THE MAGNETITE-FLUORAPATITE ORES FROM THE EASTERN ADIRONDACKS, NEW YORK: CHEEVER MINE

MARIAN V. LUPULESCU
Research and Collections, New York State Museum, Albany, NY 12230

JEFFREY R. CHIARENZELLI
Department of Geology, St. Lawrence University, Canton, NY 13617

DAVID G. BAILEY
Geosciences Department, Hamilton College, Clinton, NY 13323

SEAN P. REGAN
Department of Geosciences, University of Massachusetts, Amherst, MA 01003-9297

INTRODUCTION

Iron mining in New York State, 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, has a long and interesting history. Iron ore was mined from Grenville-age metamorphic rocks in the Adirondack Mountains and Hudson Highlands, and from Silurian-age sedimentary rocks in central and western New York (Clinton-type).

Smock (1889) was the first author to present a complete report and the first classification of the iron ores "…which occurs in beds and deposits of workable size in the State of New York". From his report we have brief descriptions, locations, and data on the ore quality, by-products, and output of the major mines operating in the late 19th century. Kemp (1897, 1908), Kemp and Ruedemann (1910), Nason (1922), Alling (1925), Gallagher (1937), Postel (1952), Buddington (1966), Hagner and Collins (1967), Baker and Buddington (1970), Foose and McLelland (1995), Valley et al. (2009), and Valley (2010) all made significant contributions to our understanding of the iron deposits in the Adirondack Mountains, but there is still no agreement as to their origin, and thus Alling's statement from 1925 directed at individuals wanting to understand the "*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*" is still as valid today as it once was.

On this trip we will visit the Cheever Mine in the eastern Adirondack Mountains. Our goal is to present a brief classification of iron ore deposits in the Adirondacks and to briefly summarize pertinent aspects of the diversity, differences, and similarities between mines and prospects across the Adirondacks and ignite discussion on their origin. According to their mineralogical and geochemical compositions, the principal iron deposits and prospects in the Adirondacks (Figure 1) are 1) low Ti iron oxide – REEs (Mineville, Cheever, Palmer Hill, Rutgers, LaVake, and Arnold Hill mines), 2) low Ti iron oxide (Lyon Mountain and Benson mines), 3) low Ti iron oxide - boron (vonsenite) (Jayville and partially Clifton mines), and 4) Ti – Fe oxides (Tahawus). Based on their general features (Valley et al. 2009; Valley 2010) these ores are considered to belong to the

IOCG (iron oxide – copper – gold) class of iron deposits (e.g., Hitzman et al. 1992) even though copper and gold mineralization is not known at these locations. One possible exception is the Lyon Mountain mines from which Callaverano and Zimmer (2009) reported on associated copper mineralization.

During this field trip we will visit the Cheever mine, Port Henry, Essex County, near Lake Champlain. Due to the elongate, sill-like geometry of the body it was worked at many locations along its length. To avoid confusion we will collectively refer to all the locations as belonging to the Cheever "mine". On this trip we will examine the morphology of the magnetite – fluorapatite ore bodies, the mineralogy of the ore and the host (foot- and hanging-wall), the relation of the ore body to the neighboring coronitic metagabbro, and discuss the igneous origin of the deposit in light of age, major and trace element chemistry, and isotopic composition of the fluorapatites from the ore and host rock.
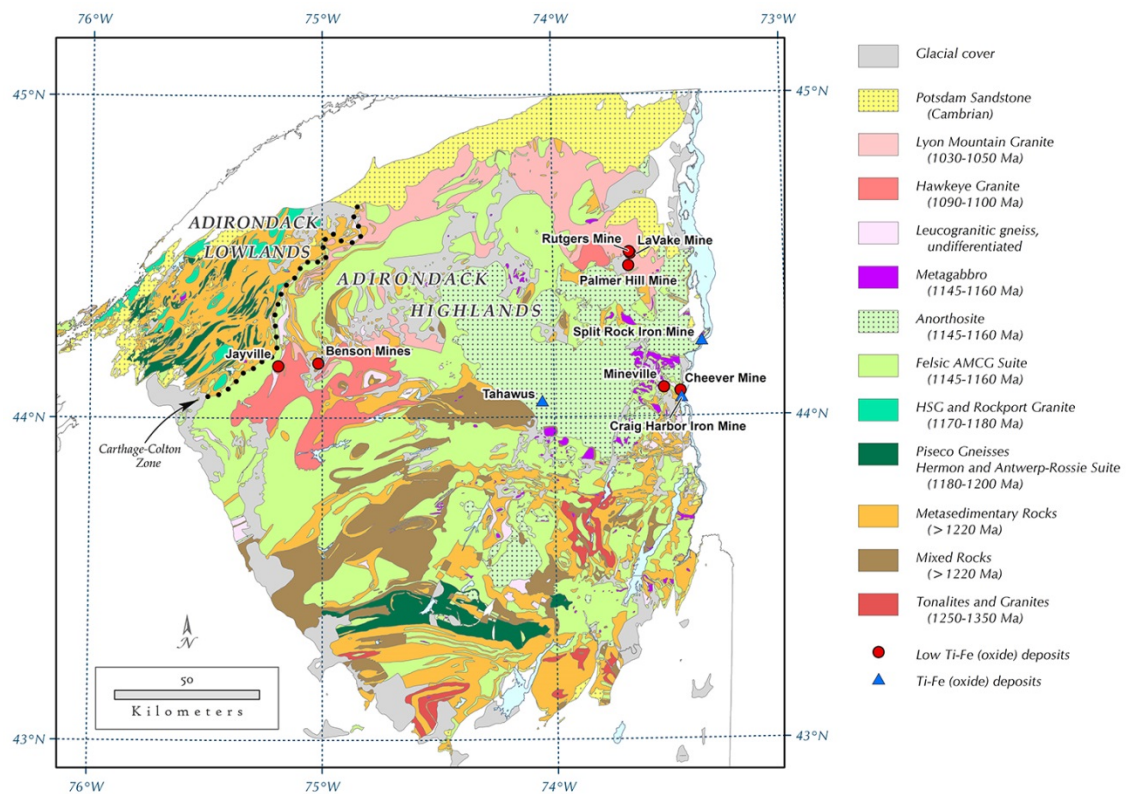

Figure 1. Location of the main iron deposits of the Adirondack Mountains

MINING HISTORY

The discovery of iron ore in the eastern Adirondacks was mentioned in 1749 in the works of the European naturalist named Kalm (Farrell 1996). The Cheever mine, located north of Port Henry, was discovered in 1804 and opened in 1820 (Linney 1943), and was the first important iron mine in the region. Subsequently, Charles Fisher opened the Fisher Hill mine that was worked discontinuously until 1893. The Cheever mine was systematically worked since 1853 and

"owned by the Cheever Ore Bed Company and leased by the New York Mining and Developing Company "(Smock 1889).

In 1824 exploration in nearby Mineville led to the discovery of a magnetite-apatite ore body that was later called the "Old Bed" (Birkinbine 1890). Soon thereafter, new workings northwest of the "Old Bed" produced a magnetite-silicate ore. These works were named the "New Bed". Before 1840, new diggings searched for and found the northern continuation of the "New Bed" and thus, the Barton Hill mines were opened (Farrell 1996). Between 1859 and 1971 when the Mineville works closed for good, the mines were worked intermittently.

The mines from Arnold Hill and Palmer Hill in the Ausable Forks region, Clinton County were small and not significant competitors of the Mineville – Port Henry district. The Arnold Ore Co. operated the Arnold Hill mine for a brief period after 1806 (Postel 1952). Smock (1889) reported some intense renewed activity after 1830. The beginnings of the Palmer Hill mine works are not very clear; it opened in 1825 according to Newland (1908) or 1844 according to Smock (1889). Both mines lasted until 1890 (Newland 1908). The Rutgers and LaVake mines belong to the same mining district, but they were too small and the ore too low-grade to be of any economic importance. The iron ore from the Lyon Mountain region was discovered around 1823 at what is now called the Chateaugay mine (Linney 1943); some prior works were reported in 1798 when the first Catalan forge was operated at Plattsburg (Linney 1943, Cavallerano and Zimmer 2009). In 1803, a new Catalan forge started to process the iron ore from the Pratt vein of what would later be known as the 81 mine (Linney 1943). Large scale operations started in 1867, but did not become significant until 1871. In 1881 the Chateaugay Ore and Iron Co. was organized and operated the mine until 1902 when it became a subsidiary of the Hudson Coal Co., a subsidiary of the Delaware and Hudson Railroad (Gallagher 1937). The mine closed temporarily from 1926 to 1929 because of the recession. Republic Steel Co. leased the mine in 1939. Mining activity in the region stopped for good in 1968 (Cavallerano and Zimmer 2009).

REGIONAL GEOLOGY

The Adirondack Mountains are part of the Grenville Province, formed by a series of orogenies that lasted from 1.3 to 1.0 billion years (Ga) ago. Three distinct orogenies are recognized in the Grenville province (Rivers 2008) including the Adirondacks. These are: (a) Elzevirian (1245 to 1225 Ma); (b) Shawinigan (1190-1140 Ma); and (c) Grenvillian, which included the Ottawan (1090-1020 Ma), and Rigolet (1000-980 Ma) pulses. An important boundary demarked by the Carthage-Colton Shear Zone (Geraghty et al., 1981; Streepey et al., 2001) separates two domains in the Adirondacks, the Central Metasedimentary Belt or Adirondack Lowlands (AL) and the Central Granulite Terrain, or Adirondack Highlands (AH). These two realms differ in terms of their lithologic content, metamorphic grade, and timing of last deformation.

 The uplifted region of the Adirondack Highlands has a dome-like shape. The AH contains supracrustal and volumetrically dominant igneous rocks that were metamorphosed at high temperature and medium pressure (granulite facies conditions) during the Shawinigan orogeny. The Ottawan pulse of the Grenville Orogeny (~1050 Ma) in this region has a strong thermal signature with zircon growth, anatexis in the lower crust, and intrusion of igneous rocks of various compositions in an extensional setting (Selleck et al. 2005). The oldest rocks are arc-related tonalities that were emplaced between 1330 and 1307 Ma (McLelland and Chiarenzelli 1990a). This event was followed by a series of younger magmatic events which included

intrusion of the AMCG suite (1165-1155 Ma; McLelland et al. 2004; McLelland and Chiarenzelli 1990b) and intrusion of younger igneous rocks such as the A-type Hawkeye granite (1100-1090 Ma), mangerites from the northern Highlands (1080 Ma), and the A-type Lyon Mountain granite (1070-1040 Ma) (McLelland et al. 1996).
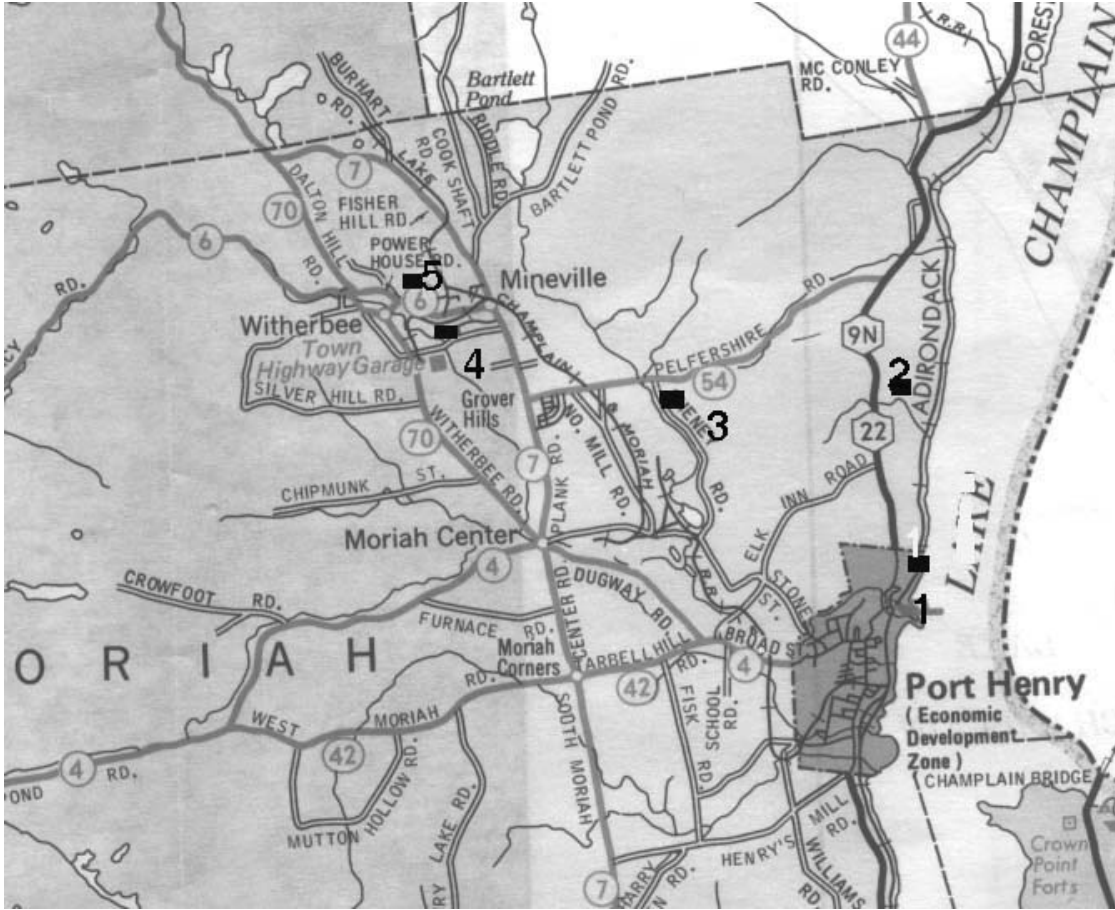
IRON DEPOSITS

The iron deposits from the eastern AH are low-Ti iron oxide ores that belong to the IOCG (iron-oxide-copper-gold) class of iron deposits (Hitzman et al 1992), although the lack of copper and gold also makes them similar to the classic Kiruna-type of iron deposit (Frietsch 1978). Proposed explanations for their origin include: 1) immiscible Fe-rich fluids (Postel 1952), 2) extraction of Fe during the breakdown of the Fe-rich silicates during metamorphism (Hagner and Collins 1967), 3) eruption of Fe-oxide-rich magmas (Whitney and Olmsted 1993), and 4) the interaction of surface-derived saline fluids with mid-crustal rocks in the late stages of the pluton emplacement (Foose and McLelland 1995; McLelland et al. 2002).

In general, the iron ores of the eastern Adirondacks consist of intrusive sheets or dikes that contain abundant low-Ti magnetite associated with fluorapatite, augitic pyroxenes, and trace minerals including zircon, stillwellite-(Ce), monazite-(Ce), and allanite-(Ce). Observations under transmitted light show polygonal and cumulate textures. The ore bodies, each with knife-edge contacts, may be temporally associated with the intrusion of A-type leucogranites (e.g. Foose and McLelland 1995; Valley et al. 2009; 2010; Valley 2010) and granitic gneisses (ca. 1040 Ma). Undeformed pegmatites cross-cutting the ore yield U-Pb zircon ages of ca. 1039 and 1022 Ma, with rims at 949 ±10 Ma (Lupulescu et al. 2011).

Based on the underground geological maps of the Republic Steel Company, McKewon and Klemic (1956) provided a detailed petrography and succession of the host rocks at Mineville. They concluded that the metamorphic sequence stratigraphically began with a basal metagabbro that was the equivalent of Kemp's (1908) "mafic syenite". This was overlain, in turn, by the magnetite-apatite ore of the "Old Bed", granite gneiss, diorite, gabbro, and the magnetite-silicate ore of the Harmony bed. Because the Mineville and Cheever deposits display close mineralogical and petrographic features, descriptions of much of the Cheever mine apply to similar occurrences in the Mineville deposits.

ROAD LOG

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.

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

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 1: Cheever mine

Location coordinates: N 44° 04' 43.5"; W 73° 27' 14.3"

At the Cheever mine, a 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 in

the Mineville area. 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, and minor pyroxene, or quartz, albite, microcline, and pyroxene-rich units. 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 (Figure 2). Some pyroxenes display exsolution of tiny elongated lamellae of another pyroxene and ilmenite as the result of the sub-solidus re-equilibration during slow cooling. In some grains, both types of lamellae occur oriented along the two pyroxene cleavages. Rare grains of ilmenite and pyrrhotite pepper the rock. The coronitic metagabbro contains a layered facies with the same composition as the massive one.
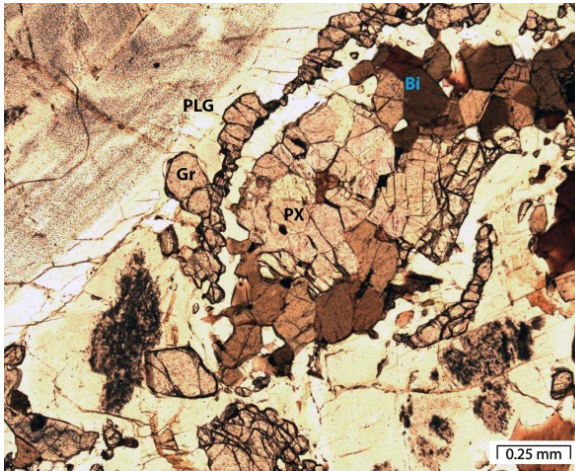

Figure 2. Coronitic metagabbro under the microscope in plane polarized light. Bi – biotite; PLG – plagioclase; Gr – garnet; PX – pyroxene. Plagioclase is clouded with spinels.
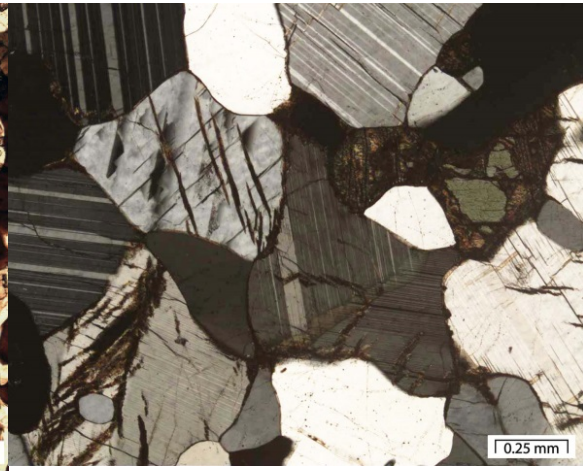
Figure 3. Host granite in cross polarized light. Albite is twinned, quartz is white, and green pyroxene is replaced by chlorite (upper corner).

The footwall rock which hosts the ore is granite that contains predominantly quartz and albite (Figure 3). Minor phases are grains of relict clinopyroxene (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. Further on, the rock displays a gneissic texture with alternating "bands" of quartz and albite, and pyroxene, amphibole, annite, magnetite, and 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 sustained also by microscopic study) and contain pyroxene, and rounded, in places 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, like those from Mineville (Figure 5a, b).

The magnetite-fluorapatite ore at the Cheever Mine forms 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 interraction 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.

Three samples of Cheever ore and host rock were selected for electron microprobe WDS analysis and in-situ U-Th-total Pb monazite geochronology. WDS compositional mapping was performed on the Cameca SX-50. Quantitative analysis of monazite was performed on the SX-100 ultrachron following procedures outlined in Allaz et al. (2013) at the University of Massachusetts, Amherst. Initially, thin sections were mapped for Mg, Y, Ce, Zr, and Ca or Fe (300 nA, defocused beam; Fig. 8). Close up maps of monazite were done with a fixed stage, using a beam rastering mode for sub-micron resolution, with the current at 200 nA. For large grains, stage mapping was employed due to the sufficient resolution at 2 micron-pixels. Preliminary geochronology will not be presented herein due to extremely low actinide contents

As mentioned above, the ore contains magnetite, apatite, allanite, monazite, stillwellite, and other phases. All thin sections contain sharp boundaries between ore and the host albite-quartz rock with augitic pyroxene crystals. All WDS full section maps show abundant zircon in host rock, but no zircon in the ore. One thin section (Figure 9) contains abundant REE bearing phases interspersed with magnetite. Most notably are medium grained stillwellite (Ca, LREE, Th borosilicate) and coarse symplectic intergrowths of allanite and monazite. Symplectic monazite has very low actinide concentrations, and has been a challenge to date (as noted above). However, the low actinide content suggests a low temperature, post mineralization origin for the symplectite formation. The other two thin sections contain coarse monazite crystals, typically associated with, and sometimes rimming, apatite crystals. Recent grain mapping has revealed several high Th grains, which should yield robust and reliable counting statistics, and thus an acceptable age determination. This work is ongoing.
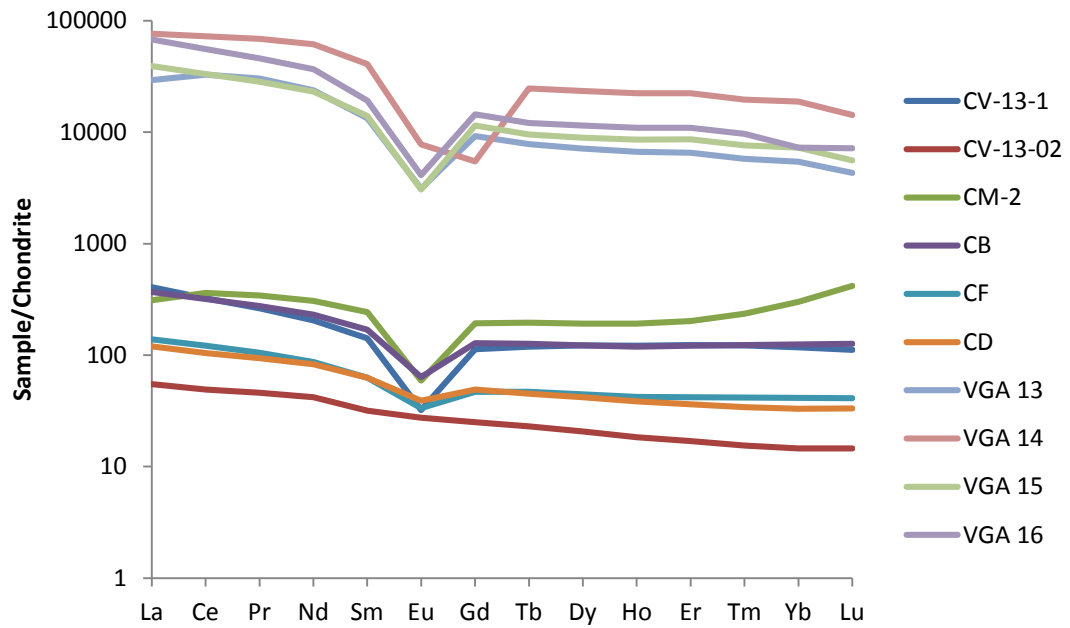
Figure 5a. Apatite/chondrite (VGA 13, 14, 15, 16 –upper group on diagram) and rock/chondrite (CV-13-1, CV-13-2, CM-2, CB, CF, CD-lower group) REE diagram for samples from the Cheever mine.
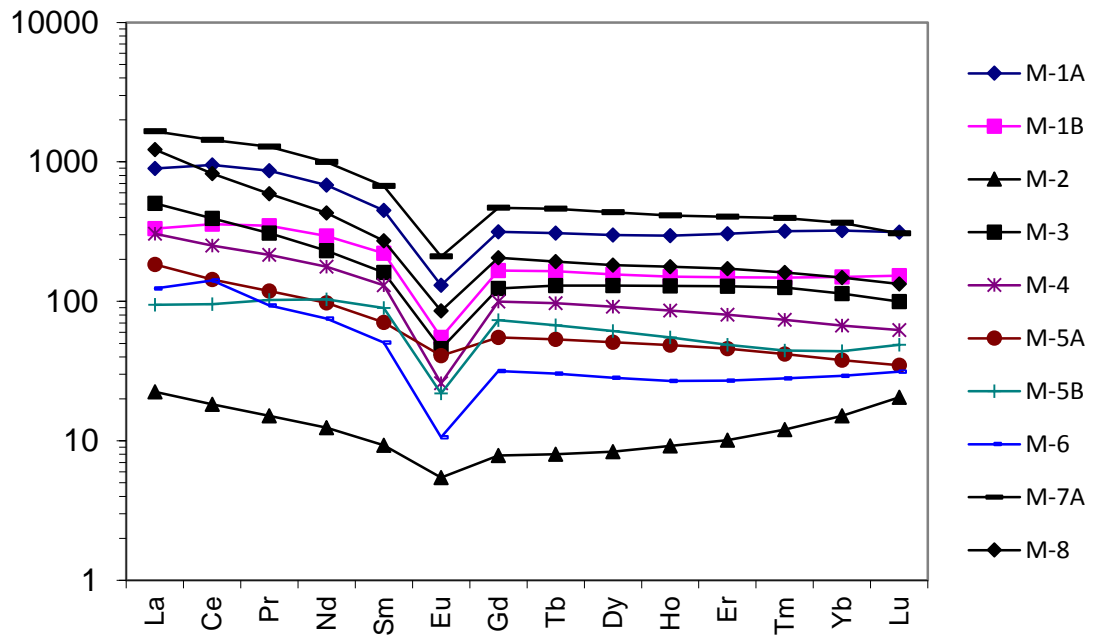

Figure 5b. Rock/chondrite REE diagram for rocks from the Mineville deposit.
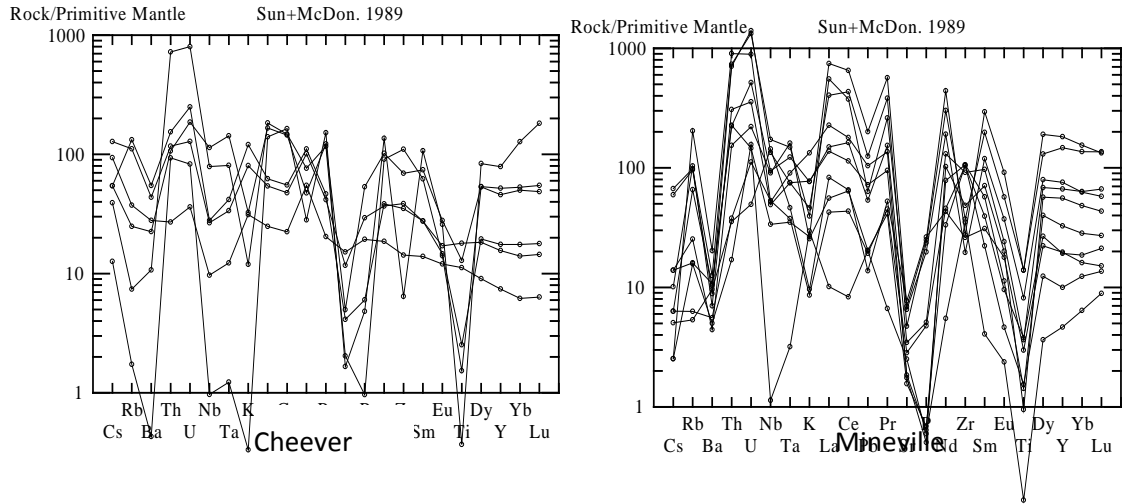
Figure 6. Rock/primitive mantle element abundance diagrams for the Cheever and Mineville rocks.
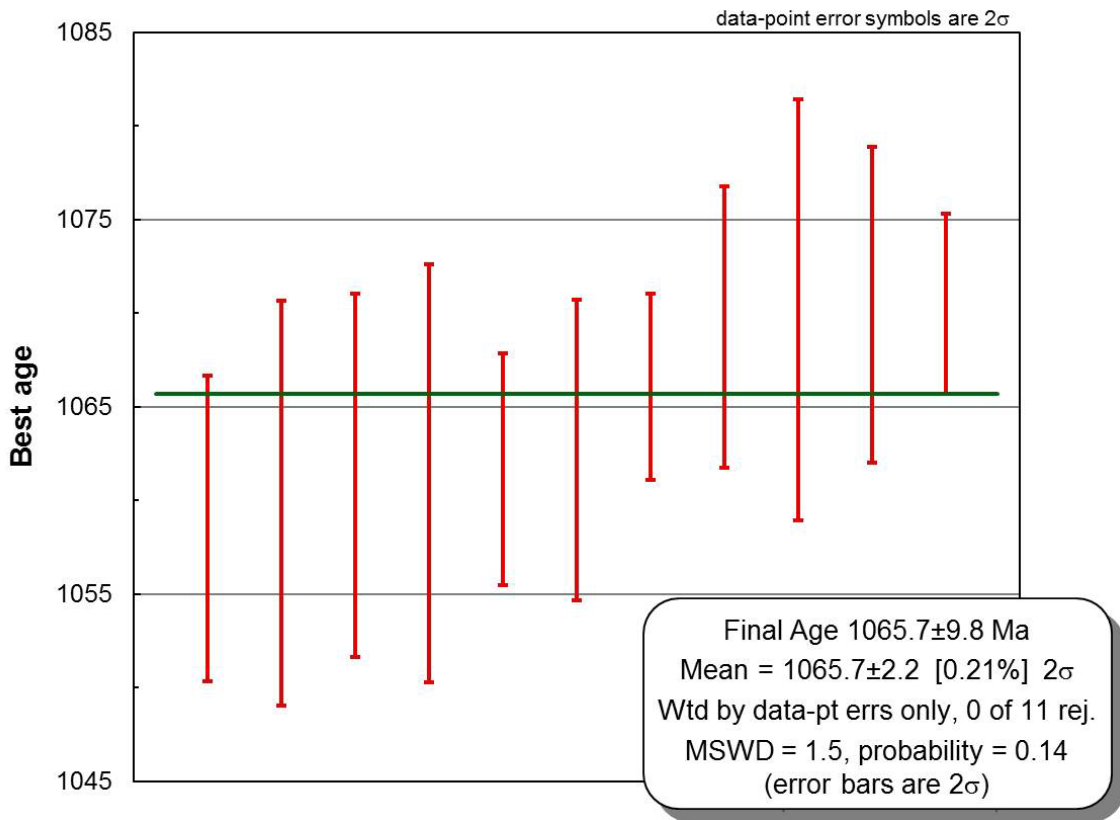

Figure 7. Zircon crystals separated from the ore-hosting rock were dated by LA-MC-IC-MS and yielded an age of 1065.7 ± 9.8 Ma.
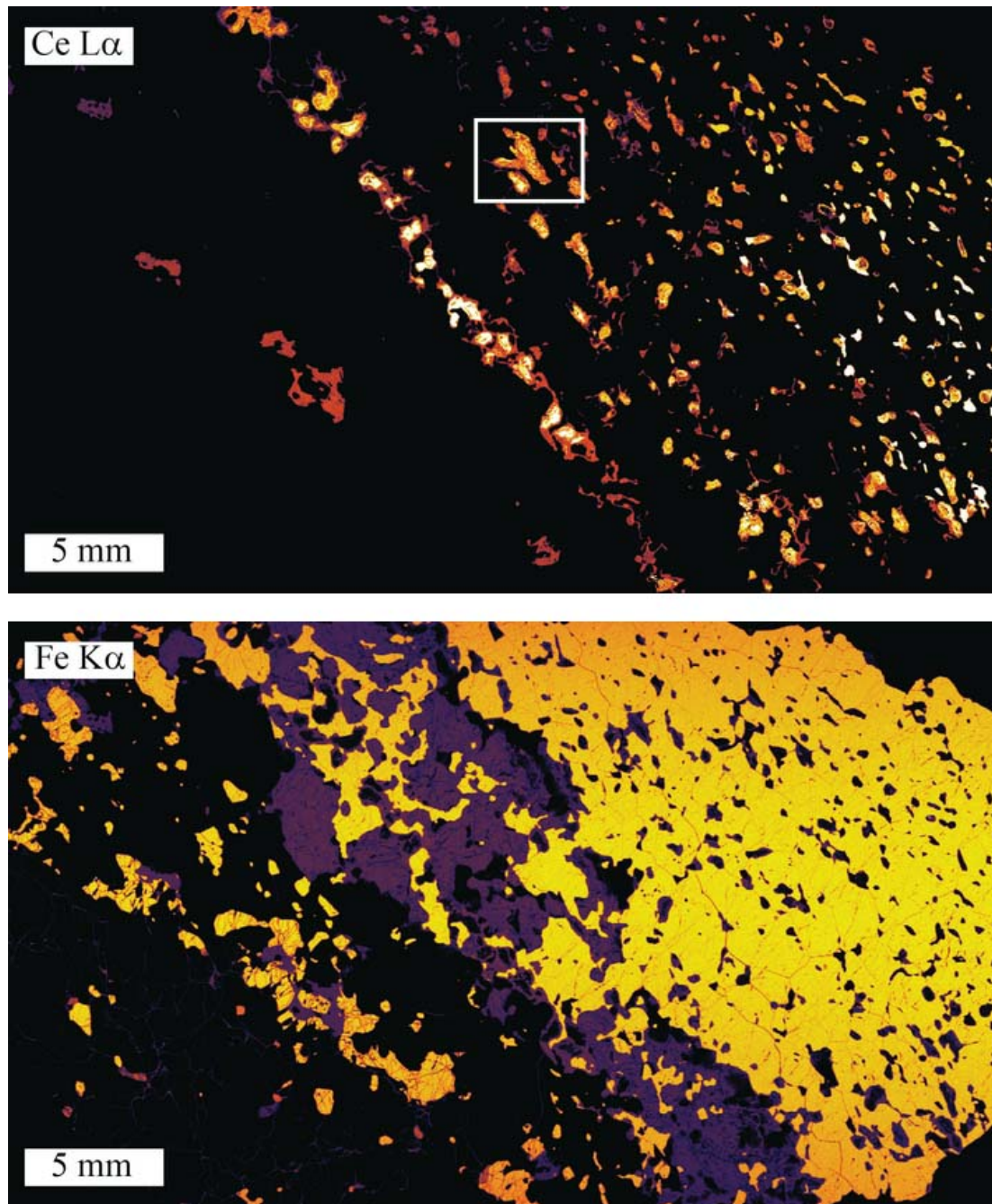
Figure 8. WDS full section maps for the Cheever mine ore. Note the abundance of Ce (proxy for monazite and other REE bearing phases) within the Fe-ore.
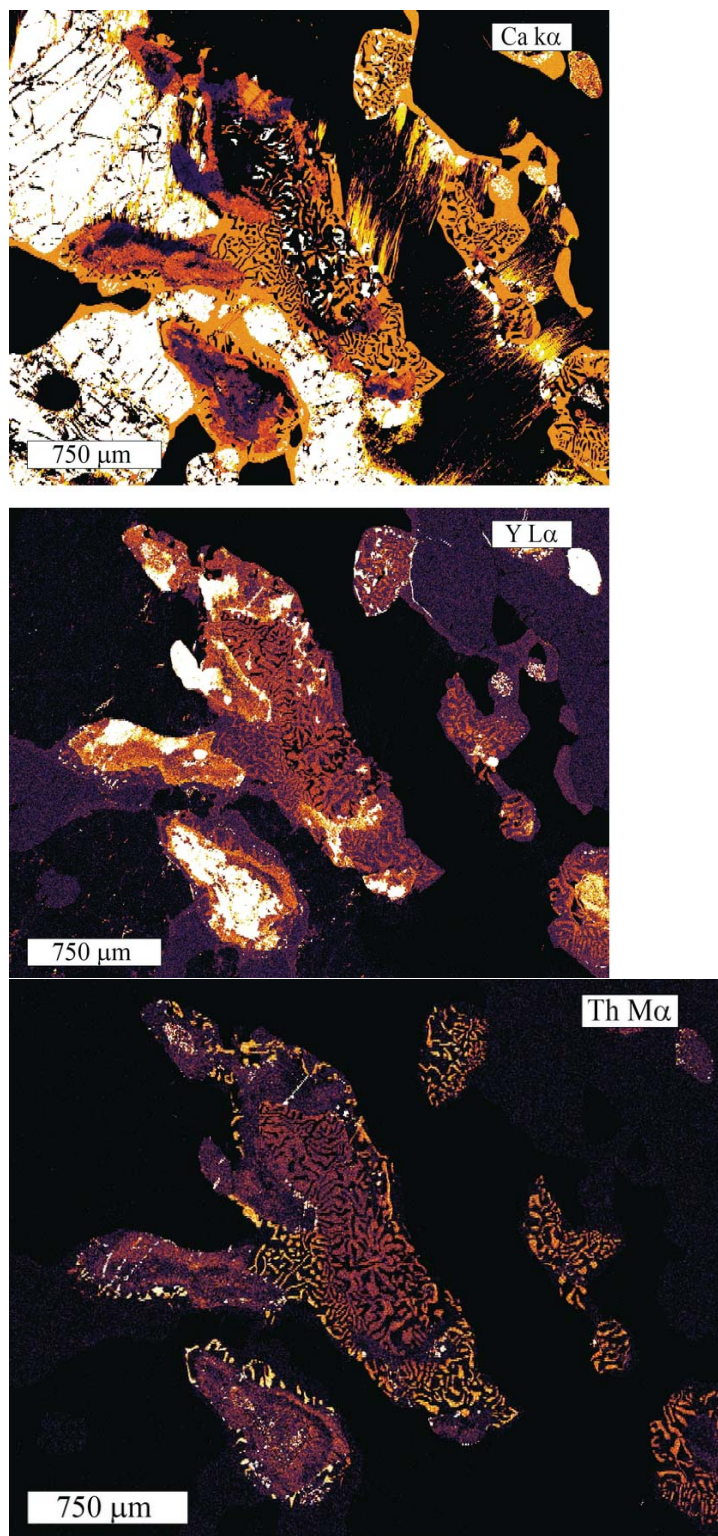
Figure 9. WDS compositional maps for monazite-(Ce) – allanite-(Ce) symplectite in Cheever mine. Within this thin section, all of the monazite contains very low total actinide compositions, consistent with low-temperature formation or dissolution-repreprecipitation reactions.

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