GEOLOGY AND MINERAL DEPOSITS OF THE NORTHEASTERN ADIRONDACK HIGHLANDS

by

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INTRODUCTION

On this trip we will examine three of the most notable features of the Adirondack Highlands. The first stop is at the NYCO wollastonite mine at Oak Hill near Lewis, where wollastonite-garnet-pyroxene skarns preserve a record of a giant Proterozoic hydrothermal system that was fed by meteoric waters and driven by heat from the nearby Westport Dome anorthosite intrusion. The following two stops, at Arnold Hill and Palmer Hill near Ausable Forks, are in the granitoids and felsic metavolcanics of the enigmatic Lyon Mountain Gneiss, host to numerous low-titanium magnetite deposits that were the basis of a flourishing iron mining industry in the late nineteenth century. The remaining three stops, one at Jay and two near Elizabethtown, are in metamorphosed anorthosite and its mafic derivatives, and illustrate the structural complexity and lithologic diversity of these rocks which ordinarily appear on maps as undifferentiated blobs.

BRIEF GEOLOGIC HISTORY OF THE ADIRONDACK HIGHLANDS

The oldest known rocks of the Adirondack Highlands are metasedimentary rocks with interlayered metavolcanics. The age of deposition is not well established, but those in the southeastern Adirondacks are intruded by 1330-1307 Ma tonalitic rocks (McLelland and Chiarenzelli 1990) and must therefore be at least 1300 Ma old. Elsewhere in the Highlands they may be as young as approximately 1150 Ma. In the west-central and northeastern regions, the metasediments are dominated by calcsilicates, marbles, and quartzites with minor metapelites. Several features of these rocks indicate hypersaline depositional environments and the former presence of evaporites (Whitney and Olmsted 1993; Whitney et al. 2002). Relative amounts of pelitic and semipelitic gneisses in the metasedimentary section increase toward the southeast. Evidence for an early (pre-1150 Ma, Elzevirian?) tectono-metamorphic event has been found by McLelland et al. (1988) in the southeastern Highlands.

Voluminous igneous rocks of a bimodal anorthosite-mangerite-charnockite- granite (AMCG) suite (McLelland and Whitney 1990; Whitney 1992) intrude the metasedimentary rocks. Multiple episodes of intrusion are likely, with intervening extensional deformation (Fakundiny and Muller, 1993). U/Pb zircon dating indicates that maximum intrusive activity probably took place in the interval 1160-1130 Ma, (McLelland et al. 1996). Similar AMCG complexes are found throughout much of the Grenville Province, and those in the Morin, Lac St. Jean, Lac Allard, and Atikonak River areas have ages close to those of the Adirondack suite (Emslie and Hunt, 1990). Oxygen isotopic evidence from contact-metamorphosed calcsilicate rocks favors a relatively shallow (< 10 km) depth of intrusion for the anorthositic rocks (Valley and O'Neil 1982; Valley 1985). The mafic and felsic portions of the AMCG suite, while approximately coeval, are probably not comagmatic (McLelland and Whitney 1990). Olivine metagabbro bodies scattered throughout the eastern and central Highlands are also approximately coeval with the AMCG magmatism. Slightly younger granitoids, lithologically and geochemically similar to those of the AMCG suite, were emplaced in the interval 1103-1093 Ma (McLelland et al. 2002). Another suite of felsic rocks, the Lyon Mountain Gneiss complex, is discussed in detail below.

Frost and Frost (1997) have proposed that large volumes of reduced, potassium- and iron-enriched type A granitic magmas may be derived from partial melting of underplated tholeiitic basalts and their differentiates in an anorogenic or extensional intraplate setting. They cite the Wolf River Batholith of Wisconsin, the Pikes Peak Batholith of the Colorado Front Range, and the Sherman Batholith of Wyoming as examples of granites that originated in this manner. Each has associated mafic and anorthositic rocks, consistent with the bimodal character of rapakivi and other A-type suites worldwide (Haapala and Ramo, 1999). AMCG granitoids have type A geochemical signatures (McLelland and Whitney 1990) and locally show rapakivi textures (Buddington and Leonard 1962; Whitney et al. 2002); they may be the deformed and metamorphosed equivalent of such intraplate complexes. Subsidence associated with underplating may give rise to intracratonic basins (Stel et al., 1993), which suggests that at least part of the metasedimentary suite in the Adirondack Highlands may be coeval with AMCG magmatism.

Regional granulite facies metamorphism of Ottawan age in the Adirondack Highlands occurred at temperatures of 700-850°C and pressures of 6.5-8.5 kbar (Bohlen and others, 1985; Spear and Markussen, 1997). Early stages of cooling may have been nearly isobaric (Spear and Markussen, 1997), and there is little evidence for sudden orogenic collapse. These conditions, recorded in rocks of supracrustal and relatively shallow intrusive origin require tectonic thickening of the crust, possibly by SE-over-NW thrusting associated with a collisional event (Whitney, 1983; McLelland and Isachsen 1985). Ottawan deformation is characterized by both large-scale folding and the development of extensive, locally mylonitic, ductile shear zones. Many of the anorthosite bodies have a domical configuration that may reflect either the initial shape of the intrusions or later gravity-driven vertical tectonics following crustal thickening (Whitney 1983). The age of the Ottawan in the Adirondack Highlands is not yet clearly established. McLelland et al. (1996, 2001) place it in the range 1090–1030 Ma, based on extensive U-Pb zircon studies of AMCG suite rocks. Florence et al. (1995) suggest a slightly younger age of 1050-1000 Ma based on U-Pb zircon and monazite ages from nelsonite and metapelites in the western Highlands. The latter interval is in agreement with the 1026–996 ma ages measured by Mezger et al. (1991, 1993) on metamorphic garnet and zircon in the central Highlands. Numerous other concordant or near-concordant zircon U-Pb ages in the 1040–990 Ma range indicate a high-temperature metamorphic event in the Adirondack Highlands after 1050 Ma (Silver 1968; Mclelland et al. 1988; and unpublished N.Y. State Geological Survey data from zircons in anorthosite). A 995 ± 19 Ma Sm/Nd mineral isochron from a garnetiferous oxide-rich gabbro dike within the Marcy anorthosite massif (Ashwal and Wooden, 1983) also suggests a late date for Ottawan metamorphism. Davidson (1995) reports Ottawan high-grade metamorphism in the ca. 1060-1020 Ma range throughout much of the Grenville Province.

ROCKS OF THE NORTHEASTERN HIGHLANDS

The map of the Ausable Forks Quadrangle (Figure 1) illustrates the mode of occurrence of the major rock units of the the northeastern Adirondack Highlands. Structurally lowermost are the domical metanorthosite bodies, here represented by the Jay and Westport Domes. Smaller amounts of mafic gneisses and granulites ranging in composition from ferrogabbro to monzodiorite are associated with the metanorthosite. Gabbroic metanorthosite also occurs as sheetlike bodies within the overlying metasedimentary section.

Metasedimentary rocks overlying the domical anorthosites consist principally of diopside-rich calcsilicate granulites, impure quartzites, and calcite marbles, with lesser amounts of phlogopite and biotite schists and metapelites, rare dolomite marble, and the economically important wollastonite ore skarns of the Willsboro-Lewis district. The metasedimentary rocks are interlayered with amphibolite and mafic and felsic gneisses of indeterminate ancestry, and contain intrusive bodies of olivine metagabbro and granitoids of the AMCG suite. In the central part of the Ausable Forks quadrangle west of Black Mountain, prominent marble "dikes" crosscut a stratiform body of anorthosite gneiss, illustrating the ductile behavior of the marble relative to that of anorthosite during deformation. These dikes led Emmons (1842) to conclude that marble was the only clearly igneous rock in the Adirondacks!

Several features of these metasedimentary rocks suggest the former presence of evaporites. The preponderance of diopside-rich calcsilicate rocks, the metamorphic equivalent of silicious dolostones, is significant in that dolomite is commonly a product of hypersaline depositional environments (Friedman, 1980). The calcsilicate rocks locally contain major amounts of microcline, possibly the metamorphic equivalent of authigenic or diagenetic adularia. Magnesium-rich metasedimentary rocks, in particular phlogopite schists and enstatite-diopside-tremolite-quartz rocks, are likely granulite facies equivalents of evaporite-related talc-tremolite-quartz schists, such as those found near Balmat in the northwest Adirondacks, in stratigraphic association with diopside-rich rocks and bedded anhydrite (Brown and Engel, 1956). Magnesite-dolomite-chlorite-quartz rocks are a possible sedimentary protolith. Granulite facies metasedimentary rocks similar to those of the Ausable Forks quadrangle occur in the Caraiba mining district of Brazil (Leake and others, 1979), and in the Oaxacan Complex of southern Mexico (Ortega-Gutierrez, 1984); in both localities anhydrite is present in the subsurface.

The metasedimentary complex is overlain in turn by heterogeneous, predominantly felsic gneisses known informally as Lyon Mountain Gneiss, host to local concentrations of low-titanium magnetite ore that were the basis for a flourishing iron mining industry in the late nineteenth century. This trip includes stops in the wollastonite skarn, LMG, and metanorthosite, each described in more detail in the following section.

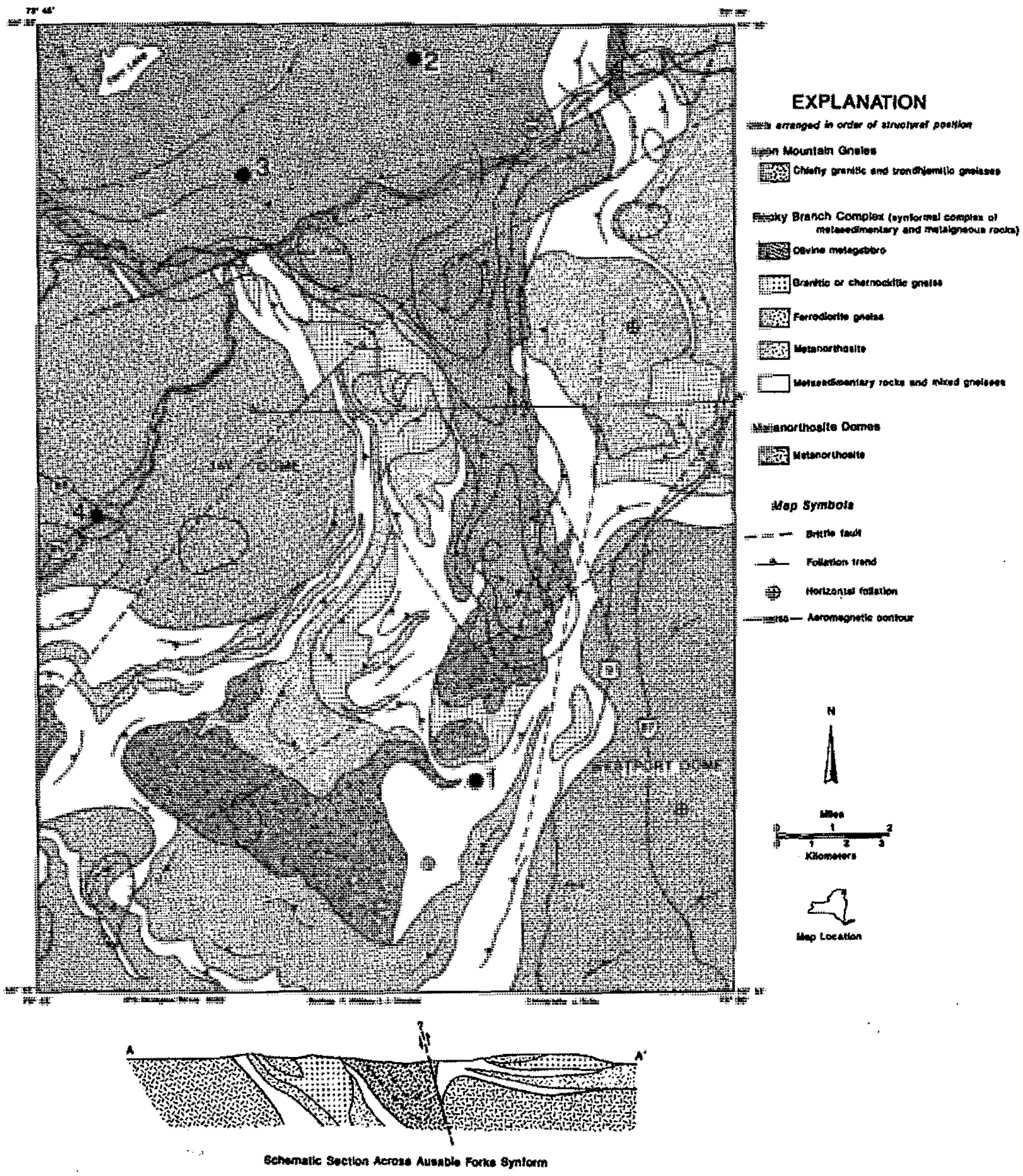

Figure 1. Geologic map of the Ausable Forks 15' Quadrangle, after Whitney and Olmsted (1993)

DESCRIPTIONS OF LITHOLOGIC UNITS

Wollastonite skarns (Stop 1). The presence of wollastonite near Willsboro in the northeastern Adirondacks (Figs. 1, 2) has been known since the early nineteenth century. The earliest reference to it in the geologic literature is by Vanuxem (1821). For over a century, the wollastonite was of little interest except as a mineralogical curiosity. Mining on a small scale began at Fox Knoll near Willsboro in 1938, with the wollastonite being used as a flux for arc welding. In 1951, the Cabot Corporation gained control, and began underground mining in 1960. Interpace Corporation took over and expanded operations in 1969. Product development resulted in uses in ceramic bodies and glazes, as a reinforcing filler in plastics and resins, and as a substitute for short-fiber asbestos. The operation, was purchased in 1979 by a subsidiary of Canadian Pacific (US), Processed Minerals Inc. Open pit mining at the Lewis Mine, ten miles southwest of Willsboro, began in 1980 and in 1982 the underground operation at Willsboro was closed. Development of the Oak Hill orebody is currently under way. All three properties are now owned by NYCO Minerals, Inc., a subsidiary of Fording Coal Company of Calgary, Alberta.

The Willsboro deposit was mentioned briefly by Buddington (1939, 1950) and Buddington and Whitcomb (1941); the geology is given in more detail by Broughton and Burnham (1944). Putman (1958) described several occurrences of wollastonite in the Au Sable Forks and Willsboro quadrangles, including those at Willsboro, Deerhead, and Lewis (Figure 2). De Rudder (1962) studied the mineralogy and petrology of the Willsboro ores, and attributed them to contact metamorphism with localized alumina metasomatism. Oxygen isotope work by Valley and O'Neil (1982) demonstrated extensive metasomatism involving meteoric water.

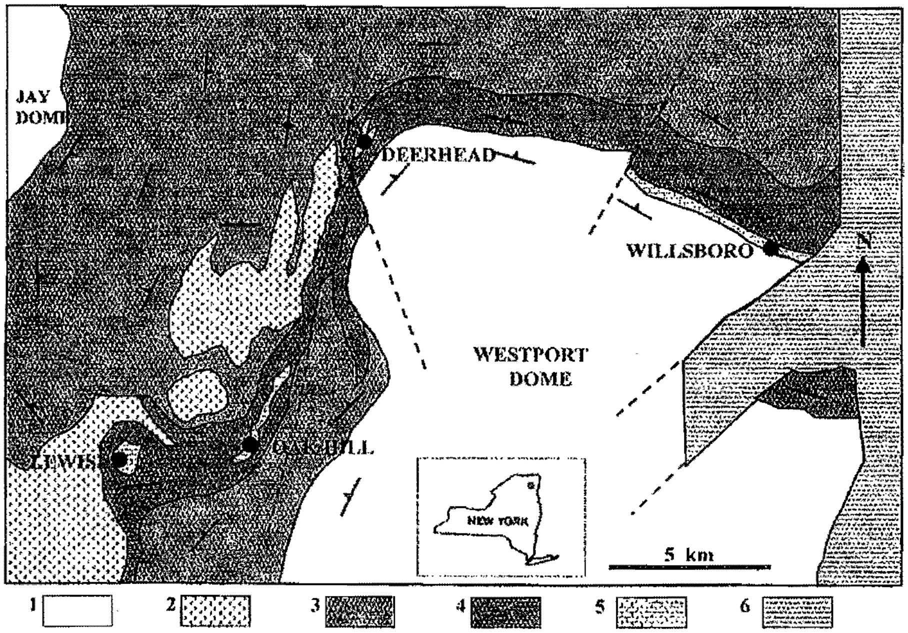

Figure 2. Willsboro-Lewis Wollastonite District. 1. Anorthosite 2. Olivine Metagabbro 3. Mixed gneisses (gabbroic anorthosite, amphibolite, charnockite, granite, metasedimentary rocks) 4. Ore-bearing zone (OBZ) 5. Skarn 6. Paleozoic

Geologic setting: The Westport metanorthosite dome (Figures 1 and 2) is located east and north of the Marcy Massif. It is overlain on its north and west flanks by interlayered granulite facies metaigneous and metasedimentary gneisses, marbles, and calcsilicate rocks. The wollastonite deposits at Willsboro, Oak Hill, and Lewis, as well as the undeveloped prospect at Deerhead, occur within a mappable zone up to 2000 feet thick that extends for at least 14 miles along strike (Figure 2). This ore-bearing zone (OBZ) is characterized throughout by strong to intense foliation and locally prominent lineation. Along the northern flank of the Westport Dome from the Willsboro mine to Deerhead, the OBZ directly overlies the metanorthosite of the dome, foliations dip NNE away from the dome, and lineations plunge NW. Southwestward, near Oak Hill and the Lewis mine, dips flatten and lineations become parallel with the regional NNE trend (Whitney and Olmsted, 1993). Foliation and compositional layering in both skarn and host gneisses is roughly parallel to the contact of the underlying metanorthosite. The skarns are nowhere far from the projected anorthosite contact in the subsurface.

Metaigneous rocks within the OBZ occur as sheets and lenses parallel to foliation, emplaced either as sills or as tectonic slivers. They include gabbroic and anorthositic gneisses, amphibolite, and minor charnockite. Interiors of thick gabbroic layers may display relict igneous textures. In addition to the skarns, metasedimentary rocks consist chiefly of diverse suite of granular-textured garnet-clinopyroxene-plagioclase rocks, calcite marbles, and minor amounts of quartzite and metapelite.

The ore at all four known locations occurs as tabular bodies ranging from a few feet up to as much as 80 feet thick. Multiple wollastonite-bearing horizons, separated by gabbroic or anorthositic gneisses and amphibolite, are present at Willsboro (DeRudder, 1962) and at Oak Hill. The orebodies consist of wollastonite-rich ore with layers and lenses ranging from less than an inch to several feet thick of garnet-pyroxene skarn (GPS). This compositional layering is ordinarily straight and sharply defined; it is probably not an original sedimentary feature but rather a result of tectonically induced metamorphic differentiation during or subsequent to ore formation. More diffuse compositional layering and foliation within the ore locally exhibits complex folding. Where layering is less prominent, garnet and pyroxene may occur in clusters or lenses up to 2 inches across.

Mineralogy: The ore layers contain the high-variance assemblage wollastonite-grandite garnet-clinopyroxene. Traces of retrograde calcite occur as thin films replacing wollastonite along fractures and grain boundaries. GPS layers within the ore consist chiefly of garnet and clinopyroxene with or without minor wollastonite. Another type of GPS, containing up to several percent of titanite and apatite, occurs at contacts between ore and metaigneous gneisses or amphibolites and, less commonly, as sill- or dike-like bodies within the ore. Minor and trace minerals occurring locally in GPS include scapolite, plagioclase, clinozoisite, vesuvianite, and zircon. Discontinuous layers up to several feet thick of nearly pure garnet, or garnet with minor plagioclase and quartz are present at some ore/gneiss contacts. These "garnetites" pinch and swell along strike or form detached lenses that resemble boudins.

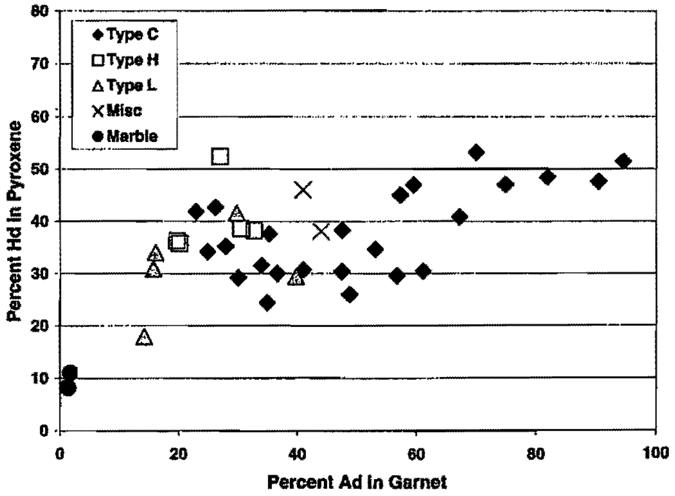

Figure 3. Garnet and pyroxene compositions in wollastonite skarns. Data from Willsboro and Lewis Mines. Hd = Hedenbergite. Ad = Andradite. For explanation of skarn types see text.

The pyroxenes in ore and GPS lie close to the diopside-hedenbergite join, containing >93% (Di + Hd), with acmite (up to 3.2%) as the most common minor component. The garnets are grossular-andradite mixtures, with > 93% (Gr + Ad); almandite (up to 4.9%) and schorlomite (up to 3.1%) are the dominant impurities. Figure 3, after Whitney and Olmsted (1998), shows the range of garnet and pyroxene compositions for the ore and GPS. Compositional variation among grains within a sample can be as great as 20% Ad and 10% Hd for garnet and pyroxene respectively. Individual grains lack detectable internal zoning that may have been initially present but was homogenized by the subsequent granulite facies metamorphism.

Geochemistry: Whitney and Olmsted (1998) describe three distinct types of wollastonite ore and skarn, based on mineralogy and distinctive rare earth element (REE) patterns (Fig. 4a). The most common, type C of Whitney and Olmsted (1998), includes most of the high grade wollastonite ore and consists of wollastonite-garnet- pyroxene and garnet-pyroxene skarns with relatively iron-rich andraditic garnet. Type H, much less abundant, is similar but with generally less wollastonite, more pyroxene, and relatively iron-poor garnet. Both type C and type H appear to be infiltration skarns involving large-scale metasomatic replacement of carbonate protoliths.

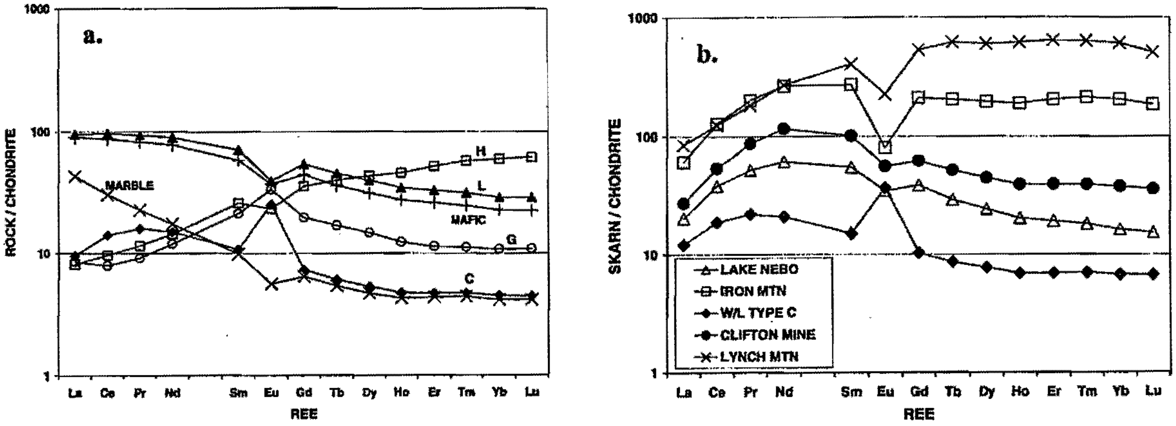

Figure 4. a. Average REE distributions in Willsboro-Lewis wollastonite skarns and in northeastern Adirondack marbles. **b.** REE in garnet-pyroxene layers in type C ores compared to garnet-pyroxene skarns from Adirondack Highlands magnetite ore deposits.

A third variety of skarn (Type L) occurs at contacts of wollastonite ore with intrusive rocks and as thin layers, possibly dikes, within and locally crosscutting wollastonite ore. Type L skarns contain variable amounts of titanite, apatite, and, less commonly, plagioclase or scapolite in addition to garnet and pyroxene; wollastonite is scarce or absent. Their limited extent and localization at igneous contacts suggest localized Ca metasomatism of igneous precursors. All three types lack primary calcite, quartz, and oxide minerals. A fourth distinct skarn type, "garnetite" (G) occurs as layers, lenses or boudins of nearly pure, relatively grossularitic garnet at or near contacts of ore with anorthosite or mafic gneiss; it is especially abundant at the Oak Hill deposit (Stop 1). Note that all skarn REE patterns are substantially different from that of the assumed marble protolith.

The origin of the distinctive REE patterns is discussed by Whitney and Olmsted (1998). Briefly, type C results from uptake of REE from solution by metasomatic garnet, with the maximum in the distribution corresponding to the closest match between the REE^{3+} ionic radius and the size of the dodecahedral (Ca) site in the garnet. The strong positive Eu anomaly may result either from prior interaction of the metasomatic fluid with nearby, Eu-positive anorthosite, preferential uptake of Eu^{2+} on garnet growth surfaces (Whitney and Olmsted 1998), or preferential solubility of Eu relative to other REE during water-rock interaction by complexation (e.g. as $EuCl_4^{-2}$) in chloride-rich solutions (Haas et al. 1995). Note the contrast in Eu anomaly and REE abundance with skarns associated with Adirondack Highlands magnetite deposits (Fig. 4b).

Hydrothermal dissolution of LREE-enriched calcite from marble containing contact-metamorphic garnet and pyroxene previously equilbrated with the calcite may be a significant mechanism in the origin of type H patterns (Whitney and Olmsted 1998). However, pyroxene and garnet in most type H skarns are more iron-rich than those in marbles, and although the shape of the REE patterns are very similar, garnet in most type H samples contains significantly more total REE than does garnet from marble. This suggests metasomatic addition of HREE, in addition to Fe. Fluid composition, pathways, temperature, and oxidation state may have differed substantially from those giving rise to type C.

Type L REE distributions in sphene- and apatite-bearing GPS probably result from localized Ca metasomatism of mafic igneous rocks in contact with ore; compare the L pattern in with that of mafic gneisses from the ore zone ("mafics" in Fig. 4a). In these rocks, LREE are retained in sphene and apatite while the heavy rare earths (HREE) remain in the relatively grossularitic garnet. The middle-REE-enriched pattern (G in Fig. 4 a) found in the garnetites has, as yet, no satisfactory explanation.

Average major and trace element concentrations for the four skarn types are shown in Table 1. Relative to a hypothetical marble protolith, types C and H are enriched in Si, Ti, Al, Fe, Zr, and Ga while Mg, K, Sr, and Ba are strongly depleted. Type H also shows enrichment in Y, Zn, and V relative to both the assumed protolith and to type C. Some of these enrichments may result from concentration of detrital silicates and their metamorphic reaction products; others, such as Fe, Ga, Y, Zn, and the REE are probably largely of metasomatic origin.

TABLE 1
AVERAGE COMPOSITIONS OF SKARNS

type	C	H	L	G
n	23	7	9	3
SiO_2	46.33	44,38	42.84	38.10
TiO_2	0.23	0.45	1.94	0.83
Al_2O_3	3.41	9.69	9.22	16.59
Fe_2O_3(T)	8.77	8.39	9.05	8.49
MnO	0.17	0.28	0.21	0.24
MgO	1.53	2.41	3.76	0.52
CaO	38.99	33.94	31.61	33.92
Na_2O	0.16	0.09	0.22	0.17
K_2O	0.00	0.00	0.01	0.04
P_2O_5	0.02	0.05	0.97	0.19
Rb	<1	<1	<1	<1
Sr	34	24	45	30
Ba	2	4	2	<2
Zr	57	73	319	121
Y	8	79	61	56
Nb	2	2	13	11
Ga	11	15	15	27

Metasomatic origin of the ores: Wollastonite commonly occurs as a contact metamorphic mineral formed by reaction of calcite and quartz. However, the Willsboro-Lewis ores show metasomatism on a large scale. The evidence includes:

a. Mineral assemblages and compositions. If the wollastonite ore had been formed by isochemical contact metamorphism, the absence of either quartz or primary calcite would imply a protolith with precisely the right balance of quartz and calcite. This highly improbable requirement, together with the high variance of the ore mineral assemblage, indicates that metasomatism has occurred (Valley and O'Neil, 1982).

b. Oxygen isotopes. Valley and O'Neil (1982) determined oxygen isotopes in both the Willsboro and Lewis deposits. They found $\delta^{18}O_{SMOW}$ in the wollastonite ore from -1.3 to 7.0‰; as much as 25‰ lower than typical Adirondack marbles. Sharp gradients occur between ore and wall rocks. They (Valley and O'Neil, 1982) showed that the $\delta^{18}O$ data could not be explained by isotopic fractionation during devolatilization reactions, but required exchange with large volumes of heated meteoric waters at the time of anorthosite intrusion.

c. Depletion of Na, K, Rb, Ba, and Sr. Only those elements that can be accomodated in the structures of wollastonite, garnet, and pyroxene are present in significant concentrations in the ores and GPS (Table 1). This is particularly clear for the large-ion lithophile elements (LILE) K, Rb, and Ba, which are present in only negligible amounts compared to a hypothetical marble protolith. This is best explained by metasomatic removal. Strontium is also depleted although to a lesser extent.

d. REE distribution. Assuming a carbonate protolith for the ore, comparison of the REE distributions in ore and GPS with those of northeastern Adirondack marbles (Fig. 4a), confirm substantial metasomatic redistribution of REE.

Sequence of ore-forming events. Origin of the ores by hydrothermal metasomatism requires a heat source to provide the minimum temperatures (ca. 450°C) for formation of wollastonite and to drive the hydrothermal circulation. This requirement, and the close spatial association between the ores and the Westport Dome (Fig. 2) strongly indicate that the ore is coeval with emplacement of the anorthosite, in agreement with the conclusions of earlier workers (Buddington 1939, 1950; Broughton and Burnham 1944, DeRudder 1962). Moreover, access of large volumes of dominantly meteoric fluids implies a relatively shallow depth of emplacement (Valley and O'Neil 1982, Valley 1985). Access of fluids would also be facilitated in an extensional tectonic setting. Massif anorthosites are widely believed to be associated with extensional tectonics (Ashwal, 1993). Whitney and Olmsted (1993) have argued that the Adirondack anorthosites were emplaced in an extensional setting that included large listric or detachment faults. We speculate that the present OBZ was the locus of one or more such faults. A similar association of extensional faulting with magmatic doming has been proposed by Lister and Baldwin (1993) for some metamorphic core complexes. Major low-angle extensional faults can provide channels for circulating hydrothermal fluids (Reynolds and Lister, 1987; Kerrich and Rehrig, 1987). When the Westport Dome was emplaced, hydrothermal circulation driven by heat from the intrusive may have followed the low-angle faults, fed from the surface by meteoric water penetrating along associated high-angle normal faults (Fig. 5; arrows show hypothetical fluid pathways). Where the faults intersected or followed reactive carbonate units, infiltration metasomatism produced wollastonite and andraditic garnet, accompanied by exchange of REE and oxygen isotopes. Ongoing or later deformation produced the foliation in the ore and concentrated garnet and pyroxene into conformable GPS layers and lenses by mechanical metamorphic differentiation. Subsequent granulite facies metamorphism during the Ottawan orogeny had little effect on the mineral assemblage in the skarns but probably resulted in intra-grain homogenization of initially zoned garnet (Whitney and Olmsted 1998).

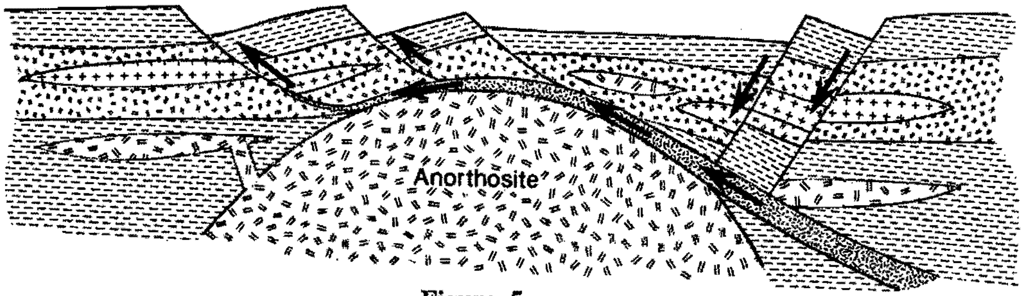

Figure 5

Lyon Mountain Gneiss (Stops 2 and 3)

Description. The Lyon Mountain Gneiss comprises several distinct facies of felsic gneisses, classified by Postel (1952) in terms of the dominant feldspar present (microperthite, microcline, microantiperthite, or plagioclase). Feldspar in the plagioclase facies, i.e. the leucocratic albite gneiss (LAG) of Whitney and Olmsted (1988), is nearly pure albite (Ab_{95}-Ab_{98}). Table 2 shows representative chemical analyses for the several facies. Note the extreme variation of Na and K, far outside the normal igneous range and indicative of extensive alkali metasomatism. Apart from the variation in alkali metals, two geochemically distinct types of LMG are present (Fig. 6). One is enriched in high field stength elements and REE relative to the other, and has significantly higher Ga/Al ratios and more pronounced negative Eu anomalies indicating a more fractionated igneous source. This high-HFS group may be the volcanic equivalent of the fayalite granite exposed at Bailey Hill, within the LMG complex (Whitney and Olmsted 1993; X's in Fig. 6)).

Mineralogy of the gneisses varies widely, not only with respect to the variety of feldspar but also in relative proportions of quartz and feldspar (Fig. 7), and the type and amount of mafic minerals. The latter include nearly ubiquitous magnetite which in some samples is the only dark mineral. The microcline and mesoperthite facies ordinarily also contain accessory to minor amounts of clinopyroxene, biotite, brown hornblende, or, rarely, fayalite. Clinopyroxene in in the antiperthite and plagioclase (LAG) facies commonly contains up to 40% acmite component and is locally accompanied by a blue-gray sodic amphibole (Whitney and Olmsted 1993). In both sodic and potassic facies, titanite occurs as discrete grains and rims on magnetite, and andraditic garnet is present very locally as narrow rims on clinopyroxene or as clusters of small grains. In the vicinity of the Palmer Hill Mine (Stop 3), fluorite is a locally abundant accessory in the gneiss and ore.

Fine- to medium- grained granoblastic textures are the most common, but considerable amounts of coarser-textured gneisses are also present. The latter ordinaily have intermediate alkali metal ratios and may be intrusive rocks that have escaped extensive metasomatic alteration due to lower permeability. In the finer-grained rocks, prominent compositional layering or gneissosity is nearly ubiquitous, although foliation *sensu stricto* is ordinarily subdued due to scarcity of minerals with dimensional anisotropy. Lineation, where present, is defined by streaks of mafic minerals or polycrystalline quartz.

The felsic gneisses are locally interlayered with lesser amounts of metasedimentary rocks and amphibolite. The former include clinopyroxene skarns, rarely with garnet, and a peculiar albite-clinopyroxene gneiss, the mafic albite gneiss (MAG) of Whitney and Olmsted (1988, 1993), with feldspar and pyroxene compositions and accessory minerals similar to those of LAG. MAG is commonly fine-grained, with a sugary granoblastic texture. In some outcrops, it displays a prominent pinstripe layering, with alternating mm-scale pyroxene- and albite-rich layers.

Megacrysts of nearly pure albite, up to 5 cm across, are present locally; quartz content is normally less than 5 percent. MAG probably originated by Na-metasomatism of a calcsilicate protolith.

TABLE 2.
REPRESENTATIVE CHEMICAL ANALYSES
LYON MOUMTAIN GNEISS

	ABS460	AF356	AF470	LMS4B	DAS01	PXS10	PVS01	PVS07	AF664	AF781A	AF658
Facies	**P**	**P**	**P**	**P**	**M**	**M**	**AP**	**AP**	**Ab**	**Ab**	**MAG**
SiO_2	70.72	69.58	74.30	66.70	68.67	70.66	71.12	65.85	71.07	74.56	62.25
TiO_2	0.56	0.50	0.42	0.82	0.54	0.42	0.76	0.58	0.48	0.36	1.01
Al_2O_3	12.24	12.20	11.88	13.25	12.97	12.04	13.37	13.34	13.13	12.00	13.37
Fe_2O_3t	5.71	7.00	5.42	4.39	6.42	6.01	4.93	5.94	5.57	5.48	5.11
MnO	0.01	0.09	0.04	0.09	0.01	0.01	0.03	0.04	0.03	0.01	0.05
MgO	0.17	0.09	0.06	0.75	0.20	0.16	0.64	1.83	0.34	0.15	2.89
CaO	0.49	1.86	1.27	3.06	0.19	0.45	1.39	3.96	2.57	0.47	7.29
Na_2O	2.96	3.88	4.57	4.06	0.97	1.06	5.91	6.64	7.63	6.80	7.89
K_2O	6.49	4.63	2.23	5.18	9.71	8.90	1.70	1.94	0.11	0.31	0.21
P_2O_5	0.11	0.05	0.03	0.21	0.11	0.06	0.21	0.03	0.07	0.03	0.07
Total	99.58	99.70	100.21	98.66	99.86	99.79	100.45	100.30	100.91	100.40	99.83
Rb	192	98	61	167	272	227	45	34	2	4	3
Sr	57	62	28	79	39	21	107	29	25	18	36
Ba	644	526	88	718	1822	905	182	93	27	10	27
Zr	515	1172	1229	635	612	641	582	858	1084	1006	315
Y	82	59	200	94	61	53	72	83	121	111	85
Nb	28	21	53	22	20	20	17	35	38	36	17
Ga	21	25	33	28	17	19	26	27	27	31	18
MOLECULAR NORMS											
qz	24.09	22.20	32.15	15.96	21.60	25.56	23.24	9.14	18.50	28.14	1.32
or	39.52	28.05	13.43	31.36	59.52	54.65	10.09	11.37	0.64	1.84	1.21
ab	27.39	35.73	41.83	37.36	9.04	9.89	53.34	59.13	67.63	61.36	69.29
an	0.97	2.26	5.42	2.70	0.23	1.88	4.96	0.86	1.24	1.31	0.44
ac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hy	5.12	3.94	4.70	0.90	6.31	5.95	5.36	2.65	1.31	4.96	0.00
di	0.63	5.50	0.64	9.16	0.00	0.03	0.48	14.75	8.72	0.67	22.76
wo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.42
il	0.80	0.71	0.60	1.17	0.78	0.61	1.06	0.80	0.66	0.50	1.38
mt	1.23	1.50	1.15	0.94	1.39	1.31	1.04	1.23	1.15	1.15	1.04
co	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00
ap	0.24	0.11	0.06	0.45	0.24	0.13	0.44	0.06	0.14	0.06	0.14

Facies:
P = Perthite
M = Microcline
AP = Antiperthite
Ab = Plagioclase
MAG = Mafic Albite Gneiss

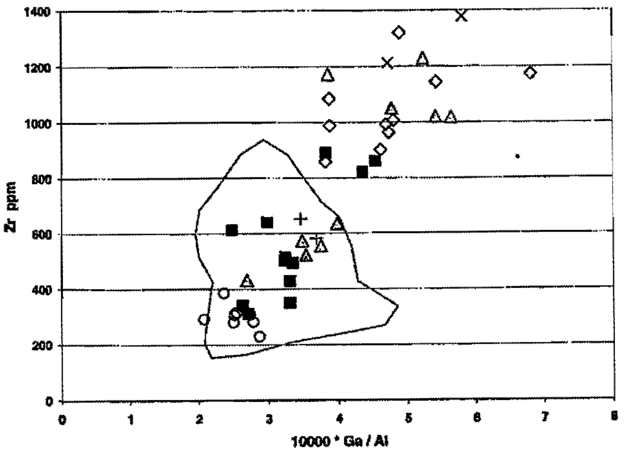

Figure 6. Filled squares: Microcline facies. Triangles: Perthite facies. +'s: Antiperthite facies. Circles: MAG X's: Fayalite granites. Outline: Range of AMCG granitoids.

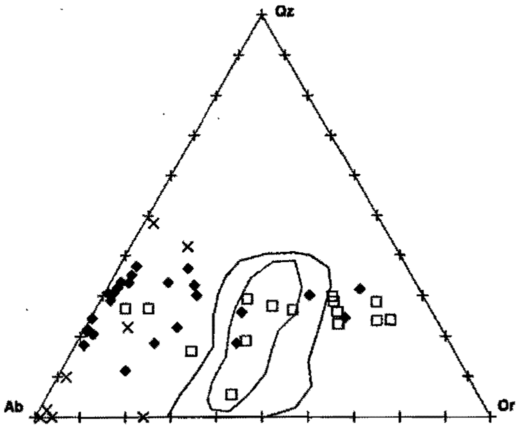

Figure 7. Diamonds: High HFS group. Squares: Low HFS group. X's: Metasedimentary rocks. Outlines: 85% (inner) and 100% (outer) of AMCG granitoids.

Structure and metamorphism: LMG has been interpreted as a late- to post-tectonic plutonic rock (Foose and McLelland 1995; McLelland et al. 2001). However, it exhibits deformation similar in style, intensity, and trend to that in other northeastern Adirondack rocks. Well-developed foliation, lineation, and complex tight to isoclinal minor folds (Stops 2 and 3) are common throughout although locally obscure in the more leucocratic facies. The foliation, lineation, and major structures are concordant with those in the underlying metasedimentary rocks, mafic and granitic gneisses (Postel 1952, 1956; Whitney and Olmsted 1993). Magnetite ore occurs as tabular bodies parallel to foliation and as cigar-shaped "shoots" parallel to lineation and regional fold axes (Postel 1952). Locally LMG contains numerous pegmatites and quartz veins (Postel 1956). Some of these are undeformed and crosscut structure in the gneiss, indicating minor late- or post-tectonic magmatic activity. Fluids associated with the pegmatites may account for localized remobilization of magnetite and secondary albitization of feldspars.

Evidence of metamorphism in the LMG is scarce because the composition of the dominant metaluminous felsic rocks is unsuitable to the development of diagnostic metamorphic assemblages. Nevertheless, pyralspite garnet and sillimanite occur locally, and metamorphic textures are ubiquitous.

Origin: Whitney and Olmsted (1988) postulated that LMG originated as volcanic ash with interlayered metasedimentary rocks deposited in a hypersaline environment and diagenetically altered to yield the wide range of K/Na ratios. This hypothesis, despite good actualistic credentials, fails to provide a plausible explanation for the magnetite concentrations unless they too are of volcanic origin. Alternatively, LMG may have originated as a volcanic-sedimentary complex including substantial volumes of subvolcanic intrusives. Barton and Johnson (1996) have proposed that circulation of fluids, driven by heat from the intusives and enriched in alkali and alkaline earth halides and sulfates mobilized from subjacent evaporites, may account for both alkali metasomatism and deposition of the magnetite ores in geologically similar regions worldwide. This is an attractive explanation for the LMG in view of the evidence for the former presence of evaporites in the underlying metasedimentary rocks. It is likely that metasomatism and ore deposition were largely confined to the more permeable volcanics; most coarse-grained, igneous-looking LMG lacks extreme K/Na ratios.

Age: Zircons in these rocks commonly consist of relatively small cores with robust overgrowths. U/Pb dating using the ion microprobe (McLelland et al. 2001) shows two distinct clusters of ages corresponding to the cores and mantles. The cores yield ages of 1152±11 and 1141±16 Ma for the microcline and plagioclase facies respectively; mantle ages for both facies are 1055±7 Ma. McLelland et al. (2001) conclude that the younger dates represent the age of igneous emplacement, with the older cores attributed to inherited zircons from assimilated AMCG-suite rocks. Other interpretations are possible under the assumption that LMG represents, at least in part, volcanics and shallow intrusives associated with the ca. 1150 Ma AMCG suite. In that case, the older zircon cores yield the igneous age, with the mantles being metamorphic or metasomatic overgrowths. The later (1055 Ma) age of emplacement has the advantage of providing, at least in the northeastern Highlands, a magmatic heat source for the subsequent Ottawan metamorphism. It requires, however, that Ottawan deformation and metamorphism occurred after 1055 Ma.

Metanorthosite and related mafic rocks (Stops 4, 5, and 6). Metamorphosed anorthositic rocks underlie large areas in the central and northern Adirondacks. These rocks, together with subordinate mafic rocks ranging from monzodiorite to ferrogabbro, comprise the mafic part of the bimodal Anorthosite-Mangerite-Charnockite-Granite (AMCG) intrusive suite (McLelland and Whitney, 1990) in the Adirondack Highlands. In the northeastern Highlands, metanorthosite forms large domical bodies as well as smaller, stratiform intrusions within supracrustal rocks. While Adirondack metanorthosites have in common the presence of intermediate plagioclase (An_{42-60}) as the dominant (70-98%) mineral, they are quite diverse and detailed description presents formidable complexities. Early Adirondack workers distinguished two facies, the "Marcy" facies, which is megacryst-rich, leucocratic, and undeformed to slightly deformed, and the "Whiteface" facies, megacryst-poor, mafic, and more deformed relative to the "Marcy". This classification is difficult to use consistently, because the three variables (abundance of megacrysts, abundance of mafic minerals, and extent of deformation) are at least partially independent. In a single outcrop each of these factors may vary over a wide range; moreover numerous distinct blocks and/or layers may be present.

a. Abundance of plagioclase megacrysts. Gray sodic labradorite to calcic andesine megacrysts are a prominent feature of most Adirondack anorthosites. Size of the megacrysts ranges from one or two cm to giant, 1/2 m "breadloaf" crystals and fragments. Faint to strong parallelism of the megacrysts is locally present, suggesting either cumulus texture or flow foliation. The proportion of megacrysts in the rock ranges from nearly 100% to nil. Where megacrysts are abundant and closely spaced in the rock, varying amounts of fine-grained, clear, recrystallized plagioclase may border the megacrysts and occupy small fractures within them. This is referred to in the older literature as "protoclastic" texture (Miller, 1916; Balk, 1931; Buddington, 1939). Where megacrysts are more widely spaced, interstitial volumes are commonly occupied by a medium-to coarse grained (up to several mm) groundmass of light gray, white or buff plagioclase together with pyroxenes and oxides. This groundmass locally displays igneous textures and may have crystallized from a gabbroic anorthosite magma or crystal mush in which the megacrysts have been entrained.

b. Abundance and type of mafic minerals. Hypersthene, augite, titaniferous magnetite, and ilmenite or hemo-ilmenite are the chief primary mafic minerals in the anorthositic rocks. Metamorphic garnet is common, and forms reaction rims around both hypersthene and oxide minerals, except in strongly deformed anorthosite where it tends to occur as porphyroblasts. Garnet is absent from anorthosites where the $MgO/(MgO + FeOt)$ ratio exceeds roughly 0.4. Metamorphic hornblende and biotite are locally present. The color index varies from one or two percent up to as much as 30% in some anorthositic gabbros.

c. Extent of deformation. Adirondack metanorthosites range from nearly undeformed, igneous-textured varieties to anorthositic gneisses with intense foliation and well-developed lineation. As the degree of deformation increases, megacrysts change from blocky to lenticular in shape, and generally decrease in size and abundance. Rocks near the margins of metanorthosite domes and massifs ordinarily are more deformed than those in the interiors, where deformation is commonly confined to relatively narrow shear zones.

Anorthositic xenoliths in anorthosite are common. This "block structure" suggests multiple intrusions. The blocks may be rounded or angular, and more or less mafic and finer-or coarser-grained relative to the host. Individual xenoliths or megacrysts may be surrounded by a zone enriched in mafic minerals. Xenoliths of metasedimentary rocks, ranging from centimeters to several meters in size, are found in all facies of the anorthosite. Most of these are pyroxene-rich calcsilicate rocks, but rare quartzite and metapelite xenoliths also occur.

Associated mafic rocks: Fractionation of plagioclase during crystallization of anorthositic magmas yields mafic residual liquids enriched in Fe, Ti, and P (Owens et al. 1993, McLelland et al. 1994, Mitchell et al. 1996). These "FTP rocks" have been given a variety of names; Owens et al. (1993) have suggested that the general term jotunite be used these rocks except where extreme concentration of Fe, Ti, and P leads to oxide-apatite gabbronorites (OAGN's). Jotunites in the Adirondack Highlands fall roughly into two groups. One occurs primarily in dikes and sheets external to large anorthosite bodies; it is commonly monzodioritic in composition and gneissic in texture. The other type forms dikes within anorthosite, usually near contacts with surrounding rocks. The latter is ferrodioritic to ferrogabbroic in composition and igneous-textured or granoblastic with little or no foliation; it is known as "Woolen Mill Gabbro" (WMG) after the best-known locality (Stop 6). There is some overlap in composition between the two types (Fig. 8), which may result from fractionation of a single residual liquid (Mitchell et al. 1996) or possibly from liquid immiscibility. Some WMG approaches OAGN in composition.

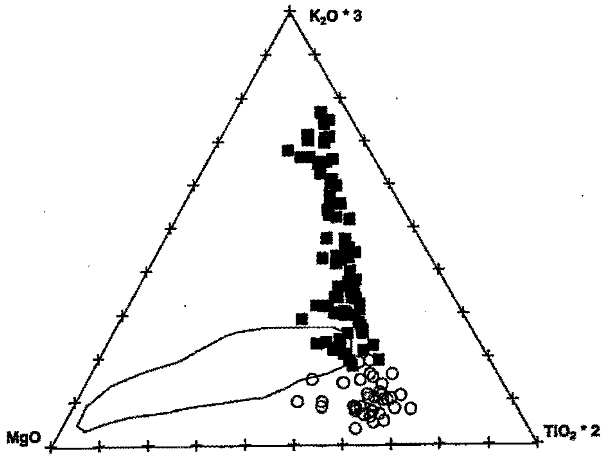

Figure 8. Diagram illustrating the compositional differences between "Woolen Mill Gabbro" (circles), other Highlands jotunites (squares), and olivine metagabbros (outline).

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ROAD LOG

Begin road log at Exit 32 of Interstate 87

Total Miles	Increment Miles	Route Description
0.0	0.0	**Exit 32, I-87.** If you are coming from the south turn **L.** at Essex Co. 12 and proceed to the southbound exit intersection to zero your odometer. If you have come from the north zero your odometer at the intersection of the exit 32 road and turn **R** on Essex Co. 12
0.45	0.45	Traveling west, "Betty Beaver's" Truck Stop on L.
1.55	1.1	Turn **R.** onto NY Route 9; Proceed north.
2.6	1.05	Turn **L.** onto Pulsifer Road.
2.85	0.25	Sharp **R.** bend; continue on Pulsifer Road.
3.15	0.3	Turn **L.** at blue gates onto Oak Hill Mine Road. This is NYCO property; if following this trip on your own, be sure to get permission at the NYCO office in Willsboro.
4.1	0.95	**Stop 1. OAK HILL WOLLASTONITE MINE.** At the first small quarry on L, park on the R well off the road. From here we will walk through the entire mine complex observing and describing the rock units. As you can see the mine is under development so there may be dangerous situations for which care must be exercised. Please use caution and follow instructions with care. The Oak Hill Mine was discovered by accident during a logging operation, when a skidder exposed white rock which the logger recognized as wollastonite. It is located at a sharp bend in the OBZ, where the structural trend changes from NNE with a gentle W dip to nearly EW with a gentle to moderate S dip. As of June 2002, mine is being actively developed. Two test pits have been blasted in ore, and work has begun removing overlying rock and glacial deposits in order to begin open-pit mining. Additional exposures may be available at the time of the trip, but others may have been removed or covered. Figure 9, constructed from drill core data, shows the complex nature of the ore body. The lowermost exposures are knobs of skarn consisting largely of orange-red grossularitic garnet, locally with abundant green, diopsidic clinopyroxene and/or veins and patches of sodic plagioclase and quartz. The garnetite encloses blocks of gabbroic anorthosite gneiss, metagabbro, and pyroxene granulite. Some of these blocks have narrow alteration haloes but otherwise are in sharp contact with the garnetite. They appear to be fragments of disrupted layers in what was probably a marble-hosted tectonic breccia, since metasomatically transformed to garnetite (other interpretations welcome!). Garnetite is much more abundant here than at either Lewis or Willsboro. Drill core data indicate that the the proportion of garnetite to ore increases toward the NE, eventually forming a layer of nearly 200', without ore. Proceeding upsection, several layers of ore are exposed, separated by septa of mafic gneiss and/or garnetite. Garnetite layers are discontinuous; some appear to be megaboudins. The hanging wall of the exposed ore consists of strongly foliated and lineated gabbroic anorthosite gneiss. This is overlain in turn by a chaotic marble

melange with detached blocks of intricately folded calcsilicates. The marble also contains masses of crumbly-weathered skarn consisting largely of black (dark orange-brown in transmitted light) garnet and dark green clinopyroxene. This skarn resembles those associated with magnetite deposits elsewhere in the Adirondack Highlands rather than the garnet-pyroxene layers in the ore. The fact that this marble has apparently escaped extensive metasomatism suggests that the metasomatizing fluids that foemed the ore were strongly channelized.

Overlying the marble is mafic gneiss with interlayers af charnockite and coarse, leucocratic augen gneiss, the latter an extreme L-tectonite. Above the gneiss complex, coronitic olivine metagabbro is exposed. The section in the mine is cut by several E-W, nearly vertical faults, one of which exhibits slickensides plunging steeply E. On the N side of the mine road, at the time of writing, bedrock is concealed beneath a thick section of varved glacial lake sediments interlayered with boulder till.

5.05	0.95	Exit NYCO property at the blue gates.
5.6	0.55	Turn L on NY Route 9, going north.
8.3	2.7	Intersection with Deerhead-Reber road; continue on Rt.9.

Section of Oak Hill Mine Development

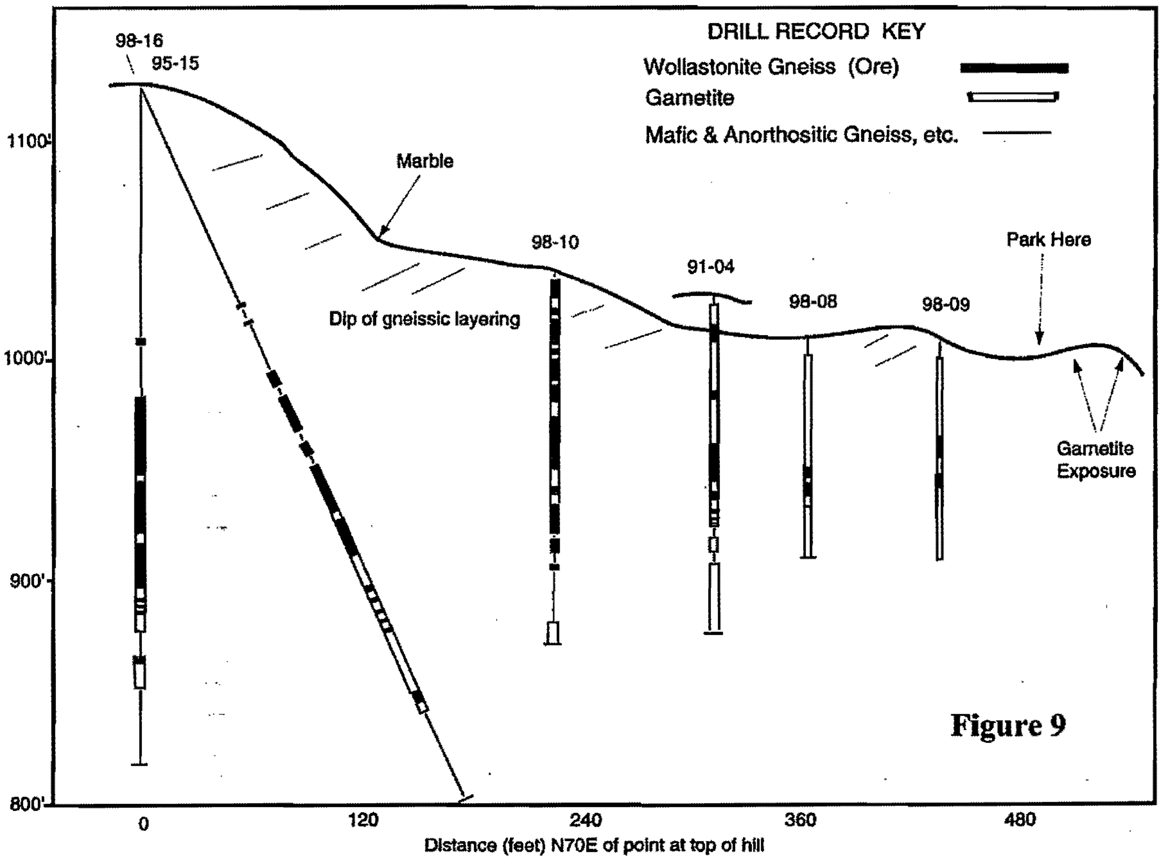

Figure 9

10.0	1.7	Crossing north branch of the Boquet River.
13.8	3.8	Spectacular fault breccia on L. This is one of the numerous NNE- to NE-trending faults that occur throughout much of the eastern and central Adirondack Highlands. Movement on these faults, possibly associated with the opening of the Iapetus Ocean, began in the latest Proterozoic and continued at least into the Ordovician.
14.3	0.5	Pokomoonshine State Park. The prominent cliff is mostly granitic gneiss of the AMCG suite, containing several layers of mafic gneiss that are probably transposed dikes.
16.2	1.9	The prominent white spot in the roadcut on the R is a marble xenolith in jotunite and badly contaminated gabbroic anorthositic gneiss. The marble contains abundant graphite, phlogopite and diopside and lesser amounts of chondrodite, grossular, and sulfides. Wollastonite is absent.
17.1	0.9	Turn **L** at caution light at the intersection with NY 22 adjacent to I-87 Exit 33.
17.2	0.1	Turn **R** at I-87 on ramp.
20.7	3.5	I-87 Exit 34. Turn **R** onto ramp.
20.9	0.2	Turn **L** onto NY Route 9N Toward AuSable Forks.
24.4	3.5	Cold Spring Road. Continue on 9N
25.5	1.1	Enter hamlet of Clintonville. Reportedly, in the late 19th century this was a town of 10,000 miners, wood cutters, iron forge workers and their families.
26.2	0.7	Bear **R** on Clintonville Rd.
27.4	1.2	Bear **R** on Harkness Road.
28.0	0.6	Turn **L** on Arnold Hill Road.
28.45	0.45	Cross Allen Hill and Thomasville roads.
28.9	0.45	**Stop 2A. LYON MOUNTAIN GNEISS; Albite gneiss facies.** Park off the road on **R**. The recently blasted low cuts on the L are largely albite gneiss with about 30% quartz, 65% plagioclase (ca. $An_2Ab_{96}Or_2$) with minor magnetite and/or hematite, and traces of biotite, clinopyroxene, titanite, apatite, and zircon. The fine-grained, equigranular texture is typical of this facies of the LMG. Note the small, nearly isoclinal Z-folds, N 10-20° E lineation, and numerous crosscutting quartz-albite pegmatites and quartz veins. The pegmatites locally contain masses of partially martitized magnetite, possibly remobilized from nearby orebodies.
29.2	0.3	**Stop 2B FOLDING IN LYON MOUNTAIN GNEISS.** These flat outcrops at the intersection of Arnold Hill Road and a logging road on the L show complex folding in albite gneiss similar to that at the last stop. Abrupt color changes in the rock crosscut the folding and appear to be contacts of more and less oxidized rock, suggesting a post-deformation oxidation event. This area is not far from the site of the Arnold and Nelson Bush Mines, opened in 1830 and

operated sporadically until 1906 (Kemp and Alling 1925; Postel 1952). The ore at Arnold Hill occurs as three foliation-parallel layers from 3-25' thick in albite gneiss. The layers were known to the miners as the gray, black, and blue "veins". The gray and black veins consist of magnetite, quartz, plagioclase, chlorite, and hornblende; in the blue vein the ore mineral is martite (Postel 1952). Turn around here and head back down the hill.

29.95	0.75	Turn **R** on Thomasville Road.
30.15	0.2	Small exposure of LMG on R side of road.
32.05	1.9	Bear **L** at fork; then cross over the Little AuSable River.
33.15	1.1	Bear **R** on Harkness Road
33.35	0.2	Continue straight on Palmer Hill road.
34.2	0.85	Coughlin road on R.
35.05	0.85	Turn **R** on Tower Road.
35.95	0.9	Road turns L at intersection with three unpaved roads. Park off road on R. Walk around the iron gate and proceed S along the unpaved road furthest to the R.

Stop 3. PALMER HILL. Follow the road approximately 0.3 miles to the top of Palmer Hill. Along the way are several small pavement outcrops exposing heterogeneous LMG showing complex folding and containing numerous small clots of magnetite ore. Were these formed in place, or are they disrupted fragments of a vein of ore emplaced before deformation? At the top of the hill are several large boulders of Potsdam Sandstone (middle to late Cambrian). The Potsdam unconformably overlies the Proterozoic rocks around much of the perimeter of the Adirondack Dome, and is exposed at the surface less than 6 miles to the NE. An abandoned firetower here has been converted to a cellphone relay. We will then follow a powerline for about 0.1 mile S to the old mine workings. **USE EXTREME CAUTION**, especially in wet weather. Cross a narrow rock bridge over the open cut and turn L to view the mine workings. **Do not go down into the cut; samples of ore will be available.** The ore here occurs in a discontinuous layer up to 20 feet thick, striking NE and dipping NW, roughly parallel to foliation on the SE limb of a NE-plunging synform (Postel 1952). It consists of magnetite with quartz, feldspar, and, locally, apatite, fluorite, and andraditic garnet. The host rock is predominantly the microperthite facies of LMG, although drill cores show almost the entire range of LMG lithologies (Postel 1952). Fluorite is a common accessory in the gneiss, and andraditic garnet occurs locally. Mining at Palmer Hill began in 1825 and continued until 1890 (Newland, 1908).

Return to vehicles, turn around, and head W on Tower Road.

36.85	0.9	Turn **R** on Palmer Hill Road.
37.45	0.6	Turn **L** on Silver Lake Road.
38.15	0.7	Turn **R** on N. Main Street at bottom of hill.
38.35	0.2	Proceed straight through caution light, now on NY 9N.

38.55	0.2	Bear **R** continuing on NY 9N.
40.45	1.9	"Lake Placid Granite" quarries entrance on R. The "granite" here is actually anorthosite.
40.55	0.1	Stickney Bridge road on L.
44.25	3.7	Turn **L** on Mill Hill Road in Hamlet of Jay.
44.55	0.3	Cross one-lane bridge over the East Branch of the Ausable River, turn **R**, and park in sandy area on the R side.
		Stop 4. ANORTHOSITE OF THE JAY DOME. Walk back across the bridge **(Beware of traffic!)** and descend the steep bank on the L to outcrops in the river. The river is usually quite low this time of year affording us good looks at several facies of anorthosite and a variety of structural features. Both leucocratic and gabbroic anorthosite are present, as well as a block of coarser gabbroic anorthosite. In one location, a thin layer of pyroxene- and oxide-rich ultramafic rock separates two anorthosite facies, and is offset by parallel small faults. The latter may have formed at relatively high temperatures; foliation in the anorthosite locally shows the effects of drag along the faults. They are subparallel to later, NE-trending brittle faults, some of which are occupied by unmetamorphosed diabase dikes. One such fault-cum-dike offsets a shallow-dipping mylonite zone in the anorthosite. A xenolith of calcsilicate rock in the anorthosite consists largely of diopsidic clinopyroxene. Numerous potholes are present in the outcrop surface. Walk back across the bridge and, if time permits, up the road beyond the parking area to a glacially polished and striated outcrop showing rouded blocks of coarse gabbroic anorthosite in finer grained, more leuococratic anorthosite.
		Return to vehicles and proceed S.
45.05	0.5	Ward Lumber Co. mill and store.
45.15	0.1	Turn **R** on Valley Road.
47.95	2.8	**R** again on Trumbel's Corners Rd.
48.65	0.7	Turn **L** on NY 9N in Upper Jay. Several exposures, of calcsilicates, mafic gneiss and contaminated anorthosites may be seen along Rt. 9N between Upper Jay and Keene.
54.45	5.8	Turn **L** at intersection of NY 9N and NY 73 at the Elm Tree Inn in Keene.
56.25	1.8	**L** on NY 9N going E toward Elizabethtown.
64.65	8.4	**Stop 5. JOTUNITE WITH XENOLITHS.** Park on R beyond the guard rails; cautiously cross the road and walk back to a small outcrop on the N side. The rock here is a jotunite containing numerous metasedimentary xenoliths and one xenolith of anorthosite. The metasedimentary rocks are diopside-rich calcsilcates, some with fine, millimeter to submillimeter-scale layering consisting of alternating pyroxene- and plagioclase-rich layers. The layering is normally straight but locally shows irregular folding or chaotic disruption. The general

appearance of the rocks is similar to that of stromatolite-bearing metasedimentary rocks in the Balmat area on the northwest Adirondack Lowlands. Is it possible that the layering here is of organic origin? What other processes might be responsible?

Carefully observe the foliation in the jotunite near the anorthosite xenolith. If this is, as it appears, a metamorphic foliation then it suggests that penetrative deformation may affect some rocks and not others. Beware of assuming that a rock that crosscuts foliation in another rock is necessarily younger!

Interestingly, jotunites in the Adirondack Highlands commonly form intrusion breccias, whereas granitoids, olivine metagabbro, and ferrogabbro do not. Why?

65.25 0.6 **Stop 6: "WOOLEN MILL" GABBRO, ANORTHOSITE, SYENITE.** Park on the L (north) side. The best exposures are the stream N of the road near the remains of an old dam. This stop provides another opportunity to study the characteristics and complexity of Adirondack metanorthosite and its associated lithologies. Fine-grained mafic granulites consisting of granoblastic plagioclase, clino- and orthopyroxene, garnet, ilmenite, and magnetite are of ferrogabbroic composition. This rock has been informally called the "Woolen Mill Gabbro". Here it intrudes the anorthosite as a network of thin, discontinuous dikes. At the upstream end of the outcrop, one of these terminates in a small bulb. More extensive exposures of this lithology are found in the roadcut on the S side of 9N just across from the parking area. A slightly coarser version of the same rock is exposed upstream on the opposite bank, in sharp contact with the anorthosite.

Also present are small dikes of coarse syenite, some with rows of pyroxene crystals along their contacts with anorthosite. Both these and the ferrogabbro appear to be intruded along fractures in the anorthosite, sometimes in the *same* fractures! (Which came first? Or are these composite dikes formed from two immiscible liquids?).

66.25 1.0 Intersection of routes NY 9 & 9N. The fastest way south is to turn **R** and go south on Rt.9 to Exit 30 of I-87. If you are going north, turn **L** on route 9N, north then east to exit 31 of I-87.

END OF TRIP