Timing of Intrusion, Anatexis, and Metamorphism in the Port Leyden Area of the Western Adirondacks

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Introduction

The purpose of this field trip is to examine evidence of the igneous, metamorphic, and tectonic history of the western Adirondack Highlands preserved in rocks in the vicinity of Port Leyden, NY. We will visit and discuss rocks and structures at six sites that include interlayered metasedimentary and metaigneous lithologies and a distinctive nelsonite (apatite-magnetite-ilmenite) dike. Rocks at these sites display structural fabrics and cross-cutting relationships formed through a sequence of metamorphic, hydrothermal, and melting events. Recent geochronological studies confirm that this area has undergone a complex tectonothermal history.

In particular, this trip will focus on uncertainties concerning the anatectic or intrusive origin of leucogranitic gneisses and melt veins in the gneiss surrounding the nelsonite dike. By clarifying structural and field relationships, we hope to discriminate between interpretations of igneous activity and metamorphism in these gneisses. Potentially, this may establish useful constraints on regional interpretations of orogenic sequence.

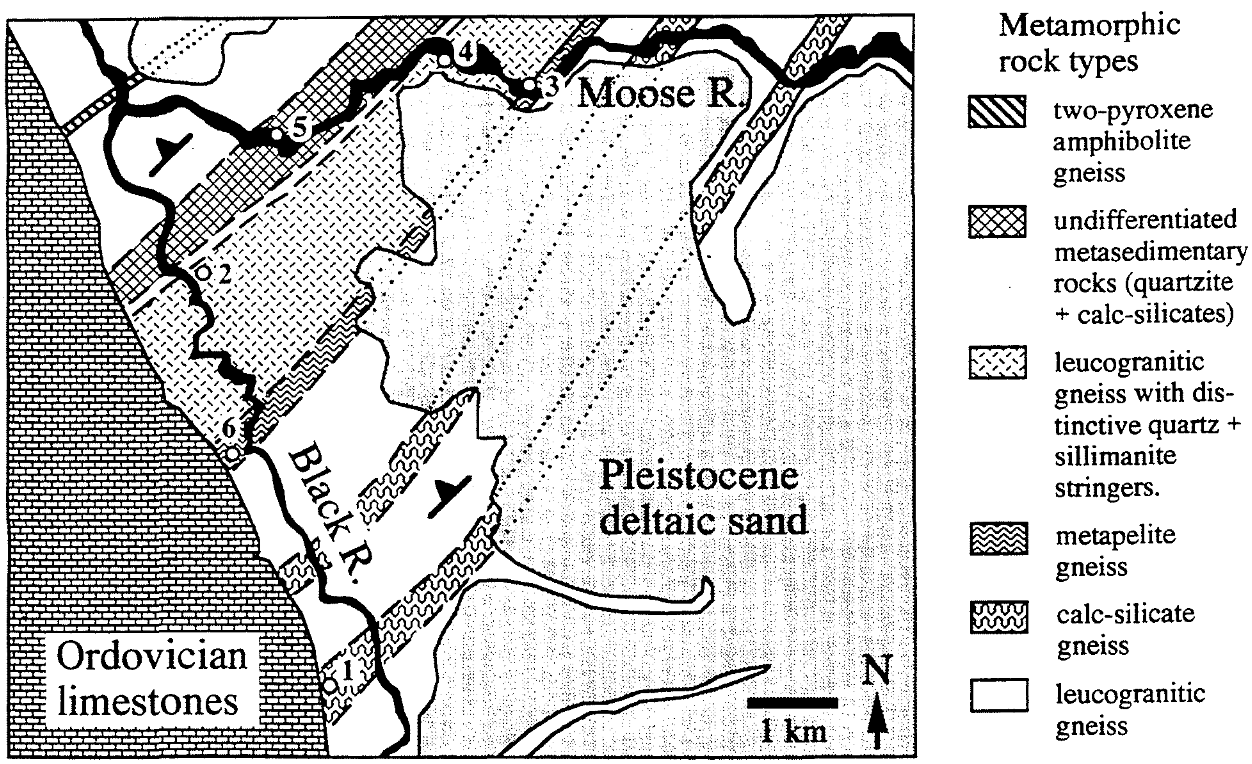

Fig. 1. Geologic Map of the northern portion of the Port Leyden 7 1/2' quadrangle. Field trip stops are indicated.

Geologic Setting

The Port Leyden area lies in the western Adirondack Highlands (Fig. 2), a region composed of Proterozoic orthogneiss and paragneiss of the Grenville Province that preserve mineral assemblages formed under granulite facies conditions. A package of interlayered metasedimentary gneisses, amphibolites, and leucocratic quartzofeldspathic gneisses are well exposed between the towns of Port Leyden and Lyons Falls, close to the confluence of the Moose and Black Rivers and immediately east of the unconformity with Ordovician carbonates (Fig. 1). They occur as uniformly northeast trending, northwest dipping compositional layers. Thick deposits of Quaternary alluvium prevent tracing these units far east of the Moose River, but lithologically similar units occur approximately 10 km along strike in the McKeever and Number Four quadrangles (Whitney et al., 1997).

The Adirondack Highlands have experienced a common igneous and metamorphic history since at least 1150 Ma. Intrusion of anorthosite massifs and associated mangerites, charnockites and leucocratic granitic rocks (the AMCG suite) occurred in the central and eastern Adirondacks between 1125 and 1157 Ma (McLelland et al., 1988; Chiarenzelli and McLelland, 1991). Whitney (1992) correlated geochemically similar charnockites, hornblende granitic gneisses, and leucocratic gneisses in the western Adirondacks with the AMCG suite. No mangerites are recognized in the western Adirondacks and only a few, small bodies of anorthositic rocks are present (Fig. 2), none of which outcrops within 25 km of Port Leyden. The AMCG suite intruded a supracrustal package of rocks that now include marbles, calc-silicate rocks, quartzites, and pelitic gneisses. Intrusion of AMCG rocks in the eastern Adirondacks probably occurred at relatively shallow crustal depths (Valley and O'Neil, 1982). Whitney (1992) has inferred similar depths of emplacement for charnockites and granitic rocks in the western Adirondacks.

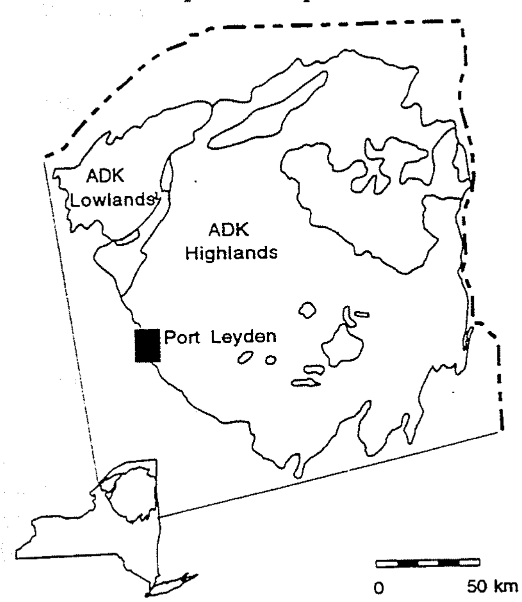

Fig. 2.. Location of the Port Leyden 7 1/2 " quadrangle. Also shown are the locations of exposed anorthosite rock in the Adirondack Highlands.

Younger episodes of intrusive activity occurred subsequent to emplacement of the AMCG suite during approximate intervals of 1090-1100 Ma and 1060-1080 Ma (Chiarenzelli and McLelland, 1991). Metamorphic mineral ages date granulite facies metamorphism throughout the Adirondack Highlands at approximately 1000-1050 Ma (Mezger et al., 1991; Chiarenzelli and McLelland, 1993; Florence et al., 1995), corresponding to the Ottawan phase of the Grenville Orogeny. 996-1026 Ma zircon ages from oxide rich rocks in the central Highlands may be the result of protracted cooling from temperatures greater than 750 ° (Mezger et al., 1991).

Recent studies of crystalline rocks in the Port Leyden area have raised questions about their origin and the relative ages of textural features in them. Darling and Florence (1995) proposed that anorthosite magmatism extended into the western Adirondacks based on the recognition of a distinctive igneous dike in Port Leyden composed of apatite-magnetite-ilmenite with minor sulfide. This rock type, named nelsonite, separates as an immisible melt from a parent ferrodiorite magma during fractional crystallization of anorthosite (Philpotts, 1967, 1981; Kolker, 1982; Epler, 1987). The nelsonite dike is hosted by metapelitic gneiss that experienced partial melting, which Florence et al. (1995) suggested was in response to contact heating from anorthosite intrusion. The metapelitic host rock is interlayered with leucocratic granitic gneisses, and both rocks contain nodular lenses and stringers containing quartz and sillimanite. These quartz-sillimanite features have recently been interpreted to result from high temperature hydrothermal alteration due to late-stage magmatic fluids in a deforming, crystallizing magmatic environment (Cunningham and Willis; 1996; Olson and Brackett, 1997). Orrell and McLelland (1995) obtained a 1031±8 Ma age from zircon in the leucogranitic gneiss. They correlated the gneiss with lithologically similar, late leucogranitic rocks in the northern and eastern Adirondack Highlands and interpreted the quartz-sillimanite features as textures produced in a deforming crystal-melt system. This interpretation brings into question the emplacement age of the nelsonite dike and the timing of partial melting in the surrounding gneiss.

Rock Descriptions

Metasedimentary rocks exposed in the field trip area include calc-silicate rocks, scattered, discontinuous marble layers, quartzites, and metapelitic gneisses (kinzigites). This association suggests that protoliths likely were deposited in a shallow marine, possibly shelf, environment. Rocks of likely igneous parentage include the nelsonite dike and amphibolite. Granitic gneisses, with variable amounts of biotite, garnet, and sillimanite may represent intrusions that have assimilated surrounding material or metavolcanics with some detrital component.

Metasedimentary rocks

Calc-silicate Rocks

Two bands of calc-silicate rocks striking approximately N50E are exposed SE of Port Leyden. These appear in outcrop as gray-green units or, occasionally, xenoliths, with a pronounced gneissic foliation. Mineralogy consists of green diopside, quartz, microcline, minor garnet, titanite, and pyrite, and scattered grains of scapolite and wollastonite. Contacts with other lithologies can be diffuse and calc-silicates rocks sometimes grade to more aluminous bulk compositions. East of Lyonsdale, along the Moose River, coarse calcite marble crops out near the contact of a 0.3 km wide band of calc-silicates with felsic gneiss.

Quartzite

Rocks largely composed of or nearly all quartz are collectively referred to as quartzites, although the nature of their protoliths is unclear. There are a number of well exposed outcrops of these rocks along the Moose River near Kosterville and Goulds Mill. In addition to quartz, these rocks contain abundant sillimanite, a few percent magnetite, as well as scattered garnet. Some acicular sillimanite is aligned with the foliation. In other places, clusters of bladed sillimanite appear as sprays. Locally, the rock appears to contain quartz nodules that may be relict pebbles. Weathered outcrop surfaces commonly are colored by hematite staining.

Metapelitic Gneiss (kinzigite)

A garnet-sillimanite-biotite metapelitic gneiss occurs throughout a zone a few hundred meters wide from the south end of the town of Port Leyden to the Moose River immediately upstream of the dam at Lyonsdale. It is a gray to pink rock with granoblastic texture made up of coarse grains of microperthite and quartz. For the most part, foliation is defined by abundant, aligned biotite and quartz-feldspar veins and leucosomes. Along the Moose River, the gneiss contains distinctly biotite-rich layers. Cm size nodular segregations of quartz and coarse sillimanite commonly occur and are elongate in the plane of foliation. Small amounts of magnetite and hercynite spinel occur in these features. Garnet is abundant in these rocks and occurs throughout.

Meta-igneous rocks

Nelsonite

The Port Leyden nelsonite is a dark, equigranular, and fine grained rock composed of approximately 40% each of magnetite and apatite, 8 to 15 % ilmenite, and up to 5 % pyrite or pyrrhotite. Scattered grains of siderite and zircon are distributed through the rock and a few percent of garnet, monazite, and chlorite are present near dike margins. Reaction zones up to 5 cm wide commonly are present at the contact between nelsonite and gneiss and contain very coarse, fluorine-rich, titaniferous biotite and unstrained, equigranular labradorite to andesine plagioclase. Similar reaction features are found surrounding xenoliths entrained in the dike.

Amphibolite

A narrow band of amphibolite crops out in the village of Lyons Falls and to the northeast. The dominant mineralogy is orthopyroxene, clinopyroxene, hornblende and plagioclase, with minor amounts of biotite, magnetite, and ilmenite. Near its southeastern margin, close to the contact with quartzofeldspathic gneiss, the amphibolite contains thin, segregated layers of microcline-quartz or sodic plagioclase-quartz.

Leucogranitic gneisses

These light pink to gray rocks are composed of abundant perthitic feldspar or microcline and quartz. Plagioclase is absent or occurs as scattered grains in perthitic varieties. Foliation in these gneisses is defined primarily by aligned quartzofeldspathic segregations and nodular lenses and elongate stringers of quartz and sillimanite with subordinate amounts of magnetite. There are intermixed layers in which biotite and plagioclase are more common but generally not abundant. Garnet is often present in the gneiss, usually as small, disseminated grains, but it may be abundant or present as large grain with irregular margins. In some layers with biotite, garnets are surrounded by cm wide biotite-free halos.

Leucogranitic rocks southeast of the town of Port Leyden are homogeneous in composition and texture. These rocks are readily distinguished in the field from granitic gneiss that occurs in a 1.5 km wide band extending northeastward from Port Leyden. In this band, virtually all outcrops contain quartz-sillimanite nodules and stringers aligned with foliation. Nodules range from a few cm to nearly 1 m length and may have originated as veins that were rotated and separated along shear planes. The volume of rock composed of these nodules and segregations ranges from a few percent to nearly 50%. Whitney et al. (1996) describes similar nodular rocks about 20 km along strike to the northeast in the area of Otter Creek.

Pegmatites

Abundant pegmatites and quartz veins are present in all lithologies other than the nelsonite. They exist as conformable layers and as cross-cutting features that are folded, boudinaged, or undeformed. Many pegmatites have granitic compositions with subequal amounts of albite and microcline. Others have only one feldspar present. Compositional zonation is recognized in some pegmatites mainly on the basis of albite-rich margins. Magnetite is a common accessory mineral and sillimanite is sometimes present. Hercynite spinel has been recognized in at least one undeformed pegmatite at Lyonsdale (Olson, pers. comm.)

Metamorphism

Throughout much of the Adirondack Highlands granulite facies metamorphism, accompanied by variable amounts of strain, resulted in extensive recrystallization and compositional modification in mineral assemblages. Preserved mineral compositions appear to represent equilibration among silicates and oxides at about the time of granulite metamorphism, followed by modification during an extended period of slow cooling (Bohlen et al., 1985; Mezger et al., 1991). In the eastern and central Adirondacks, preserved mineral compositions indicate that pressures of metamorphism were 7 to 8 kbar (Bohlen et al., 1985, Spear and Markussen, 1997). The independent geobarometry calibrations used to obtain these estimates include garnet-sillimanite-plagioclase-quartz, garnet-anorthite-ferrosilite-quartz, garnet-anorthite-fayalite, and garnet-rutile-sillimanite-ilmenite-quartz. High pressure granulite facies metamorphism is supported by the presence of akermanite close to the Marcy massif (Valley and Essene, 1980a). Temperatures of metamorphism in the eastern and central Adirondacks have been estimated at between about 675 °C and greater than 775 °C (Bohlen et al., 1985).

Although there are few geothermometry estimates of regional temperatures of metamorphism in the western Adirondacks, high temperatures caused partial melting in a variety of rock types. Granitic rocks and amphibolite locally contain leucosomes of quartz and feldspar. Felsic and metapelitic gneisses display migmatitic textures at outcrop scale and melt textures in thin section. Garnet, sillimanite, and hercynite spinel are common in metapelites and probably formed during anatectic melting.

In contrast to high pressure metamorphism elsewhere in the Adirondacks, rocks in the vicinity of Port Leyden record lower pressures of between 4 and 6.4 kbar (Florence et al., 1995). They based their pressure estimates on compositions from minerals associated with melt textures and veins. Notably, hercynite spinel was found in contact with quartz and associated with garnet neoblasts and plagioclase-rich veins. Geobarometry estimates obtained from garnet-sillimanite-plagioclase-quartz and garnet-sillimanite-spinel-quartz equilibria coincide over the temperature range 700-770 °C (Fig. 3). Partial melting involving biotite dehydration has produced resorbed biotite rimmed by plagioclase-rich veins. Experimental work by Clemens and Wall (1981) and LeBreton and Thompson (1988) locate the vapor-absent solidus for this reaction in the range 700-750 °C at pressures coincident with the mineral equilibria. It therefore seems clear that the discrepancy in calculated pressures between the Port Leyden area and the eastern and central Adirondacks can not be satisfactorily explained as an artifact of comparing results from different geobarometers.

Effects of retrograde metamorphism include the exchange of Fe-Mg between biotite, garnet, and oxides, producing garnet compositional profiles with Fe/(Fe+Mg) increasing toward the rim. In a layer of sillimanite-rich, felsic gneiss 1 km east of Goulds Mill, garnet rims are replaced by prismatic sillimanite and biotite. Biotite surrounds some garnet rims in the leucogranitic gneiss. Similar reactions have not been recognized in metapelitic gneisses.

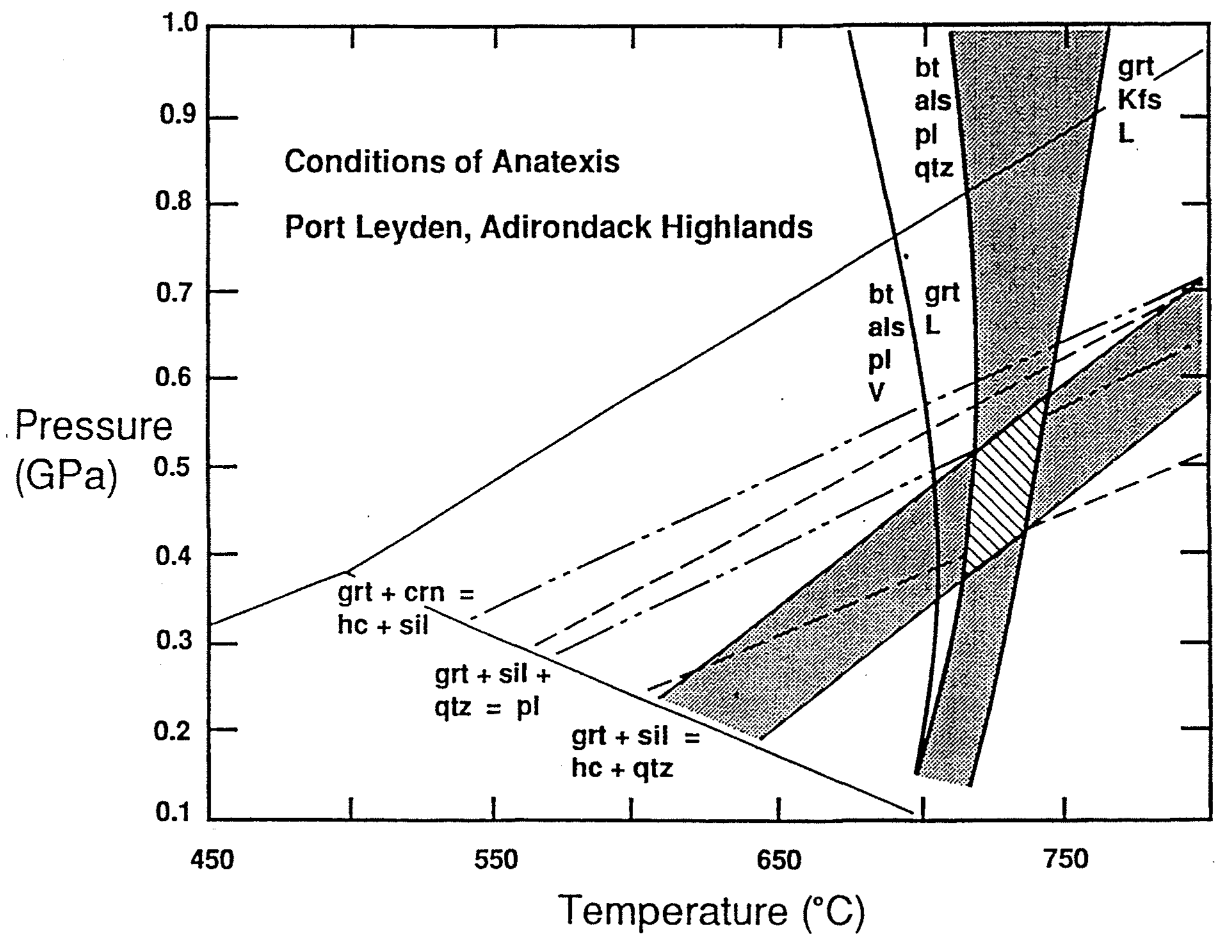

Fig. 3. P-T conditions estimated from phases associated with melt textures in metapelitic gneiss (Florence et al., 1995). Estimated P and T are defined by the intersection of the biotite dehydration melting region and garnet-sillimanite-hercynite-quartz equilibria. Dot-dash pattern shows range of garnet-corundum-hercynite-sillimanite equilibria. Dashed lines show range of garnet-sillimanite-quartz-plagioclase equilibria.

Geochronology from Port Leyden Rocks

Recent geochronologic studies in the Port Leyden area reveal complex U/Pb systematics that indicate either inheritance or isotopic resetting comparable to the disturbed U/Pb geochronology demonstrated by Chiarenzelli and McLelland (1993) in the central Highlands. Zircons from a variety of rocks record inheritance from >1100 Ma and recrystallization or profound radiogenic Pb loss at 1030-1040 Ma (Florence et al., 1995, Orrell and McLelland, 1996). In a U/Pb study of zircons from the nelsonite dike, Florence et al. (1995) obtained a discordant, non-linear array of fractions that included nine single grain measurements. A single grain analysis yielded a minimum Pb/Pb age of 1105 Ma. Three other single grain analyses were close to concordant with Pb/Pb ages between 1024 and 1035 Ma. Florence et al. (1995) attributed the non-linear array to recrystallization and lead loss dating from a profound disturbance related to granulite facies metamorphism. Zircons from the hosting pelitic gneiss were dated and 7 fractions and single grain analyses produced a linear array with an upper intercept at 1166±53 Ma. The 1105 and 1165 Ma age were interpreted by Florence et al. (1995) as minimum and maximum age constraints on the timing of anorthosite intrusion and associated contact metamorphism and melting. Orrell and McLelland (1996) obtained a concordant single grain zircon age of 1031±8 Ma from the leucogranitic rock and interpreted this as the age of granite intrusion. Other zircons from this rock form a non-linear array which were interpreted as inherited. The oldest discordant grain has a minimum Pb/Pb age of 1119 Ma.

The time of granulite facies metamorphism is dated by a monazite U/Pb age of 1041±9 Ma from the pelitic gneiss (Florence et al., 1995). Undeformed pegmatite with zircon dated at 1027±8 Ma cross-cuts regional foliation (Orrell and McLelland, 1996) and fixes the lower age of tectonism in the region.

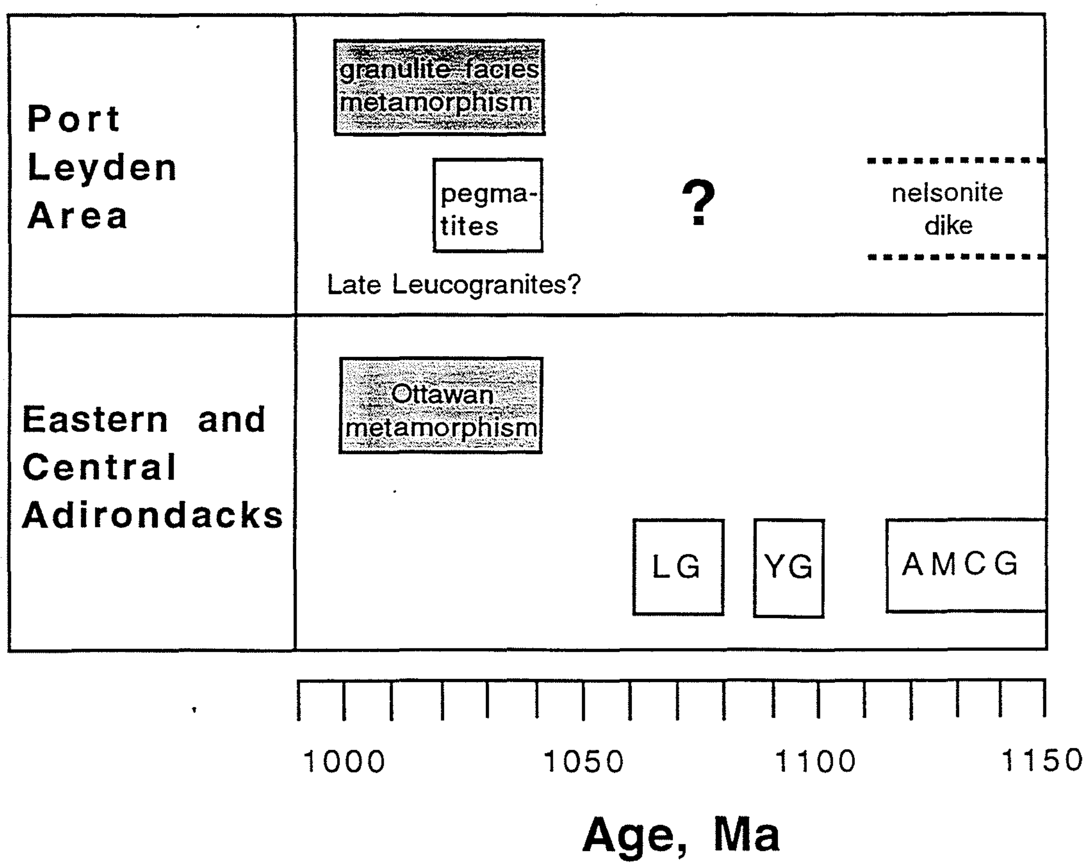

Fig. 4. Generalized geochronology from Port Leyden and from elsewhere in the Adirondack Highlands. Lg = late leucogranites. YG = younger granites. AMCG = anorthosite-mangerite-charnockite-granite suite rocks.

Trip Objectives

This trip highlights some of the controversial structural and chronological relationships among rock units. When visiting the stops on this trip, you are encouraged to consider these questions:

1. What was the timing of penetrative deformation and to what extent, if any, can mineral assemblages and textures formed during the intrusion of the AMCG suite be recognized in the Port Leyden area rocks?
2. Unstrained phases that crystallized from melts occur in veins, reaction zones, and in equigranular granitic rocks. Is granitic intrusion implied by these features? Which features might be anatectic? Can anatexis explain the 1032 Ma zircon age date from granitic gneiss?
3. Are the quartz-sillimanite nodules and stringers (or their protoliths) relatively early features that were present in the surrounding gneiss prior to penetrative deformation or did they form relatively late due to hydrothermal activity in a crystallizing magma?
4. Did pegmatites originate from late-magmatic fluids at the time of granite intrusion or are they a result of fluids evolved from *in situ* rocks at the time of the peak of metamorphism?
5. What tectonic significance can be placed on the moderate (vs. high) pressure estimates obtained from this region of the Adirondack Highlands?

Acknowledgments

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Road Log

The trip log begins on Route 12, approximately 2 miles north of Boonville. Set trip odometer to 0.0 at the Lewis County boundary sign. Proceed north on Route 12.

Cumulative Mileage	Miles From Last Point	Route Description
0.0	0.0	Lewis County line.
0.5	0.5	Low roadcuts of Ordovician Black River Group limestone.
0.7	0.2	Barrett quarry.
1.5	0.8	Highway parking area. View of historic Black River canal quadruple locks.
3.0	1.5	STOP 1. Pull off right side of road adjacent to outcrop. Park.

STOP #1. Rt. 12. Calc-silicate and Aluminous Metasedimentary Rocks

These rocks comprise one of two narrow but mappable bands of calc-silicate gneiss that extend northeastward, under the Pleistocene deltaic sands, and reappear along the Moose River (Fig. 1). Foliation in both calc-silicate bands strikes northeast and dips moderately northwest.

A variety of bulk compositions can be observed in this exposure, but the dominant minerals are clinopyroxene, biotite, K-feldspar, and quartz. Other minerals include grandite garnet, titanite, wollastonite, calcite, and scapolite. Compositional data are limited, but EDXF spectra from the garnet show mostly grossular with a small andradite component. The scapolite is mostly meionitic. In thin section, the margins of wollastonite grains contain thin rims of retrograde garnet identical to that described by Valley et al. (1983) from drill cores just 3.0 kilometers NE of this location. This garnet is unusual because it contains stoichiometric fluorine (up to 0.76 wt.%; Valley et al., 1983). Wollastonite occurs in apparent textural equilibrium with calcite and quartz.

As noted in some other Adirondack marbles, the occurrence of regional metamorphic wollastonite suggests an H_2O-rich fluid composition (Valley and Essene, 1977; 1980b). We interpret these rocks similarly. Specifically, at the PT conditions in this region (700-750 °C and 4-6 kbar), a fluid composition of $XH_2O \approx 0.80$-0.90 is necessary to stabilize these minerals (Jacobs and Kerrick, 1981). The margins of some quartz ± pink K-feldspar veins are characterized by an assemblage of epidote + specular hematite, suggesting a higher O_2 fugacity compared to that in the country rocks.

At the northernmost part of the roadcut there is a small exposure of leucocratic K-feldspar + quartz + sillimanite gneiss. Minor amounts of biotite, magnetite and almandine garnet occur locally. The presence of matrix sillimanite in these exposures, coupled with the bulk composition of the calc-silicate gneisses, strongly argue in favor of a sedimentary origin for both rock types.

		Continue north on Route 12.
4.8	1.8	Village of Port Leyden traffic light. Continue north.
5.1	0.3	Turn right. Stop at sign. Turn left (north) onto Kelpytown Road.
5.5	0.4	Intersection with Davis Bridge Road. Bear right.
5.7	0.2	Intersection with Davis Bridge Exit. Turn right (east).
5.9	0.2	One lane bridge across Black River. Proceed with care. Bear left after bridge. Continue on Davis Bridge Road.
6.2	0.3	STOP 2. Park on sandy shoulder on right side of road. Outcrop on left (west) side of road is visible through trees.

STOP #2. Davis Bridge Road. Leucogranitic Gneiss with Quartz-Sillimanite Stringers

Outcrops in the woods on both sides of the road consist of relatively homogeneous, granitic gneiss. Abundant, cm-wide stringers of quartz and sillimanite, with minor oxides, biotite, and garnet, are distributed throughout these rocks. Orientation of these stringers parallels the gneissic foliation defined by biotite and oxides, which locally varies between N20E and N50E. These exposures lie within a 1.5 km wide band of leucogranitic gneiss that can be traced N40E from the Black River to exposures along the Moose River at Lyonsdale (Fig. 1).

Immediately west of the road, and about 5 m uphill, are a few exposed knobs that also contain quartz-rich layers (leucosomes?) parallel to foliation. Biotite and magnetite occur in mm thick margins on these layers. Note that tight to isoclinal folds deform the quartz layers and are parallel to foliation and the quartz-sillimanite stringers.

Walk across to the east side of the road, enter the woods, and continue walking to the northeast for about 100 m to where a large dome of pink, granitic gneiss is exposed. On the southwest side of the outcrop there is a boudinaged quartz pegmatite layer. Sheared layers of leucogneiss parallel the margins of the boudin and flow inward around the necks. Coarse K-feldspar, possibly precipitated as a melt or hydrothermal phase, extends from margins through the pegmatite. Boudin margins contain bladed sillimanite, biotite, and magnetite. Additional folded and disrupted quartz veins are displayed around the right side of the outcrop.

Quartz-sillimanite stringers are distributed throughout the rock. Their orientation relative to penetrative deformation is well displayed across the top of the dome, where these features can be seen to form parallel to the plane of foliation. NE trending isoclinal folds deform some quartz-sillimanite segregations.

		Return to cars and continue north on Davis Bridge Road
6.4	0.2	Outcrop of leucogranitic gneiss.
6.8	0.4	Stop Sign. Turn right (southeast) onto River Road.
7.0	0.2	Turn left (east) onto Burnt Shanty Road (gravel).
8.3	1.3	Stop sign. Turn left (northeast) onto Marmon Road.
9.6	1.3	Intersection with Lowdale Road. Lyonsdale cogeneration facility on left. Turn right (northeast). Cross one lane bridge. CAUTION! Be prepared to yield right-of-way to oncoming traffic.
9.8	0.2	STOP 3. Park on sandy shoulder on right side of road by "Recreational Trail - Canoe Launch " sign.

STOP #3. Lyonsdale. Metapelitic Gneiss, Leucogranitic Gneiss, Sillimanite Nodules, and Undeformed Pegmatites

Walk down to Moose River. Follow trail upstream approximately 250 m to northward bend in river. Continue around bend, then walk down to the river's edge to metapelitic gneiss.

The river's orientation through this scenic section is parallel to lithologic layering. A low angle wall of homogenous quartzofeldspathic gneiss is exposed across the river. Garnet-rich metapelitic rock (kinzigite) is exposed for over 200 m along strike on this side, close to the water's edge. There is a sharp compositional boundary between the metapelitic gneiss and adjacent leucocratic gneiss about 5-15 m away from the river. From this contact back to the bridge, the gneiss contains less biotite and garnet.

A meter scale isoclinal fold is exposed in the metapelite layer on the southern end of the outcrop, with fold layers made up of gray, biotite-rich and pinker, perthite-rich layers. Garnet is ubiquitous; some layers contain coarse garnets > 1 cm. Elsewhere, pods of abundant small garnets form in quartz veins. Sillimanite is distributed throughout some layers and absent in others. Florence et al. (1995) found undeformed melt veins along grain boundaries locally in the metapelite. Small (0.1 mm) inclusion-free, euhedral garnet neoblasts occur with plagioclase and K-feldspar-quartz segregations surrounding embayed biotite. These textures indicate partial melting according to the biotite-dehydration reaction: Bt + Sill = Grt + Kspar + melt.

Walk back towards the parking area along the trail. Notice the pink leucogranitic rock at the canoe launch by the bridge. This gneiss clearly displays nodules of quartz and sillimanite. Two orientations can be observed, and a deformed pegmatite is seen to truncate and cross-cut the quartz-sillimanite veins.

Return to the road, cross it to a dirt road, and walk along the road in the downstream direction. After about 100 m, walk left through the woods and out onto a broad exposure of orange-pink, perthitic, leucogranitic rock with many quartz-sillimanite stringers, veins, and lenses. At least two orientations of quartz-sillimanite veins are displayed here: N50E veins are cross-cut by N20E veins (Cunningham and Willis, 1996). En echelon gash veins indicate extension and rotation within a shear zone and some small-scale granite melt veins truncate quartz-sillimanite veins. Deformed pegmatite and quartz layers are common. Large (0.5 m width), undeformed pegmatites dated at 1027 Ma cross-cut all other features.

Scattered calc-silicate inclusions are present in the gneiss throughout the outcrop area. 250 m below the bridge, biotite-rich and garnetiferous horizons become common. These layers contain sodic plagioclase, as well as microcline. Quartz-sillimanite nodules are absent in these layers, although sillimanite is present in the rock. Notice that quartz-sillimanite nodules reappear in pink, leucogranitic layers.

Postel (1952) and Whitney and Olmsted (1988) have described rocks in the northeastern Highlands that are similar to the leucogranitic gneiss. Whitney and Olmsted (1988) referred to these rocks as the Lyon Mountain Gneiss and interpreted them to be metamorphosed products of altered volcanic rocks and interlayered basin sediments. Chiarenzelli and McLelland (1990) suggest the alternative hypothesis that the interlayered lithologies may have been the result of "emplacement of sheet-like intrusions combined with high strain to yield tectonic layering." If the leucogranitic gneiss at Lyonsdale is properly correlated with Lyon Mountain Gneiss, then correctly establishing its origin is has regional consequence.

Undeformed pegmatites cross-cut all lithologies in this area. These demonstrate fluid flow at and immediately after the peak of granulite facies metamorphism and anatexis, or during late crystallization of granite intrusives. If the PT estimates of Florence et al. (1995) represent conditions of granulite facies metamorphism, then these dikes likely formed under thermal and stress conditions that permitted fractures at between 4 and 6 kbar pressure.

		Turn around. Recross one lane bridge.
10.0	0.2	Turn right (west) onto Lyonsdale Road.
10.4	0.4	Agers Falls recreation site entrance. Proceed through gate, bear left, follow signs to Agers Falls. Park within site of Moose River. STOP 4.

STOP #4. Agers Falls. Leucogranitic Gneiss

Extensive outcrops of leucogranitic gneiss are exposed along the Moose River in this vicinity. This is the same leucogranitic gneiss seen upriver at Lyonsdale, although here it appears more homogeneous. The rock is composed largely of quartz and perthitic feldspar, with minor amounts of iron oxide, biotite, sillimanite, and garnet. Through much of the outcrop the rock has an equigranular texture and is largely lacking a gneissic fabric. Numerous pegmatites and coarse, irregular granite veins transect the gneiss.

Scattered grains or cm long veins of sodic plagioclase are recognizable in thin sections from this exposure. Plagioclase is sometimes myrmekitic and commonly exhibits erose grain margins, suggestive of resorption. Locally, oxide grains surround plagioclase margins. Garnets are almandine-rich and show irregular grain margins. Some garnets are surrounded by small biotite grains. This texture suggests the retrograde reaction:
Kfs + Grt + H_2O = Bt + Sill.

Elongate and nodular quartz-sillimanite segregations are abundant throughout the outcrop. Two sets of nodules are recognizable: one is aligned with the NE trending regional structure and a second, cross-cutting set is oriented at about N20E. Discontinuous layering defined by these features sometimes exhibits swirl patterns. Hercynite spinel is commonly present in the quartz-sillimanite segregations.

The single zircon grain dated at 1031±8 by Orrell and McLelland (1996) was collected at this outcrop. They describe the sample grain as clear and prismatic and the determined age is concordant. They consider the leucogranitic gneiss to be a late- to post-tectonic intrusion emplaced into relatively shallow crust. Essentially all vein features are viewed as having formed during a single hydrothermal event that accompanied and ultimately outlasted magmatic intrusion. In this interpretation, the quartz-sillimanite features must have formed at about the time of emplacement or closely afterwards, when the intrusion was still partly molten or at a temperature sufficiently high to permit ductile deformation.

Our alternative interpretation suggests that anatexis of *in situ* lithologies has produced the many magmatic features observable in the Port Leyden region and that the zircon age reported by Orrell and McLelland (1996) dates the formation of granite veins in this rock. The quartz-sillimanite±spinel veins and nodules are considered to be relict features that have been rotated into their current configuration. The zircon age obtained at this outcrop and mineral ages from nearby sites define the time of a widespread thermal event that coincided with the development of the pervasive fabric and compositional layering seen at the regional scale. It needs to be emphasized that other zircon grains from here and at Lyonsdale demonstrate that cores and overgrowths do not record the same ages. Abraded cores yielded ages up to 1119 Ma that Orrell and McLelland (1995) view as inherited from older granitic rock present in the magma source region. We consider it more likely that these older zircon ages reflect crystallization within this crustal horizon in response to an earlier episode of igneous or metamorphic activity.

		Return to Lyonsdale Road.
10.8	0.4	Lyonsdale Road. Turn right (west).
11.4	0.6	Low outcrop of foliated, pink and gray felsic gneiss.
11.7	0.3	Moose River hydroelectric power facility.
11.8	0.1	Low outcrops of pink and gray felsic gneiss.
12.3	0.5	Outcrop of foliated, leucogranitic gneiss with deformed pegmatites.
12.4	0.1	Shibley Road. Turn right (northeast).
12.6	0.2	Continue across bridge over Moose River.
12.7	0.1	STOP 5. Park along sandy shoulder.

STOP #5. Goulds Mill, Shibley Road. Quartz-rich Gneiss

Walk along a dirt road parallel to the river for approximately 50 m, then cut down through trees to broad exposures along the river banks. A quartz-rich unit is exposed beginning under the bridge immediately below the dam and continuing downstream for over 50 m. Locally, the rock appears to be conglomeritic. In other places, it gives the appearance of being composed of many parallel quartz veins. The rock displays a red to yellowish coloration indicating presence of hematite and iron hydroxides. Portions of the rock are tinted green, probably due to formation of chlorite. Weathering of sillimanite and/or feldspar has produced a white wispy streaking throughout the rock.

Downstream from the bridge sillimanite needles occur in a quartz-rich matrix. Individual grains are often aligned with the dominant fabric in the rock. Some coarse sillimanite also forms fan-shaped sprays. Some pegmatites and potassium feldspar-rich veins are aligned with the rock fabric. Also present are relatively undeformed pegmatite veins that cross-cut lithologic layering. These veins contain commonly potassium feldspar and sillimanite associated with quartz.

The protolith for this quartz-rich gneiss is uncertain. Possibilities include arkosic sandstone, hydrothermally altered felsic volcanics, or a hydrothermally altered felsic intrusion.

Possible brittle deformation features crop out on the right (northern) side downstream of the bridge. A continuous 1 to 5 m thick, apparently horizontal rock layer displays a crackled texture, in contrast to the massive character of the rock on either side. This layer cross-cuts the steeply NW dipping foliation. Cm scale patches of dark colored, cryptocrystalline material is present on outcrop surfaces and along small scale joints or shear planes. Currently, studies are underway to determine the composition of this material.

		Return to cars. Turn around and recross bridge.
13.0	0.3	Intersection with Lyonsdale Road. Continue straight.
13.1	0.1	Intersection with Seymour Road. Continue straight.
13.3	0.2	River Road. Turn left (southeast).
14.4	1.1	Intersection with Murphy Road. Continue straight.
14.5	0.1	Marmom Road. Turn right (south) towards Port Leyden.
15.3	0.8	Turn right (west) at "T".
15.6	0.3	Cross Black River in Village of Port Leyden.
15.7	0.1	Turn right (north) onto Lincoln Street.
15.9	0.2	Turn right onto North Street (dirt). Continue for approximately 100 m. Park on left side near Cataldo Electric garage. STOP 6.
		This concludes the field trip road log. Proceed back to Lincoln Street to return to Route 12.

STOP #6. Port Leyden. Nelsonite Dike and Metapelitic Gneiss

This is the only described occurrence of titanium-rich nelsonite that does not occur within or in close proximity to large volumes of anorthositic rocks. Because of the strong field and experimental evidence supporting the formation of nelsonite by magmatic immiscibility during evolution of anorthosite suite rocks, we infer that anorthosite must have once been present in the western Adirondacks.

From the parking spot, cross to the south side of the road, walk over a rounded outcrop with quartz-sillimanite nodules and stringers, and down to the left. Continue walking for approximately 40 m to the southeast. Notice the low outcrops of foliated , light pink pelitic gneiss along the way. Abrupt transition to dark rocks delineates the contact with the nelsonite. Look at your compass to see the effect of standing over a body of rock that is about 40% magnetite! Good specimens of nelsonite material may be obtained from the waste pile on the south side of the mine shaft.

The nelsonite occurs as an elongate, nearly parallel sided body. Width is between 3 and 4 m and the dike is 30 m along strike at the surface. Contacts with the surrounding metapelitic gneiss are generally sharp, and locally parallel to foliation. At the northern end of the dike, the contacts truncate regional foliation defined by quartzofeldspathic layering. Detailed mapping and geophysical studies indicate that the nelsonite strikes north-south and has a near-vertical dip (LaForce et al., 1994). This attitude cross-cuts the N30E to N50E foliation in surrounding outcrops of gneiss.

The rock is equigranular and homogenous except towards the margins, where the relative abundance of pyrite increases shows a weak foliation. Garnet crystallizes interstitially to magnetite and apatite at the expense of ilmenite in this zone. A silicate-rich, 5 cm wide outer portion of the contact zone contains abundant plagioclase and is essentially sillimanite-free. A variety of textures indicate that plagioclase crystallized from a melt, including myrmekitic and symplectic plagioclase, and intergranular veins of plagioclase with associated magnetite. Anorthite content in plagioclase decreases with distance away from the dike margin. This suggests plagioclase grew in response to apatite breakdown and Ca flux outward from the dike. A model whole rock reaction for the contact zone is

Mag + Ap + Ilm + perthitic Kfs + Qtz + Sill = Grt + Mnz + titaniferous fluoro-Bt + Pl-rich melt.

Florence (1997) proposed that halogen release associated with apatite breakdown lowered the solidus temperature, leading to partial melting. Did this melting event occur at the time of nelsonite intrusion or during later granulite facies metamorphism?

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