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PETROLOGY AND MINERALOGY OF THE MOUNT ROSA AREA, EL PASO AND TELLER COUNTIES, COLORADO. II. PEGMATITES[1]

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ABSTRACT

Two contrasting swarms of pegmatite dikes occur intermingled in the Pikes Peak granite and in related alkalic granites in the Mount Rosa area, west of Colorado Springs. One is the older calc-alkalic Pikes Peak type; the younger is the alkalic Mount Rosa type. The accessory assemblage of the Mount Rosa quartz-microcline-riebeckite pegmatites consists chiefly of radioactive zircon, fluorite, astrophyllite, thorite, and lesser amounts of pyrochlore, rutile, niobian rutile, columbite, bertrandite and rare aluminofluorides. These dikes intrude both the Pikes Peak and its derivative fayalite granites along northeast-trending fractures. These pegmatites contrast markedly with the coexisting Pikes Peak pegmatites, which are characterized by quartz and amazonite crystals, zircon, biotite, siderite, and minor topaz, allanite, cassiterite and genthelvite. The Pikes Peak type occurs as segregations and injected bodies only within Pikes Peak granite.

Age determinations on zircons from pegmatites of the Mount Rosa type proved to be inconsistent, but ages determined by means of the K^{40}/Ar^{40} method on pegmatitic riebeckite are consistent with geological evidence and age determinations on the granites, giving an age of 1040 my.

INTRODUCTION

Discovery of unusual minerals in pegmatites of the St. Peters Dome district, Mount Rosa area, Colorado, attracted the attention of mineralogists as early as 1877 (Koenig, 1877). Bastnaesite and fluocerite were among the earliest found (Allen and Comstock, 1880). Later the fluorides cryolite, pachnolite and prosopite were identified and analyzed from these pegmatites (Cross and Hillebrand 1883, 1885; Hillebrand, 1899). Brief reports on the mineralogy appeared subsequently (Eakins, 1886, 1891; Lacroix, 1889; Genth, 1892; Over, 1929; Palache and Over, 1933; Peacock, 1935; Landes, 1935; Pearl, 1941; Glass and Smalley, 1945; Mohr, 1948; Glass and Adams, 1953; Pauly, 1954; Scott, 1957).

Approximately 150 pegmatite dikes were examined. Two small swarms of dikes occur in Pikes Peak granite and its variants within the Mount Rosa area. The pegmatites belong to two principal types, a calc-alkalic granitic and an alkalic granitic type. Most are of the latter variety.

Although the area has long been one of the famous mineral districts of

[1] Contribution No. 275 from the Mineralogical Laboratory, Department of Geology and Mineralogy, The University of Michigan.

the United States—a Mecca for mineralogists and collectors, considerable confusion has existed with respect to the various mineral assemblages reported there. The recognition that two distinctly different types and ages of pegmatites occur side-by-side in the district has led us to a clarification of the paragenesis. The two groups had previously been lumped together in a single province—the "Pikes Peak-Florissant Province" by Heinrich (1957). Owing to the lack of muscovite and scarcity of beryl, the district received scant attention during World War II (Hanley *et al.*, 1950).

This is the second of a series of papers on the igneous petrology of the Mount Rosa area. For a description of the granitic rocks see Gross and Heinrich (1965).

Acknowledgments

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Pikes Peak Pegmatites

Distribution. Pegmatites of the calc-alkalic type occur north and northeast of Stove Mountain, with concentrations on a ridge north of Fairview and along a narrow ridge southwest of Mount Buckhorn (Fig. 1). The greatest number of dikes is found outside of the Mount Rosa area, primarily near Crystal Park, three miles north of Kineo Mountain. Best exposures are in prospect pits. All of the dikes are interior-type pegmatites occurring within Pikes Peak granite, and both segregation- and injection-type pegmatites are present (Heinrich, 1957).

Character of the pegmatites. The Pikes Peak-type pegmatites are small, irregular to lenticular bodies, usually less than six feet thick. They strike north-northwest and dip gently east. A few contain miarolitic cavities with openings ranging in size from a few inches to several feet across; this variant becomes more common northward, and is very common in the Crystal Park area. Structurally, those pegmatites that have cavities are constructed of a thin border zone composed of a graphic intergrowth of quartz and microcline, and a wall zone of quartz and microcline-perthite. Uncommonly small red-brown zircons are attached to the feldspar. From the interior border of this zone smoky quartz crystals, microcline-perthite, and commonly amazonite crystals project into the central vug.

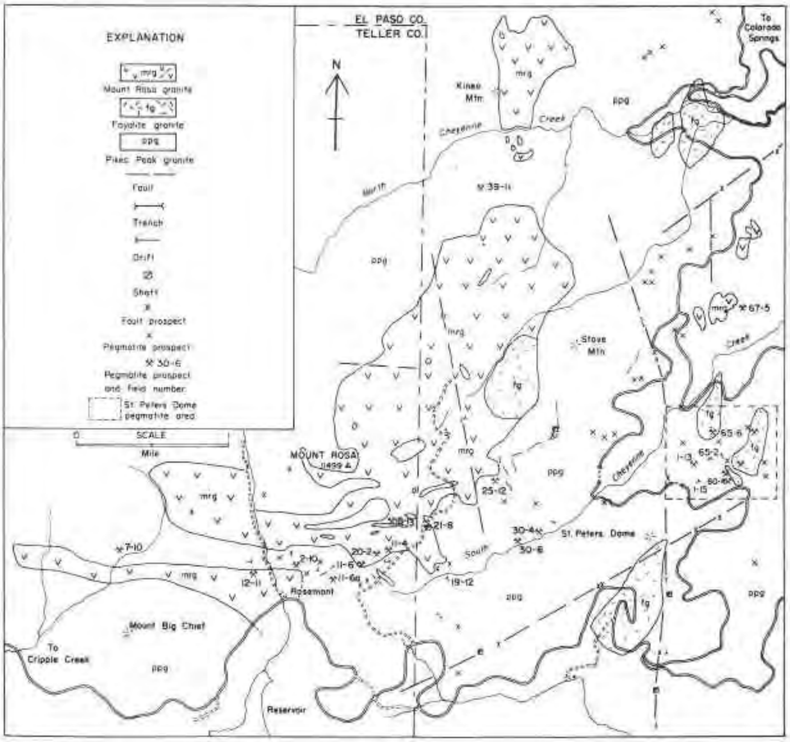

FIG. 1. Geologic map of the Mount Rosa area, El Paso and Teller Counties, Colorado, showing distribution of pegmatites.

Attached to the quartz or feldspar crystals or lying loose in the cavity may be topaz (Peacock, 1935) or genthelvite crystals (Scott, 1957).

The crystals of quartz range from a few centimeters to 40 cm long and from one centimeter to 15 cm across. They are clear, milky or smoky gray to black and commonly show small overgrowths on prism faces.

Microcline-perthite crystals which project into cavities are salmon-pink in color and range in size from a centimeter to 30 cm in length and up to 10 cm in diameter. Some crystals are twinned according to Manebach and Carlsbad laws. The amazonites commonly project into cavities in multiple-crystal groups up to 25 cm long and 5 cm in diameter associated with smoky quartz. Siderite and hematite commonly coat the cavity crystals.

Mineralogy. Minerals occurring in the Pikes Peak-type pegmatites include quartz,[1] microcline, albite (incl. cleavelandite), biotite, fluorite,

[1] For a collecting account, see Hurianek (1938).

allanite, fayalite, topaz,[1] cassiterite, zircon, yttrotantalite, phenacite, genthelvite, chlorite, siderite, and hematite. Those pegmatites which do not have central cavities usually contain combinations of quartz, microcline, albite, zircon, fluorite and hematite. Very rarely phenacite, genthelvite, and topaz crystals occur in miarolitic cavities (Cross and Hillebrand, 1885; Glass and Adams, 1953; Scott, 1957). Most of the pegmatite rock is stained red brown by hematitic and limonitic alteration. Yttrotantalite has been identified associated with zircon, albite, fluorite and microperthite in pegmatite (19-12) that intrudes Pikes Peak granite. Also reported are columbite and tourmaline (Pearl, 1951; Pearl and Pearl, 1954).

Paragenesis. The paragenetic sequence for the Pikes Peak-type pegmatites is as follows:

Early 1. Border zone—quartz, microcline-perthite, commonly intergrown as graphic granite
2. Wall zone—quartz, microcline-perthite
3. a. Core—coarse quartz ± microcline-perthite
b. Vugs—amazonite, albite, biotite, phenacite, genthelvite, fayalite, allanite, zircon.
Late 4. Hydrothermal replacement species—fluorite, cleavelandite
5. Low-temperature alteration species—hematite, siderite, limonite, chlorite

The presence of fayalite as a late mineral in these pegmatites is an important piece of evidence that links the Pikes Peak granite to the fayalite granite and strongly supports the idea that the fayalite granite is a late-fractionated derivative of the Pikes Peak magma (Gross and Heinrich, 1965).

Mount Rosa Pegmatites

Distribution. Pegmatites of the Mount Rosa type are concentrated primarily in two areas: 1) a mile north of Rosemont and 2) two miles east-northeast of Mount Rosa (Fig. 1). In the area on the southern flank of Mount Rosa (No. 1) a group of pegmatites has been exposed chiefly as the result of prospecting for radioactive minerals between 1950 and 1958. The second area, called the St. Peters Dome district, has been a source of unusual minerals since 1880 (Fig. 2).

Most of the Mount Rosa-type pegmatites have been intruded along fractures in Pikes Peak granite or in the fayalite granite (Gross and Heinrich, 1965). The dikes are very abundant along the eastern margin

[1] For a collecting account, see Wulff (1934).

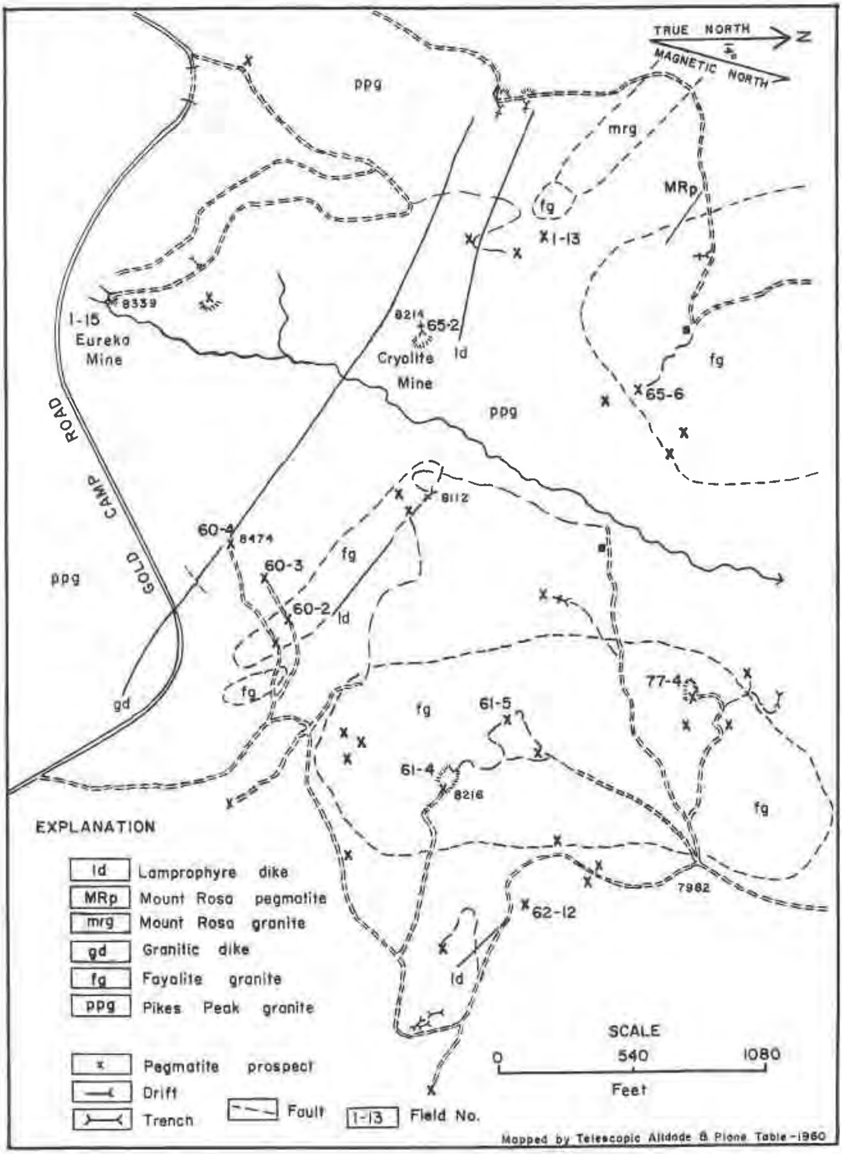

FIG. 2. Pegmatite occurrences in the St. Peters Dome area, El Paso County, Colorado.

of the Mount Rosa sheet. Only two types of pegmatites occur: 1) interior, 2) exterior (Heinrich, 1948). Field observations indicate that approximately 8 per cent belong to the interior type and 92 per cent to the exterior type. The exterior type occurs in two variants (see further on). One prospect has exposed a pegmatite localized along the contact of Pikes Peak granite (footwall) and Mount Rosa granite (hanging wall). More than a mile from the major riebeckite granite sheet, Mount Rosa pegmatites intrude both the Pikes Peak granite and fayalite granite. The trend of most of these pegmatites is north-northeast with gentle dips of less than 35° southeast. A few of the dikes dip northwest.

Character of the pegmatites. The alkalic pegmatites range in thickness from one foot to 15 feet, averaging 4 feet, and are exposed in outcrops from a few feet to 50 feet long. They are tabular in shape and have irregular contacts with the country rock. Pinch-and-swell structure is a common feature, especially where they have intruded fayalite granite. Those pegmatites that are well within the Mount Rosa granite sheet are small, lenticular segregations or small injected pegmatites. In these interior pegmatites, contacts are typically gradational with the riebeckite granite. These dikes contain quartz, microcline, albite, riebeckite, astrophyllite, zircon and thorite. Pegmatites in the Pikes Peak granite near the margin of the Mount Rosa sheet (exterior pegmatites) are injected bodies, which are larger than the interior type but are usually less than 6 feet thick and show surface exposures commonly less than 20 feet long. These exterior dikes have coarser grained textures than their interior relatives, and their contacts with the Pikes Peak granite are sharp. In some instances a thin aplitic border zone is present along the footwall,

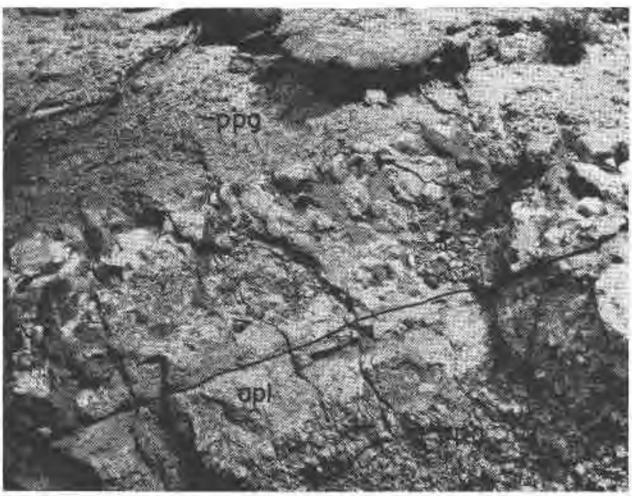

FIG. 3. Photograph of pegmatite (20-2) (center) transecting Pikes Peak granite (ppg). Pegmatite has aplitic border zone (apl) along footwall side.

FIG. 4. Close-up view of riebeckite crystals (above and right of hammer) in microcline-quartz rock of Mt. Rosa pegmatite.

generally less than five centimeters thick (Fig. 3). In other examples the border zone is missing. Usually other zoning is poorly developed or absent. In one pegmatite (25-12) the zoning is asymmetrical with respect to the core. A small quartz core lies toward the footwall side, and coarse-grained quartz and feldspar are on the hanging-wall contact with Pikes Peak granite. Feldspar and riebeckite crystals in these pegmatites are developed to a maximum size of 5 cm by 25 cm.

Exterior pegmatites of the Mount Rosa type several miles from the Mount Rosa sheet intrude Pikes Peak and fayalite granites. These are the largest dikes of the area; however, they are few in number. Most are 6 to 8 feet thick and are irregular, lenticular bodies with sharp contacts with the granites. They are poorly zoned, but mineralogically very complex. Most of the zonal structure is asymmetric, with the quartz core usually displaced towards the hanging wall. One pegmatite (61-4) consists of astrophyllite, quartz and thorite on the footwall side of the quartz core and riebeckite, quartz, and microcline on the hanging wall. In these exterior pegmatites, riebeckite may form crystals up to 15 cm by 75 cm (Fig. 4), and micaceous astrophyllite has been found in tablets as large as 2.5 cm by 10 cm by 25 cm.

A consistent feature of the alkalic pegmatites that intrude fayalite granite is a 15 to 50 cm-thick bleached zone of fayalite granite and a 10 to 15-cm aplitic border zone on the footwall. The bleached-zone color change is from olive green to light gray. The mineral changes include replacement of hornblende by riebeckite and an increase in quartz, which occurs in small granules in astrophyllite. Also small granules of riebeckite are included in astrophyllite. In a few dikes the aplitic border zone occurs along the hanging-wall contact, but never in a single dike does it ap-

FIG. 5. Caved portal of Eureka Tunnel, famous for Mt. Rosa-type pegmatite rich in cryolite and other rare aluminofluoride minerals. Pegmatite is exposed on right side of adit portal.

pear at both contacts. The border zone is composed of quartz, microcline, astrophyllite and riebeckite (77-4).

The exterior pegmatite exposed in the Eureka tunnel, famous for cryolite and related minerals, intrudes Pikes Peak granite (Landes, 1935). It trends N.48°W. at the portal and dips 50°NE (Fig. 5). A 100-foot drift along the pegmatite trends S.50°W. to S.25°W. A large quartz core, 20 feet wide, is exposed in the drift 48 feet from the portal. At the face the rock is composed of quartz, microcline-perthite and weberite. This pegmatite (1–15) as well as two others (65-2), (30-4) are relatively rich in aluminofluoride minerals.

Mineralogy. Rare minerals were found in pegmatites of the Mount Rosa type as early as 1877 (Cross and Hillebrand, 1883). Bastnaesite, astrophyllite and the uncommon aluminofluorides were described by the early investigators. The first detailed study of the fluoride pegmatites, with an attempt to present a paragenetic sequence and discussion of origin, was made by Landes (1935). The relative abundance of the pegmatite minerals, in order from greatest to least, is quartz, microcline, riebeckite,

TABLE 1. MINERALS OF MOUNT ROSA-TYPE PEGMATITES GROUPED BY ZONES

Border Zone	Wall Zone	Intermediate Zone	Core	Hydrothermal Replacement Unit	Low Temperature Alteration stage
quartz	quartz	quartz	quartz	albite	sericite
microcline	microcline	microcline		astrophyllite	kaolinite
riebeckite	riebeckite	riebeckite		fluorite	hematite
zircon	zircon	zircon		fluorides	chlorite
astrophyllite	rutile	niobian rutile		sulfides	siderite
microlite	monazite	monazite		thorite	gearksutite
	bastnaesite	bastnaesite		bertrandite	
		pyrochlore			
		microlite			
		doverite(?)			

albite, zircon, astrophyllite, thorite, niobian rutile, pyrochlore and fluorides. Columbite, microlite, bastnaesite, monazite and sulfides are very scarce. In Table 1, the minerals are arranged according to their structural position in the pegmatite zones.

NOTES ON INDIVIDUAL MINERALS

Aegirine. Present only in aggregates of bright green, prismatic crystals that fill cavities less than 5 cm in diameter in the border zone of pegmatite 77-4.

$$\alpha = 1.770, \quad \beta = 1.81, \quad \gamma = 1.825, \quad 2V_Z = 115°$$

These data indicate 94% acmite molecule in the diopside-acmite series (Winchell and Winchell, 1951, p. 414, Fig. 304).

Riebeckite. All the Mount Rosa-type pegmatites contain riebeckite. The blue-black crystals range in size from less than 0.5 cm across and 2.5 cm in length to large tapering crystals 10 to 15 cm in diameter and 50 to

75 cm long (Fig. 6). In most of the pegmatites the riebeckite crystals are randomly oriented. In a few exposures they are aligned nearly normal to the hanging-wall contact, tapering upward (Fig. 7). The amphibole occurs in quartz-microcline pegmatite. The *x*-ray diffraction powder patterns for riebeckites from the Mount Rosa granite and for those from its pegmatites are similar. However, S. R. Hart (pers. comm., 1961) found that riebeckites from pegmatites (21-8, 1-13) had about 10 per cent more

FIG. 6. Large Mt. Rosa pegmatite, showing core of large microcline crystals and quartz anhedra cut by prismatic riebeckite crystals as much as several feet long.

glaucophane molecule than that from the Mount Rosa granite (15-6). According to Coleman (1951) the chemical analysis and *x*-ray examination prove that the mineral is a true riebeckite, although some mineralogists have referred to it as arfvedsonite (Table 2). Table 2 also shows that the riebeckites *do* differ in composition, but the riebeckite analyzed by Kunitz (1930) is unspecified as to its exact occurrence.

Astrophyllite. This mineral also occurs as a late species along fracture surfaces in the Mount Rosa granite, in the absence of pegmatite. It is present in many of the pegmatites, commonly in the border zone along the footwall contact, especially where the country rock is fayalite granite. In a few dikes the micaceous strips of golden-brown astrophyllite exceed 5 cm in thickness by 10 cm in width and 25 cm in length (61-4). Astrophyllite is associated with quartz, feldspar, thorite and galena in pegmatites, and is particularly well-developed and coarse in quartz. In the Mount Rosa granite the mineral was formed during the deuteric stage, and in pegmatites it belongs to an intermediate stage of formation. In fine-grained border zones the astrophyllite replaces riebeckite. It was

FIG. 7. Large riebeckite crystals tapering toward surface in pegmatite 61–4.

followed by late sulfides such as galena and sphalerite and by fluorite. No differences appear in the optical properties of the astrophyllite that occurs in fractures of the Mount Rosa granite and that which occurs in the pegmatites (Table 2). Chemical analysis of astrophyllite shows a decrease in MgO from that in riebeckite. This may account in part for the Mg in the fluorides, weberite and ralstonite.

Zircon. The mineral occurs abundantly in the pegmatites in euhedral crystals and in anhedral, granular aggregates. Crystals are bipyramids, usually with a narrow prism form. They are red brown to light brown, rarely green. Clear crystals are wine-red or green in color and only weakly radioactive. The larger red-brown crystals are zoned, highly radioactive, and show weak fluorescence under ultraviolet light. Under the microscope they show small patches of orange-brown alteration but are never completely metamict. Zircons range in size from a few millimeters to 2 cm in cross-section. All of the larger crystals are translucent and zoned. Uncommonly green and red-brown zircons occur in the same specimen,

TABLE 2. CHEMICAL ANALYSES AND OPTICS OF RIEBECKITE AND ASTROPHYLLITE, MOUNT ROSA AREA, COLORADO

	1 Riebeckite	2 Riebeckite	3 Astrophyllite
SiO_2	50.58	55.88	35.23
Al_2O_3	1.53	0.60	Tr
Fe_2O_3	16.15	6.74	3.73
FeO	14.53	19.97	29.02
MgO	.49	1.18	.13
CaO	.41		.22
Na_2O	9.97	8.96	3.63
K_2O	2.17	1.25	5.42
H_2O+	.72	4.36	4.18
H_2O-	.10		
MnO	1.23	1.06	5.52
TiO_2	.28		11.40
ZrO_2			1.21
Ta_2O_5			.34
F	2.67		
Less 0 for F_2	1.13		
Total	99.70	100.00	100.03

1. Riebeckite, St. Peters Dome, El Paso County, Colorado. Analyst, Coleman (1951)
2. Riebeckite, "Pikes Peak," Kunitz (1930).
3. Astrophyllite, St. Peters Dome, El Paso County, Colorado. Analyst, Eakins (1891).

	Optical Properties		
1. Riebeckite (Coleman, 1951)	$\alpha=1.687$	$\gamma-\alpha=.009$	X—indigo blue
	$\beta=1.691$	$2V=70°(-)$	Y—blue
	$\gamma=1.696$	$\gamma\wedge c=5°$	Z—yellow-green
Pegmatite (59-1)	$\alpha=1.680$	$\gamma-\alpha=.020$	X—dark indigo
		(+)	Y—blue
	$\gamma=1.705$		Z—yellow-green
2. Riebeckite (Kunitz, 1930)	$\alpha=1.695$,	$\gamma=1.699$ $\gamma-\alpha=0.004$	$\gamma\wedge c=3°$
Astrophyllite	$\alpha=1.695$	$\gamma-\alpha=0.060$	X—red-orange
	$\beta=1.725$	$2V=\text{large}(+)$	Y—lemon yellow
Pegmatite (61-4)	$\gamma=1.755$		Z—dark yellow-green

but only the brown ones are strongly radioactive. The crystals occur in quartz and feldspar and are associated with thorite and pyrochlore. Radial fractures in quartz stream from the larger crystals. Small clear crystals occur at the Eureka drift (1–15) and the green variety at the 30-6 pegmatite. Zircons are abundant in pegmatites 11-4, 25-12 and 39-11.

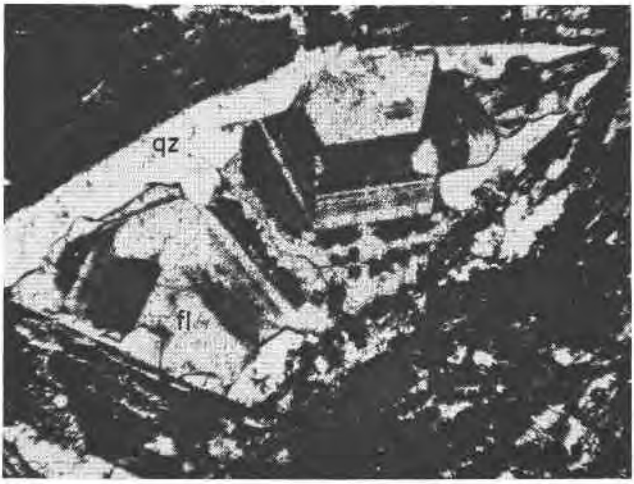

FIG. 8. Photomicrograph of niobian rutile blades with interstitial material containing fluorite (fl) showing color zones and quartz (qz). Pegmatite 65–6. Polars not crossed, ×75.

Rutile. Occurs in small greenish-black crystals in a few pegmatites. The grains are several millimeters in diameter and are clustered in groups associated with quartz and zircon. Because of their greenish-black color, they are easily confused with pyrochlore. The mineral has been found in pegmatites 11-4 and 11-3.

Niobian rutile (ilmenorutile). Found in many of the mineralogically complex pegmatites and in a few border zones. It forms dark greenish-gray blades measuring as much as 7 mm wide by 8 cm long. It penetrates quartz and microcline in a criss-cross of blades, producing triangular interstitial areas that contain columbite, fluorite, sphalerite, chlorite and quartz (Fig. 8). In an ultra-thin section the blades are seen to consist primarily of quartz grains with included, parallelly aligned granules of grayish rutile. Thus an *x*-ray pattern of the aggregate shows strong quartz and fluorite lines among weaker lines of the Ti-oxide mineral. A spectrographic analysis indicates that the following elements are present in approximate percentages, given in order of decreasing abundance:

Si	>1.0	Ca	1.0	Pb	<0.1
Fe	>1.0	Al	0.7	Mn	0.05
Ti	>1.0	Zr	0.6	Mg	0.02
Nb	>1.0	Cr	0.5	Va	<0.01
Sn	>1.0	Ni	0.1	Cu	0.006
Est.	1–5				

Spectroscopic analysis by Union Carbide Nuclear Co., William McCarty, Analyst.

The mineral is high in Nb, Sn, Ti, Si and Fe. Much of the Ca and Si are due to contamination by quartz and fluorite. Thin seams of fluorite, chlorite and galena are commonly included in the mineral. In pegmatite 65–6 the niobian rutile is best developed in a zone 3 to 4 feet thick above a 6-inch zone of zircon-quartz rock. Other pegmatites containing notable amounts of niobian rutile are 25-12 and 62-12.

Thorite. Occurs in red brown, tabular to irregular massive crystals associated with quartz and zircon. Crystals range in length from a few millimeters to 30 mm and are less than 20 mm thick. It is highly radioactive and metamict. The radioactivity of the thorite has prompted most of the prospecting for uranium in the area. Nearly all of the more mineralogically complex pegmatites contain some thorite.

Columbite. Has been observed in pegmatites 65-6 and 7-10. The black, subhedral crystals are in small grains associated with microcline and quartz, or in interstitial areas in specimens containing niobian rutile.

Pyrochlore. Occurs in small greenish-black to pale yellow euhedral to subhedral crystals less than 4 mm in cross section. The *x*-ray diffraction powder pattern gives values close to those of pyrochlore, but Weissenberg single crystal *x*-ray values suggested betafite (W. H. Boyer, pers. comm.). However, Hogarth (1961, p. 627) in a detailed study on pyrochlore and betafite stated that, "The fact that odd numbered planes of betafite are suppressed may, in an extreme case, produce an apparent half-sized primitive cell." Thus, the value of the cubic cell edge determined by Boyer of 5.20 Å should be 10.40 Å. This value is at the lower end of the range of values for pyrochlores studied by van der Veen (1963). The mineral is closely associated with zircon and quartz in pegmatite 11-4. It occurs as waxy yellow grains 5 mm across in pegmatite 77-4.

Microlite. Appears as an isotropic yellow-orange mineral in the border zone of pegmatite 60-3. Associated with zircon and quartz and as a yellow granular material around thorite. Identified by means of its *x*-ray powder diffraction pattern.

Monazite. Observed only as a crushed fragment in an immersion mount and has been identified by means of *x*-ray powder methods. The mineral is relatively rare, occurring in small red-brown grains associated with quartz and feldspar.

Bastnaesite. A rare mineral in light-brown to orange grains associated with monazite. An unusual occurrence of bastnaesite is in pegmatite 67-

5 in which the grains are scattered in fluorite which is graphically intergrown with quartz.

Metallic sulfides. Galena, sphalerite, pyrite and molybdenite are found in a few pegmatites. Pyrite and molybdenite are very rare, occurring with microcline in Mount Rosa-type pegmatites that intrude Pikes Peak granite. Sphalerite is associated with niobian rutile. The most abundant sulfide, galena, occurs in large masses, up to 15 cm in diameter, with an alteration coating of anglesite. The galena is closely associated with astrophyllite, quartz, and thorite. Galena belongs to the late-stage hydrothermal replacement suite. Pegmatites containing considerable galena are 60-4 and 61-4.

Fluorides. These minerals are found in the exterior zone of pegmatites 30-4, 1-15 (Eureka tunnel) and 65-2 (Cryolite mine-caved). They include cryolite and its alteration products, pachnolite, prosopite, ralstonite, thomsenolite, elpasolite, and weberite. The minerals are grouped according to the pegmatites in which they are found:

1-15	*65-2*	*30-4*
cryolite	cryolite	cryolite
pachnolite	pachnolite	pachnolite
elpasolite		thomsenolite
ralstonite		prosopite
thomsenolite		ralstonite
prosopite		gearksutite
weberite		
gearksutite		

Cryolite occurs in coarse massive light gray aggregates which show a light pink tint when fresh. Cleavage in three directions, nearly at right angles, produces a blocky appearance on weathered surfaces. The cryolite is associated with quartz and microcline. It alters to massive blue-gray pachnolite, or red-brown stained prosopite. Ralstonite, thomsenolite and elpasolite (Frondel, 1948) are very rare in minute crystals that require *x*-ray diffraction patterns for positive identification. The first identification of weberite from El Paso County, Colorado, was made by Pauly (1954). The mineral is common in the Eureka drift, associated with quartz and microcline. Because of its brick-red color, it has been confused with iron-stained feldspar. All of the fluorides, which have been described in detail by early investigators, were identified by the writers except for thomsenolite and elpasolite. The fluorides alter to gearksutite, which occurs as a white powder in cavities rimmed by microcline.

Fluorite. A very abundant mineral occurring in most of the pegmatites. Veinlets and aggregates of purple to green fluorite are associated with quartz and microcline. The surface of fluorite bleaches light gray in sunlight.

Bertrandite. Has been identified by means of the oil immersion method from red-brown samples obtained from pegmatites 1-15 and 11-3a. The crystals are associated with quartz, microcline and fluorite. Although visual evidence suggests that bertrandite is rare, berylometer surveys by prospectors in the St. Peters Dome district have detected several small anomalies indicating weak concentrations of beryllium. At the Eureka Tunnel and along the prospect roads near pegmatites 60-1 and 61-4, a berylometer registered above-background counts. The beryllium is probably in bertrandite, and it is probably more widespread than was originally believed.

Doverite. A very rare mineral which has been tentatively identified by means of x-ray and index of refraction measurements from pegmatite 7-10. Associated with quartz, microcline and zircon.

Chlorite, hematite and sericite. Chlorite and hematite are formed from the breakdown of riebeckite and astrophyllite. Sericite replaces feldspar which has been attacked by hydrothermal solutions. The sericite and hematite filled fractures in pegmatites in a late, low-temperature stage of hydrothermal replacement.

Paragenesis

Zircon is one of the earliest minerals to form. In Mount Rosa-type pegmatites it is associated with quartz and microcline, some of which may include skeletal zircon. Larger zircon crystals include quartz and microcline or albite in a sieve structure. Pyrochlore euhedra are included in quartz and zircon and usually show a thin reddish alteration rim. Other minerals which probably formed relatively early are fine granules of monazite and bastnaesite which occur in quartz. Massive zircon has been replaced by niobian rutile and riebeckite which are of intermediate age. Microlite also belongs to this period. Much of the rutile has been replaced by fluorite and sericite of the late hydrothermal alteration stages. Generally astrophyllite and thorite are associated with galena and/or fluorite, having been formed in an intermediate to late period during the hydrothermal replacement stage. Some late quartz was deposited as vein fillings during this stage. Chlorite, hematite, sericite and gearksutite fill fractures in earlier formed minerals.

Regional Zoning of Alkalic Pegmatites

The Mount Rosa type pegmatites have been grouped into interior and exterior pegmatites. Certain mineralogical as well as structural features distinguish each type. Thus the interior pegmatites are small and mineralogically simple. Just beyond the margin of the Mount Rosa sheet but within the Pikes Peak granite the dikes are larger and mineralogically more complex. Thorite and pyrochlore are characteristic minerals of those pegmatites close to the Mount Rosa sheet. Farther from the Mount Rosa sill, the alkalic pegmatites are the largest and the most complex mineralogically, having as their characteristic minerals fluorides and niobian rutile. Riebeckite and zircon are common to nearly all pegmatites of both zones.

Age Data on Zircons and Thorites

Introduction. An attempt has been made to determine age of the pegmatites and Mount Rosa granite by means of the alpha count-isotopic lead method. Eight pairs of zircons and two pairs of thorite samples from various pegmatites and one zircon sample from Mount Rosa granite were submitted to the U. S. Geological Survey for age analysis. The age determinations were performed by T. W. Stern, of the U. S. Geological Survey, whose work is greatly appreciated by the writers. The samples consisted of large single crystals or of numerous small grains of red-brown radioactive zircons. A very weakly radioactive wine-colored zircon was also tested for age determinations. The results are given in Table 3.

Character of the zircons used. Most of the zircons used for age determinations were zoned. Larger crystals also were fractured. The crystals are bipyramids with the prism zone subordinate to absent. Pyramid faces in larger crystals are concave. Most of the zircons are partially metamict, commonly in zones.

From an examination of Table 3, it can be seen that α counts and lead contents of the zircons increase with size of the crystals. The smallest zircons, 2 to 4 mm diameter, were from pegmatite 11-6a, whereas the largest crystals of about 10 mm diameter were from deposit 39-11. In most of the zircons the U/Th ratio is too low to measure, but the largest zircons contain uranium > thorium, in a ratio of 3:1. The estimated geologic age would be late Precambrian, but results of the zircons and thorite samples in the alpha count-isotopic lead method produced values ranging from 320–2100 my for zircons, and of 120–150 my for thorites. Thus the samples from pegmatites gave completely unsatisfactory results.

Actually, most of the zircons of the Mount Rosa area show few metamict zones. All give sharp x-ray powder patterns without heating. Holland and Gottfried (1955) state that determinations on zircons are satisfactory, if radiation dosage is not greater than 300 $\alpha/mg \times 10^{13}$. Only two zircon pairs satisfy this requirement (11-4, 11-6a, Table 3). These two

TABLE 3. ALPHA COUNT—ISOTOPE LEAD METHOD AGE DETERMINATIONS OF PAIRS OF ZIRCONS AND THORITES FROM PEGMATITES, MOUNT ROSA AREA, COLORADO

Specimen No.	Mineral	Count	Pb	U/Th	Age (m y)
1-15 I	Z		20	—	
1-15 II	Z		20		
2-10 I	Z	397	210	0.3	1135±125
2-10 II	Z	425	322	0.4	1580±175
7-10 I	Z	431	650	0.5	2400
11-4 I	Z	285	145	—	1140±130
11-4 II	Z	259	175	—	1460±165
11-6a I	Z	182	183	—	2100±235
11-6a II	Z	147	120	—	1810±205
12-11 I	Th	30,014	1750	—	120± 15
12-11 II	Th	27,100	1750	—	130± 15
20-1 I	Z	583	216	—	855± 95
20-1 II	Z	300			
		312 306	210	—	1480±165
25-12 I	Z	625	81	0.6	320
			76		300
25-12 II	Z	606	135	1.3	525± 60
30- 6 I	Th	35,500	2575	.04	130± 15
30- 6 II	Th	35,400	2675	.03	150± 20
39-11 I	Z	4,048	1050	3.0	630± 70

(Z) Zircon (Th) Thorite (—) U/Th ratio too low to measure.
All lead values are averages of duplicates.
Determinations by T. W. Stern, U. S. Geological Survey.

are from exterior pegmatites less than 1000 feet apart near the border of the Mount Rosa sheet. Even their ages give a range from 1140 to 2100 my. Two zircon pairs giving low ages, between 300 and 630 my (25-12, 39-11), were large crystals. In most cases only two large zircons were submitted for each run. These were fractured, showed concave faces, and were partially metamict.

According to Tilton *et al.* (1957) the loss of isotopic lead through solution in fractured zircons and reheating of the zircon during metamorphic processes are the probable causes of abnormally low ages. Griffin and Kulp (1960, p. 220) state that—"the youngest metamorphic-igneous event in the Colorado basement appears to have occurred at about 1000 my ago. It seems that this activity centered in the Pikes Peak region and may have produced some of the granites in the vicinity such as the Windy Point and the Mount Rosa as well as the pegmatites near St. Peters Dome."

Another possible cause for erratic ages of the zircons from pegmatites of the Mount Rosa area is isotopic diffusion in the crystals. Nicolaysen (1957, p. 55) states that "In zircon additional vacancies and interstitial ions in damaged zircon might be expected to raise the diffusion coefficient. Formation of disoriented crystallites presents possibility of grain boundary diffusion taking place along crystallite boundaries."

Age determinations on zircons from granites of the region show fewer discrepancies. Zircon age data from Pikes Peak granite by Larsen *et al.* (1952) gave a date of 980 my by the isotopic lead method, using calculations for Pb^{207}/Pb^{206}. The data for zircons separated from Mount Rosa granite gave a lead-alpha age of 1110 ± 125 my. Also the helium method *vs.* The radiation damage method in pegmatitic zircon from St. Peters Dome gave a value of 860 my for an estimated "true age" of 900 my (Hurley, 1954).

The inconsistent ages from zircons in pegmatites, especially those from large single crystals compared with those from small crystals and those obtained from granites, strongly suggest hydrothermal alteration of pegmatitic zircons. Partly metamict zircons are especially susceptible to attack. The extremely low ages of thorite samples, which have very high alpha counts and high lead contents, suggest possible contamination of common lead and other impurities. All the thorites were completely metamict and would be thorogummites prior to reheating for *x*-ray diffraction study. These thorites, which are common to most of the Mount Rosa type pegmatites, were probably introduced into the pegmatites during a late hydrothermal replacement stage. The mineral is absent in typical, unaltered Mount Rosa granite. Therefore one of the principal causes of age discrepancies in the zircons is the effect of hydrothermal alteration of the pegmatites with formation of thorite, astrophyllite and galena.

Gottfried *et al.* (1958, p. 102) mention that—"the agreement with other methods Ar^{40}/K^{40} and Sr^{87}/Rb^{87} is poor for zircons from Precambrian rocks, inasmuch as the lead-alpha age corresponds with the Pb^{206}/U^{238} age which is commonly lower than the Pb^{207}/Pb^{206} age and concordant Ar^{40}/K^{40} and Sr^{87}/Rb^{87} ages on mica."

Conclusion. The discordant ages given by the α count-isotopic lead method on zircon and thorite of the Mount Rosa pegmatites may be due to one or more of the following factors:

1. Radiation dosage in many examples exceeded the limit set by Holland (1955) of less than $300\alpha/\text{mg} \times 10^{13}$.
2. Complexity of composition of radioactive zircons.
3. Possible common lead contamination along or in microfractures of crystals during Precambrian or even early Tertiary mineralization.

4. Physical or chemical changes during growth or at a later date, about 1000 my (Griffin and Kulp, 1960) in deformed larger crystals.
5. Isotopic diffusion of daughter products or lead loss resulting from reheating or metamorphism suggested by (3) above.
6. Metasomatic alteration of the zircons in pegmatites.

Comparison of the Two Pegmatite Types

The Mount Rosa-type pegmatites are concentrated in a relatively small area on the south and northeast flanks of Mount Rosa, and are closely related spatially to the Mount Rosa riebeckite granite sheet which extends primarily northeastward from Rosemont. The pegmatites crop out chiefly in two swarms of small tabular dikes of relatively complex mineralogy. Although most of the pegmatites intrude the Pikes Peak granite, their mineralogy is similar to that of the Mount Rosa granite; *i.e.*, they are themselves alkalic-granitic.

The pegmatites of the Pikes Peak type are scattered in small outcrops northeast of Stove Mountain but increase in size outside of the Mount Rosa area to the north. They occur primarily within the Pikes Peak batholith near and along its margin.

Those pegmatites related to the Pikes Peak granite are considerably smaller than the Mount Rosa type, except those in the South Platte district and in the area north of Florissant. Pegmatites of both types are commonly lenticular bodies with sharp contacts with the country rocks. Zoning is more common in the Pikes Peak type, commonly in those containing cavities, a feature characteristic only of the Pikes Peak group. The differences in mineral assemblages are presented in Table 4.

In the Pikes Peak pegmatites the trace element assemblage contains Y > Ce group rare earths, Ta, Nb, Zr and Mo. The minerals in which these elements are found include yttrotantalite, fluocerite, samarskite, xenotime, ancylite, genthelvite, allanite, fergusonite and euxenite. Mount Rosa-type pegmatites contain the trace elements Nb > Ta, Ce > Y, Th, W and Be. These are present in astrophyllite, niobian rutile, monazite, pyrochlore, microlite, bastnaesite and bertrandite.

The chief elemental differences between the two pegmatite types are the high contents of Be, Ce, Ta and Y in the Pikes Peak type compared to high Nb, Ti, Zr and Th in the Mount Rosa type:

Pikes Peak pegmatite	Fe	Ti	Ce	La	Y	Zr	F	Be	Mo	Nb	Ta		
Mount Rosa pegmatite	Fe	Ti	Ce	La	Y	Zr	F	Be	Nb	Ta		Th	Mg

Paragenesis of Cryolite and Related Fluorides

The aluminofluoride minerals, cryolite and its relatives, are unusually rare species, and in Colorado four of their verified occurrences (three in the Mount Rosa area) are represented. Table 5 lists information on

Table 4. Mineralogical Comparison of Mount Rosa and Pikes Peak Type Pegmatites

Classification	Element	Mount Rosa Type	Pikes Peak Type
Sulfides	Pb	Galena	
	Zn	Sphalerite	
	Mo	Molybdenite	Molybdenite
Simple Oxides	Ti	Rutile	
	Ti, Nb	Niobian rutile	
Multiple Oxides	Nb	Columbite	
	Nb, Ta	Pyrochlore	
	Ta, Nb	Microlite	
	Y, Ce		Euxenite
			Fergusonite
			Samarskite
	Y, Ta		Yttrotantalite
Halides	F	Fluorite	Fluorite
	F, Ce, La		
		Cryolite	
		Elpasolite	
		Pachnolite	
		Thomsenolite	
		Gearksutite	
		Prosopite	
	Mg	Ralstonite	
	Mg	Weberite	
Carbonates	Fe	Siderite	Siderite
	Ce, La	Bastnaesite	
	Ce, Sr		Ancylite
	Y, F	Doverite (?)	Doverite (?)
Sulfate	Ba		Barite
Phosphates	Ce, La	Monazite	Monazite
	Y, Th		Xenotime
Silicates	Be, Zn		Genthelvite
	Be, Y		Gadolinite
	Na, Fe	Aegirine	
	Na, Fe	Riebeckite	
	Ca, La, Fe		Allanite
	Be		Beryl
	B	Bertrandite	Bertrandite
	Na, Fe, Ti Mn, Zr	Astrophyllite	
	Zr, Hf, Th	Zircon (cyrtolite)	
	Th, U	Thorite	
	Be		Phenacite
	Al, F		Topaz

TABLE 5. PARAGENESIS OF CRYOLITE AND RELATED FLUORIDE MINERALS

Locality	Type of deposit	Fluorides	Remarks	References
Ivigtut, Greenland	Alkalic granitic pegmatite	cryolite, chiolite, fluorite, pachnolite, thomsenolite, gearksutite, cryolithionite, weberite, jarlite, prosopite, stenonite	A replacement body in a zoned pegmatite. Associated are siderite, barite and numerous sulfides	Palache *et al.*, 1951; Pauly, 1960
Goldie deposit, Texas Creek, Fremont Co., Colorado	Fluoritic, baritic carbonatite dike	cryolite, pachnolite, prosopite, ralstonite, weberite, gearksutite(?), fluorite	Replacement nodules with associated barite in hematitic calcite carbonatite	Heinrich and Quon, 1963
Pegmatite 1-15, Mt. Rosa area, Colorado	Alkalic granitic pegmatite	cryolite, pachnolite, elpasolite, ralstonite, thomsenolite, prosopite, weberite, gearksutite	Replacement unit in central part of pegmatite	This paper
Pegmatite 65-2 (Cryolite Mine), Mt. Rosa area, Colorado	Alkalic granitic pegmatite	cryolite, pachnolite	Replacement unit	This paper
Pegmatite 30-4, Mt. Rosa area, Colorado	Alkalic granitic pegmatite	cryolite, pachnolite, thomsenolite, prosopite, ralstonite, gearksutite	Replacement unit	This paper
Green River, Wyoming	Shale associated with fresh-water evaporite deposits (trona)	cryolite, unnamed Na-Mg fluoride		Charles Milton, pers. comm.; Milton and Eugster, 1959
Jos Plateau, Nigeria	Accessory mineral in alkalic granite	cryolite, thomsenolite	Associated accessories are zircon, topaz, astrophyllite, thorite, pyrochlore, monazite and columbite	Williams *et al.*, 1956; Beer, 1951
Miask, Ilmen Mtns., U.S.S.R.	Alkalic syenitic (?) pegmatite	cryolite, chiolite, flourite, gearksutite	Associated are topaz, phenacite, cryolithionite	Palache *et al.*, 1951

known and reported occurrences of cryolite and related minerals. Palache *et al.* (1951, p. 112) also mention another occurrence: A minor occurrence is with fluorite near Sallent in the Pyrenees, Huesca province, Spain." Efforts to obtain cryolite from this locality proved fruitless, as specimens from this locality are apparently not represented in any major United States collection. Sr. J. Folch of Barcelona, an authority on Spanish minerals and mineral localities, has been unable to verify this locality and regards its reported occurrence there as erroneous (pers. comm.).

Noteworthy in the paragenesis of cryolite is that all but the Green River occurrence are in alkalic rocks, as late constituents in alkalic granites, alkalic granitic pegmatites, alkalic syenitic pegmatites and a carbonatite. The Green River paragenesis is completely atypical of evaporites, but it may be pointed out that it can be explained by combining a normal continental evaporite assemblage with an assemblage of authigenic species derived in part from extrinsic elements (Ba, Sr, Ce, Ti, Nb, Zr, Zn, F) introduced during alkalic igneous vulcanism (Heinrich, 1966).

Conclusions

The pegmatites of the Mount Rosa area are consanguineous with two different parent magmas on the basis of mineralogical and geochemical characteristics. Pegmatites of the Pikes Peak type are structurally more uniform and contain mineral assemblages that are less complex than those of the Mount Rosa type. Well developed zonal structure and miarolitic cavities are characteristic of the Pikes Peak type. The Pikes Peak type is calc-alkalic granitic, whereas the Mount Rosa type is alkalic granitic. Geochemically, the Pikes Peak pegmatites contain considerable Be, Ta > Nb, Y and Ce, which occur also in trace amounts in the granite of the pluton. Mount Rosa pegmatites are larger in size, mineralogically more complex, and zoning and other structural features are poorly represented. Mineral species characteristic of these pegmatites also occur consistently in the Mount Rosa granite: riebeckite, astrophyllite, zircon, thorite and bastnaesite. The distinguishing features of these pegmatites are the abundance of radioactive zircon and the complexity of their mineralogy—such as cryolite (and its alteration products), pyrochlore, columbite, thorite and niobian rutile. Elements diagnostic of these pegmatities include Zr, Th, Ti, Nb > Ta and Ce > Y. These features strongly indicate that the pegmatites were derived from an alkalic igneous magma—the parent magma of the Mount Rosa granite.

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