THE CHEEVER AND MINEVILLE IRON OXIDE-APATITE (IOA) DEPOSITS

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INTRODUCTION

The iron deposits of New York State were an important source for the U.S. iron industry during the nineteenth and twentieth centuries. The main component of the ore was magnetite; it was accompanied in some deposits by hematite, with gangue minerals such as feldspar, quartz, amphibole, and fluorapatite. Most of the medium-to high-grade magnetite ore was mined underground.

Iron mining in New York State has a long history. There are two main regions where iron mining was developed, the Hudson Highlands in the south, and the Adirondack Mountains in the north. After more than a century of iron production, Smock (1889) completed the first report on the iron ores of New York State and the first classification based on a "geologico-geographical arrangement." His classification included almost all the iron occurrences known at that time and all the major ore types (magnetic iron, hematite, limonite, and carbonates).

The iron deposits from the Adirondack Mountains (Figure 1) can be divided into two major types: (a) iron oxide – apatite (IOA) deposits, and b) titanium iron oxide deposits. The most significant IOA deposits are those associated with the A-type Lyon Mountain Granite (gneiss), the Benson Mines magnetite-sillimanite-garnet ores, and the Jayville and Clifton magnetite ± vonsenite deposits, all of which are in St. Lawrence County. The most significant Ti-Fe oxide deposits are those found at Tahawus in association with rocks of the Anorthosite-Mangerite-Charnockite-Granite (AMCG) suite (nelsonites associated with gabbroic anorthosite), and smaller occurrences at Split Rock ("cumberlandite"), Craig Harbor (hornblendite), Tunnel Mountain (gabbro), all in Essex County, and the Port Leyden nelsonites in Lewis County.

The IOA deposits of the eastern Adirondacks display many similarities with Kiruna-type iron deposits. The IOA deposits found in Scandinavia, the Americas, Russia, Iran, Australia, and China, vary in age from Archean to Pleistocene (Williams et al. 2005), are all associated with volcanic to subvolcanic rocks, and were intensely metasomatized (Harlov 2016 and references therein). Their origin is strongly debated by modern researchers, but three hypotheses prevail: (a) primary igneous origin altered by secondary hydrothermal replacement (Sillitoe and Borrows 2002); (b) igneous derivation by liquid immiscibility (Nyström and Henriquez 1994; Naslund et al. 2002; Chen et al. 2010; Tornos et al. 2016); (c) flotation of silica melt-derived magnetite microlites (Knipping et al. 2015).

During this trip we will visit two IOA deposits, the Cheever Mine located north of Port Henry, and the # 21 mine at Mineville (Essex County) where we will examine the mineral composition of the ore, the contact with the host rock, the petrographic features of the host, and discuss the geochemistry, geochronology, and origin of the deposits. Both were significant iron producers but are also widely known for the association of REE-bearing apatite, and the exquisiteness of the magnetite crystals that can be seen today in many museums around the world. The mining history of the Mineville-Port Henry district is well presented by Farrell (1996) and summarized by Lupulescu and Pyle (2008) in their report for the NYSGA Annual Meeting at Lake George.

New data and comments for this field trip improve and bring new knowledge to the prior field trips offered by NYSGA in 2008 (Mineville) and 2015 (Cheever). Some parts of the text are comparable with those from Lupulescu and Pyle (2008) and Lupulescu et al. (2015) field guides.

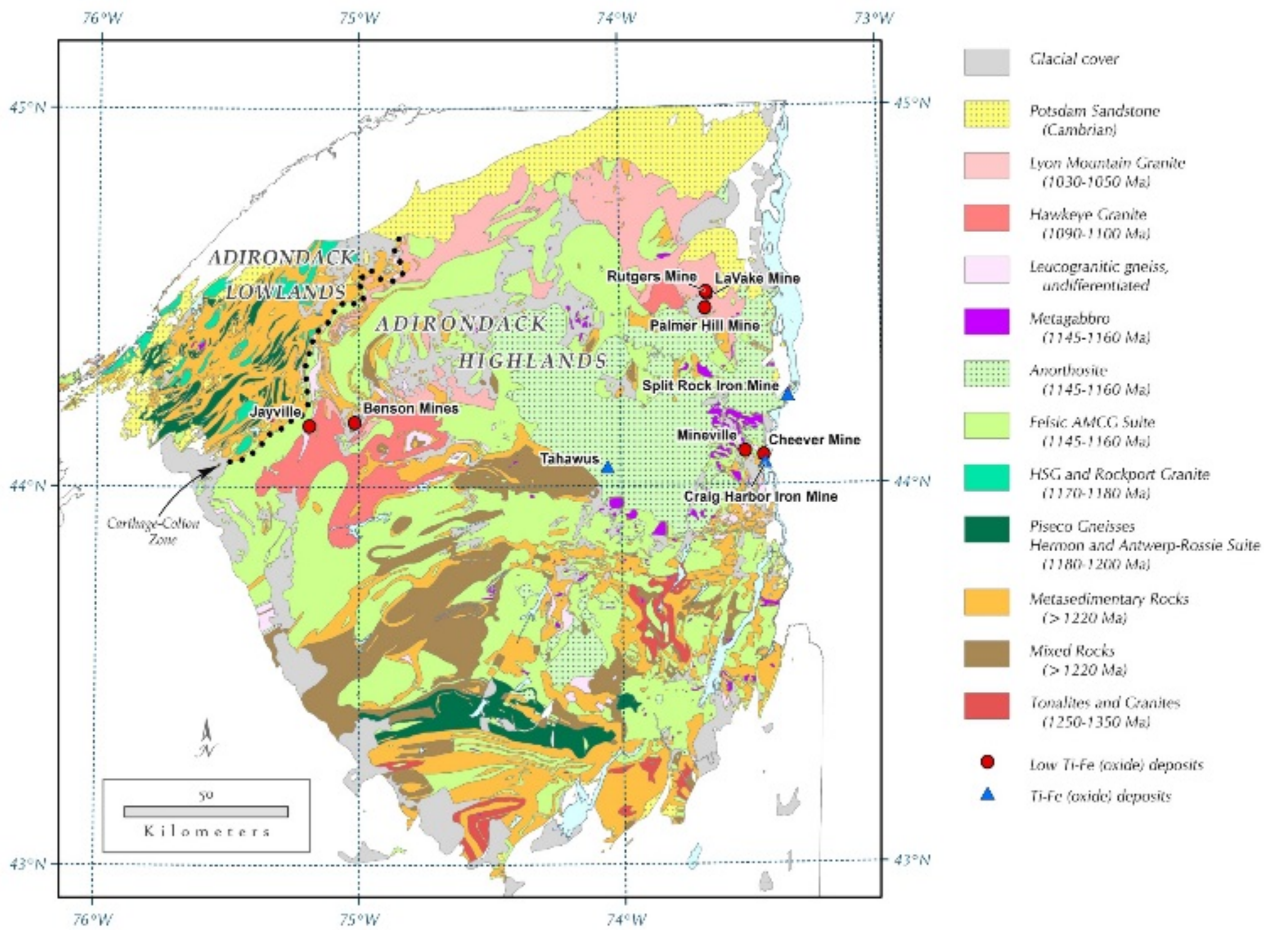

Figure 1. Distribution of IOA and Fe-Ti oxide deposits in the Adirondacks.

GENERAL GEOLOGY

The Adirondacks are in the Mesoproterozoic Grenville Province situated between the Archean Superior Province and the Paleozoic rocks of the Appalachian Orogen. The Grenville Province is characterized by large volumes of massif anorthosite and related rocks (Anorthosite-Mangerite-Charnockite-Granite or AMCG suite) that are abundant in the Adirondack Highlands where they were intruded toward the end of the Shawinigan Orogeny (ca. 1140-1165 Ma).

The Grenville Province was shaped by three orogenies: (a) Elzevirian (1245-1220 Ma); (b) Shawinigan (1200-1140 Ma); and Grenvillian (1090-980 Ma). The Grenvillian Orogeny is considered to include the Ottawan (1090-1020 Ma) and Rigolet (1010-980 Ma) pulses (Rivers 2008). The extent of deformation and metamorphism associated with each of these events varies geographically and division of the Grenville into the monocyclic and polycyclic belts (Rivers, 1989).

The Adirondacks have been subdivided into the Adirondack Highlands (AH) and Lowlands (AL), based on lithology and metamorphic grade. In the Adirondack Region the Lowlands do not record the latter two events, while in the Highlands both the Shawinigan and Ottawan events are noted (Chiarenzelli et al. 2011). The boundary between the AH and AL is known as the Carthage-Colton shear zone. The AH is characterized by the intrusion of the AMCG suite and granulite-facies metamorphism. The AMCG members are rare in the AL where the rocks reached the upper amphibolite facies metamorphic grade during the Shawinigan Orogeny.

The IOA deposits are found only in the Adirondack Highlands. The Mineville-Port Henry mining district is in the eastern Adirondacks between the Marcy anorthosite massif and Lake Champlain. This region contains metasedimentary rocks, anorthosite, gabbro, leucogranitic rocks of the Lyon Mountain granite, and pegmatites. The magnetite-apatite deposits cross-cut all lithologies except the late pegmatites and are typically associated with hydrothermally-altered rocks of the Lyon Mountain granite (Valley et al. 2011). The Lyon Mountain granite is a regionally extensive rock unit hosting varied iron deposits across the eastern and northern areas of the Adirondacks. Chiarenzelli et al. (2017) interpreted it as a ferroan granite formed during the extension and collapse of an elevated plateau after the cessation of the Ottawan Orogeny.

While widely distributed throughout the northern half of the Adirondack Highlands the Lyon Mountain Granite also serves as the host rock for the iron deposits. It often shows chemical alteration near the ore dominated by quartz-albite assemblages thought to represent hydrothermal alteration during and/or after ore emplacement (Valley et al. 2011). While the spatial relationship between IOA ore and the Lyon Mountain Granite is well known, the possible genetic relationship is less clear.

Although complications exist from xenocrystic zircon, geochronological study of the Lyon Mountain Granite over the last three decades indicates that it was intruded between 1030-1070 Ma throughout the Highlands, with peak emplacement between 1040-1050 Ma (Figure 2). Numerous samples of IOA ore in the eastern Adirondack Highlands have also been dated by zircon and yield a range of ages from ca. 1040 to 980 Ma; leading some workers (Valley et al., 2010; Valley et al. 2011) to conclude that the ore has a long and complicated history including alteration, remobilization, and that it was possibly intruded at several times. The ages substantiate field relations where planar dike/sill-like bodies cross-cut the Lyon Mountain Granite. Abundant generations of monazite and apatite and other radiogenic minerals have been documented by Lupulescu et al. (2017). It should be noted that in Mineville and elsewhere the IOA ore is cross-cut by a widespread suite of pegmatites yielding ages between 1020-1040 Ma (Lupulescu et al. 2011).

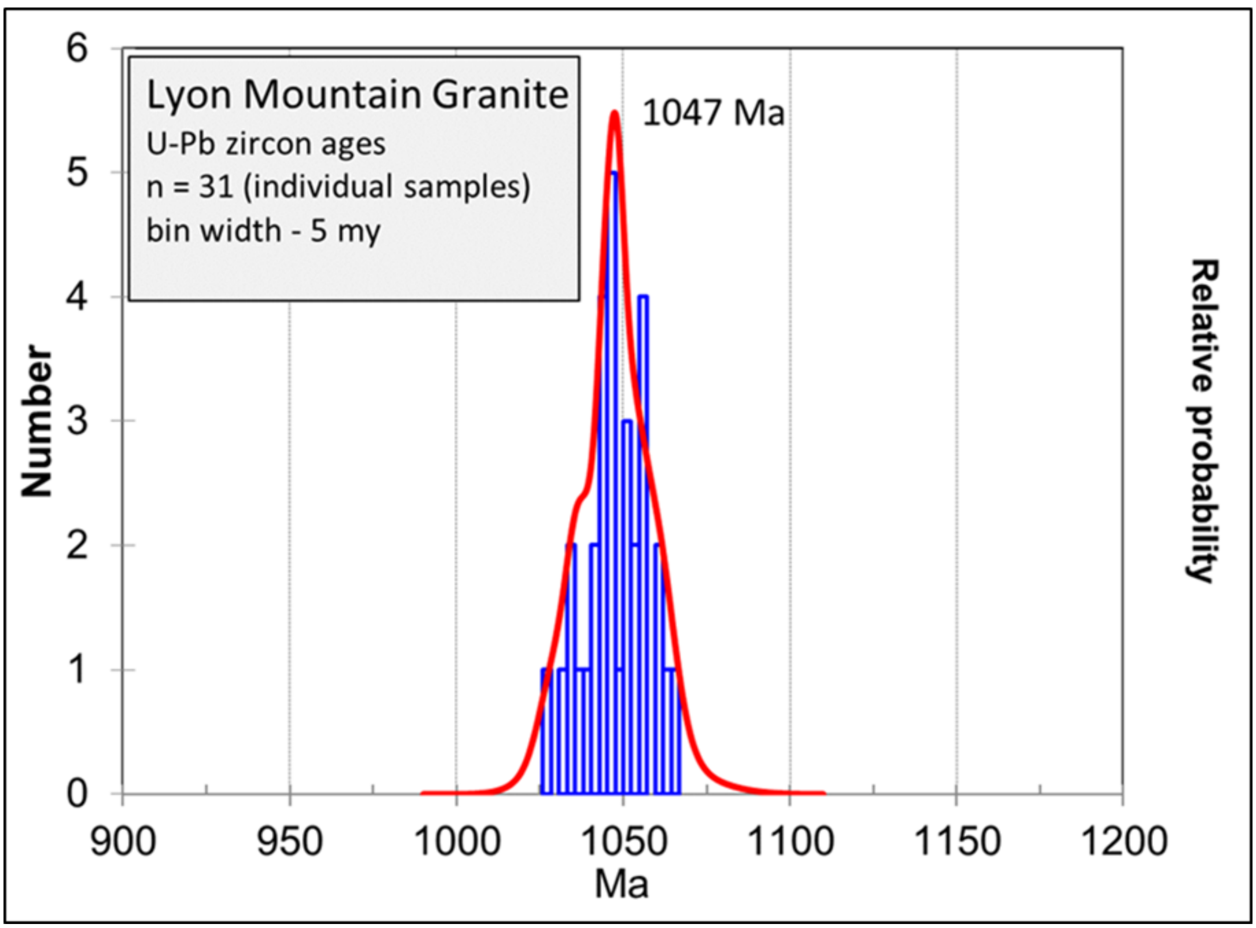

Figure 2. Distribution of ages of the Lyon Mountain Granite throughout the Adirondack Highlands (after Chiarenzelli et al. 2018)

ROAD LOG

The field trip starts at the Port Henry Boat Launch Site at 8:30 AM. The site is at the intersection of Dock and Velez lanes in Port Henry, Essex County. There is no problem to find the meeting place, Port Henry is a small town and the access to the site is from Rt. 22. No need for carpooling, there is enough parking space at both sites

Stop 1. CHEEVER MINE. Location coordinates: N 44° 04' 43.5"; W 73° 27' 14.3"

The Cheever Mine is located above Lake Champlain north of the village of Port Henry. The ore strikes approximately north-south, dipping toward the west. The old mine workings are preserved as several trenches that follow the ore body for more than 0.5 km. The local bedrock geology consists of rocks of the Grenville Supergroup (marble and pelitic gneiss), coronitic gabbro, amphibolite, and pink to green variably altered rocks of the Lyon Mountain granite.

The metasedimentary rocks are represented by marbles containing folded and disrupted lenses of calc-silicates and gneisses. The coronitic metagabbro is spatially associated with the leucocratic rocks containing the magnetite-apatite ore. A similar situation can be seen at the Barton Hill mines at Mineville. The nature of the contact (tectonic vs. intrusive) is not obvious, being obscured by recent alluvium and cover in both cases. The coronitic metagabbro from Cheever mine is sheared toward the contact with the leucocratic rocks which contain quartz, albite, pyroxene, +/- microcline. Lenses of mafic rocks containing pyroxene, amphibole, fluorapatite, and magnetite can be found in the tailings (the underground works are not accessible).

The coronitic metagabbro occurs in massive or layered form. The massive form contains plagioclase "clouded" with spinels, pyroxenes, garnet and annite. Both ortho- and clinopyroxene grains are present, and most display tiny elongated exsolution lamellae of other pyroxenes and ilmenite as the result of the sub-solidus re-equilibration during slow cooling. Rare grains of ilmenite and pyrrhotite pepper the rock. The coronitic metagabbro contains some layered facies with the same composition as the massive variety.

The footwall rock which hosts the ore is a granitic rock composed predominantly of quartz and albite. Minor phases are grains of relict clinopyroxene (largely replaced by chlorite), zircon (some grains are partially metamict), and magnetite with ilmenite lamellae. The hanging wall rock contains more relict pyroxenes than the footwall, and the magnetite/ilmenite grains are rounded and, in places, associated with pyroxene replaced by chlorite. In other areas, the rock displays a gneissic texture with alternating "bands" of quartz and albite, and pyroxene, amphibole, annite, magnetite, ilmenite, and rare grains of apatite and pyrrhotite (altered to goethite). Exsolution textures within the pyroxenes are common. This rock grades into a microcline, albite, quartz, pyroxene, amphibole, and ilmenite-rich gneiss. The ore-hosting rocks are undeformed (this observation is supported by field and microscopic study) and contain pyroxene, and in places rounded, droplet-looking, grains of magnetite and or ilmenite.

The rocks have high concentrations of Na_2O (3.48 wt.% in the metagabbro, to 6.31 wt.% in the footwall leucogneiss); K_2O varies from 0.36 % in the footwall rock to 3.63 % in the highest stratigraphic unit of the hanging wall leucogneiss. All rocks display normative "hypersthene". The rocks are enriched in REEs and have steep profiles, like those from Mineville.

The magnetite-fluorapatite ore at the Cheever Mine exists as dikes / sills that have sharp contacts with the host rock. The ore contains abundant magnetite, fluorapatite, and augitic pyroxene. Other mineral phases present include ilmenite, titanite rimming magnetite, zircon, monazite-Ce, stillwellite-Ce, allanite-Ce, and thorite. The amphibole tremolite is very rare, and mostly is the result of the low temperature interaction of clinopyroxene, quartz, and later fluids. A relatively F-rich (1. 19 to 1.58 wt.%) amphibole with blue pleochroism under plane polarized light seems to be the last igneous mineral in the succession. Rare spinel phases were exsolved along the {111} crystallographic planes of the large magnetite grains. Lupulescu et al. (2017) interpreted the fluorapatite textures as result of the intense metasomatism; the products of the metasomatic reactions are monazite-(Ce) and allanite-(Ce) (Figure 2). The fluorapatite grains display high REE concentrations, especially heavy REEs and Y (Lupulescu et al. 2017). A detailed overview of the geology of the Cheever mine is in the report for the NYSGA Annual Meeting 2016 (Lupulescu et al. 2015).

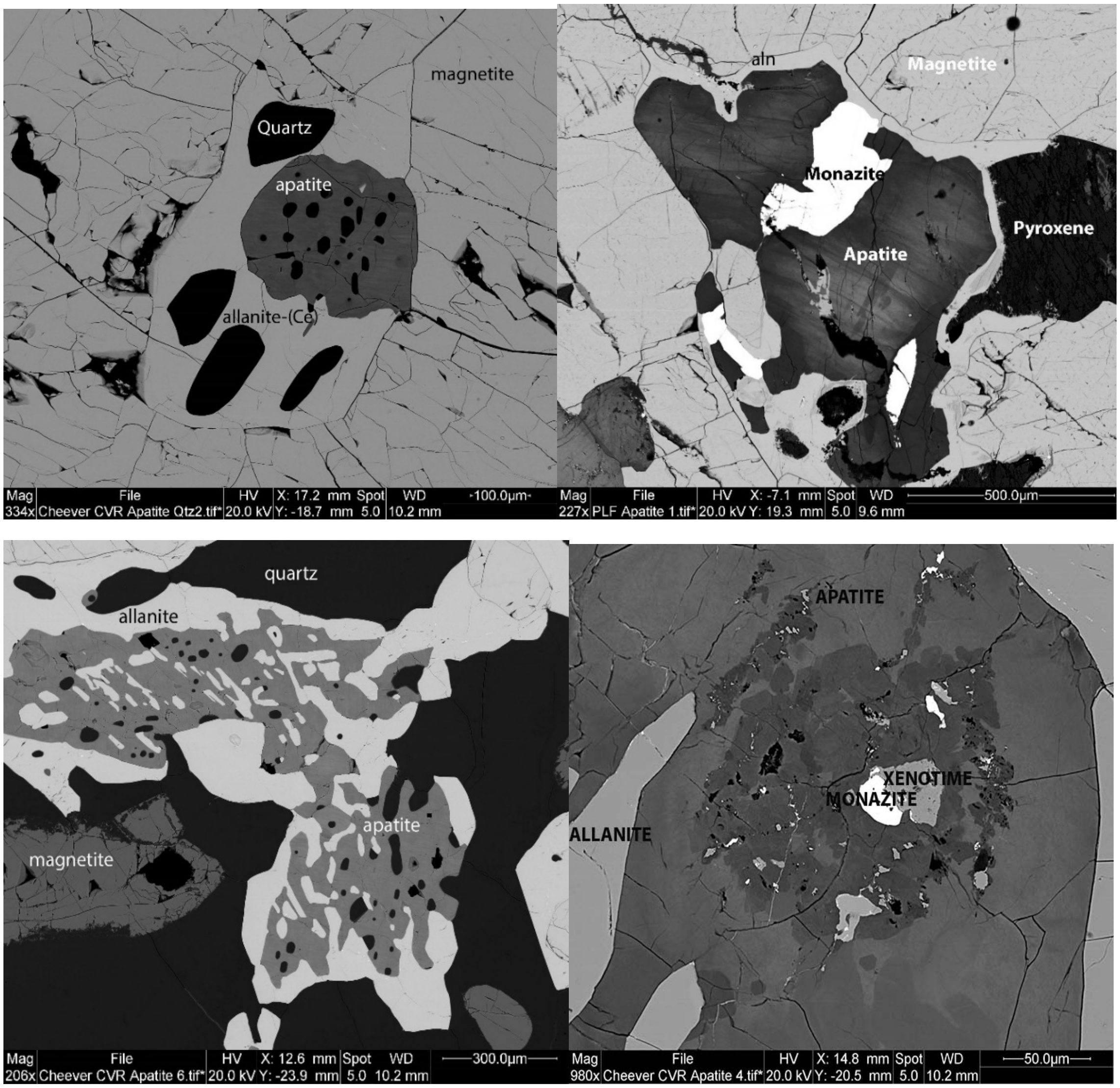

Figure 3. Textures of fluorapatite in the Cheever IOA deposit. Metasomatic reactions between REEs-bearing fluorapatite and fluids produced monazite-(Ce), allanite-(Ce), and xenotime-(Y).

The field relations and results of samples of the Lyon Mountain Granite collected for U-Pb zircon geochronology at the Cheever mine are shown in Figure 4. At these localities zircon xenocrysts were absent in several of the samples and ranged in age up to 1242 Ma where present. Lyon Mountain Granite samples range in age from 1040-1066 Ma in concert with ages obtained from numerous samples of the unit throughout the Highlands, suggesting multiple intrusive events along a magmatic conduit or fault. Note that the Lyon Mountain Granite is intruded by a gabbroic rock. The ore sample here yielded a sparse population of zircons, interpreted as igneous in origin, whose age was 1033.6±2.9 Ma.

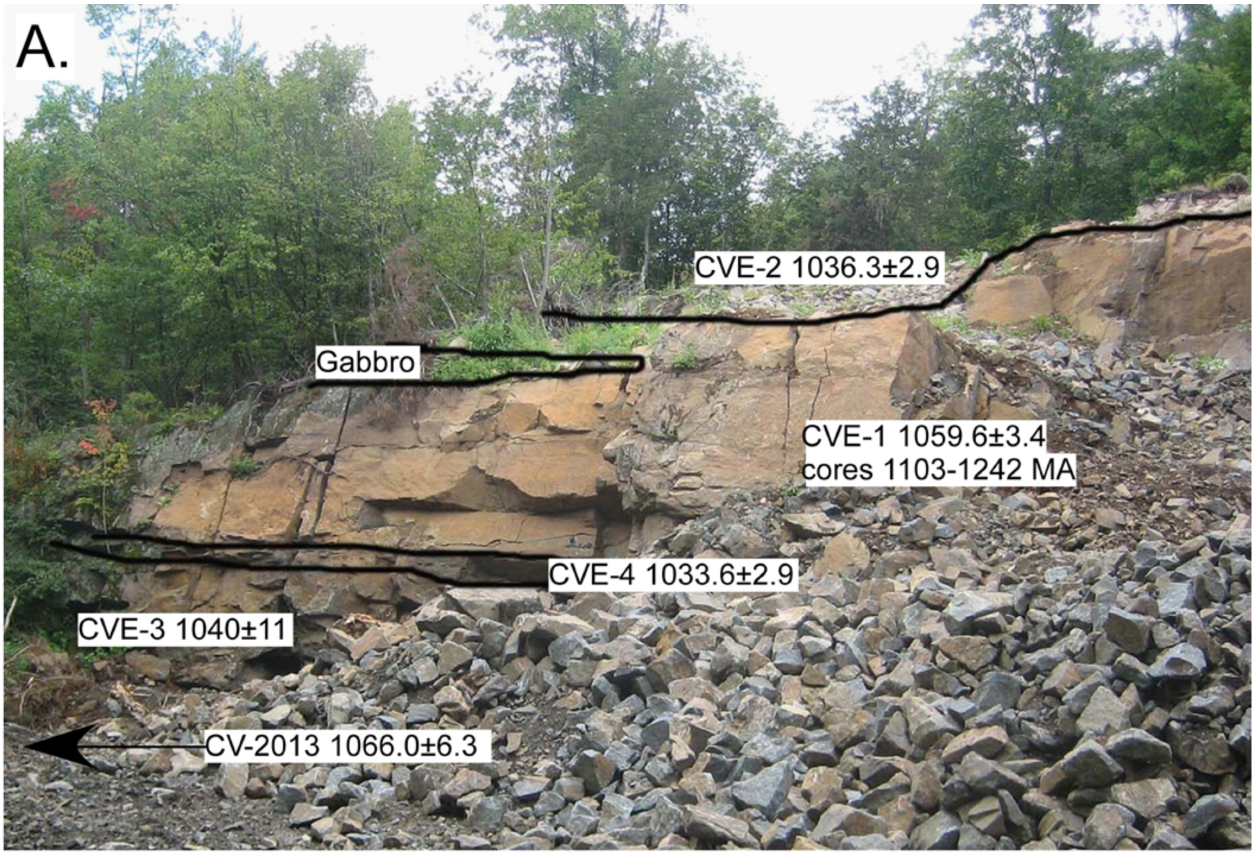

Figure 4. Existing quarry face at the Cheever Mine showing the samples collected for U-Pb zircon geochronological study and the results. Sample CVE-4 is from the ore horizon. Sample CV-2013 is located about 50 m south of the quarry face. Sample CV-7 is located approximately 300 m southeast of the quarry face and yields an age of 1043.9±4.1 Ma. After Chiarenzelli et al. (2018).

Stop 2. MINEVILLE. Location coordinates: N 44º 05’ 22.5”; W 73º 31’ 30.5”

The host rocks at the Mineville mines have both mafic and felsic compositions and display igneous features. The metasedimentary rocks from the area include marbles, calc-silicates, and gneisses that structurally overly the igneous sequence. One of the first researchers at the Mineville mines, Kemp (1908), described the host rocks as “augite syenites and related types” with granite and diorite compositions being the “related types.” Alling (1925) suggested an igneous and sedimentary origin for the various protoliths that were later metamorphosed during the Grenville orogenic cycle. Buddington (1939) considered the composition of the host rocks as a petrographic hybrid between granite and metasedimentary or metagabbroic rocks. McKeown and Klemic (1956), using the maps of the Republic Steel geologists, described a structural sequence of metamorphic rocks, starting with a basal metagabbro (Kemp’s mafic syenite) followed by the magnetite ore and granite gneiss from the “Old Bed”, passing into a diorite, then to gabbroic rocks and the associated magnetite ore of the “Harmony Bed”.

Our observations show that the first unit above the magnetite-apatite ore in the hanging wall is a pinkish rock that compositionally grades from granite to syenite. Above this unit, there is a leucocratic granite, which is in turn overlain by amphibolite (Figure 3A). The foot wall is a gabbro intruded by two sheets of leucocratic granite and a pegmatite (Figure 3B).

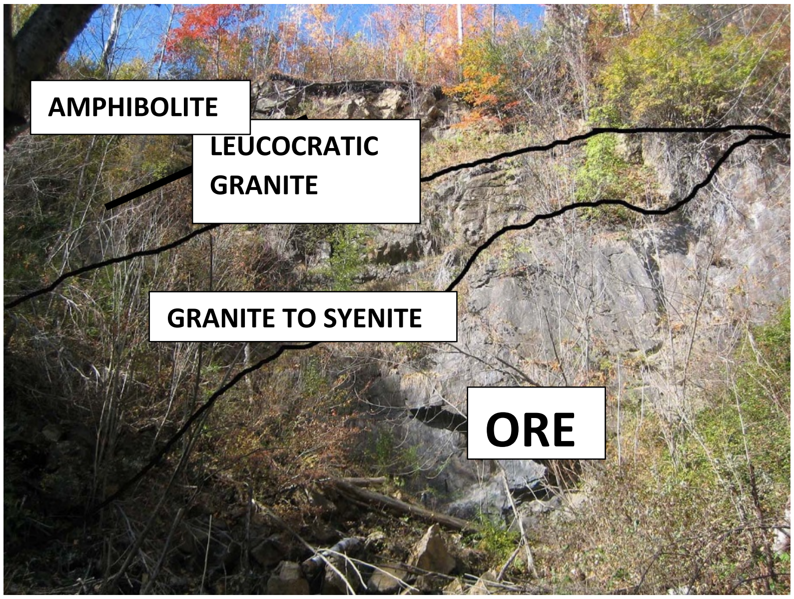

Figure 3A. Succession of rock units in the hanging wall at the # 23 mine, Mineville.

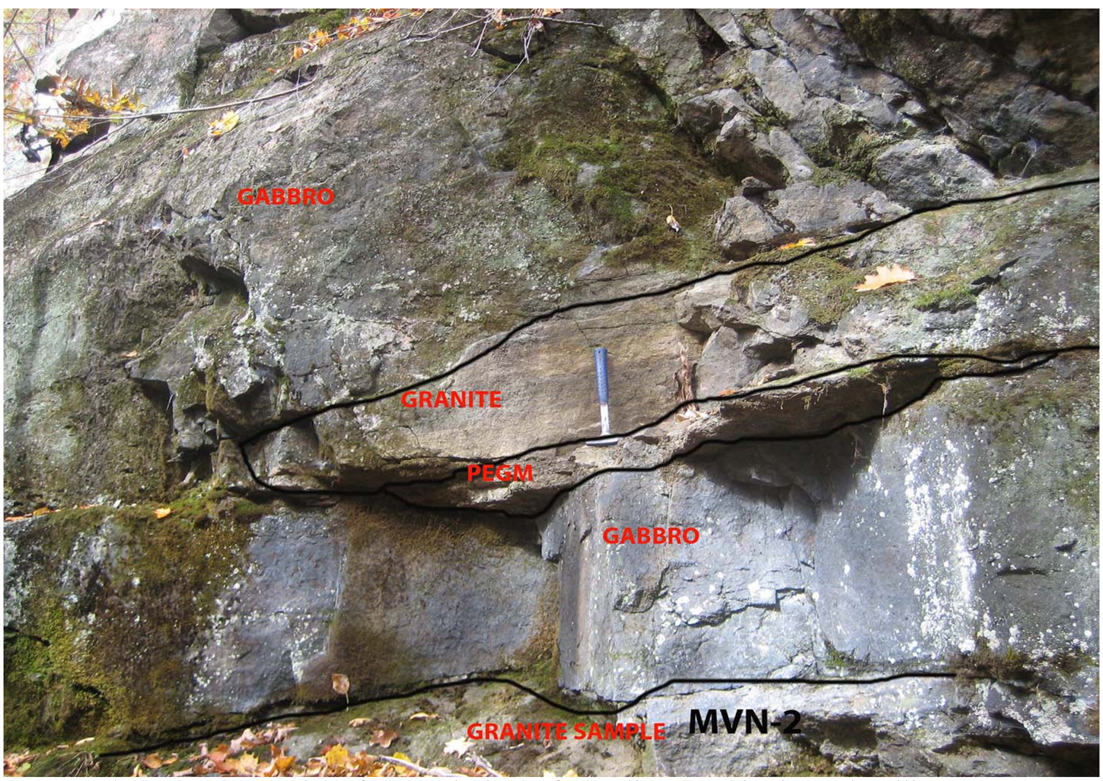

Figure 3B. Succession of rock units in the footwall at the #23 mine, Mineville.

The main minerals that were identified at Mineville in association with the ore are: magnetite, hematite (martite), fluorapatite, stillwellite-(Ce), allanite-(Ce), monazite-(Ce), edenite, actinolite, ferro-actinolite, scapolite, titanite, and zircon and dolomite, smoky quartz, calcite in late veins, and ilmenite and titanian hematite as tiny disseminations in the host rock. Micron-size mineral phases of secondary thorite, allanite-(Ce), parisite, and monazite-(Ce) in some apatite crystals were recognized under the polarizing microscope and by SEM – EDS in thin/polished sections. Bastnaesite-(Ce) and lanthanite-(Ce) previously reported by McKeown and Klemic (1956), and Blake (1858), respectively, were found as very rare and tiny crystals based on the electron microprobe data (Figure 4A). A detailed mineralogy of the Mineville deposit was presented in the report for the NYSGA Annual Meeting 2008 (Lupulescu and Pyle 2008).

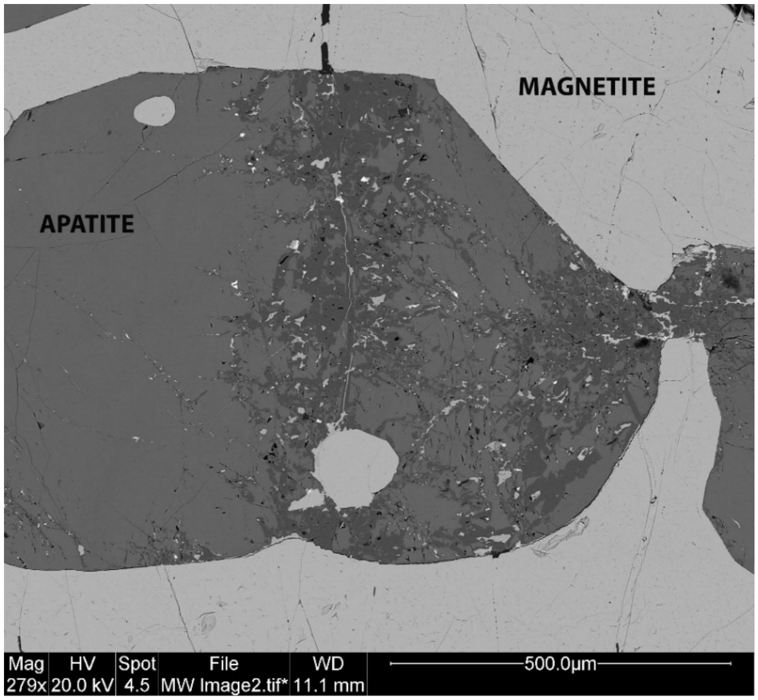

Figure 4A. BSE image of a metasomatic texture of an apatite crystal. The apatite is fractured, reacted with the invading fluids, and generated secondary REEs-bearing mineral phases. The new formed phases are too tiny to be positvely identified.

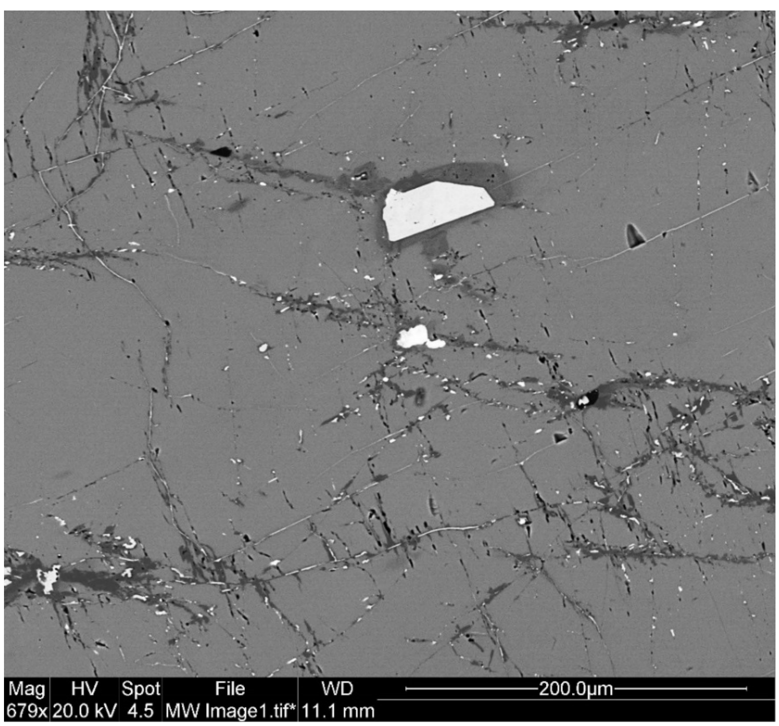

Figure 4B. BSE image of a metasomatized apatite crystal. The bright large crystal is bastnaesite-(Ce).

Fluorapatite from the Mineville deposit contains high concentrations of LREEs and especially HREEs. According to Molycorp estimation in 1980, the 5 million cubic meter tailings (Figure 5) contain "8-9 million kilograms of Y_2O_3 with an average grade of 0.12 wt.% Y_2O_3 and 0.6 wt.% REO" (Mariano & Mariano 2012).

surface volume

Plane_Height	Reference	Z_Factor	Area_2D	Area_3D	Volume
217.3	ABOVE	1	116200	131548.284257	5705965.216065

0 125 250 500

Meters

Figure 5. View of the Mineville tailings from Google Earth (Credit: David Tewksbury-Hamilton College).

MEETING LOCATION

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.

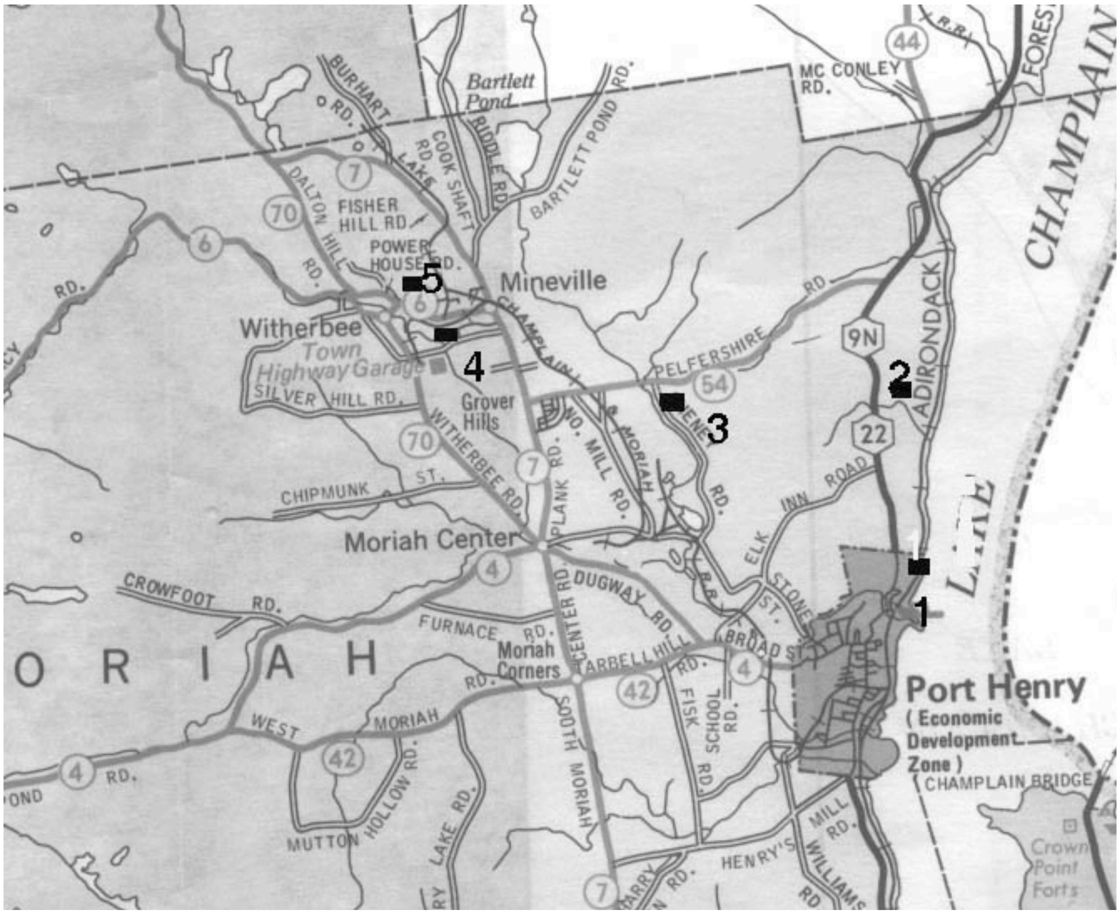

Figure 6. Location map of the Cheever and Mineville IOA deposits and neighboring mines (1. Craig Harbor Mine; 2. Cheever Iron Mine; 3. Pelfshire iron Mine; 4. Mineville group of mines; 5. Barton Hill group of mines). We will visit only the Cheever (2) and Mineville (4) mine.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. Anthony and John Real for granting access to their Cheever property and Mr. Paul Trombley for providing help while visiting the Mineville area.

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