An occurrence of cryolite and related aluminofluoride minerals near the Lake George ring complex, Pikes Peak batholith, central Colorado*

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Introduction: Pegmatites of the Mount Rosa complex, a part of the 1.08Ga A-type (anorogenic) Pikes Peak batholith in central Colorado, have long been known for their globally significant occurrence of unusual aluminofluoride minerals (e.g. Cross and Hillebrand, 1883) (Figure 1). Aluminofluoride species identified from the Mount Rosa complex include cryolite $[Na_3AlF_6]$, gearksutite $[CaAl(OH)F_4 \cdot H_2O]$, hydrokenoralstonite $[Na_{0.5}(Al,Mg)_2(F,OH)_6 \cdot H_2O]$; pachnolite/ thomsenolite $[NaCaAlF_6 \cdot H_2O]$, prosopite $[CaAl_2(F,OH)_8]$, weberite $[Na_2MgAlF_7]$, and others. Several of these can be locally abundant, and the area is the type locality for elpasolite $[K_2NaAlF_6]$.

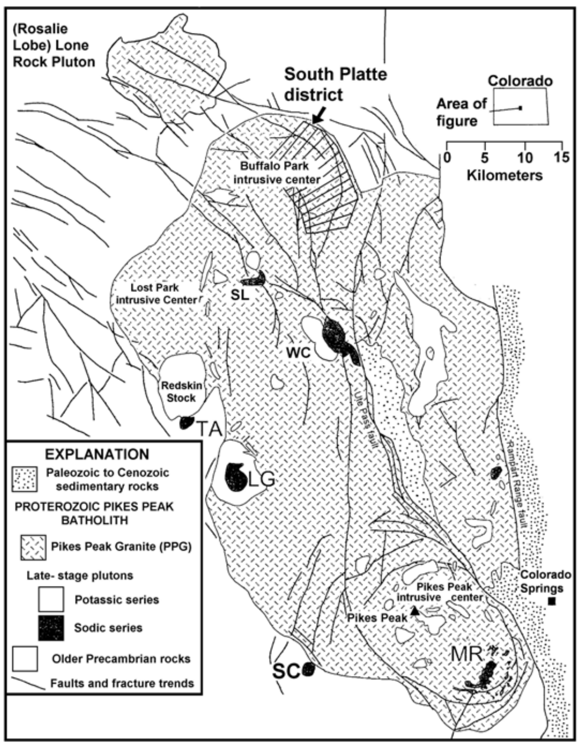

Figure 1. Pikes Peak batholith, showing locations of the Mount Rose complex (MR) and Lake George ring complex (LG) (Simmons, *et al.*, 2016).

The Mount Rosa complex consists of a petrologically diverse series of genetically related rocks of general peralkaline affinity (Persson, 2017; Gross and Heinrich, 1967), including the Na-amphibole bearing Mount Rosa granite. These rocks are confined to a 10 km^2 area situated ca. 10 km southwest of Colorado Springs. Aluminofluoride minerals are restricted to certain types of pegmatites (Gross and Heinrich, 1968; Persson, 2017), which occur on the outer margins of the Mount Rosa complex, typically hosted in Pikes Peak Granite. "Pods" and segregations of aluminofluoride minerals can reach millimeter to decimeter scale and often consist of complex intergrowths of cryolite (inferred to be primary) with a host of later (presumably secondary) species, including those listed above. Prosopite, perhaps the most widely distributed species, typically occurs as small (<1 cm) bladed, euhedral crystals lining small vugs in pegmatites.

To the best of our knowledge, aluminofluorides have not been described from the Pikes Peak batholith outside of the Mount Rosa complex. The only other reported occurrence of aluminofluoride minerals in Colorado is from the Goldie carbonatite, an unusual carbonatite dike in southwestern Fremont County. The Goldie occurrence is associated with the Cambrian-age

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McClure Mountain-Iron Mountain carbonatite complex and hosts rare cryolite, pachnolite, and weberite (Heinrich, 1977).

Here we describe a previously unreported occurrence of cryolite and associated aluminofluoride species discovered in 2018 ca. 30 km WNW of Colorado Springs. The location is several km east of the village of Lake George, on the margin of the Lake George ring complex, a late, dominantly peraluminous, sodic to potassic pluton in the Pikes Peak batholith. In a coarse grained, mineralogically simple quartz-microcline pegmatite dike that is otherwise typical for the Pikes Peak batholith, a single ca. 30-cm-diameter pod of coarse grained cryolite, partially altered to a mixture of secondary aluminofluorides, was discovered by a local resident and mineral collector, who brought it to the attention of the authors.

Geologic background: Ivittuut (Ivigtut), Greenland has long been known for its unusual suite of aluminofluoride minerals. The Ivittuut cryolite deposit occurs near the top of a 1.28Ga A-type granite stock that underwent strong Na-F metasomatism, followed by greisenization (Pauly and Bailey, 1999).

In the mid-19th Century, aluminum was more precious than gold (sciencehistory.org, accessed January, 2021). The invention of the Hall-Héroult makes use of cryolite as a flux to reduce the melting point of aluminum oxide. This allows electrolytic extraction of aluminum from refractory ores. Development of the combined Hall-Hérault and Bayer processes for refining aluminum in 1886-1889, nearly coincident with introduction of methods for long distance electricity transmission in 1889, then lowered the aluminum price significantly. These nearly simultaneous developments allowed exploitation of large deposits of refractory bauxite, making aluminum the ubiquitous (and cheap) metal we know today.

Cryolite from Ivittuut was of strategic importance from the late 19th Century through WWII. However, synthetic cryolite soon replaced the natural material, and while the Ivittuut deposit was mined until the late 1960s (with support from the government of Denmark), it was eventually abandoned (sciencedirect.com, accessed January, 2021).

Figure 2. General view of the Bertram locality.

Figure 3. Larry Bertram with cryolite trench.

Aluminofluoride occurrences in Colorado: Mindat.org (accessed January, 2021) lists 55 world-wide verified cryolite occurrences, including 21 in the United States. Twelve of these are in Colorado, where cryolite is often associated with other aluminofluorides. Among the U.S. occurrences are several NYF-type pegmatites (e.g. Little Three mine, San Diego County, California; Zapot pegmatite, Mineral County, Nevada; Morefield mine, Amelia County, Virginia; and the Mount Rosa/St. Peters dome area, El Paso County Colorado). In the latter, small occurrences are found in the 1.09Ga Pikes Peak Granite of central Colorado. Until now those reported Pikes Peak occurrences have been confined to locations in the area of St. Peters dome, west of Cheyenne Mountain, El Paso County. Here, cryolite-bearing pegmatites are found in or near the Mt. Rosa pluton, a late-stage (1.04Ga) stock of peralkaline to peraluminous character within the larger Pikes Peak batholith.

Gross and Heinrich (1966) recognized 2 types of pegmatites in the older peraluminous Pikes Peak Granite and younger Mt. Rosa peralkaline granite in the area west of Colorado Springs. Pegmatites of the older Pikes Peak type outside of the Mt. Rosa complex are relatively small and may contain miarolitic cavities with microcline (commonly amazonite) and smoky quartz crystals. Accessory minerals, including albite, fluorite, hematite, goethite, siderite, and topaz may accompany major quartz and microcline.

In contrast, the younger aluminofluoride bearing pegmatites were described as early as 1883 around St. Peters dome and the Mt. Rosa complex (Cross and Hillebrand, 1883). Heinrich (1948) recognized 2 groups of Mt. Rosa-type pegmatites: interior and exterior types. The *interior-type pegmatites*, which are less abundant and which occur within or marginal to the Mt. Rosa pluton, are small, mineralogically relatively simple segregations or intrusions (Gross and Heinrich, 1966). Some contain exotic minerals, such as rare thorite, thorogummite, uranothorite, REE oxides, and fluorocarbonates (Persson, 2017). The more abundant *exterior-type pegmatites* are somewhat larger (but commonly less than 2 x 5 m) and include various phases of the Pikes Peak Granite, including fayalite granite and aplite dikes. They are "exterior" to the main mass of Mt Rosa granite and generally are larger and more mineralogically diverse than the interior-type pegmatites. Minerals that may be present include masses of aluminofluorides, as well as compounds of Be, Rb, Y, F, Zr, and Ce. Those that are especially rich in aluminofluorides are concentrated near St. Peters dome, about 5 km southeast of Mt. Rosa.

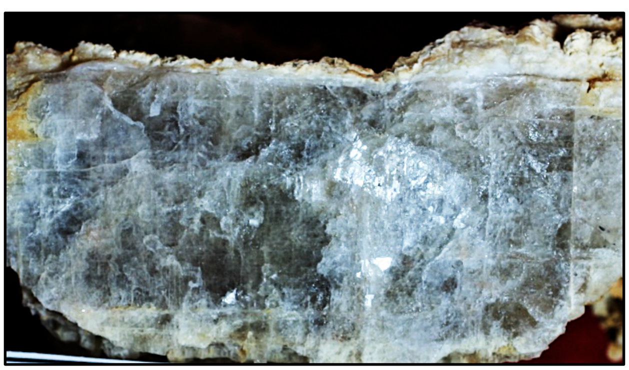


Figure 4. Coarsely crystalline cryolite, showing "cubic" parting and reaction rim. FOV is 5.7 cm. across. (Carnein specimen no. 0573D)

Cryolite discovery in the Lake George area: In 2018, Larry Bertram, a member of the Lake George Gem & Mineral Club, brought to the attention of one of the authors (CRC) a collection of pieces of coarse grained, gray-pink cryolite up to ~20 cm across that he collected from a pegmatite exposed northwest of the village of Florissant, on the margins of the Lake George ring complex (LGRC) (Figures 2 and 3). Visually, the material resembled, in texture and appearance, cryolite from St. Peters Dome (and Greenland). Although monoclinic, it exhibits characteristic parting on {001} and {110} that resembles cubic cleavage and that produces a typical "boxwork" fracture system with alteration and overgrowth by secondary aluminofluoride species (Figures 4 and 5). Typically, altered cryolite retains the "boxwork" structure even as it is dissolved and as secondary aluminofluorides are formed along the relict parting planes.

Macroscopically, the cryolite and associated aluminofluoride minerals of the Bertram locality exhibit sharp contacts with enclosing microcline and quartz, with microcline near the aluminofluorides often exhibiting a thin coating of purple fluorite along cleavage planes and contacts with other minerals. This mode of occurrence is very similar to that observed in pegmatites near St. Peters dome and numerous other aluminofluoride occurrences around the world.

Figure 5. Alteration products left along "cubic" parting after dissolution of cryolite. FOV is 1.5 cm across. (Carnein specimen no. 1740B)

Mineral analyses: Samples collected for this study were studied optically with immersion oils and then analyzed by XRD and EDX. Semiquantitative SEM-EDX was performed by MR at the University of Colorado, Boulder, in order to characterize the secondary aluminofluorides, alterations, and overgrowths on the cryolite. Among the minerals identified are prosopite (Figures 6 and 7), which occurs as bladed, translucent crystals up to ~5 mm as overgrowths on cryolite, and gearksutite (Figures 8 and 9), which occurs as ubiquitous coatings and as aggregates up to a few cm all around the cryolite mass. Rare elpasolite (Figure 10) was identified as sub-mm crystals.

Figure 6. Prosopite crystals (gray) with gearksutite (white) from the Bertram trench. FOV is 1.5 cm across. (Carnein specimen no. 1892B)

Several of the aluminofluoride phases were closely intergrown with heterogeneity on the scale of 10s of microns (Figure 10), making identification difficult. The presence of weberite and pachnolite/thomsenolite was indicated by phases dominated by Mg and Na, or Na with Ca, respectively, but neither phase could be identified with certainty. Powder XRD was performed by Kelsey McNamara (New Mexico Bureau of Mines and Geology, Socorro New Mexico), confirms the presence of gearksutite, hydrokenoralstonite (formerly ralstonite), and pachnolite. Overall, the assemblage of minerals identified by EDX and XRD closely resembles that of cryolite and its secondary alteration products from the Mt. Rosa area.

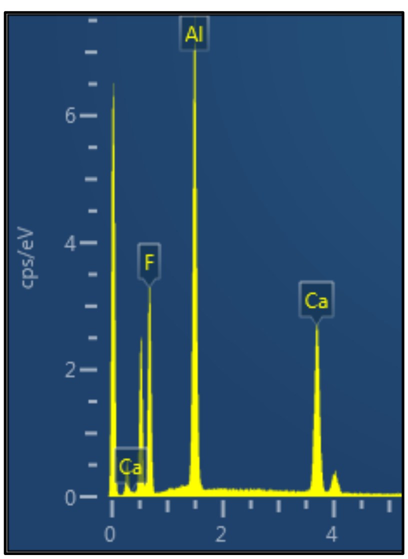


Figure 7. EDX spectrum (no. 45) of prosopite from the Bertram trench (horizonal axis in keV).

In contrast to the occurrences in the Mt. Rosa complex, the pegmatite at the new locality does not appear to contain riebeckite, zircon, or the suite of rare-earth minerals and other accessory minerals that characterize the “exterior”-type pegmatites of the Mt. Rosa/St. Peters dome occurrences. The host granite at the new locality is on the southeast margin of the LGRC, a ring-like structure that is another late-stage component of the Pikes Peak Granite (Smith, *et al.*, 1999) (Figure 1). Unlike the typical red, coarse grained Pikes Peak Granite that dominates the LGRC volumetrically, the rocks near the Bertram locality include abundant gray aplite. The cryolite trench itself exposes a contact between granitic pegmatite and what appear to be weathered metamorphic rocks of the 1.75Ga Idaho Springs Formation. Additional field work and thin-section petrography are needed to elucidate the relationship between the host rocks and the cryolite-bearing pegmatite, and how they relate to the overall structure of the LGRC.

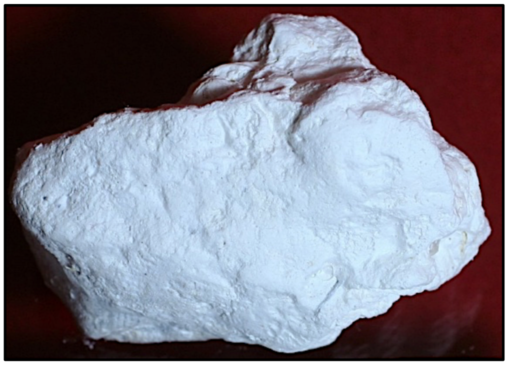


Figure 8. Pulverulent mass of gearksutite. FOV is 4.0 cm across. (Carnein specimen no. 0847C)

Conclusion: Although serious mineral collecting and geologic fieldwork in Teller County, Colorado date back at least 150 years, this is the first reported occurrence of cryolite and its alteration products for the Pikes Peak batholith outside of the Mt. Rosa complex. This find suggests locally more variable geochemical and petrologic conditions around the LGRC than previously assumed (Smith, *et al.*, 1999). Recent work by Guitreau and others (2016) focused on geochronology of the LGRC and also suggested a more complex magmatic timing and petrogenesis, which warrants further investigation. More systematic and finer scale field work seems necessary as a starting point to assess the variability of hitherto unknown mineral occurrences in this area. On request, the authors will make sample material available for research.

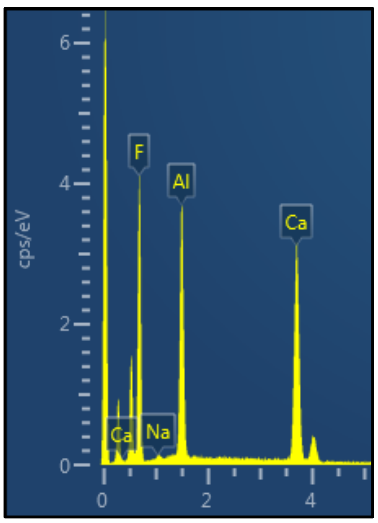
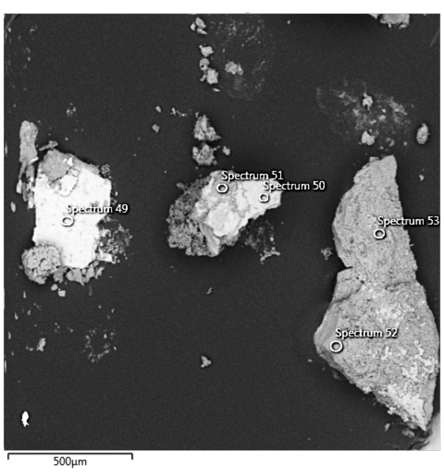


Figure 9. EDX spectrum (no. 46) of gearksutite from the Bertram trench (horizontal axis keV).



Acknowledgements: We appreciate the willingness of Larry Bertram to provide access to the site and to supply some of the samples on which this work is based. The Lake George Gem & Mineral Club provided funds for the XRD analyses.

Figure 10. Complex intergrowth of aluminofluoride minerals from aggregates of typical material from the Bertram trench. EDX spectrum of no. 50 agrees with elpasolite.

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