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## A Study of Heavy Minerals Found in a Unique Carbonate Assemblage from the Mt. Mica Pegmatite, Oxford County, Maine

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**A Study of Heavy Minerals Found in a Unique Carbonate  
Assemblage from the Mt. Mica Pegmatite,  
Oxford County, Maine**

An Honors Thesis

Presented to

The Department of Earth and Environmental Sciences  
of the University of New Orleans

In Partial Fulfillment

of the Requirements for the Degree of

Bachelor of Science, with University Honors

and Honors in Earth and Environmental Sciences

by

Christopher M. Johnson

May 2013

This Thesis is Dedicated to:

Dr. William “Skip” Simmons &

Dr. Karen L. Webber

Who have greatly assisted in making me a better geologist

By exposing me to many rocks

To Mein Bruder, Alexander Falster

Words can never express my appreciation and gratitude

To my fellow Office Colleagues:

Karen, Kim, Drew, Leah, Jon, Miles, and Sasha

Who have been of tremendous help and support

And especially to my fiancé, Nick

Whose love and tolerance have been

A true saving grace

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## Abstract

Granitic pegmatites are coarse-grained igneous intrusive rocks produced from late-stage crystallization of felsic magma. During the fractional crystallization process of cooling magma, the residual melt becomes enriched in rare elements and volatiles. The presence of volatiles and fluxes concentrated in the resulting melt decreases viscosity, solidification temperature, and nucleation rates and increases diffusion rates. This generally produces fewer larger crystals compared to other granites. Final stages of cooling may culminate in the formation of miarolitic cavities. In the core margins of the Mt. Mica pegmatite, unusual carbonate-apatite-tourmaline units exist near larger, primary miarolitic cavities, masses of lepidolite, and pollucite masses. These units are rich in mineral species, some of which are very rare (such as kosnarite and mccrillisite). This study investigates the heavy minerals ( $>3.0 \text{ g/cm}^3$ ) near the carbonate-rich units and attempts to gain insight into their formation. The heavy minerals found include: pollucite, chalcopyrite, tantalite-columbite, arsenopyrite, lithiophilite, montebrasite, cassiterite, pyrite, uraninite, eosphorite-childrenite, zircon, albite, apatite, tourmaline, siderite, rhodochrosite, members from the monazite group as well as clays and zeolites. The presence of these minerals suggests that carbonate units crystallize during late stages of cooling or as  $\text{CO}_2$ -rich fluid reacts with other components or minerals. The carbonate minerals siderite and rhodochrosite suggest reaction of the  $\text{CO}_2$ -rich fluid with iron and manganese. Zeolites, clays, sulfides, carbonate minerals, and eosphorite-childrenite indicate crystallization at lower temperatures ( $<450^\circ\text{C}$ ). The phosphate minerals apatite, montebrasite, and possible lithiophilite indicate late stage crystallization from a highly fractionated melt rich in the fluxes Li and P. The presence of the silicate assemblage lepidolite, tourmaline and pollucite indicate that the melt was also rich in the fluxes boron, lithium and cesium. Crystallization of apatite, lepidolite and schorl remove phosphorus, lithium and boron from the melt, which reduces the solubility of the remaining melt and promotes the exsolution of a water and  $\text{CO}_2$  rich fluid. The water-rich fluid leads to the formation of miarolitic cavities. Fluids rich in  $\text{CO}_2$  are responsible for the formation of the carbonate units. More comprehensive research is recommended to further test conditions of formation.

Keywords: Pegmatite, Mt. Mica, carbonate assemblage, heavy minerals

## **Objective:**

This thesis focuses on heavy mineral species found in a unique carbonate assemblage in the Mt. Mica pegmatite in order to determine the conditions of their formation and their mineral paragenesis as well as to gain insight on the origin of this very unusual carbonate-rich unit.

## **Introduction**

Pegmatites are a type of igneous intrusive rock with coarse-grained texture, produced as magma cools during late-stage crystallization (Simmons et al., 2003). Pegmatites form dike-like structures that contrast in appearance and color with the surrounding country rock (Simmons et al., 2003). Most pegmatites are granitic in composition (some pegmatites are gabbroic, syenitic, or dioritic compositionally), but not all granites can be considered pegmatites. The classification of a granitic body as pegmatitic also includes the size of the grains as well. The length of the crystals must be at least 2 centimeters in order for the body to be described as having a pegmatitic texture (London 2008). Pegmatites are known for immense grain size variation over several orders of magnitude in relatively short distances. Due to their very coarse crystal size, pegmatites are easily recognizable in the field. Pegmatites are of economic importance because minerals such as feldspar can be mined and used for the production of ceramics. The larger grain size makes mining more efficient and cost-effective. They are also a source of rare-element-bearing and gem-quality minerals. Beyond these important natural resources, pegmatites offer geologists and geochemists the opportunity to study the unique conditions of a highly fluxed and very low-temperature melt under which a

pegmatite may form.

As the granitic magma cools, it undergoes a process called fractional crystallization. During this process, the melt becomes increasingly enriched in rare elements and volatiles as compatible elements are incorporated into crystallizing phases (Simmons et al., 2003). Rare and incompatible elements are not accommodated in the common rock-forming minerals during this early stage of crystallization because of their ionic size, charge, or both (Simmons et al., 2003). As minerals crystallize and the magma body reduces in volume, the remaining melt becomes more enriched in incompatible and rare elements. The presence of volatiles (H<sub>2</sub>O) and fluxes (such as boron, fluorine, lithium, and phosphorus) within the melt lowers viscosity and the solidification temperature (Simmons et al., 2003). Volatiles also reduce nucleation rates and increase diffusion rates, resulting in fewer larger crystals. Thus, the presence of volatiles assists in the formation of the characteristic texture of pegmatites. The final cooling stages of the melt will sometimes culminate with the formation of miarolitic cavities lined with minerals that are rich in these incompatible and rare elements.

Even though the external morphology of pegmatites will differ in appearance from one location to the next, the internal structure can be used to classify pegmatites as one of three types. Simple pegmatites are uniform in grain size, composition, and texture throughout. These pegmatites consist of quartz and feldspar with minor amounts of a mica species. Zoned pegmatites are not uniform in texture, composition, or grain size. Zones in these pegmatites can be mapped based on the differences in texture and mineral content. The zones will commonly display an increase in grain size from wall to core zones. Complex pegmatites are mineralogically and morphologically more elaborate

than zoned or simple pegmatites due to secondary replacement of primary units.

Complex pegmatites are also much rarer than simple or zoned pegmatites. Grain sizes are irregular and these pegmatites will often host rare or exotic mineral species that may be enriched in volatiles.

Along with the three types of internal structure, pegmatites can be divided into two types based on common and minor/trace element assemblages. The first of which, LCT, is much more abundant than NYF types (London 2008). LCT pegmatites are enriched in Lithium, Cesium, and Tantalum and to a lesser extent in beryllium, boron, fluorine, phosphorus, manganese, gallium, rubidium, niobium, tin, and hafnium (London 2008). NYF pegmatites are enriched in Niobium, Ytrium, and Fluorine and may also be enriched in beryllium, titanium, rare earth elements (REE), and zirconium (London 2008). This thesis focuses specifically on Mt. Mica, an LCT type pegmatite located in Paris, Oxford County, Maine.

## **Regional Geology**

Mt. Mica is one the most famous pegmatites in the Unites States. It is also renowned for the first reported gem quality tourmaline in the United States (Hamlin 1895). For nearly 200 years, Mt. Mica has produced gem-quality tourmaline (Simmons et al., 2005). Mt. Mica is part of a greater complex of pegmatites spanning the western portion of Maine which is known as the Oxford Pegmatite Field (OPF) (Wise & Francis 1992). The OPF is spatially related to the Sebago batholith (Simmons et al., 2005). The spatial proximity of the pegmatites to the Sebago batholith, suggests a genetic

relationship (Simmons et al., 2005). An approximate age of  $296 \pm 3$  million years for the Sebago batholith was determined by uranium-lead isotopes found in zircons (Foord et al., 1995). Mt. Mica is a poorly zoned pegmatite. The wall zone is very thin (approximately 2-5 cm in width), but the intermediate zone, located within the more substantial portions of the pegmatite, can reach up to 1.5 meters in thickness (Simmons et al., 2005).

Principal mineralogy within the intermediate zone yields sodic plagioclase, muscovite, schorl, and very little K-feldspar (Simmons et al., 2005). The core of the pegmatite consists mainly of quartz and albite, with locally abundant K-feldspar, schorl, pods of cleavelandite, rare masses of lepidolite and minor amounts of spodumene, pollucite, cassiterite, columbite, and very rare beryl (Simmons et al., 2005). Pockets with rare-element-bearing and gem-quality minerals are located within the inner zones of the pegmatites (Simmons et al., 2005).

Located within the core margins of Mt. Mica are smaller units representing a distinctly different late-stage environment. These carbonate zones contrast with the assemblage of the much larger primary miarolitic cavities. The carbonate minerals form a graphic intergrowth with blue tourmaline. Quartz, feldspar, and mica (common constituents of all pegmatites) are located near these carbonate units, but also present are sulfide minerals which are rarely found in pegmatites (Černý & Harris 1978). Pollucite, a rare cesium-rich hydrated aluminosilicate, has been found near these assemblages as well. Other rare and exotic minerals have been discovered within and near these carbonate zones. Lepidolite is often found next to these zones, but has not yet been found within the main carbonate unit. The rare minerals kosnarite and mccrillisite had been previously found in these units. For both species, Mt. Mica is the type location

(Brownfield et al., 1993 & Foord et al., 1994). Iron-rich tourmaline and montebrasite are also nearby. These carbonate assemblages with blue tourmaline are rare, only found in the Mt. Marie and Mt. Mica. However, late stage carbonate replacement units have been noted in other locations as well, such as the Palermo #1 pegmatite in New Hampshire. There, the unusual texture typical at Mt. Mica is not present as these units are secondary replacement processes around triphylite pods. The carbonate assemblages at Mt. Mica and Mt. Marie are primary in origin. This thesis focuses on heavy minerals (density greater than  $2.75 \text{ g/cm}^3$ ) found within these unique carbonate/apatite/blue tourmaline units in order to better understand their genesis.

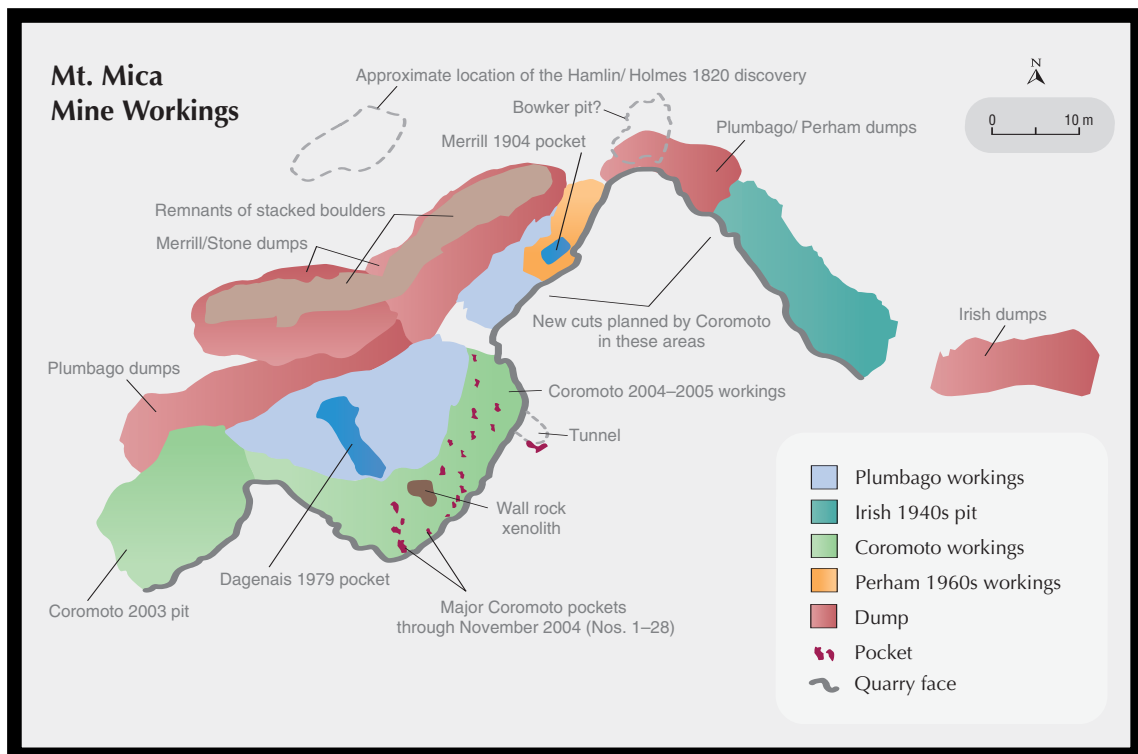







Fig. 1: by Gary Freeman illustrates the areas where pockets are located as well as previous mining activity.



Fig. 2: Color Overlay Image of carbonate pod *in situ* and close-up of the graphic intergrowth of the carbonates and blue tourmaline.

- |  |                       |
|--|-----------------------|
|  | Lepidolite            |
|  | Schorl                |
|  | Mica                  |
|  | Montebrasite          |
|  | Rimmed Carbonate Pods |

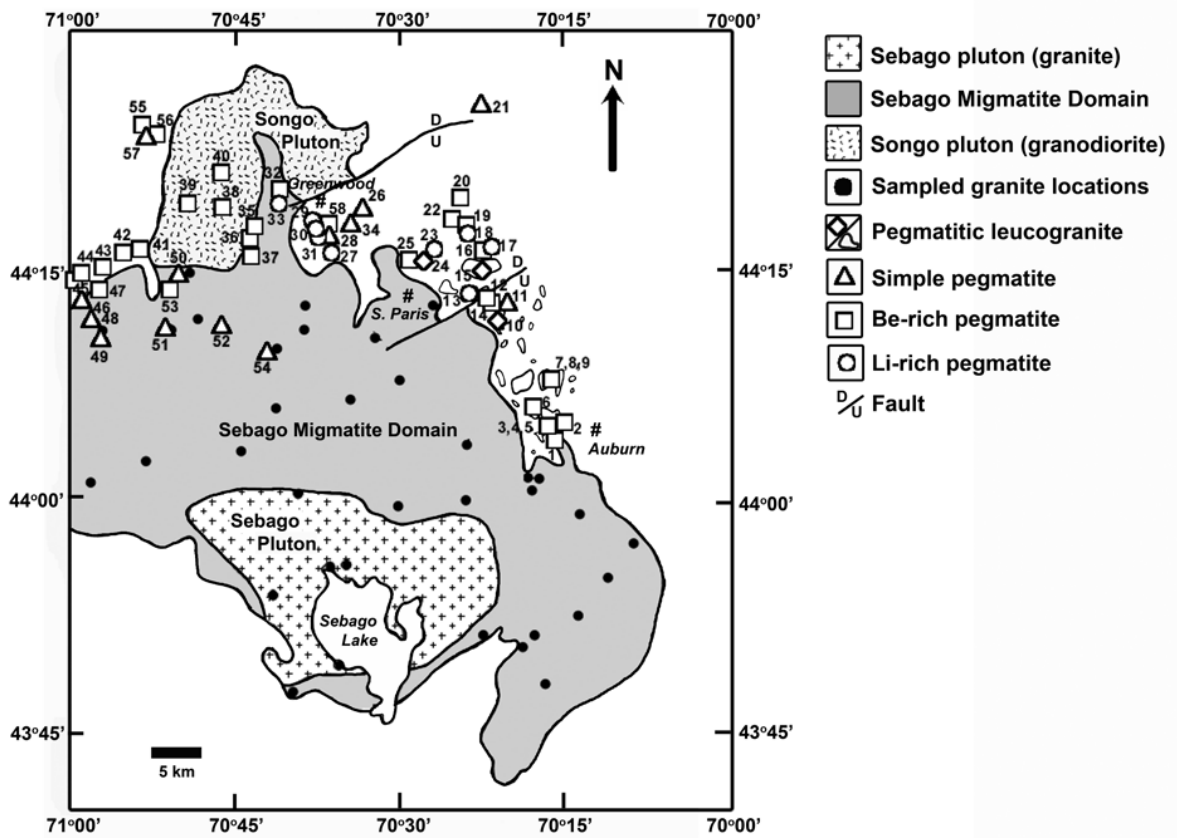


Fig. 3: Southern Portion of Oxford Pegmatite Field from Wise & Brown (2010).



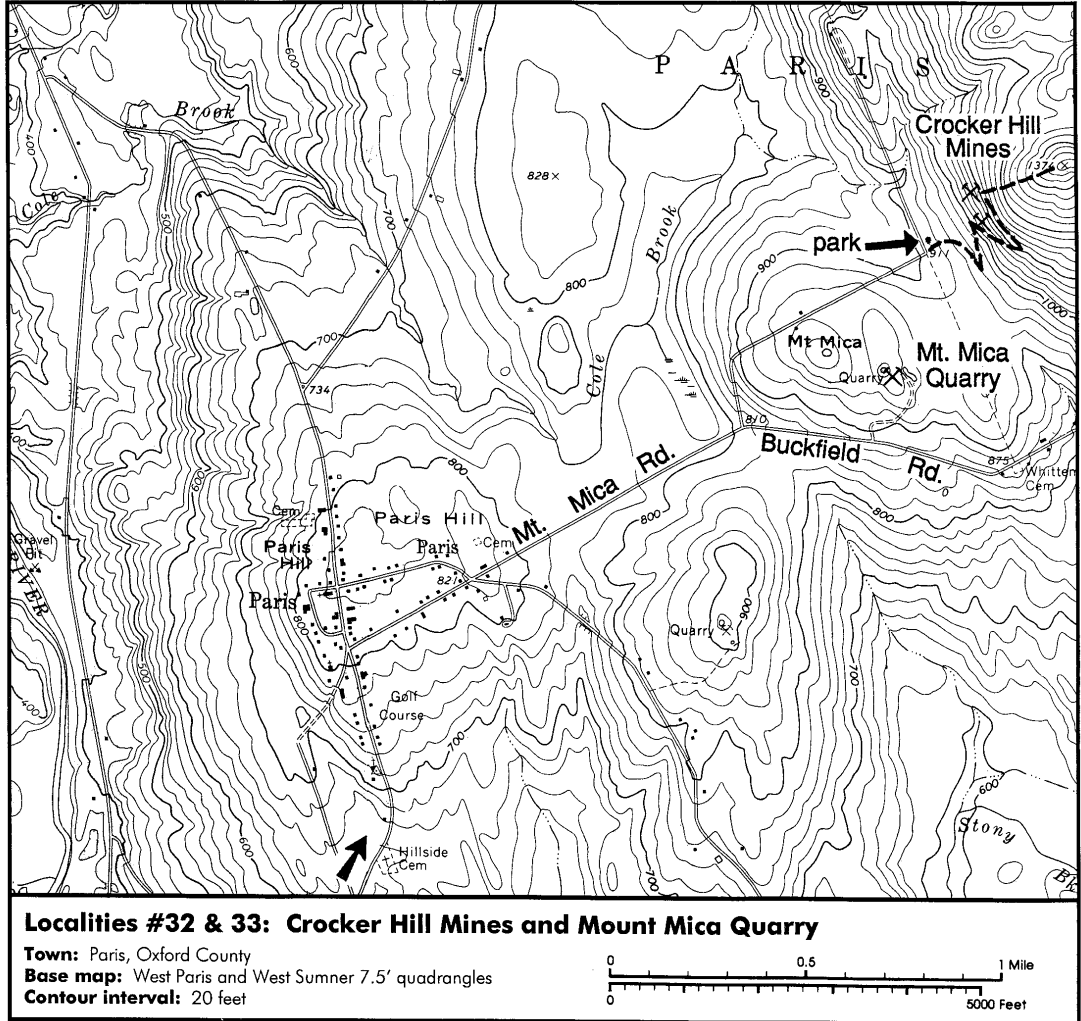


Fig. 4: Mt. Mica Quarry Paris, Maine (Thompson et al., 1998)

## Methods

Samples collected from Mt. Mica were crushed into millimeter-sized particles (Fig. 7). Following this step, the fine-grained sample was wet sieved through a 1mm mesh sieve (Fig. 8). These grains were placed in a drying oven at 80°C to dry. One sample was exposed to hydrochloric acid to remove carbonate minerals.

After drying, grains were immersed in lithium metatungstate (LMT), a heavy liquid of variable density depending on the amount of water added or removed (Fig. 9). A density of approximately 3.0 g/cm<sup>3</sup> was chosen to separate mineral species heavier than quartz, feldspars, and micas. Any grain with a density greater than 3.0 g/cm<sup>3</sup> would sink to the bottom of the plastic sampling tubes. The bottoms of the tubes were exposed to liquid nitrogen to freeze the base of the tube where the heavier minerals had accumulated (Figs. 10 & 11).

After pouring off the unfrozen LMT where the lighter minerals were located, the heavy minerals were rinsed with water to remove traces of LMT. A final rinse was done with acetone to accelerate drying. Once drying in the oven was complete, grains were handpicked using tweezers and a microscope (Fig. 12). Grains were mounted on a labeled stub (Fig. 13), sprayed with a RadioShack brand of anti-static compound to make them conductive, and investigated in an AMRAY 1820 Scanning Electron Microscope (SEM) to determine mineral chemistry and record morphology (Fig. 5). Twenty-seven tubes with anywhere from 10 to 35 individual grains were investigated for a total of 470 grain analyses. The mineral compositions were recorded in spreadsheets along with a guess as to the identity of the mineral. Species counts were totaled to complete the Relative Abundance tables (Tables 1 & 2).

## Instrumentation

An AMRAY 1820 digital Scanning Electron Microscope (SEM) was used in this study. The SEM was operated with an acceleration potential of 20 kV, 18 mm working distance, sample tilt from 0 - 35°, and a final aperture of 400 microns. Images and spectra were collected at the resolution of 1024x1024 pixels and two screen averages. Energy dispersive spectra were acquired for 60 second count times. X-ray maps were collected at the resolution of 512x512 pixels with a dwell time per point of 50 milliseconds and one frame average on polished epoxy mounted grain mounts. Images were acquired using the integrated software package Iridium Ultra by IXRF Systems, Inc.

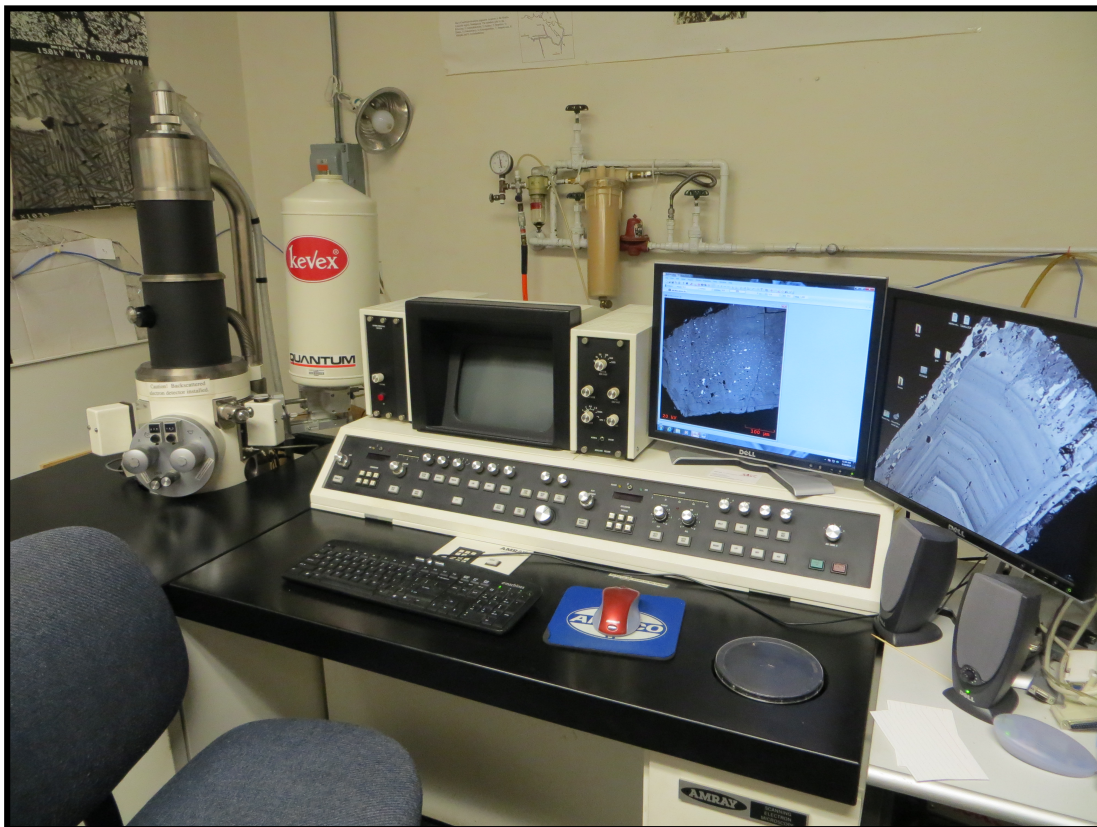


Fig. 5: Scanning Electron Microscope

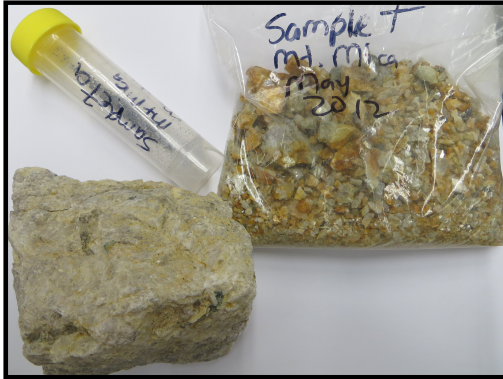


Fig. 6: Mt. Mica Sample



Fig. 7: Rock Crusher



Fig 8: 1 mm mesh sieve

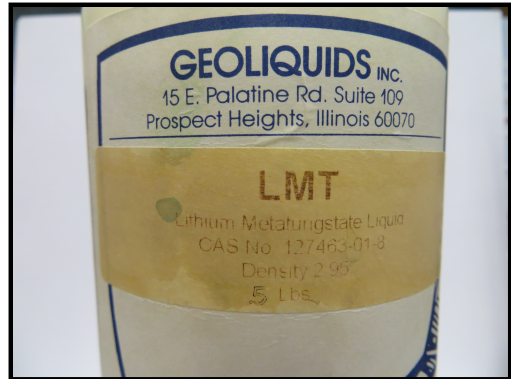


Fig. 9: Lithium Metatungstate Liquid



Fig. 10: Grain Immersion in LMT



Fig. 11: Frozen Heavies



Fig. 12: Microscope



Fig. 13: Stub Samples

## Results

The following minerals were identified.

### Siderite/Rhodochrosite

Formula:  $(\text{Fe}^{2+}, \text{Mn}^{2+})\text{CO}_3$

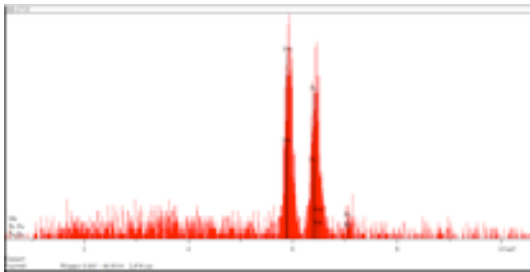


Fig. 14: Siderite/Rhodochrosite Spectrum

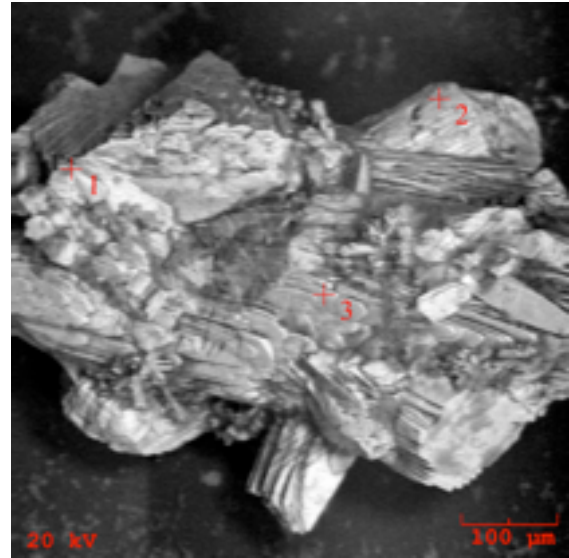


Fig. 15: Siderite/Rhodochrosite Crystals

*Siderite and Rhodochrosite* are carbonate minerals, pink to brown in color. Rhodochrosite and siderite are rarely found in pegmatites. As carbonates, both are soluble in hydrochloric acid. The density of rhodochrosite ranges from 3.5 to 3.7  $\text{g}/\text{cm}^3$  and the density of siderite is 3.96  $\text{g}/\text{cm}^3$ . These two minerals often form a solid solution series.

## Apatite

Formula:  $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$

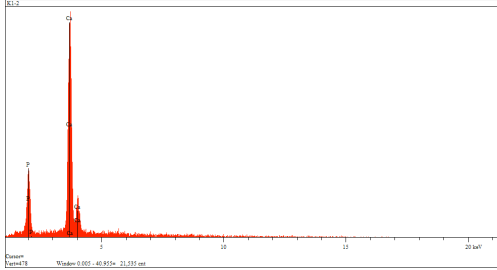


Fig. 16: Apatite Spectrum

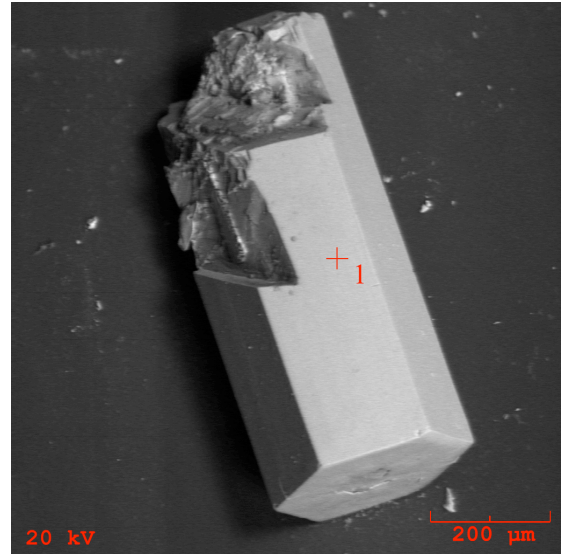


Fig. 17: Apatite Crystal

*Apatite* is a common phosphate mineral present in many environments. The color of apatite varies from colorless, to brown, green or yellow and occasionally blue or red. Apatite classification is based on the dominant anion present: fluorapatite (F), hydroxylapatite (OH), and chlorapatite (Cl). Fluorapatite is the most common member found in pegmatites. The density of apatite ranges from 3.10 to 3.25 g/cm<sup>3</sup>.

## Zircon

Formula:  $\text{ZrSiO}_4$

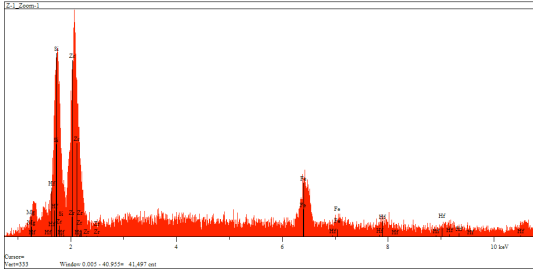


Fig. 18: Zircon Spectrum

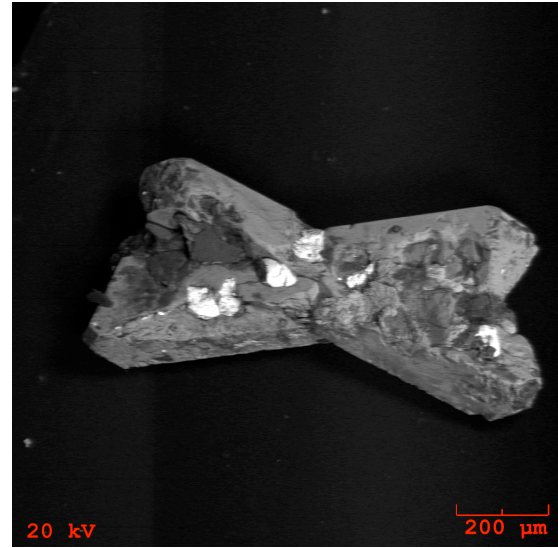


Fig. 19: Uraninite on Zircon Twinned Crystal

**Zircon** is a silicate mineral commonly found in pegmatites. Colors range from brown, green, white, red, to blue. Zircon has a density of 4.6 to 4.7  $\text{g/cm}^3$ . Zircon is incredibly durable and can survive for millions of years. It is resistant to both chemical attack and melting. Zircon contains the element uranium that will decay to lead over millions of years. By measuring the uranium-lead isotopic data recorded in zircon, the age at which the mineral formed can be determined. The hafnium present within zircon serves as an indicator for the degree of geochemical evolution of a pegmatite.



## Eosphorite/Childrenite

Formula:

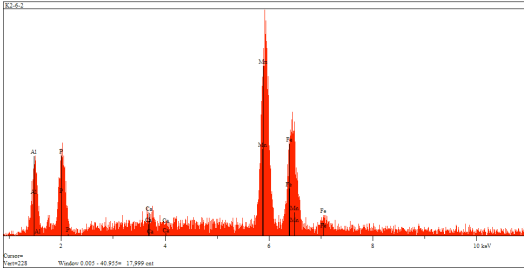


Fig. 20: Eosphorite/Childrenite Spectrum

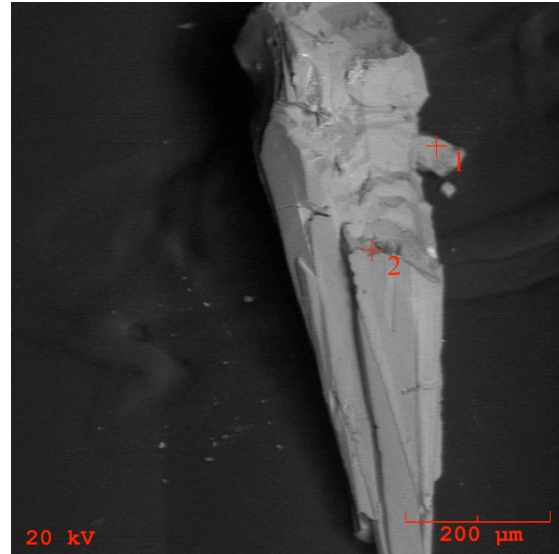


Fig. 21: Eosphorite/Childrenite Crystal

*Eosphorite* is a hydrated manganese aluminum phosphate whereas *Childrenite* is the iron dominant end-member. These two minerals form a solid solution series. The range in color and density depends on the dominant element present. Eosphorite crystals tend to be pink to brownish-pink; childrenite tends to be more brownish in color. Eosphorite ranges from 3.06 to 3.08g/cm<sup>3</sup> and childrenite from 3.11 to 3.19g/cm<sup>3</sup>. These minerals form in LCT-type pegmatites under low temperature metasomatic processes.

## Uraninite

Formula:  $\text{UO}_2$

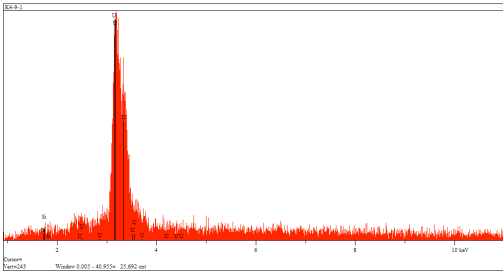


Fig. 22: Uraninite Spectrum

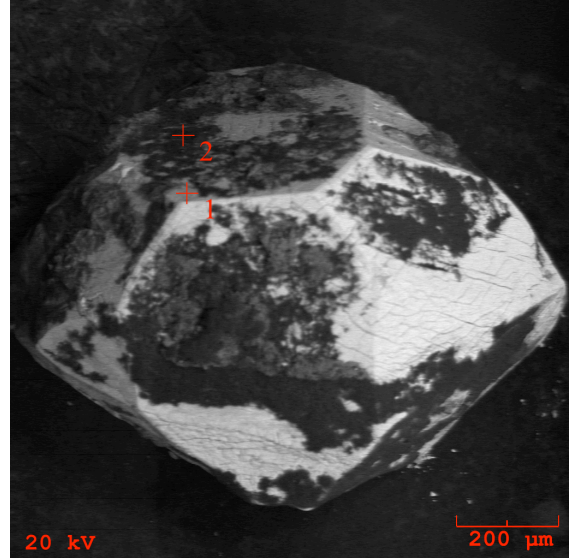


Fig. 23: Uraninite Crystal

*Uraninite* is a highly radioactive oxide mineral found in pegmatites. Uraninite crystals are usually black in appearance, but secondary uranium crystals can be orange, yellow, or green in color. The density ranges from 7.5 to 9.7 g/cm<sup>3</sup>.

## Pyrite

Formula:  $\text{FeS}_2$

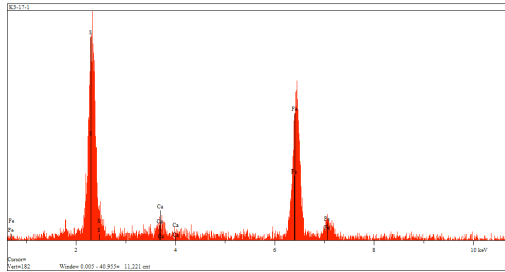


Fig. 24: Pyrite Spectrum

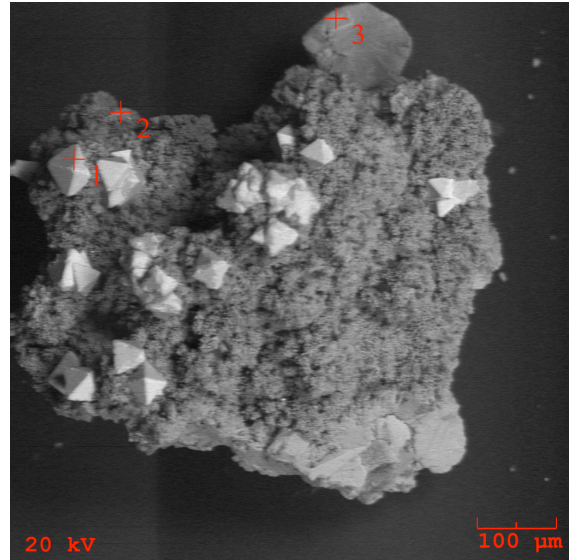


Fig. 25: Pyrite Crystals on Apatite

**Pyrite** is an iron sulfide occurring in minor quantities in pegmatites. Pyrite is brassy yellow in appearance with a density of  $4.82\text{g/cm}^3$ .

## Cassiterite

Formula:  $\text{SnO}_2$

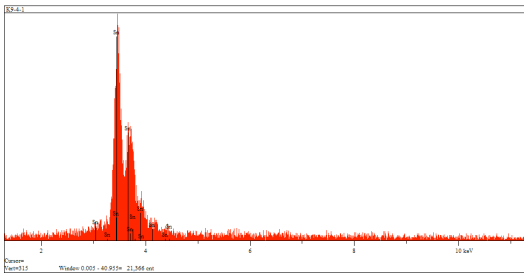


Fig. 26: Cassiterite Spectrum

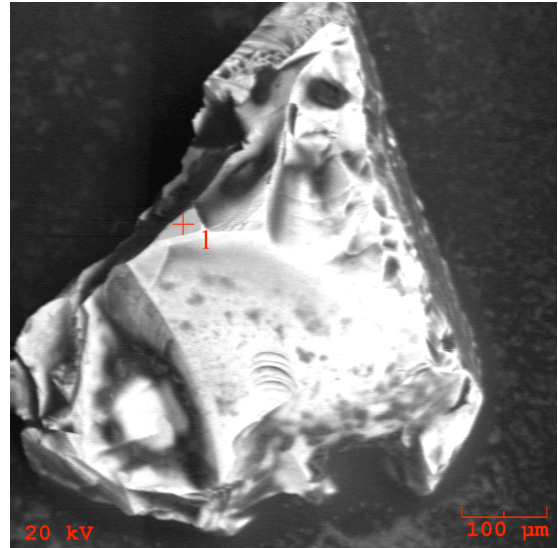


Fig. 27: Cassiterite Grain

*Cassiterite* is a tin oxide mineral very commonly found in pegmatites and notably abundant at Mt. Mica. The color is generally dark brown to black. The density of cassiterite is  $6.99 \text{ g/cm}^3$ . Cassiterite generally occurs within the assemblages of pegmatites that are more evolved.

## Montebrasite

Formula:  $\text{LiAlPO}_4(\text{OH}, \text{F})$

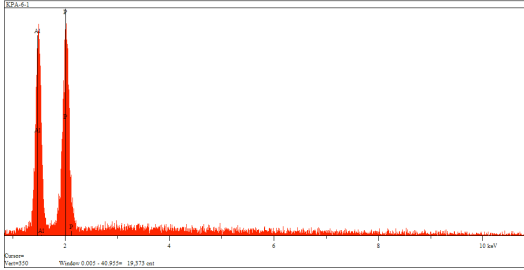


Fig. 28: Montebrasite Spectrum

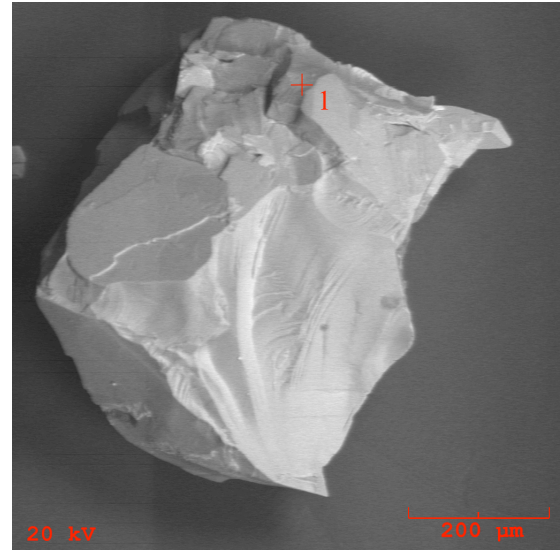


Fig. 29: Montebrasite Grain

**Montebrasite** is the hydroxyl-dominant member of the amblygonite-montebrasite phosphate series. Amblygonite is the fluorine dominant species. More commonly found only in LCT-type pegmatites that are moderately to highly-evolved, Montebrasite-amblygonite crystallizes during the late stages of pegmatite formation. Color can range from colorless, white, or gray to yellowish or pink. The density ranges from 2.98 to 3.11g/cm<sup>3</sup>.

## Arsenopyrite

Formula: FeAsS

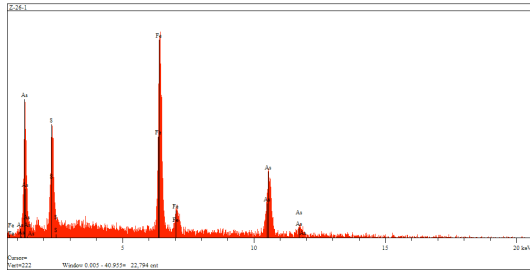


Fig. 30: Arsenopyrite Spectrum

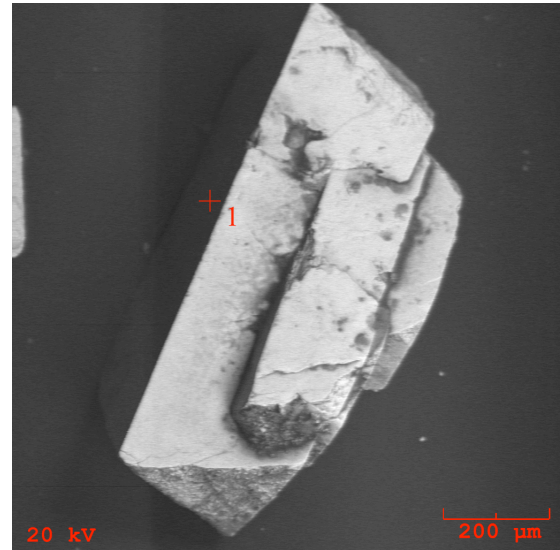


Fig. 31: Arsenopyrite Crystal

*Arsenopyrite* is an uncommon sulfide mineral found in pegmatites. The density of arsenopyrite is  $6.18\text{g/cm}^3$  and the color ranges from silvery gray to silver whitish-gray.

## Columbite/Tantalite Group

Formula:  $(\text{Fe, Mn})(\text{Nb, Ta})_2\text{O}_6$

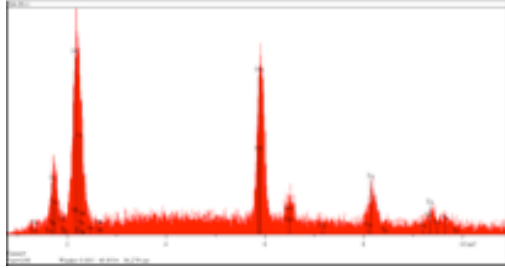


Fig. 32: Manganocolumbite Spectrum

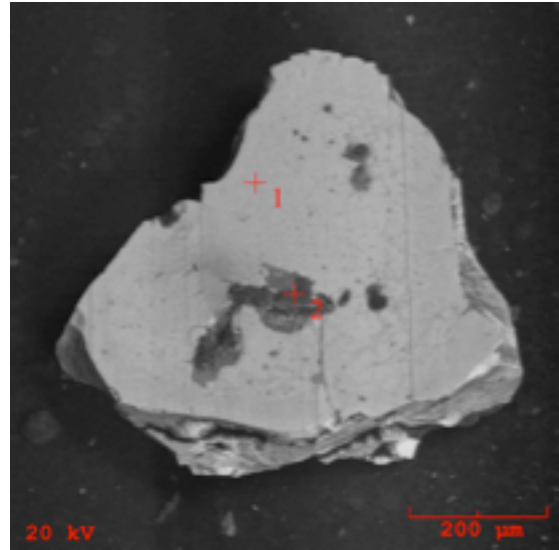


Fig. 33: Manganocolumbite Grain with quartz patches

The *columbite-tantalite group* consists of four members (Černý and Ercit, 1986). Due to the dominance of manganese in the spectrum and the greater quantity of niobium over tantalum, this particular grain is considered to be a manganocolumbite. Color can range from black to brown sometimes even reddish brown to an orange-red if Mn and Ta are present in sufficient quantities. Density ranges from 5.2 to 7.9g/cm<sup>3</sup>. The ratios of Ta/(Ta+Nb) and Mn/(Mn+Fe) are useful gauges of the geochemical evolution of pegmatites (Černý, 1992).

## Chalcopyrite

Formula:  $\text{CuFeS}_2$

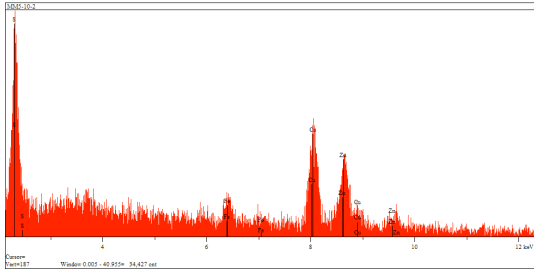


Fig. 34: Chalcopyrite Spectrum

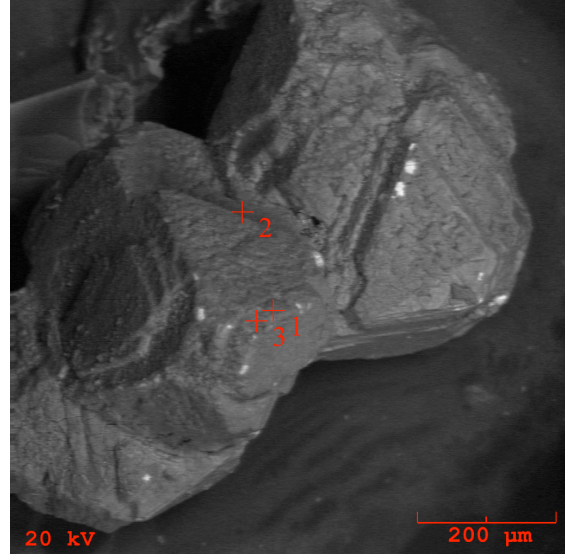


Fig. 35: Chalcopyrite Crystal

*Chalcopyrite* is an iron copper sulfide that rarely occurs in pegmatites even though it is the most abundantly existing copper mineral. The morphology of this crystal is rare as well. The density ranges from  $4.1$  to  $4.3\text{g/cm}^3$ . Chalcopyrite is brass-yellow in appearance, but often tarnish will lend an iridescent or bronzy finish.



## Monazite Series & Goyazite

Goyazite Formula:

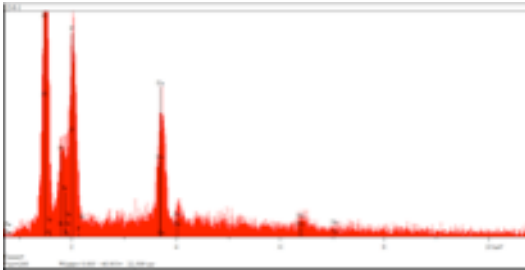
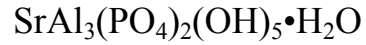


Fig. 36: Goyazite Spectrum

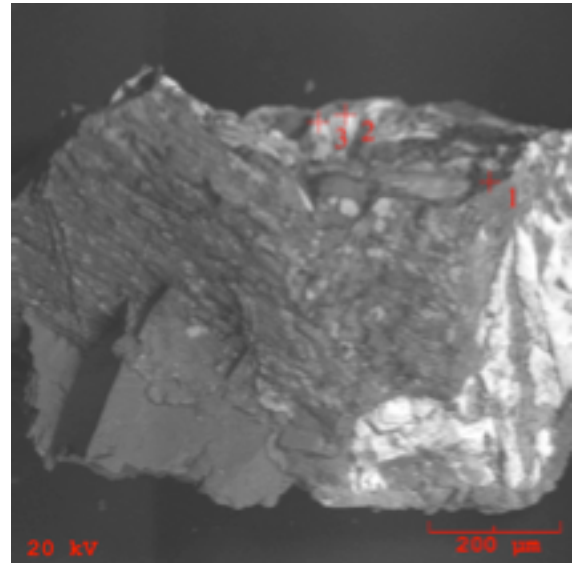


Fig. 37: Monazite & Goyazite Crystal

**Goyazite** is a rare mineral occurring in granitic pegmatites. Goyazite has an average density of  $3.22 \text{ g/cm}^3$ . The color of goyazite will vary from colorless to pink to lemon yellow.

Monazite Formula:  $(\text{Ce, La, Y, Th})\text{PO}_4$

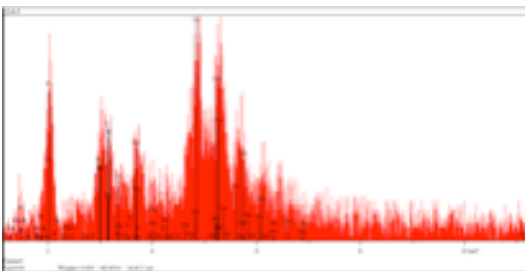


Fig. 38: Monazite Spectrum

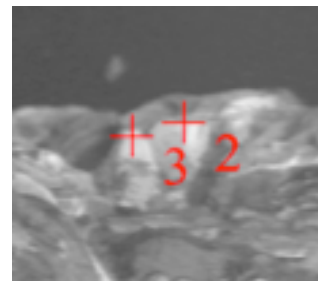


Fig. 39: Close-up of Monazite Crystal

**Monazite** is a phosphate mineral consisting of many rare earth elements. It has a density ranging from  $4.6$  to  $5.4 \text{ g/cm}^3$ . Color ranges from reddish brown to a yellowish hue. Like zircon, monazite is resistant to chemical attack and weathering. Radioactivity increases with increasing thorium. Monazite is often used for radiometric age dating.

## Pollucite

Formula:  $\text{CsAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$

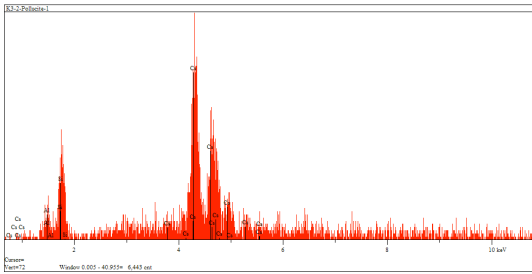


Fig. 40: Pollucite Spectrum

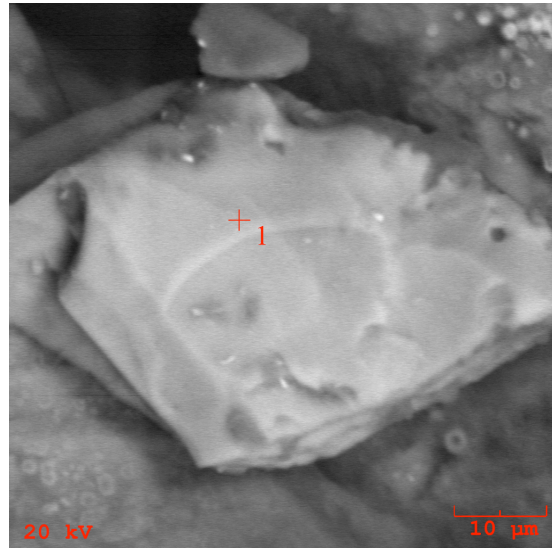


Fig. 41: Pollucite Grain

***Pollucite*** is a very rare mineral occurring almost entirely in pegmatites, especially in evolved LCT-types. Pollucite has a density of 2.67 to 3.03g/cm<sup>3</sup>. Color ranges from colorless to white, gray or pink.

In addition, *albite*, *tourmaline*, and *lithiophilite* (or hureaulite) were identified in samples.

# Relative Mineral Abundance

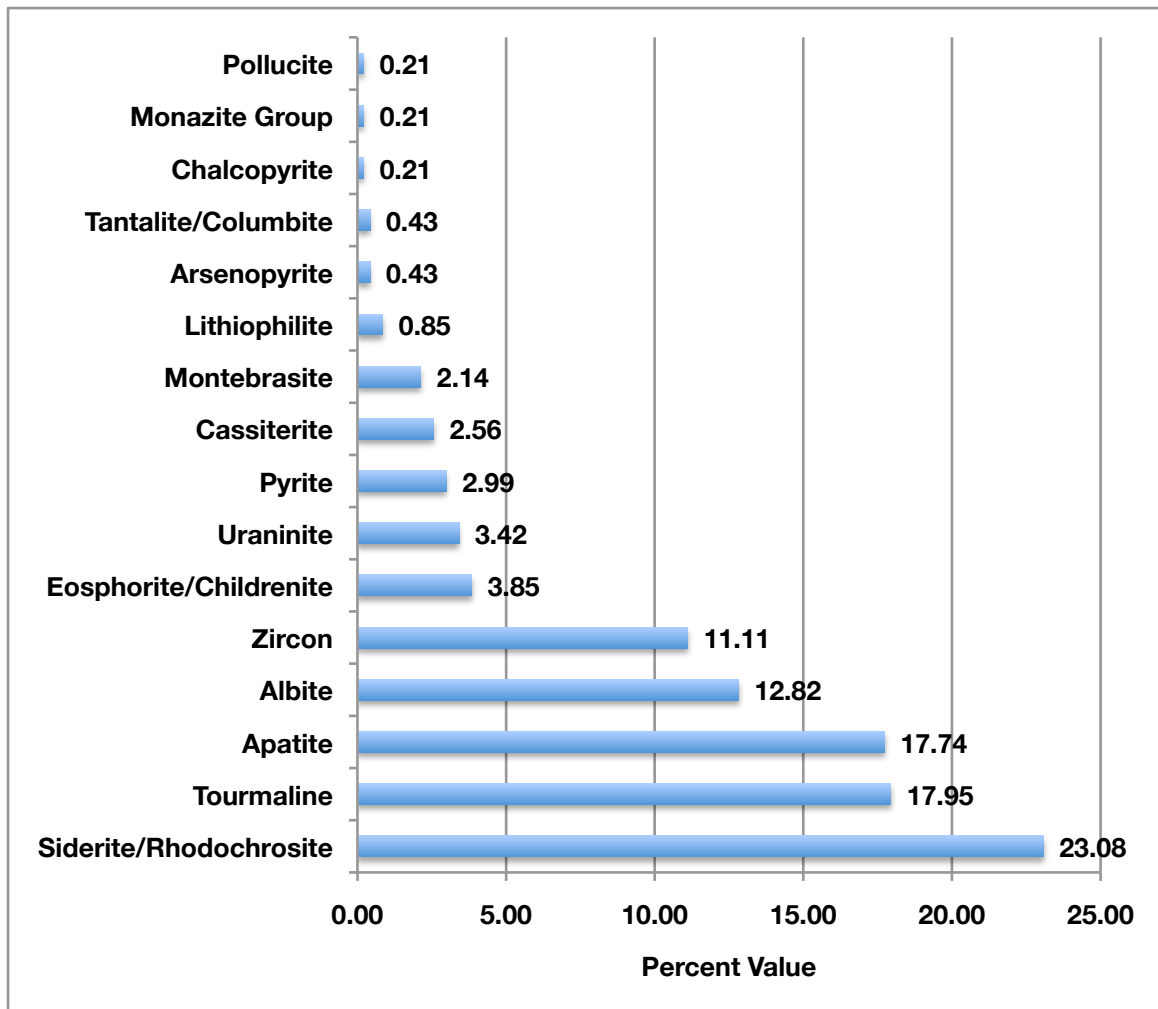
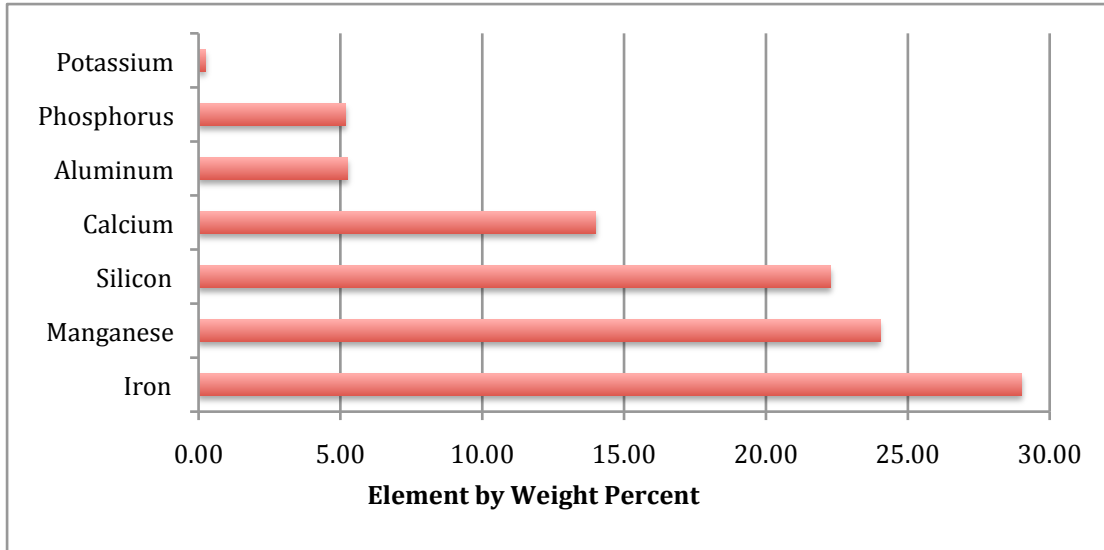


Table 1

# EDS Semi-Quantitative Analysis



**Table 2**

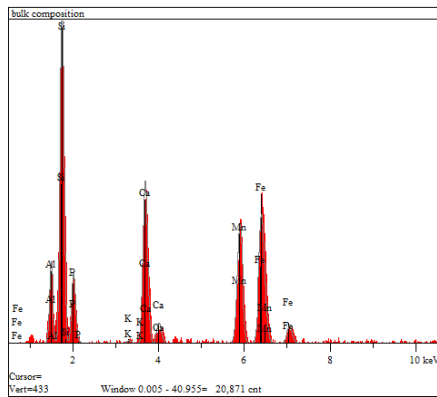


Table 2 & Fig. 42: 8 fields of 4x4mm polished carbonate-rich unit were analyzed for bulk composition. Background subtraction of the EDS spectrum was completed by background modeling. Data were then ZAF corrected using standardless quantification.

**Fig. 42: Bulk Composition Spectrum**

## Conclusions

While CO<sub>2</sub>-rich fluid inclusions are present in many pegmatites, carbonate assemblages within pegmatites are rare. Research suggests that these minerals crystallize during late stages of cooling or are reaction products of this CO<sub>2</sub>-rich fluid with other components or minerals, in particular calcium, iron, and manganese (London 2008). The carbonates siderite and rhodochrosite are abundant within the studied samples, suggesting that these minerals were formed by reaction of Fe and Mn with the CO<sub>2</sub>-rich fluid.

Zeolites from lower density separates (<3.0g/cm<sup>3</sup>) and possible clay coatings on heavy mineral samples were not included in relative abundance tables; however, zeolites and clay minerals together with the presence of carbonates and sulfides indicate temperatures at or below 450°C (London 2008). Eosphorite-childrenite in samples also implies crystallization at relatively low temperatures.

Pollucite has only been found in highly fractionated LCT-type pegmatites (London 2008) and was identified in samples from this unit as well. Pollucite is associated with elbaïtic tourmaline and albite, both of which were found in abundance. In addition, montebbrasite and lithiophilite-triphyllite (or possibly hureaulite) were identified. These minerals are commonly located near core margins or intermediate zones. Since pollucite, montebbrasite, and possible lithiophilite were collected from core margins, the presence of these mineral species suggests late stage crystallization from a highly fractionated melt. The abundance of tourmaline and apatite from samples indicates a melt rich in the volatiles boron and phosphorus. Whereas the quantity of lithium cannot be directly measured in tourmaline by the instrumentation used, the

presence of lithium (also a flux) can be inferred based on the occurrence of other minerals such as montebrasite and pollucite.

The identified minerals suggest that the carbonate assemblages crystallized under higher CO<sub>2</sub> fluid enrichment than present in other pegmatite zones as well as under elevated levels of phosphorus, boron, and fluorine in a highly fractionated, low temperature fluid. Due to the mineralogy identified, the carbonates crystallized under low temperature and by reaction with other available elements, in this case, iron and manganese. Location of the carbonate assemblages with minerals that commonly crystallize at core margins suggests that formation occurred during later stages of formation. Considering the mineralogy located near these carbonate assemblages (Fig. 2), it appears that concentrations of lithium, fluorine, and boron were temporarily reduced by the formation of lepidolite, montebrasite, and schorl, thus causing undercooling and likely, rapid crystallization (Webber 1999). A zone of albite surrounds and abruptly ends with thin rims of blue tourmaline that are intergrown with the carbonate pods. The abundance of other minerals such as apatite located within and near these pods suggests that there was still sufficient flux within the melt to facilitate the mobilization of the carbonate fluid at lower temperatures. The tourmaline intergrowths suggest that boron and lithium may also have participated in this process. Boron, lithium, and fluorine must have existed within the fluid to form the tourmaline and other crystals. After concentrations of fluxes were reduced for a second time, the melt must have become sufficiently concentrated with the carbonate fluid to cause the final crystallization of this carbonate assemblage. More comprehensive research focusing on the entire suite of

minerals found in carbonate assemblages at Mt. Mica, Mt. Marie, and Palermo #1 is recommended to further test the conditions of their formation.

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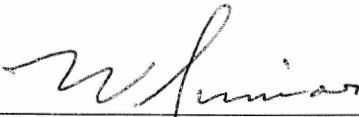



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APPROVAL SHEET

This is to certify that Christopher Mark Johnson has successfully completed his Senior Honors Thesis, entitled:

*A Study of Heavy Minerals Found in a Unique Carbonate Assemblage  
from the Mt. Mica Pegmatite, Oxford County, Maine*

  
\_\_\_\_\_  
William B. Simmons Director of Thesis

  
\_\_\_\_\_  
Alexander V. Falster for the Department

  
\_\_\_\_\_  
Abu Kabir Mostofa Sarwar for the University  
Honors Program

April 24, 2013  
Date