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

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ABSTRACT

The Mount Rosa area includes many small segregations and sill-like bodies of igneous rocks occurring in an arc-like pattern within the Pikes Peak batholith. The segregations consist of small elongate bodies of fayalite granite and porphyritic granite. These igneous bodies are transected by northwest-trending dikes of granite and aplite. Accessory minerals of the fayalite granite are fayalite, fluorite and allanite. Sill-like bodies of Windy Point granite contain accessories similar to those of the porphyritic granite, namely, fluorite, anatase and pyrrhotite, with lesser monazite and bastnaesite.

The Mount Rosa body, an alkalic riebeckite granite, forms a small irregular sheet, one by four miles in plan and less than 150 feet thick, intrusive into Pikes Peak. Finer grained dike-like variants of the Mount Rosa granite include xenoliths of Pikes Peak granite. The Mount Rosa granite contains accessory astrophyllite, bastnaesite, and zircon with rare pyrochlore and monazite.

Age determinations by the alpha count-lead isotope method on zircons from the Mount Rosa granite and by the K^{40}/Ar^{40} method on riebeckite of the granite and pegmatites gave satisfactory ages of 1040 m.y. Field relationships and age determinations, as well as similar petrological and mineralogical characteristics, support the theory that the Pikes Peak, fayalite granite, Windy Point, and Mount Rosa granites are comagmatic.

INTRODUCTION

The Mount Rosa area comprises about 25 square miles at the southern termination of the Colorado Front Range, Teller and El Paso Counties, Colorado. It may be reached from Colorado Springs on the east and from Cripple Creek on the west by State Highway 336 (Fig. 1). The area is characterized by mountainous topography with elevations ranging from 7,200 to 11,500 feet. Between 9,500 and 10,500 feet are U-shaped valleys with small mountain meadows, whereas at elevations between 7,500 and 9,000 feet, prominent narrow ridges and steep V-shaped canyons are flanked by conspicuous talus slopes.

Earliest accounts of the area record the discovery of unusual minerals in pegmatites of the St. Peters Dome district, which attracted attention of mineralogists as early as 1883 (Cross and Hillebrand). Mathews (1900) and later Finlay (1916) described the various granites of the region, and Finlay was the first to outline and describe the Mount Rosa granite and

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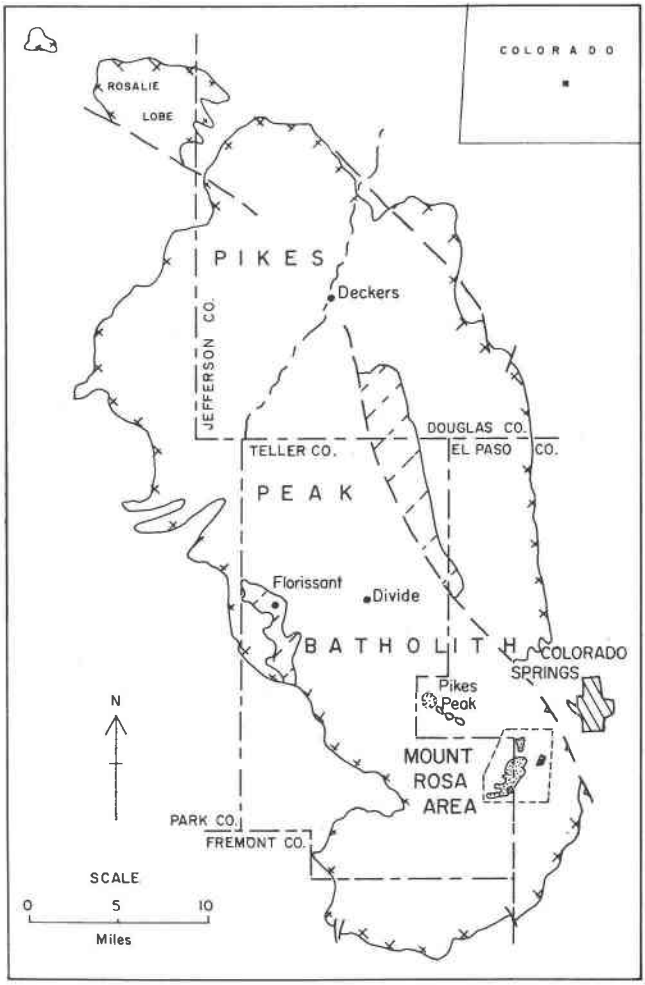

FIG. 1. Index map of the Mount Rosa area, Colorado.

other plutons southeast of Pikes Peak. Stevens (1949) has investigated the fluorite deposits and their structural control in the Mount Rosa area.

GENERAL GEOLOGY

All of the rocks occur as units within the southeastern part of the Precambrian Pikes Peak batholith, fewer than seven miles airline from its eastern contact with Paleozoic sediments. All of the igneous rocks are of Precambrian age with the possible exception of a few of the small lam-

prophyres. A description of the Windy Point granite is included in this report, although it occurs several miles northwest of the area mapped in detail. It appears to be genetically related to the other alkalic granites, although it is nowhere in contact with them.

The major petrologic units are 1) Pikes Peak granite and its fine-grained variants, 2) porphyritic granite, 3) granitic dikes and aplites, 4) fayalite granite, 5) Mount Rosa alkalic granite and its fine-grained equivalent dike phase, and 6) Windy Point granite (Fig. 2). Generally internal structural features such as foliation are absent or weakly developed. Jointing is locally conspicuous in most of the finer grained variants.

Pikes Peak Granite

Extent and distribution. The Pikes Peak granite (Cross, 1894) is a large mesozonal batholith (Buddington, 1959) covering approximately 1,200 square miles in the southern Colorado Front Range. The batholith extends from the Rosalie lobe (an outlier north of the North Fork of the South Platte River in Park County) to the Canon City embayment, a distance of about 60 miles; and from the faulted contact with Paleozoic sediments on the east, 30 miles to its western contact against both the Cripple Creek pluton and older gneisses and schists. Within the batholith are widely scattered bodies and irregular sills of younger igneous rocks and small "island" caps of Paleozoic sediments, such as those along the Ute Pass fault. To the west the Florissant lake beds of Miocene age cover the granite.

Contacts with other granites. The Pikes Peak granite encloses elongate to rounded bodies of dark fayalite granite and light porphyritic granite. These segregation-type bodies that show gradational contacts with the Pikes Peak are more resistant to weathering than the Pikes Peak (Fig. 3). At Devils Slide on the Gold Camp Road, a body of porphyritic granite overlies fayalite granite. Between the two granites is a 30-inch zone that has the textural appearance of Pikes Peak granite. These rocks are believed to represent special phases of the Pikes Peak pluton.

Northwest of the Mount Rosa area eight small irregular bodies of Windy Point granite extend along a southeast axis from the summit of Pikes Peak. These bodies have sharp, nearly horizontal lower contacts with the Pikes Peak. Lovering and Goddard (1950) concluded that they represented sill-like bodies that intruded the Pikes Peak.

Within the Mount Rosa area, small irregular sheet-like intrusions of medium- to fine-grained riebeckite granite occur in the Pikes Peak granite. Contact relations between the two are exposed in only a few local-

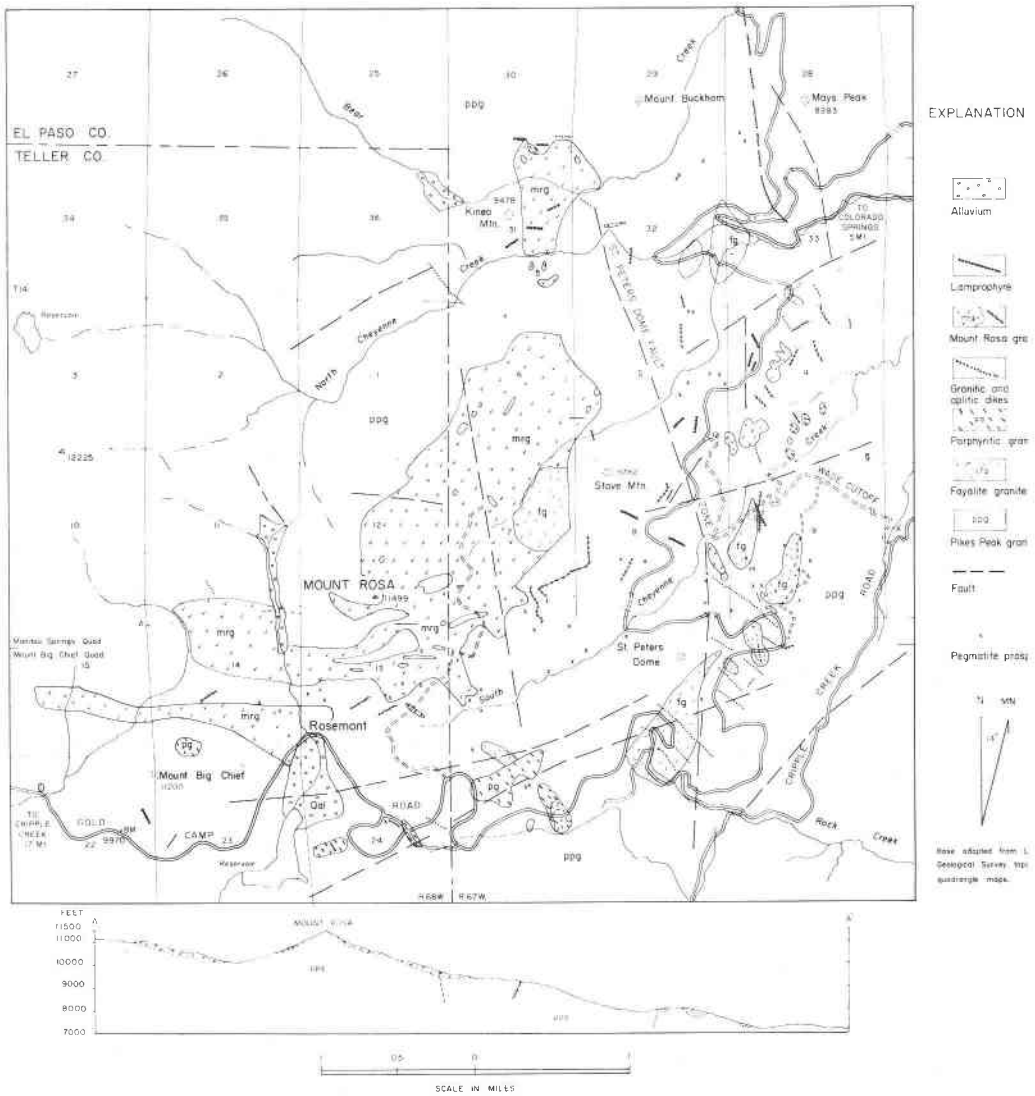

FIG. 2. Geologic map and section of the Mount Rosa area, El Paso and Teller Counties, Colorado.

ities, *e.g.*, in a small prospect pit at an elevation of 10,200 feet near the Summit Wye Road. Here the contact is sharp and the Mount Rosa granite has a chilled margin an inch or less thick. At the head of South Cheyenne Creek near the Summit Wye Road, a dike of fine-grained Mount Rosa granite contains Pikes Peak xenoliths as large as 6 by 18

inches, usually elliptical, and with sharp contacts against Mount Rosa granite (Fig. 4).

These relations demonstrate that both the Mount Rosa and the Windy Point granites are younger than the Pikes Peak and intruded it after it had solidified and cooled. On the other hand, the porphyritic

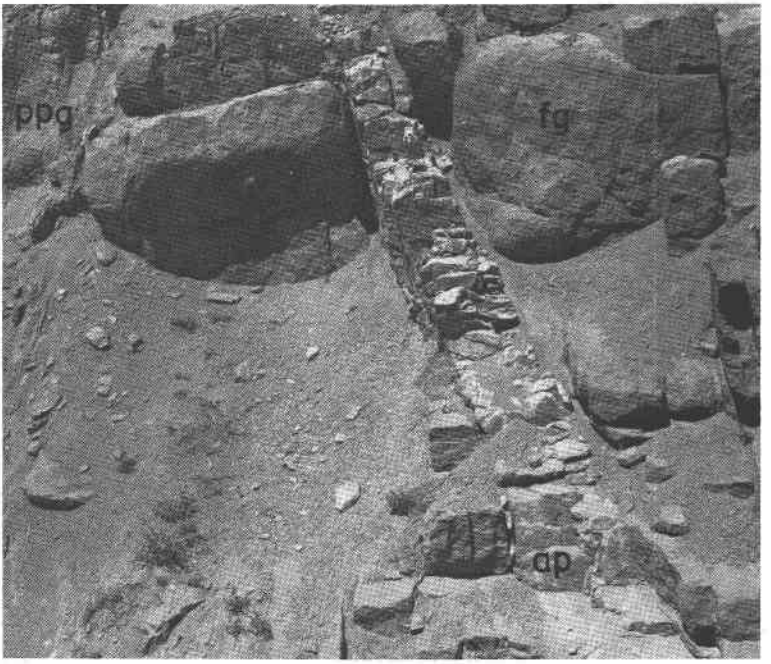

FIG. 3. Photograph showing rounded segregations of fayalite granite (fg) in weathered Pikes Peak granite (ppg), both cut by aplite dike (ap). Gold Camp Road.

granite and the fayalite granite have gradational contacts with the Pikes Peak and are not distinctly younger than it.

Small faults have been traced for a few thousand feet in the Pikes Peak granite. Along these the rock is brecciated and characterized by introduction of fine-grained quartz, barite, fluorite or chlorite. Most of the breccia zones are less than 10 feet wide and trend generally northwest, with conspicuous local departures from this trend along small minor transverse fractures. The major fault in the area, named the St. Peters fault zone (Boos, 1957), can be traced from Timberline tunnel at Rock Creek on the south to North Cheyenne Canyon. It strikes N. 55° E. and dips 56° SE. to 76° NW. Brecciation, silicification, chloritization, deposi-

tion of fluorite, or presence of a linear radioactive anomaly characterize fault or fractures zones in the granite.

Jointing is particularly widespread and conspicuous in the Pikes Peak granite on the north-facing slope along the ridge west of St. Peters Dome. The joints trend mainly north-northwest with a few minor sets trending northeast and south-southwest. Dips are steep to nearly vertical. A third set strikes northeast and has gentle dips. In the St. Peters Dome district,

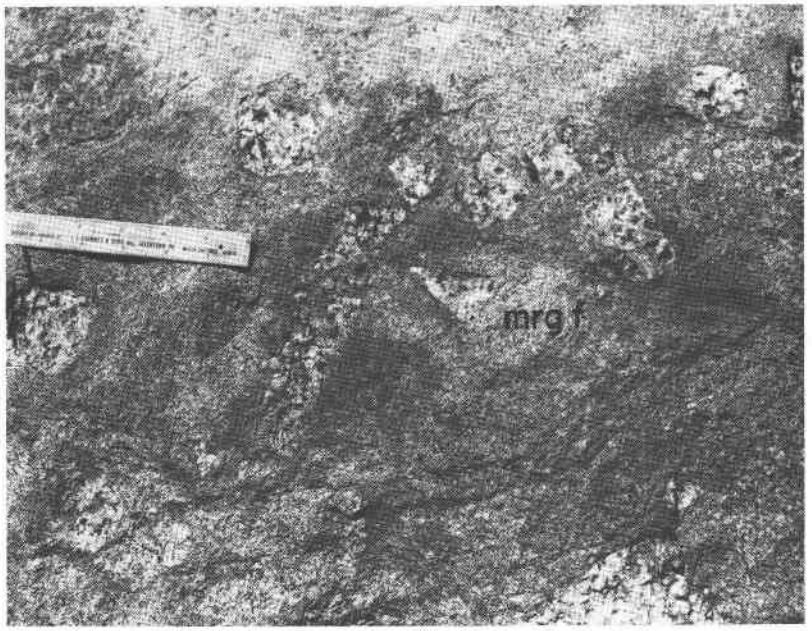

FIG. 4. Photograph showing xenoliths of Pikes Peak granite in fine-grained Mount Rosa granite. Summit Wye Road.

Stevens (1949, p. 268–269) distinguishes three sets of joints which he described as follows: "1) strike N. 40–50° W., dip between 80° S.W. and 80° N.E.,—contain aplite dikes; 2) strike N.-N.E., dip 35°–45° S.E., and W.-N.W., and dip 25°–35° S. or S.W.—contain pegmatites; 3) strike N. 40°–75° E., dip 80° N.W. and from 50°–75° N.W." According to Stevens, a massive granite, which trends northeast through the district, appears to form an arch-like structure with the joints dipping away from the "massive granite" core which appears to plunge gently southwest. Our mapping showed that this "massive granite" is one of the larger fayalite granite bodies (Fig. 2).

The jointing occurred in Precambrian time after the emplacement and

cooling of the Pikes Peak granite. The earliest northwest set of joints were filled in part with aplite dikes. The second set, which contains pegmatites, formed after the intrusion of Mount Rosa granite. Stevens (1949) states that the third set of joints, which strike northeast, are the youngest and do not contain dikes.

Petrology. The composition of the Pikes Peak granite is generally uniform except at some border areas where Hutchinson (1960) has identified four rock types—leucogranite, granite, quartz monzonite and granodiorite—all with gradational contacts. In the Mount Rosa area, which is near the eastern batholith margin, leucogranitic, granitic and granodioritic phases have been identified petrographically, but these rock types are difficult to distinguish in outcrops.

Typical Pikes Peak granite is a salmon-pink granular rock containing large crystals of pink microcline ranging from 10–22 mm, quartz grains 4 to 7 mm and scattered biotite flakes. Under the microscope the Pikes Peak granite appears as a medium-grained hypidiomorphic-granular igneous rock composed essentially of quartz, perthitic microcline, albite and biotite. A mode is given in Table 1.

The most abundant constituent is microcline-perthite, which displays all stages of replacement by oligoclase (Ab 84), from thin irregular veinlets to nearly complete removal with only "islands" of microcline remaining. Hematite dust included in the microcline produces the typical reddish hue of the rock.

Commonly quartz grains are embayed and may show overgrowths of second-generation quartz. The later quartz has partly replaced plagioclase and microcline.

Accessory minerals include one or more of the following: hornblende, chlorite, muscovite, zircon, apatite, magnetite, allanite and fluorite.

Subhedral grains of fluorite are closely associated with biotite and minor accessory minerals. Where present in unaltered granite, the fluorite appears to be primary (Lindgren and Ransome, 1906). Zircons occur in two forms: one as minute rounded grains in biotite showing a pleochroic halo; the other as small, clear, rectangular to square crystals that may show zoning, but where included in biotite have not produced halos. Minute yellow-brown grains of radioactive allanite are also present in biotite.

Few rare or unusual minerals have been found in the Pikes Peak granite. Allanite and, in one case only, bastnaesite, have been observed. The proportions of heavy minerals vary considerably among the various samples of Pikes Peak granite. Table 2 shows the heavy-minerals content of the various granites of the Mount Rosa area. In Table 3 heavy-mineral assemblages from other Front Range plutons are compared with those from the Pikes Peak granite. Although the cerium fluocarbonate, bastnaesite, is extremely rare in the Pikes Peak of the Mount Rosa area, bastnaesite in rare megascopic grains has recently been found by Adams and Young (1961) in Pikes Peak granite from Raleighs Peak area, Jeffer-

TABLE 1. MODES OF IGNEOUS ROCKS OF THE MOUNT ROSA AREA, INCLUDING WINDY POINT GRANITE

Mineral Field No.	ppg 15–1A	pg 72-2	gd 66-15	ap 71-10	fg 75-3	mrg 15-6	mrgf 38-7	wpg 44-3
Quartz	34.0	23.5	32.3	33.4	29.1	23.9	36.5	35.2
Micro-perthite	28.1	49.7	38.4	40.1	54.8	30.4	31.0	36.9
Anorthoclase	21.5							
Plagioclase	16.4	20.0	17.6	19.4	17.5	23.1	21.2	21.8
Biotite	0.3	6.8	11.3	7.1	7.0	—	—	6.1
Hornblende					Tr			
Riebeckite						22.6	10.3	
Fayalite					0.1			
Fluorite	Tr				0.1			0.3
Plagioclase	An16	An32			An22	An26	An26	An34
Johannsen No.	216P	226P			226P	226P	226″P	226P

Modes of samples at contact between Pikes Peak and fayalite granites

Mineral Field No.	ppg 75-5-1	2	fg 3	fg 4
Quartz	33.0	33.0	23.9	26.4
Micro-perthite	42.8	38.0	39.8	52.3
Plagioclase	19.2	28.0	27.1	14.8
Biotite	5.1	12.0	8.0	6.0
Hornblende	—	1.0	0.3	0.5
Fayalite	—	—	Tr	0.3
Magnetite	Tr	0.2	Tr	Tr
Fluorite	Tr	0.3	0.1	0.1
Plagioclase	An16	An18	An22	An22
Johannsen No.	126P	226″P	226″P	226P

Specimen Locations—Modes

15-1A Pikes Peak granite, Rosemont, Teller County.
72-2 Porphyritic granite, Bear Creek, 1½ miles east of Jones Park, Teller County.
66-15 Granitic dike, Near Wade cutoff, El Paso County.
71-10 Aplite dike, near Green Mountain settlement, El Paso County.
75-3 Fayalite granite, Gold Camp Road, El Paso County.
15-6 Mount Rosa granite, Rosemont, Teller County.
38-7 Mount Rosa granite (fine-grained), south of Stove Mountain, El Paso County.
44-3 Windy Point granite, Pikes Peak, Teller County.

75-5-1 Pikes Peak granite, Gold Camp Road, El Paso County.
75-5-2 Contact zone specimen.
75-5-3 Fayalite granite six inches from Pikes Peak granite.
75-5-4 Fayalite granite 12 inches from Pikes Peak granite.

TABLE 2 HEAVY MINERALS OCCURRING IN THE GRANITES OF THE MOUNT ROSA AREA

Minerals	ppg[1]	pg[2]	gd[3]	fg[4]	mrg[5]	mrgf[6]	wpg[7]
Allanite	x			x			
Anatase		x					x
Apatite	x			x			x
Astrophyllite					x	x	
Bastnaesite	x				x		
Biotite	x	x	x	x	x	x	x
Chlorite			x				x
Epidote				x			
Fayalite				x			
Fluorite	x	x	x	x	x	x	x
Hornblende				x			
Ilmenite	x						x
Magnetite	x	x	x	x	x	x	
Molybdenite	x						
Monazite					x		x
Muscovite		x	x				x
Pyrite		x					x
Pyrochlore					x		
Pyrrhotite							x
Riebeckite					x	x	
Rutile		x					x
Zircon	x	x	x	x	x	x	x

[1] ppg—Pikes Peak granite.
[2] pg—porphyritic granite.
[3] gd—granitic dike.
[4] fg—fayalite granite.
[5] mrg—Mount Rosa granite.
[6] mrgf—Mount Rosa granite (fine-grained).
[7] wpg—Windy Point granite.

son County, Colorado. They believe the bastnaesite has been formed from allanite by late magmatic solutions containing fluorine and carbon dioxide.

Chemical composition of analyzed specimens of Pikes Peak granite and other granites of the Mount Rosa area are shown in Table 4. Fluorine is present in small amounts in the Pikes Peak granite, in fluorite and in the very rare bastnaesite. Analysis A-11 (Table 4), which shows considerable departure from the composition of Pikes Peak granite, represents an aplite. A Harker diagram (as modified by Larsen) of the granites of the Mount Rosa area is presented in Fig. 5. The positions of the plots of the analyses suggest that the fayalite granite, Windy Point granite, and aplite dikes are genetically related to the Pikes Peak.

Porphyritic Granite

Distribution. With the porphyritic granite is included the fine-grained granite that has been correlated with the Cripple Creek granite by Finlay (1916). Outcrop areas of these porphyritic and fine-grained granites are elliptical to rounded, with a maximum size of 2,800 by 900 feet. Many are less than a thousand feet in length and a few hundred feet in width. Most of the exposures are in Sec. 24, T. 15 S., R. 68 W., along the Gold Camp Road, a mile east of Rosemont. A few small bodies occur also along South Cheyenne Creek in Sec. 4, T. 15 S., R. 67 W. Together, these granites comprise only a few tenths of a square mile of the total granitic outcrop area.

Porphyritic granite correlatives. In its general appearance the porphyritic granite is similar to some, but not all, of the Cripple Creek granite. Both rocks are medium-grained, containing widely scattered phenocrysts of feldspar and local aggregates of biotite; but the porphyritic granite is consistently porphyritic, whereas the Cripple Creek granite may be equigranular over large areas. However, field evidence shows that the

Table 3. Heavy Minerals Occurring in the Plutons of the Colorado Front Range

Minerals	Kenosha	Boulder Creek	Sherman	Pikes Peaks	Cripple Creek	Indian Creek	Silver Plume	Longs Peak
Allanite	x	x	x	x	x	x	x	x
Apatite	x	x	x	x	x	x	x	x
Bastnaesite				x				
Biotite	x	x	x	x	x	x	x	x
Chlorite								x
Epidote		x				x		x
Fluorite			x	x				x
Garnet	x							x
Hornblende		x	x	x				
Ilmenite	x	x	x	x	x	x	x	x
Magnetite	x	x	x	x	x	x	x	x
Molybdenite				x				
Monazite	x					x	x	
Muscovite		x	x	x				x
Pyrite						x	x	x
Tourmaline					x			x
Xenotime	x					x		
Zircon	x	x	x	x	x	x	x	x

Data after Phair (1954).
Data on Pikes Peak granite by Gross and Heinrich.

TABLE 4. ANALYSES AND NORMS OF IGNEOUS ROCKS OF THE MOUNT ROSA AREA

	A-7	A-11	FG	MRR	MRF	WP-2
SiO_2	77.03	77.31	72.00	73.82	73.22	75.17
Al_2O_3	12.00	12.45	13.50	10.59	10.93	12.66
FeO	.76	.43	1.30	2.18	3.94	1.23
Fe_2O_3	.86	.33	2.30	2.98	1.20	1.40
MgO	.04	Tr	.03	.04	—	.05
CaO	.80	.50	1.10	.28	.41	.83
Na_2O	3.21	4.72	4.30	4.20	3.63	2.88
K_2O	4.92	3.84	5.00	4.57	4.59	5.75
H_2O^+	.30	.40	.43	.49	.99	.62
H_2O^-	.14	.42		.39	.89	.16
TiO_2	.13	.06	.28	.13	.22	.10
P_2O_5	Tr		.11			.03
MnO	Tr	.01	.03	.02	.03	Tr
BaO	Tr					.03
F	.36	.15	.39	.06	.10	.31
Total	100.55	100.62	100.38	99.75	100.13	100.26
			Norms			
Q	37.68	34.98	25.71	30.72	34.28	33.18
or	28.91	22.24	29.50	27.74	27.24	34.47
ab	26.72	39.82	36.17	28.82	30.39	24.63
an	3.89	1.39	13.60	—	—	3.89
hy	.10	.13		4.72		2.34
di				.75		
C		.10				.10
mt	2.32	.70	1.85	.23	3.25	.23
il	.30	.15	6.07	.30	.46	.15
fa			2.17			
fr			.61			
hm		.31				
ac				6.01		
wo					.81	
zr					1.76	

Specimen Location

A-7 Pikes Peak granite, Sentinel Point, Teller County, W. F. Hillebrand, Analyst. Clarke and Hillebrand, 1897.

A-11 Granitic-aplitic dike. Duffields, El Paso County, George Steiger, Analyst. Clarke, 1910.

FG Fayalite granite, (75-3) Gold Camp Road, El Paso County, Matti Tavela, Analyst. 1963.

MRR Mount Rosa granite, Rosemont, Teller County, G. Steiger, Analyst. Clarke, 1910.

MRF Mount Rosa granite (fine grained), Fairview station on Gold Camp Road, El Paso County, G. Steiger, Analyst. Clarke, 1910.

WP-2 Windy Point granite, near Windy Point on cog road, Teller County, W. F. Hillebrand, Analyst. Mathews, 1900.

Cripple Creek granite intrudes the Pikes Peak, whereas the porphyritic granite grades into Pikes Peak. Mineralogically, the rocks are dissimilar. Microcline-perthite is the common feldspar of the porphyritic granite, whereas orthoclase is common in the Cripple Creek granite.

Structure. In Sec. 24, T. 15 S., R. 68 W., adjacent to the Gold Camp Road, a prospect pit exposes a gradational contact less than a foot wide between porphyritic and Pikes Peak granite. Several of the porphyritic granite bodies closely associated with the fayalite granite usually lie above the fayalite granite.

The porphyritic granite is conspicuously joined, with the predominant joint-plane sets striking between N. 70° to 80° W., dipping 70° NE., N. 10° to 15° W., dipping 78° W. and N. 70° to 85° E., dipping 87° NW.

Petrology. The rock is a light-gray porphyritic granite with phenocrysts of feldspar and quartz in a fine-grained groundmass of quartz, feldspar and biotite. An average spacing of 2.5 cm between phenocrysts makes the weathered surface look knobby.

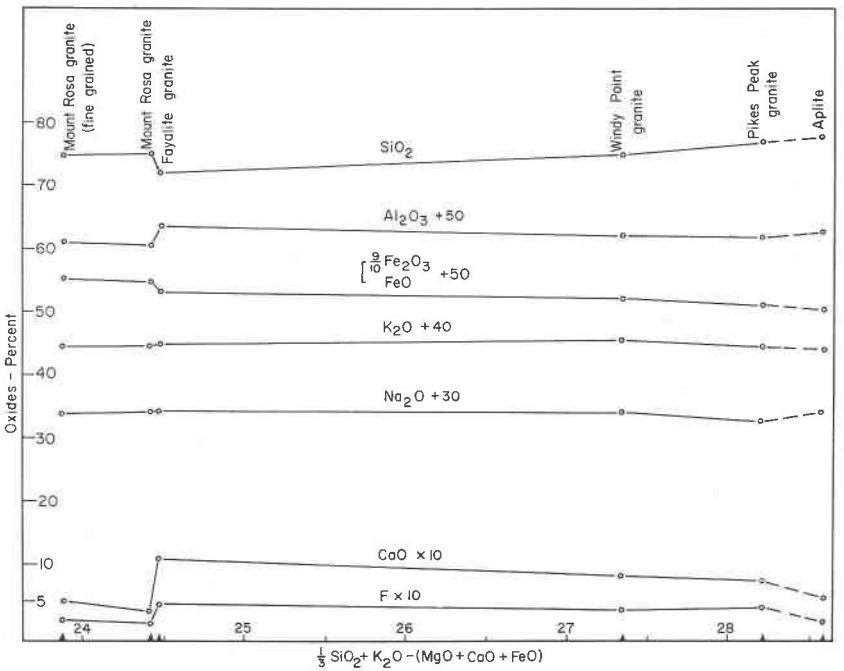

FIG. 5. Larsen plot of analyses of igneous rocks, Mount Rosa area, Colorado.

FIG. 6. Photograph of granitic dike (gd) transecting Pikes Peak (ppg) and fayalite granites (fg). Gold Camp Road.

Under the microscope the texture appears medium-grained, hypidiomorphic-granular, with phenocrysts 1 to 10 mm in a matrix of smaller grains 0.4 to 0.6 mm. The essential minerals are quartz, microcline-perthite, plagioclase and biotite. Accessories include zircon, apatite, magnetite, anatase and pyrite. Hematite, muscovite and chlorite occur as alteration products of biotite. A mode is given in Table 1.

The variants are mineralogically similar to the porphyritic phase. One such occurrence, mapped as Cripple Creek by Finlay (1916) in Sec. 34, T. 15 S., R. 68 W., is medium-grained, nonporphyritic, hypidiomorphic-granular, and is composed of quartz, plagioclase, microcline-perthite, and clots of small flakes of red-brown biotite. Muscovite and apatite are rare. Some of the biotite has altered to chlorite.

Accessory minerals in the porphyritic granite are similar (Table 2) to those in the Windy Point granite—zircon, magnetite, anatase, fluorite, and pyrite. Probably a chemical analysis of this granite would plot close to the Windy Point on the Larsen diagram (Fig. 5).

GRANITIC DIKES

Distribution. A number of medium-grained granitic dikes intrude Pikes Peak granite, chiefly in the St. Peters Dome district (Fig. 6). They are more resistant to erosion than their host and crop out as sharp ridges. Most are fractured and silicified and range in thickness from 2 to 13 feet.

Generally their outcrops can be traced for less than 1,000 feet. Most strike northwesterly and dip steeply.

The dikes are medium-grained, with grain sizes ranging from 0.5 to 5.0 mm, partly silicified, and show thin milky quartz veinlets along subparallel fractures.

The hypidiomorphic-granular rocks contain essential quartz, microcline, plagioclase and biotite and accessory zircon, apatite, allanite, fluorite, magnetite and anatase (Table 5).

The dikes have been intruded into both the Pikes Peak and fayalite granites.

Mineral composition of the granitic dikes is similar to that of the porphyritic granite. Their essential minerals are similar and the accessory minerals are identical. Structurally the granitic dikes conform in orienta-

TABLE 5. ABSOLUTE AGE DETERMINATIONS OF PRECAMBRIAN GRANITES OF THE MOUNT ROSA AREA, INCLUDING OTHER PIKES PEAK AGES, EL PASO, TELLER AND DOUGLAS COUNTIES, COLORADO

I. Helium method vs radiation damage-zircon
Pikes Peak granite (990 m.y.), St. Peters Dome, El Paso County, Hurley, 1954.

II. Alpha count-isotope lead method—zircon
Mount Rosa granite (1110 ± 125 m.y.), $\frac{3}{4}$ mile northeast of Rosemont, Teller County, Stern, 1961.

III. Potassium-argon isotope method—riebeckite
Mount Rosa granite (1040 m.y.), northeast of Rosemont, Teller County, Hart, 1961.
Potassium-argon isotope method—biotite
Mount Rosa granite (1020 m.y.), Teller County, Hutchinson, 1960.
Other ages near Pikes Peak

III. Potassium-argon isotope method—biotite, Hutchinson
Pikes Peak granite (1080) m.y., Douglas County
Pikes Peak granodiorite (1050 m.y.), Douglas County
Pikes Peak granite (1050 m.y.), Douglas County
*Pikes Peak granite (1030 m.y.), El Paso County
*Pikes Peak granite (1010 m.y.), El Paso County
Windy Point granite (1060 m.y.), Summit of Pikes Peak
*Windy Point granite (980 m.y.) Summit of Pikes Peak

IV. Isotope lead method—zircon Pb^{206}/Pb^{206}
Pikes Peak granite (980 m.y.), near Manitou Springs, El Paso County, Tilton *et al.*, 1957.

V. Rubidium-strontium isotope method—biotite
Pikes Peak granite (1020 m.y.), near Manitou Springs, El Paso County, Aldrich *et al.*, 1957.
Windy Point granite (1080 m.y.), Summit of Pikes Peak, El Paso County, Aldrich *et al.*, 1957.

* Griffin and Kulp, 1961.

tion to Stevens' (1949) northwesterly-trending joint set, which he believes were the earliest joints to form.

Aplitic Dikes

Many widely scattered dikes of aplite are exposed within the Mount Rosa area. They range in thickness from 3 to 40 feet but average 15 feet, and can be traced for less than a thousand feet. A few occur as irregular masses with subordinate pegmatitic phases. The largest body, exposed 3 miles northeast of Rosemont, adjacent to the Summit Wye Road on the northeast-facing slope of Mount Rosa, is surrounded by Mount Rosa granite and is probably a fenster. A vertical aplite dike, 4 feet thick and 1,500 feet long, crops out at Duffield on the Gold Camp Road. It strikes N. 40° W. and transects both Pikes Peak and fayalite granites. Another aplite of similar size on North Cheyenne Creek trail southwest of Kineo Mountain is 25 feet thick, can be traced for 1,000 feet, and strikes N. 53° W. It contains small lenses of pegmatite.

Most of the aplites trend northwest, with steep dips southwest. A few have a northeasterly strike. These are the aplites that are confined to the early joint set of Stevens (1949).

Under the microscope the aplite shows essential anhedral quartz, microcline, plagioclase and biotite, with minor accessories zircon, muscovite and fluorite. Nearly all of the grains are less than a millimeter in diameter. Most of the microcline has been partly replaced by oligoclase (Ab 84). Uncommon zircon and fluorite are present in small anhedral grains associated with biotite. A mode is given in Table 1.

A chemical analysis of the Duffield aplite has been given by Finlay (1916) who correlated it with the Cripple Creek granite (Table 4). However, its mineralogy, texture and attitude suggest a closer relation to the granitic dikes of Pikes Peak affinity.

Fayalite Granite

Distribution. Dark greenish-gray medium-grained fayalite granite occurs primarily within the Pikes Peak granite in ellipsoidal bodies. A few also occur associated with Mount Rosa granite two miles northeast of Mount Rosa. The masses of fayalite granite range from a few feet in diameter to large lenticular bodies 1,000 feet wide and 2,700 feet long. Most are less than 100 feet wide and several hundred feet long. We estimate that the total of fayalite granite is not more than one percent of the total volume of the Pikes Peak pluton in the Mount Rosa area.

Numerous smaller bodies of fayalite granite occur in the pegmatite swarm area of the St. Peters Dome district and along the Gold Camp Road from Devils Slide to Bruin Inn. A large body and two smaller ones

two miles northeast of Mount Rosa are extensively stained by hematite. These bodies, which are associated with Mount Rosa granite, show brecciation in part and hematitic alteration along a fault zone.

Outside of the Mount Rosa area only one body of fayalite granite was noted. It is exposed in a roadcut on Colorado State Highway 67 approximately 6.2 miles south of Deckers, Colorado, as an elongate body about 400 feet wide and 800 feet long and trending N. 20° W. The mineralogy of this fayalite granite is very similar to that of those further south, except for the presence of augite in the northern one.

The fayalite granite occurs primarily within the Pikes Peak granite with which it has gradational contacts. At one contact zone in a cut on the Gold Camp Road, the change from typical granite to fayalite granite takes place in less than a foot. Modes of four samples across the contact are given in Table 1. These show that as quartz and microcline-perthite decrease from the Pikes Peak to the fayalite granite, mafic minerals increase. Fayalite occurs only in the specimen low in quartz.

At Devils Slide, fayalite granite is in gradational but faulted contact with porphyritic granite. A zone 30 inches wide between the two granites is bleached and the fayalite granite is shattered.

Fayalite granite bodies along a ridge northeast of Mount Rosa are exposed in contact with Mount Rosa granite. The fayalite granite is altered and in part brecciated along a fault. Contact relations between the two granites are obscured due to alteration. Where Mount Rosa-type pegmatites cut fayalite granite, a 3- to 6-inch-thick aplitic border zone composed of quartz, microcline, zircon and abundant astrophyllite is commonly present.

Petrology. The fayalite granite is a medium-grained, dark olive-green rock that forms resistant rounded outcrops resulting from spalling of shell-like exfoliated slabs. Scattered one-centimeter or larger crystals of greenish feldspar occur among smaller grains of quartz and biotite less than a centimeter in diameter. Quartz grains of greenish tint are clustered, but appear sparsely among feldspar, which gives the megascopic impression that the rock is a syenite. Biotite forms flakes 1 to 4 millimeters in diameter.

The fayalite granite is a hypidiomorphic-granular rock composed of essential quartz, antiperthite, microcline-perthite, plagioclase, biotite and fayalite. The accessories include allanite, zircon, apatite, pyroxene, amphibole and fluorite. Chlorite, calcite, hematite and antigorite are alteration products. Grain size of the minerals ranges from 0.4 mm to 4 mm.

Microcline, the dominant feldspar, is perthitized to varying degrees by sodic oligoclase in irregular veinlets. This oligoclase occurs in small interstitial grains penetrating microperthite and is closely associated with quartz, some of which shows corrosion in contact with replacement perthite.

Dark-brown biotite, the chief mafic mineral, usually includes allanite and zircon, both with radioactive halos. Other species in biotite are fayalite, apatite and magnetite. Much of the biotite occurs in mafic clusters with fayalite and accessory minerals. Locally a green hornblende is associated with biotite. Uncommonly, a reaction rim bordering fayalite includes a pale-green sodic pyroxene, a blue sodic amphibole (riebeckite), and where adjacent to microcline-perthite, a red-brown biotite.

Fayalite, in subhedral to anhedral fractured grains, displays varying stages of alteration to hematite, antigorite and calcite, and locally chlorite and magnetite. Yoder and Sahama (1957) determined the percent Fo, applying the value of d_{130} line in equation $4233.91 - 1494.59\ d_{130} = \text{Fo mole}\%$. Calculations in which $d_{130} = 2.823$ and $d_{130} = 2.816$ were used for fayalites from Mount Rosa area give a value of 14.68% Fo.

Red-brown anhedral grains of allanite are bordered by radially fractured quartz. Allanite is more abundant in fayalite granite than in the other granites.

There is considerably more biotite and fluorite in the fayalite granite than in Pikes Peak granite (Table 2), and the marked increase in allanite was not indicated by radiometric results.

Origin. Fayalite granite occurs in spheroidal to ellipsoidal bodies texturally similar to the Pikes Peak granite. The mineralogy of the fayalite granite is similar to that of the Pikes Peak, except for an increase in abundance of the accessory minerals and the appearance of fayalite.

The following structural relations indicate that the fayalite granite bodies are pene-contemporaneous segregations rather than post-consolidation dike-like differentiates of the Pikes Peak granite or xenolith remnants of an older granite.

1. Contacts between the fayalite granite and Pikes Peak granite are invariably gradational.
2. In small bodies of fayalite granite, the lower contact is visible and gradational; the larger bodies may also be bottomed at shallow depths.
3. No chilled margins occur against Pikes Peak granite.
4. No cross-cutting relations with Pikes Peak granite are apparent.

Mount Rosa Granite

Distribution. Small bodies of riebeckite granite, exposed on the side of Mount Rosa near Rosemont, were mapped as a separate unit by Finlay (1916), who called the rock the Mount Rosa granite. The bodies are in the form of several small irregular sheets. The largest, which is $2\frac{1}{2}$ miles long and a mile wide, is $\frac{1}{2}$ mile northeast of Rosemont (Fig. 2). A smaller body 1,000 feet wide can be traced for 2 miles from Rosemont westward to Eagle Rock Campground. The sheets range in thickness from 12 to 150 feet, with an average of about 50 feet.

A fine-grained phase occurs as small dikes also cutting the Pikes Peak granite. One crops out on the Summit Wye Road $\frac{3}{4}$ mile northeast of Rosemont, and two narrow elongate dikes occur on the southeast-facing

slope near Stove Mountain. At Fairview and a half mile south of it adjacent to the Gold Camp Road are scattered many small irregular dikes of the fine-grained type, which can be traced only for a few hundred feet. The total areal extent of Mount Rosa granite does not exceed 4 square miles.

Structure. Only rarely, in a prospect pit or on a cliff face, are contacts exposed between the Pikes Peak granite and the riebeckite granite or its fine-grained equivalent. The Mount Rosa granite shows a 1- to 3-cm chilled and bleached marginal band adjacent to Pikes Peak granite. Locally, apparently unmodified xenoliths of Pikes Peak are included in fine-grained Mount Rosa. No contact relations have been observed between Mount Rosa granite and either fayalite granite or porphyritic granite.

At the contact with Pikes Peak granite the alkalic granite is fine-grained and granulated.

Locally a weak lineation produced by the alignment of astrophyllite or riebeckite appears in the fine-grained riebeckite granite.

Petrology. The Mount Rosa granite is a light-gray medium-grained equigranular rock composed of quartz, feldspar and blue-black riebeckite. The amphibole occurs in jagged rosettes, which give the rock a mottled appearance. On some fresh surfaces astrophyllite appears as golden blades (Fig. 7).

In thin section, the medium-grained phase appears as a hypidiomorphic granular rock with grains ranging in size from 0.2 to 4 mm. It is composed essentially of microcline-perthite, quartz, plagioclase (Ab 74), and riebeckite. Accessory minerals include aegirine, sodic hornblende, biotite, zircon, ilmenorutile, pyrochlore, monazite, bastnaesite, astrophyllite, chlorite, muscovite, magnetite, fluorite pyrite and hematite.

Microcline-perthite crystals ranging in size from 0.6 to 4.0 mm appear in all stages of replacement by oligoclase (Ab 84). A poikilitic texture is common between microcline-perthite and quartz.

Riebeckite forming small elongate prisms with irregular borders alters to red-brown biotite and magnetite. Astrophyllite showing strongly pleochroic colors from lemon yellow to bright red-orange occurs closely associated with riebeckite and red-brown biotite; the micaceous plates of astrophyllite are embayed and show sinuous contacts with quartz and feldspar. Alteration of astrophyllite produces a milky-white clay-like material. Aegirine in short prisms is rimmed and replaced by riebeckite.

Pyrochlore, monazite and bastnaesite in small grains associated with the mafic minerals were identified by *x*-ray powder methods. Anhedral fluorite is less common than in the Pikes Peak and Windy Point granites.

The fine-grained phase contains minerals that are less than 1 mm in section. Aggregates of small grains of quartz and plagioclase surround larger feldspar crystals. Poikilitic development of biotite, riebeckite and microcline with quartz is common. The fine-grained type has less microcline-perthite than the normal Mount Rosa granite (Table 1).

The Mount Rosa alkalic granite is, of all the granites in the area, the most complex mineralogically. Although a careful search in thin sections was made for rare fluorides such as cryolite and thomsenolite, recognized in Nigerian riebeckite granites by Jacobson *et al.* (1958), none were observed.

Windy Point Granite

Extent and distribution. The principal occurrences of Windy Point

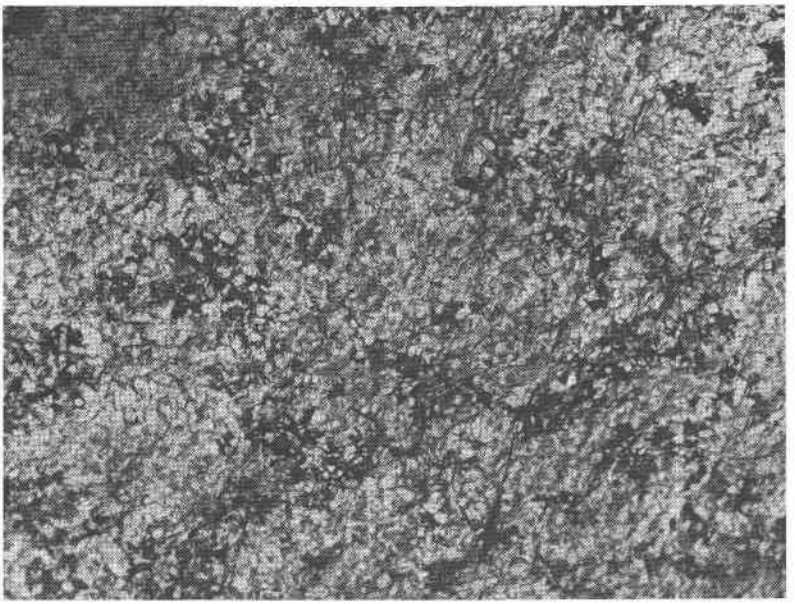

Fig. 7. Photograph of Mount Rosa granite showing clusters of riebeckite (black). Teller County.

granite comprise the summit of Pikes Peak and seven smaller bodies on the ridge southeast to Windy Point along the cogroad to Manitou. All the outcrops are above 11,800 feet.

Intrusive bodies that have been correlated with the Windy Point granite crop out near Crystal Park, a few miles southwest of Manitou, and two other small outcrops about 5 miles northeast of Woodland Park (Boos, 1957). However, Finlay (1916) has designated the Crystal Park granite body as the Cripple Creek type.

Petrology. The fresh granite is a lavender-gray, medium-grained, porphyritic rock containing feldspar phenocrysts and scattered biotite clus-

ters. The matrix contains quartz, feldspar, biotite, and scattered minute grains of iron sulfide and fluorite. The fluorite imparts the lavender tint.

Under the microscope the granite is seen as a hypidiomorphic-granular, medium-grained igneous rock with grains ranging in size from 4.4 to 0.8 mm. It is composed essentially of quartz, microcline, perthite, plagioclase and biotite. Accessory minerals include zircon, anatase, pyrite and pyrrhotite.

Poikilitic intergrowths of quartz in feldspar or biotite are common. Myrmekitic development of quartz and feldspar may be present where the contacts between larger grains of microcline-perthite with quartz or plagioclase are irregular and embayed. The plagioclase (Ab 64), more calcic than that of the porphyritic granite, is commonly altered to sericite and minor calcite. The replacement plagioclase of the microcline-perthite is oligoclase (Ab 84).

Blue-black anatase crystals were identified from heavy residues by powder x-ray diffraction. Euhedral pyrrhotite crystals, about 0.3 mm in diameter, display the forms (0001), $(10\bar{1}2)$, and $(20\bar{2}1)$.

A chemical analysis and norm are given in Table 4. The Larsen plot from chemical analysis of Windy Point granite is shown in Fig. 5. The mode is given in Table 1. The Windy Point granite has chemical similarities to the Pikes Peak.

Ages

The sequence of granites in the Mount Rosa area is: 1) Pikes Peak granite, 2) porphyritic granite, granitic dikes and aplites, 3) fayalite granite, and 4) Mount Rosa granite. The Windy Point granite is mineralogically similar to the porphyritic granite. The above sequence is suggested from field and laboratory studies.

Absolute age determinations of the granitic rocks of the Mount Rosa area are listed in Table 5, along with other age results for the Pikes Peak granite.

Seven age determinations on Pikes Peak granite, four on the Mount Rosa granite, and three on Windy Point granite, all of which fall within the range of 1010 to 1080 m.y., strongly support the comagmatic character of these granites. The suggestion by Lovering and Goddard (1950) that the Windy Point granite is Tertiary in age is not supported.

Discussion

The four main granites in the area are closely related in time and are, we believe, part of a comagmatic series, in which the sequence as we have been able to define it from field relationships and compositional variation trends is:

Oldest 1. Pikes Peak granite and porphyritic granite
2. Fayalite granite

3. Granitic, aplitic and pegmatitic dikes of Pikes Peak derivation
4. Windy Point granite
5. Mt. Rosa granite

Youngest 6. Mt. Rosa pegmatites

There are no contacts between the Windy Point and the Mt. Rosa granites, and thus their ages relative to each other cannot be demonstrated exactly. However, the Mt. Rosa is more strongly alkalic, has the largest and most varied concentration of accessory species and is accompanied by a swarm of complex alkalic pegmatities[1]—all suggesting that it represents the last differentiate. The Mt. Rosa granite also is the most radioactive of the group, and it has been demonstrated that in both alkalic and calc-alkalic consanguineous series the youngest differentiate is the most radioactive (Heinrich, 1958, p. 174).

Fayalite granites and related rocks are rare; some of the better described examples include:

1. Rockport, Mass.—"a fayalite-bearing nordmarkite granite" and its cogenetic pegmatites (Palache, 1950), older than, and intruded by, the Rockport granite. Considered to be closely allied to the White Mountain magma series (Greenwood, 1951).
2. Younger Granite province of Northern Nigeria—a quartz-fayalite-hedenbergite porphyry and hornblende-fayalite granites. Jacobson *et al.* (1958) comment (p. 26–27) " . . . it is certain that the low magnesia content of the Younger Granite magma was an important factor controlling the crystallization of the fayalite and hedenbergite."
3. The Assorutit Syenite, Tugtutôq, South Greenland (Upton, 1964). Actually a quartz syenite; the mafics are fayalite, several Fe-rich pyroxenes, hornblende, riebeckite, grunerite and biotite. Similar quartz syenites occur in the Kûngnât intrusion.
4. The granite of Monte Mulat near Predazzo, Valle di Fassa, Italy. Contains fayalite and accessory fergusonite (Emiliani and Balzani, 1962).

In addition to its presence as a constituent of late-crystallizing granitic and quartz-syenitic igneous fractions (particularly in those in which Na is present in larger amounts than K), fayalite also occurs, not rarely, as a mineral of lithophysae in rhyolites and obsidians, together with tridymite. The composition of the fayalite-tridymite-albite eutectic (980° C.)

[1] The subject of the next paper in this series.

in the system $NaAlSiO_4$-FeO-SiO_2 (Bowen and Schairer, 1938) approximates the composition of some fayalite-bearing rhyolites.

The occurrence of fayalite in the fayalite granite derivative of the Pikes Peak granite is but another example of the late concentration of Fe^{2+} in crystallizing granitic magmas. Its reaction to form sodic pyroxene, sodic amphibole and locally biotite is in agreement with the scheme of the discontinuous reaction series of the ferromagnesian minerals as developed by Upton (1964, p. 46) for the Assorutit quartz syenite.

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References

Adams, J. W. and E. J. Young (1961) Accessory bastnaesite in the Pikes Peak granite Colorado. *U. S. Geol. Survey. Prof. Paper* **424C,** C293.

Aldrich, L. T., G. W. Wetherill and G. L. Davis (1957) Occurrence of 1350 million-year old granitic rocks in western United States. *Geol. Soc. Am. Bull.* **68,** 655–656.

Boos, M. F. and C. M. Boos (1957) Tectonics of eastern flank and foothills of Front Range, Colorado. *Am. Assoc. Petrol. Geol. Bull.* **41,** 2603–2676.

Bowen, N. L. and J. F. Schairer (1938) Crystallization equilibrium in nepheline-albite-silica mixtures with fayalite. *Jour. Geol.* **46,** 397.

Buddington, A. F. (1959) Granite emplacement with special reference to North America. *Geol. Soc. Am. Bull.* **70,** 671–747.

Cross, Whitman (1894) Pikes Peak, Colorado. *U. S. Geol. Survey Geol. Atlas, Folio* **7.**

——— and W. F. Hillebrand (1883) On minerals of the cryolite group recently found in Colorado. *Am. Jour. Sci.* 3rd. ser. **26,** 271–294.

Emiliani, F. and G. C. V. Balzani (1962) Sulla presenza di fayalite e fergusonite nel granito di Monte Mulat presso Predazzo (Valle di Fassa). *Accad. Naz. Lincei. Fasc.* 1, *Ser. VIII,* **32,** 112–115.

Finlay, G. I. (1916) Colorado Springs, Colorado. *U. S. Geol. Survey Geol. Atlas, Folio* **203.**

Greenwood, Robert (1951) Younger intrusive rocks of Plateau Province, Nigeria, compared with the alkalic rocks of New England. *Geol. Soc. Am. Bull.* **62,** 1151–1178.

Griffin, C. E. and J. L. Kulp (1960) Potassium-argon ages in the Precambrian basement of Colorado. *Geol. Soc. Am. Bull.* **71,** 219–222.

Hart, S. R. (1961) pers. comm.

HEINRICH, E. WM. (1958) *Mineralogy and Geology of Radioactive Raw Materials*. McGraw-Hill Book Co., N.Y.

HURLEY, P. M. (1954) Helium age method and distribution and migration of helium in rocks. *Nuclear Geology*, Ed. Faul, John Wiley & Sons, Inc., New York, 301–329.

HUTCHINSON, R. M. (1960) Structure and petrology of north end of Pikes Peak batholith, Colorado. *Guidebook to the Geology of Colorado*. Rocky Mountain Assoc. Geol., 170–180.

JACOBSON, R. R. E., W. N. MACLEOD AND RUSSEL BLACK (1958) Ring complexes in the Younger Granite province of Northern Nigeria. *Geol. Soc. London Mem.* **1,** 1–72.

JOHANNSEN, ALBERT (1939) *Petrology of Igneous Rocks, vol. 1.* Univ. of Chicago Press, 141–158.

LINDGREN, WALDEMAR AND F. L. RANSOME (1906) Geology and ore deposits of the Cripple Creek district, Colorado. *U. S. Geol. Survey Prof. Paper* **54.**

LOVERING, T. S. AND E. N. GODDARD (1950) Geology and ore deposits of the Front Range, Colorado. *U. S. Geol. Survey Prof. Paper* **223,** 52–56, 74.

MATHEWS, E. B. (1900) The granitic rocks of the Pikes Peak quadrangle. *Jour. Geol.* **8,** 214–220.

PALACHE, CHARLES (1950) Fayalite at Rockport, Massachusetts. *Am. Mineral.* **35,** 877–881.

PHAIR, GEORGE (1954) Precambrian granite rocks of the Colorado Front Range. *U. S. Geol. Survey Trace Elements Invest. Rept.* **540,** 241–244.

STERN, T. W. (1961) pers. comm.

STEVENS, T. A. (1949) The fluorspar deposits of the St. Peters Dome district, El Paso County, Colorado. *Colo. Sci. Soc. Proc.* **15,** 259–282.

TILTON, G. R., G. L. DAVIS, G. W. WETHERILL AND L. T. ALDRICH (1957) Isotopic ages of zircons from granites and pegmatites. *Am. Geophys. Union Trans.* **38,** 360–371.

UPTON, B. G. J. (1964) The geology of Tugtutôq and neighbouring islands, South Greenland. Part II Nordmarkitic syenites and related alkaline rocks. *Med. Grønland* **169** (2).

YODER, H. S. AND TH. G. SAHAMA (1957) Olivine *x*-ray determination curve. *Am. Mineral.* **42,** 475–495.

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