TIMING OF FLUID ALTERATION AND Fe MINERALIZATION IN THE LYON MOUNTAIN GRANITE: IMPLICATIONS FOR THE ORIGIN OF LOW-Ti MAGNETITE DEPOSITS

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INTRODUCTION

The Lyon Mountain granite (LMG), which crops out extensively in the northeastern Adirondack Highlands (Fig 1), is the host to numerous Kiruna type low-Ti magnetite deposits. The LMG experienced extreme metasomatic alteration by potassic- and sodic-rich fluids related to the Fe mineralization and during which time high field strength elements (HFSE) including Zr Y, U, and light and middle rare earth elements were highly mobilized during Fe mineralization.

This field trip will examine features associated with Fe mineralization, alkali metasomatism, the relative and absolute timing of the processes involved in the formation such deposits and the tectonic context in which these processes have occurred. Such processes are complicated and debate is encouraged.

GEOLOGIC SETTING

The LMG is a 1060-1045 Ma, syn- to late-tectonic granite that intruded the ~1150 Ma anorthosite-mangerite-charnockite-granite (AMCG) suite in the Adirondack Highlands (McLelland et al., 2001). Intrusion is syn-extensional between 1045 and 1037 Ma along the Carthage Colton shear zone in the western Adirondacks (Selleck et al., 2005). The Chateaugay mine is situated in the most northern and eastern region of exposed LMG (Fig. 1). By the early 1950s 15,000,000 tons of ore had been taken from the Chateaugay mine (Postel, 1952. This is one of several mines in and around the town of Lyon Mountain, New York. This Fe mineralized zone in the LMG lies near the northwestern flank of a large dome of Hawkeye granite. The Hawkeye granite intruded between 1103 and 1093 Ma (McLelland et al., 2001). Its age and characteristic quartz ribbon lineations provide a maximum age for the Ottawan orogeny in the Adirondack Highlands. A magnetic anomaly associated with Fe mineralization can be seen wrapping around the dome (Postel, 1952). This association suggests that either the mineralized zone was folded during subsequent doming/core complex formation, or that post-tectonic fluids penetrated into the LMG along a pre-existing structural interface with the Hawkeye granite. It is common throughout the LMG to find Fe mineralization in close proximity to the contacts of the LMG with other units, both igneous and sedimentary.

LITHOLOGY

At the Chateaugay mine and throughout the LMG three dominant lithologies persist; mesoperthite granite or granite gneiss, microcline granite and leucocratic albite/antiperthite granite

Mesoperthite granite

The granite consists mainly of mesoperthite, quartz, minor clinopyroxene and amphibole, biotite, minor apatite, titanite and zircon, and ubiquitous magnetite. This is the most common rock type in the LMG and probably was the original granite prior to alkali metasomatism. The unit is a pink, medium grained with varying amount of ferro-magnesian minerals. The unit may exhibit a gneissic fabric, which varies from locally penetrative to non-existent. Lamellae in the perthite grains are very coarse, sinuous, and free of micropores. These characteristics are consistent with perthites that have experienced metamorphism and deformation (e.g., Parsons et al. 2005).

Microcline granite

Microcline granite is representative of rocks in the LMG that have undergone extreme K metasomatism. Microcline granite consists of microcline as the dominant feldspar, quartz, minor clinopyroxene, disseminated magnetite, and minor titanite, apatite and zircon. The unit is pink to reddish pink and granoblastic. Any fabric is difficult to discern, as the main constituent minerals are equigranular. This suggests that these rocks experienced recrystallization after potassic fluid alteration if fluid temperatures were initially low or that fluid temperatures remained hot enough for triclinic microcline to form instead monoclinic orthoclase.

Leucocratic albite/antiperthite granite

These Na-rich granites are the result of rocks that have undergone complete (e.g., albite granite) or partial (e.g., antiperthite) albitization. Evidence that the albite granite and the antiperthite are the result of replacement is common. Both the perthitic granite and the microcline granite have been observed, at the outcrop as well as thin section scale, being crosscut and replaced by albite. Leucocratic albite granite is typically comprised of albite and quartz, minor amphibole, clinopyroxene, biotite, chlorite, magnetite, and minor titanite apatite and zircon. The unit is white to light gray and has a granoblastic texture. Fluorite has been observed in rocks that have experienced albitization.

LOW-Ti MAGNETITE DEPOSITS

Low-Ti magnetite deposits are part of larger class of deposits known as iron oxide (-Cu-Au) (IOCG) deposits. The characteristics of these deposits vary significantly from locality to locality. Olympic Dam in south central Australia contains significant amounts of Cu, Au and U, of significant economic proportions, while the dominant ore at Kiruna in northern Sweden, is magnetite and apatite (e.g. Reynolds, 2000; Harlov et al., 2002). The unifying characteristics of all these deposits are low-Ti Fe-oxides (magnetite and hematite, or pseudomorphic replacement of magnetite by hematite – so called martite), extreme hydrothermal alteration (Na, K, Si, seritization), and occur in extensional tectonic settings (Hitzman et al., 1992).

Low-titanium magnetite deposits in the LMG are associated with Na alteration of both the microcline and perthitic lithologies listed above (McLelland, 2002). The ores are comprised of magnetite, and/or hematite, and typically include quartz, apatite, feldspar, and clinopyroxene. The LMG ore bodies are associated with shear zones, the hinge regions of folds, and at the contact of the LMG with other units (Postel 1952, Whitney and Olmsted, 1993). The ore bodies generally conform to the foliation of the host granites but locally crosscut the gneissic fabric, where present, at a high angle. Barren zones nearly devoid of magnetite occur in the granite immediately adjacent to the ore bodies (Hagner and Collins, 1967). Outside of these barren zones disseminated magnetite occurs in the host granites.

Previous workers have discussed the origin of magnetite ores in the LMG. These include: 1) differentiation of immiscible Fe-rich fluids derived from the latest stages of granitic magmatism (e.g., Postel, 1952; Buddington, 1966); 2) preexisting mafic silicates that have broken down during deformation and metamorphism (Hagner and Collins, 1967); 3) eruption of Fe-oxide magmas and their interaction with evaporitic sediments (Whitney and Olmstead, 1993); and 4) brines that have interacted with the latest stages of pluton emplacement (McLelland et al., 2002).
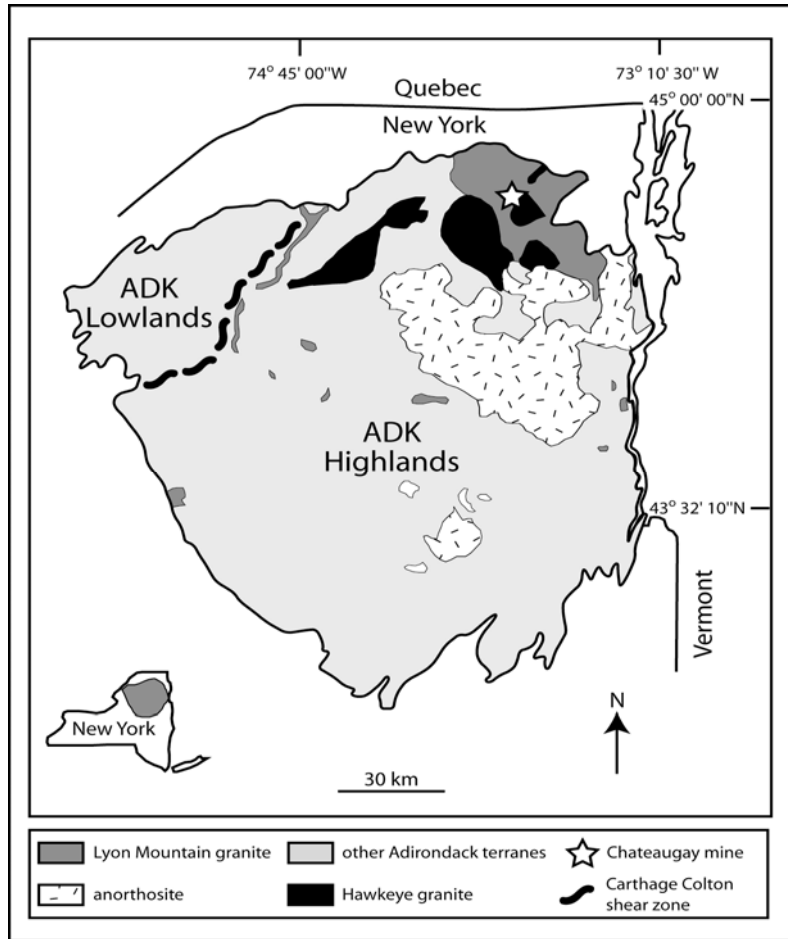
Figure 1. Generalized geologic map of the Adirondack Mountains.

ROAD LOG

This field trip has only one stop which is at the large open pit Chateaugay mine in Lyon Mountain, NY. To reach the mine from the parking area involves a short hike of approximately 200m. Accessing the mine is not difficult but extreme care should be taken while at the mine especially if the rocks are wet. Hiking boots are necessary since there is much loose rock in and around the mine some which we will traverse. Permission to visit the mine must be made in advance with the town office in Dannemora, New York. Hammers are welcome and flashlights may be useful for looking into adits and areas in shadow.

Mile
00.0   Exit 38N off of I87, from exit ramp follow routes NY 374W and NY 22N
00.2   Turn right at first light on route 22N.
00.7   Meet at Shell gas station.
        Left out of gas station parking lot on route 22S. Proceed back to traffic light, turn right onto route 374W. Outcrops of Beekmantown dolostone on left.
03.6   Cross route 190, continue west on route 374.
13.0   Clinton County Correctional Facility on right. Downtown Dannemora.
14.2   Outcrops of microcline granite on right side of road.
15.0   Outcrops of highly migmatized metasediments on left side of road

19.7	Chazy Lake on left. View of Lyon Mountain to the SW. This mountain is a large dome of Hawkeye granite
26.2	Just past Mobile gas station, turn left onto Standish Road
26.9	Left onto Power House Road
27.2	At "T" in road, turn left. Park on side of road just before gate to town sand pile

To reach the mine, proceed past the gate and around to the right around an old garage until you reach the first dirt road. Turn right on old dirt road. Follow road past a small old building and follow road to the right. After Approximately 30 meters the road forks. Follow the right fork. After only 3-5 meters there is a small overgrown road on the left goes downhill for 20 meters where it opens in the mine quarry. The area from the where the cars are parked to the mine is modified from time to time by logging operations, so the details above may change a bit. Total distance from the cars to the mine should not be more than a few hundred meters.

STOP 1: CHATEAUGAY MINE, LYON MOUNTAIN, NEW YORK

The Chateaugay mine is one of a series of large open pit and underground mines in the Lyon Mountain area. Mining began in the town of Lyon Mountain in 1867. By the early 1950s 15,000,000 tons of ore had been taken from the Chateaugay mine (Postel, 1952). The Lyon Mountain mines closed in 1967. Much iron remains but removal is not cost effective compared with cheaper foreign sources.

The strike of the quarry is approximately SW. The footwall and hanging wall of the ore body are perfectly exposed on the SE and NW walls of the pit, respectively. The ore follows the general trend of the pit and the gneissic layering, but locally crosscuts the gneissic banding (Gallagher, 1937). The local structure here appears to be that of a monocline with dip increasing towards the hanging wall. Overall the ore bodies here occur as "cigar-shaped" shoots in the limbs and core of a synclinal structure that plunges to the NE (Postel, 1952). These NE plunging structures are sometimes mimicked on a smaller scale by mafic and magnetite layers when observed in overhanging ledges in the quarry wall. Locally the ore may pinch and swell and may be openly folded.

Magnetite is the constituent ore mineral and is associated with pyroxene skarn and pegmatite and locally apatite and quartz. Magnetite rims pyroxene at both the outcrop and thin section scale. Late amphibole and chlorite are also associated with the pyroxene.

New age data from U/Pb zircon dating of various samples from the LMG and associated rocks will be discussed doing the field trip but are not listed here as they are in the process of being published elsewhere in a peer reviewed journal.

Mylonite

On the SE wall of the mine is a mylonitic shear zone (Fig. 2). The shear zone appears approximately parallel to the gneissic layering of the granite. "In-place" measurement is not possible as the mylonite is exposed high in the footwall of the mine and is not easily accessible. Blocks of the mylonite, however, lay at the base of the wall. Mylonitization is accompanied by partial melting of the felsic component of the host rock. Thin sections from this mylonite show that Fe mineralization is contemporaneous with shearing (Fig 3). Mineralogically, the mylonite contains remnant perthitic feldspar and microcline. The matrix consists of fine-grained albite, quartz, calcite, "strings" of magnetite and minor apatite and titanite.

Migmatites

In the hanging wall, on the northwest wall of the quarry immediately opposite the mylonite, is an approximately meter wide zone of migmatization. Here, the felsic component of the rock has melted leaving behind the more competent mafic rock to be deformed in a brittle manner. In places leucosomes are clearly rimmed by mafic selvages indicating that melting took place relatively in-situ and that these zones of melting are not intrusions into the LMG. The migmatite zone continues along the quarry wall. The felsic portion of this rock consists of quartz and coarse microcline. The mafic portion is dominantly

cpx with late amphibole. Sugary-textured microcline granite borders the migmatized zone consisting of quartz, microcline and clinopyroxene.

Localized migmatite zones may also be evidence for fluid pathways. If this is true and the fluids are related to Fe mineralization then these fluids must have been hot enough to melt the felsic component of the rock. Fluid temperature estimates between 675 and 565 °C were determined from quartz-magnetite $\delta^{18}O$ fractionation elsewhere in the LMG (McLelland et al., 2002). Melting of granitic rocks in the presence of even small quantities of H_2O may begin at 600 °C (Robertson and Wyllie, 1971). Experimental data for granitic melts in the presence of F show that melt may be present as low as 550 °C (Manning, 1981). The presence of fluorite and F bearing alteration minerals and the previous temperature estimates by McLelland in the LMG suggests that partial melting during fluid alteration is a reasonable assumption.

Ore

The quarry steps down ~5 meters just beyond the migmatite locality. This step provides an excellent cross section view to the northeast of un-mined ore and the contact of the ore with the hanging wall and footwall (Fig.2). The ore here varies from "strings" or layers of "lean" ore to massive magnetite. The layers of magnetite in the "lean" ore are generally concordant with the gneissic fabric of the host, but locally these strings of magnetite are highly variable in orientation. Pegmatites containing amphibole and orange potassium feldspar are common near the edges of the ore as well as pyroxene skarn. There is a general transition from massive ore to layered magnetite + pyroxene skarn + pegmatite to barren granite (see below) to microcline granite with disseminated magnetite in the hanging wall (Fig.2). The contact of the ore with the footwall is not well exposed here. Further along in the quarry to the southwest a transition from ore to layered magnetite, to perthitic granite with pyroxene and disseminated magnetite occurs in the footwall. The ore commonly consists of magnetite, quartz, pyroxene and varying amounts of apatite and remnant perthitic feldspar.

"Barren" Granite

Disseminated magnetite is ubiquitous throughout the LMG. In the granite immediately adjacent to the ore body, however, there is commonly found a zone depleted in magnetite. These so-called "barren" zones are most likely a source for much of the magnetite in the ore body (the breakdown of Fe bearing pyroxene may be another). The barren zone can be traced along the length of the quarry just above the ore body and appears to be "sandwiched" between two zones of "lean" ore. There is possibly a second barren zone above the top "lean" ore but this is inaccessible and as such difficult to verify. The width of the barren zone is ~2 meters in most places. Approximately 50m beyond where the floor of the quarry steps down is an easily accessible place to view the barren zone on the NW side of the quarry. The rock is dominated by microcline and quartz with essentially no ferromagnesian minerals. Remnant pyroxene where present, usually occurs as inclusions in "forest" green amphibole. Late albite crosscuts microcline and there is some Ca alteration as well in the form of calcite. These zones depleted in magnetite are common around most of the ore deposits in the LMG (Postel, 1952). At the Palmer Hill mine this zone is up to 150m wide (Hagner and Collins, 1967).

Crosscutting Dike

Approximately 250 meters from the entrance to the quarry, located on the northwest side of the quarry, is a dike that crosscuts the gneissic fabric of the granite. The dike consists of quartz, plagioclase, magnetite, and minor sulphide and is approximately one meter wide. The composition of the plagioclase is oligoclase (McLelland, 2001). We will discuss the U-Pb age of this dike and its implications for Fe mineralization and deformation of the ore and host granites. A number of cross-cutting pegmatitic dikes are present throughout the quarry and range from plagioclase rich to syenite pegmatites to granite pegmatite and younger cross-cutting diabase dikes. These dikes do crosscut the ore but seem closely related, exclusive of the diabase dikes, to the mineralization and fluid alteration based on their chemistry and mineralogy.

Possibly related to these pegmatitic dikes are miarolitic cavities that also truncate the layering in the ore and the granite. These cavities are often up to a meter long. One is said to be large enough for a man to stand in (Gallagher, 1937). These cavities may contain very large crystals of orthoclase more than a foot in

length, quartz, titanite, apatite, agerine/augite, amphibole and late nearly pure albite. It is not clear how these formed but for open spaces this large they could not have experienced much deformation. These cavities are difficult to find in the quarry but a number of them are present. One can be observed on the backside of an ore pillar at the southwest end of the quarry. It is associated with an orange granitic pegmatite dike that crosscuts the layering in the ore.

Ore Pillar

Most of the quarry we have walked through has been filled in after mining ceased for safety reasons. However at the far end of the quarry it is still possible to view a deeper section of the mine. Here, two ore pillars are still standing where it is possible to view the true thickness of the ore. Access is difficult due to the steep slope, but the pillars can be viewed from a distance. The massive ore is approximately 3 meters thick with lean ore above and below. You may also be able to observe the NE plunging lineation in the rocks that overhang the ore pillar as well as another crosscutting dike, the barren zone, and migmatite layer.

Another feature at the mine are discontinuous mafic layers. They consist of amphibole and/or biotite and plagioclase that take on a "salt and pepper" appearance. These mafic layers may exhibit gneissic banding internally and vary in thickness from a few centimeters to meters in width and are common throughout the LMG. During this study they were observed to be continuous beyond the limit of exposure. When exposures were better during active mining, these layers are reported to anastomose and pinch out, but can persist for over 100 meters (Gallagher, 1937).
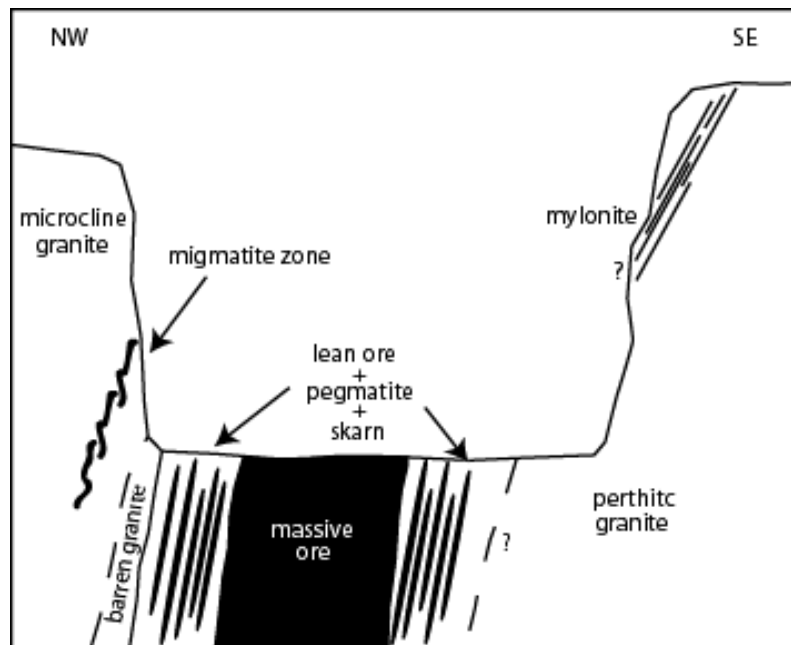

Figure 2. Generalized cross-section of the Chateaugay Mine with important features of this field trip labeled.
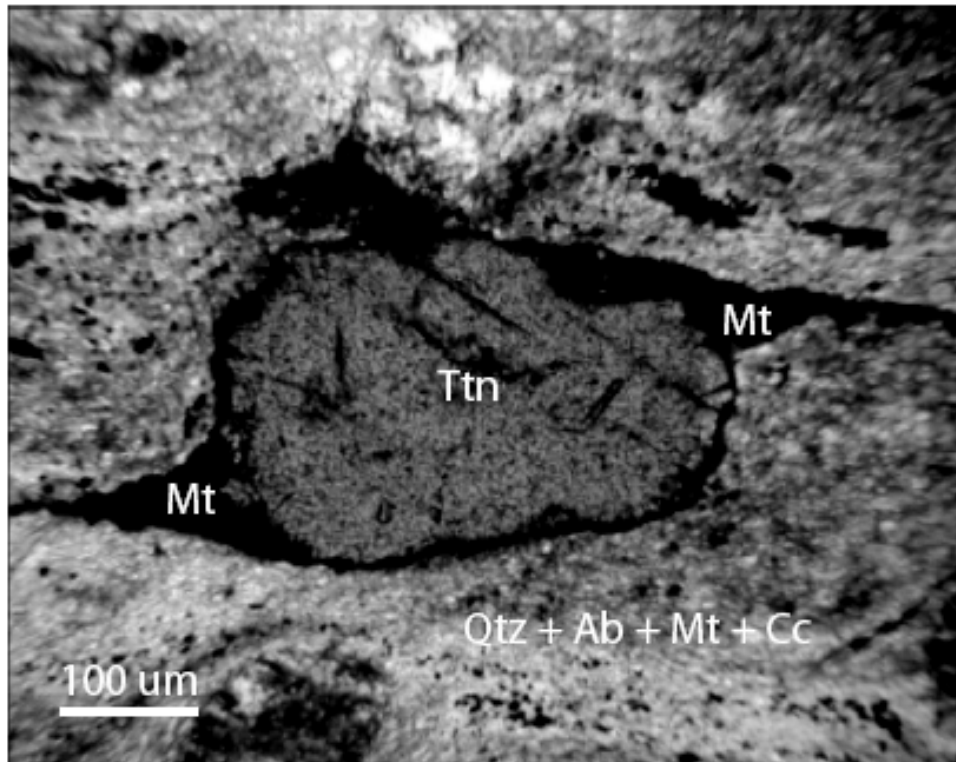
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Figure 3. A plane polarized light photomicrograph from a mylonite in the Lyon Mountain granite. Photomicrograph shows magnetite growing during deformation. Mineral abbreviations after Kretz (1983).

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