# MINING HISTORY, MINERALOGY AND ORIGIN OF THE GNEISS (GRANITE)-HOSTED Fe-P-REE AND Fe OXIDE AND GABBRO-HOSTED Ti-Fe OXIDE DEPOSITS FROM THE MINEVILLE-PORT HENRY REGION, ESSEX COUNTY, NY

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"*…genesis of these important ore bodies in Northern New York may reach the conclusion that there is a hopeless disagreement among those who have studied these deposits" (Alling, 1925)*

## INTRODUCTION

New York State was a significant supplier of iron ore used in developing the resources and industries of the United States through the first part of the 20th century. The most important regions with iron deposits in the Adirondack Mountains are the northwestern area extending from Jefferson County into St. Lawrence County that includes the Antwerp-Keene hematite belt (Sterling and Caledonia mines) and the Jayville and Clifton mines; the central region with the Benson mines (St. Lawrence County) and Tahawus (Essex County); and the northeastern region with the Mineville-Port Henry-Fisher Hill group of mines (Essex County), and Ausable and Lyon Mountain mines (Clinton County). The earliest discoveries and mining operations of iron ores in the Adirondack Mountains were in the northeastern part (Linney 1943).

Iron ore was mined on the northeastern side of the Adirondack Mountains between Lake Champlain and the Adirondacks as early as 1804 (Birkinbine 1890). At the end of the 19th century three main areas were mined for iron in this region: Mineville-Port Henry-Fisher Hill, Chateaugay Mine at Lyon Mountains and Crown Point. The Mineville-Port Henry-Fisher Hill mines were considered "to represent one of the greatest magnetite deposits in the world" at that time (Anderson and Jones 1945). The first record of mining in the Mineville-Port Henry was in 1775 at a location that later came to be called Cheever Mine (Farrell 1996), but the first lease reported for this mine has been given later in 1820 (Smock 1889). The Mineville-Port Henry Iron Mining District had a cyclical pattern of boom and bust in its long mining history that spanned over 150 years. The various mines were repeatedly opened and then shutdown only to be reopened later depending on world events, economic changes and ownership's interests.

The Mineville-Port Henry mines were important and continuous iron producers, but they were also known for their apatite by-product and for the beauty and specific forms of the magnetite crystals that can still be seen today in many museums.

In this field trip we will examine the mineral composition and texture of the iron ore, the characters of the country and host rocks, and the relationships between magnetite ore and the host rock from the Craig Harbor, Cheever, Pelfshire, Mineville (the waste dumps of the Clonan and Bonanza pits), and the Barton Hill mines (Essex County).

## MINING HISTORY

Although the presence of iron ore was known since 1775, the first significant operating mine in the Mineville district was the Cheever Mine, located north of Port Henry, which was opened in 1820 by Charles Fisher. Soon thereafter, the same owner started the works for the Fisher Hill Mine that was worked intermittently until 1893;

later exploration in the 1920's proved that the Fisher Hill ore body would yield at least 40,000,000 long tons of ore and in 1941 it began operations as a Defense Plant Corporation project of the Republic Steel Corporation (Anderson and Jones 1945).

The Mineville district produced two distinct varieties of iron ore (Birkinbine 1890): magnetite-apatite and magnetite-silicate ore. The magnetite-apatite ore was produced from what was called the "Old Bed" and the magnetite-silicate ore came from the "New Bed". These names were applied to the ore mined from different mining works. The name "Old Bed" was derived from the initial opening made in 1824 at the eastern end of the Sanford Pit. In 1829 the "Old Bed" was mined by the Ore Bed Company at the Sanford Pit and the 21 Mine. It was thought to represent a series of lenses "lying en echelon, or nearly parallel, of varying thickness and dip" (Birkinbine 1890). New mine works were made northwest of the "Old Bed" and produced magnetite-silicate ore. These works opened the "New Bed" along a large area. The "New Bed" was apparently a continuous vein, but was separated in different sub-layers and complicated by "horses" (faults). Hall in his "Laurentian Magnetic Iron Ore Deposits of Northern New York" considered the "Old Bed" and "New Bed" to be located at different levels in the metamorphic succession (Birkinbine 1890).

Prior to1840, the Barton Hill Mine began as a series of openings on a magnetite body that seemed to be the northern continuation of the New Bed. The extensive development of iron mining in the area took place after 1849 when the properties came into possession of the Witherbee and the Sherman interests that were later incorporated into Witherbee, Sherman & Co (Farrell 1996). The Barton Hill area, especially the "Lover's Hole" opening is well known for the well crystallized magnetite crystals exhibiting pseudo-cleavage (octahedral parting) and interesting and rare crystallographic forms.

Not only was the magnetite of interest at that time, but also the apatite ("red sand") which accompanied magnetite in the "Old Bed". Apatite was first mined in 1852 by the Moriah Phosphate Company with the intention of producing fertilizers. The mine initially exploited the outcrop, and the amount of apatite from the surface was greater than it was from the underground works (Maynard 1874). The phosphate came to the attention of the State Geologist, Professor Ebenezer Emmons who supervised the American Mineral Company formed in 1853. The company mined mainly apatite for fertilizers and iron as by-product, but because the market did not react very well to their products, the company had to lease their properties and mineral rights to Port Henry Iron Ore Company.

Between 1858 and 1900, due to the pressure of economic factors, some of the mines were sold to different groups of investors or the "old" companies changed their names. The decline of the Mineville mining district started as early as 1875, when only a few mines were operating. The main economic factor that led to the decline of the Mineville deposits was the competition from the large and newly found iron ranges in Minnesota and Michigan.

The year 1900 brought new mining development in Mineville and it became the largest operating iron district east of Mississippi River (Farrell 1996). The only competitors were the Chateaugay Mine at Lyon Mountain and the small mines at Crown Point and Ausable, all producing the same type of ore as Mineville, but not in such high quantity or quality, and the Lake Sanford deposit that was Ti-rich, a property not relished by metallurgists.

After 1920 mining economically collapsed again in the Mineville region; a few mines operated until 1932 – 1933 when they were completely shut down. After 1935 there was an attempt to revitalize the mining, with a small spurt of production in 1936 – 1937 plus the creation of the Republic Steel Corporation in 1938 which leased all the Witherbee Sherman and Company's properties. Production and mining interest in the area again started to decline; the mines were repeatedly shut down and reopened for short periods until they permanently closed in 1971.

A new era for apatite began in 1940. Initially apatite was considered only useful for the production of fertilizers, but a U. S. Geological Survey report showed that the phosphate was very rich in rare earth elements. Immediately, Molycorp, a REE producing company leased the mineral rights and started their recovery from the tailings, but further feasibility studies were unfavorable and they did not acquire the property. Interest in the REE-bearing apatite was renewed in 1983 and Williams Strategic Metals of Colorado purchased the apatite-rich tailings then re- sold them in 1986 to Rhone-Poulenc, Inc. a French state-owned company (Farrell 1996). Now, Rhodia Inc. of New Jersey has the surface and mineral ownership.

The history of iron mining at Mineville is a reflection of the most important historical events in the world and in the United States. Figure 1 displays a very irregular pattern for the iron production at Mineville through the 20th century until the mines closed in 1971. These many ups and downs can be easily correlated with periods of economic depression, wars or the discovery of more competitive deposits elsewhere. Today, Mineville remains an important mineral locality and an iron deposit that still requires more research to be completely understood and explained.

The Craig Harbor mine situated above the Lake Champlain shore, in Port Henry, was not an important mining operation. It was mentioned by Emmons (1842) as a small mining development, but was not cited by subsequent researchers. The deposit will be visited during this trip to examine the gabbro, the pyroxene hornblendite, and the ilmenite-magnetite ore.

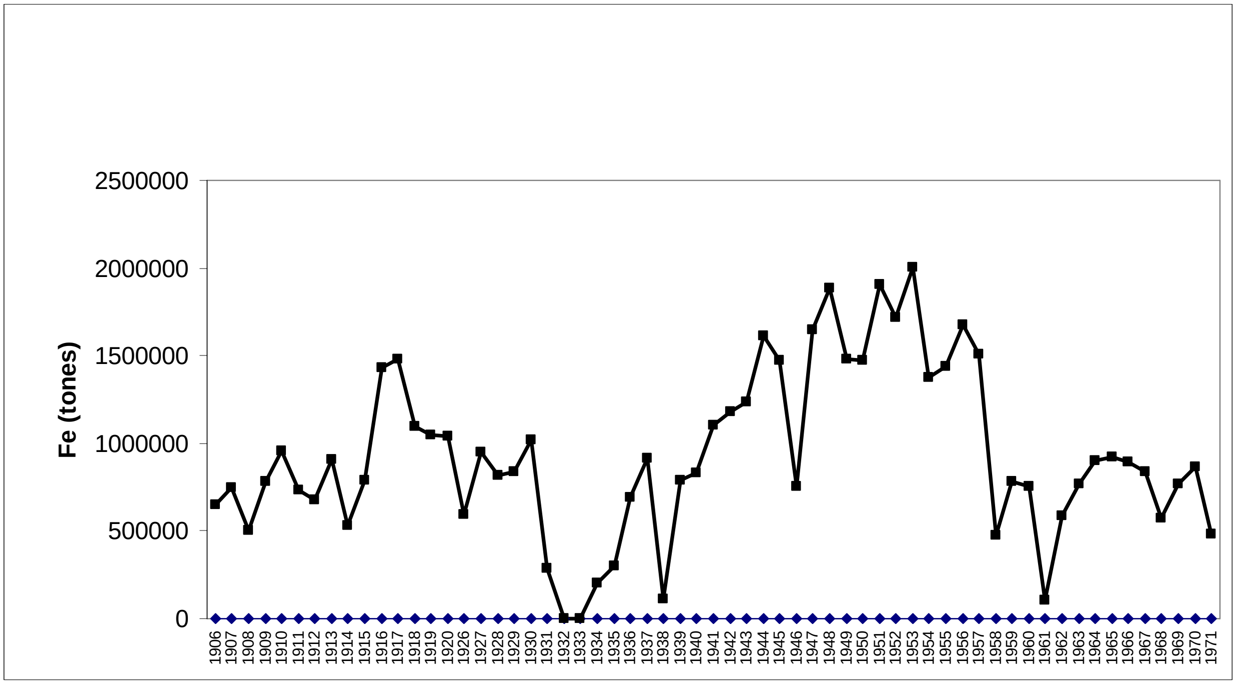


Figure 1. Iron production at Mineville in the 20th century until 1971 when the mines closed (data from Farrell 1996).

## GEOLOGY OF THE IRON DEPOSITS IN THE MINEVILLE – PORT HENRY REGION

The iron deposits in the Mineville – Port Henry area, (Essex County), NY, belong to a large metallogenetic belt that developed in the Grenville rocks in New York and New Jersey.

The Mineville deposit is a low – Ti Fe (oxide)–P–REE ore, that is, in part, similar to Kiruna-type iron deposits in Sweden based on its mineralogical and chemical composition. The host rocks have both mafic and felsic compositions, display igneous features, and probably are correlative with the informally named Lyon Mountain granitic gneiss with 1070 to 1050 Ma radiometric ages (McLelland et al. 1988). A metasedimentary series containing Proterozoic marbles, calc-silicates and gneisses structurally overlies the igneous sequence. Kemp (1908) described the host rock for the Mineville iron deposit as "augite syenites and related types" with granite and diorite composition representing the "related types." Buddington (1939) considered a hybrid composition between granite and metasedimentary or metagabbroic rocks, and Alling (1925) suggested an igneous and sedimentary origin for the protolith metamorphosed in the Grenville orogenic cycle. McKeown and Klemic (1956), based on the mapping of the Republic Steel geologists, described a metamorphic sequence starting with a basal metagabbro (Kemp's mafic syenite) followed by the magnetite ore from the "Old Bed" ore and granite gneiss passing into a diorite then to gabbroic composition and magnetite ore from the Harmony Bed. Whitney and Olmsted (1988) proposed an anorogenic bimodal, dominantly leucocratic volcanic suite with minor sedimentary sequences metamorphosed to granulite-facies, origin for the Lyon Mountain gneiss. An igneous genesis was inferred by Foose and McLelland (1995) and is based on field and geochemical evidences. The gneiss (granite) displays felsic Na - and K -rich compositions that alternate with more basic, amphibole-, pyroxene-, and phlogopite-bearing rocks, both characterized by high amounts of REE. Pegmatite bodies with simple compositions (mostly quartz, feldspar ± magnetite ± allanite-(Ce) and minor scapolite, titanite, epidote and zircon) crosscut the magnetite ore. Both the host rock and the magnetite ore commonly exhibit similar fabrics and layering.

The petrographic study of polished thin sections made from samples of the ore, and from hanging wall and footwall rocks shows a range of compositions from gabbro to monzodiorite to tonalite (Fig. 2).

The iron ore is composed of magnetite (partially replaced by hematite), apatite and clinopyroxene. Allanite and titanite commonly rim the magnetite and zircon (in places millimeter size crystals) is associated with the iron oxide in all the rock types. Rarely, magnetite displays spinel exsolution along {111}. Ilmenite is present in the more mafic compositions (gabbro) in rounded grains, has exsolutions of titanian-hematite in variable patterns, and in places, has a narrow or wide rim of titanite (Fig. 3).

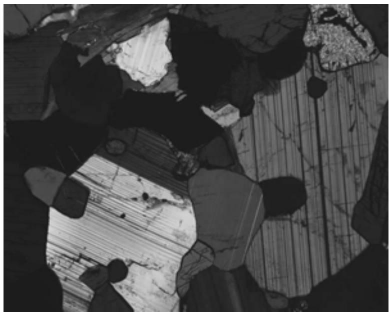
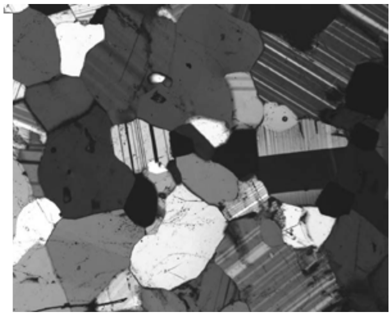


Figure 2. Left: microscopic image (transmitted light) of the gabbro in thin section. The rock contains plagioclase, clinopyroxene (dark), titanite (upper right corner). Right: tonalite (quartz as light grains and twinned oligoclase). The rocks are not deformed. Field of view: 4.5 mm.



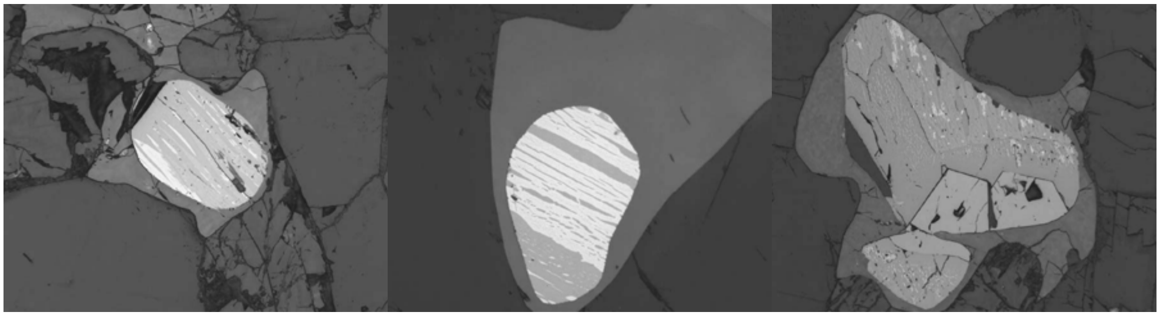


Figure 3. Rounded grains of ilmenite (reflected light) with exsolution of titanian-hematite rimmed by titanite (light gray). The other minerals (dark gray) are clinopyroxene and plagioclase. Field of view: 3 mm.

The host rock does not show any deformation at microscopic scale even though it displays folds in outcrop (Barton Hill); the oligoclase is twinned after Albite law and quartz displays only incipient undulatory extinction. K-metasomatism and formation of microcline (Fig. 4) is a late process, and proceeds initially along the contacts of magnetite and/or oligoclase; the Na-metasomatic alteration is latter than the K-metasomatism.

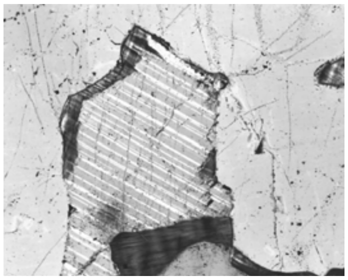


Figure 4. K-metasomatism and formation of microcline in the host rock: microcline develops on the contact between quartz (light gray) and oligoclase (with parallel twins). Field of view: 4.5 mm

Sprays of ferro-actinolite developed between magnetite and quartz. Late, low temperature veins of chlorite crosscut the magnetite ore.

Some of the general geological features of the Precambrian iron deposits mentioned by Foose and McLelland (1995) can be recognized in the Mineville iron deposit:

a. Occurs as lenses and/or layers in leucocratic rocks containing albite-oligoclase + quartz + K-feldspar composition above more mafic layers;
b. The iron ore displays similar fabrics to the host rock;
c. The crosscutting pegmatite bodies are not or are only slightly deformed;
d. Both the host rock and the ore have high amounts of REE and the gneiss is strongly enriched in Na, K, P, B, etc.

## MINERALS FROM THE MINEVILLE IRON DEPOSIT

The main minerals that were identified at Mineville are magnetite, hematite (martite), fluorapatite, stillwellite-(Ce), allanite-(Ce), monazite-(Ce), edenite, actinolite, ferro-actinolite, scapolite, titanite, and zircon in the main ore and, in part, in the pegmatite bodies dolomite, smoky quartz, calcite in late veins and ilmenite and titanian hematite as tiny disseminations in the host rock. Minor tiny (µm size) phases of secondary thorite, allanite-(Ce), parisite, and monazite-(Ce) in some apatite crystals and kainosite-(Y) in edenite were recognized under the polarizing microscope and by SEM – EDAX in thin/polished sections. Bastnaesite-(Ce) (McKeown and Klemic 1956) was previously reported but not identified by the authors, and probable lanthanite-(Ce), mentioned by Blake (1858), was detected based on the electron microprobe data.

*Magnetite* is by far the most spectacular mineral at Mineville, though some other minerals also show interesting compositional and crystallographic features. It probably first came to mineralogists' attention at the end of the 19th century when some remarkably unique specimens from the Lover's Hole pit were found around 1887 – 1888 (Jensen 1978). The main crystallographic form was the octahedron, but some had interesting modifying forms that were well documented at that time by Professor Koenig from the University of Pennsylvania (Birkinbine 1890). Besides the octahedron (Fig. 5), he described combinations of octahedron with rhombic dodecahedron, pentagonal dodecahedron, cube or icositetrahedron. Perhaps, the most intriguing forms are the pseudocleavages (parting planes), where the parted fragments develop a pseudo-prismatic appearance (Fig. 5) with stilpnomelane coating the parting planes and crystal faces. One of the most spectacular specimens has a "…perfect octahedron with faces of over one inch, resting loosely in the socket…" (Birkinbine 1890). According to Farrell (1996) this outstanding specimen was called "Big Diamond" and is now in the collection of the A. E. Seaman Mineral Museum, at Michigan Technological University, Houghton, Michigan. The magnetite crystals that display a combination of octahedron and rhombic dodecahedrons have striations parallel to the octahedron faces (Kemp1890). Cathrein (1887) and Mügge (1889) both in Kemp (1890) previously noted and considered this type of striation as polysynthetic twinning of the spinel law. Kemp (1890) interpreted them as pressure-generated pseudocleavage planes in the mineral.

Figure 5. Magnetite crystals from the Lover's Hole, Barton Hill mines, Mineville. Left: magnetite octahedrons ((3.5 x 2.5 x 2.5 cm, NYSM 12495). Right: unusual morphology of magnetite crystals (4.7 x 1 x 1.5 cm) resulting from parting along octahedral faces (NYSM 12258). On top of the crystal on the right there is stilpnomelane.

*Fluorapatite*, the "red sand", was found in the ore from the "Old Bed" and is characterized by high concentrations of rare earth elements. It appears as red, brown or yellow small, 1 to 3mm, hexagonal prisms embedded in magnetite. The red and/or brown color is due to infiltrations or inclusions of hematite along the fractures or within the crystal. McKeown and Klemic (1956) described a very narrow rim of 0.05 mm of a reddish-brown aggregate of monazite, bastnaesite and hematite rimming some of the apatite crystals. We examined apatite grains in thin/polished sections under polarizing and scanning electron microscopes and found that most of the fluorapatite grains are fractured, "flushed" by late fluids, and contain tiny grains of magnetite/hematite, monazite-(Ce), allanite-(Ce) and thorite. Parts of the "Old Bed" ore are composed only of magnetite and fluorapatite in variable proportions. The textural features of the Mineville apatite are in Figures 6, 7, 8, and 9. Fluorapatite is a main component of the ore also at the Cheever Mine, but not in the same amount as in the Old Bed from Mineville.

*Allanite-(Ce)* is found in the pegmatite bodies that crosscut the magnetite ore and/or the host gneiss and in the pyroxene-rich rocks. It was first mentioned by Blake (1858) occurring "abundantly along the plane of contact of the bed of ore with a mass of granitic rocks…maybe an intrusion or segregation in its midst." The crystals described by Blake were very large, 20 – 25 cm long, 6 to 20 cm wide and 2.5 to 5 cm thick suggesting a pegmatitic origin. The crystals displayed "smoothed and perfect" surfaces and conchoidal fractures. He considered Mineville at that time "the best locality for obtaining cabinet specimens of allanite yet known in the United States."

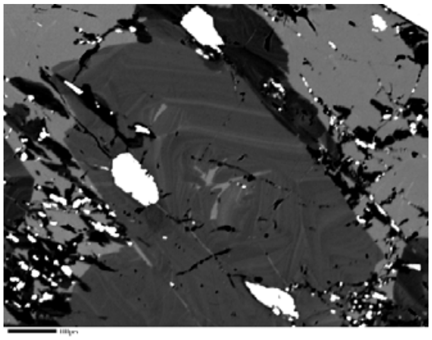


Figure 6. Zoned apatite. The bright grains are magnetite. BSE image. Scale bar: 300 microns.

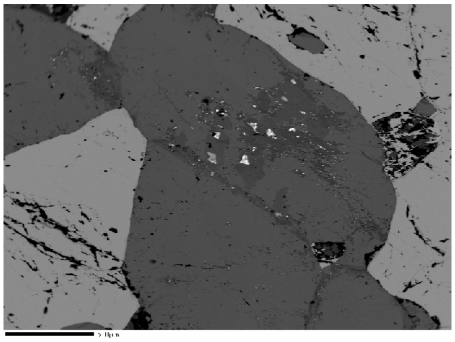


Figure 7. Factured apatite with fluid infiltrations and secondary thorite, allanite and monazite as bright spots. BSE image. Scale bar: 300 microns.

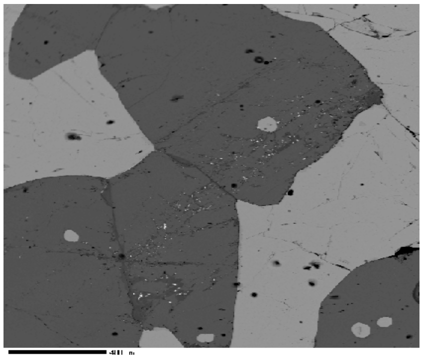


Figure 8. "Trails" of secondary thorite, allanite and monazite (all as light gray) along the fractures in apatite. BSE image. Scale bar: 300

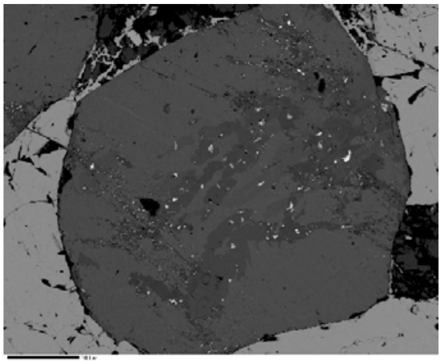


Figure 9. Fractures and patches of apatite leached by fluids and secondary thorite, allanite and monazite (bright spots). BSE image. Scale bar: 300 microns.

Allanite-(Ce) from Mineville also captured the attention of Dana (1884) and Ries (1894), who described it in short mineralogical notes. In this study allanite crystals associated with quartz and monazite-(Ce) from Mineville, were analyzed by polarized light microscopy and electron microprobe. The large, smooth-faced crystals are metamict and the chemical data are in the compositional field of allanite-(Ce). The microscopic study showed that the metamict allanite-(Ce) in the pyroxene-rich rocks is decomposed to monazite-(Ce) and has a fresh rim of Y-dominant allanite that is strongly pleochroic, in dark-brown shades.

*Monazite-(Ce)*. There are two generations of monazite-(Ce) based on their relationships with other minerals. In some pegmatite bodies, 1-3 mm to almost 1 cm crystals of monazite-(Ce) appear associated with or as inclusions in allanite-(Ce) both embedded in quartz. The breakdown of allanite-(Ce) generated secondary monazite-(Ce) as minute grains.

*Stillwellite-(Ce)*. Mineville is the unique occurrence of this mineral in New York. Identified for the first time by Mei et al. (1979) in a sample from the "Old Bed" collected near a fault at the 2100-feet level, and confirmed by X-ray diffraction, stillwellite-(Ce) appears as 1 to 2 mm wide tabular crystals with waxy luster and pink to reddish color in association with fluorapatite and magnetite. Under the electron microprobe, the authors detected some very tiny inclusions in stillewellite-(Ce) that contained 27.05 wt. % $Ce_2O_3$, 18.02 wt. % $La_2O_3$, 6.44 wt. % $Nd_2O_3$, 1.71 wt. % $Pr_2O_3$ and 1.50 wt. % $Sm_2O_3$. These small grains are probably lanthanite-(Ce).

*Zircon* is a common mineral from the Mineville mines. The mineral occurs in three environments characterized by different mineral associations. The first is the zircon appearing as accessory mineral in the host rock and it does not form any crystals of aesthetic interest. Then there are the beautiful, up to 1cm or more, dark colored, well developed, and terminated zircon crystals in the quartz – feldspar pegmatite segregations. These display tetragonal prisms with tetragonal pyramids, and are mostly metamict. In places, the edges between the prism and pyramid are slightly rounded. One specimen from the Barton Hill Mine has small, up to 1 mm pink and transparent zircon crystals within magnetite and/or scapolite. When zircon is included in magnetite, the whole aggregate is surrounded by titanite.

*Dolomite* is not a very common mineral in the Mineville ore. It forms "saddled", 3 to 5 cm crystals covered by iron hydroxides and is partially replaced by calcite.

*Quartz* occurs as short, terminated "smoky" prisms on top of magnetite and associated with calcite.

## ORIGIN

For many years, geologists debated the origin of the iron deposits in the Grenville province of New York and New Jersey. The genesis of the Mineville iron deposit was related to the contact replacement due to highly heated igneous solutions (Kemp 1897), igneous emplacement (Kemp 1908), basic segregations due to differentiation (Kemp and Ruedemann, 1910), replacement of the country rock by igneous-derived iron-rich solutions (Alling, 1925) or possible metamorphosed sedimentary sequence (Nason 1922). Buddington (1966), Baker and Buddington (1970) and Foose and McLelland (1995) leaned toward a hydrothermal or hydrothermal-metasomatic origin.

The nature of the host rock was also in dispute for a long time. The iron deposits at Mineville are located in a metamorphic unit composed from meta-igneous and metasedimentary sequences that are crosscut by pegmatite dikes, with sharp or diffusive contacts, and with simple or complex composition. McKeown and Klemic's (1956) description (see above in the general geology section), based on their own field observations and information from the mining geologists working for the Republic Steel Company, is very important because it is the first and most substantial work emphasizing the real relationships between the magnetite ore and the gabbro as the host rock. Today, the gabbro with magnetite and the magnetite-bearing pegmatite facies can be seen at the former Barton Hill Mine. At the mines that exploited the Cheever ore body, the contact between the magnetite ore with the felsic and more mafic compositions can be easily examined. The granitic facies (Kemp's gneiss) seems to be the hanging wall and not the host for the ore in the Old Bed (McKeown and Klemic, 1956).

Our own field observations confirm that the magnetite and/or magnetite-apatite ore-bearing rock is mostly an un-deformed rock with igneous characteristics, ranging in composition from gabbro to tonalite, cross cut in some places by magnetite-bearing pegmatite bodies with simple mineral compositions. The magnetite-apatite and magnetite ores occur as layers and lenses in the rocks having mafic and/or felsic mineral compositions. In outcrop, the magnetite-apatite ore seems to occur as a dike cutting the granitic host. The mineralogical composition of the ore seems to be simple, but the field, microscopic and geochemical data show a complex process (or processes) that shaped the iron deposits at Mineville. The main ore mineral, magnetite, contains MgO (0.01 to 0.28 wt. %), $Al_2O_3$ (0.04 to 3.18 wt. %), and $TiO_2$ (0.08 to 2.43 wt. %). It is rarely associated with ilmenite in the massive ore, but ilmenite containing titanian hematite exsolution is a constant presence as disseminations in the low grade ore of the hanging wall and footwall. Fluorapatite is enriched in REE ($La_2O_3$ 1.29 wt. %, $Ce_2O_3$ 2.72 wt. %, $Nd_2O_3$ 1.28 wt. %, and $Y_2O_3$ 1.50 wt. %) and Th ($ThO_2$ 0.21 wt. %). The morphology of the ore bodies, their mineral composition, the presence of the ilmenite grains with titanian-hematite exsolutions, the nature of the host rock and the relationship between the ore layers or lenses and the country rocks suggest a probable igneous origin. One possibility is that the ore formed through two liquids (oxide and silicate) immiscibility. This origin is in accordance with the results of the early experimental works that showed the possibility of forming two immiscible liquids, one being a mixture of magnetite and apatite and the other a rock with dioritic composition (Philpotts 1967). Further experiments showed that for a broad range of rock compositions formed under conditions of high $fO_2$, an immiscible FeO liquid can segregate within a magma having a felsic composition (Naslund 1976). The presence of P, Ti and Fe enhances the immiscibility in magmas (Naslund 1983). Another possibility is that the ore represents a fragmented (intruded?) synplutonic mafic dike(s) in felsic (granitic) rocks. Unfortunately, the outcrop showing these relationships is the Rutgers Mine in Ausable Forks (Clinton County) but this location is not included in our trip and won't be examined during this tour. Didier and Barbarin (1991) showed that the mafic inclusions from the granodiorite-tonalite-diorite plutons have different possible origins but many of them derived from fragmented synplutonic mafic dikes and blobs of mafic magmas in felsic rocks.

To constrain the timing of the magnetite ore formation a zircon crystal (up to almost 2 cm in size) from the Old Bed magnetite ore was analyzed for U-Th-Pb isotopes by LA-MC-ICP-MS. It yielded a 1040 ± 9 Ma radiometric age compatible with that of the Lyon Mountain granite (McLelland et al. 1988). Small, pink zircon crystals (2 to 5 mm in size) found in magnetite grains surrounded by titanite in a pegmatite from the Barton Hill mines yielded an age of 1028 ± 20 Ma (Chiarenzelli et al. 2008 – unpublished data).

The host rocks are much enriched in Na and/or K as well as in REE. The apatite also has very high REE concentrations. The chondrite-normalized REE distribution pattern for the apatite (Fig. 10) and the host rock (Fig. 11) are comparable. This trend could be interpreted in at least two ways: *(a)* synchronous introduction of REE in both the apatite and host rock and correlated probably with Na and/or K metasomatism or (b) the REE pattern of the host rock is strongly influenced by the REE pattern of accessory apatite. Apatite has small negative Sr and Eu anomalies and the $(Ce/Yb)_N$, $(Nd/La)_N$ and $(La/Yb)_N$ ratios indicate that the source was not a highly fractionated fluid, but was strongly enriched in both LREE and HREE.

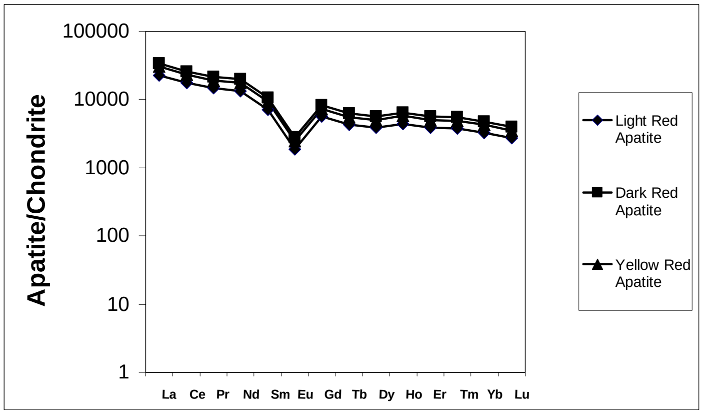


Figure 10. Chondrite-normalized REE pattern for fluorapatite (selected by color) from the Old Bed ore, Mineville iron deposit. Note the high concentration of the REE and the Eu anomaly. The apatite has the same chondrite-normalized REE pattern as the host rock but is enriched in REE by a factor of 10 or more.

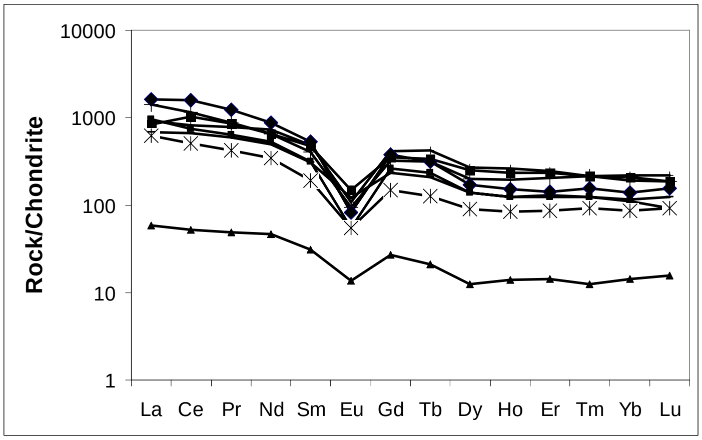


Figure 11. Chondrite-normalized REE pattern for the host rock (samples from Mineville and Barton Hill) of the magnetite and magnetite-apatite ores from the Mineville iron deposit. Note the enrichment in both LREE and HREE and the Eu anomaly.
- triangles: sample from Barton Hill;
- all other samples are from Mineville

The ore contains also small allanite-(Ce) crystals that have been partially replaced in a late event by the assemblage thorite – monazite-(Ce) – kainosite-(Y) – Y-dominant allanite. Results of twenty-two EMPA age determinations on secondary allanite yielded age populations of 240 Ma (primary population) and 165 Ma (minor secondary population), dating the allanite-(Ce) alteration event as Mesozoic. However, the apatite fission-track ages that centered on 113 Ma (Stone et al. 2006- unpublished data) suggest complex and/or multiple hydrothermal events during the Mesozoic or simply represent exhumation during the Mesozoic.

### Craig (Crag) Harbor Mine

The mine is located on the Lake Champlain shore at about 15 m above the water. Emmons (1842) mentioned that "the vein is in hornblende … is twelve feet wide and dips southwest".

The host rock is a gabbro and the magnetite ± ilmenite ore is contained by a layer of pyroxene hornblendite. The amphibole (hastingsite) is dominant and associated with clinopyroxenes. Magnetite has spinel exsolution (Figure 12) along {111}. Ilmenite is subordinate, forms grains with sharp contact with or lamellae in magnetite. Apatite, as rounded grains, is also a component of the ore as well as pyrite that appears to be related to a later mineralizing episode. Almandine is a common metamorphic mineral in the gabbro, but not in the ore.

The magnetite-ilmenite ore from the Craig Harbor mine seems to be of igneous origin. It probably formed as result of liquid immiscibility between the iron-titanium oxide melt and the mafic silicate magma, but a late magnetite-ilmenite bearing pyroxene hornblendite intrusion into the gabbro cannot be excluded without further research.

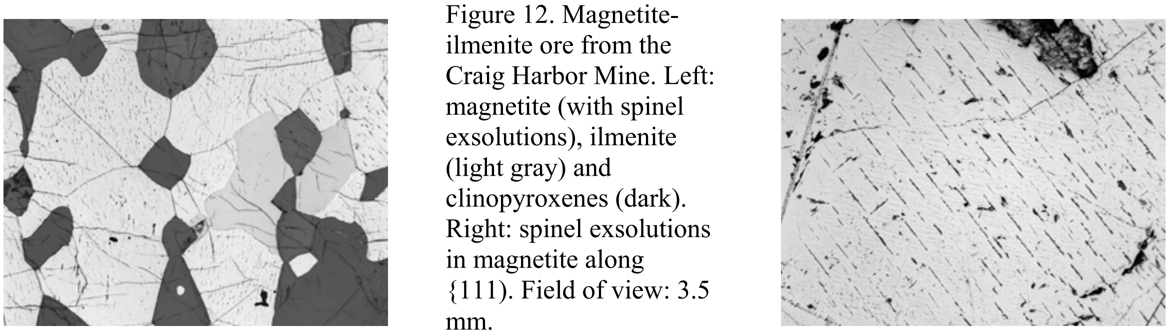


Figure 12. Magnetite-ilmenite ore from the Craig Harbor Mine. Left: magnetite (with spinel exsolutions), ilmenite (light gray) and clinopyroxenes (dark). Right: spinel exsolutions in magnetite along {111). Field of view: 3.5 mm.

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**ROAD LOG FOR THE TRIP**…(Fig. 13)

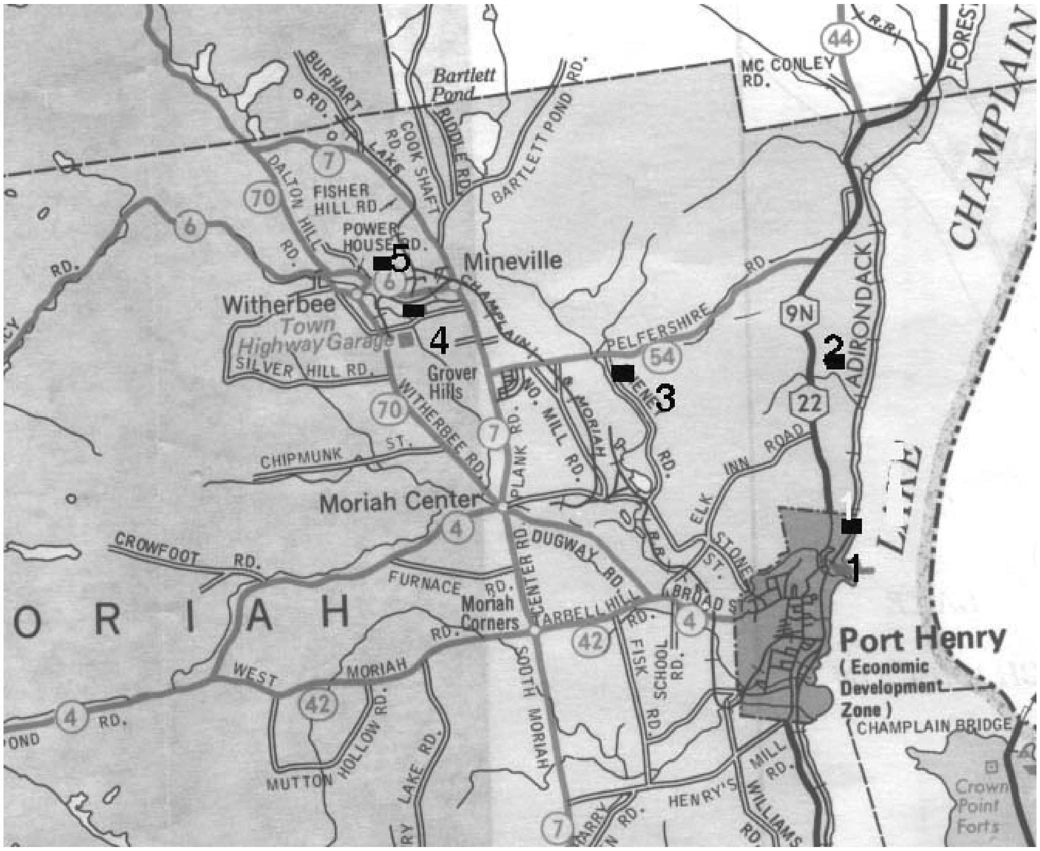

Figure 13. Road map of the field trip. 1. Craig Harbor Mine; 2. Cheever Iron Mine; 3. Pelfshire iron Mine; 4. Mineville group of mines; 5. Barton Hill group of mines.

The field trip starts at the Port Henry Boat Launch Site. The site is at the intersection of Dock and Velez lanes in Port Henry, Essex County. Follow the Amtrack railroad north but be careful because the Amtrack passengers and freight trains are coming fast and cannot be seen very easy due to the curves. Do not move or stay on the tracks. There is enough room to stand and walk safely on the side of the railroad. Also, be aware of poison ivy.

**Stop 1. Craig Harbor Mine** (N 44º 03’ 47.9”; W 73º 27’ 0.00”)

**200m. Stop 1a**. Upper Cambrian limestones with layers of chert. Small vugs and veinlets with pyrite are along the chert layers. Vertical faults cut the limestones.

**100 m. Stop 1b**. Craig Harbor faultline scarp. Beautiful view of the Craig Harbot faultline scarp. On the southern side of the fault there are Ordovician limestones and on the northern side there are Precambrian rocks. Here, a gabbroic intrusion is overlain by a metasedimentary sequence containing gneisses and marbles with deformed inclusions of gneisses, calcsilicates, metagabbro and quartzites. A very good description of the outcrop is in McHone (1987). The faultline zone was mentioned first by Emmons (1842); he noted inclusions of high-temperature minerals in the marble and considered them of igneous origin. Wiener et al. (1984) and McHone (1987) considered the marble to overlie the Eagle Lake gneiss. Roden-Tice (2002) reported that a sample from the gneisses below the marble yielded apatite-fission-tracks (AFT) age of 123 Ma.

**200 m. Stop 1c**. Craig Harbor Mine. The ore-hosted metagabbro displays micro- to coarse-texture: the coronitic character is obvious in places. The metagabbro contains garnet, hastingsite, phlogopite, plagioclase (oligoclase), clinopyroxene and orthopyroxene. The magnetite-ilmenite ore is in a pyroxene hornblendite layer (intrusion?) in the gabbro. Narrow veins of pyrite cut the iron-titanium ore. Whitney and McLelland (1975) and McLelland and Whitney (1980) studied the coronitic gabbros across the Adirondacks and determined that this texture formed in the granulite facies conditions of 8 kb and 800º C.

| Cumulative mileage | Miles from the last point | Route description |
|---|---|---|
| 1.5 miles | 1.5 miles | Follow Rt22/9N toward north. Stop on the right side of the road in front of the metal gates. Walk around the gates and follow the unpaved Jeep road going north. |

**Stop 2. Cheever ore body (Port Henry mines):** N 44º 04’ 47.9”; W 73º 27’ 10.1”

**250 m. Stop 2a**. There is a marble outcrop on the side of the Jeep road. The marble contains deformed inclusions of metapelites, calc-silicates and quartzites.

**500 m. Stop 2b**. On the left side of the road is the Witherbees-Sherman pit that opened the Cheever ore body. Fragments of felsic rocks with granitic to dioritic compositions containing layers of magnetite with sharp contact with the host are piled above the pit opening. Be careful and do not go very close to the rim. The gabbro outcrops on the right side of the road. Examine the texture, the mineral composition, the nature of the contact, and the gabbro outcrop.

**500 m. Stop 2c**. On the left side of the road there is a small mining work that opens the contact between the magnetite ore and the host rock. Examine the contact, the mineral composition of the ore, and the host rock. Coarse aggregates of amphiboles and clinopyroxenes are common in the ore.

**250 m. Stop 2d**. A large pit appears on the left side of the road. Take the left avoiding the pit and climb an easy slope on a deer trail heading north-north west. The trail goes between small pits and after 25 m you will reach a barbwire fence. Do not cross, just follow it along the trail. After 5 m another barbwire fence appears; go over and after 50 m you are at the Three Holes Mine. The host rock and the magnetite “layers” can be examined in the mine (the hanging wall and footwall are solid and there is no danger to going inside). Flash lights are not necessary because the Three Holes Mine was a very small operation and the day light is enough to help us to see the contact of the ore and to study the mineral composition of the ore and the host rock.

Go back to the parking place following the same Jeep road you hiked in along. Head north on Rt. 22.9N.

| | | |
|---|---|---|
| 3.4miles | 1.9 miles | Turn left onto Pelfshire Road. |
| 4.4 mile | 1 miles | Turn left onto Cheney road. |
| 4.9 miles | 0.5miles | Stop for the Pelfshire mines (pits). |

**Stop 3. Pelfshire (Pilfshire) mines (pits)**: N 44º 04’ 30.8”; W 73º 29’ 17.7”

The Pelfshire (Pilfshire) mines were mentioned by Smock (1889) and described by Kemp (1908). The ore and the host rock are similar to the Port Henry mines (Cheever ore body). The gabbro forms a ridge not far from the pits. The magnetite ore strikes north-south and dips 60º west; it is hosted by a felsic rock with transitions to more mafic compositions. Examine the characters of the gabbro, the host rock and the magnetite ore. The pits and dumps are the property of Rhodia Inc. (New Jersey). Ask for permission to visit and collect samples (Mr. Paul Tramblee of Mineville is the guardian of the property).

| | | |
|---|---|---|
| 5.4 miles | 0.5 miles | Turn back to the Pelfshire Road. Turn left on Pelfshire Road. |
| 6.3 miles | 0.9 miles | Turn left onto Swichback Road. |
| 7.6 miles | 1.3 miles | Turn right onto Titus Road. |

| | | |
|---|---|---|
| 8.3 miles | 0.7 miles | Turn right onto Essex County 7. |
| 10.2 miles | 1.9 miles | Turn left onto Raymond-Wright Road. |
| 11.2 miles | 1 mile | Stop at the Firehouse. Park the car in the parking lot toward the picnic area. |

**Stop 4. Mineville group of mines:** N 44º 05’ 22.5”; W 73º 31’ 30.5”

We will examine the rocks from the waste dumps of the Clonan, Joker and Bonanza shafts. Large fragments of magnetite-apatite, magnetite-apatite-pyroxene, magnetite, and magnetite-pyroxene ore display interesting textures. Examine the mineral composition and the texture of the ore and the host rock. The dumps are the property of Rhodia Inc. (New Jersey). Ask for permission to visit and collect samples (Mr. Paul Tramblee of Mineville is the guardian of the property). Turn left (SW) on the Raymond-Wright Road when you are done with this stop.

| | | |
|---|---|---|
| 11.5 miles | 0.3 miles | Follow the Raymond-Wright Road and turn right on the Barton Hill Lane |
| 11.8 miles | 0.3 miles | Park the car on the left side of the road. The mine is on the right side of the road. |

**Stop 5. Barton Hill mines**: N 44º 05’ 34.6”; W 73º 32’ 05.2”

The Barton Hill group of mines is located half mile to the northwest from Mineville. Half mile north of the Barton Hill group is the Fisher Hill mine (actually on and under the Moriah Shock Correctional Facility). Here, we will examine the host rock with gabbroic character, its fabrics and the large body of pegmatite with magnetite and allanite-Ce cutting the gabbroic rock. The Lover’s Hole from the Barton Hill mines is the location where beautiful magnetite crystals came from at the end of the 19th century.

| | | |
|---|---|---|
| 12.1 miles | 0.3 miles | Turn right onto Powerhouse Road that continues as Essex County Route 6. |
| 20.1 miles | 8 miles | Turn right onto Route 9. |
| 20.1 miles | 0.1 miles | Turn left onto I-87. |

End of the field trip