

**GEOLOGY AND MINING HISTORY OF THE BARTON GARNET MINE, GORE MT. AND THE NL
ILMENITE MINE, TAHAWUS, NY AND A REVIEW OF THE MACINTYRE IRON PLANTATION OF
1857**

WILLIAM M. KELLY
New York State Museum
3140 Cultural Education Center
Albany, NY 12230

ROBERT S. DARLING
Department of Geology
SUNY, College at Cortland
Cortland, NY 13045

INTRODUCTION

This field trip examines the geology and history of mining at two types of ore deposits, one a metal and one an industrial mineral. Both are strongly identified with the Adirondack Mountains of New York and both have histories that extend for more than a century. While mining activities began at both in the nineteenth century, only the Barton garnet mining venture has remained in continuous operation. Attempts, successful and unsuccessful, to exploit the ore at Tahawus occurred sporadically through the nineteenth and twentieth century. During this time the minerals that were the target and gangue at Tahawus essentially reversed roles.

BARTON GARNET MINE, GORE MT.

The Barton Mines Corporation open pit mine is located at an elevation of about 800 m (2600 ft) on the north side of Gore Mountain. For 105 years, this was the site of the world's oldest continuously operating garnet mine and the country's second oldest continuously operating mine under one management. The community at the mine site is the highest self-sufficient community in New York State. It is 16 km (10 mi) from North Creek and 8 km (5 mi) from NY State Route 28 over a Company-built road that rises 91 m (300 ft) per mile. This road, like others in the vicinity, is surfaced with coarse mine tailings. About eleven families can live on the property. The community has its own water, power, and fire protection systems. On the property are the original mine buildings and Highwinds, built by Mr. C.R. Barton in 1933 as a family residence.

Garnet is used in abrasive blasting, coated abrasives, metal, ceramic, and glass polishing, water filtration, waterjet cutting and has been used to remove the red hulls from peanuts (Fig. 1). Paint manufacturers add garnet to create non-skid surfaces and television manufacturers use it to prepare the glass on the interior of color picture tubes prior to the application of the phosphors. However, this latter use is decreasing with the advent of LCD and other flat screen technologies. Garnet, including Barton's garnet, has advantages relative to other abrasive materials. Garnet lacks toxic elements and is chemically inert. Garnet provides greater cutting speed, less dust, and lower volume requirements than competing abrasives. Overall, however, garnet comprises only a small portion (~2%) of the abrasives market (Fig. 2).

The markets currently served by Barton Mines Co. LLC are, in decreasing order, waterjet cutting, television glass lapping, finishes, and abrasive coatings. Abrasive airblasting and water filtration media are minor. Barton Mines supplies 10 plants that produce abrasive paper and cloth in New York, Virginia, Massachusetts, Michigan, Minnesota, Mississippi, Ohio, and Pennsylvania. Barton provides virtually all of the garnet exported by the United States (13,300 tons in 2005) (Evans and Moyle, 2008). Domestic garnet consumption was 50,300 tons in 2005 (Olson, 2006). In 2004, the price for crude concentrates ranged from \$50-150/t, refined garnet was \$60-400/t, and garnet used for waterjet cutting was \$300-600/t.

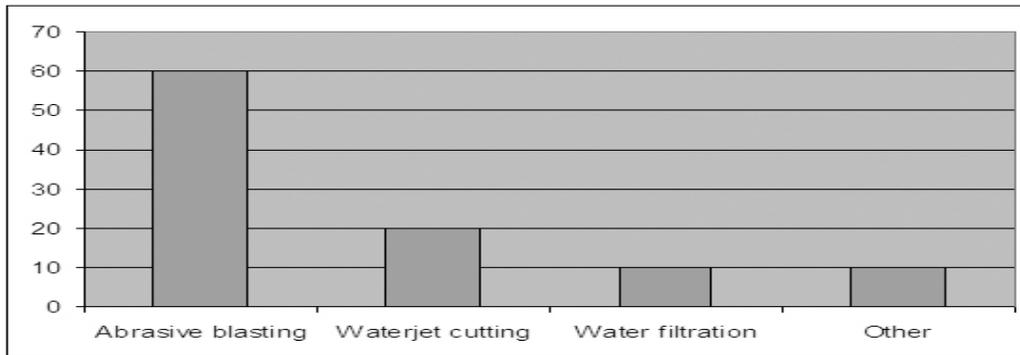


Figure 1. Chart showing principal uses of garnet, in percent, in the world (Olson, 2004)

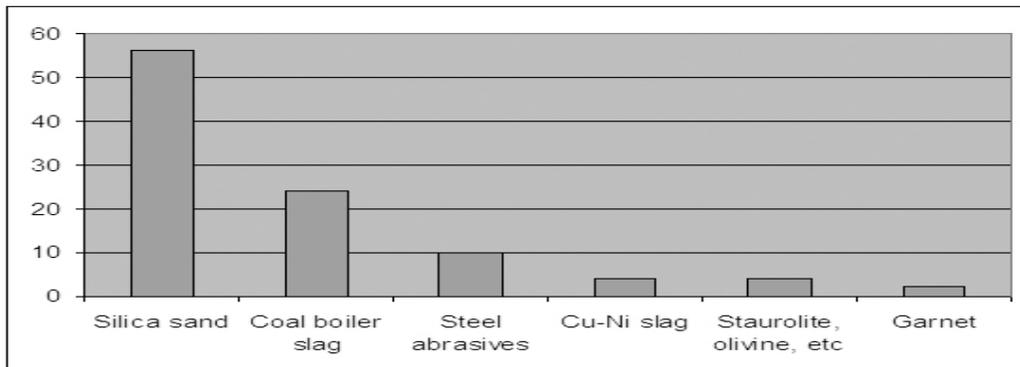


Figure 2. Chart showing U.S. abrasive demand, in percent.

Garnet has been designated as the official New York State gemstone. Barton produces no gem material but collectors are able to find rough material of gem quality. Stones cut from Gore Mountain rough material generally fall into a one to five carat range. A small number of stones displaying asterism have been found. Garnets from this locality are a dark red color with a slight brownish tint. Special cutting schemes have been devised for this material in order to allow sufficient light into the stone.

History

The early history of the Barton garnet mine has been compiled by Moran (1956) and is paraphrased below. Mr. Henry Hudson Barton came to Boston from England in 1846 and worked as an apprentice to a Boston jeweler. While working there in the 1850's, Barton learned of a large supply of garnet located in the Adirondack Mountains. Subsequently, he moved to Philadelphia and married the daughter of a sandpaper manufacturer. Combining his knowledge of gem minerals and abrasives, he concluded that garnet would produce better quality sandpaper than that currently available. He was able to locate the source of the Adirondack garnet stones displayed at the Boston jewelry store years before. Barton procured samples of this garnet, which he pulverized and graded. He then produced his first garnet-coated abrasive by hand. The sandpaper was tested in several woodworking shops near Philadelphia. It proved to be a superior product and Barton soon sold all he could produce.

H.H. Barton began mining at Gore Mountain in 1878 and in 1887, bought the entire mountain from the State of New York. Early mining operations were entirely manual. The garnet was hand cobbled *i.e.* separated from the waste rock by small picking hammers and chisels. Due to the obstacles in moving the ore, the garnet was mined during the summer and stored on the mountain until winter. It was then taken by sleds down to the railroad siding at North Creek whence it was shipped to the Barton Sandpaper plant in Philadelphia for processing. The "modern" plant at Gore Mountain was constructed in 1924. Crushing, milling, and coarse grading was done at the

mine site. In 1983, the Gore Mountain operation was closed down and mining was relocated to the Ruby Mountain site, approximately 6 km (4 mi) northeast, where it continues at present.

Mining and milling

The mine at Gore Mountain is approximately 2 km. in length in an ENE-WSW direction. The ore body varies from 15 m (50 ft) to 122 m (400 ft) and is roughly vertical. Mining was conducted in benches of 9 m (30 ft) using standard drilling and blasting techniques. Oversized material was reduced with a two and one-half ton drop ball. The ore was processed through jaw and gyratory crushers to liberate the garnet and then concentrated in the mill on Gore Mountain. Garnet concentrate was further processed in a separate mill in North River at the base of the mountain. Separation of garnet was and is accomplished by a combination of concentrating methods including heavy media, magnetic, flotation, screening, tabling and air and water separation. Processes are interconnected and continuous or semi-continuous until a concentrate of 98% minimum garnet for all grades is achieved (Hight, 1983). Finished product ranges from 0.6 cm to 0.25 micron in size.

Characteristics of Gore Mountain garnet

The garnet mined at Gore Mountain is a very high-quality abrasive. The garnets display a well-developed tectonic parting that, in hand specimen, looks like a very good cleavage. This parting is present at the micron scale. Consequently, the garnets fracture with chisel-like edges yielding superior cutting qualities. The garnet crystals are commonly 30 cm in diameter and rarely up to 1 m with an average diameter of 9 cm (Hight, 1983). The composition of the garnet is roughly 43% pyrope, 40% almandine, 14% grossular, 2% andradite, and 1% spessartine (Levin, 1950; Harben and Bates, 1990). Chemical zoning, where present, is very weak and variable (Luther, 1976). The garnet has been so well analyzed isotopically that it is frequently used as an $^{18}\text{O} / ^{16}\text{O}$ standard (Valley et al., 1995). Typical chemical analyses of the garnet are presented in Table 1. Hardness of the garnet is 7.5 and the average density is 3.95 gm/cm³.

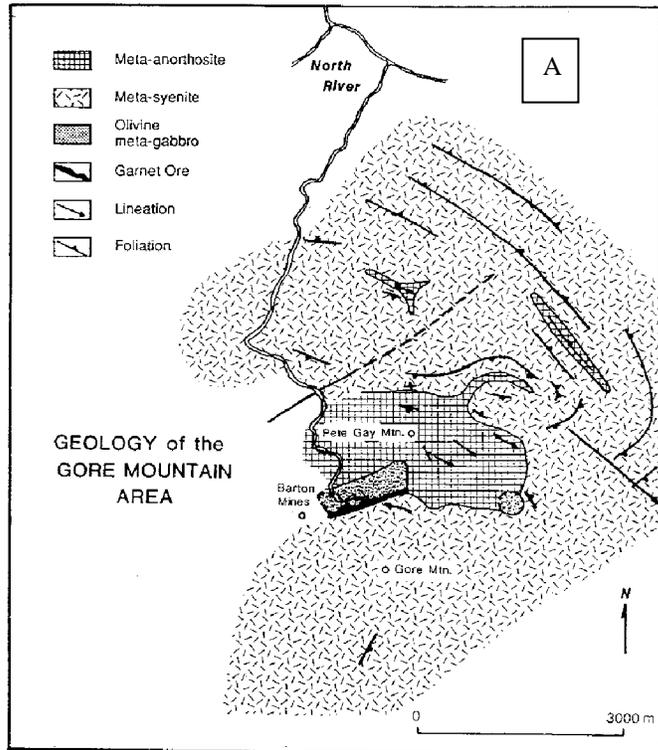
Table 1. Electron Microprobe analyses of Gore Mt. garnet (almandine-pyrope) normalized to 8 cations and 12 anions. * Calculated by charge balance (Kelly and Petersen, 1993).

<u>Oxide Weight Percent</u>	<u>#29</u>	<u>#41</u>
SiO ₂	39.43	39.58
Al ₂ O ₃	21.40	21.20
TiO ₂	0.05	0.10
FeO*	22.80	24.45
Fe ₂ O ₃ *	1.44	0.72
MgO	10.65	9.60
MnO	0.48	0.74
CaO	3.85	3.97
Na ₂ O	0.00	0.00
K ₂ O	<u>0.00</u>	<u>0.00</u>
Total	100.09	100.36

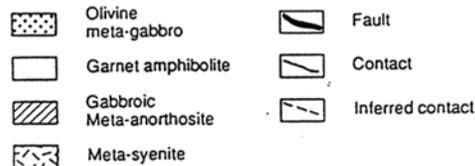
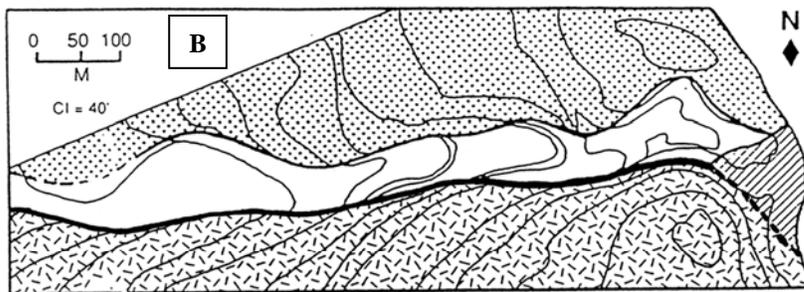
Geology

The garnet mine is entirely hosted by a hornblende-rich garnet amphibolite unit along the southern margin of an olivine meta-gabbro body (Fig. 3). The garnet amphibolite grades into garnet-bearing gabbroic meta-anorthosite to the east. To the south the garnet amphibolite is in contact with a meta-syenite; a fault occurs parallel to this contact in places.

Figure 3. Geologic maps of Barton garnet mine
(A.modified from Bartholome, 1956, B. Goldblum & Hill, 1992)



The olivine meta-gabbro bordering the ore zone is a granulite facies lithology with a relict subophitic texture. Preserved igneous features, faint igneous layering, and a xenolith of anorthosite have been reported in the meta-gabbro (Luther, 1976). Prior to metamorphism, the rock was composed of plagioclase, olivine, clinopyroxene and ilmenite. During metamorphism, coronas of orthopyroxene, clinopyroxene and garnet formed between the olivine and the plagioclase and coronas of biotite, hornblende and ilmenite formed between plagioclase and ilmenite (Whitney & McLelland, 1973, 1983). The contact between the olivine meta-gabbro and the garnet amphibolite ore zone is gradational through a narrow (1 to 3 m wide) transition zone. Garnet size increases dramatically across the transition zone from less than 1 mm in the olivine meta-gabbro, to 3 mm in the transition zone, to 50 to 350 mm in the amphibolite (Goldblum and Hill, 1992). This increase in garnet size coincides with a ten-fold increase in the size of hornblende and biotite, the disappearance of olivine, a decrease in modal clinopyroxene as it



is replaced by hornblende, and a change from green spinel-included plagioclase to white inclusion-free plagioclase (Goldblum and Hill, 1992). Mineralogy in the garnet amphibolite ore zone is mainly hornblende, plagioclase and garnet with minor biotite, orthopyroxene, and various trace minerals. In both the olivine meta-gabbro and the garnet amphibolite, garnet content averages 13 modal percent, with a range of 5 to 20 modal percent (Luther, 1976; Hight, 1983; Goldblum, 1988).

The garnet amphibolite unit is thought to be derived by granulite facies metamorphism of the southern margin of the olivine meta-gabbro. At the west end of the mine, a garnet hornblendite with little or no feldspar is locally present. This rock may represent original ultramafic layers in the gabbro (Whitney et al., 1989). In the more mafic portions of the ore body, the large garnet crystals are rimmed by hornblende up to several inches thick. Elsewhere, in less mafic ore, the rims contain plagioclase and orthopyroxene. Chemical analyses of the olivine meta-gabbro and garnet amphibolite show that the garnet ore was derived by isochemical metamorphism, except

for an increase in the H₂O and *f*O₂, of the olivine meta-gabbro (Table 2; Luther, 1976). A strong, consistent lineation and weak planar fabric coincide with the zone of large garnet crystals and are an important feature of the garnet ore zone (Goldblum and Hill, 1992). The lineation is defined by parallel alignment of prismatic hornblende crystals, elongate segregations of felsic and mafic minerals, plagioclase pressure shadows, and rare elongate garnet. The foliation is defined by a slight flattening of the felsic and mafic aggregates.

Origin of garnet

Although the garnet crystals in the ore zone at Gore Mountain are atypical in size, the modal amount of garnet is not unusually high for Adirondack garnet amphibolites. Garnet amphibolite that is texturally and mineralogically similar occurs elsewhere in the Adirondacks, usually on the margins of gabbroic rock bodies. The ore at the currently operating Barton Corporation mine at Ruby Mountain, for example, is of the same tenor but the garnets rarely are larger than 2.5 to 5 cm.

Petrologic studies (Buddington, 1939, 1952; Bartholome, 1956, 1960; Luther, 1976; Sharga, 1986; Goldblum, 1988; Goldblum and Hill, 1992) have agreed that the growth of the large garnets is related to a localized influx of water along the margin of the granulite facies olivine meta-gabbro body. The Gore Mountain garnets are chemically homogeneous suggesting that (a) the garnets grew under conditions in which all chemical components were continuously available and the (b) temperature and pressure conditions were uniform during the period of garnet formation. A zone of high *f*H₂O along the southern margin of the original gabbro body may have enhanced diffusion and favored growth of very large garnets and thick hornblende rims at the expense of plagioclase and pyroxene. Luther (1976) speculates that physical and chemical conditions were favorable for the growth of garnet but poor for the nucleation of garnet so that the garnet crystals that did nucleate grew to large size. The presence of volatiles, particularly H₂O, promotes the growth of large crystals by aiding transport of components. The formation of the garnets has been dated at *ca.* 1050 Ma (Mezger, *et al.*, 1992).

Recognition that the garnet ore body and deformation fabric coincide with the southern margin of the olivine meta-gabbro body led Goldblum and Hill (1992) to hypothesize that the high fluid flow required for growth of large garnet crystals was the result of ductility contrast at a lithologic contact during high-temperature shear zone deformation. The olivine meta-gabbro is a granulite facies rock with a poorly developed foliation and little evidence of ductile deformation. In the transition zone between the olivine meta-gabbro and the garnet amphibolite, increased ductile deformation resulted in grain-size reduction of plagioclase and pyroxene. Microstructures in plagioclase in the transition zone indicate plastic deformation, and the concurrent modal increase in hornblende indicates an influx of fluid. Fabric development and hydration are most apparent in the garnet amphibolite of the ore zone. According to Goldblum and Hill (1992), the olivine meta-gabbro remained competent and initially deformed by brittle processes along its southern margin while the adjacent feldspar-rich meta-syenite and gabbroic meta-anorthosite deformed plastically during deformation at amphibolite facies conditions. Initial grain-size reduction by cataclasis along the margin of the meta-gabbro allowed hydration and metamorphism to produce the garnet amphibolite. As the hydrated ore body replaced the olivine meta-gabbro, ductile deformation mechanisms replaced cataclasis. During metamorphism, the garnet amphibolite was likely a high-strain zone of reaction-enhanced ductility. Eventually, metamorphic reactions apparently outpaced the rate of deformation and grain coarsening impeded ductile deformation processes (Goldblum and Hill, 1992).

Inclusions in Gore Mountain garnet

Gore Mountain garnet hosts a number of inclusion types, the most common of which is acicular rutile. Many rutile needles are crystallographically controlled and the asterated specimens (Figure 4a) described earlier may be due to the orientation of these inclusions parallel to {111} of the garnet. Other common solid inclusions include pyrite, plagioclase, pyroxene, hornblende, ilmenite, apatite, and biotite (Valley, *et al.*, 1995).

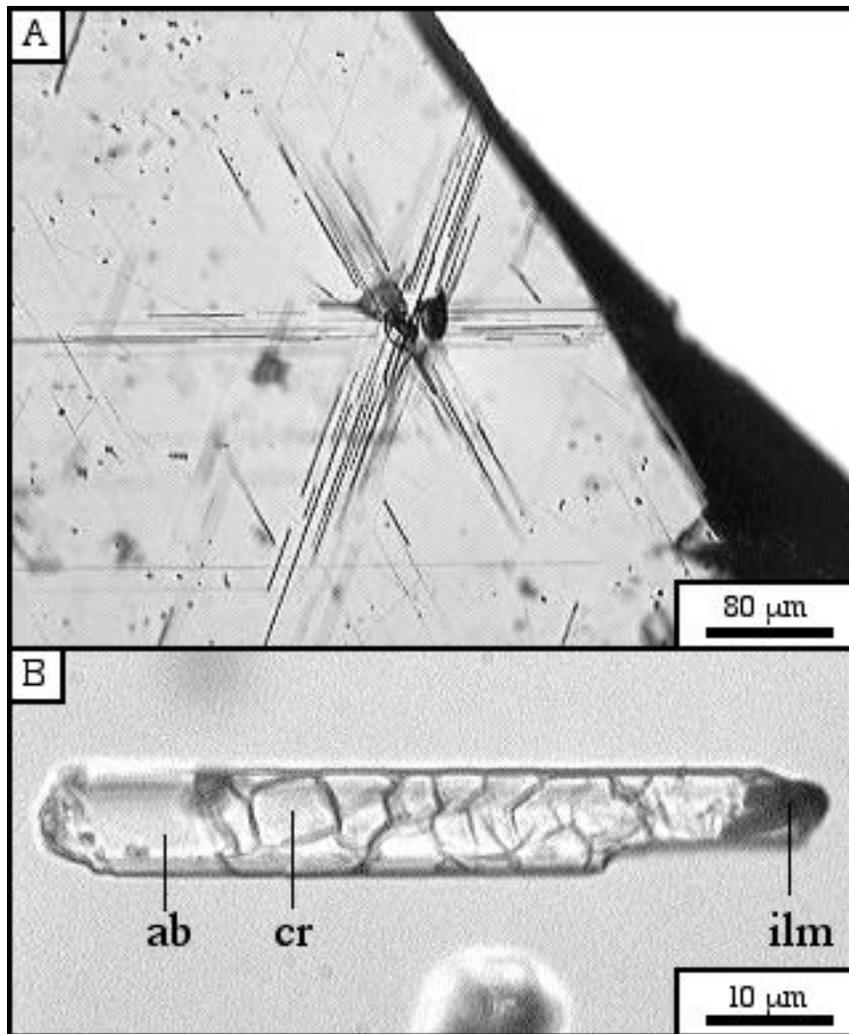


Figure 4. (a) Crystallographically-controlled rutile needles in garnet
(b) Cristobalite, ilmenite, albite inclusion

Darling et al. (1997) report a most unusual type of multiple solid inclusion containing the low pressure, very high temperature SiO_2 polymorph, cristobalite (Figure 4b). This phase is accompanied by albite and a small quantity of ilmenite. The cristobalite is easily recognized by its inherent fractures, formed by the 5% volume decrease upon transforming from the beta-phase at temperatures between 260 and 270°C. Darling et al. (1997) propose the cristobalite + albite + ilmenite inclusions began as small water-rich melt inclusions which then experienced diffusive loss of water. This led to an internal pressure decrease (under nearly isochoric, isothermal conditions) to the point where cristobalite, instead of quartz, crystallized in the melt inclusions. It should be noted that identical cristobalite-bearing multiple-solid inclusions also occur at the former Hooper and North River Mines (Charles et al., 1998) so their formation is not unique to Barton Mine garnet. The most remarkable outcome is that the cristobalite never reconstructively transformed to quartz even during protracted cooling from starting conditions of approximately 800°C. Darling et al. (1997) infer the absence of water was the primary reason for the preservation of cristobalite.

Fluid inclusions are rare in Gore Mountain garnet despite the importance of water in the formation of garnet amphibolite as well as large crystal sizes. Ironically, the most common fluid inclusion in Gore Mountain garnet is CO_2 -rich and is texturally secondary. These inclusions, like those in many other Adirondack rocks, most likely formed along the retrograde path following peak metamorphic conditions. Precisely how CO_2 -rich inclusions can

form in garnet (or more commonly quartz) is unknown as neither mineral is soluble in liquid CO₂. Two possible explanations include: 1) low temperature mineral growth from the aqueous portion of an immiscible H₂O-CO₂ fluid while trapping CO₂, or 2) diffusive loss of H₂O from an original mixed H₂O-CO₂ inclusion.

NL ILMENITE MINE, TAHAWUS, NY

History

The history of mining operations in the vicinity Tahawus extends from the early nineteenth century to the end of the twentieth. The following account is drawn from Stephenson (1945) and National Lead Company literature (Anon. 1963). Gradual expansion of industrial development in the United States in the nineteenth century drove exploration for mineral resources into increasingly "back-country" locations. Such was the case when the iron ore in the region around Sanford and Henderson Lakes was discovered by Europeans in 1826 (a Native American led them to the ore). They were purportedly led to the deposit over what is now the Indian Pass Trail. The ore mineral sought was magnetite. The original discoverers were not initially aware of the presence of ilmenite in the ore. Since 1826, great sums of money have been spent in attempts to bring the resource into production. The first and ultimately unsuccessful try was made by the original discoverers, Archibald MacIntyre, Duncan and Malcolm MacMartin, and David Henderson. Their first blast furnace was built in 1838 and a "new" furnace was constructed in 1854. However, the venture completely failed owing to a number of circumstances including the accidental killing of Henderson in 1845, a flood in 1856, an economic recession in 1857 and, most importantly, the presence of titanium in the ore and transportation difficulties.

Beginning in 1894, another attempt was made to exploit the ore as a source of iron. The MacIntyre Iron Company planned a railroad (never constructed) and did extensive diamond drilling. A crushing plant and concentrator were constructed in 1912-13 and ore was hauled over very bad roads to blast furnaces in Port Henry. However, there was insufficient interest in the deposit and it languished.

In 1941, the deposit was acquired by National Lead Company (later NL Industries, Inc.). Production began in 1942. The target mineral in this case was ilmenite. Iron (magnetite) was a co-product. In 1908, a French metallurgist working for the MacIntyre Co. discovered that titanium dioxide made an excellent white paint pigment. With the advent of World War II, TiO₂ became a critical strategic resource. It was used in paint, paper, rubber and ceramics but it was an essential raw material in chemical smoke screens. To bring the mine into production required the construction of 8.5 miles of road, a 42 mile power line from Ticonderoga, 29 miles of railroad from North Creek, housing for 180 families and 160 single men, schools, fire department, medical services, and recreational facilities. Over the years, 4,564 men and women worked at the mine.

The mine continued in production until 1982 when the closure of the NL ilmenite processing plant in New Jersey led to the closure of the mine. Magnetite concentrates continued to be shipped from stockpile until 1989. Attempts were made to use the magnetite as blast furnace feed stock but these were not particularly successful. The bulk of the magnetite was sold as ballast, for ferroconcrete, and most importantly, to coal producers for use in a slurry to separate coal from waste rock. The mine site was reclaimed in 2005-2006. Of the 11,000 acres owned by NL (now Kronos Worldwide, Inc.) most was purchased by the Open Space Institute with plans for eventual transfer to the State of New York. The lands will become part of the surrounding Adirondack Park. A total of more than 141 million tons of rock were removed during the course of mining to process sixty million tons of ore. From this ore, more than twelve million tons of ilmenite and seventeen million tons of magnetite were extracted. Thirty-one million tons of ilmenite and twenty-one million tons of magnetite remain.

Mining and milling

The ore in the most recent operation was blasted in forty-foot high benches, hauled to the mill in Euclid trucks where it was reduced from run-of-the-mine size (pieces up to four feet) to minus 7/16 inches by jaw and cone crushers. This product was further reduced to twenty-eight mesh by six foot by twelve foot rod mills. Magnetic separators then removed some of the magnetite which was sent to a sintering plant or stockpile. The ilmenite and remaining gangue minerals were sent to reciprocating tables which retained the heavy ilmenite behind riffles and discharged the lighter (silicate) particles as waste. This ilmenite concentrate was dried and subjected to a final magnetic separation after which it was sent to storage bins or loaded directly onto railroad cars for shipment to a

titanium pigment plant. The very fine grained fraction of the ground ore was separated by froth flotation. In this process, reagents in water are added to the feed stock in a processing tank which is agitated by air. The reagents coat the ilmenite only and cause the ilmenite particles to adhere to air bubbles and rise to the surface while the uncoated waste particles fall to the bottom of the tank and are removed. This fine grained ilmenite is collected in the froth on the top of the tank, then dried, loaded or stored.

Characteristics of the Tahawus ore

The ore deposits of the Tahawus region consist of roughly equal amounts of titaniferous magnetite and hemo-ilmenite with ilmenite being slightly more abundant. Lamellae of ilmenite in magnetite originated via subsolidous oxidation-exsolution (Buddington and Lindsley, 1964). Pleonaste spinel is a common exsolution phase in magnetite. Iron sulfides occur as accessory phases. Gangue minerals include plagioclase (10-20%), garnet (grossalm-and) 3-8%, ortho-and clinopyroxene (4-7%), hornblende (1-3%), biotite (\cong 1%) Heyburn, 1960). Other minor phases include apatite, prehnite, barite, orthoclase, scapolite, "leucoxene", epidote and quartz (Gross, 1968). Both titanomagnetite and hemo-ilmenite form abundant, small, rod-like inclusions in the plagioclase, making the feldspar appear black in hand specimen. The average composition of the titanomagnetite is $Mt_{81}Usp_{19}$ and of the hemo-ilmenite is $Ilm_{94}Hem_6$ (Kelly, 1979).

The Sanford Lake District ores occur in two major modes: (1) as lean or disseminated ore in gabbro (gabbroic ore) and (2) as rich ore generally located in anorthosite but locally in gabbro (anorthositic ore). The lean ore within gabbro displays a gradational contact with the host rock with which it is commonly conformably layered (Ashwal, 1978) while in anorthosite, the massive, rich ore has a sharp crosscutting relationship. The gabbro, which bears the lean ore, also has a crosscutting relation to the anorthosite. With the exception of nelsonitic rocks near Cheney Pond (discussed below), the P_2O_5 concentration is very low. Whole rock chemical analyses are given below.

	Tahawus <u>gabbro</u>	Tahawus <u>massive ore</u>	Woolen Mill <u>gabbro</u>
SiO ₂	39.04	4.59	45.59
TiO ₂	6.78	18.58	3.49
Al ₂ O ₃	13.09	5.48	14.23
Fe ₂ O ₃	19.09	nd	18.42
FeO	nd	66.37	nd
MnO	0.24	0.28	0.27
MgO	5.31	3.39	3.07
CaO	9.77	0.31	9.25
Na ₂ O	2.02	0.22	2.63
K ₂ O	0.66	0.09	0.79
P ₂ O ₅	0.23	0.01	1.26
V ₂ O ₅	nd	0.45	nd
H ₂ O	<u>0.03</u>	<u>0.01</u>	<u>0.70</u>
Total	96.26	100.06	100.14

nd = not determined

Geology and origin of the ore

Open pit mining and diamond drilling have demonstrated that the ore is concentrated in westward dipping lenses measuring 600-700 meters long and 150-300 meters wide. This configuration could be the result of crystal settling, intrusion, or accumulation of immiscible oxide-rich liquid. Late differentiates of the anorthosite liquid tend toward enrichment in iron-titanium oxides giving rise to rocks of increasingly ferrogabbroic composition along with mafic cumulates. The gabbro at Tahawus is similar to the Woolen Mill gabbro and other gabbros, which are typical of late anorthosite differentiates (Bohlen, *et al.* 1992). This suggests that the ores at Tahawus are the result of progressive differentiation from a gabbroic anorthosite parent and that, late in the differentiation process, the magma became so enriched in Fe and Ti that they either precipitate oxide cumulates (Ashwal, 1978)

or a (presumably immiscible) Fe-Ti liquid forms (Stephenson, 1945, Kelly, 1979). In the former case, the conformable oxide-rich layers represent cumulates and the cross cutting ore represents mobilized cumulates. In the later case, both the conformable and cross-cutting ore is due to oxide liquid. A third possibility is that magnetite and ilmenite begin to precipitate along with the silicate minerals that form the gabbro but continued fractionation might still result in an oxide liquid at a very late stage.

It has long been argued that liquid immiscibility could not have occurred in the Tahawus ore because of the lack of apatite in the rock (except at Cheney Pond, see below). However, Lindsley (1991) noted that phosphate and Fe-Ti oxides mutually enhance their solubility in silicate liquids. Apatite may not necessarily travel with the immiscible oxide liquid. The key role of apatite, then, may have been to enhance the concentration of an Fe-Ti-rich phase of the residual liquid until immiscibility occurs. The absence of apatite in the resulting ore may not be proof of the lack of immiscibility. Furthermore, it has been shown experimentally that the melting temperatures of Fe oxides are significantly reduced in the presence of carbon (Weidner, 1982). Consequently, the formation of liquid oxide melt at geologically reasonable temperatures is possible.

Cheney Pond nelsonite

Kolker (1980, 1982) describes an occurrence of nelsonite hosted by gabbro just southwest of the Cheney Pond test pit, 2 km west of the Tahawus mill site. This is one of two occurrences of nelsonite in the Adirondacks; the other is located 110 km to the southwest in the village of Port Leyden (Darling and Florence, 1995). Nelsonite near Cheney Pond contains approximately 44-52% magnetite, 4-18% ilmenite, and 24-31% apatite and is the same orebody as that described by Stephenson (1945) except the "gangue silicates" are properly identified as apatite (Kolker, 1982). The host gabbro contains plagioclase, orthopyroxene, clinopyroxene, garnet and abundant magnetite and ilmenite. It is petrographically similar to oxide-apatite gabbro norites (OAGN) described by Owens and Dymek (1992). Nelsonites are believed to form by magmatic immiscibility (Phillpotts, 1967; 1981) or by cumulate processes (Owens and Dymek, 2001), but in both cases the source rocks are either anorthosites or OAGN's. Both rocks occur in the Cheney Pond area but the chemical relationships between the anorthosites, OAGN's, and nelsonites, have not been determined.

Chronology of Tahawus ores

The Tahawus magnetite-ilmenite ores were dated by Silver (1969) and gave an essentially concordant age of 1000 +/- 13 Ma. Chiarenzelli and McLelland (pers. comm., 2002) dated a concentration of magnetite-ilmenite on Forest Road that passes along the north shore of Upper Saranac Lake and got a nearly concordant age of 998 +/- 10 Ma. Recent SHRIMP dating by Bickford and McLelland (pers. comm., 2002) have revealed the presence of abundant *ca.* 1000 Ma zircon overgrowths in *ca.* 1150 Ma anorthositic-gabbroic rocks. Overgrowths in granitoid rocks are generally not so young and cluster around 1050 Ma. McLelland suggests that the explanation for the 1000 Ma ages in the mafic rocks rests upon the fact that they - and the ores - are rich in ilmenite in which Zr is a proxy for Ti.

When ilmenite crystallizes from magma, it accepts small quantities of Zr as a substitute for Ti. Titaniferous pyroxene behaves similarly. Upon cooling from magmatic temperatures, the Zr will tend to reside metastably in the ilmenite unless a pulse of activation energy occurs. Post-1150 Ma there were two such pulses: Hawkeye Granite heating at *ca.* 1100 Ma followed by the Ottawa Orogeny at 1090-1030 Ma. Both of these were high temperature events and tectonism may have been insufficient to promote widespread exsolution at these high temperatures. Notwithstanding, the common occurrence of 1050 rims and discrete metamorphic grains attests to liberation of Zr either by exsolution or more likely by the reaction $\text{plag} + \text{opx} + (\text{mgt-ilm}) = \text{gt} + \text{cpx} + \text{SiO}_2$ (McLelland, Appendix A, IGCP-304 Guidebook, 1992, Bohlen (ed.)). The involvement of ilmenite as a reactant releases Zr that combines with the SiO₂ to form zircon. In ilmenite-rich rocks, especially the ores, the plagioclase and orthopyroxene are scarce so this reaction is a minor factor and Zr remains fixed. After 1050, the area cools down and Zr becomes increasingly metastable in the ilmenite. At ~ 1000 Ma a late orogenic but low relatively temperature pulse hits the area and Zr exsolution takes place, probably in the presence of SiO₂-bearing hydrothermal solutions. It is at this time that the 1000 Ma overgrowths form. This late pulse is recorded on the Grenville Front Tectonic Zone, in the Green Mts. (Stamford Granite), and in the eastern

Grenville Belt where it is referred to as the Rigolet Pulse (Rivers, 1997). McLelland (pers. comm., 2002) proposes that the ilmenite-rich rocks are dating this event due to the factors described above.

ADIRONDACK IRON AND STEEL COMPANY

The "new furnace" at Tahawus

The word "plantation" connotes to most people a large antebellum agricultural operation located in the southeastern United States where cotton or sugar cane might have been the principal product. However, the term can equally be applied to certain isolated, more or less self-contained, communities built around iron production in the Pennsylvania, New York and elsewhere. One such example is the community of Tahawus and the operations of the Adirondack Iron and Steel Company from about 1830 until 1857. The requirements of blast furnace technology of the era dictated that ore, water power and vast amounts of fuel be located in close proximity. This generally dictated that the facilities be located in rural, if not remote, areas. The Adirondack Iron and Steel Company works were located on 106,000 acres of forested land, forty-five miles west of Lake Champlain near the source of the Hudson River but over 100 miles north of the limit of navigability. The Town of Adirondac (sic) was built entirely by the Company. It consisted of a church and school, twenty-five houses, a massive boarding house, ice house, carpenter shop, blacksmith shop, saw mill, grist mill and power house (Seely, 1978, 1981). Two farms provided some of the staples needed by the residents such as hay, barley, potatoes, sheep and cattle but due to the climate, flour, salt pork and everything else to supply the community had to be imported from Albany. The ore deposits were at the surface, actually outcropping in the Hudson River and surrounding the community. The ore was mined by open-pit methods. The blast furnace(s) were supported by charcoal kilns, a puddling furnace, magnetic and wet ore separators, and a not-very-successful cast-crucible steel plant (Seely, 1981).

Two blast furnaces were constructed, both charcoal fueled, fed by wooden charging bridges. The first was in operation in 1844 and the second was constructed in 1854. The second furnace, the "new furnace", was sixty feet (including chimney) high and had a hotter blast than the first, a requirement necessitated by the titanium content of the ore. This furnace featured ore stamps on the bridge to reduce the size of the feed stock and a hot blast stove to preheat the blast air stream (Fig. 5). Water power was used at both installations (Fig.6). A dam was key to increase storage capacity. The new furnace had a dam 180 feet long across the Hudson River that stood twenty-five feet high. Because of the large loss of power in line-shaft transmission, the furnace has to be close to the water wheel.

All of these features, the community, the materials, the power supply and the layout of the operation are characteristic of a charcoal iron works of the 19th century. The Adirondack Iron and Steel Company was a true iron plantation. The owners spent about \$500,000 on the project and lost it all. The titaniferous quality of the ore and the ever-envisioned, never-built railroad connection to the property contributed greatly to their downfall.

The second of the two blast furnaces built by the Adirondack Iron and Steel Company stands in outstanding condition. It is the most intact iron furnace in the northeastern United States and arguably, in the world (Youngken, 1989). While the iron industry in general has a long history of consuming its past (old technology is fed to the furnace as new technology is introduced) the circumstances of the failure and closing of this operation led to much better preservation. In a short span of time three events transpired which were fatal to the company. First, one of the principal and very active owners, David Henderson, was accidentally killed by an abdominal gunshot wound. Secondly, a flood destroyed the dam at the "lower works" allowing an artificial lake to drain. This lake had been used to move supplies and pig iron by water for several miles downstream from the furnace site. Finally, a "financial panic", i.e. an economic recession, in 1857 caused the mine and furnace to cease operations. The furnace was idled. The community dissipated. The facility stood, essentially undisturbed and un-scraped, for nearly 150 years.

Even though the Adirondack Iron and Steel Company was located in a very remote part of the mountains, the owners clearly kept abreast of iron technology innovations that occurred in Britain and elsewhere in the United States. Some of these innovations, such as a hot blast stove, were added to the Company's equipment within just

few years introduction into the US from England. The new furnace shows many such technological improvements (Fig. 7).

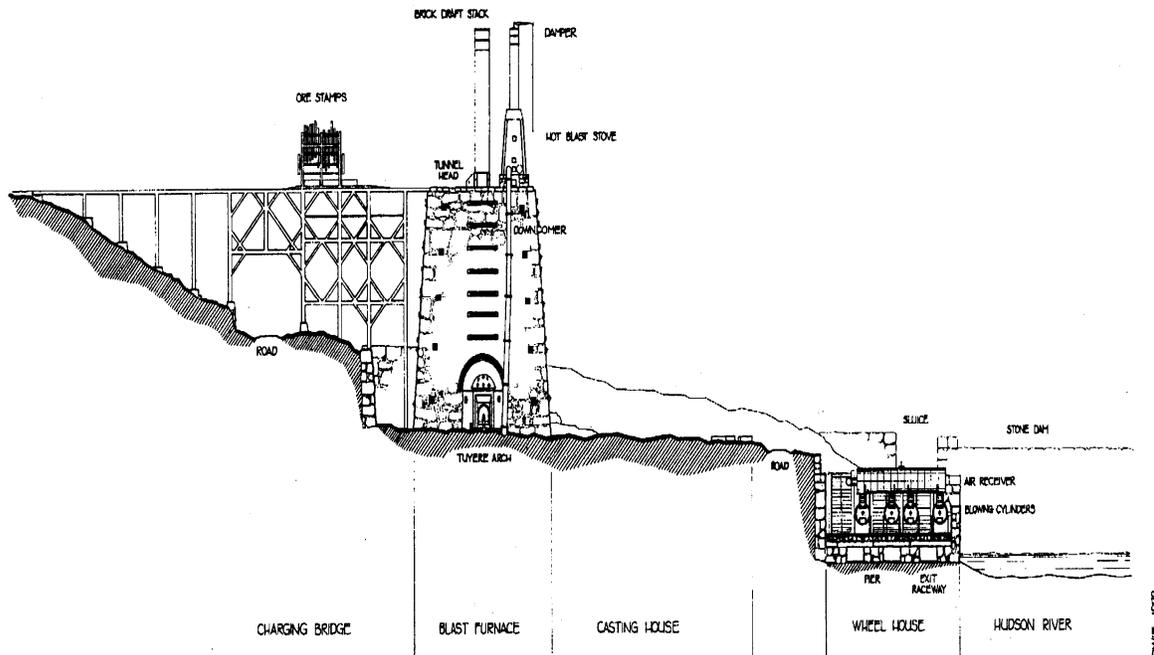


Figure 5. Partially restored sectional view of the "new" furnace and wheel house. (Seely, 1978)

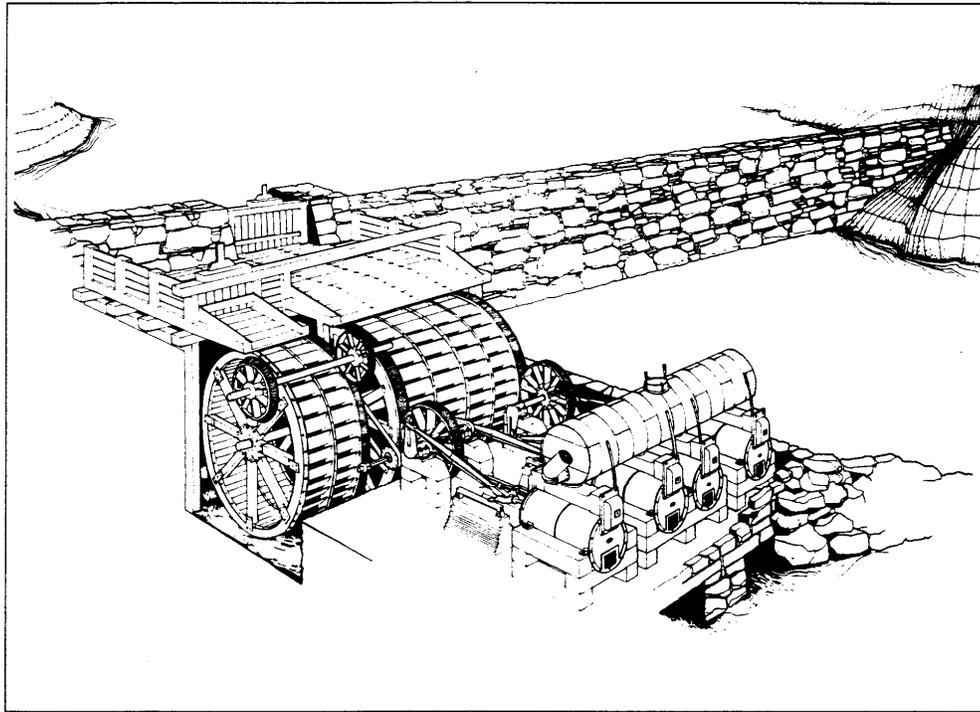


Figure 6. Reconstruction of the dam and blowing engine of the "new" furnace.(Seely, 1978)

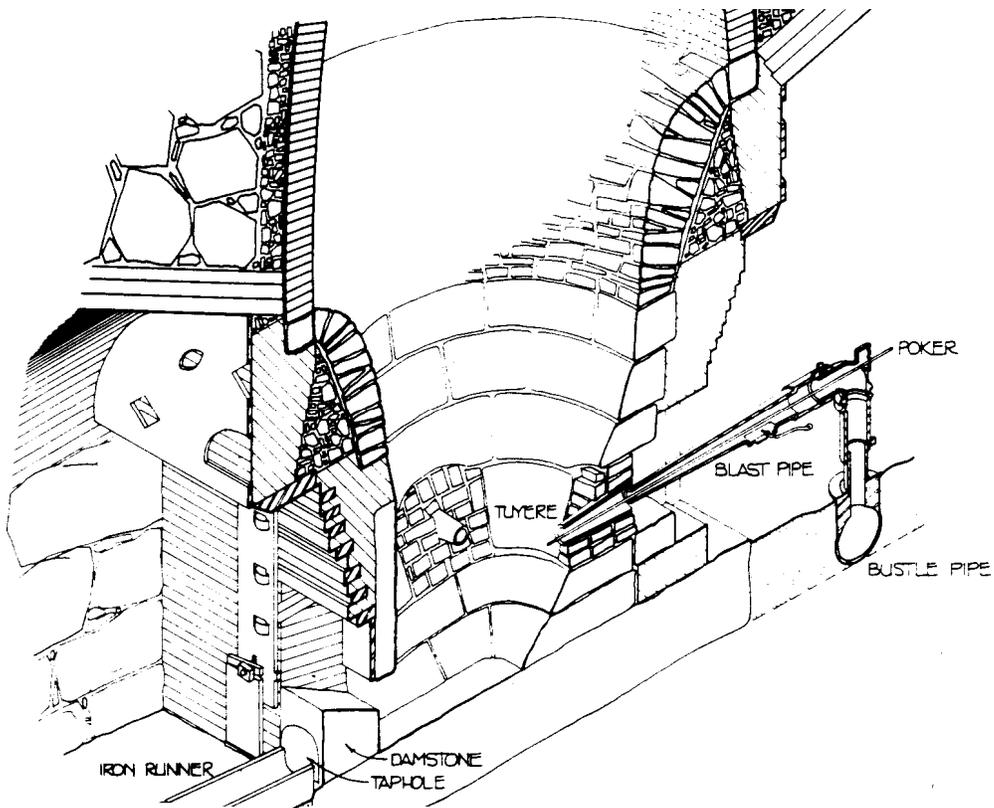


Figure 7. Isometric drawing of "new" furnace, Adirondack Iron & Steel Co.(Seely, 1978)

Many of these first appeared in iron furnaces using mineral fuels in Pennsylvania. Although the owners of the Adirondack Iron and Steel Company recognized that the importation of coal was impossible, they did adapt their charcoal-burning furnaces with up-to-date improvement. First of all, the height of the stack new furnace was forty-five feet with a brick chimney topping that. The old furnace probably was originally constructed at twelve to fifteen feet, and eventually increased to thirty to thirty-five feet. The bosh diameter of the new furnace is twelve feet (seven feet in old furnace). The new furnace had a top-mounted hot-blast stove to increase the temperature of the blast air from ambient to 400-600°F. The old 1844 furnace had a hot blast stove sitting beside it on the ground, and then located on top in 1845. This idea was only introduced in US from Britain in 1840, demonstrating the company's commitment to new technology. Not surprisingly, the introduction of one new technological development drives others. The hotter furnace caused damage to the cast iron tuyeres so these had to be water cooled. The downcomer pipe, carrying hot air from the stove, had to be upgraded to inch-thick cast iron from galvanized sheet metal to accommodate the hot blast. The stack was reinforced with wrought iron bars to improve stability. These bars doubtless enhanced the preservation of the stack. In order to increase the pressure of the blast air, double acting cylinders were installed with adjustable cranks that could vary the stroke from thirty-six to sixty-six inches.

A visit to the site of the new furnace offers a glimpse into an industry that flourished a century and a half ago. The site of the new furnace was cleared and documented in the late 1970s under the auspices of the Historic American Engineering Record Program. NL Industries was closely involved in this study. Although the forest has reclaimed the site, much of the equipment is still well exposed. Since the transfer of the property from Kronos to the Open Space Institute, archeologists from the NYS Department of Conservation and the NYS Museum have cleared the site and begun documentation and restoration.

REFERENCES

- Anonymous, 1963, National Lead Company – Titanium Division, Macintyre Development, history and development: 13pp.
- Ashwal, L.D., 1978, Petrogenesis of massif-type anorthosites: Crystallization history and liquid line of descent of the Adirondack and Morin complexes: PhD Thesis, Princeton Univ.,136p.
- Austin, G.T., 1993a, Garnet: Mining Engineering, v.45, no. 6, p. 569-570.
- Austin, G.T., 1993b, Garnet (Industrial): Mineral Commodity Summaries 1992, p. 68-69.
- Bartholome, P.M., 1956, Structural and petrologic studies in Hamilton County, NY: Unpubl. Ph.D. Thesis, Princeton University, 188 p.
- Bartholome, P.M., 1960, Genesis of the Gore Mt. garnet deposit, New York: Economic Geology, v. 55, no.2, p. 255-277.
- Bohlen, Stephen, McLelland, James, Valley, John, and Chiarenzelli, Jeffrey, 1992, Petrology and Geochronology of the Adirondack Mountains: A Critical Look at a Classic Granulite Terrane and its Associated Anorthosite-Mangerite-Charnockite-Granite (AMCG) Suite: IGCP-304, pp. 96-98.
- Buddington, A.F., 1939, Adirondack igneous rocks and their metamorphism: Geol. Soc. Amer. Mem. 7, 295 p.
- Buddington, A.F., 1952, Chemical petrology of metamorphosed Adirondack gabbroic, syenitic, and quartz syenitic rocks, New York: Amer. Jour. Sci. Bowen Volume, p. 37-84.
- Buddington, A.F., and Lindsley, D.H., 1964, Iron-titanium oxide minerals and synthetic equivalents: J. Petrol, v.5, pt. 2, pp.100-128.
- Charles, M.A., Gordon, J.H., Jr., Walter, P.J., and Darling, R.S., 1998, More cristobalite in Adirondack garnet: Geological Society of America, Abstracts with Programs, v. 30, p. 10.
- Darling, R.S., Chou, I-M., and Bodnar, R.J., 1997, An occurrence of metastable cristobalite in high pressure garnet granulite: Science, v. 276, p. 91-93.

- Darling, R.S., and Florence, F.P., 1995, Apatite light rare earth chemistry of the Port Leyden nelsonite, Adirondack Highlands, NY: Implications for the origin of nelsonite in anorthosite suite rocks: *Economic Geology*, v. 90, p. 964-968.
- Dymek, R.F., and Owens, B.E., 2001, Petrogenesis of apatite-rich rocks (nelsonites and oxide-apatite gabbroanorthosites) associated with massif anorthosites: *Economic Geology* v. 96, p. 797-815
- Evans, J.G., and Moyle, P.R., 2008, U.S. Industrial Garnet: Chapter L of Contributions to Industrial-Mineral Research, J.Bliss, P. Moyle, K. Long, eds., USGS Bull. 2209-L, 54p.
- Goldblum, D.R., 1988, The role of ductile deformation in the formation of large garnet on Gore Mountain, southeastern Adirondacks: Unpubl. M.A. Thesis, Temple University, 108 p.
- Goldblum, D.R., and Hill. M.L., 1992, Enhanced fluid flow resulting from competency contrasts within a shear zone: the garnet zone at Gore Mountain, NY: *Jour Geol.* v. 100, p. 776-782.
- Gross, S.O., 1968, Titaniferous ores of the Sanford Lake District, New York: *in Ore Deposits of the United States, 1933-1967*, Vol. 1, The Graton-Sales Volume, Ridge, J.D., (ed.), AIME, pp. 104-154.
- Harben, P.W., and Bates, R. L., 1990, Garnet: *in Industrial Minerals: Geology and World Deposits*, Metal Bulletin Plc., London, p. 120-121.
- Heyburn, M.M., 1960, Geological and geophysical investigations of the Sanford Hill ore body extension, Tahawus, NY: MS Thesis, Syracuse Univ., 58p.
- Hight, R.P., 1983, Abrasives: *in Industrial Minerals and Rocks*, S.J., LeFond, ed., Volume I, 5th Edition, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., pp. 11-32.
- Kelly, W.M., 1979, Chemistry and genesis of titaniferous magnetite and related ferromagnesian silicates, Sanford Lake Deposits, Tahawus, NY: PhD Thesis, Univ. of Massachusetts, 181p.
- Kelly, W.M., and Petersen, E.U., 1993, Garnet ore at Gore Mountain, NY: *in Selected Mineral Deposits of Vermont and the Adirondack Mountains*, E. U. Peterson, ed., Soc. Econ. Geol. Guidebook Series, v. 17, p. 1-9.
- Kolker, Allan, 1980, Petrology, geochemistry and occurrence of iron-titanium oxide and apatite (nelsonite) rocks: MS Thesis, Univ. of Massachusetts, 156p.
- Kolker, A., 1982, Mineralogy and geochemistry of Fe-Ti oxide and apatite (nelsonite) deposits and evaluation of the liquid immiscibility hypothesis: *Economic Geology*, v. 77, p. 1146-1158.
- Levin, S., 1950, Genesis of some Adirondack garnet deposits: *Geol. Soc. Amer. Bull.* v.61, p. 516-565.
- Lindsley, D.H., 1991, Origin of Fe-Ti deposits in the LAC: IGCP-290 Abstracts, Colgate Univ., Hamilton, NY, p.5.
- Luther, F.R., 1976, The petrologic evolution of the garnet deposit at Gore Mountain, Warren County, NY: Unpubl. Ph. D. Thesis, Lehigh University, 224 p.
- Mezger, K, Essene, E. and Halliday, 1992, Closure temperatures of the Sm---Nd system in metamorphic garnets: *Earth Planet. Lett.*, v.113, p.397-409.
- Moran, R., 1956, Garnet Abrasives: An 80 year history of the Barton Mines Corporation: *Business Biographies* New York, 47p.
- Owens, B.E., and Dymek, R.F., 1992, Fe-Ti-P rocks and massif anorthosites: Problems of interpretation illustrated from the Labrieville and St-urbain plutons, Quebec: *Canadian Mineralogist*, v. 30, p. 163-190.
- Olson, D. W., 2004, Garnet, industrial: *Minerals Yearbook 2004*, v.1, p. 29.1-29.4.
- Philpotts, A.R., 1967, Origin of certain iron-titanium oxide and apatite rocks: *Economic Geology*, v. 62, p. 303-315.
- Philpotts, A.R., 1981, A model for the generation of massif-type anorthosites: *Canadian Mineralogist*, v. 19, p. 233-253.
- Sharga, P.J., 1986, Petrologic and structural history of the lineated garnetiferous gneiss, Gore Mountain, New York: Unpubl. M.S. Thesis, Lehigh University, 224 p.
- Seely, B.E., 1978, Adirondack Iron and Steel Company, New Furnace, 1849-1854,: *Historic American Engineering Record Survey Report NY-123*, US Dept of Interior, US Govt. Printing Office.
- Seely, B. E., 1981, Blast furnace technology in the mid-19th century: A case study of the Adirondack Iron and Steel Company: *Jour. Soc. Ind. Archeol.*, v. 7, no. 1, pp.27-54.
- Stephenson, R. C., 1945, Titaniferous magnetite deposits of the Lake Sanford Area, New York: *NYSM Bull.* 340, 95pp.

Silver, Lee, 1969, A geochronological investigation of the anorthosite complex, Adirondack Mts., New York: in Isachsen, Y. (ed.), Origin of Anorthosites and Related Rocks, NYSM Mem. 18, p.233-252.

Valley, J.W., Kitchen, N., Kohn, M.J., Niendorf, C.R., and Spicuzza, M.J., 1995, UWG-2, a garnet standard for oxygen isotope ratios" Strategies for high precision and accuracy with laser heating: Geochimica et Cosmochimica Acta, v. 59, p. 5223-5231.

Weidner, J.R., 1982, Iron-oxide magmas in the system Fe-C-O: Canadian Mineralogist, v. 20, p. 55-566.

Whitney, P.R., and McLelland, J.M., 1973, Origin of coronas in metagabbros of the Adirondack Mountains: Contrib. Mineral. Petrol., v. 39, p. 81-98.

Whitney, P.R., and McLelland, J.M., 1983, Origin of biotite-hornblende-garnet coronas between oxides and plagioclase in olivine metagabbros, Adirondack region, NY: Contrib. Mineral. Petrol., v. 82, p. 34-41.

Whitney, P.R., Bohlen, S.R., Carl, J.D., deLorraine, W., Isachsen, Y.W., McLelland J.D., Olmsted, J.F., and Valley, J.W., 1989, The Adirondack Mountains - a section of deep proterozoic crust: 28th International Geological Congress Field Trip Guidebook T164, American Geophysical Union, Washington, DC, 63 p.

Youngken, J.M., 1989, A blast from the past: Adirondack Life, Sept/Oct., pp.32-38.

ROAD LOG

The Gore Mountain mine of the Barton Mines Corporation is generally open seasonally for visitors. However, it is suggested that visitors call in advance to be sure the mine is open. Arrangements for group tours at any time should be made through Barton Mines Corp., North Creek, NY 12853, (518) 251-2296. The mine at Tahawus and the gate on the road to the development pit at Cheney Pond, currently owned by Kronos Worldwide, Inc., Houston TX, are not open to visitors without prior permission. For information, call (518) 582-2601.

This trip log begins at the Warrensburg exit (23) of the Northway, Route 87. From Lake George Village, travel north on Rt. 87 to reach Exit 23.

	<u>Mileage</u>	<u>Cumulative mileage</u>
Travel north on Rt. 87 to Warrensburg, Exit 23	0	0
Go to end of exit ramp, turn left	0.3	0.3
Go to traffic light at NYS Rt. 9 north, turn right	0.1	0.4
Travel through Warrensburg on Rt. 9		
Traffic light, go straight	0.2	0.6
Traffic light at Rt. 418, go straight	0.6	1.2
Traffic light at fork, fork to right on Rt. 9	0.5	1.7
Travel Rt. 9 north to intersection with NYS Rt. 28,		
Turn left on Rt. 28 west	2.9	4.6
Blinker at Rt. 8 intersection, go straight	11	15.6
Intersection with Rt. 28N, go straight	6.6	22.2
Turn left on Barton Mine Road	4.6	26.8
Travel to end of Barton Mine Road	5	31.8

Note: the intersection of Barton Mine Road and Rt. 28 is marked by a small cluster of buildings. Among these is Jasco's mineral shop. On the east side of Rt. 28 facing south there is a sign opposite Barton Mine Road indicating the Barton Mine (Gore Mt.) mineral shop.

STOP 1. BARTON MINES, GORE MT. (1.5-2 hours) Note: there is a charge of \$1.00 – 2.00 per pound of material collected, payable at the mineral shop. There is also a charge to visit the mine as a tourist. The cost is usually reduced for school groups. This NYSGA trip will visit the No. 4 pit of the Gore Mt. mine. Visitors are normally escorted into the No. 1 pit, the earliest and lowest, which was developed in the garnet hornblendite. The No. 4 pit offers access to the olivine gabbro protolith of the ore in addition to the garnet ore per se. Proceeding down the access road on the north side of the pit takes the visitor across the contact zone between the protolith and the ore. In a matter of a few meters, the rock changes from altered olivine gabbro to garnet amphibolite. Garnets appear in the rock and increase in size and abundance over a very short distance. The

texture and minerals of the olivine gabbro disappear. Description of the ore is presented in the text above. The opposite (south) side of the mine is in a “syenitic” gneiss, separated from the ore by a vertical fault. Minor granitic pegmatite occurs at the contact with the fault.

Travel back to Rt. 28	5	36.8
Turn right at stop sign, go to Rt 28N at North Creek	6.6	43.4
Turn left on Rt 28N, go straight at 4-way stop	0.1	43.4
Turn right at Blue Ridge Road	21.5	64.9
Note: Sign for NL Ind., MacIntyre Development and sign for High Peaks Wilderness Area		
Turn left at Tahawus Road	1.1	66
Turn left at Upper Works Road	6.5	72.5
Proceed to dirt road to Cheney Pond	0.6	73.1
Boulders on right, gate on left		

STOP 2. KRONOS Worldwide, INC., CHENEY POND DEPOSIT (1.5-2 hours)

At this stop, examine the large boulders that block the dirt roads on the east and west side of the main road. Both “gabbroic” (disseminated) and “anorthositic” (massive) ore types are displayed here. The massive ores contain xenoliths of anorthosite and xenocrysts of plagioclase derived from the anorthosite, attesting to the intrusive nature of this ore. Garnet reaction rims occur on both the xenoliths and xenocrysts. Deformed (sheared) and relatively undeformed representatives of the host rocks are present. Minerals are: blue-gray plagioclase (~An₄₅) megacrysts, white, fine grained plagioclase matrix (~An₂₈), magnetite, ilmenite, garnet, amphibole and clinopyroxene. Sulfide mineralization is minor and late stage.

Walk (or drive) up the old haul road about 1km to the prospect pit developed in the Cheney Pond deposit. This is entirely disseminated ore. However, a great deal of “massive” ore of low grade has been hauled to this site to build the road so confusion regarding the exact source of the ore is possible. Sampling is recommended along the haul road.

South of the top of the pit at Cheney Pond an overgrown logging road leads to the left into the woods. Follow this road about 75 m to a prospect pit, perhaps 7 meters across, on the right. This prospect was developed in nelsonite, although the identity of the apatite was not recognized when the pit was excavated.

Return to cars. Proceed north on Upper Works Road	2.0	75.1
Furnace stack is on the right, by the edge of the road, wheel house is close to the river.		

STOP 3. ADIRONDACK IRON AND STEEL CO. "NEW" FURNACE (1 hour)

Please take only photographs at this stop. Do not take artifacts as souvenirs. Visible at the present time are the furnace stack, tuyere arches and tuyeres, casting arch, slag piles, and the entire contents of the wheel house with cross-heads, blowing tubs, and manifold more or less intact and in working position. Of the dam, wooden water wheel and casting house, little remains. Description given in text above.