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# A1: Lithium-Boron-Beryllium Gem Pegmatites, Oxford Co., Maine: Havey and Mount Mica Pegmatites

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## **A1: LITHIUM-BORON-BERYLLIUM GEM PEGMATITES, OXFORD CO., MAINE: HAVEY AND MOUNT MICA PEGMATITES**

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### **INTRODUCTION**

This fieldtrip will visit two world renowned gem-producing pegmatites, in the Oxford County pegmatite field of western Maine: Havey and Mount Mica pegmatites. This is intended to be primarily an instructional fieldtrip lead by pegmatite experts from the Maine Mineral and Gem Museum (MMGM) MP<sup>2</sup> (Mineralogy, Pegmatology, Petrology) research group. This is an opportunity to learn about the latest research and advances in the field of pegmatology in Maine. Mt. Mica and the Havey pegmatites are enriched in Be, B, and Li and over the last ten years have produced significant finds of gem tourmaline. The Havey produces a very consistent mint green elbaite with lesser amounts of pink and some rare blue gem elbaite. Mt. Mica has produced a huge quantity of gem elbaite in a wide range of colors. Some of the elbaite crystals recently mined from Mt. Mica are exceptionally large and many are fine museum-quality mineral specimens.

This field trip guide is divided into the following four sections:

1. Field trip summary with the leaders identified (A1-1)
2. General geology background information – Falster, Simmons & Bradley (A1-2)
3. Mt. Mica Pegmatite – Simmons, Falster, Webber, Felch & Freeman (A1-8)
4. Havey Pegmatite – Roda-Robles, Falster, Simmons, Morrison, Felch, Nizamoff (A1-22)

**TIME, PLACE, LOGISTICS:** Friday September 29th at 8:30 am meet in the back-parking lot of the Maine Mineral and Gem Museum located at 99 Main Street in Bethel, Maine (357595.99 m E, 4918691.40 m N). The field trip will begin with a brief discussion in the parking lot. We encourage carpooling to limit the number of vehicles entering the mines. A convoy of vehicles will travel approximately one hour to the Havey Quarry located off of Levine Road in Poland (395997.39 m E, 4880613.82 m N). Plan to spend approximately 2hrs at this location, starting with a discussion and later an opportunity to collect. Departing the Havey Quarry, the convoy will travel north approximately 40 minutes to the Mt. Mica Quarry located off of Mt. Mica road in Paris (382422.66 m E, 4902813.15 m N). Plan to spend approximately 2 hrs. at this site, which will begin with a discussion and end with an opportunity to collect on the dumps afterwards. There will not be an opportunity to go underground. At 4:00 pm, participants will leave the mine and travel north approximately 40 minutes back to Bethel. We encourage all participants to attend the Friday night reception at the Maine Mineral and Gem Museum. For this field trip, be prepared with a lunch as we will not be stopping along the way. There will be bathroom facilities available at each of the mine sites. Enrollment will be limited to 25 participants. Expect cold and unpredictable weather and dress accordingly. Please note: both quarries we are visiting are not open to the public except via previous arrangement.

## GENERAL GEOLOGY OF THE OXFORD COUNTY PEGMATITE FIELD IN MAINE

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### REGIONAL GEOLOGY

The New England Appalachians formed during a prolonged Wilson Cycle between the breakup of the supercontinent Rodinia in the Neoproterozoic and the staged assembly of the supercontinent Pangea in the Phanerozoic. The pre-Silurian rocks mainly fall into two groups: those of Laurentian or peri-Laurentian affinity, toward the west, and those of peri-Gondwanan affinity, toward the east (Hibbard et al., 2006). These rocks were juxtaposed via mainly convergent plate motions, deformed, metamorphosed, and intruded by granitic plutons during a succession of Paleozoic orogenies, the main ones being the Taconic (Ordovician), Acadian (Late Silurian-Early Devonian), Neoacadian (Late Devonian-Early Mississippian), and Alleghanian (Pennsylvanian-Permian) (Robinson et al., 1998). By the end of the Alleghanian orogeny, the Appalachian chain stretched thousands of kilometers across the interior of the now-assembled Pangea supercontinent. Supercontinent breakup began soon after, with Triassic to Early Jurassic within-plate magmatism and rifting leading, eventually, to the opening of the Central Atlantic from Early Jurassic to present.

The Oxford pegmatites of western Maine are situated in the Central Maine Belt (Figure 1) in a belt of metasedimentary rocks (Figure 2.) that were deposited in the late Ordovician, Silurian, and earliest Devonian. These rocks were deposited in a deep-water basin, the Central Maine Basin, immediately before and during the Acadian orogeny (Bradley et al., 2000). Deformation and metamorphism took place during the Acadian, Neoacadian, and Alleghanian orogenies. Eusden et al. (2017, this volume) present a summary of the geologic history.

Plutons were emplaced during multiple pulses spanning the late Neoproterozoic to the Cretaceous (Bradley et al., 2015). The Oxford pegmatite district includes plutons related to four igneous episodes. Examples include the Songo pluton (Neoacadian granodiorite,  $364 \pm 1.3$  Ma, Gibson et al., 2017), the Sebago pluton *sensu lato* (Alleghanian granite,  $288 \pm 13$  to  $297 \pm 14$  Ma, Solar and Tomascak, 2016), the Whale's Back pluton (a White Mountain Series granite,  $184 \pm 3$  Ma, Foland and Faul 1977), and the Pleasant Mountain pluton (Cretaceous,  $112 \pm 3$  Ma, Foland and Faul, 1977).

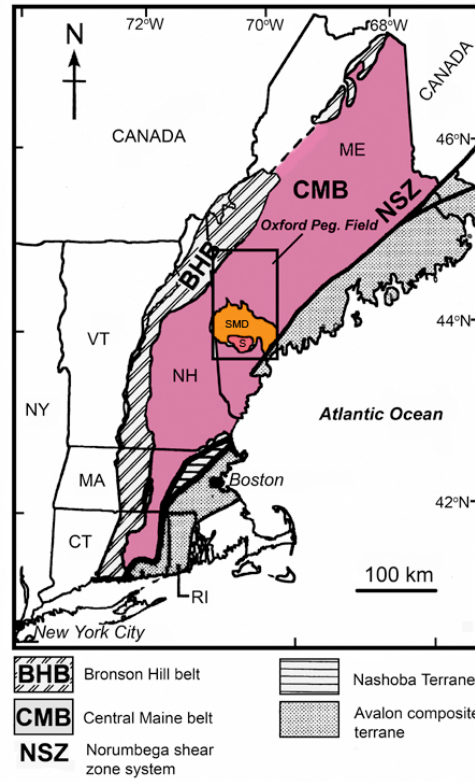
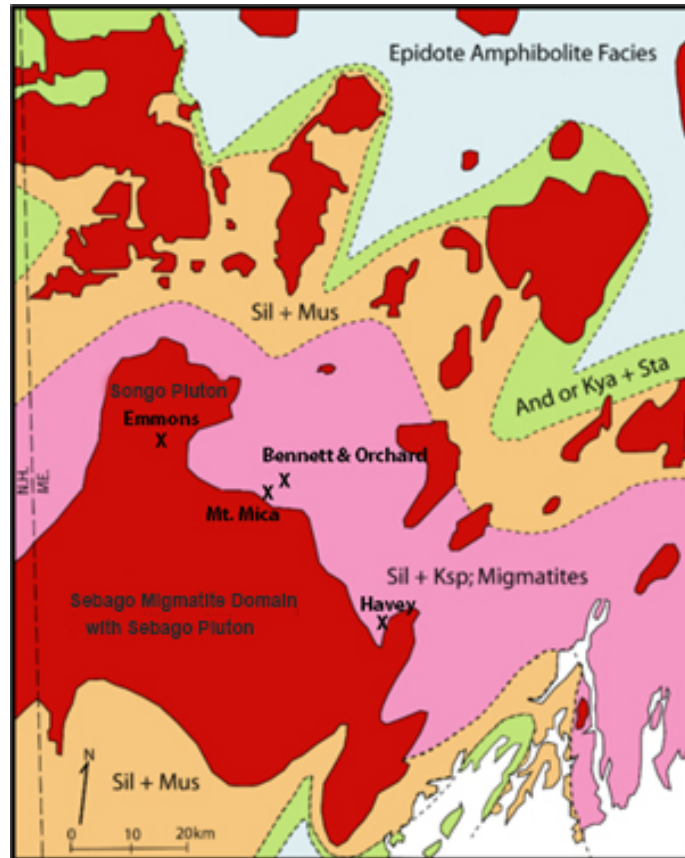


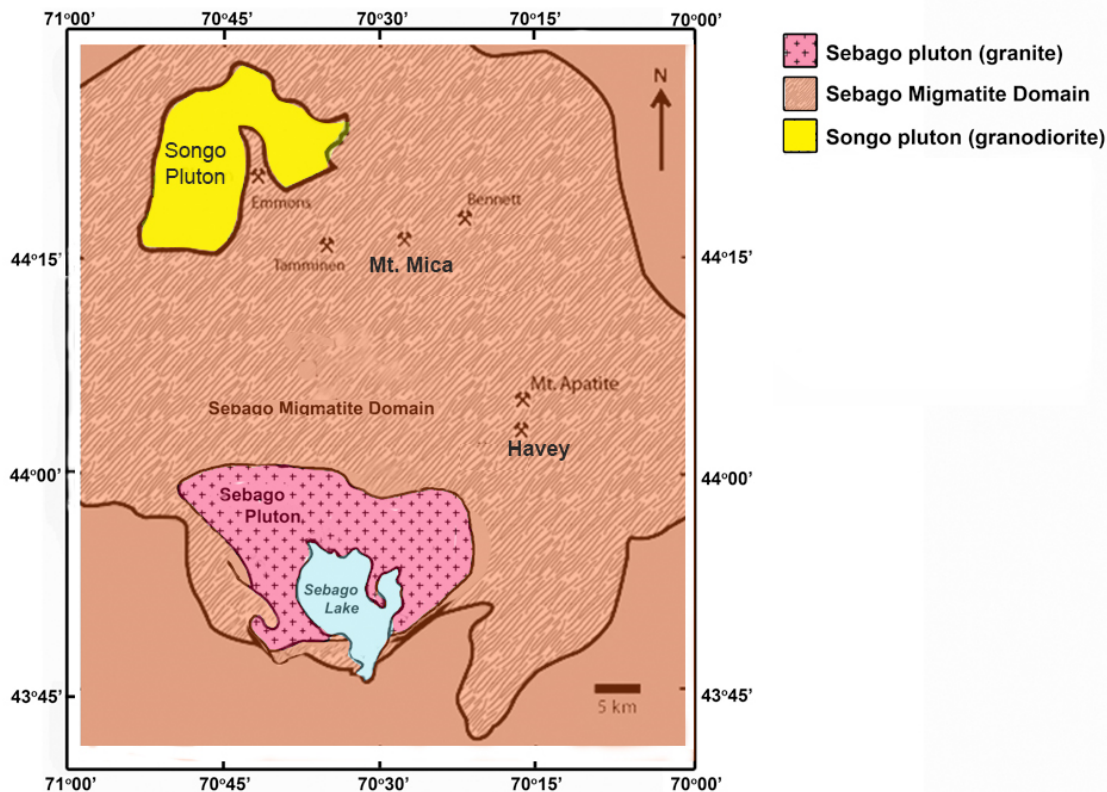
Figure 1. General geology of New England (from Brown & Solar, 1998).



**Figure 2:** Metamorphic facies in the Oxford pegmatite field and the locations of pegmatites. Modified from Roda-Robles (2011), after Guidotti *et al.* (1989).

### LOCAL GEOLOGY

The Oxford pegmatite district largely coincides with the area formerly mapped as the Sebago batholith (Osberg *et al.*, 1985). The mapped extent of the Sebago batholith has gotten much smaller in recent years. This tract has now been subdivided into the Sebago pluton and the Sebago Migmatite Domain (SMD) (Solar and Tomascak, 2009), (Figure 3). As noted above, the Sebago pluton has been dated at  $288 \pm 13$  to  $297 \pm 14$  Ma, Solar and Tomascak, 2016), whereas the migmatites have been dated at  $376 \pm 14$  Ma (Solar and Tomascak, 2016). The metasedimentary, Central Maine Basin country rocks have been metamorphosed to middle- to upper-amphibolite facies (Tomascak *et al.*, 1996).



**Figure 3.** Map showing Oxford pegmatite field in the Sebago Migmatite Domain and the location of the Havey and Mt. Mica Pegmatites. Modified from Solar & Tomascak (2009).

### OXFORD FIELD PEGMATITES

Overall, pegmatite bodies in the SMD are concordant with the foliation of the host rocks, although some display irregular and locally discordant contacts. Generally, pegmatites in the SMD exhibit internal mineralogical and textural zonation. The outermost wall-zone is typically less than 1m thick, with a homogeneous pegmatitic texture. K-feldspar, albite, quartz, biotite, muscovite, garnet  $\pm$  schorl are the most common minerals in this zone, except in Mt. Mica which has only albite in the wall zone with microcline appearing only in the core zone. Many pegmatites exhibit a comb structure of wedge-shaped schorl crystals, some up to 50 cm in length, that grow directly from the contact with the country rock in the hanging wall, inside a homogeneous pegmatite matrix (particularly well developed in the Emmons pegmatite). The wall-zone is gradational into the intermediate zone of graphically intergrown feldspar and quartz (graphic granite), with accessory garnet, biotite, muscovite and black tourmaline. In some pegmatites, the intermediate zone is asymmetric and thicker under the core zone, *e.g.* at the Havey pegmatite. The core-zones consist of meter-sized masses of blocky K-feldspar and/or quartz with a more evolved assemblage of finer-grained, irregular pods consisting of albite, muscovite, lepidolite, Li-tourmaline, Li-Al and Fe-Mn-phosphates, Sn-, Nb- and Ta-oxides, beryl and Cs-beryl, spodumene, petalite and pollucite. Within the core-zone pods, pockets are relatively common. The pockets contain gemmy elbaite associated with quartz, lepidolite, albite, cassiterite and clay minerals. Another notable feature in the foot wall of Oxford Field pegmatites is the existence of a garnet layer or line under the core zone roughly paralleling the contact of the pegmatite. The garnet line helps the miners to determine the limits of the core and pockets, as pockets never occur below this layer. Prismatic schorl crystals intergrown with or close to the garnet line are oriented perpendicular to the contact and indicate the sense of upward crystal growth. In some cases, a second line of schorl occurs below the garnet line. Overall, the composition of Oxford Field pegmatites is not significantly enriched in rare-elements, as these are concentrated only in the

innermost parts of the bodies and constitute a low percentage of the volume of the pegmatite. Textural and mineralogical criteria indicate that the pegmatites crystallized from the borders inward. Fractionation processes were highly effective during the crystallization of these pegmatites. In general, the composition of the primary minerals changes progressively from the contact to the core zone where compositions change more sharply. The Li/(Fe+Mg) ratio of tourmaline increases, the K/Rb of micas and K-feldspar and the Fe/(Fe+Mn) of phosphates decreases, Li and F in mica and Cs in beryl increases as well as a general increase in the proportion of Li-, F- and/or Cs-bearing minerals, parallel to a decrease in Fe-Mn-Mg-bearing phases (Roda-Robles *et al.* 2015, Wise and Brown 2010).

Pegmatites of the Oxford field are enriched in Be, B, Li and Cs, with low Ta. Wise and Francis (1992) and Wise (1995) classified them as LCT type (Černý & Ercit 2005) pegmatites, but pegmatite classification is currently being revised and for this paper we use the actual elements for the classification. The inferred relationship between the Oxford field pegmatites and surrounding rocks has evolved over the years. The parent bodies of Oxford field pegmatites were once thought to be the Sebago batholith in the south and some smaller plutons in the north, such as the Rumford, Phillips and Mooselookmeguntic (Wise and Francis, 1992 & Wise, 1995). As the Sebago Pluton is now about 30 km distant from Oxford pegmatite field and is about 30 Ma older than the pegmatites, we no longer consider it a viable source for the origin of the pegmatitic melts. Our MP<sup>2</sup> group has proposed an anatexitic origin for some of the Oxford pegmatites (Simmons *et al.*, 1995, 1996, 2016), Roda-Robles (2015).

A recent geochronology study of Appalachian rare-element pegmatites included a few in western Maine. There are many single-crystal U-Pb zircon ages from these rocks because of a combination of abundant xenocrystic grains, severe lattice damage in high-uranium zircons, and common-lead-bearing inclusions. The tightest age control is from the Irish Pit at Mt. Mica. Its age is bracketed between 263.89 ±0.18/-0.35 Ma (U-Pb zircon, CA-TIMS) and 259.9±2.3 Ma (<sup>40</sup>Ar/<sup>39</sup>Ar muscovite, plateau age), ranking it one of the youngest igneous rocks in New England before the onset of igneous activity related to breakup of Pangea. A pegmatite sample from the Main Pit at Mt. Mica yielded only xenocrystic zircons but did give a <sup>40</sup>Ar/<sup>39</sup>Ar muscovite plateau age of 253.5±2.2 Ma. The Emmons pegmatite yielded a <sup>40</sup>Ar/<sup>39</sup>Ar muscovite plateau age of 250.4±2.3 Ma. The Lord Hill pegmatite yielded a <sup>40</sup>Ar/<sup>39</sup>Ar muscovite plateau age of 231.8±3.0 Ma. Farther north, the Black Mountain pegmatite, near Rumford, yielded a <sup>40</sup>Ar/<sup>39</sup>Ar muscovite plateau age of 295.0±3.7 Ma. This pegmatite is therefore significantly older than the Oxford pegmatites. All of the dated pegmatites are of LCT (lithium-cesium-tantalum) type, except Lord Hill, which is a hybrid LCT-NYF (niobium-yttrium-fluorine) type.

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**MOUNT MICA PEGMATITE, PARIS, OXFORD COUNTY, MAINE**William B. (Skip) Simmons<sup>1</sup>, Alexander U. Falster<sup>1</sup>, Karen Webber<sup>1</sup>, Myles M. Felch<sup>1</sup> and Gary Freeman<sup>2</sup><sup>1</sup>MP<sup>2</sup> Research Group, Maine Mineral & Gem Museum, 99 Main Street, Bethel, Maine<sup>2</sup>48 Lovejoy Road, Paris, ME**ABSTRACT**

Mt. Mica pegmatite is famous for gem tourmaline production for nearly 200 years. The dike, ranging in thickness from 1 to 8 meters and dipping 20° SE, has a simple zonal structure consisting of a wall zone and core zone. The wall zone is essentially devoid of K-feldspar. The outer portion of the pegmatite consists of quartz, muscovite, albite (An 1.8) and schorl. Muscovite is the dominant K-bearing species in the outer portion of the pegmatite. K-feldspar only appears in the core zone adjacent to pockets. The pegmatite is subparallel to the foliation of the enclosing migmatite, and leucosomes show a gradational contact with the pegmatite where juxtaposed. Texturally, the pegmatite and leucosomes appear to be in equilibrium with no change in grain size or composition where the two are in contact. Garnet-biotite thermometry of the migmatite at the contact yields an average temperature of 630°C, which is consistent with the P-T conditions inferred for a Sebago Migmatite Domain (SMD) assemblage of sillimanite, quartz, muscovite, biotite and alkali feldspar of 650°C and 3 kb. Gradational contact between leucosomes and pegmatite suggests that the pegmatitic melt was at the same temperature. Coromoto Minerals began mining in 2003 and the mine now extends down dip for over 100 meters to a depth of 33 meters. A very detailed and accurately surveyed geologic map produced by owner/operator Gary Freeman during mining shows the total area of pegmatite removed, the spatial distribution and aerial extent of pockets, massive lepidolite (compositions near trilithionite) pods, microcline, and xenoliths. The map was analyzed using image analysis and thickness values of the units to calculate the total volumes of pegmatite mined, lepidolite pods and all pockets found. Forty-five drill cores were taken across the pegmatite from the hanging wall to foot wall contacts along a transect intentionally avoiding lepidolite pods and miaroles. Cores were pulverized, thoroughly mixed and homogenized and the percent Li content calculated from the mapped volume was added to produce a sample that was representative of the bulk composition of Mt. Mica. The sample was then analyzed by fusion ICP spectroscopy for major and trace elements and DCP spectroscopy for B and Li. Structural water was determined by LOI. Water content was calculated using the calculated volume of open space (pocket volumes), assuming that the pockets were filled with water-rich fluid. This fluid content was added to LOI water (above 500°C) to estimate a maximum H<sub>2</sub>O content of 1.16 wt. % of the pegmatite melt. REE plots of bulk pegmatite vs. leucosomes from the migmatite are strikingly similar. Chondrite normalized REE patterns of leucosomes and pegmatite are very flat with no Eu anomaly, whereas Sebago granite is more strongly LREE-enriched and displays a pronounced negative Eu-anomaly. Spider diagrams of leucosomes and pegmatite vs. average crust show very similar patterns. These results suggest that the Mt. Mica pegmatitic melt did not form by fractional crystallization of the older Sebago pluton, but instead was derived directly from partial melting of the metapelitic rocks of the SMD. Batches of anatectic melt accumulated and coalesced into a larger volume that subsequently formed the pegmatite. This is the first chemical evidence presented for the formation of an LCT type pegmatite by direct anatexis.

**INTRODUCTION**

Mt. Mica pegmatite (Figure 1) is the site of the first reported occurrence of tourmaline in North America (Hamlin 1873, 1895) (Figures 2 and 3) and is famous for gem tourmaline production for nearly 200 years. It is experiencing a remarkable new chapter in its long-lived and historically important mining history. Coromoto Minerals LLC acquired the property and began mining in 2003. Recent mining by owner Gary Freeman has produced a large amount of quantitative information about the pegmatite. Careful mapping of the location and sizes of lepidolite (used as the series name for trioctahedral micas near trilithionite in composition) masses, pockets and the volume of pegmatite mined underground has provided an unprecedented database which we utilized in this study. Over the last dozen years of mining several hundred pockets have been carefully documented. Their sizes and contents have been carefully measured and recorded. These pockets have yielded large gem quality crystals of green and pink tourmaline rivaling the best material ever produced from Mt Mica in its almost 200-year history. The new

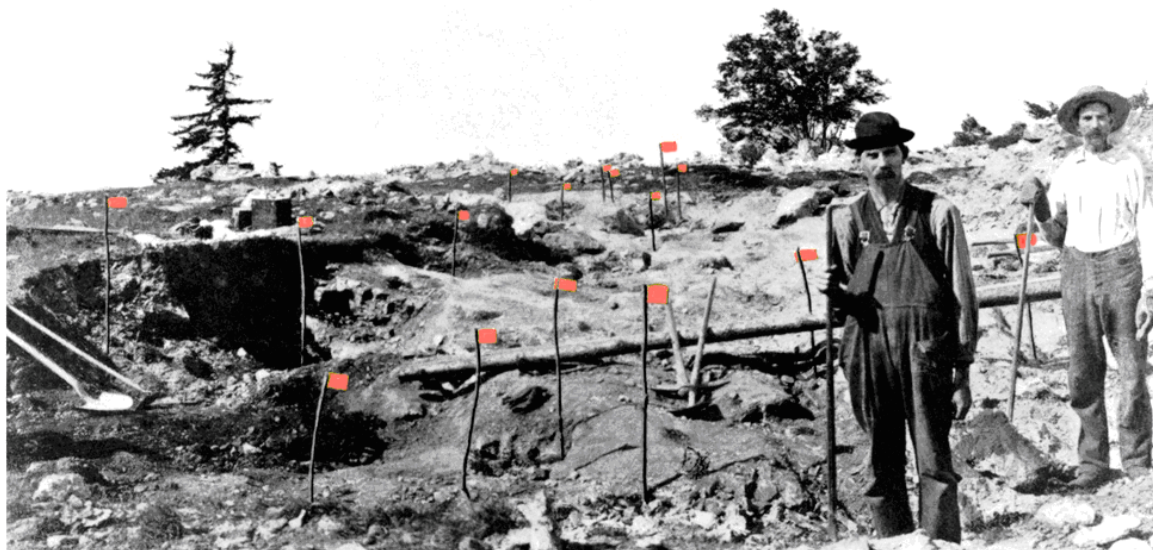
phase of mining activity by Coromoto Minerals, which began as an open trench mine in 2003, now continues down dip underground for over 100 meters to a depth of about 30 meters. The pockets range in size from a few cm<sup>3</sup> to one in excess of 500 m<sup>3</sup>. Several dozens of the intermediate to larger pockets have produced thousands of carats of gem quality tourmaline and lesser quantities of morganite. Pocket density averages about one every 3 meters with larger pockets having greater spacing and small ones having less, making this one of the most pocket-rich pegmatites in North America. In addition to the gem material, thousands of high-quality mineral specimens including tourmaline, beryl, apatite, lepidolite, rose and smoky quartz, hydroxylherderite, cassiterite, pollucite, and kosnarite have been recovered.

## GENERAL GEOLOGY OF THE PEGMATITE

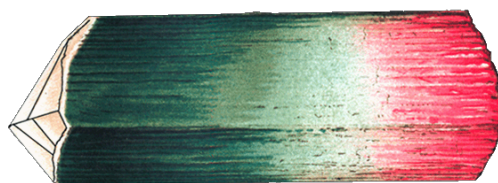
Mt. Mica intrudes stromatic migmatite of the SMD (Figure 1). The migmatite consists of felsic leucosomes of quartz and feldspar and melanosomes of biotite-quartz-feldspar schist. The contact is sharp between the pegmatite and melanosomes but completely gradational between the leucosomes and the pegmatite. In a few places along the contact, a weakly developed 2-4 cm comb structure of oriented muscovite crystals is present. In most places the contact is parallel to foliation, but in places where the pegmatite cuts foliation, ductile deformation is clearly evident. In general, zoning in the Mt. Mica pegmatite is indistinct. Internal zoning is asymmetric and not well developed and, basically, in most places no intermediate zone can be distinguished. The wall zones extend inward from the hanging wall and foot wall contacts to the core zone. Grain size increases gradually up to the core zone which is marked by an abrupt increase in grain size, especially of muscovite which forms in large 4 to 10 cm “A” shaped twinned books and the appearance of more evolved minerals and miarolitic cavities. The dike ranges in thickness from 1 to 8 meters and dips about 20° to 25° to the SE. To date, the mining extends underground down dip about 100 m to a depth of 33 m beneath the surface. The outer zones of the pegmatite consist of nearly end-member albite (An ~ 0.5), quartz, muscovite, and schorl. Visual estimates and point counts of polished slabs yield a modal composition of the wall zone of roughly 40 % quartz, 39 % albite and 19 % muscovite.



**Figure 1.** Mt. Mica pegmatite with entrance to the underground workings, showing the contact with the overlying stromatic migmatite host rock. Mine opening 2.5 m.



**Figure 2.** A photograph of the mining at Mt. Mica ca. 1890. Sticks with red flags mark positions of pockets. The persons in the image are L. Kimball Stone (left) and Loren B. Merrill (right). Modified from Bastin (1911).

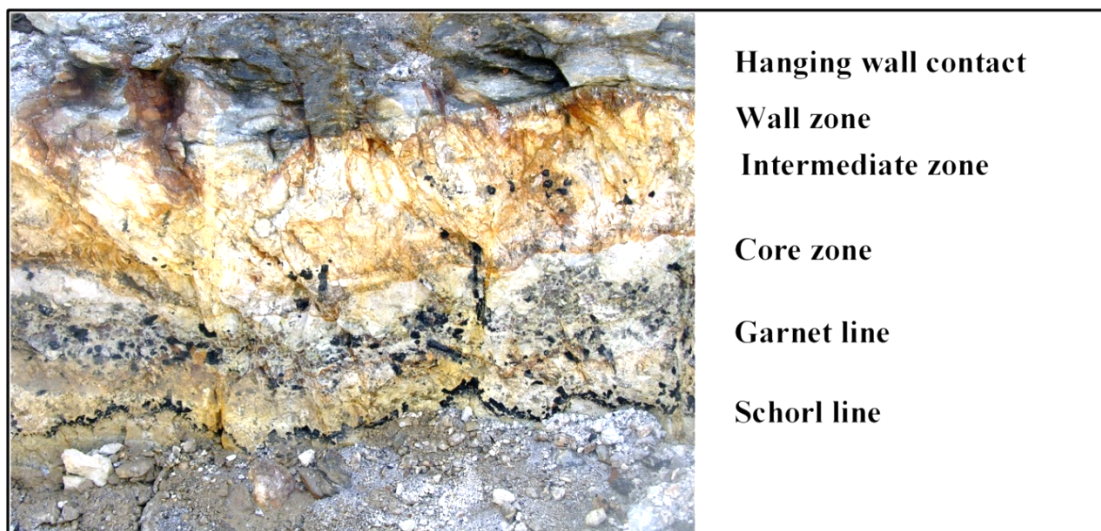


**Figure 3.** Elbaite crystal reproduced from *The Tourmaline* by A. C. Hamlin, 1873

The wall zone of Mt. Mica is unusual as it is essentially devoid of K-feldspar; and the major K-bearing mineral is muscovite. K-feldspar only appears as large masses in the core zone of the pegmatite adjacent to some of the larger pockets, where it serves as a pocket indicator in some cases. Notably, one, or in some instances, two distinctive garnet and schorl lines occur along the somewhat finer grained footwall portion of the dike (Figure 4). The lines are about 0.5 to 1.0 m above the base of the pegmatite and are roughly parallel to the pegmatite-country-rock contact. The line consists of an undulating, somewhat sinusoidal to irregular concentration of 1 to 5 cm garnet crystals in a matrix of quartz and feldspar. The most evolved portion of the pegmatite is always above this horizon in the more incompatible-rich core zone of the pegmatite, where the pockets occur. Thus, this line is an important marker that the miners interpret to be the bottom of the productive zone, below which no pockets occur.

The core consists mainly of quartz, albite, microcline, and schorl with local pods of white cleavelandite and, less commonly, pods of deep purple lepidolite with elbaite, spodumene, pollucite, cassiterite, columbite group minerals, and rare beryl (Figures 5-17). Thin section analyses of the lepidolite masses revealed that bulk modal composition is 71% lepidolite and 29 % quartz and albite.

Miarolitic cavities or pockets are relatively common in Mt. Mica and are the source of the gem elbaite that this pegmatite is so famous for. The pockets are ovoid in shape and tend to be most elongated in the horizontal plane and range in size from a few centimeters to one chamber in excess of 11 meters across.



**Figure 4.** Internal structure of a thinner part of the Mt. Mica Pegmatite, showing hanging wall contact, wall zone, core zone and the positions of the garnet and schorl lines below the core zone in the lower wall zone. Pegmatite cross section 1.5 x 2.5 m.

## MINERALOGY

### Feldspars

The dominant feldspar in Mt. Mica is a white albite. K-feldspar is virtually absent in the outer zone of the pegmatite. The Ca content of the albite is uniformly low in the wall zone, averaging about  $An_{2.0}$ . Albite in the core zone approaches pure end-member albite, averaging  $An_{0.2}$ . K-feldspar is only present in the core zone, where large crystals of microcline occur, up to a meter in maximum dimension, near larger pockets and rare pollucite masses. The crystals are perthitic and determined by X-ray diffraction to be near maximum microcline. The average K/Rb ratio of 150 for K-feldspar (Marchal *et al.* 2014) is somewhat high for a B-rich LCT pegmatite, suggesting that Mt. Mica is not very evolved. However, the lower K/Rb ratio of 40 for K-feldspar located in and around pockets and pollucite pods reveals that Mt. Mica is moderately evolved in the core regions (Marchal *et al.* 2014).

This suggests a Na-dominant pegmatitic melt where micas are the dominant K minerals. Feldspars throughout the pegmatite are dominantly Na-rich plagioclase with the highest An content ( $An_{14.45}$ ) occurring at the hanging-wall contact with the country rock. The sodic plagioclase from the wall zones ( $An_{0.05}$ – $An_{5.71}$ ) and core zone ( $An_{0.13}$ – $An_{0.88}$ ) correspond to nearly pure albite. The composition of the K-feldspar shows that the Ab content ranges between 2.37% near the pocket, to 4.79% next to a pollucite mass, and is confirmed by X-ray diffraction to be near maximum microcline. The Rb content ranges from 0.001 to 0.023 apfu, and Cs content ranges from 0 to 0.005 apfu. Overall, K-feldspar is not very enriched in either Rb or Cs, but there is a population of microcline spatially associated with miarolitic cavities and pollucite masses that has higher Rb and Cs. The K/Rb (apfu) ratio of microcline ranges from about 40 to 730.

### Quartz

Quartz is the second most abundant rock-forming mineral in the pegmatite. It forms scattered pods up to m-size in maximum dimension in the core region, but no distinct quartz core is present. The color ranges from white to colorless to smoky brown. Crystals of colorless, smoky and white quartz occur in miarolitic cavities and can reach several dm in maximum dimension. Rose quartz crystals are found rarely in a few pockets. Unusual rings of rose quartz crystals encircle large smoky quartz crystals. An example of a quartz crystal-filled pocket is shown in Figure 5.



**Figure 5.** A miarolitic cavity, primarily filled with quartz crystals. About 50 cm field of view.

### **Muscovite and Lepidolite**

Muscovite and lithium muscovite are the principal micas and are the dominant K-species in the wall zone of the pegmatite. Micas are small and show little change in composition from the pegmatite contact up to the core zone margin, with Li content ranging from  $>0.01$  to  $0.9$  *apfu* (Marchal *et al.* 2014), (Figure 6). There is an abrupt increase in Li-muscovite crystal size at the core zone where large, euhedral, twinned mica crystals, up to 17 cm across occur. Crystals in close proximity or extending into pockets are commonly rimmed with lepidolite. The rims consist of a mosaic overgrowth of 2 to 5 mm lepidolite crystals. There is a sharp boundary in composition between the muscovite and the lepidolite rim (Figure 7). Pods of lepidolite, up to several meters in size, are intermittently distributed within the core zone. The lithium content of all lepidolite from pods and rims ranges from 2.0 to 3.4 *apfu* (Marchal *et al.* 2014). In a few instances, macroscopic interlayering of muscovite and lepidolite on a several micron scale occurs where a muscovite crystal extends into pockets or lepidolite pods. The details of the mica compositional ranges are presented in Marchal *et al.* (2014).



**Figure 6.** A-type twinned lithian muscovite crystal rimmed with lepidolite from a miarolitic cavity.

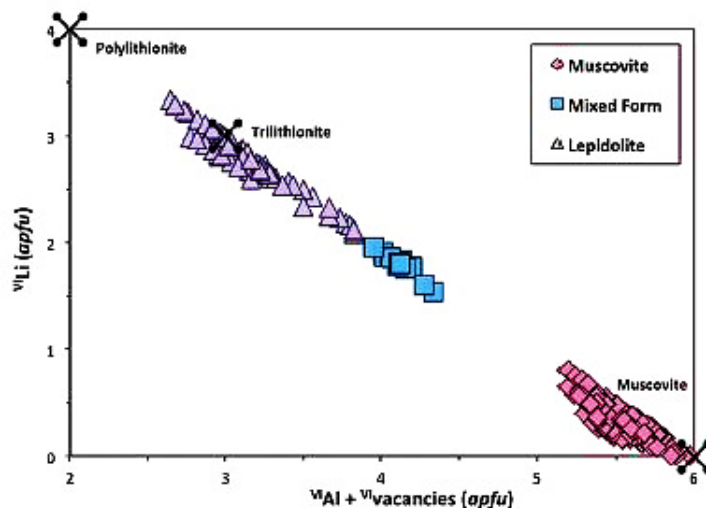


Figure 7. Mica compositions across Mt. Mica pegmatite. Octahedral  $^{IV}Al$  for muscovite, mixed form, and lepidolite, showing a negative relationship between  $^{VI}Al$  & Li (Marchal *et al.* 2014)

### Tourmaline

Tourmaline is present in all the pegmatite zones. In the wall zone, tourmaline occurs as fine- to coarse-grained anhedral to subhedral prisms of black schorl and is occasionally graphically intergrown with quartz. Most of the tourmaline at Mt. Mica is schorl, which occurs abundantly in the wall zone and the core zone. Colored gemmy tourmalines are mainly restricted to the miarolitic cavities (pockets) (Figures 8-10), where they occur as blue to green to pink crystals, almost entirely of elbaite composition or color zoned from black to green to pink. Rossmanite has been found rarely in pink or colorless portions of pocket tourmaline. Foitite occurs sometimes as well, typically as the more or less fibrous black termination on some elbaite tourmalines. Very rarely, tourmalines have been found in miarolitic cavities that have a base of schorlitic composition that was overgrown by elbaite tourmaline of various colors and eventually had a rossmanitic portion near the termination and a black cap of foititic composition (Simmons *et al.*, 2005a and 2005b).

In places, a distinct comb structure of tapered or wedge-shaped crystals fan out from the contact into the wall zone, pointing toward the interior of the pegmatite. This texture is similar to that described from San Diego Co. California pegmatites that have been attributed to rapid crystal growth (Webber *et al.* 1997, 1999). Schorl crystals also radiate around some pockets and the convergence direction of their long axes serves as a pocket indicator. Crystals that extend close to or into a pocket are typically color zoned grading from black to green to pink in color (Figure 8). In the core zone, around and near pockets, tourmaline is dominantly elbaite that occurs as opaque to translucent green, mm- to cm-size prisms. In the pods of fine-grained lepidolite masses, small pinkish tourmaline crystals are relatively common, but most are altered to clay minerals. Inside the pockets in the core zone, spectacular, gem-quality, prismatic crystals of blue to green to pink, pink and green color zoned prisms and watermelon tourmaline occur, some as large as 15 cm in length (Figures 9 and 10). This elbaite is associated with albite *var.* cleavelandite, quartz crystals up to 30 cm and medium-to-very coarse crystals or books of Li-muscovite that may be rimmed by lepidolite (Figure 6). The tops of some pink elbaite crystals are capped with a thin layer of black tourmaline (foitite) and the crystals are similar to the Mohrenkopf crystals from Elba, Italy.



**Figure 8.** Color zoned tourmaline adjacent to a pocket, near the entrance to the underground workings. Field of view about 1 m.

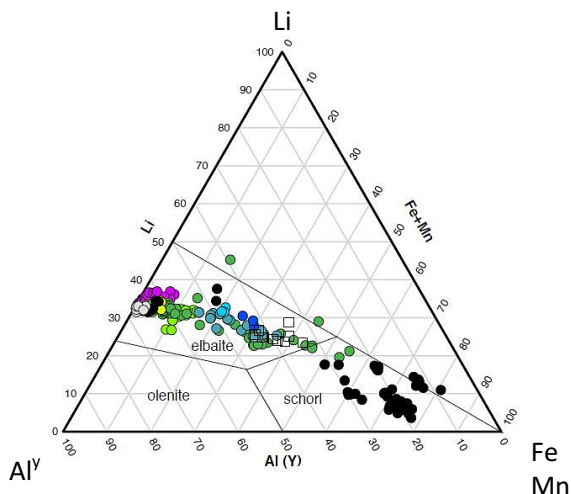


**Figure 9.** Green tourmaline crystals recovered from a miarolitic cavity. The crystal on the left is 10 cm in length.

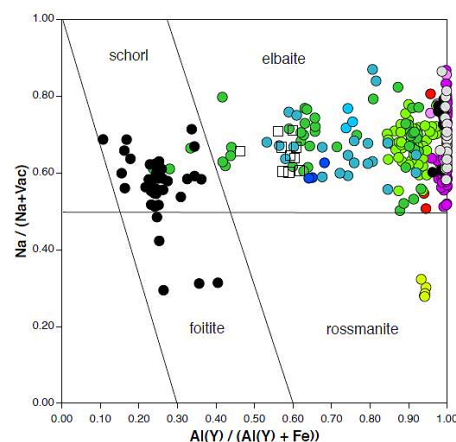


**Figure 10.** Two of the most significant tourmalines found to date. On the left is a 19-cm tall, tricolored elbaite crystal, on the right is a 22-cm tall multi-colored crystal with a thin foitite termination.

Tourmaline exhibits the expected trend of Fe-rich schorl in the outer portion of the pegmatite evolving to greater contents of Al and Li in the core zone of the pegmatite (Simmons *et al.* 2005a & b) (Figures 11 and 12). The pink and green color of elbaite in pockets is mainly a consequence of Fe content. Colors grade from black to blue and blue-green to light green to pink as Fe content drops in the core zone and particularly in pockets (Simmons *et al.* 2005a & b).



**Figure 11.** Ternary Al-Li-Fe+Mg diagram of Mt. Mica tourmaline compositions and species from pocket.



**Figure 12.** Mt. Mica elbaite -schorl-foitite-rossmanite plot

### Beryl

Beryl is not as abundant in the massive pegmatite as in many other Oxford field pegmatites. However, in miarolitic cavities, superb specimens have been found (Figures 13 and 14). Beryl found in the massive pegmatite is bluish-green to yellowish whereas in miaroles, beryl is white. Most of the crystals found in the miarolitic cavities consist of white to colorless or pinkish cesium-enriched beryl or pink morganite. Compared to other pegmatites in the Oxford field, notably the Orchard, the Emmons and the Bennett pegmatite, Mt. Mica pegmatite appears to have a paucity of common beryl. It is more abundant in the miarolitic cavities, suggesting that Be was retained until the pocket stage was reached



**Figure 13.** A miarolitic cavity with green tourmaline and a large thick tabular beryl crystal. Field of view about 25 cm.



**Figure 14.** A fine, giant beryl, var. morganite. (Gary Freeman photo).

### Pollucite

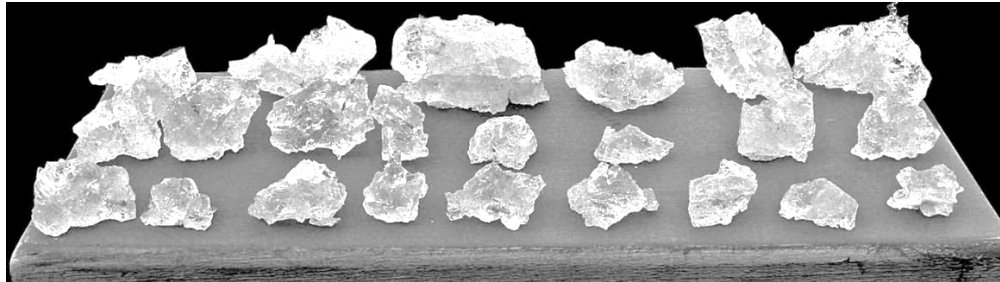
Pollucite has been found in m-sized masses (Figure 15) in the inner zones of the pegmatite, associated with cleavelandite, microcline, montebasite, lepidolite and spodumene. Recently, exceptional gem-quality extensively etched pollucite (Figure 16) has also been found in miarolitic cavities and is associated with crystals of cleavelandite, quartz, lepidolite, fluorapatite, gem-quality elbaite and beryl. Etched pollucite is easily mistaken for etched beryl.



Some domains in the etched pollucite have anomalous birefringence, which can further obscure their proper identification.



**Figure 15.** A meter-sized pollucite mass.



**Figure 16.** Etched, gem-quality, pocket pollucite crystals

### **Montebrasite**

Montebrasite occurs as masses and crude white crystals in the core zone, commonly with lepidolite and spodumene (Figure 17). The maximum dimension can reach several dm. No amblygonite has been found to date in any Oxford field pegmatites, even though in the older literature, amblygonite is commonly cited.



**Figure 17.** Large montebrasite pods with lepidolite and altered spodumene in the core zone. About 2 m field of view (Gary Freeman photo).

**Spodumene**

Spodumene has been observed in dm-sized crystals but is typically completely replaced by clay minerals or mica species in most cases (Figure 17).

**Garnet**

Garnet, typically almandine-spessartine solid solution composition, occurs dominantly in the garnet layer in the foot wall of the pegmatite (Figures 4 and 18). Garnet as isolated crystals is rare, but somewhat more abundant near the contact of the pegmatite; it is sparse in the rest of the pegmatite. The garnet line consists of an undulating, somewhat sinusoidal to irregular concentration of 1 to 5 cm garnet crystals in a matrix of quartz and feldspar. The most evolved portion of the pegmatite is always above this horizon in the more incompatible-rich core zone of the pegmatite, where the pockets occur. Thus, this line is an important marker that the miners interpret to be the bottom of the productive zone, below which no pockets occur. The garnet layer marks a distinct boundary layer of the pegmatite. In microenvironments, a highly fractionated mineral assemblage is present (Felch, 2014; Felch *et al.*, 2016). Garnets may reach up to 2-3 cm in diameter and in garnet layer portion below miarolitic cavities, a characteristic alteration rim of dark blue tourmaline (Figure 18) is typically present (see Felch *et al.* (2016) for more details about the garnet line and the associated evolved mineral assemblage).

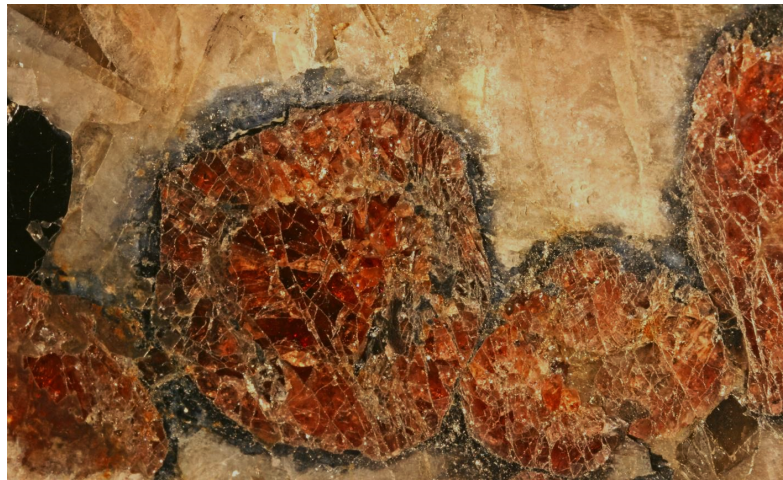


Figure 18. A 1.5 cm wide garnet with tourmaline rim from the garnet layer.

**Columbite Group Mineralogy**

Columbite group minerals show only minor to moderate enrichment in Mn and Ta, reaching only columbite-(Mn) (Simmons *et al.* 2013). The Mt. Mica pegmatite is not very rich in columbite group minerals. Among the high field-strength element bearing minerals, cassiterite and zircon are the most abundant. In fact, Mt. Mica seems rather depleted in Ta relative to other B-rich LCT pegmatites.

**Cassiterite**

Masses of cassiterite are abundant at Mt. Mica. In the past, a short-lived attempt was made to mine cassiterite for its tin content.

**List of mineral species identified in the Mount Mica pegmatite**

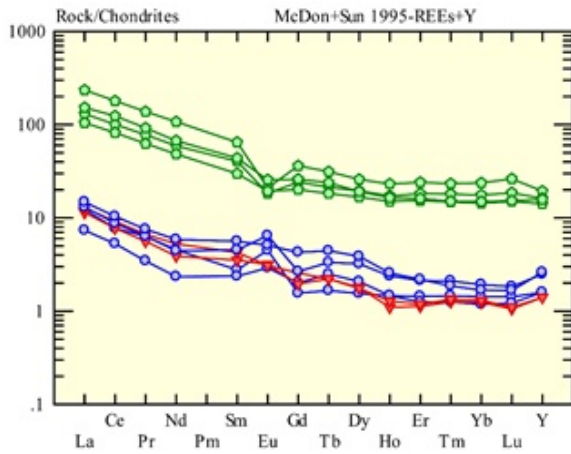
Albite	Heterosite	Plagioclase group
Almandine	Hureaulite	Pollucite
Arsenopyrite	Hydroxylapatite	Purpurite
Autunite	Hydroxylherderite	Pyrite
Beraunite	Jahnsite-(CaMnMn)	Quartz
Bertrandite	Kaolinite group	Reddingite
Beryl	Kosnarite	Rhodochrosite
'Biotite'	Laueite	Roscherite group
Cassiterite	'Lepidolite'	Rossmanite
Columbite-(Fe)	Löllingite	Schorl
Columbite-(Mn)	Mccrillisite	Scorodite
Cookeite	'Manganese oxides'	Siderite
Crandallite	Meta-autunite	Sphalerite
Dahllite	Metatorbernite	Spodumene
Elbaite	Microcline	Stewartite
Fairfieldite	Microlite group	Strunzite
Fluorapatite	Mitridatite	Tantalite-(Mn)
Foitite	Montebrasite	Tapiolite-(Fe)
Glucine	Montmorillonite group	Torbernite
Goethite	Moraesite	Tourmaline group
Goyazite	Muscovite	Triphylite
Graphite	Opal	Uraninite
Greifensteinite	Phosphosiderite	Zircon
Hematite	Phosphouranylite	

**BULK COMPOSITION OF MT. MICA**

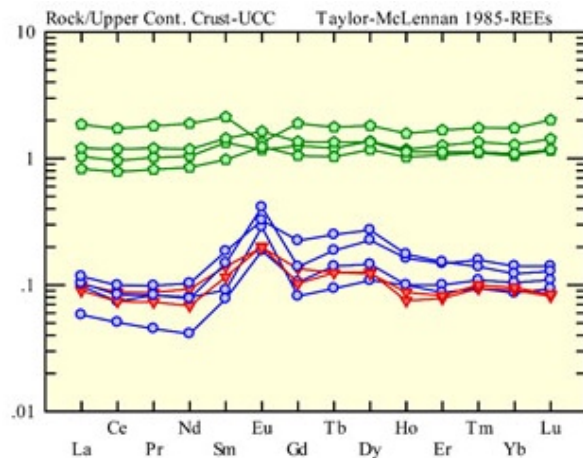
A very detailed and accurately surveyed geologic map produced by owner/operator Gary Freeman during mining shows the total area of pegmatite removed, the spatial distribution and aerial extent of pockets, massive lepidolite (compositions near trilithionite) pods, microcline, and xenoliths. The map was analyzed using image analysis and thickness values of the units to calculate the total volumes of pegmatite mined, lepidolite pods and all pockets found. Forty-five drill cores were taken across the pegmatite from the hanging wall to foot wall contacts along a transect intentionally avoiding lepidolite pods and miaroles. Cores were pulverized, thoroughly mixed and homogenized and the percent Li content calculated from the mapped volume was added to produce a sample that was representative of the bulk composition of Mt. Mica. The sample was then analyzed by fusion ICP spectroscopy for major and trace elements and DCP spectroscopy for B and Li. Structural water was determined by LOI. Water content was calculated using the calculated volume of open space (pocket volumes), assuming that the pockets were filled with water-rich fluid. This fluid content was added to LOI water (above 500°C) to estimate a maximum H<sub>2</sub>O content of 1.16 wt. % of the pegmatite melt. REE plots of bulk pegmatite vs. leucosomes from the migmatite are strikingly similar. Chondrite normalized REE patterns of leucosomes and pegmatite are very flat with no Eu anomaly, whereas Sebago granite is more strongly LREE-enriched and displays a pronounced negative Eu-anomaly (Figures 19 and 20). Spider diagrams of leucosomes and pegmatite vs. average crust show very similar patterns (Figure 21). These results suggest that the Mt. Mica pegmatitic melt did not form by fractional crystallization of the older Sebago pluton, but instead was derived directly from partial melting of the metapelitic rocks of the SMD. Batches of anatectic melt accumulated and coalesced into a larger volume that subsequently formed the pegmatite. This is the first chemical evidence presented for the formation of an LCT type pegmatite by direct anatexis.

We believe that we have obtained a very accurate estimate of the whole rock composition of Mt. Mica Pegmatite and it illustrates that the pegmatite was not close to water saturation at the time of emplacement and that overall the pegmatite is only moderately evolved (Simmons *et al.* 2016), only areas within the core zone and the

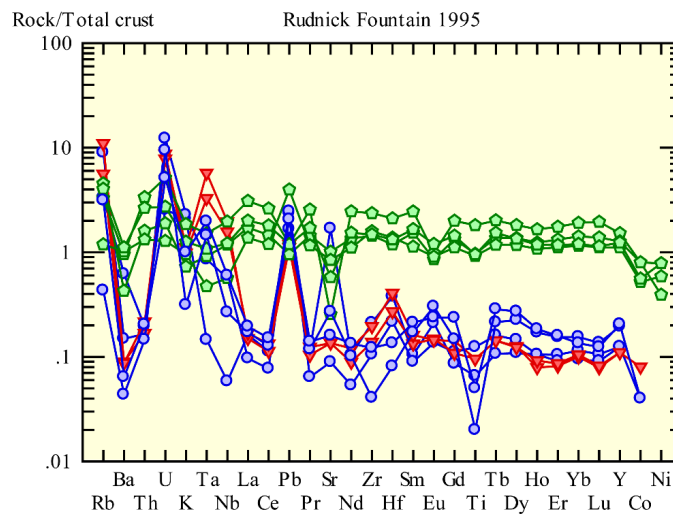
pockets are highly evolved. Also, although Mt. Mica is generally considered to be a relatively pocket-rich pegmatite, the actual volume of open space is quite small, less than 1.0 % and the calculated amount of water contained in the melt that formed the pegmatite is about 1.16 wt.%.



**Figure 19.** Whole-rock chondrite normalized REE plot of Mt Mica Pegmatite (red), SMD Leucosomes (blue), Sebago Pluton Granitic rock (green). Chondrite values of McDonough and Sun (1995).



**Figure 20.** Whole-rock spider diagram sample of Mt. Mica pegmatite (red) and SMD leucosomes (blue) and Sebago Pluton Granite (green) relative to upper continental crust. Normalization values from Taylor and McLennan (1985).



**Figure 21.** Whole-rock spider diagram of Mt. Mica pegmatite (red) and SMD leucosomes (blue) and Sebago Pluton Granite (green) relative to total crust. Normalization values from Rudnick and Fountain (1995).

## MODEL FOR POCKET FORMATION

The model for pocket formation employed in the calculations of pocket volume and total water content of the pegmatite is that described by Simmons *et al.* (2003, 2012 and 2016), which involves exsolution of a second fluid phase after most of the pegmatitic melt has crystallized. The residual melt accumulates toward the center of the dike and becomes progressively enriched in water and other fluxing materials until ultimately, a second aqueous fluid

exsolves forming more or less spherical segregations (“bubbles”) of a flux-rich aqueous fluid that constitutes a protopocket. According to the most widely accepted theory of pocket formation (Jahns & Burnham 1969), once the supercritical aqueous fluid starts to exsolve, diffusion of ions from the coexisting silicate melt into the fluid supplies nutrients to the crystals growing in the protopocket. Continued rapid diffusion of ions from the silicate melt to the growing crystal surfaces in the fluid of the protopocket is proposed to explain the greater volume of crystals found in the pockets than what could have grown from the less dense, aqueous, pocket-forming fluid alone. Thus, the flux-rich aqueous fluid is the medium through which ions diffuse to the growing crystal surfaces. We note that this model of pocket formation is directly opposed to that of London, (2013), but we feel this model best supports the observations of pockets found at Mt. Mica.

## CONCLUSIONS

In contrast to suggestions of previous authors (Wise & Brown 2010, Wise & Francis 1992) that this pegmatite was derived by fractional crystallization from the Sebago Granite pluton (or any other pluton), we believe the chemical evidence strongly suggests that the Mt. Mica pegmatitic melt could be derived directly from partial melting of the metapelitic rocks of the Sebago Migmatite Terrain. We suggest that the Mt. Mica pegmatitic melt did not form *in situ*, but that batches of anatectic melt accumulated and coalesced into a larger volume that subsequently formed the Mt. Mica pegmatite. This is new chemical evidence for the formation of an LCT type pegmatite by direct anatexis.

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## THE HAVEY PEGMATITE, POLAND, ANDROSCOGGIN COUNTY, MAINE

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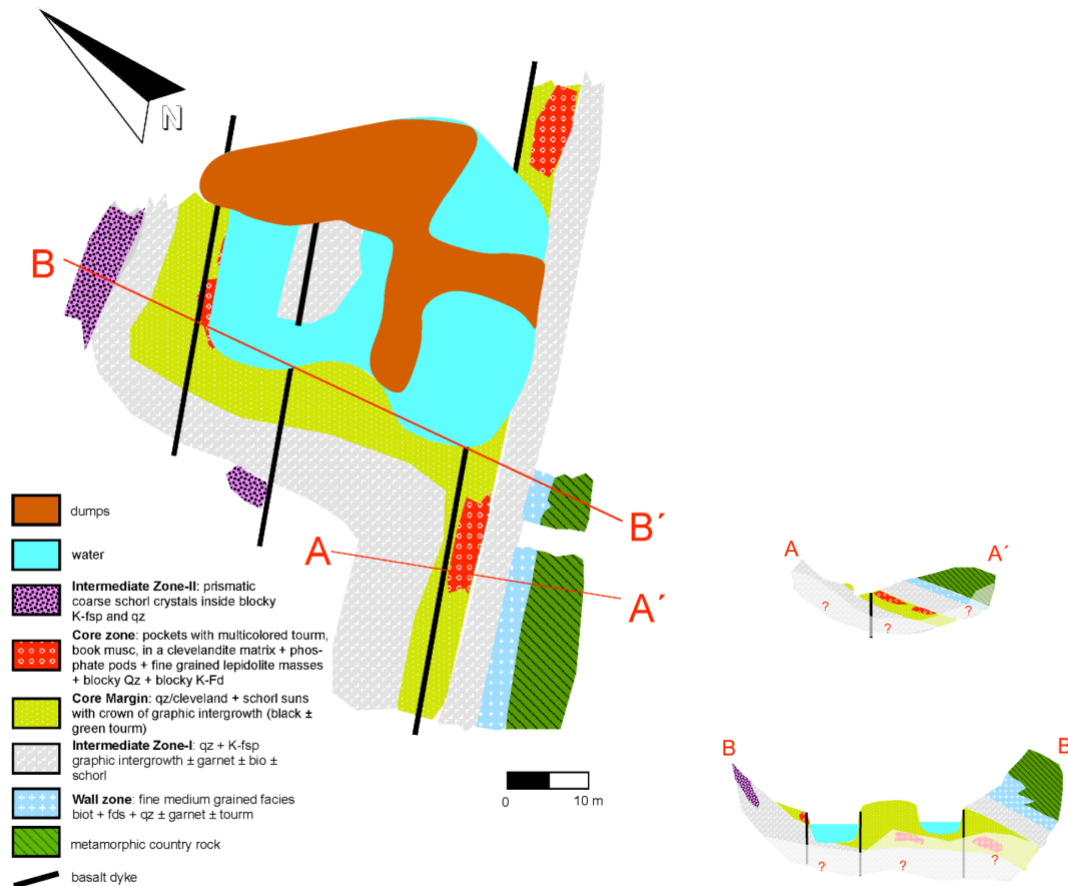
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### INTRODUCTION

The Havey pegmatite (Figure 1) in Androscoggin County, Maine belongs to the Oxford pegmatite field. The pegmatite is named the Berry-Havey and is owned by different parties. The Havey pegmatite portion is operated by Jeffrey Morrison. The pegmatite is one of the more evolved Oxford field rare-element pegmatites. It is enriched in Li, F, B, Be and P and contains miarolitic cavities with gem tourmaline (Figures 2-4 and 6-8). Lepidolite masses are common, but pollucite is rare. The pegmatite is complexly zoned with a border zone, two intermediate zones, a core margin and a core zone (Figure 1). Tourmaline is abundant throughout the pegmatite. The pegmatite has been cut by several younger basaltic composition dikes (Figure 5).



**Figure 1.** Map and cross sections of the Havey pegmatite, 2011.

## PEGMATITE ZONING

The Havey pegmatite is a tabular to irregular body, conformable to the host-rock (biotite- amphibole-rich schist), to the SW of the quarry (~40° SSE), whereas in the northern part the body is more horizontal. The lack of outcrop of the foot-wall makes it difficult to determine the thickness of the body but, according to the present level of exposure, it is over 30 m. The pegmatite shows a well- developed internal structure, with five different zones: wall zone, intermediate zone I & II, core margin and core zone. These zones are subparallel, with quite irregular limits among them, mainly for the core margin-core zone transition. From the contacts inward, the following zones are distinguished (Roda- Robles et al., 2015) (Table 1): (1) Wall zone, commonly with a fine to medium sized pegmatitic texture, although a gneiss-like facies is locally common. Main minerals are quartz, K-feldspar, plagioclase, biotite and muscovite, with tourmaline and garnet as common minor phases. (2) Intermediate zone volumetrically is the most important, mainly in the lower portion of the dyke, with more than the 85 % belonging to graphic intergrowths of quartz-K-feldspar (intermediate zone I). Biotite, garnet and black tourmaline are minor phases. In the lower part of the intermediate zone, locally the texture and mineralogy change to coarse quartz, K-feldspar and black prismatic tourmaline (intermediate zone-II). Moreover, a > 30m<sup>3</sup> “xenolithic” gneiss-like body is located in the lower intermediate zone-I, showing similar mineralogy and gradual textural changes with the pegmatitic material. (3) Core margin, volumetrically important, this unit hosts the different pods that constitute the core of the pegmatite. Main minerals are albite (cleavelandite), quartz and tourmaline. Moreover, garnet commonly occurs as medium sized reddish- brownish crystals concentrated in a layer just below the core pods. This “garnet layer” is common to most of the pegmatites from this region. (4) Core zone is not a continuous unit, but several pods of different sizes (2 to ~10m), frequently interconnected and hosted by the core margin.

**Table 1.** Main characteristics of the Havey pegmatitic units and the associated tourmaline.

ZONE	MINERALOGY	GENERAL TEXTURES	TOURMALINE TEXTURE	COMPOSITIONAL VARIATION
<b>WALL</b>	Qtz, Kfs, Pl, Bt, Ms ± Grt ± BLACK Tur	Homogeneous, very fine to medium grained facies. Locally greenish Kfs	Very fine grained, black prismatic crystals. Very scarce	Dravite-Schorl
<b>INTERMEDIATE-I</b>	Qtz, Kfs ± Grt ± Bt ± BLACK Tur	Qtz-Kfs graphic intergrowths (> 90% volume)	Fine to medium subhedral crystals	Schorl-Foitite
<b>INTERMEDIATE-II</b>	Qtz, Kfs, BLACK Tur	Blocky Kfs and Qtz	Coarse prismatic black crystals	Schorl-Foitite
<b>CORE MARGIN</b>	Ab, Qtz, BLACK ± GREEN Tur	Matrix of tabular crystals of Clv, where coarse tourmaline crystals occur	Coarse black tourmaline prisms (< 70 cm length) crowned by an intergrowth of black±green Tur and Ab Sharp contact between black and green Tur	From Schorl -Foitite to Elbaite
<b>CORE</b>	Lpd, Ms, Qtz, Kfs, Mon, Ab, Brl, Fe-Mn Pho GREEN, PINK & MULTICOLORED Tur	Irregular pods of fine grained Lpd, coarse book Ms, Mon, Fe-Mn-Pho±Cst±Col-Tan Coarse morganite (Brl) sub- to euhedral crystals are common. Pockets with elbaite in a Cookeite matrix	In the pods, subhedral, fine to medium zoned xls watermelon, pink or green crystals with lepidolite and muscovite. In pockets, green, teal or watermelon gem-quality xls.	Pods: Elbaite-Rossmanite  Pockets (gem): Elbaite -Rossmanite

Qtz=quartz; Kfs=feldspar; Pl=plagioclase; Ms=muscovite; Bt=biotite; Grt=garnet; Tur=tourmaline; Ab=albite; Clv=cleavelandite; Mon=montebrasite; Cst=cassiterite; Col-Tan=columbite-tantalite; Lpd=lepidolite; Pho=phosphates; Brl=beryl; Cook=cookeite. \*Grain size: very fine = <6 mm; fine = 6 mm to 2.5 cm; medium 2.5 cm to 10 cm; coarse = >10 cm.



## CRYSTALLIZATION SEQUENCE AND CHEMICAL EVOLUTION

The asymmetry indicates that the crystallization from the footwall and from the hanging-wall proceeded in different ways. Textures such as the quartz-K-feldspar and quartz-tourmaline graphic intergrowths, and the comb tourmaline crystals, suggest that crystallization proceeded under disequilibrium conditions from an undercooled melt (Simmons *et al.* 2003). Crystallization of the tourmaline layer in the core margin followed different steps. It starts with the crystallization of the tapered prisms, in general perpendicular to the contacts. Then, it follows with the formation of the crowns of quartz-tourmaline graphic intergrowth around the tapered prisms, where the composition and color often change from black schorl to greenish (or bluish) elbaite. Finally, it ends with the breaking of some of the tourmaline crystals, mainly belonging to the crowns. The occurrence of a significant volume of tourmaline in this layer implies a pronounced depletion of B in the melt during its crystallization. The saturation in volatiles in the melt is increased the crystallization of anhydrous and non-volatile-bearing minerals, such as quartz and feldspars, in the wall and intermediate zones of the pegmatite, which would have increased the mole fraction of the volatile components in the melt, ultimately resulting in the exsolution of a fluid phase, and the formation of pockets. The presence of  $B_2O_3$  enhances the solubility of water in the melt (Holtz *et al.* 1993; London 2009). Accordingly, the formation of the tourmaline layer dramatically lowers the solubility of water in the remaining melt, which also promotes exsolution of a water-rich fluid to form pockets. Assuming a closed system, we speculate that the breaking of some of the last formed tourmaline crystals in the tourmaline layer of the core margin could be related to a sudden increase in the fluids pressure provoked by the exsolution of the water-rich fluids from the melt, which imply a significant volume increase that could cause brecciation (Phillips 1973; Burnham and Ohmoto 1980; Burnham 1985). At this point, the concentration of Fe was low enough and Li was high enough to allow the crystallization of the first colored tourmalines in the core margin, followed by the crystallization of the core zone, where all the tourmaline corresponds to elbaite, with variable amounts of F, Li, Al, Mn, and vacancies. On the other hand, garnet crystallization ends in the core margin, below the core zone. This is likely related to the increase of the Li and F content in the pegmatite-forming system making Mn compatible in micas and tourmaline, which would destabilize garnet, that had evolved to Mn-richer compositions (Černý *et al.* 1985; London *et al.* 2001; London 2008). Overall, tourmaline compositions evolve from schorl in the outer zone of the pegmatite to elbaite in the core zone of the pegmatite.



**Figure 2.** Pockets in Havey Pegmatite



**Figure 3.** The “Spaniard” pocket being worked in 2011.



**Figure 4.** Jim Nizamoff in “Otto’s” pocket.



**Figure 5.** Large spray of colorful pink elbaite in massive pegmatite.



**Figure 6.** Basaltic dike cutting Havey pegmatite.



**Figure 7.** Open gem tourmaline pocket. Green and pink elbaite visible along bottom of pocket



**Figure 8.** Close up of Figure 6 showing bi-colored gemmy elbaite.



Figure 9. Cleavelandite adjacent to a pocket



Figure 10. Lepidolite adjacent to a pocket

## MINERALS

### List of mineral species identified in the Havey pegmatite

Albite	Hydroxylherderite	Rhodochrosite
Almandine	Lacroixite	Rockbridgeite
Apatite-(CaF)	Landesite (TL)	Rossmannite
Arsenopyrite	Lepidolite	Schoepite
Autunite	Lithiophilite	Schorl
Bertrandite	Meta-autunite	Siderite
Beryl	Metaschoepite	Spodumene
Biotite	Microcline	Stewartite
Cassiterite	Microlite group	Strunzite
Columbite-(Fe)	Mitridatite	Tantalite-(Mn)
Columbite-(Mn)	Montebrasite	Todorokite
Cookeite	Montmorillonite	Tourmaline
Cryptomelane	Muscovite	Triplite
Dahllite	Phosphosiderite	Uraninite
Dickinsonite-(KMnNa)	Plagioclase group	Uranophane
Elbaite	Pollucite	Wardite
Eosphorite	Purpurite	Zircon
Fairfieldite	Quartz	
Hureaulite	Reddingite	

### Tourmaline

Tourmaline is the most sought after mineral species in this pegmatite. In the past few years, some very fine gem tourmalines have been produced (Figures 11-15). Whereas the size is not as large as the tourmalines from Mt. Mica, the crystals consist of a high proportion of gem material. The pocket tourmalines are primarily green but some pink and watermelon colors have also been produced. In Figure 4, a pink tourmaline spray is shown that occurred in the inner zones of the pegmatite, seemingly of fracture-controlled origin. Schorl is the common tourmaline of the outer, massive zones in the pegmatite. Compositionally, tourmaline from the Havey pegmatite ranges from schorl to elbaite, with some rossmanite (Figure 16).



**Figure 11.** Green elbaite just recovered from a 2011 find.



**Figure 12.** A selection of gem tourmaline from the Havey pegmatite. 1-2 cm range.



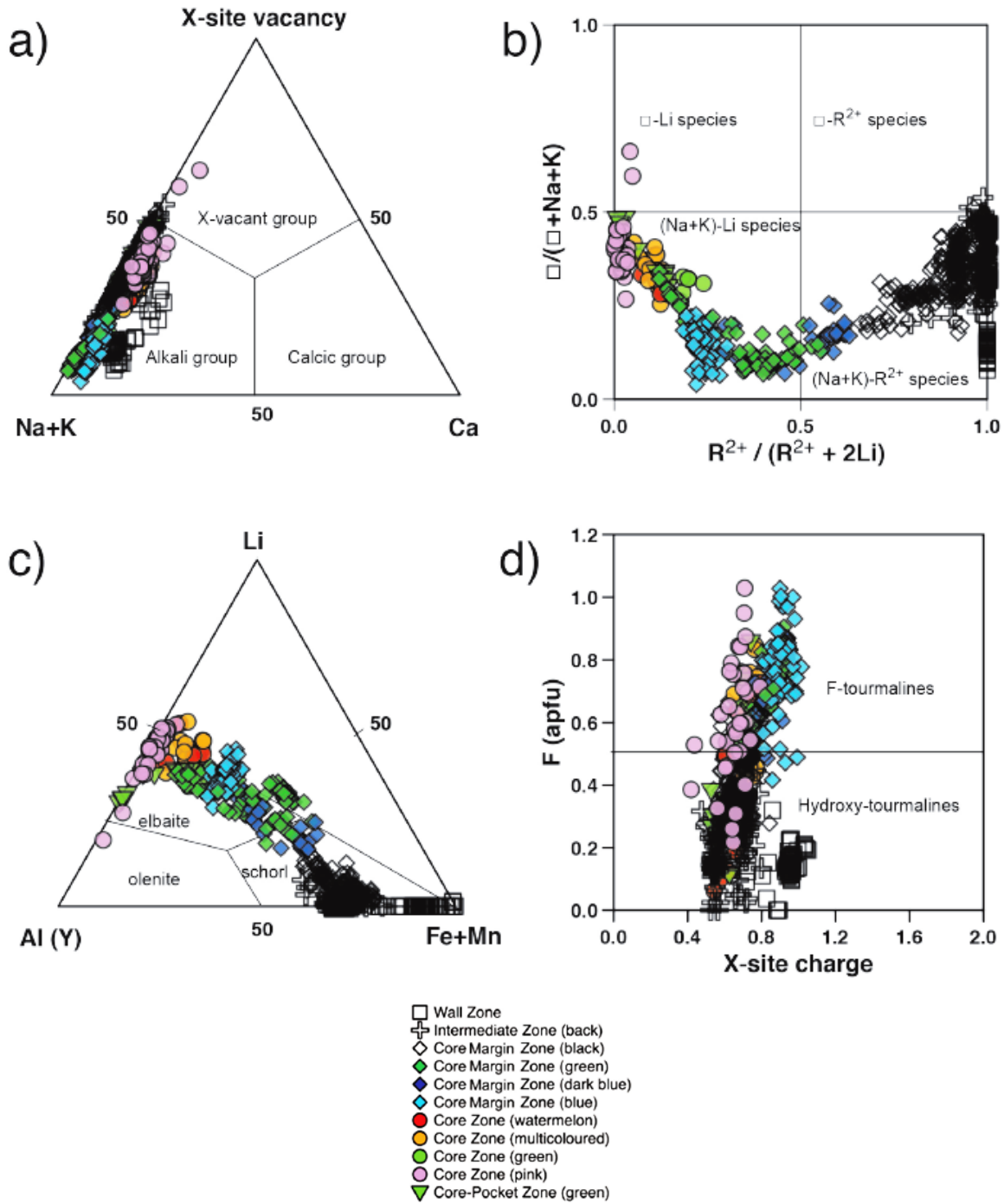
**Figure 13.** Two gem crystals from the Havey pegmatite, about 3 cm tall.



**Figure 14.** Multicolored elbaite. (J. Scovil photo)



**Figure 15.** Fractured gem elbaite prism in albite.



**Figure 16.** Plots of the chemical composition of tourmalines from the different units in the Havey pegmatite (Roda-Robles, 2011): (a) X-site plot of (Na+K)-Ca-X-site vacancy; (b) variation in  $R^{2+}/(R^{2+}+2Li)$  vs.  $o/(o+Na+K)$  as proposed by Henry et al. (2011) for the classification of tourmaline; (c) triangular plot of Li-Al(Y)-Fe+Mn; and (d) X-site charge vs. F. All data in apfu.

### Fluorapatite

Fluorapatite occurs as an accessory phase in all the zones of the Havey, except in some pockets of the core zone, where it may be abundant. In the wall zone and intermediate zone apatite appears as fine-grained (< 5 mm) greyish crystals (Table 1). Bigger bluish prismatic to anhedral crystals are relatively abundant in the core margin, frequently intergrown with garnet in the garnet layer. In the core zone apatite has only been found in pockets, frequently coating some coarse smoky quartz crystals. In the pockets apatite may occur as bluish or purple short hexagonal prisms (Figure 17), and as euhedral, sharply zoned, hexagonal lenses, with a clear blue to greyish core and a narrow white rim. As for garnet, chemical composition of apatite changes notoriously regarding the pegmatite zone (Table 1). All the analyzed apatite crystals are F-rich fluorapatite. Apatites from the wall zone, intermediate zone and core margin are the F-poorest; whereas those from the pockets show the highest F contents. Manganese contents change in a great extent (Table 1). Mn-rich apatite is only found in the inner zones of the pegmatite (core margin and core zone), with the highest values in the apatite from the garnet layer of the core margin, and intermediate values in the core of the zoned lenticular crystals of the pockets. The rest of the apatites from the pockets, as well as those from the wall zone and intermediate zone, are Mn-poor. Iron contents are low in all the analysed crystals. Interesting zoned crystals (Figure 18) have recently been found.



**Figure 17.** Large fluorapatite matrix specimen, about 25 cm maximum dimension



**Figure 18.** Zoned fluorapatite, 4 cm across.

### Quartz

Quartz is abundant as smoky quartz crystals in miarolitic cavities. Complexly grown crystal groups (Figure 15) or well-crystallized single crystals (Figure 19) have been found in the past few years.

### Feldspars

Feldspars are the major mineral group in the pegmatite. Potassium feldspars are typically microcline and are white to off-white unless they have been metasomatized near miarolitic cavities, then the color changes into beige to tan. Albite is abundant and in replacement units and in miarolitic cavities it is generally found as the platy variety cleavelandite (Figure 9).

### Garnet

Garnet occurs as a minor phase in all the zones of the Havey pegmatite, with the exception of the core zone, where it has not been found. Most of the garnet crystals exhibit subrounded forms and reddish to brownish colours in hand sample. Only some crystals are irregular or poikilitic, mainly in the gneiss-like material from the wall zone. The biggest crystals are found in the garnet layer of the core margin, just below the core zone. There is a marked and continuous chemical variation in the garnet composition from the wall zone inwards, with a Mn increase parallel to the Fe decrease (from Mn-rich almandine in the wall zone to Fe-rich spessartine in the core margin) (Table 1). In contrast, only garnets from the wall zone show a core-to-rim systematic variation, with a Fe-, Mg-, and Ca-decrease, parallel to a Mn-increase. In the other zones of the pegmatite garnet chemical profiles of single crystals are flat or saw-shaped. In one case, extensive replacement of almanditic garnet by löllingite has been documented (Simmons & Falster, 2017)

**Hydroxylherderite**

Hydroxylherderite is a common accessory mineral in miarolitic cavities in the Havey pegmatite (Figure 20)



**Figure 19.** Mosaic smoky quartz crystal



**Figure 20.** Hydroxylherderite (J. Scovil photo)

**Lepidolite**

Lepidolite is abundant in the pegmatite as masses in the inner zones of the pegmatite as well as unusual, pillar-shaped crystals in the miarolitic cavities (Figures 21-22). Notably, the massive lepidolite is very colorful with attractive lilac hues (Figure 10).



**Figure 21.** Columnar lepidolite from a pocket.



**Figure 22.** Columnar lepidolite from a pocket.

**Beryl** has been found as large (25 cm+) etched masses of morganite in the pegmatite (Figure 23). It also occurs as common, bluish to greenish beryl in the massive pegmatite.



**Figure 23.** Etched beryl, var. morganite. 6 cm across.

## SUMMARY

The continuous increase in the Mn content in the garnet from the wall zone to the core margin, parallel to the decrease in Fe, Mg and Ca (Table 1), is a typical fractionation-induced trend, with almandine in the less fractionated outer zones of the pegmatite, and spessartine in the core margin. No garnet has been found in the core zone. In this zone crystallization of phosphates (both, Fe-Mn-rich and Al-F-rich) becomes important, occurring as common subrounded pods of montebrasite and/or Fe-Mn-phosphates. The lack of garnet once the phosphates start crystallizing has been reported in many other pegmatites (e.g. Roda-Robles *et al.*, 2013). This is interpreted to be the result of the sequestering of the remaining Fe and Mn by the phosphates, which prevents the crystallization of garnet. The increase of Mn from core to rim in the garnet indicates that minerals other than garnet control the Fe and Mn contents of the melt (Müller *et al.*, 2012). Iron would incorporate preferentially into tourmaline, whereas Mg partitions into biotite and Mn into garnet. The main chemical variations for major elements in apatite correspond to the F content. The incompatible character of F makes that melt becomes F-richer with fractionation. Thus, the minerals growing at the final stages of the Havey crystallization tend to be F-rich, as it is the case of apatite, tourmaline, micas and montebrasite.

The development of pockets inside the core zone was most probably related to the exsolution of a fluid phase from the melt. The pockets represent the space that was once filled by accumulated supercritical fluid (Nabelek *et al.* 2010; Simmons *et al.* 2012), and show that the exsolved fluid was collected in discrete spaces instead of one continuous space between the hanging wall and lower portions of the dikes (Maloney *et al.* 2008). Fluid inclusions in the quartz crystals from the pockets at the Havey are mainly aqueous (Fuertes-Fuente, personal communication), which supports this model. Taking into account the mineralogy of the pegmatite, the presence of pockets, and that the regional metamorphism occurred at low pressure (Tomascak *et al.* 2005), we can assume that the crystallization of the Havey pegmatite developed under pressures in the range 2–3 kb. The maximum water solubility in silicate melts at those pressures is ~6 wt% in the absence of boron (Holtz *et al.* 1995). This amount of H<sub>2</sub>O, given its molar volume at 400 °C and 2 kbar, would occupy ~28% of the chamber volume (London 2008; Maloney *et al.* 2008). Based on these estimations, and on the relation between the volume of the pockets and the volume of the core zone, it seems plausible that the exsolution of fluids from the pegmatitic melt took place close to the end of the crystallization of the core margin. According to London (2008), the crystallization of granitic melt containing 6 wt% H<sub>2</sub>O promotes a volume increase of 21% at constant pressure, and this release of vapor could cause the rupture of the pegmatite. In our case, the rupture of the tourmaline crystals close to the core zone and pockets therein.



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**ROAD LOG****STOP 1: HAVEY PEGMATITE.** UTM: 396013.86E 4880609.96N**Mileage**

- 0.0 **Meeting Point.** Back parking lot of the Maine Mineral & Gem Museum, the Museum address is 99 Main Street, Bethel. The back-parking lot can be accessed from Chapman Street, off of Main street. UTM coordinates: 357596.60E 4918695.79N.
- 0.0 Cars will line up going north on Main street by the Museums front entrance.
- 0.2 Head north on Main Street toward Mechanic Street
- 23.6 Main Street becomes ME-26. Continue on ME-26 S.
- 24.8 **Turn Right** onto Main Street in Paris (This is still ME-26 S)
- 25.2 At the stop light **Turn Left** onto Fair street (This is still ME-26 S)
- 31.4 Continue travelling down ME-26 S (Main street)
- 36.1 **Turn Left** onto ME-121 N
- 39.8 After the traffic light in Mechanic Falls turn left onto ME-121 N (ME-11, Lewiston Street)
- 40.0 Take slight **Right** off of ME-121 N onto Lower Street
- 40.2 **Turn Right** onto Empire Road
- 41.8 **Turn Left** onto Hardscrabble Road
- 41.9 DANGEROUS TURN BEFORE HILL, PROCEED WITH CAUTION. **Turn Left** onto Levine Road
- 50.0 **Turn Left** off of Levine Road to access Havey Quarry entrance. Parking spaces will be located along the left side of the mine road. WHEN PARKING, DO NOT BLOCK ACCESS ROAD.
- After parking the group will convene and walk down into the quarry.

**STOP 2: MT. MICA PEGMATITE.** UTM: 382422.43E 4902825.20N

- 50.1 Exit the Havey Quarry and **Turn Right** onto Levine Road
- 50.2 **Turn Right** onto Hardscrabble Road
- 51.8 **Turn Right** onto Empire Road
- 52.1 CAUTION DANGEROUS INTERSECTION. **Turn Left** onto ME-121/ME-11 (Minot Ave).
- 52.8 **Turn Right** onto ME-119N (Woodman Hill Road).
- 59.1 In the village of West Minot, **Turn Left** onto ME-119 N

67.6 **Turn Right** onto ME-117 (Buckfield Road). Be prepared to turn left.

384ft **Turn Left** onto Hill Street

68.5 Merge onto Old Route 26/Paris Hill Road

69.1 Take a slight **Right** onto Paris Hill Road

70.3 In the village of Paris, **Turn Right** onto Lincoln Street.

70.7 Continue straight, Lincoln Street turns into Mt. Mica Road.

72.1 Continue driving down Mt. Mica Road

**Turn Left** onto a gated dirt road (UTM 382373.27E 4902591.54N), this is the access road to the Mt. Mica Mine. Drive up the access road and find parking in the lots on the right. After parking the group will convene before walking down into the mine. WHEN PARKING, DO NOT BLOCK ACCESS ROAD.

#### **End of Field Trip Stops**

The road log continues to return to the meeting point at the Maine Mineral & Gem Museum, where the Welcoming Reception is being held.

72.1 Exit the Mt. Mica Mine access road by taking a **Right Turn** onto Mt. Mica Road, heading west.

73.4 Continue going straight onto Lincoln Street

73.3 **Turn Right** onto Paris Hill road

75.6 **Turn Right** onto ME-26 N and continue north.

95.1 Continue straight onto ME-26 N/Main Street, crossing the railroad tracks.

95.3 The Maine Mineral & Gem Museum is located on the left at 99 Main Street.

Friday night from 5-7 pm (hors d'oeuvres and cash bar) there will be an *open house at the Maine Mineral and Gem Museum*. See world class Maine minerals and discover the otherworldly Stifler Collection of Meteorites. Led by the MMGM staff.