Here, the river cuts through northwest-dipping, calc-silicate gneisses and quartzites. Stay high on the river bank until the rapids disappear. The path will descend and cross a small, wet, muddy creek bed. Afterwards, the Moose River pools and turns north and the first outcrops on the west side of the river are the prismatine-bearing rocks. Please exercise caution while walking among the river boulders and talus at the base of the outcrops. Also, please DO NOT USE HAMMERS at this stop and refrain from collecting prismatine specimens unless you're planning to study them scientifically; a future geologist will be grateful someday.

Prismatine, the boron-rich endmember of the kornerupine solid solution (Grew et al., 1996; ideally $Mg_3Al_6Si_4BO_{21}(OH)$) occurs in metapelitic and quartzitic rocks along the Moose River. Kornerupine-group minerals are generally rare, having been described from nine localities in the Grenville Province (Grew, 1996; Darling et al., 2004; Korhonen and Stout, 2005) including two in the Adirondacks (Farrar and Babcock, 1993; Farrar, 1995; Darling et al., 2004).

Along the Moose River, prismatine occurs at two locations (separated by about 400 meters, Figure 10) within a unit of heterogeneous metasedimentary rocks (Figure 10, unit BL) mapped by Whitney et al. (2002). This unit comprises mostly quartzite and biotite-quartz-plagioclase gneiss with lesser amounts of calcsilicate rocks, and minor amphibolite, quartzofeldspathic gneiss, and calcite marble (Whitney et al., 2002). These rocks are interlayered with other metasedimentary and meta-igneous rocks (Figure 10). These units occur in a complex, southeast-verging overturned synform bordered on the northwest by a tabular, northwest-dipping body of charnockitic gneiss (CG) several kilometers thick, and on the southeast by a domical body of batholithic proportions consisting of relatively leucocratic CG (Whitney et al, 2002). Although the granitic and charnockitic rocks have not been dated, they are lithologically and geochemically similar to felsic rocks of the ca. 1150 Ma anorthosite-mangerite-charnockite-granite (AMCG) suite found throughout much of the Adirondack Highlands (McLelland et al., 2001; Whitney et al., 2002).

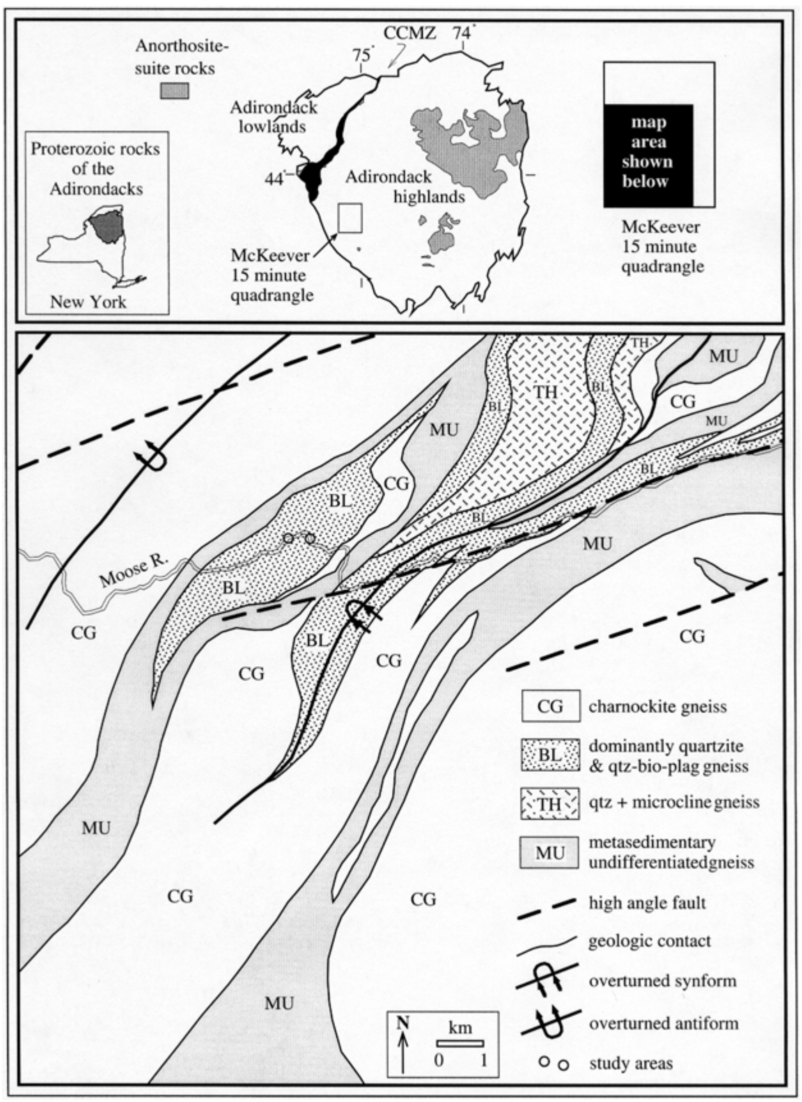

Fig. 10. - Map showing location of prismatine-bearing metapelites and quartzites (open circles on Moose River) and surrounding bedrock geology. Stop 6 is the easternmost open circle. Geologic map units, structures, and relations illustrated are from Whitney et al. (2002). *Taken from Darling et al. (2004).* Bio—biotite; CCMZ—Carthage-Colton mylonite zone; pl—plagioclase; qtz—quartz.

In addition to prismatine-bearing assemblages, the surrounding rocks contain metapelitic assemblages of a) cordierite + spinel + sillimanite + garnet + plagioclase + quartz + ilmenite + rutile +/- biotite, b) cordierite + orthopyroxene + biotite + K-feldspar + quartz, and c) orthopyroxene + plagioclase + K-feldspar + quartz +/- biotite, +/- garnet (Darling et al., 2004).

The feature of geologic interest at STOP 6 are the exceptionally well-developed prismatine crystals in coarse-grained, feldspathic lenses. Here, prismatine crystals form dark greenish-black, euhedral, elongated grains (up to 10 cm in length). Ed Grew (personal communication) indicates that only the prismatine crystals from the Larsemann Hills, Antarctica (Grew and Carson, 2007) are comparable in length to those at Moose River. The prismatine commonly displays radiating patterns in feldspathic lenses one to three cm thick (Figure 11A).

The prismatine crystals *appear* to have grown only within the plane of the foliation. However, upon closer examination, the prismatine grains are seen to be arranged randomly, but the longest and best-developed crystals formed parallel to the foliation plane. Because of this, Darling et al. (2004) inferred that nondeviatoric pressure conditions prevailed locally during prismatine formation. It should also be noted that a number of prismatine-bearing feldspathic lenses are located adjacent to fine-grained tourmaline + plagioclase + biotite–rich zones near the north end of the exposed rocks. In these locations, the prismatine-bearing feldspathic lenses texturally embay, cross-cut earlier foliation, and appear to form at the expense of the tourmaline-bearing zones (Figure 11B). The embayed country rocks, coarser grain size, and the random arrangement of the prismatine crystals led Darling et al. (2004) to interpret the feldspathic lenses and the prismatine found in them to be of anatectic origin.

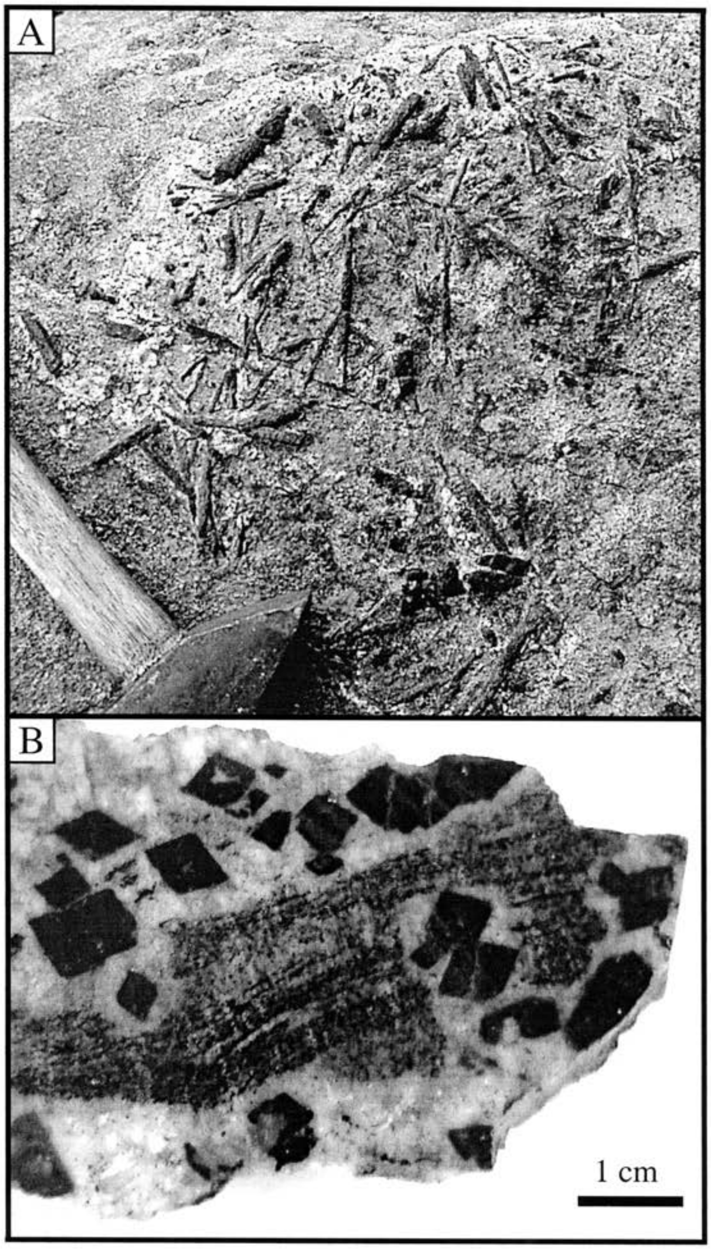

Fig. 11. - (A) Prismatine crystals (black) in coarse-grained feldspathic lens, taken parallel to plane of lens. Hammer for scale. (B) Euhedral prismatine (black) in coarse-grained feldspathic lens embaying fine-grained, foliated tourmaline + biotite + plagioclase–rich zones. *Taken from: Darling et al. (2004).*

Plagioclase, K-feldspar, minor quartz and rutile are the most common phases associated with prismatine, but biotite, cordierite, garnet and rarely sillimanite occur locally as well. The prismatine contains 0.73 to 0.79 formula units of B (out of 1.0) and has Mg / Mg + Fe between 0.70 and 0.73 (Table 3 of Darling et al., 2004). After determining the associated mineral compositions, Darling et al. (2004) proposed the following prismatine-forming reaction:

Tourmaline + sillimanite + biotite + cordierite → prismatine + rutile + melt (2).

Reaction 2 is similar to a number of proposed prismatine-forming reactions from other granulite terranes (Grew, 1996), including those in sapphirine-free rocks found in the Reading Prong, New Jersey (Young, 1995), and in Waldheim, Germany (Grew, 1989). In those cases, garnet rather than cordierite was a proposed reactant.

Metamorphic temperatures and pressures are difficult to estimate from prismatine-bearing mineral assemblages as little is known about the stability of boron-rich kornerupine at pressures less than 10 kb (Schreyer and Werding, 1997). However, the prismatine occurs in proximity to low-variance metapelitic assemblages in the surrounding rocks. Specifically, thermobarometry calculations from net transfer and exchange equilibria record temperatures and pressures of 850° ± 20°C and 6.6 ± 0.6 kilobars for orthopyroxene + garnet assemblages and 675° ± 50°C and 5.0 ± 0.6 kilobars for cordierite + garnet + sillimanite + quartz assemblages (Darling et al., 2004). The former assemblage is interpreted to have formed during partial melting whereas the latter assemblage is interpreted to have formed on the early retrograde metamorphic path (Darling et al., 2004). The ~850°C temperatures derived from the orthopyroxene + garnet assemblage are reasonable for partial melting conditions. Although the cordierite + garnet + sillimanite + quartz assemblage occurs at STOP 6, it and the orthopyroxene + garnet assemblage are better developed farther downstream at the second prismatine location (the westernmost open circle in Figure 10). These exposures can be reached by following the footpath on the south bank of the Moose River for a distance of about 400 meters.

Because many of the prismatine-bearing feldspathic lenses are saturated in both quartz and rutile, Storm and Spear (2009) intensely studied the prismatine-bearing lenses as part of a natural test of the titanium-in-quartz geothermometer of Wark and Watson (2006). Storm and Spear (2009) determined a wide range of metamorphic temperatures, specifically from 630 + 63 / -86 to 879 ± 8 °C, but most determinations fell between 700°C and 880°C (see Figure 8a of Storm and Spear, 2009). This is in good agreement with metamorphic temperatures determined by the aforementioned methods (Darling et al., 2004). Storm and Spear (2009) also provide convincing textural evidence that prismatine was locally replaced by leucosomatic quartz, most likely during melting of prismatine. Interestingly, it was the leucosomatic quartz that yielded the highest Ti-in-quartz temperatures (800-880°C; Figure 8a of Storm and Spear, 2009).

The age of partial melting is unknown at this time but is likely associated with either intrusion of the AMCG suite at ~ 1160-1145 Ma, or burial associated with the Ottawan phase of the Grenville Orogenic cycle and the associated intrusion of Lyon Mtn. granite at ~ 1050-1030 Ma (McLelland et al., 2010).

ACKNOWLEDGEMENTS

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Miles from last point	Cumulative mileage	Route description
0.0	42.1	Turn around and head back (west) along the Moose River Rd.
4.7	46.8	Turn left (south) onto Moose River Rd going toward Boonville. Yes, it's another Moose River Rd.
8.1	54.9	Follow the Moose River Rd for about 8.1 miles until it intersects State Route 12 and head back toward Utica (about 30 additional miles).