Trip A-2

IGNEOUS AND METAMORPHIC ROCKS OF THE BLACK AND MOOSE RIVER VALLEYS, WESTERN ADIRONDACK HIGHLANDS, NY

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INTRODUCTION

Trip A-2 IGNEOUS AND METAMORPHIC ROCKS OF THE BLACK AND MOOSE RIVER VALLEYS, WESTERN ADIRONDACK HIGHLANDS, NYThe Black and Moose Rivers, the largest rivers in the western Adirondack Highlands, have exposed numerous Middle Proterozoic metamorphic rocks, with the former largely paralleling the unconformity between Ordovician sedimentary rocks of the Tug Hill Plateau and Proterozoic gneisses of the Adirondack Highlands (to the east; Figure 1). Consequently, the region has attracted sedimentologists, stratigraphers, paleontologists, and metamorphic & igneous petrologists. Our trip, however, will focus almost entirely on the Middle Proterozoic meta-igneous and meta-sedimentary rocks.

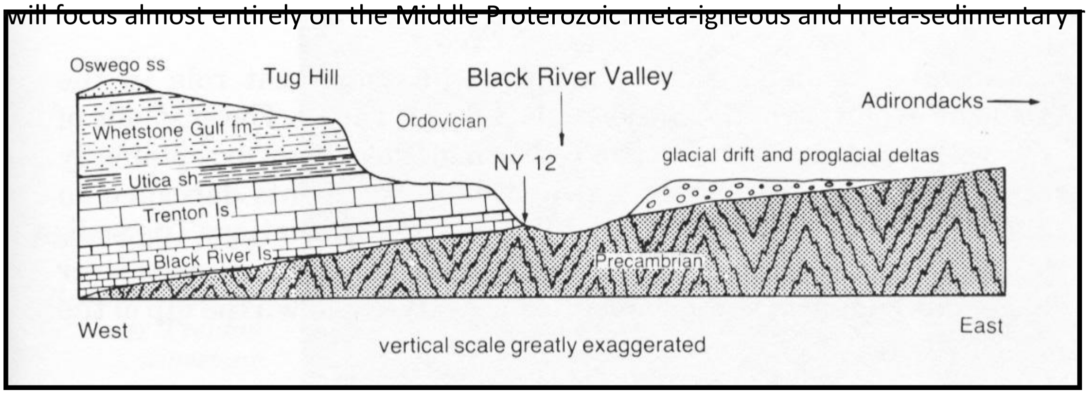

Figure 1. *Simplified west-east cross section across the Black River Valley showing relationship of Ordovician sedimentary rocks of the Tug Hill Plateau to Middle Proterozoic metamorphic rocks of the Adirondack Highlands. From Van Diver (1985).*

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 age and facies boundary as well, with upper amphibolite facies and *Shawinigan age* (1190-1140 Ma) metamorphic rocks in the Lowlands and granulite facies and *Ottawan age* (1090-1020 Ma) metamorphic rocks in the Highlands (Darling and Peck, 2016)

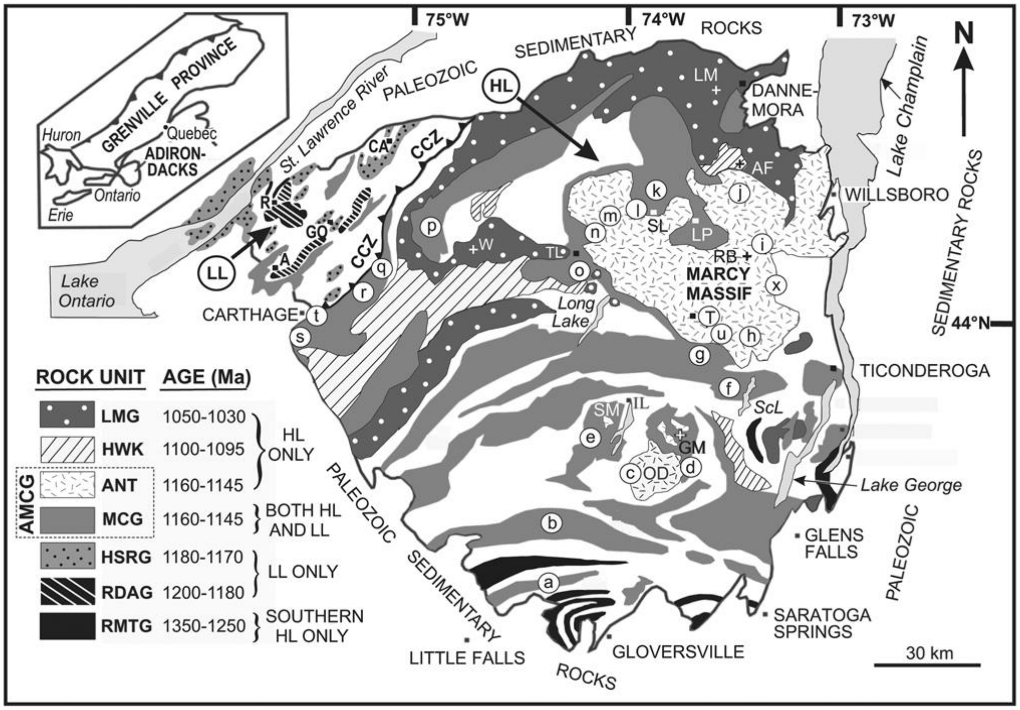

Figure 2. *Generalized geologic and geochronological map of the Adirondacks from McLelland et al. (2004). Ages of meta-igneous rocks shown in legend. Refer to McLelland et al. (2004) for sample locations and unit descriptions.*

As shown in Figure 2, Middle 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).

Metapelitic rocks in the western Adirondack Highlands have been the focus of three metamorphic studies (Florence et al., 1995; Darling et al., 2004; Darling, 2013) and pressure-temperature (PT) conditions of >780^{o}C, 6.0 ± 0.5 kbar near Port Leyden, NY, and 830-870^{o}C and 6.0-7.2 kb near Moose River, NY, have been determined. These PT conditions are well into the granulite-facies, but the lower than average pressures reported by Florence et al. (1995) and Darling (2013) 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. A summary of Adirondack metamorphic conditions is provided by Darling and Peck (2016), and new evidence of ultrahigh temperature metamorphism (UHT, >900°C) has recently been described in the central Adirondacks by Shinevar et al. (2021), Ferrero et al. (2021), and Metzger et al. (2022).

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.— Ordovician-age spheroidal weathering at the Knox unconformity.

Stop 2.— Port Leyden nelsonite.

Stop 3.— Two-pyroxene amphibolite at Lyons Falls, NY

------------ Lunch --

Stop 4.— Hydrothermal quartz + sillimanite veins and pegmatite at Lyonsdale, NY

Stop 5.— Prismatine locality at Moose River, NY

------------ Head back west on Moose River Road ---------------------

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

FIELD GUIDE AND ROAD LOG

Meeting Point: Parking lot of the Edge Hotel, Route 12, Lyons Falls, NY.

The Edge Hotel is located 40 miles north of Utica on Route 12.

Meeting Point Coordinates: 43.6217°N, 75.3717°W

Meeting Time: 8:30 AM

From the Edge Hotel parking lot, turn right and proceed north on Rt. 12 for 9.0 miles and turn right onto Cannan Rd. Proceed for 0.2 miles and park on the left side next to Roaring Brook.

STOP 1. -- Ordovician spheroidal weathering in Middle Proterozoic gneiss

Parking Coordinates:	43.7427°N, 75.4251°W
Site Coordinates:	43.7425°N, 75.4251°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 3). The spheroidal weathering is characterized by closely spaced (3-4 mm) bands of iron hydroxide, the bands extending into the gneiss a few centimeters 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 3. *Vertical view onto surface of Ordovician–age, spheroidal weathering preserved in middle Proterozoic felsic gneiss just below the Knox unconformity at Roaring Brook (Stop 1). Hammer for scale.*

From this location, walk upstream about 30 meters and observe the lowermost red and green sands and pebble conglomerates of the Pamelia Formation (Middle Ordovician) resting directly on top of Middle Proterozoic gneiss. This is the widely known *Knox Unconformity* and represents nearly 600 million years of missing rock record. The unconformity is easily observed 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. 3) 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 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 here cannot be associated with retrograde metamorphism that occurred during exhumation of Middle Proterozoic rocks following the Grenville Orogeny.

From STOP 1, get back on Rt. 12 and head south for 12.1 miles to the village of Port Leyden and turn left at the traffic light. Proceed for 0.2 miles on East Main Street and turn left into the former Port Leyden Elementary School and park. Walk northeastward across the lawn and into the woods about 100 meters and look for a water-filled, mine shaft. Beware of old barbed wire and poison ivy!

STOP 2. – Port Leyden nelsonite

Parking Coordinates: 43.5842°N, 75.3418°W

Site Coordinates: 43.5851°N, 75.3411°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 on the surface. The host rock is metapelitic gneiss comprising K-feldspar, quartz, garnet, biotite, sillimanite and spinel.

Nelsonites are unusual igneous rocks comprising apatite and Fe-Ti oxides such as ilmenite, or magnetite and rutile. They are one of the few igneous rocks on Earth that have little or no silicate minerals. The Port Leyden nelsonite has 32-50% magnetite, 8-15% ilmenite, 30-45% apatite, and 5-11% pyrite (Darling and Florence, 1995). Chlorite is present as well and easily observed in hand specimens, whereas garnet, zircon and monazite are best observed in thin section. The pyrite commonly defines planar bands and lenses in what could be described as a foliation.

A characteristic feature of nelsonite is its overall, fine-grained texture compared to other rocks of the anorthosite suite (A. Philpotts, personal communication,) see Figure 4. However, ilmenite in the Port Leyden nelsonite actually forms much larger, oikocrystic grains up to 5 cm across (Figure 5). Although hard to observe in Figure 4, all of the ilmenite shown is actually part of one larger grain. Oikocrysts are *large crystals that enclose smaller crystals to form a poikilitic texture.* At Port Leyden, the ilmenite fills voids between millimeter scale apatite and magnetite grains (Figure 4). Nearly all ilmenite in the Port Leyden nelsonite is oikocrystic and is best observed by reflections from the (0001) parting on freshly broken or cut surfaces (Figure 5). Ilmenite also occurs as oxy-exsolution lamellae in magnetite (Fenner et al., 2018).

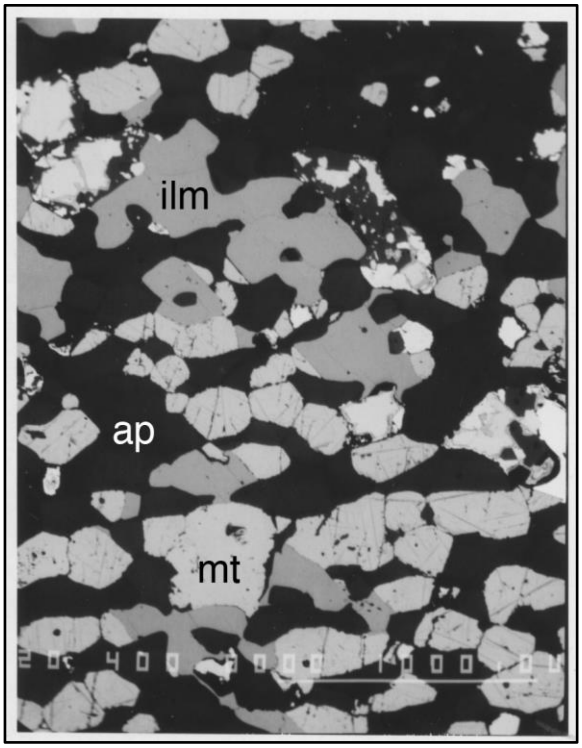

Figure 4. *Backscattered electron image of the Port Leyden nelsonite. Bar scale at bottom is 1 mm. Note distinctive fine-grained texture. ap = apatite; mt = magnetite; ilm = ilmenite. Brightest grains are pyrite (unlabeled).*

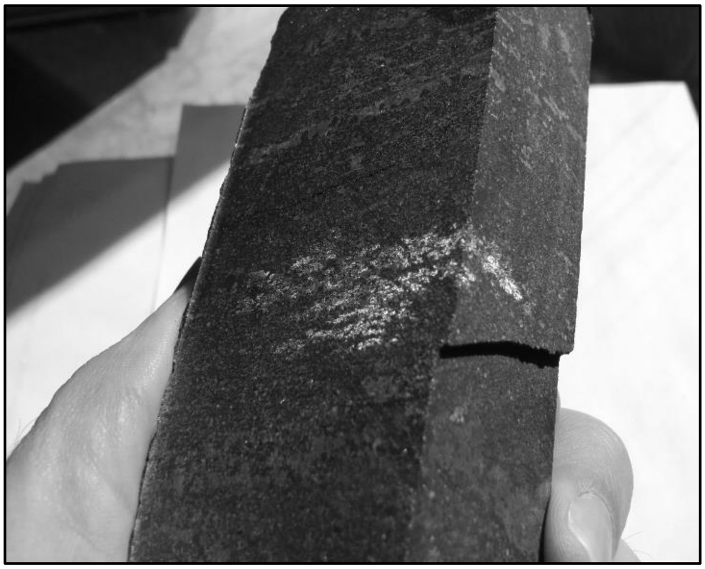

Figure 5. *Cut slab of the Port Leyden nelsonite showing reflections from (0001) parting of single oikocrystic ilmenite grain (center). Slab width is 4 cm.*

It is tempting to infer that the ilmenite oikocrysts have a late igneous origin, but Duchesne (1996) argues against late liquids with a pure ilmenite composition. Although the texture is indicative of late crystallization, the origin of interstitial ilmenite could be the result of post-igneous deformation instead (Duchesne, 1996).

Nelsonites are normally associated with anorthosite-suite rocks (like at Cheney Pond) and there are two proposed theories on their origin. They are believed to form by either magmatic immiscibility (Philpotts, 1967; 1981) or by cumulate processes (Dymek and Owens, 2001; Duchesne and Liégeois, 2015), but in both cases the source rocks are either oxide-apatite gabbro norites or jotunites of the anorthosite suite. Neither of these two rocks occurs within the vicinity of Port Leyden, so the parent rock of the Port Leyden nelsonite has thus far not been identified. It is conceivable 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; see Buddington, 1939) 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 than 50 km of horizontal displacement along the CCMZ, however. Lastly, the most likely and nearest source rocks (stratiform anorthosites and jotunites) occur as little as 25 km to the northeast (near Crooked Creek, roughly along strike) in the Number Four 15' quadrangle (Whitney et al., 2002). These could be potential source rocks that were later separated from the nelsonite during regional Ottawan shearing.

Darling et al. (2018) provide radiometric dates on zircon from the Port Leyden nelsonite. Two zircon textures were observed: 1) highly oscillatory-zoned cores with homogeneous rims, and 2) homogeneous grains. The concordant age on oscillatory zoned cores (n = 14) is 1145.5 ± 4.2 Ma, whereas the concordant age on homogeneous grains and rims (n = 16) is 1036.8 ± 3.8 Ma. Interestingly, the oscillatory zoned cores contain 2-10 micrometer size inclusions of K-feldspar and quartz (Darling, 2016), mineral phases generally not associated with oxide-apatite gabbro norites or jotunites. Therefore, the zircon cores are interpreted as inherited xenocrysts and may suggest mixing of felsic melts with that of the nelsonite parent melt (Darling, 2016). The identification of the included phases was based on EDS analysis so it is plausible that the tiny grains in zircon could actually be kokchetavite and cristobalite, the high temperature, metastable polymorphs of K-feldspar and quartz, respectively, typical of nanogranite melt inclusions (Ferrero et al., 2016). The *homogeneous grains and rims* are interpreted to have formed during igneous crystallization of the Port Leyden nelsonite. The 1036.8 ± 3.8 Ma age of igneous crystallization is similar to an obtained zircon age (1032.1 ± 3.8 Ma) on the aforementioned stratiform jotunite / anorthosite body, occurring along strike of the regional foliation, 25 km to the northeast, near Crooked Creek (Whitney et al. 2002). The similarity of ages strongly suggests that regionally extensive, folded jotunite / anorthosite layers mapped in the western and central Adirondacks are a likely parental magma source for the Port Leyden nelsonite.

The inferred Ottawan age of the Port Leyden nelsonite intrusion has some interesting consequences. First, the nelsonite dike cross-cuts the regional foliation of the metapelite host rocks which suggests the foliation predates the intrusion. If so, when was the nelsonite separated from its inferred parent rocks 25 km to the northeast? Also, if the pyrite banding represents a metamorphic foliation, when was it produced? Is the pyrite banding parallel to the foliation in the country rocks? Only an oriented core of the nelsonite would answer this question. Lastly, the nelsonite does contain metamorphic garnet inferred to have formed by the reaction plagioclase + Fe-oxide → garnet (McLelland and Whitney, 1977). This suggests that garnet-producing metamorphic reactions continued after 1036 Ma.

Darling et al. (2018) report that apatite from the Port Leyden nelsonite, contains 1.1 to 2.1 wt.% total rare earth element oxides, which is about 5 to 10 times more than reported REE contents of apatites from some Norwegian nelsonites (Duchesne, 1999). Chondrite normalized plots of REE abundances in apatite and zircon show: 1) LREE enrichment in apatite, 2) a similar (in magnitude) negative Eu anomaly for apatite and zircon, 3) HREE enrichment in zircon, and 4) a positive Ce anomaly in zircon. No systematic difference was recognized in the REE patterns between the aforementioned zircon types. Furthermore, the REE patterns are typical for igneous zircon (Hoskin and Schaltegger 2003). The negative Eu anomalies of both phases suggest significant plagioclase crystallization in the parent magma. Although the Port Leyden nelsonite contains small amounts of metamorphic garnet, the HREE enrichment in zircon indicates no zircon grew in the presence of garnet.

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 et al., 2019). 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, they are the only reported sapphires in New York State, and their presence here demonstrates a previously undescribed geological occurrence in nelsonite.

From STOP 2, go west on East Main Street 0.2 miles and turn right at the traffic light onto on Rt. 12 north. Proceed 2.1 miles and turn right onto Franklin Street Extension. After 350 feet, turn left onto River Road. Proceed 0.3 miles and turn right onto Laura Street. Proceed for 0.2 miles (you'll cross over the Black River) and turn left onto Lyons Falls Rd. Process 0.3 miles (you'll cross over the Moose River now) and turn left onto the parking area. Walk down the path to Lyons Falls.

STOP 3. – Two-pyroxene amphibolite at Lyons Falls

Parking Coordinates:	43.6186°N, 75.3568°W
Site Coordinates:	43.6185°N, 75.3574°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 northeast, normal to the course of the Black River. The amphibolite here is strongly lineated with discontinuous, thin, plagioclase-rich bands. Foliation is poorly developed. D. Valentino (personal communication) describes it as an L-tectonite. The unit has a sharp contact with feldspar-quartz gneiss to the south (observed at the foot of the upstream board dam) but the north contact is not exposed here.

Petrologically, the unit is best described as a medium-grained, two-pyroxene amphibolite. Plagioclase, hornblende, clinopyroxene, and orthopyroxene are the dominant mineral phases. A red-brown (presumably Ti-rich) biotite and opaque magnetite occurs as well (Figure 6). Quartz has been observed but is uncommon. Unlike the central and eastern Adirondacks, the amphibolite at Lyons Falls contains no garnet, despite the fact they are compositionally similar.

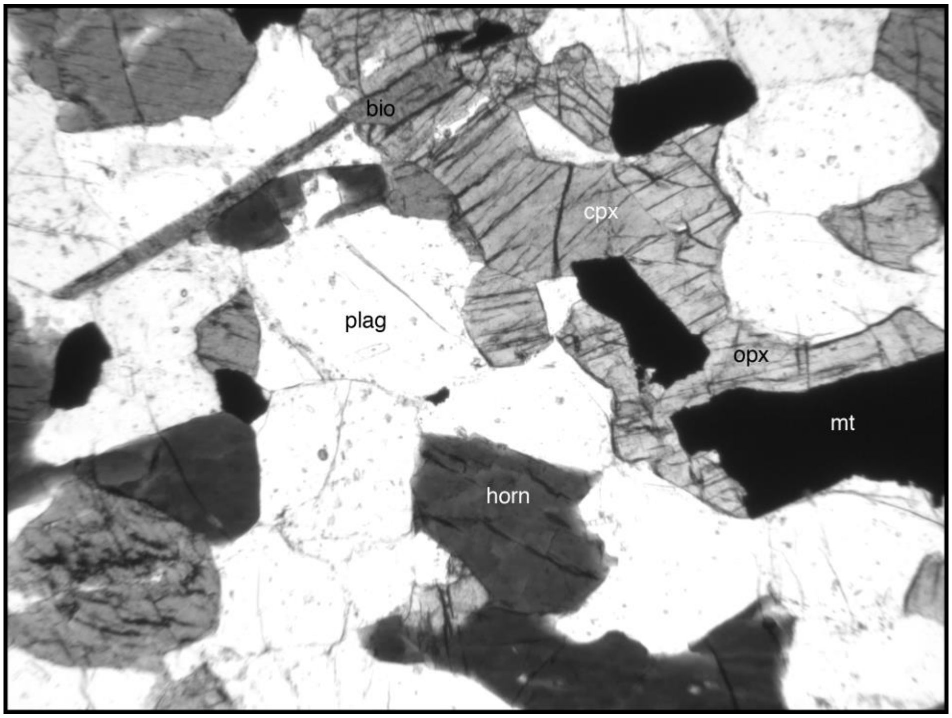

Figure 6. *Photomicrograph of amphibolite at Lyons Falls. Note granoblastic texture and medium grain size. (plag = plagioclase; horn = hornblende; cpx = clinopyroxene; opx = orthopyroxene; bio = biotite; mt = magnetite) Note absence of garnet (see text for discussion). Field of view = 2.5 millimeters 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 7 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:

orthopyroxene + anorthite = clinopyroxene + garnet + quartz (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.

The garnet + clinopyroxene isograd across the central Adirondacks has received little attention since first mapped by de Waard (1967). Why the isograd makes two nearly right angle and opposite turns as it sinuates from south to north is unknown. Also unknown is the inferred temperatures and pressures along the isograd and how this compares to other thermobarometric estimates from non-mafic lithologies. The southern terminus of the isograd should have been affected by both the Moose River Plain and the Piseco Lake shear zones (Gates et al., 2004) unless shearing pre-dates garnet formation in mafic lithologies.

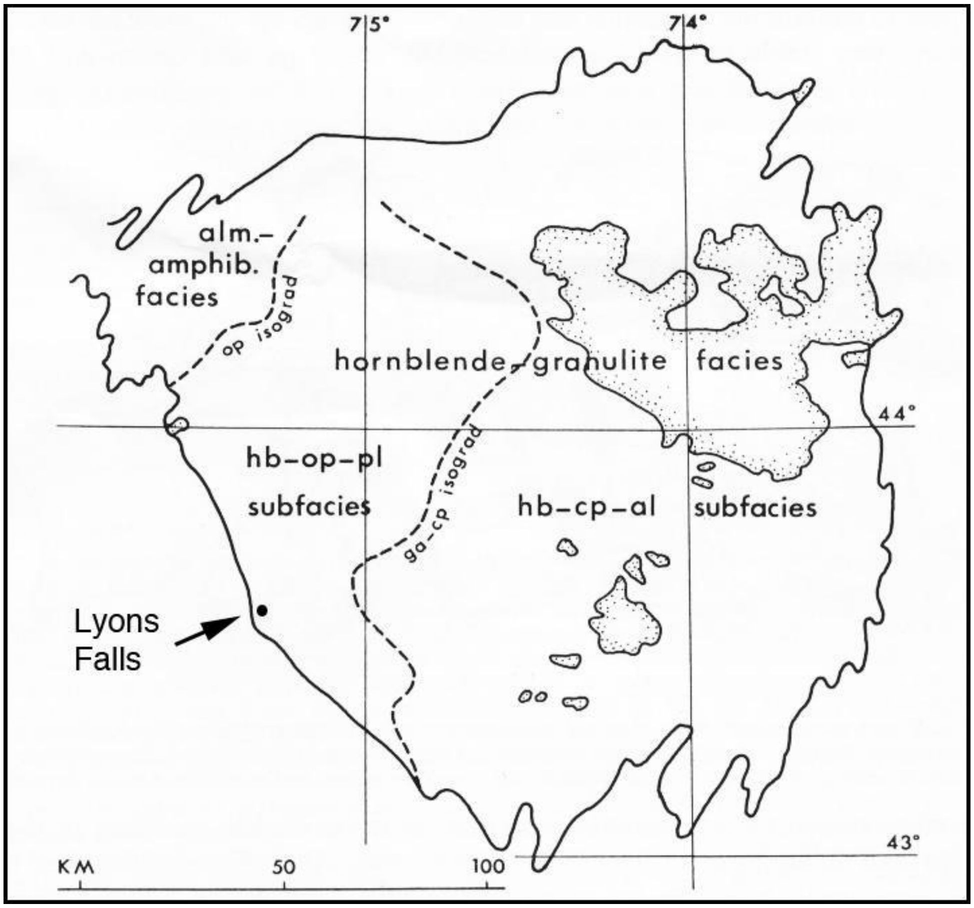

Figure 7. *Simplified metamorphic isograd map for the Adirondacks modified from de Waard (1967). Note the amphibolite at Lyons Falls is located west of the garnet + clinopyroxene isograd.*

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 waterfall.

For our lunch stop, we'll drive to Stewart's on Rt. 12. From STOP 3, go back 0.3 miles to Laura St. (while again crossing the Moose River) and turn right, proceed 0.2 miles (while again crossing the Black River) and turn right onto Franklin St. Continue for 0.5 miles as Franklin St. turns into Center St. while passing through the village of Lyons Falls. At the end of Center St. turn left onto McAlpine St. and proceed for 0.2 miles and turn left at the flashing light onto Cherry St. After 0.2 miles turn right into the Stewart's Shop.

Parking Coordinates for Stewart's Shop: 43.6164°N, 75.3682°W

From the Stewart's Shop, get on Rt. 12 and head southeast for 0.5 miles and turn left onto Franklin St. Ext. After 350 feet, turn left onto River Road. Proceed 0.3 miles and turn right onto Laura Street. Proceed 0.8 miles and turn left onto Lyonsdale Rd. Continue for 2.4 miles. After passing the Twin Rivers Paper Co. (on the left), the road turns into the Marmon Rd. Continue 0.3 miles and turn left onto Hunkins Rd. Continue 1.1 miles and turn left onto Fowlersville Rd. Continue 2.5 miles (while again crossing the Moose River) and turn left onto Fowler Rd. Continue 1.4 miles and turn left onto Lowdale Rd. Continue 0.8 miles and park at the end of Lowdale Rd. Follow the trail south of Lowdale Rd. to the Moose River bedrock exposures just below the former bridge location.

STOP 4. – Undeformed pegmatite and hydrothermal sillimanite + quartz veins in Lyon Mtn. granite.

Parking Coordinates:	43.6194°N, 75.3030°W
Site Coordinates:	43.6196°N, 75.3035°W

This stop demonstrates important igneous and hydrothermal features of Lyon Mtn. granite along the Moose River. These exposures were first recognized by Buddington and Leonard (1962, p. 93) and 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 ductilely 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 altered 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 former 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 8 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 this part of Adirondacks (Orrell and McLelland, 1996).

Figure 8. *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 9). 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 10 shows the rock texture in thin-section. Note the presence of tartan-twinned microcline; this is in contrast to many nearby metagranites that are characterized by a hypersolvus quartz-mesoperthite mineralogy.

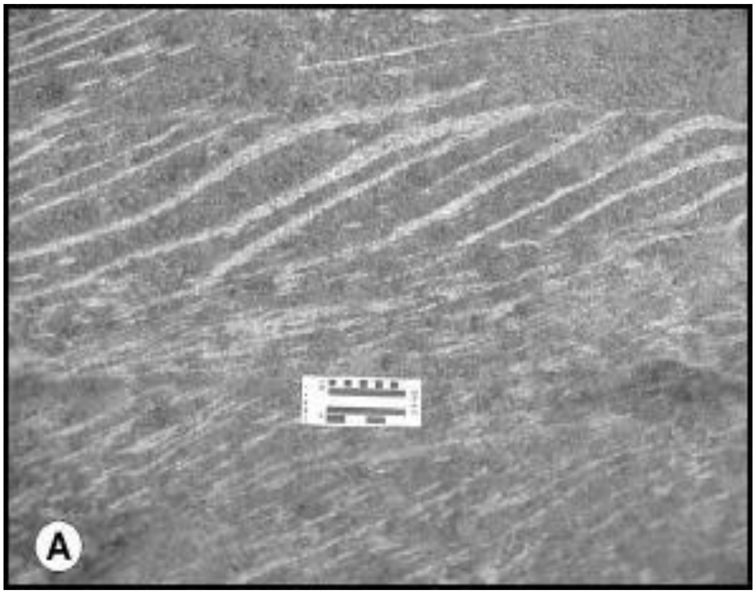

Figure 9. *Hydrothermal quartz + sillimanite veins in Lyon Mtn. granite at Stop 4. Taken from Figure 2a of Selleck et al. (2004).*

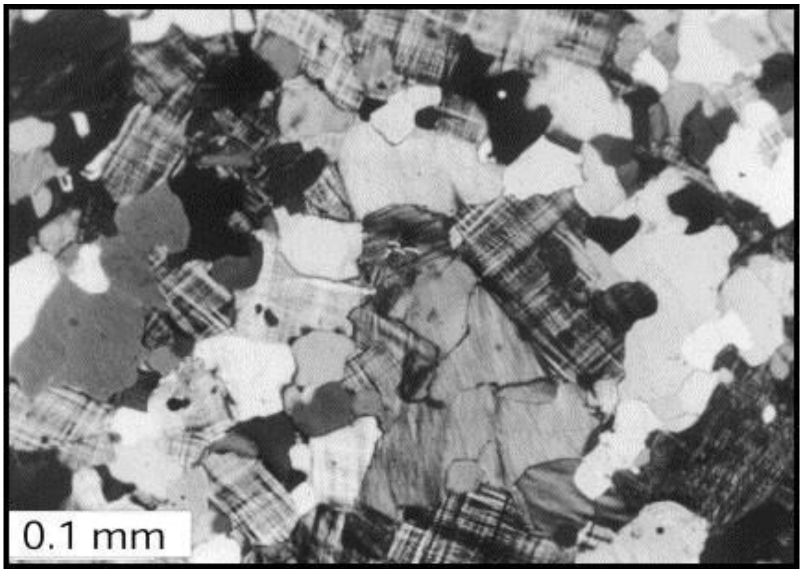

Figure 10. *Photomicrograph of Lyon Mtn. granite. Note little or no grain shape fabric of quartz and microcline. From Figure 11 of McLelland et al. (2002b).*

The hydrothermally altered Lyon Mtn. granite here at Lyonsdale is not the only occurrence of this unusual Adirondack rock. Identical sillimanite + quartz vein-hosted granite occurs in a number of locations along strike (to the SW) until ending at Johnson Dam, on the Black River 4.6 kilometers to the southwest.

From STOP 4, go back along Lowdale and Fowler Roads (2.2 miles) to Fowlersville Rd and turn right. Proceed south for 2.8 miles to Penney Settlement Rd. and turn left. Proceed 0.5 miles and turn right onto North-South Rd. Proceed 2.0 miles and turn left onto Moose River Rd. Follow Moose River Rd. for 7.1 miles, turn left and park in the sandy area close to the Moose River. From this point, 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.

STOP 5. – Moose River Prismatine locality.

Parking Coordinates: 43.6080°N, 75.1624°W

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 petrologist or mineralogist will be grateful someday. Moreover, none of the prismatine grains are gem-quality, they are too dark and too fractured!

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).

Prismatine is identified here by X-ray diffraction, electron microprobe analyses, SIMS analyses and laser Raman microspectroscopy (Bailey et al., 2019). However, it was first suspected by observing its interfacial angles of about 80 and 100 degrees between the {110} prism faces, values in between those of an amphibole (56° and 124°) and a pyroxene (87° and 93°).

Along the Moose River, prismatine occurs at two locations (separated by about 400 meters, Figure 11) within a unit of heterogeneous metasedimentary rocks (Figure 11, unit BL) mapped by Whitney et al. (2002). This unit comprises mostly quartzite and biotite-quartz-plagioclase gneiss with lesser amounts of calc-silicate 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 11). 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).

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 5 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 12A).

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 12B). 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.

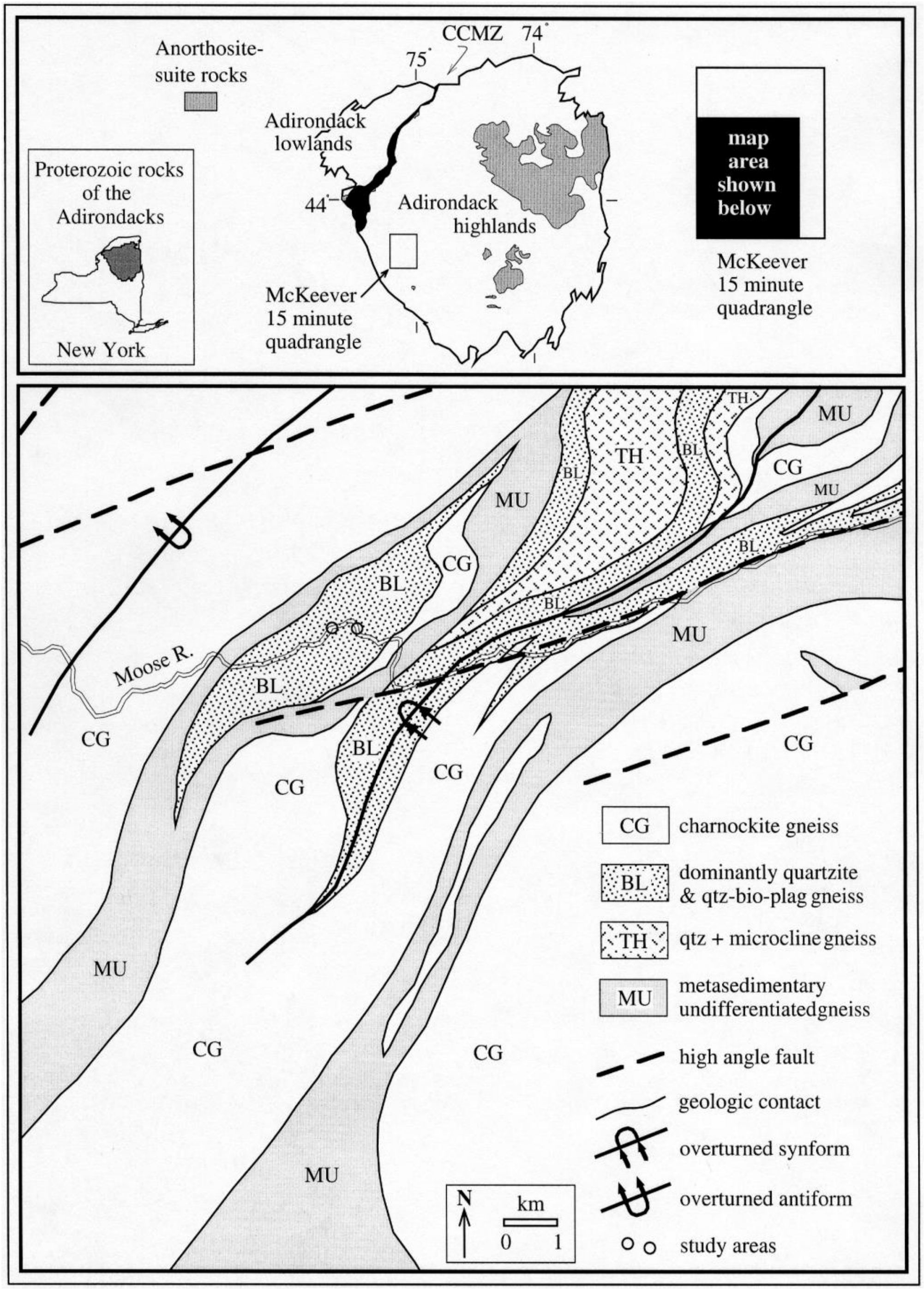

Figure. 11. *Map showing location of prismatine-bearing metapelites and quartzites (open circles on Moose River) and surrounding bedrock geology. Stop 5 is the easternmost open circle. Geologic map units, structures, and relations illustrated are from Whitney et al. (2002). Taken from Darling et al. (2004). Bio—biotite; CCMZ—Carthage-Colton mylonite zone; pl—plagioclase; qtz—quartz.*

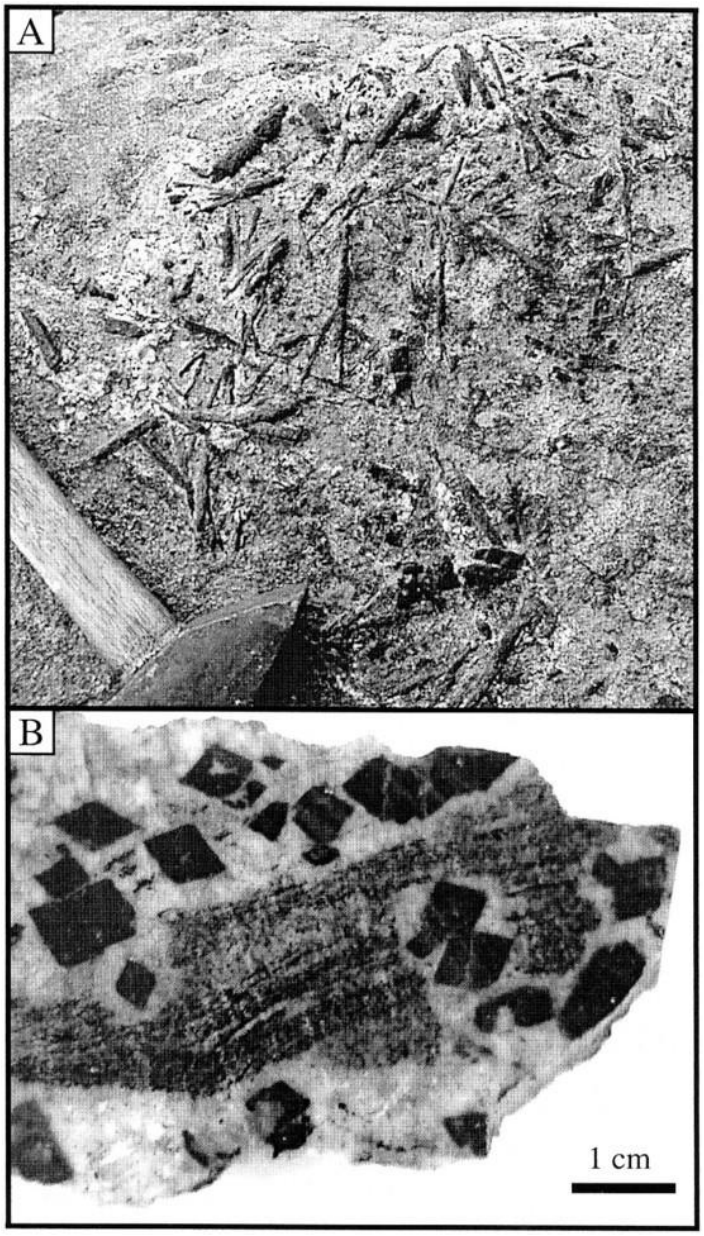

Figure 12. *(A) Prismatine crystals (black) in coarse-grained feldspathic lens, taken parallel to plane of lens. Hammer for scale. (B) Euhedral prismatine (black) in coarse-grained feldspathic lens embaying fine-grained, foliated tourmaline + biotite + plagioclase–rich zones. Taken from: Darling et al. (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. Because prismatine is inferred to form as a direct result of anatectic melting, it is considered a peritectic phase.

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 5, it and the orthopyroxene + garnet assemblage are better developed farther downstream at the second prismatine location (the westernmost open circle in Figure 11). 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).

Lastly, and perhaps most interestingly, prismatine from the Waldheim granulite, in Germany, was recently found to contain tiny mineral inclusions of coesite, the high pressure polymorph of silica. Moreover, almandine garnet from these same rocks were found to contain the first ever described inclusions of stishovite, the super high pressure polymorph of silica (Thomas et al., 2022)!

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