MT. MICA: A RENAISSANCE IN MAINE'S GEM TOURMALINE PRODUCTION

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The Mt. Mica area in southwestern Maine has been mined for tourmaline and other pegmatite gems since the 1820s. Most tourmaline production occurred during the late 1800s to the 1910s, with occasional finds made from the 1960s to 1990s. Since May 2004, a new mining venture has produced gem- and specimen-quality tourmaline in a variety of colors. The faceted stones typically are yellowish green to greenish blue, although pink and bicolored or tricolored stones have been cut. Their gemological properties are typical for gem tourmaline. Chemical analysis shows that the tourmaline mined from pockets at Mt. Mica is mostly elbaite, with lesser amounts of schorl, rossmanite, and foitite.

The Mt. Mica deposit has been famous for 185 years as a producer (and the original source) of gem tourmaline in Maine. Tourmaline crystals and cut gems from this historic locality are found in museums and private collections worldwide, and they have been documented in classic works of literature (Hamlin 1873, 1895). After years of no or little activity, recent mining by Coromoto Minerals (Gary and Mary Freeman) has yielded large tourmaline crystals and a modest amount of gem rough. Several stones have been cut, in a wide range of colors (see, e.g., figure 1). Prior to this venture, from 1998 to 2003, Coromoto Minerals successfully mined the Orchard pegmatite in Maine for aquamarine and heliodor.

With the cooperation of Coromoto Minerals, two of the authors (WBS and KLW) recently documented some of the gem pockets as they were excavated, and chemically characterized the tourmalines that were produced. This article first reviews the history of Mt. Mica and then examines the gemological and chemical properties of tourmaline from this historic locality.

HISTORY

Mt. Mica is the site of the first reported occurrence of gem tourmaline in the U.S. (Hamlin, 1895). Since tourmaline was discovered there in 1820 by Elijah L. Hamlin and Ezekiel Holmes (Hamlin, 1873), the pegmatite deposit has been worked by numerous ventures. Some of these activities, as they relate to tourmaline production, are summarized in table 1.

An important development occurred in 1886, when a large pocket found by Augustus C. Hamlin and mine superintendent Samuel Carter yielded a great number of specimens, including a 24 x 5 cm green tourmaline crystal that was broken into four pieces. Faceting of this tourmaline produced the 34.25 ct center stone for the famous Hamlin necklace (Perham, 1987). This necklace, commissioned by A. C. Hamlin, featured 70 cut stones from Mt. Mica with a total weight of 228.12 carats, which included pink,

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Figure 1. Recent mining at the historic Mt. Mica pegmatite has produced gem tourmaline in a variety of colors. Shown here are some of the samples that were characterized for this report (0.78–11.72 ct). The stones were faceted by Dennis Creaser (Creaser Jewelers, South Paris, Maine) and are courtesy of Coromoto Minerals Inc.; photo © Jeff Scovil.

blue-green, blue, and green tourmaline, as well as colorless tourmaline and beryl (figure 2). It was donated to the Harvard Mineralogical Museum in 1934 and is considered one of the most significant pieces of North American jewelry ever produced (Fales, 1995).

Using simple drilling and blasting techniques, the early miners at Mt. Mica uncovered numerous pockets from shallow workings (figure 3). As these excavations progressed to deeper levels of the pegmatite, the miners began employing more innovative techniques. During the period from 1890 to 1913, when Loren B. Merrill and L. Kimball Stone had the mineral exploration rights at Mt. Mica, they used a large derrick to remove boulders from a deep trench (figure 4). The location of the stacked boulders that formed one side of the trench is shown in figure 5, along with the sites of other workings and discoveries.

Mining activity at Mt. Mica was eventually affected by the fabulous new tourmaline finds in southern California that began in the early 1900s. The abundance of tourmaline from California contributed to the decline in mining at Mt. Mica, where activity was sporadic at best from the 1920s until recently.

TABLE 1. Chronology of gem tourmaline production at Mt. Mica, prior to mining by Coromoto Minerals.

Year	Event	Reference
1822	Cyrus and Hannibal Hamlin produce red and green tourmaline.	Hamlin (1873)
~1866	Ordesser Marion Bowker[a], owner of the farm that encompasses Mt. Mica, opens a large pocket of tourmaline. This creates a renewed interest in the mine by Augustus and Elijah Hamlin.	Hamlin (1895)
1868–1890	Augustus and Elijah Hamlin produce numerous fine tourmaline specimens and gem material from several pockets; much of the top-quality material is acquired by Harvard University and Tiffany & Co. in New York.	Hamlin (1895); Perham (1987)
1891	Loren B. Merrill and L. Kimball Stone recover exceptional blue tourmalines.	Hamlin (1895)
1899	Merrill and Stone find a 411 ct blue-green tourmaline gem nodule that was part of a crystal over 20 cm long. A second 584 ct gem nodule found in a later pocket is now in the Harvard Mineralogical Museum collection.	Perham (1987)
1904	Merrill and Stone open a large pocket that produces over 75 pounds (34 kg) of tourmaline crystals, including near-colorless nodules and a single multicolored tourmaline crystal over 30 pounds (13.6 kg).	Perham (1987)
1926	Howard Irish purchases Mt. Mica, but the deposit lays idle until the 1940s. In 1949 he leases the deposit to the United Feldspar Corp.	King (2000)
1964–65	Frank Perham produces green and bicolored tourmaline.	King (2000)
1979	Plumbago Mining Corp. excavates the large "Dagenais" pocket.	Francis (1985)
1990s	Specimen- and gem-quality tourmalines are occasionally produced by Plumbago Mining Corp.	R. Naftule, pers. comm. (2005)

[a] *Although the spelling is commonly indicated as "Odessa" Bowker in the literature, independent research by R. Sprague (e.g., 1870 U.S. Federal Census, State of Maine) indicated that the farm owner and miner of the tourmaline pocket was a man named Ordesser.*

Figure 2. The Hamlin necklace is considered one of the most significant pieces of North American jewelry. It was commissioned by Augustus C. Hamlin after he and Samuel Carter found a large pocket of tourmaline at Mt. Mica in 1886. The necklace contains 228.12 carats of colored tourmaline, as well as colorless tourmaline and beryl. Courtesy of Harvard Mineralogical Museum; photo © Tino Hammid.

Figure 3. The yellow flags mark the location of gem pockets in the early days of mining at Mt. Mica, circa 1890. Shown are L. Kimball Stone (left) and Loren B. Merrill (right); modified from Bastin (1911, plate 12, p. 84).

In 1964–65, Frank Perham mined the old Merrill and Stone diggings and produced some notable tourmalines, from which an eye-clean 25 ct green stone and a flawless 59.59 ct blue-green stone were cut (King, 2000). The latter stone and the original crystal were documented by Crowningshield (1966a,b). Perham continued to work the property after it was purchased by Plumbago Mining Corp. in 1973. In 1979, the large "Dagenais" pocket (4 x 5.5 x 16 m) was found and required two months to excavate (Francis, 1985). Later, after a brief period of inactivity, Plumbago and private investors re-opened Mt. Mica in 1989. Although tourmaline was recovered sporadically, the results were not considered economically viable, and mining ceased in the late 1990s.

Coromoto Minerals acquired the Mt. Mica property in 2003 and soon started to systematically remove portions of the entire pegmatite. This approach has proven highly successful, with 43 pockets found in the first two years of mining. Two of the pockets have produced large gemmy crystals of tourmaline, which rival the best material that has come from Mt. Mica in its 185-year history (see Mining and Production section).

LOCATION AND ACCESS

The Mt. Mica mine, which is closed to the public, is located about 6 km northeast of the small town of South Paris in Oxford County, southwestern Maine (figure 6). The mine is situated on a small hill, at an elevation of 295 m (970 feet), in forested terrain. Due to typically severe winter conditions, most of the pegmatite mines in this area are operated from March through October. The Mt. Mica mine is operated year round, weather permitting.

GEOLOGY

The Mt. Mica tourmaline deposit is a large, pocket-bearing granitic pegmatite that belongs to the Oxford pegmatite field of southwestern Maine (Wise and Francis, 1992). The Oxford field is spatially related to the Sebago batholith. Pegmatites are concentrated within and around the northeastern margin of this batholith, and they are therefore inferred to be genetically related. Uranium-lead isotopic data indicate that the age of the Sebago Batholith is 296 ± 3 million years (Foord et al., 1995).

According to recent observations by the authors, the Mt. Mica pegmatite strikes northeast and dips moderately southeast (typically about 30°) within

Figure 4. The images on these post cards show mining activities at Mt. Mica around the turn of the 20th century. A large derrick (left; printed by The Hugh C. Leighton Co., Portland, Maine) was used to remove boulders from a deep trench (right; printed by The Metropolitan News Co., Boston, Massachusetts). Remnants of the stacked boulders shown in the right image still can be seen today. From the private collection of Jane C. Perham.

the metasedimentary host rock. It is exposed for about 135 m along strike and ranges in thickness from about 1.5 m at the western exposure near the surface to over 8 m thick in places further down dip. The pegmatite is poorly zoned, with a thin (2–5 cm) wall zone and a 1.5-m-thick intermediate zone in the thicker portion of the dike. The intermediate zone consists principally of quartz and K-feldspar, with lesser amounts of schorl and muscovite. The core consists mainly of quartz, microcline, and schorl, with local pods of cleavelandite and rare areas of lepidolite with spodumene, pollucite, cassiterite, columbite, and very rare beryl. Pockets are relatively abundant in the central area of the dike (again, see figure 5), where Coromoto Minerals has averaged about one cavity every 3 m. In this area, the miners have learned to recognize several indications of pocket mineralization, including wisps of lepidolite, large muscovite "books" (particularly near pods of massive quartz), masses of friable cleavelandite, rust-colored fractures crosscutting the inner zones, and large schorl crystals that point downward toward the cavities.

MINING AND PRODUCTION

Coromoto Minerals began mining at Mt. Mica in July 2003; they have posted detailed reports about

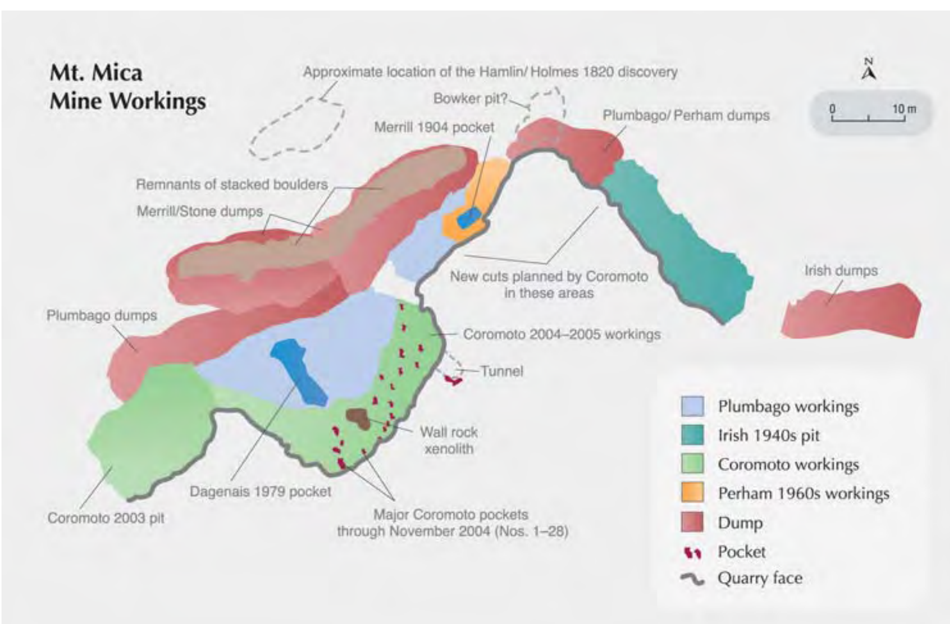


Figure 5. The locations of both historic and modern mining activities at Mt. Mica are shown on this diagram. From a drawing by Gary Freeman.

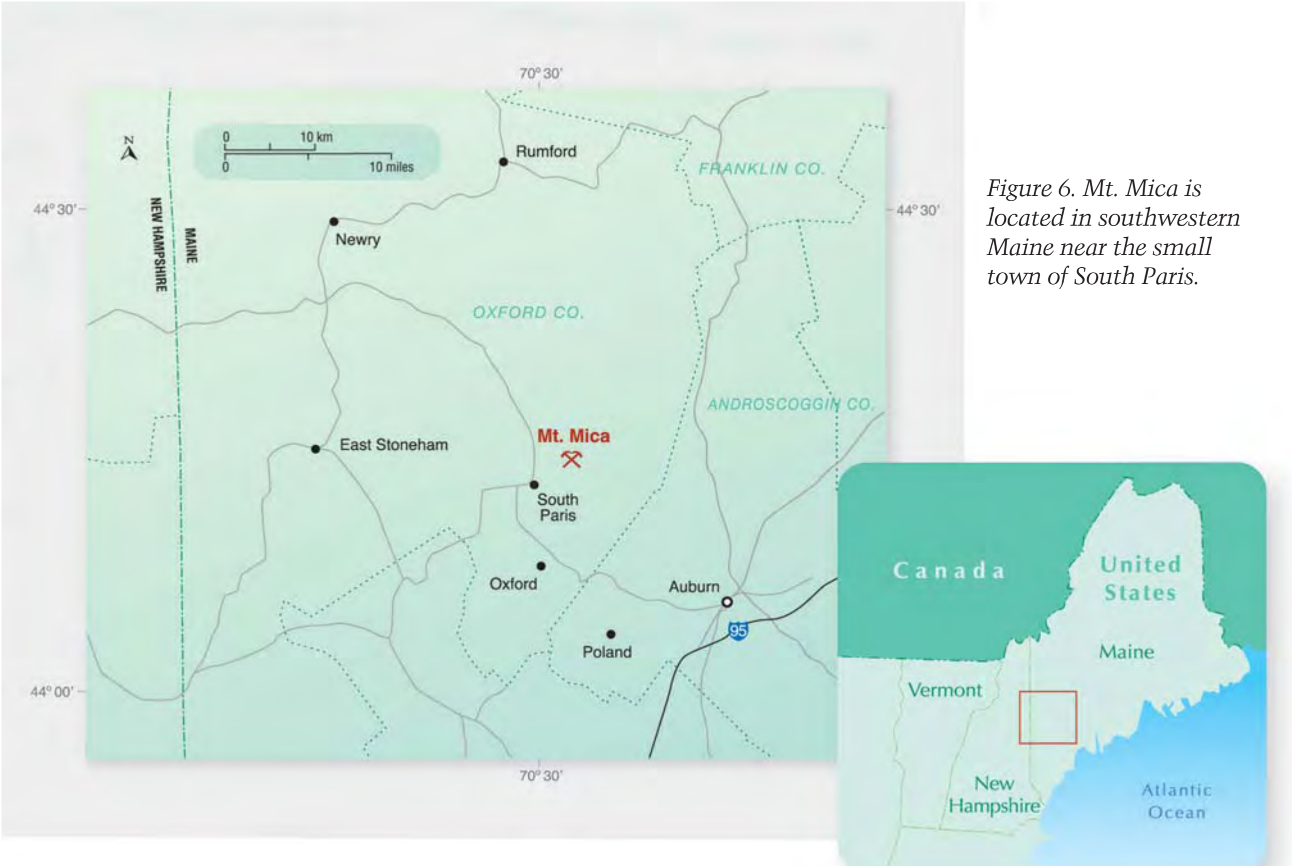


Figure 6. Mt. Mica is located in southwestern Maine near the small town of South Paris.

Figure 7. An excavator and dump truck are used to remove mined material from the open cut at Mt. Mica, as shown in this October 2004 photo by Gary Freeman.

Figure 8. The entrance to a large pocket (no. 7) containing mostly green tourmaline is marked by the small tunnel just in front of the men in the pit. Note the location of this pocket within a pronounced bulge in the thickness of the predominantly light-colored pegmatite. Photo by Alexander Falster.

significant finds on the Internet at www.coromotominerals.com. In addition, a separate article (Simmons et al., 2005) will review the history and recent specimen mining in more detail.

The miners (Gary and Mary Freeman, together with Richard Edwards) initially used an excavator to expose the pegmatite from beneath the old dump material. Subsequently, they used drilling and blasting to mine the pegmatite in an open cut, and they removed material from the pit using an excavator and dump truck (figure 7).

Several small pockets containing smoky quartz and blue apatite were encountered in 2003, but the first significant tourmaline discovery did not occur until May 2004, when pocket no. 7 was entered. This cavity was found in an area where the pegmatite showed a local bulge in thickness (figure 8). Hundreds of gemmy crystals of predominantly green tourmaline were produced. Most ranged up to 3 cm long and 0.5 cm in diameter, with pink cores that were commonly altered to a pink clay. The zoned crystals with unaltered pink cores resembled the classic "watermelon" pieces pictured in Hamlin (1895). A modest number of small gem-quality pink crystals also were recovered from this pocket. In all, about 1 kg of gem rough was produced, and most of the faceted stones examined for this article came from this pocket.

Figure 10. Two of the most significant tourmaline crystals recently recovered by Coromoto Minerals are shown here. On the left is a 19-cm-tall tricolored elbaite crystal (reassembled from three pieces) on a matrix of cleavelandite and lepidolite that was recovered from pocket no. 10. On the right is a multicolored crystal from pocket no. 28 that measures 22 cm tall, and forms the top portion of a crystal that was originally 54 cm long. Chemical analyses showed the colored portion to be elbaite, while the thin black flat termination is foitite. Composite photo by Gary Freeman.

Figure 9. In June 2004, fine tourmaline crystals were recovered from pocket no. 10. The crystal on the left (approximately 10 cm long) forms the top portion of the reassembled specimen shown in figure 10. The crystal on the lower right is part of a separate specimen. A chisel is shown for scale. The dark material consists of fragments of the overlying metasedimentary host rock. Photo by Gary Freeman.

In June 2004, the miners opened a series of pockets that appeared to line up with pocket no. 7 and the 1979 Dagenais pocket (again, see figure 5). It is possible that this zone of pockets extends even further down dip. Most notable was pocket no. 10, which contained more well-formed green and multicolored tourmalines (figure 9), including a broken 19-cm-long color-zoned crystal that is probably the finest tourmaline specimen found at Mt. Mica and one of the best ever mined in New England (see the left crystal in figure 10).

From June through December 2004, an additional 18 pockets were encountered. The company's most important discovery was made in late December 2004, with the opening of pocket no. 28 (figure 11). This cavity, which exceeded 7 m long, consisted of three connected chambers. Several cathedral-type smoky quartz crystals weighing ~20 kg were found at the edges of the pocket. The miners eventually recovered several hundred bicolored green/pink and green/colorless tourmaline crystals ranging up to 5–8 cm long and <1 cm in diameter

Figure 11. The largest and most important cavity found by Coromoto Minerals at Mt. Mica was 2004 pocket no. 28. Here, Richard Edwards (left) and Frank Perham are shown at the beginning of the excavation in late December. Photo by Gary Freeman.

by screening the pocket mud. They also recovered some much larger tourmalines, including a 22-cm-tall elbaite crystal that grades from reddish pink to orange with a thin black flat termination (see figure 10, right). When four additional pieces of this crystal were subsequently recovered, it was determined that the entire crystal was originally 54 cm long—the largest elbaite tourmaline known from Maine and perhaps the largest from North America.

The 2005 mining season began in March, with the miners clearing debris from the pit and driving a decline (tunnel) into the pegmatite from the northeastern portion of the 2004 open cut, near pocket no. 28. A new loader for working underground was purchased (figure 12), and Jim Clanin—an experienced gem pegmatite miner from southern California—joined the mining crew. As of mid-June 2005, the decline reached approximately 20 m deep and they had encountered nine small pockets—some with fine green and greenish blue gem tourmaline.

Figure 12. A small loader is used to remove pegmatite material from the underground workings at Mt. Mica. June 2005 photo by Brendan Laurs.

The crystal specimens produced by Coromoto Minerals are being marketed to mineral collectors through Graeber & Himes, Fallbrook, California. As a byproduct of the crystal mining, the mine owners have accumulated a few kilograms of gem rough. Most of this material shows various shades of green (from pocket nos. 7 and 11). So far, a few dozen gemstones (described below) have been faceted from broken crystals. As mining progresses in 2005, such rough material will continue to be stockpiled for future cutting and marketing.

MATERIALS AND METHODS

Standard gemological properties were obtained on 45 faceted Mt. Mica tourmalines that were cut from material produced from May 2004 to early 2005. The samples weighed 0.78–16.48 ct and were faceted in a variety of shapes, including rectangular (some with a checkerboard style), round, oval, pear, square, and freeform. The samples reportedly were not treated in any way.

We used a GIA Instruments Duplex II refractometer with a near-sodium equivalent light source for refractive index readings, and determined specific gravity by the hydrostatic method. The samples were tested for fluorescence in a darkened room with four-watt long- and short-wave UV lamps. Internal features were observed with a standard gemological microscope, and a polariscope was used to view optic figures and check for strain. Inclusions in four samples were investigated by Raman spectroscopy at GIA in Carlsbad, using a Renishaw 2000 Ramascope.

Quantitative chemical analyses were obtained by electron microprobe at the University of New Orleans, Louisiana, on 363 fragments of tourmaline from pocket nos. 7 and 28. Some of these samples were taken from the same pieces of rough used to facet the stones described above. The fragments were mounted on 1 inch (2.5 cm) glass disks with epoxy, and were ground and polished with 0.05 μm alumina powder. The mounted samples were then ultrasonically cleaned and carbon coated. When possible, the samples were mounted so that analytical traverses could be performed from core to rim. Also analyzed were two Mt. Mica tourmaline crystals that were collected in 1890 by A. C. Hamlin (from the collection of Peter Lyckberg) and 10 additional tourmaline crystals mined in 1964 by Frank Perham (from the collections of Ray Sprague and Jane Perham). These crystals were partially mounted in epoxy so that the smoothest, glass-like prism surfaces could be used for analysis.

Analyses were conducted with an ARL SEMQ electron microprobe operated at an acceleration potential of 15 kV, a beam current of 15 mA, and a spot size of 2 μm. An acquisition time of 45 seconds per spot was used. The number of cations in the formula of each analysis was calculated so that the data could be plotted and the tourmaline species identified. Since some elements in tourmaline (i.e., boron, lithium, and hydrogen) cannot be measured by electron microprobe, we calculated the cations (and wt.% oxides) according to standard assumptions and conventions (see Deer et al., 1992).

RESULTS AND DISCUSSION

The gemological properties are summarized in table 2, with details described below.

Visual Appearance. Overall, the faceted samples could be separated by color into groups of yellowish green, pink (including orangy pink and brownish purplish red), greenish blue, and bicolored or tricolored with green, pink, and/or near-colorless zones. Most of the stones showed weak-to-moderate saturation and light-to-medium tone—with dark tones seen in some of the green stones that were cut with their tables oriented perpendicular to the c-axis.

All of the samples were transparent. In general, the pink, yellowish green, and greenish blue stones were lightly included (commonly with no inclusions visible to the naked eye), whereas the multicolored samples contained obvious partially healed fractures and feathers.

Physical Properties. There were only slight variations in the refractive indices, which could not be correlated to color. The most typical values were n_o = 1.639 and n_e = 1.620 (yielding a birefringence of 0.019). Although S.G. values ranged from 3.04 to 3.08, the lower values (3.04–3.05) were obtained for the multicolored stones, probably due to the presence of abundant fluid inclusions. Most of the samples that were only lightly included had S.G. values ranging from 3.05 to 3.07.

In the polariscope, typical uniaxial optic figures could be resolved in all of the stones in which the faceting did not obscure view of the optic axis. Subtle patchy or sector-like patterns were seen along the optic axis direction in a few samples; no evidence of significant strain was noted in any of the tourmalines.

The gemological properties of the Mt. Mica samples are consistent with those reported in the litera-

TABLE 2. Properties of the 45 faceted samples of tourmaline from Mt. Mica, Maine.

Property	Description
Color	Most were yellowish green or multicolored in yellowish green, pink, and/or near colorless. Other stones were pink, orangy pink, brownish purplish red, and greenish blue.
Pleochroism	*Yellowish green:* Weak to strong (depending on color saturation), in yellowish green and slightly bluish green *Pink:* Weak, in purplish pink and orangy pink *Greenish blue:* Weak or very weak, distinguishable by a slight brown tint
Clarity	Transparent; lightly to heavily included
Optic character	Uniaxial negative
Refractive indices	
n_o	1.638–1.640
n_e	1.619–1.622
Birefringence	0.018–0.020
Specific gravity	3.04–3.08
UV fluorescence	
Short-wave	Inert
Long-wave	Inert
Internal features	Most common were partially healed fractures, “feathers,” and growth zoning. Other features included color zoning, fine needle-like tubes, linear or planar trails of pinpoints, planar two-phase (liquid-gas) inclusions, mineral inclusions (feldspar and low-relief grains that could not be identified), and cavities.

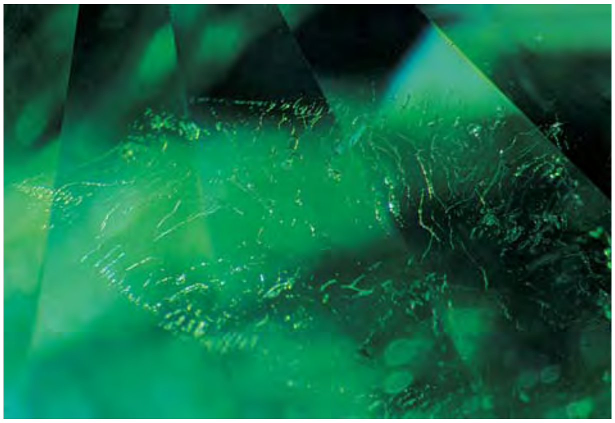


Figure 13. Network stringers of filamentary fluid inclusions known as "trichites" are characteristic of tourmalines from many localities, including Mt. Mica. Photomicrograph by John I. Koivula; magnified 10x.

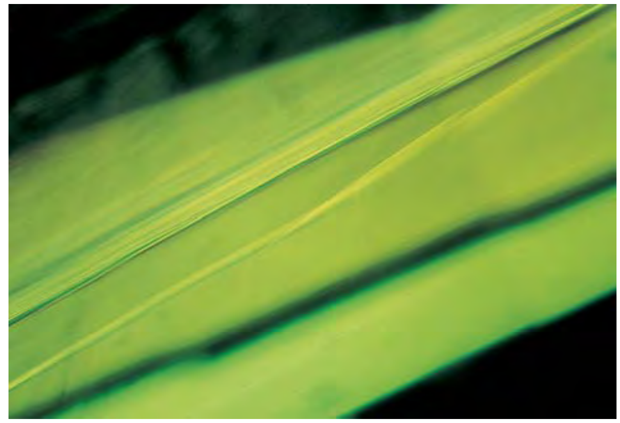


Figure 14. Sharp-edged, elongated straight-to-angular growth zoning, as revealed by shadowed illumination in this Mt. Mica tourmaline, is often encountered in tourmalines in general. Photomicrograph by John I. Koivula; magnified 15x.

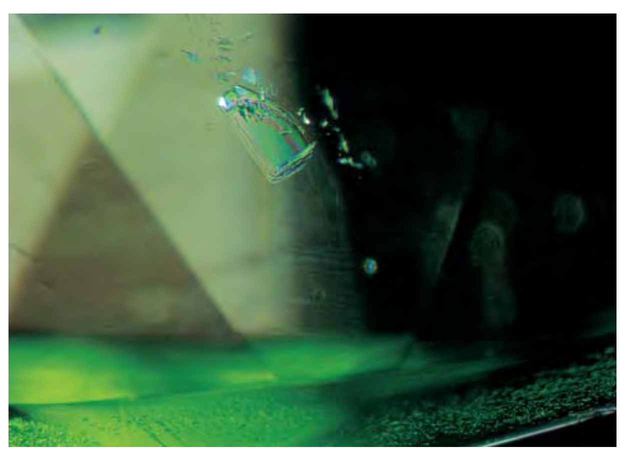
ture for gem tourmaline (see, e.g., Webster, 1994). Although the lowest R.I. values we obtained were slightly below the range reported by Webster (1994), they fell within the values given by Dunn (1975) for tourmaline from Newry, Oxford Co., Maine (1.612–1.644). The lack of any correlation between R.I. and color in our Mt. Mica samples also was documented for Newry tourmaline by Dunn (1975). However, the weak violet fluorescence to short-wave UV observed by Dunn (1975) in pink and red Newry tourmaline was not found in the similar-colored samples from Mt. Mica that we studied.

Microscopic Features. The most conspicuous inclusions consisted of partially healed fractures and "feathers". A wide diversity of characteristics related to healed fractures were recorded: flat planar-to-curved aggregates of minute fluid inclusions, spindle- and irregular-shaped "trichites" (figure 13), linear or planar trains of pinpoints, and flat two-phase inclusions with conspicuous gas bubbles suspended within fluid. Growth zoning was also quite common, but relatively inconspicuous, forming linear, planar, or angular patterns (figure 14). The growth zoning was most prevalent in the greenish blue samples and the multicolored stones; in the latter, the growth lines were oriented parallel to the color zoning.

Other microscopic features included fine needle-like tubes (often in parallel arrays) and small

Figure 15. This inclusion in a Mt. Mica tourmaline was identified as feldspar by Raman analysis. Fluid inclusions also are visible in the immediate vicinity. Photomicrograph by John I. Koivula; magnified 20x.

Figure 16. Cross-polarized light has produced interference colors in this inclusion, which is probably a crystal of tourmaline within tourmaline from Mt. Mica. Photomicrograph by John I. Koivula; magnified 15x.



cavities. Mineral inclusions were seen in six of the 45 samples, typically as isolated, high-relief, rather equant colorless grains. In three of the samples, these inclusions were identified as feldspar by Raman analysis (see, e.g., figure 15), probably sodic plagioclase (i.e., "cleavelandite"), since this variety of albite is commonly associated with the tourmaline in the Mt. Mica gem pockets. Two additional samples contained low-relief colorless grains exhibiting strong birefringence (figure 16), but these could not be identified by Raman analysis due to their small size and/or position within the stones. Their appearance suggested that they were inclusions of tourmaline within their tourmaline hosts.

Chemical Composition. The tourmalines analyzed for this study were found to consist of four species: elbaite, schorl, foitite, and rossmanite (table 3). Notably, all four species were present in one pocket (no. 28). Representative electron-microprobe data for tourmalines from pocket nos. 7 and 28 are shown in table 4. As shown in figure 17, the analyses mostly fell in the elbaite field, although a few corresponded to rossmanite. The elbaite colors ranged from dark green/black to lighter green to pink. Most of the pink and red elbaites were distinctly enriched in Ca (liddicoatite component) relative to other colors. The green tourmalines were mostly lower in Ca and richer in Na (elbaite component). Near-colorless samples tended to have low Ca and greater X-site vacancies (rossmanite component).

TABLE 3. General chemical formulas of tourmaline species found at Mt. Mica.

Species	Formula[a]
Elbaite	$Na(Li_{1.5},Al_{1.5})Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Schorl	$NaFe^{2+}_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Rossmanite	$\square(LiAl_2)Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Foitite	$\square(Fe^{2+}_2Al)Al_6(BO_3)_3Si_6O_{18}(OH)_4$

[a] $\square$ = *vacancy*

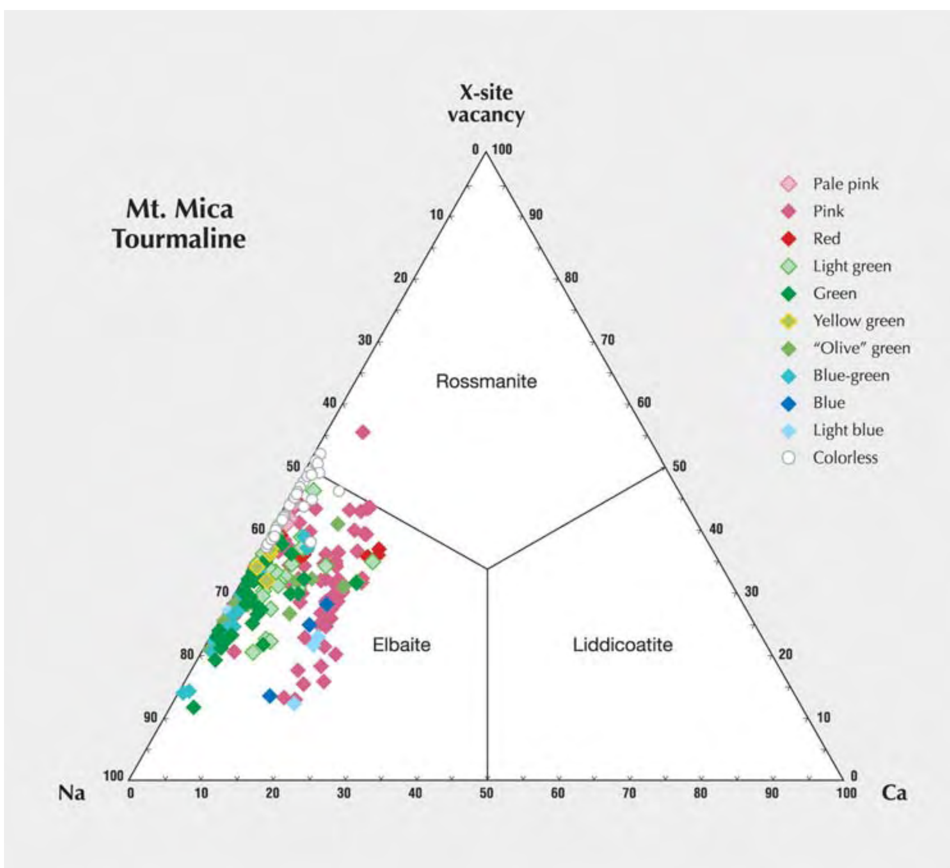


Figure 17. This diagram shows the X-site composition of all the tourmaline samples analyzed from Mt. Mica pocket nos. 7 and 28. The analyses predominantly fell within the elbaite field, although a few points fell on the border or slightly into the rossmanite field. Black tourmaline samples from these pockets consisted of schorl or foitite, but these compositions are not shown on this diagram.

TABLE 4. Representative compositions by electron microprobe of various colors and species of Mt. Mica tourmaline.[a]

Chemical composition	Pale pink Elbaite	Pink Elbaite	Red Elbaite	Light green Elbaite	Green Elbaite	Yellow-green Elbaite	"Olive" green Elbaite	Blue-green Elbaite	Blue Elbaite
Oxides (wt.%)									
SiO_2	36.80	36.78	36.84	36.79	36.59	36.63	36.76	36.55	36.78
TiO_2	bdl	bdl	bdl	bdl	0.08	bdl	0.18	bdl	bdl
B_2O_3 (calc.)	11.02	11.10	11.07	10.99	10.80	10.97	11.00	10.79	10.83
Al_2O_3	42.89	42.46	42.70	41.78	38.67	41.93	41.57	39.55	38.49
FeO^{tot}	0.07	0.11	bdl	1.33	4.46	0.96	1.79	4.35	5.22
MnO	0.12	0.55	0.29	0.44	1.70	0.41	0.82	0.43	1.20
MgO	bdl	bdl	bdl	0.03	0.03	bdl	0.02	bdl	bdl
CaO	0.07	1.11	1.01	0.32	0.15	0.22	0.14	0.06	0.75
Li_2O (calc.)	1.90	2.11	2.02	1.82	1.43	1.87	1.71	1.48	1.49
Na_2O	2.00	2.01	1.55	2.07	2.38	2.22	2.12	2.10	2.00
K_2O	bdl	0.04	0.01	0.02	bdl	0.02	0.02	0.02	0.03
H_2O (calc.)	3.33	3.36	3.40	3.33	3.18	3.27	3.35	3.31	3.12
F	0.99	1.01	0.88	0.97	1.14	1.09	0.95	0.88	1.31
Subtotal	99.18	100.62	99.78	99.91	100.60	99.61	100.42	99.52	101.22
–O=F	0.42	0.42	0.37	0.41	0.48	0.46	0.40	0.37	0.55
Total	98.76	100.20	99.41	99.50	100.12	99.15	100.02	99.15	100.67
Ions on the basis of 31 (O,OH,F)									
Si	5.802	5.755	5.783	5.815	5.889	5.801	5.805	5.886	5.900
Al	0.198	0.245	0.217	0.185	0.111	0.199	0.195	0.114	0.100
Tet. sum	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al (Z)	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.771	1.585	1.683	1.599	1.226	1.628	1.541	1.394	1.177
Ti	bdl	bdl	bdl	bdl	0.009	bdl	0.021	bdl	bdl
Fe^{2+}	0.009	0.015	bdl	0.176	0.600	0.126	0.236	0.586	0.700
Mn	0.015	0.073	0.039	0.059	0.231	0.055	0.109	0.059	0.163
Mg	bdl	bdl	bdl	0.006	0.007	bdl	0.005	bdl	bdl
Li	1.204	1.326	1.277	1.160	0.927	1.190	1.087	0.961	0.960
Y sum	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Ca	0.011	0.186	0.170	0.054	0.026	0.038	0.024	0.011	0.129
Na	0.610	0.609	0.471	0.634	0.743	0.683	0.648	0.654	0.620
K	bdl	0.007	0.002	0.004	bdl	0.004	0.005	0.005	0.005
Vacancy	0.378	0.198	0.357	0.308	0.231	0.275	0.324	0.330	0.245
X sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
F	0.496	0.498	0.435	0.486	0.582	0.548	0.472	0.446	0.664
OH	3.503	3.502	3.564	3.514	3.417	3.451	3.528	3.553	3.335

[a] Selected from analyses of 363 samples from pocket nos. 7 and 28, as well as the two 1890 Hamlin and the ten 1964 Perham crystals. Backgrounds were determined by the mean atomic number (MAN) method (Donovan and Tingle, 1996). Standards used include both natural and synthetic materials: albite (Na), adularia (K), quartz and clinopyroxene (Mg, Ca, Fe, Ti), chromite (Cr), rhodonite (Mn), V_2O_5 (V), PbO (Pb), ZnO (Zn), Bi-germanate (Bi), sillimanite (Si and Al), and fluortopaz (F). MAN standards used in addition to those above were corundum, fayalite, hematite, rutile, MgO, $SrSO_4$, and ZrO_2. Detection limits (in wt.% oxide): Ti = 0.008, Fe = 0.005, Mn = 0.006, Mg = 0.012, Ca = 0.007, and K = 0.014. Detection limits of elements analyzed but not detected (in wt.% oxide): V = 0.007, Cr = 0.013, Zn = 0.022, Pb = 0.009, and Bi = 0.016. Li_2O, B_2O_3, and H_2O were calculated based on an assumed elbaite tourmaline stoichiometry. Abbreviation: bdl = below detection limit.

Foitite is a rare tourmaline species that is iron rich in the Y-site and has an X-site that is more than 50% vacant (MacDonald et al., 1993); it formed the thin black flat terminations on some of the pink elbaite crystals (e.g., figure 10, right). The schorl analyses corresponded to the black basal portions of some of the elbaite crystals. The analyzed crystals that were mined in 1890 and 1964 were all elbaite, with compositions that overlapped the more recently mined tourmaline.

As expected, the chromophoric elements Fe, Ti, and Mn showed strong correlation with color (see table 4 and figure 18). Fe was highest in the black tourmaline, and virtually absent in the near-colorless and pink tourmaline. The next-highest Fe values were found in the "olive" green, green, and blue tourmaline. Ti correlated with elevated Fe in the black and green to "olive" green samples. All other colors had very low Ti contents. On average, Mn was highest in the blue and green tourmaline, and was lowest in all light-colored tourmaline.

Fluorine contents were relatively constant, averaging 1.08 wt.% and ranging from 0.8 to 1.31 wt.% in all analyses. Mg was present mainly in the black tourmaline, where it averaged 0.54 wt.% MgO and ranged from below the detection limit to 1.38 wt.%

Light blue Elbaite	Colorless Elbaite	Colorless Rossmanite	Black Schorl	Black Foitite
36.60	36.83	37.26	36.51	36.36
bdl	bdl	bdl	0.54	0.07
10.87	11.02	11.10	10.48	10.45
39.50	42.90	43.43	32.65	34.77
3.45	bdl	0.05	13.20	12.54
1.11	bdl	0.20	0.26	0.63
bdl	bdl	bdl	1.30	bdl
0.88	bdl	bdl	0.09	bdl
1.69	1.91	1.79	0.54	0.52
2.04	2.03	1.48	1.82	0.92
0.02	bdl	bdl	0.03	bdl
3.20	3.27	3.38	3.08	3.19
1.17	1.11	0.94	0.88	0.88
100.53	99.09	99.63	101.38	100.32
0.49	0.47	0.40	0.47	0.37
100.03	98.62	99.24	100.91	99.95
5.853	5.809	5.832	6.055	6.046
0.147	0.191	0.168	0.000	0.000
6.000	6.000	6.000	6.055	6.046
3.000	3.000	3.000	3.000	3.000
6.000	6.000	6.000	6.000	6.000
1.299	1.785	1.843	0.381	0.814
bdl	bdl	bdl	0.068	0.008
0.461	bdl	0.007	1.831	1.743
0.151	bdl	0.026	0.036	0.088
bdl	bdl	bdl	0.322	bdl
1.089	1.214	1.124	0.361	0.346
3.000	3.000	3.000	2.999	3.000
0.151	bdl	bdl	0.015	bdl
0.633	0.622	0.449	0.586	0.298
0.004	bdl	bdl	0.007	bdl
0.212	0.378	0.551	0.393	0.702
1.000	1.000	1.000	1.000	1.000
0.590	0.555	0.467	0.589	0.463
3.409	3.444	3.533	3.411	3.537

MgO. In all other colors, Mg was very low to below the limit of detection.

Schorl is found as black tourmaline along the pocket margins, and therefore formed early in crystallization of the miarolitic cavities. As the crystals grew into the pocket, they were progressively enriched in Al relative to Fe. As Fe diminished, elbaite became the dominant tourmaline. Foitite, and possibly rossmanite, represent the final stages of tourmaline compositional evolution in the pockets. Interestingly, the black foitite "caps" noted on some Mt. Mica tourmalines are similar to the "Mohrenköpfe" found on elbaite crystals from Elba, Italy (Pezzotta, 2001). Elba is the only locality besides Mt. Mica where four tourmaline species have been documented from a single gem pocket (Pezzotta et al., 1998). Although it is not uncommon for multiple tourmaline species to be present in a particular pegmatite deposit or district (see, e.g., Selway, 1999), the occurrence of such a diverse composition of tourmaline in a single pocket appears to be quite unusual.

CONCLUSIONS AND FUTURE POTENTIAL

Gem- and specimen-quality tourmalines were produced in a wide variety of colors at Mt. Mica, mainly in the late 19th century and sporadically from the 1960s to 1990s. In 2004–2005, renewed mining by

Figure 18. These graphs show the average compositions of chromophoric elements Fe, Ti, and Mn (as wt.% oxides) in various colors of tourmaline from Mt. Mica. Fe and Ti are found mainly in the black and green samples, whereas Mn is present in tourmaline of all colors to varying degrees.

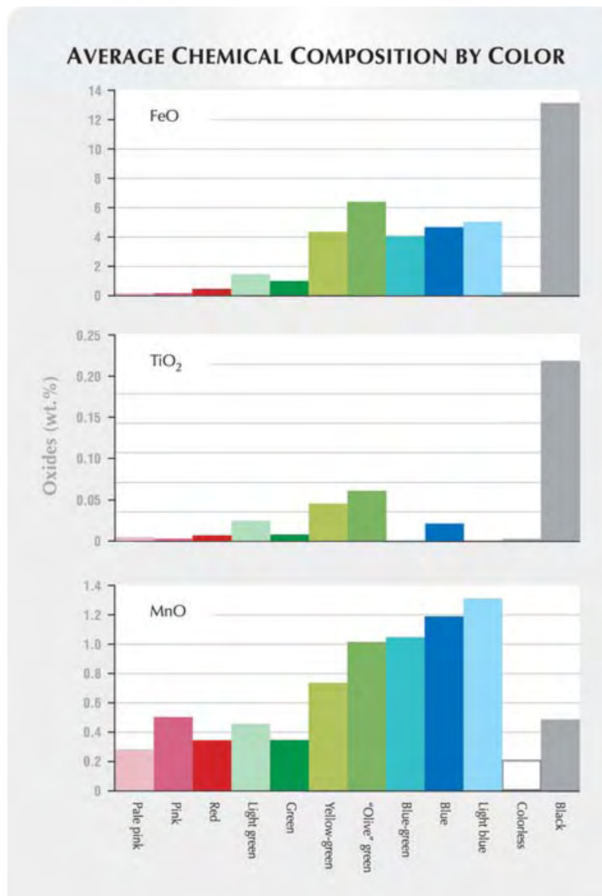
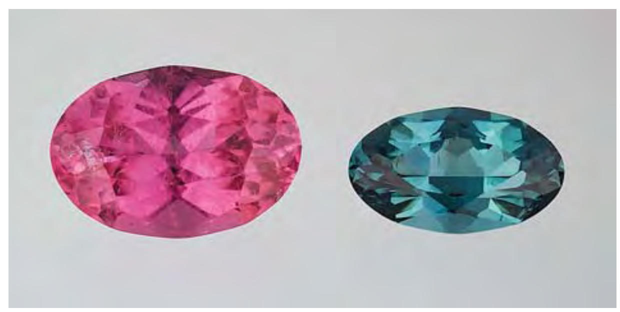


Figure 19. Well-formed gem-quality crystals of green tourmaline such as this one (5.4 cm long) from Mt. Mica pocket no. 11 are prized by collectors and connoisseurs. Courtesy of Graeber & Himes, Fallbrook, California; photo © Jeff Scovil.

Coromoto Minerals again produced attractive crystals and cut stones (figures 19 and 20), including some of the finest tourmaline ever recovered from the deposit.

Based on the deposit geology and on the projected mineralization of the pegmatite down dip, Mt. Mica shows considerable potential for additional tourmaline production. Future mining will focus on the deeper extension of the 2004–2005 mineralized zone, as well as on areas of the pegmatite to the northeast that are closer to the surface. As the pegmatite is explored by both open-cut and underground methods, the miners anticipate that more tourmaline will be found at this historic deposit.

Figure 20. Continued mining of the Mt. Mica deposit is expected to yield additional gem tourmaline, such as the bright pink and bluish green stones shown here (9.86 and 4.77 ct). These tourmalines were faceted in early 2005 by Dennis Creaser and studied for this report. Courtesy of Coromoto Minerals Inc.; photo by C. D. Mengason.



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