

Geologic and Aeromagnetic Maps of the Fossil Ridge Area and Vicinity, Gunnison County, Colorado

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Pamphlet

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Description of Map Units

Qu Alluvial and glacial deposits, undivided (Holocene and Pleistocene)

Alluvium, colluvium, talus, and landslide deposits (Holocene); rock glaciers, till, glacial outwash, ground moraine, and lateral moraine (Pleistocene). Alluvium most widespread in Union Park and along Quartz Creek near Pitkin. Talus common in most steep-walled valleys where it mantles glacial deposits. Probable landslide deposits in Belden Formation south of Pitkin.

Glacial material of Pinedale and Bull Lake ages, undivided. Rock glaciers most numerous in high cirques north of Fairview Peak at the head of Lottis Creek, in cirques west of South Lottis Creek, and in cirques surrounding Henry Mountain at the heads of Gold and Crystal Creeks. Till and glacial outwash particularly abundant south of Tincup along Willow Creek, southeast of Fairview Peak along Halls Gulch, in upper reaches of Crystal Creek, and upper reaches of South Lottis Creek and Lottis Creek. Ground moraine abundant along northwest edge of Fossil Ridge and in upper reaches of Crystal Creek. Lateral moraine well developed along South Lottis Creek, upper reaches of Lottis Creek and Willow Creek, and east of Pitkin along South and Middle Quartz Creeks.

Refer to Zech (1988) for distribution of all deposits in area between southwestern end of Fossil Ridge and Taylor River. Minor deposits not shown. Thickness 0–65 m

Ts Gravel and alluvial deposits (Pliocene and Miocene?)

Well-rounded, poorly consolidated gravel deposits and minor alluvial material south of Taylor River in northwest part of area, and along Beaver and East Beaver Creeks in southwestern part of area. May be related to an ancestral Taylor River or may be equivalent to Dry Union Formation (Tweto and others, 1976). Thickness 0–15 m. Deposits on south side of Lottis Creek in Union Park may correlate with Dry Union Formation farther north in Taylor Park (Tweto and others, 1976)

Tr Rhyolite dikes, sills, and stocks (Oligocene)

Light-tan to gray, fine-grained, porphyritic alkali rhyolite to rhyolite (classification of De la Roche and others, 1980, used for all igneous rock types, except where noted). Includes rhyolite porphyry (Crawford and Worcester, 1916; Zech, 1988) and rhyolite (DeWitt and others, 1985) in Quartz Creek area, Neolean quartz monzonite porphyry (Whitebread, 1951) and quartz latite porphyry (Herald, 1981; Daly, 1983) in Chicago Park area, part of unit called andesite (DeWitt and others, 1985) in the Chicago Park area, and parts of the Tincup Quartz Monzonite Porphyry (Dings and Robinson, 1957) in the Cumberland Pass area and the area immediately north of Tincup. Also includes fine quartz porphyry (unit Tt₂), euhedral

quartz porphyry (unit Tt₃), coarse quartz porphyry (unit Tt₄), and white, square quartz porphyry (unit Tt₅) of Rosenlund (1984) in the Cumberland Pass area, and fine-grained plagioclase porphyry (unit Tt_{fp} of Jefferson, 1985) and alkali feldspar aplite (unit Tafa of Jefferson, 1985) in the area west of Tincup.

Stock southwest of Cumberland Pass (unit Tqcg, Rosenlund, 1984) included in unit although texture is medium grained, equigranular. Small plugs are exposed along Gold Creek near Hills Gulch and south of its confluence with Comanche Gulch. Two plugs, inferred from subcrop, are covered by glacial debris in upper drainage of Crystal Creek. Dikes are widespread, but locally concentrated near Quartz Dome and north toward the plug in Gold Creek, and along and northwest of the Boulder fault, especially near Mill Lake. Sills in Chicago Park north of Pitkin and south of Halls Gulch intrude Belden Formation and Leadville Limestone.

Groundmass of light-gray to tan, very fine grained (10–20 μm), equant quartz, albite, and orthoclase that contains 20–50-μm-diameter sericite-rich patches and minor calcite-rich patches. Microphenocrysts (30–40 μm long) of rounded to subhedral, clear, strongly embayed and unembayed quartz grains common. Glomerocrysts and phenocrysts of 0.2–2-mm-long, clear, subhedral to rounded, but unembayed quartz grains and 0.2–8-mm-long turbid to extremely altered plagioclase or oligoclase(?) grains. Glomerocrysts and phenocrysts of plagioclase commonly completely altered to mat of fine-grained sericite and disseminated opaque minerals. Minor phenocrysts of 0.1–1-mm-diameter biotite(?) completely altered to chlorite, ilmenite(?), and rutile(?). Phenocrysts much more altered than groundmass. Accessory apatite and zircon common. Anatase noted as low temperature alteration product of rutile. Sills in Chicago Park have groundmass of oligoclase and quartz and minor apatite, magnetite, and other opaque minerals. Phenocrysts in those sills are oligoclase partly altered to sericite and clay minerals, embayed quartz, biotite replaced by chlorite and epidote, and very minor hornblende.

Average modal composition of dikes and plugs near Mill Lake, in Gold Creek, and in the upper reaches of Crystal Creek: 65% groundmass of albite (50%), quartz (35%), and orthoclase (15%); 35% phenocrysts of plagioclase altered to sericite (60%), quartz (30%), biotite(?) altered to chlorite, rutile, and ilmenite (8%), and opaque grains (2%).

The fresh dikes, sills, and stocks in the Quartz Creek and Crystal Creek drainages are alkali rhyolite and are alkali-calcic (fig. 1A). All rocks are moderately to strongly peraluminous (fig. 1B), sodic (fig. 1C), and have no appreciable Fe enrichment (fig. 1D). Altered and mineralized rhyolite are depleted

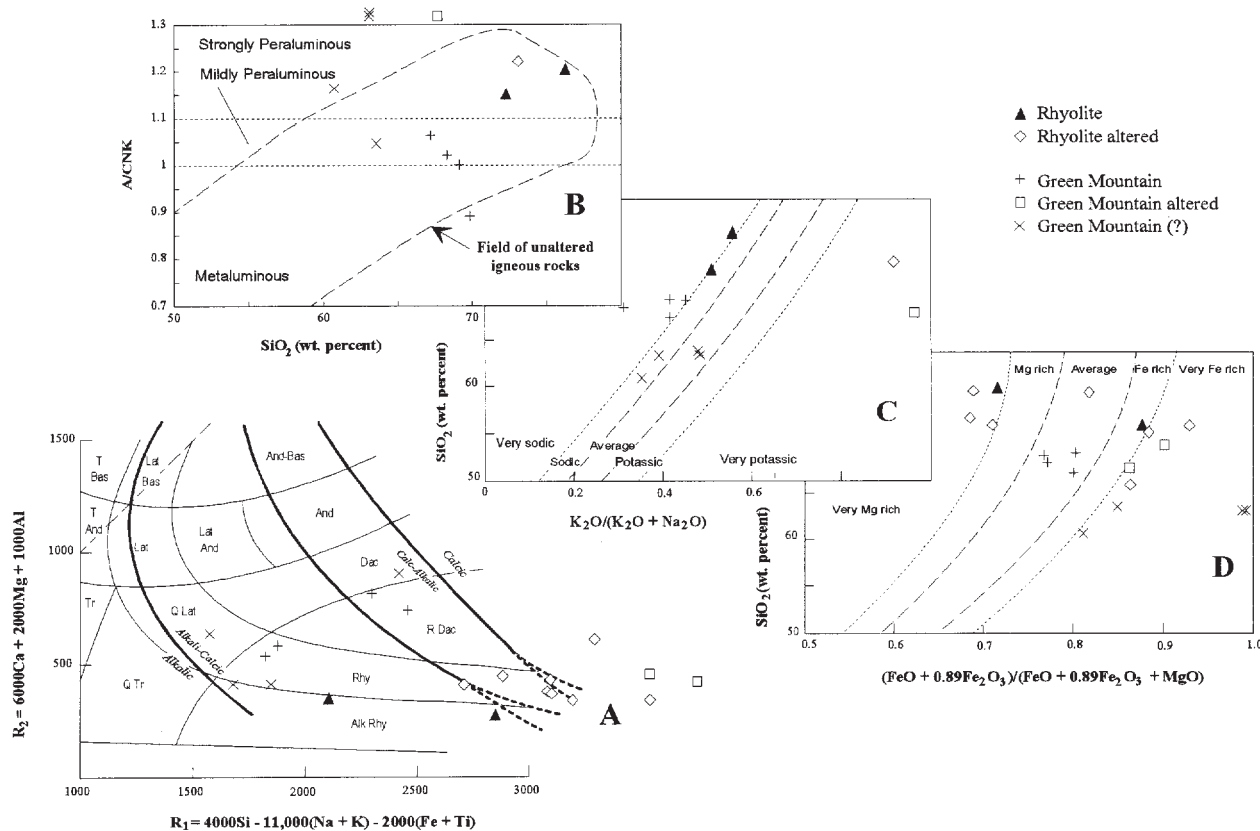


Figure 1. Summary geochemical diagrams for rhyolite (unit Tr) and the porphyry of Green Mountain (unit Tgm). Data from this study and Herald (1981). Refer to tables 1 and 5 for analytical data.

(A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Alk Rhy, alkali rhyolite; Rhy, rhyolite; R Dac, rhyodacite; Dac, dacite; And, andesite; And-Bas, andesitic basalt; Lat And, latite-andesite; Q Lat, quartz latite; Q Tr, quartz trachyte; Tr, trachyte; Lat, latite; T Bas, trachybasalt; T And, trachyandesite; Lat Bas, latibasalt. Volcanic rock names used because of fine-grained nature of most rocks. Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).
 (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O .
 (C) Alkali classification diagram ($\text{K}_2\text{O}/(\text{K}_2\text{O} + \text{Na}_2\text{O})$ versus SiO_2). Field boundaries from this study.
 (D) Iron enrichment classification diagram $(\text{FeO} + 0.89\text{Fe}_2\text{O}_3)/(\text{FeO} + 0.89\text{Fe}_2\text{O}_3 + \text{MgO})$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others, 1998).

in Na and plot in the calc-alkalic to calcic fields (fig. 1A). The mineralized samples are strongly peraluminous, very potassic, and range widely in Fe/Fe+Mg. Mineralized samples contain less Na_2O and barium than unaltered samples (Table 1). Uranium concentrations are high (>15 ppm) and Th/U ratios (<1) are much lower than typical rhyolites.

The sill in Chicago Park is reversely zoned, having a thin felsic margin and a slightly more mafic core (Herald, 1981; Table 2). The felsic margin, too thin to be shown on the geologic map, ranges from alkali-calcic rhyolite to calc-alkalic rhyolite, is strongly peraluminous, varies widely in K/Na ratio, and is slightly Mg rich (fig. 2). The core is an alkali-calcic rhyolite that is strongly peraluminous, has no preferred alkali enrichment, and is Mg rich. The core is not significantly affected by hydrothermal alteration (fig. 2).

The sill-like body northwest of Napoleon Pass is an alkali-calcic alkali rhyolite that averages mildly

peraluminous (one sample lies outside the field of unaltered igneous rocks), is sodic to average, and has variable Fe or Mg enrichment (fig. 3). Rhyolitic intrusive rocks near Tincup (far northeastern part of map area) are grossly similar to those at Napoleon Pass, with the exception of one latite-andesite (monzodiorite) rock (fig. 3) that is associated with the stock at Tincup, just northeast of the map area (Koksoy, 1961; Brock and Barker, 1972). This stock, based on the similarity of its chemistry to that of the tonalite at Cumberland Pass (see section below), could be much older than the rhyolites.

Oligocene age based on fission-track date of 34.5 ± 3.0 Ma from zircon in plug along Gold Creek (table 4)

Tgm Porphyry of Green Mountain (Oligocene)—Grayish-green to cream, fine-grained, porphyritic rhyolite to dacite(?) that is equivalent to part of the Tincup Quartz Monzonite Porphyry (Dings and Robinson, 1957) in the Cumberland Pass area. Includes part of

Table 1. Major- and minor-element chemistry of Oligocene rhyolite (unit Tr) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (8-, and 9- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Herald (1981) for analytical techniques for altered rhyolite samples beginning with HT-]

Condition	fresh	fresh	altered	altered	altered	altered	altered	altered	altered	altered
Sample number	8-11-82-1	8-5-82-1	HT-103	HT-122	HT-073	HT-072	9-6-83-1	HT-124	HT-080	HT-121
Major elements										
SiO ₂	72.30	76.30	65.90	71.52	72.21	72.31	73.10	73.48	75.77	75.97
TiO ₂	0.08	0.07	0.40	0.29	0.07	0.09	0.05	0.04	0.10	0.04
Al ₂ O ₃	15.10	12.60	20.13	17.26	17.81	16.61	13.10	15.99	16.21	16.55
Fe ₂ O ₃	0.69	0.38	--	--	--	--	--	--	--	--
Fe _t O ₃	--	--	2.95	2.64	1.83	0.67	0.74	0.14	1.42	0.34
FeO	0.35	0.18	--	--	--	--	--	--	--	--
MnO	0.02	0.02	--	--	--	--	0.13	--	--	--
MgO	0.14	0.21	0.43	0.32	0.13	0.25	0.31	0.23	0.29	0.14
CaO	0.41	0.13	0.26	0.20	0.10	0.65	1.45	2.65	0.08	0.05
Na ₂ O	4.50	3.42	--	--	--	--	0.60	--	--	--
K ₂ O	4.63	4.28	6.09	6.89	7.10	8.94	6.59	6.83	6.29	7.94
P ₂ O ₅	0.05	0.05	--	--	--	--	0.05	--	--	--
H ₂ O+	0.71	0.81	--	--	--	--	--	--	--	--
H ₂ O-	0.03	0.23	--	--	--	--	--	--	--	--
CO ₂	0.01	0.01	--	--	--	--	--	--	--	--
LOI	--	--	--	--	--	--	2.33	--	--	--
TOTAL	99.02	98.69	96.16	99.12	99.25	99.52	98.45	99.36	100.16	101.03
Minor elements										
Ba	491	1144	--	--	--	--	86	--	--	--
Rb	131	221	--	--	--	--	326	--	--	--
Sr	275	48	--	--	--	--	40	--	--	--
Y	13	6	--	--	--	--	17	--	--	--
Zr	78	64	--	--	--	--	74	--	--	--
Nb	66	32	--	--	--	--	39	--	--	--
U	3.3	17.0	--	--	--	--	21.1	--	--	--
Th	< 2.6	24.0	--	--	--	--	< 7.3	--	--	--
Calculations										
R ₁	2105	2849	2881	3079	3101	2707	3094	3292	3537	3193
R ₂	347	272	444	376	367	408	428	609	341	337
A/CNK	1.15	1.20	--	--	--	--	1.22	--	--	--
Fe No.	0.87	0.71	0.86	0.88	0.93	0.71	0.68	0.35	0.82	0.69
K No.	0.51	0.56	--	--	--	--	0.92	--	--	--

unit called andesite by DeWitt and others (1985) in the Fossil Ridge area. Includes part of fine-grained quartz porphyry (unit Tt₂) of Rosenlund (1984), southeast of Cumberland Pass. Andesine porphyry (unit Tt₁) of Rosenlund (1984) on Napoleon Pass, east of Cumberland Pass, is included in the unit because of its similar chemistry, but it may be a separate intrusive mass.

Groundmass of light-gray, very fine grained (10–20 μm) mixture of quartz, oligoclase(?), and orthoclase containing <10-μm-diameter opaque grains and 30–45-μm-diameter clots of sericite and minor calcite. Microphenocrysts in groundmass are 40–50-μm-long clear apatite prisms and 40–50-μm-diameter anhedral chlorite grains. Phenocrysts and glomerocrysts of 1–4-mm-long, euhedral

Table 2. Major- and minor-element chemistry of Oligocene porphyry near Chicago Park (unit Tr) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Herald (1981) for analytical techniques for porphyry samples beginning with HT-; see Rosenlund (1984) for analytical techniques for porphyry samples beginning with TCFT-; see Daly (1983) for analytical techniques for all other porphyry samples]

Type	Sill, border	Sill, border	Sill, border	Sill, border	Sill, border	Sill, border	Sill, border	Sill, border	Dike, border	Sill, border	Sill, border
Sample number	HT-279	HT-189	HT-200B	HT-310	HT-252	HT-335	HT-192	HT-262	HT-307	HT-290	
Major elements											
SiO ₂	71.52	72.01	72.55	72.70	72.79	73.28	73.58	73.82	74.02	74.95	
TiO ₂	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	
Al ₂ O ₃	16.91	15.98	16.22	16.09	16.02	16.47	16.45	15.79	16.75	16.69	
Fe _t O ₃	0.36	0.24	0.65	0.28	0.62	0.57	0.55	0.63	0.25	0.55	
MgO	0.36	0.20	0.14	0.08	0.32	0.09	0.14	0.16	0.22	0.09	
CaO	2.60	2.24	0.15	0.93	1.29	0.16	0.14	0.19	0.14	0.10	
Na ₂ O	1.86	2.69	3.17	3.70	2.77	3.54	3.10	3.20	1.87	3.44	
K ₂ O	4.52	3.88	4.78	4.01	4.26	3.93	4.62	4.48	4.71	2.83	
TOTAL	98.18	97.29	97.71	97.85	98.12	98.09	98.63	98.32	98.01	98.70	
Calculations											
R ₁	3035	2925	2570	2581	2851	2688	2704	2715	3156	3092	
R ₂	628	563	341	419	468	345	345	338	355	343	
A/CNK	1.34	1.26	1.52	1.33	1.39	1.59	1.59	1.51	1.99	1.88	
Fe No.	0.47	0.52	0.81	0.76	0.64	0.85	0.78	0.78	0.51	0.85	
K No.	0.71	0.59	0.60	0.52	0.61	0.53	0.60	0.58	0.72	0.45	

Table 2. Major- and minor-element chemistry of Oligocene porphyry near Chicago Park—*continued*.

Type	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core	Sill, core
Sample number	HT-184	HT-255	HT-294	HT-311	HT-129	HT-142	HT-152	HT-200A	HT-258	HT-267	HT-157
Major elements											
SiO ₂	68.69	68.93	69.23	69.37	69.62	69.86	69.86	70.06	70.11	71.18	71.33
TiO ₂	0.27	0.25	0.24	0.23	0.44	0.24	0.26	0.29	0.24	0.23	0.24
Al ₂ O ₃	16.49	16.17	15.57	15.79	15.58	15.73	15.85	14.97	15.10	15.33	15.14
Fe _t O ₃	2.08	2.09	2.06	1.98	1.98	1.99	2.14	2.44	2.04	1.85	2.00
MgO	0.72	0.76	0.75	0.78	0.76	0.80	0.78	0.76	0.62	0.66	0.72
CaO	0.49	1.54	1.31	1.53	2.61	0.93	0.68	0.58	1.07	0.77	1.13
Na ₂ O	3.60	3.44	3.42	3.27	3.01	3.60	3.72	3.27	3.35	3.44	3.65
K ₂ O	4.51	4.19	4.25	4.57	4.26	4.83	4.34	4.46	4.53	4.59	3.85
TOTAL	96.85	97.37	96.83	97.52	98.26	97.98	97.63	96.83	97.06	98.05	98.06
Calculations											
R ₁	2183	2330	2344	2334	2511	2189	2256	2393	2363	2393	2497
R ₂	412	520	483	512	623	448	422	393	441	416	454
A/CNK	1.41	1.25	1.24	1.21	1.09	1.23	1.32	1.33	1.22	1.28	1.24
Fe No.	0.72	0.71	0.71	0.70	0.70	0.69	0.71	0.74	0.75	0.72	0.71
K No.	0.56	0.55	0.55	0.58	0.59	0.57	0.54	0.58	0.57	0.57	0.51

Table 2. Major- and minor-element chemistry of Oligocene porphyry near Chicago Park—*continued*.

Type	Sill, border	Dike	Sill, core	Sill, altered border	Dike, altered
Sample number	49	26	33	TCFT9	7
Major elements					
SiO ₂	73.90	74.70	75.50	67.10	70.50
TiO ₂	0.50	0.06	0.50	--	0.37
Al ₂ O ₃	12.10	14.60	11.30	14.20	15.70
Fe ₂ O ₃	--	--	--	1.10	--
Fe _t O ₃	2.90	0.60	3.10	--	3.50
FeO	--	--	--	0.54	--
MnO	0.05	0.08	0.06	--	0.06
MgO	1.00	0.15	1.20	0.63	0.48
CaO	0.95	0.12	0.92	1.50	0.24
Na ₂ O	2.00	3.94	2.30	4.00	0.47
K ₂ O	4.50	4.75	4.60	4.50	6.31
P ₂ O ₅	0.18	0.05	0.19	0.02	0.19
TOTAL	98.08	99.05	99.67	93.59	97.82
Calculations					
R ₁	3073	2448	3045	1953	2956
R ₂	389	307	380	470	358
A/CNK	1.23	1.24	1.08	1.00	1.96
Fe No.	0.72	0.78	0.70	0.71	0.87
K No.	0.69	0.55	0.67	0.53	0.93

plagioclase variably to completely altered to sericite and minor calcite; 2–6-mm-diameter clear, slightly rounded and embayed quartz grains; 2–8-mm-diameter biotite(?) grains completely altered to chlorite, opaque material, and minor calcite and epidote; and 100–200- μ m-long apatite prisms. Biotite(?) phenocrysts contain fragments(?) of plagioclase and much (~1%) zircon and allanite. Trammel (1961) noted hornblende in porphyry, but none was seen in this study. Intrusive on Napoleon Pass contains much less quartz, much more plagioclase, and greater amounts of altered mafic phenocrysts, principally biotite and hornblende.

Much of porphyry of Green Mountain, especially the northeastern part of body, and adjacent Proterozoic wallrock, is intensely altered to a sericite-quartz mixture and cut by quartz-pyrite veins and huebnerite-molybdenite veins (Goddard, 1935; Tweto, 1943; Dings and Robinson, 1957; Rosenlund, 1984). Northeastern part of body near Cumberland Pass has been drilled extensively as a molybdenum porphyry prospect (King, 1964; Kirkemo and others, 1965; AMAX Exploration Inc., and AMOCO Minerals Co., unpub. data, 1984). Mineralization appears to be related to emplacement of the porphyry and younger rhyolite (unit Tr, above) and their subsequent late-stage hydrothermal alteration (Rosenlund, 1984).

Average modal composition of porphyry on Green Mountain: 45% groundmass consists of

quartz (40%), oligoclase(?) (30%), orthoclase (15%), sericite and calcite (5%), opaque grains (3%), apatite (3%), and chlorite (4%); 55% phenocrysts consist of plagioclase variably to completely altered to sericite (75%), quartz (10%), biotite(?) completely altered to chlorite and opaque material (10%), and apatite (5%).

The porphyry of Green Mountain is an alkali-calcic to calc-alkalic rhyolite to rhyodacite that is mildly peraluminous, very sodic, and has no Fe or Mg enrichment (fig. 1). The porphyry has high and variable concentrations of barium and strontium (table 5). The alkali-calcic rhyolite samples come from a dike along the Athens fault to the south of the main mass (Herald, 1981) and may not be the same as the main mass on Green Mountain. Secondary epidote noted in altered rocks by Rosenlund (1984) could account for the calc-alkalic nature of some samples from the main body on Green Mountain. Hydrothermally altered and mineralized porphyry is calcic (loss of alkali elements), strongly peraluminous, potassic, and very Fe rich (fig. 1). The fresh porphyry is texturally and compositionally similar to the Lincoln Gulch stock (K-Ar biotite date of 34.8 ± 1.1 Ma as recalculated to decay constants recommended by Steiger and Jaeger, 1977) in the Grizzly Peak caldera north of Taylor Park (Candee, 1971; Cruson, 1973; Fridrich, 1986; Fridrich and Mahood, 1984; Fridrich and others, 1998).

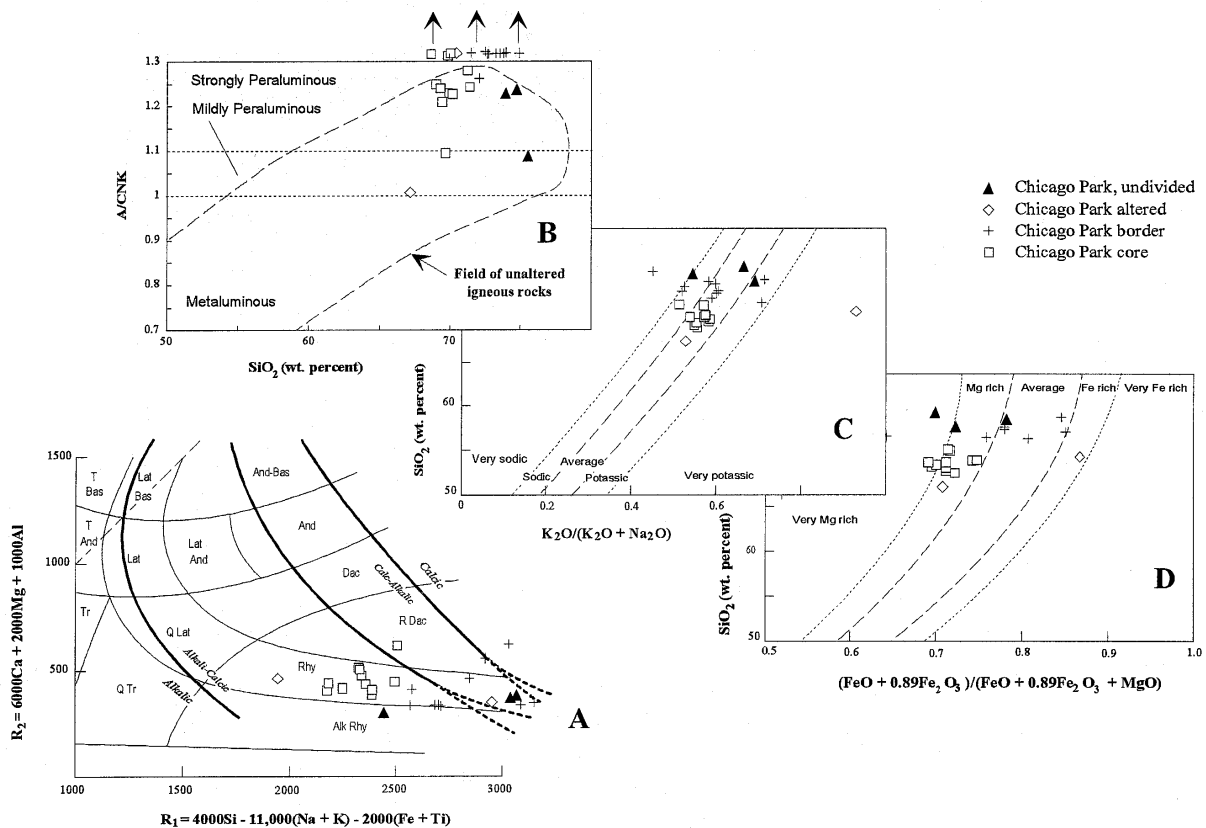


Figure 2. Summary geochemical diagrams for rhyolite (unit Tr) from the Chicago Park area. Rock names listed in figure 1. Data from Herald (1981), Daly (1983), and Rosenlund (1984). Refer to table 2 for analytical data. (A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Volcanic rock names used because of fine-grained nature of most rocks. See figure 4 for the equivalent plutonic rock names. Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998). (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O . Samples outside the outlined box plot well above the field of unaltered rocks. (C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study. (D) Iron enrichment classification diagram $(FeO + 0.89*Fe_2O_3)/(FeO + 0.89*Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

Oligocene age assignment of the porphyry of Green Mountain based on fission-track date of 34.5 ± 2.8 Ma from zircon collected 0.2 km west of summit of Green Mountain (Naeser and Cunningham, 1976; Cunningham and others, 1977). Porphyry intruded Fairview Peak Granodiorite (newly named) in the east as a west-trending dike, but to the west was emplaced as a sill cutting up into Sawatch Quartzite

TKt Tonalite stock and sill at Cumberland Pass (early Tertiary to Late Cretaceous?)—Dark-greenish-gray, medium-grained, equigranular to porphyritic hornblende-biotite tonalite near Cumberland Pass that is equivalent to quartz diorite porphyry stock of Dings and Robinson (1957), tonalite porphyry stock of Trammel (1961), and granodiorite (unit Tgd) and diorite porphyry (unit Tdp) of Rosenlund (1984). Includes part of unit called andesite (DeWitt and others, 1985) in the Cumberland Pass area. Stock consists of two textural varieties, a diabasic core and an equigranular to porphyritic, variably flow-foliated margin. According to Trammel (1961), the diabasic core contains labradorite,

pyroxene mantled by hornblende, biotite, minor orthoclase, and very little quartz. Equigranular to porphyritic margin contains andesine, hornblende containing pyroxene cores, orthoclase, biotite, and quartz. Rosenlund (1984) did not note pyroxene in the stock or sill. Granite dikelets cut the stock and Paleozoic sedimentary rocks east of Cumberland Pass; dikelets may be late-stage intrusives related to the granodiorite (Trammel, 1961), but may also be related to granitic bodies in the Cumberland Pass area (Rosenlund, 1984) shown as unit Tr.

Average modal composition of stock, according to Trammel (1961) and Rosenlund (1984): andesine [An_{40}] (40–45%), quartz (15–18%), hornblende (8–18%), orthoclase (16–26%), biotite (7–8%), pyroxene (trace–5%), magnetite (2–4%), and accessory sphene, apatite, and zircon (Trammel, 1961). Sill (Rosenlund, 1984) contains 60–65% plagioclase, 3–5% quartz, 30% combined hornblende and biotite, 0.5% magnetite, 1.5% orthoclase, and trace amounts of sphene, apatite, and zircon.

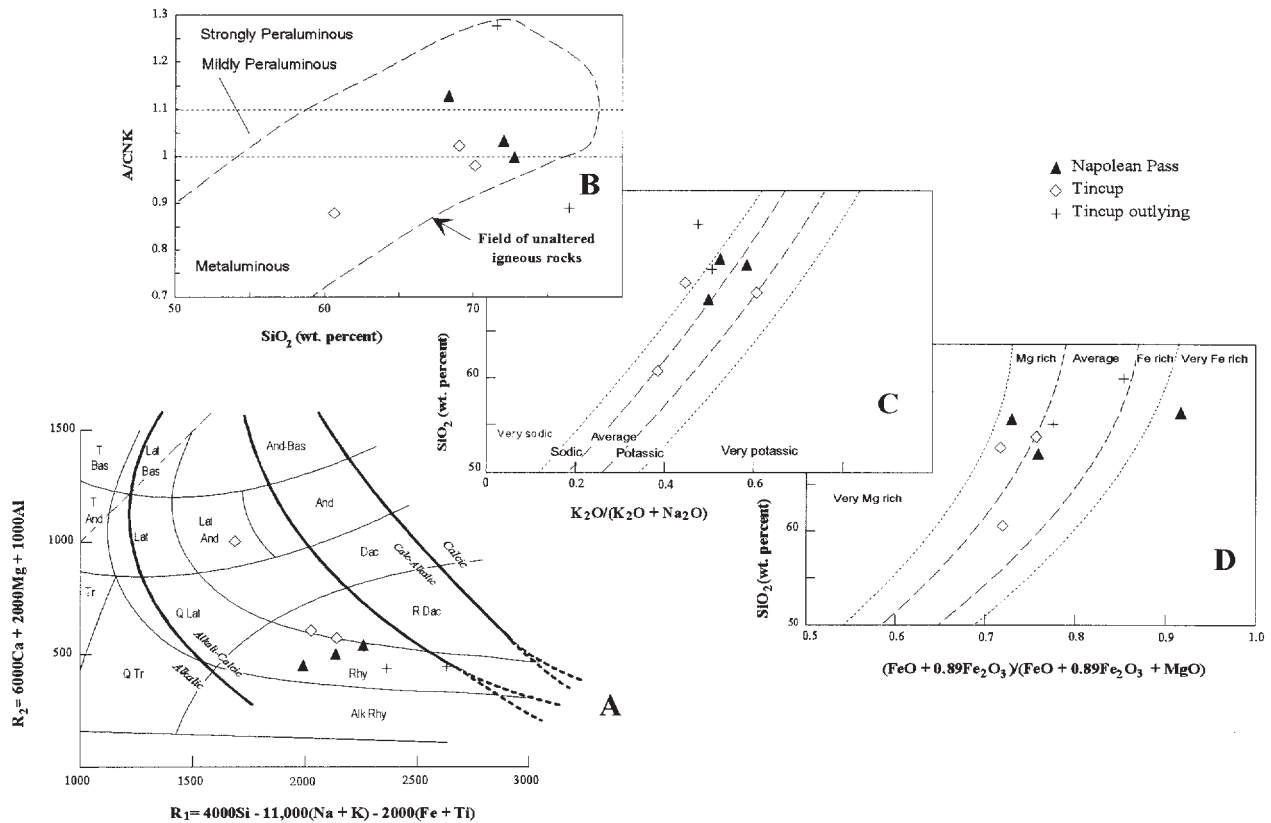


Figure 3. Summary geochemical diagrams for rhyolite (unit Tr) from the Napolean Pass area and the Tincup area. Rock names listed in figure 1. Data from Rosenlund (1984). Refer to table 3 for analytical data.
 (A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Volcanic rock names used because of fine-grained nature of most rocks. See figure 4 for the equivalent plutonic rock names. Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).
 (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O .
 (C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study.
 (D) Iron enrichment classification diagram $(FeO + 0.89Fe_2O_3)/(FeO + 0.89Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others, (1998).

The stock and sill are alkali-calcic tonalite to granodiorite that is metaluminous, has no preferred alkali enrichment, and is Mg rich (fig. 4; table 6). The stock and sill are geochemically distinct from Late Cretaceous latite sills (unit Kf), below.

Early Tertiary to Late Cretaceous age based on geochemical dissimilarity to younger Oligocene rocks and geochemical similarity to granodiorite to tonalite bodies in the Sawatch Range such as the Twin Lakes pluton (Fridrich and others, 1998). Stock and sill are chemically similar to the granodiorite phase of the Tincup Quartz Monzonite Porphyry in the Tincup area (Jefferson, 1985, unit Tgd), which is a monzodiorite that is inferred to be Tertiary, but is undated

Kf Fossil Ridge Latite (Late Cretaceous)—Named herein for exposures at its type area on Fossil Ridge, especially at the head of Comanche Gulch and on Fossil Mountain in T. 51 N., R. 3 E., secs. 28 and 33, and in T. 51 N., R. 3 E., sec. 23. Grayish-green, fine- to medium-grained, porphyritic latite forms dikes and

small plugs in Early Proterozoic granitic and metamorphic rocks and forms sills and minor dikes and plugs in Paleozoic sedimentary rocks. Includes part of unit called andesite (DeWitt and others, 1985) and andesite porphyry and diorite porphyry (Crawford and Worcester, 1916; Zech, 1988) in the Fossil Ridge area. Also includes monzodiorite porphyry (unit Tmdp) of Jefferson (1985) west of Tincup. Sills most numerous along crest of Fossil Ridge and north-trending ridge separating Lottis and South Lottis Creeks. Sills cut all Paleozoic rocks, and are especially abundant in Sawatch Quartzite and Belden Formation. Feeder dike and small plug of latite exposed in cirque wall west of Mill Lake. Small plug exposed at Crystal Lake, just northwest of Fossil Ridge. Large sill-like body of latite at the head of Comanche Gulch may be, in part, laccolithic at depth.

Groundmass of light-grayish-green, very fine grained (10–30 μm diameter) mixture of slightly turbid, zoned andesine(?) and quartz containing

Table 3. Major- and minor-element chemistry of Oligocene quartz porphyry near Napoleon Pass (unit Tr) and rocks in the Tincup area (units Tr and TKt?) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Rosenlund (1984) for analytical techniques for porphyry samples beginning with TCFT; see Jefferson (1985) for analytical techniques for all other samples]

Unit	Tr	Tr	Tr	TKt	Tr?	Tr	Tr	Tr
Sample number	TCFT-6	TCFT-1	TCFT-5	Tgd	Ttcp	Ttep	Ttfp	Tafa
Major elements								
SiO ₂	68.20	71.9	72.60	60.50	68.90	70.00	71.40	76.30
TiO ₂	--	--	--	0.83	0.38	0.37	0.23	0.06
Al ₂ O ₃	15.30	15.10	15.30	16.80	14.80	15.60	15.50	12.70
Fe _t O ₃	0.43	1.30	0.30	3.40	1.60	1.60	1.70	0.27
FeO	1.70	1.20	0.62	3.10	1.60	1.30	1.20	0.46
MnO	--	--	--	0.08	0.03	0.02	0.02	0.01
MgO	0.66	0.88	0.08	2.40	1.20	0.88	0.79	0.12
CaO	1.50	1.80	1.30	5.10	2.00	2.30	0.80	1.70
Na ₂ O	4.00	3.60	4.60	4.30	3.30	4.70	3.90	4.30
K ₂ O	4.00	5.10	5.10	2.70	5.10	3.80	4.00	3.90
P ₂ O ₅	0.07	0.06	0.02	0.26	0.16	0.15	0.12	0.02
LOI	--	--	--	0.60	0.90	0.70	1.40	1.00
TOTAL	95.86	100.94	99.92	100.07	99.97	101.42	101.06	100.84
Calculations								
R1	2128	2251	1984	1678	2130	2018	2353	2621
R2	493	532	443	994	564	596	429	437
A/CNK	1.12	1.03	0.99	0.87	1.02	0.98	1.27	0.88
Fe No.	0.76	0.73	0.92	0.72	0.72	0.76	0.78	0.85
K No.	0.50	0.59	0.53	0.39	0.61	0.45	0.51	0.48

Table 4. Fission-track data for Late Cretaceous and Oligocene igneous rocks, Fossil Ridge area, Gunnison County, Colorado

[Decay constant, 7.03×10^{-17} /yr; (436), number of tracks counted; DF-4948, laboratory number; Analyses by C.W. Naeser, U.S. Geological Survey, Denver, CO]

Sample	Mineral	Fossil tracks ($\times 10^{-6}$ t/cm ²)	Induced tracks ($\times 10^{-6}$ t/cm ²)	Dose ($\times 10^{-15}$)	Date (Ma)	+/- 2 sigma (Ma)	No. of grains	U (ppm)
Fossil Ridge								
Latite								
FR-UM-AND (DF-4948)	zircon	5.26 (1096)	4.19 (436)	0.756	56.6	6.85	6	180
Rhyolite								
9-6-83-4 (DF-4949)	zircon	7.86 (1492)	10.28 (976)	0.756	34.5	3.0	6	430

50–150- μ m-diameter, irregularly shaped clots of slightly to highly pleochroic epidote or zoisite and minor chlorite. Microphenocrysts in groundmass are 30–60- μ m-diameter apatite and sphene and minor hornblende. Phenocrysts are 0.5–6-mm-diameter euhedral, twinned, and oscillatorially zoned plagioclase, variably to completely altered to sericite and nonpleochroic zoisite(?); 0.2–3-mm-long dark green hornblende that is unaltered to variably replaced by calcite, epidote, and chlorite;

0.3–0.5-mm-diameter euhedral apatite; and 0.3–1-mm-long euhedral and variably needle-like sphene. Zircon common in groundmass. Red-brown, twinned, 0.1–0.2-mm-diameter allanite noted locally. Clots of epidote or zoisite in groundmass locally appear to fill vug-like cavities containing 0.2–0.5-mm-diameter quartz grains and 0.5–0.75 mm calcite grains.

Average modal composition of the latite: 50% groundmass consists of oligoclase and andesine(?)

Table 5. Major- and minor-element chemistry of Oligocene porphyry of Green Mountain (unit Tgm) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample 7-27-82-1 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmagem Exploration, Seattle, WA; Fe₂O₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Herald (1981) for analytical techniques for mineralized porphyry samples beginning with HT-; see Rosenlund (1984) for analytical techniques for mineralized porphyry samples beginning with TCFT-]

Sample number	7-12-82-1	7-27-82-1	TCFT-3	TCFT-4	HT-223	HT-217	HT-229	HT-239	HT-235	HT-216
Major elements										
SiO ₂	67.20	68.28	69.10	69.50	67.71	70.20	60.72	63.12	63.17	63.56
TiO ₂	0.25	0.25	--	--	0.33	0.33	0.38	0.39	0.48	0.28
Al ₂ O ₃	16.10	16.28	16.10	15.70	19.73	19.03	17.42	16.90	17.09	17.74
Fe ₂ O ₃	1.15	1.80	1.70	2.70	--	--	--	--	--	--
Fe ₁ O ₃	--	--	--	--	5.87	5.22	4.56	4.70	5.25	2.94
FeO	1.25	0.50	1.00	1.40	--	--	--	--	--	--
MnO	0.05	0.03	--	--	--	--	--	--	--	--
MgO	0.58	0.64	0.78	0.96	0.86	0.53	0.97	0.06	0.05	0.48
CaO	1.78	2.17	3.60	4.30	0.25	0.21	2.29	0.70	0.67	4.94
Na ₂ O	4.97	5.65	3.80	4.30	0.13	--	4.87	4.75	3.87	3.05
K ₂ O	3.50	2.55	3.10	3.00	3.31	3.37	2.63	3.03	3.60	2.79
P ₂ O ₅	0.12	0.24	0.02	0.05	--	--	--	--	--	--
H ₂ O+	1.10	--	--	--	--	--	--	--	--	--
H ₂ O-	0.02	--	--	--	--	--	--	--	--	--
CO ₂	0.77	--	--	--	--	--	--	--	--	--
LOI	--	1.50	--	--	--	--	--	--	--	--
TOTAL	98.84	99.89	99.20	101.91	98.19	98.89	93.84	93.65	94.18	95.78
Minor elements										
Ba	1720	970	--	--	--	--	--	--	--	--
Rb	79	71	--	--	--	--	--	--	--	--
Sr	1054	440	--	--	--	--	--	--	--	--
Y	13	< 5	--	--	--	--	--	--	--	--
Zr	179	160	--	--	--	--	--	--	--	--
Nb	22	29	--	--	--	--	--	--	--	--
U	2.4	--	--	--	--	--	--	--	--	--
Th	7.8	--	--	--	--	--	--	--	--	--
Calculations										
R ₁	1822	1879	2457	2293	3533	3747	1575	1681	1847	2416
R ₂	535	583	740	816	457	422	635	409	409	900
A/CNK	1.06	1.02	1.00	0.87	4.65	--	1.16	1.37	1.49	1.04
Fe No.	0.80	0.77	0.76	0.80	0.86	0.90	0.81	0.99	0.99	0.85
K No.	0.41	0.31	0.45	0.41	0.96	--	0.35	0.39	0.48	0.48

(65%), quartz (25%), epidote and zoisite (5%), calcite (2%), and microphenocrysts of opaque material, apatite, and sphene (3%); 50% phenocrysts consist of plagioclase variably to completely altered to sericite and zoisite(?) (65%), hornblende variably altered to chlorite, epidote, and calcite (30%), sphene (3%), and apatite (2%).

The sills, dikes, and plugs are alkali-calcic to slightly alkalic latite (plutonic equivalent is

monzonite) that is metaluminous and that has no preferred alkali or Fe enrichment (fig. 4). Latite is characterized (table 6) by very high concentrations of strontium (>1,000 ppm) and high zirconium (>200 ppm).

Late Cretaceous age based on ⁴⁰Ar/³⁹Ar hornblende plateau date of 69.0 ± 1.0 Ma from dike cutting basement rocks west of Fossil Ridge (table 7; fig. 5A). A sample from a sill in Sawatch Quartzite

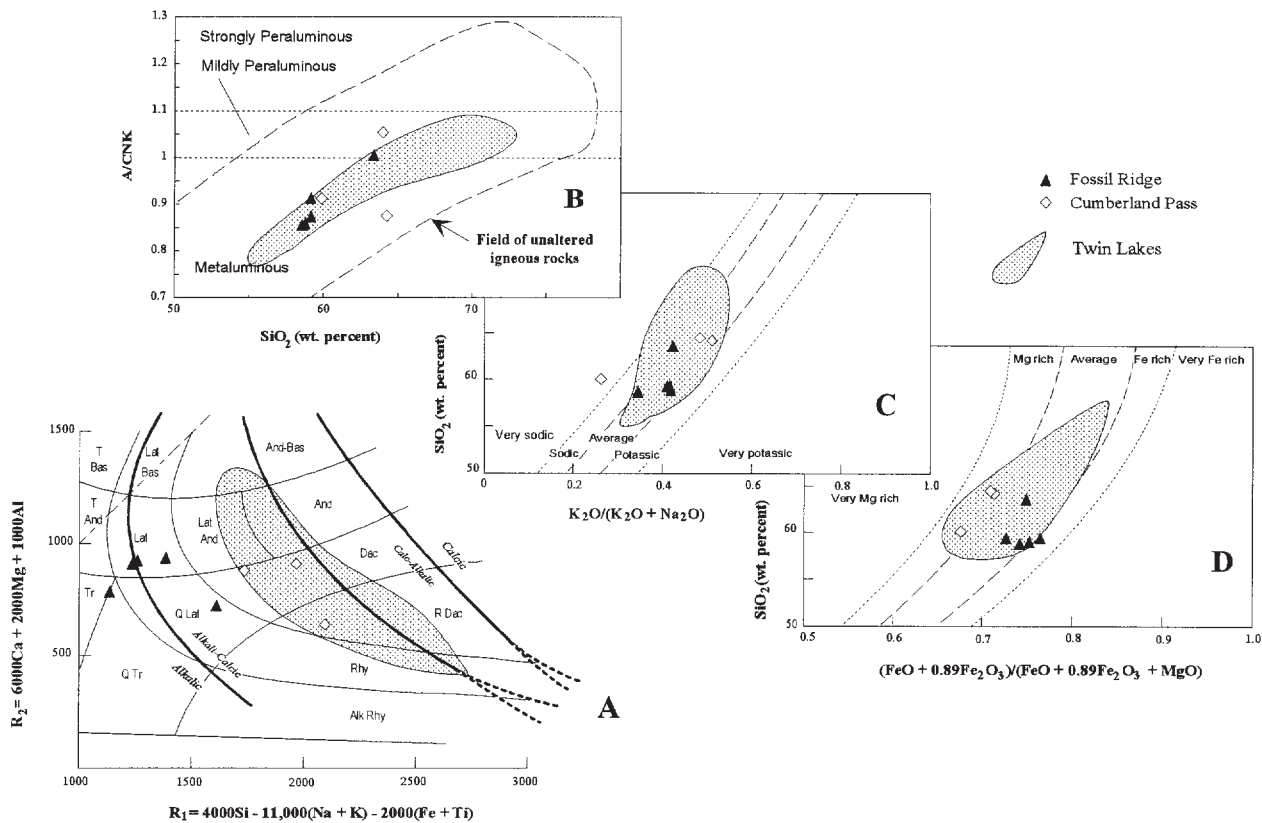


Figure 4. Summary geochemical diagrams for Fossil Ridge Latite (unit Kf) and tonalite at Cumberland Pass (unit TKt). Gr, granite (equivalent to rhyolite); Gd, granodiorite (equivalent to rhyodacite); Ton, tonalite (equivalent to dacite); Mon, monzonite (equivalent to latite). Data from this study, Jefferson (1985), and Earley (1987). Refer to table 6 for analytical data.
 (A) R_1/R_2 major element classification diagram (De la Roche and others, 1980. Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).
 (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO ; N, molar Na_2O ; K, molar K_2O .
 (C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study.
 (D) Iron enrichment classification diagram $(FeO + 0.89*Fe_2O_3)/(FeO + 0.89*Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

just north of the map area gave a slightly disturbed spectra, with most of the calculated dates in the range of 70–72 Ma (table 7; fig. 5B). The $^{40}Ar/^{39}Ar$ data indicate that the latite was emplaced near the end of the Late Cretaceous. A fission-track date of 56.6 ± 6.8 Ma for zircon from latite (table 4) indicates regional uplift and cooling of surrounding rocks in early Eocene time, which is in agreement with uplift of the ancestral Sawatch Range at that time (Bryant and Naeser, 1980)

- Ku Sedimentary rocks, undivided (Upper Cretaceous)**—Includes shale and sandstone younger than the Dakota Sandstone, principally the Mancos Shale. Mapped only in the northeastern part of the Almont area. Thickness undetermined
- Kd Dakota Sandstone (Upper Cretaceous)**—White and tan to yellowish, medium- to coarse-grained, cliff-forming sandstone. Upper part friable, thin-bedded sandstone and minor siltstone and shale. Locally contains plant remains. Lower part cross-bedded, locally quartzitic sandstone containing basal, coarse-grained quartz or chert pebble conglomerate.

Locally contains petrified wood. Thickness 50–60 m. Exposed in southwestern part of area, southwest of Beaver Creek, and in Almont area

- Jm Morrison Formation (Upper Jurassic)**—Variegated green to red-brown calcareous siltstone, shale, and mudstone containing local lenses and channel fillings of fine-grained calcareous sandstone. Thickness 40 m. Exposed in southwestern part of area, southwest of Beaver Creek, and in Almont area
- Jj Junction Creek Sandstone (Upper Jurassic)**—White to yellowish, medium- to fine-grained aeolian quartz sandstone containing local large-scale cross-beds. Local quartz pebble conglomerate at base. Thickness 10–20 m. Exposed in southwestern part of area, southwest of Beaver Creek, and in Almont area
- Jmj Morrison Formation and Junction Creek Sandstone (Upper Jurassic)**—Combined unit shown in Almont area
- Pg Gothic Formation (Middle Pennsylvanian)**—Light- to dark-gray, pale-green, and brown interbedded

Table 6. Major- and minor-element chemistry of Tertiary-Cretaceous tonalite at Cumberland Pass (unit TKt) and Fossil Ridge Latite (unit Kf) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- and 8- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Jefferson (1985) for analytical techniques for latite sample beginning with TMdp; see Earley (1987) for analytical techniques for latite sample beginning with 38]

Map unit	TKt	TKt	TKt	Kf	Kf	Kf	Kf	Kf
Sample number	TCFT-8	TCFT-2B	TCFT-7	8-4-82-4	8-4-82-2	7-14-82-3	38	Tmdp
Major elements								
SiO ₂	63.90	64.20	59.80	58.50	58.70	59.10	59.10	63.30
TiO ₂	--	--	--	0.67	0.71	0.72	0.70	0.55
Al ₂ O ₃	15.10	15.90	16.10	16.90	16.90	17.20	16.60	16.70
Fe ₂ O ₃	0.73	3.00	1.70	--	2.37	2.73	2.64	2.90
Fe _t O ₃	--	--	--	5.98	--	--	--	--
FeO	2.30	2.60	2.60	--	3.39	2.87	2.94	2.10
MnO	--	--	--	0.17	0.19	0.15	0.18	0.13
MgO	1.20	2.20	2.00	1.89	1.84	1.66	2.02	1.60
CaO	2.60	4.50	4.30	4.61	4.49	4.78	3.32	2.90
Na ₂ O	3.50	3.80	4.90	5.19	4.80	4.64	5.08	4.70
K ₂ O	3.60	3.50	1.70	2.69	3.41	3.17	3.56	3.40
P ₂ O ₅	0.11	0.10	0.22	0.38	0.36	0.33	0.32	0.20
H ₂ O+	--	--	--	--	1.54	1.25	1.49	--
H ₂ O-	--	--	--	--	0.06	0.09	--	--
CO ₂	--	--	--	--	0.36	0.01	0.59	--
LOI	--	--	--	1.91	--	--	--	1.60
TOTAL	93.04	99.80	93.32	98.89	99.12	98.70	98.54	100.08
Minor elements								
Ba	--	--	--	850	924	1090	1290	--
Rb	--	--	--	74	80	101	78	100
Sr	--	--	--	844	1213	1358	1016	--
Y	--	--	--	21	28	29	28	--
Zr	--	--	--	217	216	214	226	--
Nb	--	--	--	30	28	29	--	--
U	--	--	--	3.6	4	4.5	--	--
Th	--	--	--	12.8	12.5	14	--	--
Calculations								
R ₁	2088	1960	1729	1257	1236	1381	1134	1607
R ₂	634	902	875	918	903	931	781	717
A/CNK	1.05	0.87	0.91	0.85	0.86	0.87	0.91	1.00
Fe No.	0.71	0.71	0.67	0.74	0.75	0.76	0.72	0.75
K No.	0.51	0.48	0.26	0.34	0.42	0.41	0.41	0.42

shale, sandstone, and pebble conglomerate that form tree-covered slopes. Upper 15 m is sandstone and interbedded shale. Basal 100 m is covered by dense stands of aspen, but appears to be shale containing interbedded sandstone. Thickness about 130 m; upper part removed by erosion. Exposed only in

northwestern part of area, on ridge tops north of Doctor Park

IPb Belden Formation (Middle Pennsylvanian)—Dark-gray to brownish-black, locally carbonaceous shale; dark-gray to black, dense limestone; and light-gray to grayish-green and yellowish-gray, fine-grained,

Table 7. $^{40}\text{Ar}/^{39}\text{Ar}$ analytical data for hornblende from sill and dike of Fossil Ridge Latite (unit Kf), Fossil Ridge area.

[$^{40}\text{Ar}_R$, radiogenic ^{40}Ar ; $^{39}\text{Ar}_K$, ^{39}Ar produced from ^{39}K by neutron interaction; $^{36}\text{Ar}_{Ca}$, ^{36}Ar produced from calcium by neutron interaction; uncertainty in date (± 2 sigma) is an estimated analytical uncertainty calculated in the manner suggested by Dalrymple and Lanphere (1974); Analyses by E. DeWitt and M. Kunk, U.S. Geological Survey]

Temp, °C	$^{40}\text{Ar}/^{39}\text{Ar}$ measured	$^{37}\text{Ar}/^{39}\text{Ar}$ measured	$^{36}\text{Ar}/^{39}\text{Ar}$ measured	$^{40}\text{Ar}_R/^{39}\text{Ar}_K$	$^{39}\text{Ar}_K$ % of total	Apparent K/Ca	$^{40}\text{Ar}_R$ (100)/ ^{40}Ar measured	Date (Ma) +/-
Sample 7-14-82-3	J=0.007375	wt. = 0.3482 g	Dike in Henry Mountain Granite					
850	35.568	1.730	0.0960	7.335	0.8	0.03	20.6	5.05 \pm 0.98
1000	39.493	5.567	0.1102	7.366	1.3	0.009	18.7	95.44 \pm 0.86
1050	29.215	10.59	0.0692	9.579	0.6	0.005	32.8	123.15 \pm 0.91
1100	9.796	3.631	0.0151	5.604	4.6	0.14	57.2	73.06 \pm 0.38
1150	6.287	3.045	0.0044	5.329	16.4	0.17	84.8	69.54 \pm 0.46
1200	5.821	3.063	0.0027	5.256	19.2	0.17	90.3	68.60 \pm 0.41
1225	5.920	3.115	0.0029	5.278	10.7	0.17	89.2	68.89 \pm 0.34
1250	5.848	3.224	0.0027	5.287	12.2	0.16	90.5	69.01 \pm 0.35
1275	6.197	3.276	0.0037	5.334	5.0	0.16	86.1	69.60 \pm 0.35
1300	6.379	3.327	0.0043	5.347	4.8	0.16	83.9	69.78 \pm 0.40
FUSE	6.456	3.549	0.0044	5.423	24.4	0.15	84.0	70.75 \pm 0.45
Total Gas								70.56
Weight average plateau age (1150°C–1300°C)								68.96 \pm 0.49
Sample FR-UM-AND	J=0.007367	wt.=0.4948g	Sill in Sawatch Quartzite					
700	49.250	2.590	0.0746	27.393	0.8	0.20	55.6	331.62 \pm 4.54
850	25.276	2.272	0.0511	10.341	0.5	0.23	40.9	132.48 \pm 1.37
1000	10.948	4.075	0.0172	6.167	2.6	0.13	56.4	80.16 \pm 0.86
1100	5.798	3.137	0.0025	5.370	34.6	0.16	92.7	70.00 \pm 0.35
1200	5.701	3.234	0.0017	5.424	35.0	0.16	95.2	70.68 \pm 0.36
1250	5.903	3.381	0.0020	5.572	17.8	0.15	94.2	72.57 \pm 0.38
FUSE	6.966	3.470	0.0056	5.583	8.7	0.15	80.2	72.71 \pm 0.37
Total Gas								73.89
NO PLATEAU								

thin- to medium-bedded sandstone. Upper and middle parts of limestone, shaley limestone, and limestone breccia. Basal part consists of sandstone and interbedded shale.

Thicknesses, in a northwest to southeast section across the map, from Manganese Peak and Doctor Park (O'Connor, 1961); Fossil Ridge (Crawford and Worcester, 1916; Johnson, 1944; this study); Cross Mountain (Johnson, 1944; this study); Pitkin area (Whitebread, 1951; Daly, 1983); to Cumberland Pass and Tincup (Goddard, 1935; Koksoy, 1961; Jefferson, 1985; Rosenlund, 1984) are as follows: Doctor Park, as much as 200 m, but upper 15 m removed by erosion; on Fossil Ridge, 90 m, but upper part removed by erosion; north of Pitkin, at least 50 m; south of Pitkin and north of the Powderhouse fault, as great as 280 m or more, but exact figure unknown; Cumberland Pass and Tincup, as great as 420 m, but exact figure unknown. Boulder

fault has decollement surface in part of Belden Formation

MI Leadville Limestone (Lower Mississippian)—Dark-gray to dark-bluish-gray, cliff-forming, fossiliferous dolomite and limestone. Massive in upper part, medium to thick bedded and cherty in lower part.

Thickness not determined on Manganese Peak nor near Doctor Park, but about 91 m on Cement Creek, farther north; on Fossil Ridge at the head of Comanche Gulch, Leadville composed of high-calcium limestone (DeWitt and others, 1985) and is 99 m thick; north of Pitkin, 114–129 m; south of Tincup near Cumberland Pass, 80–90 m

MDc Chaffee Group (Lower Mississippian? and Upper Devonian)—Consists, from top to bottom, of dark-gray dolomitic breccia, thinly laminated dolomite, and thin-bedded, medium- to fine-grained sandstone of the Gilman Sandstone (previously included by some workers as a basal sandstone in

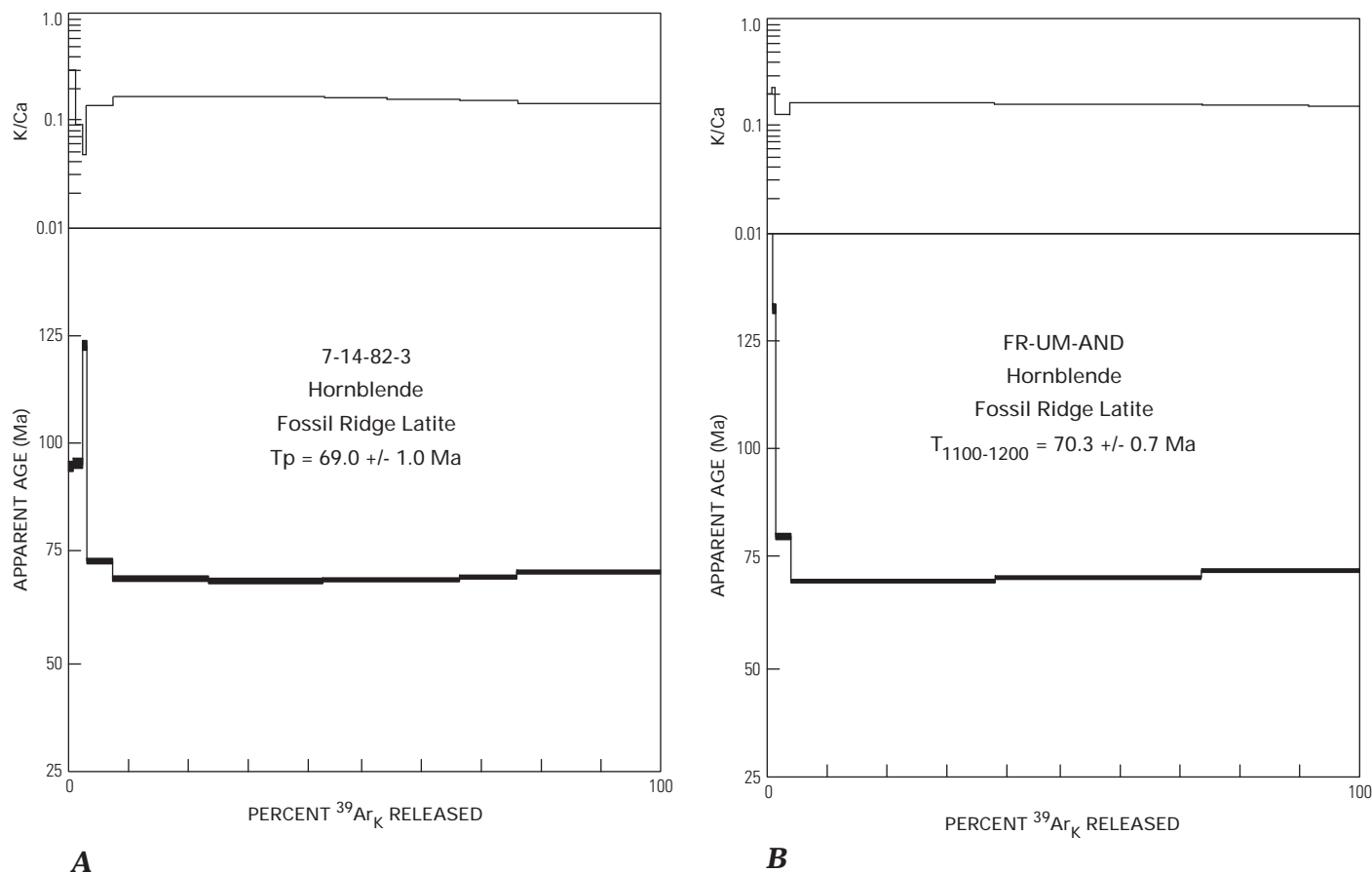


Figure 5. $^{40}\text{Ar}/^{39}\text{Ar}$ release spectra for hornblende from Fossil Ridge Latite (unit Kf), Fossil Ridge area, Gunnison County, Colorado. (A), Hornblende from dike in Early Proterozoic basement; (B), Hornblende from sill in Paleozoic rocks.

the Leadville). Reddish-gray to grayish-pink and dark-gray, thin- to medium-bedded dolomite of the Dyer Dolomite underlies the Gilman. Grayish-orange, very thin- to thin-bedded sandy dolomite to dolomite and minor cross-bedded sandstone and shale of the Parting Formation underlies the Dyer. Individual formations of the Chaffee recognized in the Fossil Ridge and surrounding area, but group mapped as a whole.

Thickness north of Manganese Peak, 76 m, where Parting is 26 m and Dyer is 47 m; on Fossil Ridge, 97 m; on Cross Mountain, minimum of 64 m, where Parting is 30 m; in Pitkin area, thickness 49–89 m, where Parting is 13–24 m and Dyer is 30 m; west of Tincup, 125 m, where Parting is 70 m and Dyer is 55 m; near Cumberland Pass, 56 m, where Parting is 21 m and Dyer is 35 m. Most thickness measurements did not consider Gilman Sandstone part of the Chaffee Group

Ofh Fremont Limestone (Upper Ordovician) and Harding Sandstone (Middle Ordovician)— Consists, from top to bottom, of brownish-gray to medium-gray massive dolomite of the Fremont. Dark-gray, jagged weathering surfaces of Fremont contain fragments of horn corals, chain corals, and crinoid stems. Yellowish-gray and light greenish-gray, fine- and

coarse-grained, massive to bioturbated, dolomitic sandstone of the Harding Sandstone underlies the Fremont and contains fragments of fossil fish plates. Weathers to a mottled light gray or white.

Thickness of Harding relatively constant from northwest to southeast, 1–3 m. Thickness of Fremont near Doctor Park, 19 m; on Fossil Ridge, 11–15 m; on Cross Mountain, 10 m; in Pitkin area, 12–33 m, west of Tincup, 15–30 m; near Cumberland Pass, 30 m

Om Manitou Dolomite (Lower Ordovician)—Medium-bluish-gray to light-brownish-gray, thin- to medium-bedded dolomite. Locally contains zones of thin-bedded, gray to black chert in upper and middle parts of unit.

Thickness near Manganese Peak, 66 m; on Fossil Ridge 47–64 m; near Taylor Park Dam, 63 m; on Cross Mountain, 61 m; near Pitkin, 76–80 m; west of Tincup and at Cumberland Pass, 75–85 m

Ou Fremont Limestone, Harding Sandstone, and Manitou Dolomite, undivided (Upper Ordovician to Lower Ordovician)

Cs Sawatch Quartzite (Upper Cambrian)—White to grayish-pink and reddish-brown, fine- to coarse-grained, medium- to very thick bedded, silica cemented sandstone. Light-tan to buff, shaley limestone and

sandy shale of Peerless Formation, recognized by Johnson (1944) on Cross Mountain and by O'Connor (1961) near Manganese Peak, is included in Sawatch map unit.

Thickness near Manganese Peak, 78 m; on Fossil Ridge, 9–58 m, but averaging 36 m; on Cross Mountain, possibly as thick as 106 m, but structurally complicated by thrust faults; in Pitkin area, 7–40 m; west of Tincup, 35–45 m; at Cumberland Pass, 32 m

Yg Granite (Middle(?) Proterozoic)—Mass of fine-grained, equigranular, muscovite-biotite granite in far southeastern corner of map that is northwesternmost exposure of large mass of granite on Monarch Pass and area to the north (Tweto and others, 1976). Middle(?) Proterozoic age assignment based on textural, mineralogical, and chemical (Ed DeWitt, unpub. data, 1990) similarity of granite to granitic bodies such as the St. Kevin Granite in the Sawatch Range

Yt Granite of Taylor River (Middle (?) Proterozoic)—Exposed along the Taylor River, especially in the steep canyon walls between Crystal Creek and South Lottis Creek in T. 15 S., R. 83 W., secs., 9 and 10. Body extends past map area to north and west and is exposed in the steep canyon walls of Spring Creek, northeast of Almont. Granite extends north of the map area and crops out in the southwest and western parts of Taylor Park, north of Fossil Ridge (Fridrich and others, 1998). Granite not exposed east of Gold Creek, the Cameron Creek fault, or Cross Mountain. Known southernmost part is body south of Comanche Creek on the north side of the Willow Monzonite (newly named). Pluton is a minimum of 12 mi by 12 mi in extent and was included in parts of Yg and YXg by Tweto (1979).

Granite is light tan to light gray, medium grained, equigranular to slightly porphyritic, homogeneous and undeformed except in shear zones and faults of Phanerozoic age, leucocratic, and is characterized by phenocrysts of both muscovite and biotite. Characteristic turbid plagioclase (0.5–2.5-mm diameter) that is altered to sericite was originally oligoclase. Clear, unaltered intermediate microcline and perthite (1–10 mm diameter) form phenocrysts and overgrow plagioclase. Anhedral to amoeboid quartz is interstitial to feldspar. Minor myrmekite is noted along phenocryst margins. Muscovite (0.4–2.5 mm diameter) forms both original phenocrysts and minor alteration products along cleavage traces of plagioclase. Green to brown, ragged, ilmenite(?) -rich biotite (0.2–1.0 mm diameter) is less abundant than muscovite. Pink garnet (0.1–0.2 mm diameter) that ranges from fresh to variably resorbed and cracked is characteristic of the most leucocratic varieties of granite.

Average modal composition of the most mafic phase (#6-30-82-6) is oligoclase (37%), microcline and perthite (22%), quartz (32%), biotite (5%), muscovite (3.5%), ilmenite (0.2%), and epidote (0.1%),

and traces of apatite and zircon. Average modal composition of the least leucocratic phase (#7-13-82-6) is oligoclase (21%), microcline and perthite (23%), quartz (44%), muscovite (11%), garnet (0.8%), ilmenite (0.2%), and traces of apatite and zircon.

The granite is alkali-calcic, strongly peraluminous, and has little alkali or Fe enrichment (fig. 6). The granite is characterized by Sr and Zr concentrations averaging less than 100 ppm and U concentrations of 3–14 ppm (table 8). Granite of similar textural, mineralogical, and chemical composition is exposed along Spring Creek, to the north of the map area, and appears to be the granite of Taylor River. Both are similar in composition to the St. Kevin Granite in the Sawatch Range (fig. 6), but characterized by lower concentrations of Th (Fridrich and others, 1998).

Middle Proterozoic age is based on Rb-Sr geochronology of Wetherill and Bickford (1965) and U-Th-Pb geochronology of this study. Sample #CO-64 of Wetherill and Bickford (1965), from the granite of Taylor River, has a whole-rock potassium feldspar-plagioclase-muscovite isochron of 1380 ± 19 Ma (mean squares of the weighted deviates (MSWD) of 0.03 recalculated by Ed DeWitt using program of Ludwig, 1990) and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (Sr_i) of 0.715. The granite must have been formed from partial melting of Early Proterozoic crustal materials or must have been extensively contaminated with rubidium-rich crust to have a Sr_i ratio this high. Muscovite containing traces of quartz and feldspar from the granite of Taylor River near Lamphier Lake has a conventional K-Ar date of 1326 ± 44 Ma (table 9). One zircon fraction from sample #6-30-82-6 along the Taylor River in T. 15 S., R. 83 W., sec. 9 has a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 1406 Ma (Ed DeWitt and R.E. Zartman, unpub. data, 1990)

YXgb Gabbro dikes (Middle to Early Proterozoic)—

Dark-greenish-black, fine-grained, equigranular to slightly porphyritic dikes of olivine gabbro composition. Most dikes 1–3 m wide and variably to highly foliated along their margins to mixture of biotite, dark-green chlorite, plagioclase, and minor black tourmaline. West- to northwest-striking dikes cut Henry Mountain Granite (newly named) in cirque wall south of Henry Mountain (T. 51 N., R. 3 E., sec. 15, northeast part) and cut Fairview Peak Granodiorite (newly named) along ridge north of Fairview Peak (T. 51 N., R. 4 E., sec. 9, central part). Includes some parts of quartz diorite of Zech (1988).

Subequal amounts of fine-grained, euhedral hornblende and biotite (maximum grain size of 0.2 x 0.3 mm) and interstitial plagioclase and minor quartz include and overgrow early allanite rimmed by epidote, sphene, and magnetite and apatite. Estimated

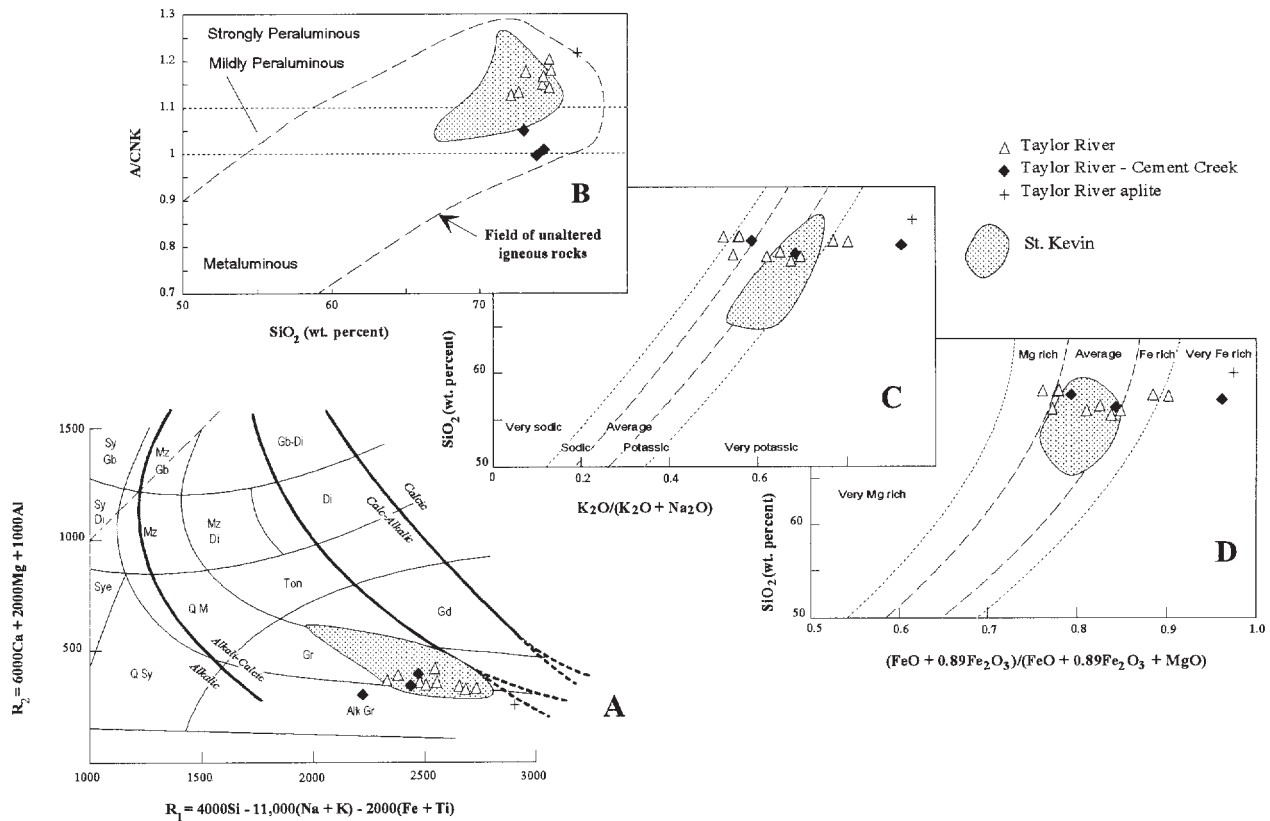


Figure 6. Summary geochemical diagrams for granite of Taylor River (unit Yt). Rock names listed in figure 4. Data from this study, Urbani and Blackburn (1974), and Earley (1987). Refer to table 8 for analytical data. (A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998). (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O . (C) Alkali classification diagram ($\text{K}_2\text{O}/(\text{K}_2\text{O} + \text{Na}_2\text{O})$ versus SiO_2). Field boundaries from this study. (D) Iron enrichment classification diagram $(\text{FeO} + 0.89\text{Fe}_2\text{O}_3)/(\text{FeO} + 0.89\text{Fe}_2\text{O}_3 + \text{MgO})$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

average mode is hornblende (35–40%), biotite (35–40%), plagioclase (7–10%), quartz (2–5%), sphene (1–2.5%), magnetite plus ilmenite (0.2–0.7%), allanite and epidote (1–3%), and trace apatite.

One sample of the gabbro is alkali-calcic, metaluminous, very potassic, very Mg rich (fig. 7), and characterized by very high Rb (>3,500 ppm) and Sr (>1,300 ppm; table 10). Quartz-bearing gabbro plug in the Almont area (fig. 7) is potassic and very Mg rich, but is calcic and may result from pyroxene accumulation (plots outside the field of unaltered igneous rocks on fig. 7B). The elevated Rb, Sr, and K_2O suggest that this gabbro may be unrelated to other, more numerous gabbro and metagabbro bodies discussed below.

Middle to Early Proterozoic age based on observation that dikes cut Henry Mountain Granite but have not been found cutting the granite of Taylor River. Dikes are similar in major-element composition to older metagabbro dikes(?) in the Almont area (Urbani and Blackburn, 1974), but their alkali-rich nature is distinctly different (fig. 7; table 10). Also, metagabbro dikes (?) in the

Almont area apparently are older than the granodiorite at Almont (biotite tonalite of Urbani and Blackburn, 1974), which we equate with the Fairview Peak Granodiorite. Dikes may be younger than the granite of Taylor River, but have a restricted areal extent. If so, the dikes may be about 1150 Ma and related to diabase dike and sill swarms that are common in Arizona and California (Granger and Raup, 1959; Shride, 1967; Wrucke, 1989). Dikes could also be Early Cambrian or Late Proterozoic and be related to mafic plutons and carbonatite complexes such as those in south-central Colorado (Olson and others, 1977; Armbrustmacher and Hedge, 1982; Bickford and others, 1989a).

Xa Granodiorite at Almont (Early Proterozoic)—Compositionally layered to massive biotite granodiorite that crops out in the Taylor River canyon at and downstream from Almont. Originally referred to as biotite tonalite (Urbani and Blackburn, 1974). Intrudes Early Proterozoic metasedimentary units, including metamorphosed sandstone, graywacke, and shale. Cut by quartz-bearing gabbro.

Table 8. Major- and minor-element chemistry of the Middle Proterozoic granite of Taylor River (unit Ye) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- and 8- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample 6-30-82-6 and 7-10-82-1 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmachem Exploration, Seattle, WA; Fe_TO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Earley (1987) for analytical techniques for granite samples beginning with 65; see Urbani (1975) for analytical techniques for granite samples beginning with CC]

Sample number	65G	6-30-82-6	7-10-82-4	7-10-82-1	7-13-82-6	8-5-82-2
Major elements						
SiO ₂	72.10	72.60	72.80	73.10	74.20	74.30
TiO ₂	0.13	0.16	0.10	0.11	0.04	0.05
Al ₂ O ₃	14.22	14.20	14.50	14.20	14.20	14.40
Fe ₂ O ₃	0.78	0.36	--	0.33	0.28	0.24
Fe _T O ₃	--	--	1.21	--	--	--
FeO	0.49	1.22	--	0.79	0.21	0.17
MnO	0.02	0.02	0.04	0.03	0.15	0.08
MgO	0.23	0.36	0.32	0.31	0.05	0.05
CaO	0.73	1.17	0.84	0.62	0.74	0.58
Na ₂ O	2.95	3.03	3.32	3.08	4.00	3.90
K ₂ O	5.97	5.03	5.41	5.45	4.12	4.52
P ₂ O ₅	0.09	0.09	0.14	0.14	0.05	0.05
H ₂ O+	0.49	0.53	--	0.65	0.38	0.42
H ₂ O-	--	0.01	--	0.01	0.01	0.01
CO ₂	0.01	0.06	--	0.02	0.01	0.01
LOI	--	--	0.56	--	--	--
TOTAL	98.21	98.83	99.24	98.84	98.43	98.77
Minor elements						
Ba	501	508	310	308	49	58
Rb	296	213	305	283	421	433
Sr	87	95	67	73	22	21
Y	44	25	33	32	34	38
Zr	114	135	100	80	35	29
Nb	--	20	30	23	42	48
U	--	4.89	3.98	4.76	12.00	13.90
Th	--	27.30	14.00	18.00	16.10	< 5.2
Calculations						
R ₁	2322	2536	2371	2467	2543	2494
R ₂	368	422	390	360	360	347
A/CNK	1.13	1.13	1.13	1.18	1.15	1.17
Fe No.	0.84	0.81	0.77	0.78	0.90	0.89
K No.	0.67	0.62	0.62	0.64	0.51	0.54

Composition and texture similar to Fariview Peak Granodiorite.

The granodiorite is alkali-calcic to calc-alkalic, metaluminous to strongly peraluminous, and averages Mg rich (fig. 8). Similar in composition to the Fairview Granodiorite. The unusual

sodic nature, high Sr concentration, and low Rb (table 11) are distinguishing characteristics shared by the Kroenke Granodiorite (fig. 8) in the Sawatch Range (Fridrich and others, 1998). The granodiorite at Almont (fig. 8) shows greater scatter on most diagrams, but has the same

Table 8. Major- and minor-element chemistry of the Middle Proterozoic granite of Taylor River—*continued*.

Sample number	7-7-82-2	8-8-82-4	7-26-82-3	7-2-82-4	CC299	CC297	CC298
Major elements							
SiO ₂	74.70	74.70	74.80	76.60	72.95	73.82	74.29
TiO ₂	0.07	0.11	0.09	0.02	0.28	0.05	0.22
Al ₂ O ₃	14.10	13.10	13.30	12.60	13.22	13.04	12.68
Fe ₂ O ₃	0.23	--	--	--	1.11	0.08	0.30
Fe ₁ O ₃	--	1.17	1.18	0.21	--	--	--
FeO	0.24	--	--	--	1.73	1.20	1.57
MnO	0.10	0.03	0.05	0.03	0.04	0.03	0.03
MgO	0.14	0.30	0.30	0.01	0.51	0.05	0.48
CaO	0.56	0.54	0.54	0.10	1.04	0.42	0.66
Na ₂ O	3.64	3.36	3.35	1.37	3.17	4.40	3.36
K ₂ O	4.37	4.60	4.44	7.33	5.09	4.73	5.43
P ₂ O ₅	0.13	0.09	0.10	0.12	--	--	--
H ₂ O+	0.51	--	--	--	--	--	--
H ₂ O-	0.01	--	--	--	--	--	--
CO ₂	0.04	--	--	--	--	--	--
LOI	--	0.69	0.70	0.53	--	--	--
TOTAL	98.84	98.69	98.85	98.91	99.14	97.82	99.02
Minor elements							
Ba	125	220	150	75	791	184	449
Rb	274	296	334	504	254	332	257
Sr	33	43	31	27	127	77	141
Y	13	42	38	1	--	--	--
Zr	37	104	92	22	185	50	150
Nb	20	35	43	58	--	--	--
U	2.74	13.60	7.28	2.46	--	--	--
Th	5.20	20.60	19.50	< 2	--	--	--
Calculations							
R ₁	2646	2674	2721	2895	2459	2211	2428
R ₂	343	330	334	258	396	303	343
A/CNK	1.20	1.14	1.18	1.22	1.05	1.00	1.01
Fe No.	0.76	0.78	0.78	0.97	0.84	0.96	0.79
K No.	0.55	0.58	0.57	0.84	0.62	0.52	0.62

overall chemical attributes as the Fairview Granodiorite (table 11)

Xf Fairview Peak Granodiorite (Early Proterozoic)—Named herein for exposures at its type area on and surrounding Fairview Peak (T. 51 N., R. 4 E., secs. 16 and 17) and the mountainous terrain extending north from Fairview Peak. Granodiorite intrudes Early Proterozoic metavolcanic rocks and the Henry Mountain Granite and is cut by the granite of Taylor River. Kroenke Granodiorite in the Sawatch Range to the north and east (Barker and Brock, 1965; Brock and Barker, 1972; Barker and others, 1974) is equivalent to this granodiorite. Fairview Peak Granodiorite in the Cumberland Pass and Tincup areas was called granite gneiss by Goddard (1935), gneissic granite by Trammel (1961), gneissic quartz monzonite by Koksoy (1961), and gneissic granite by Rosenlund (1984) and Jefferson (1985). East of Pitkin,

Whitebread (1951) and Dings and Robinson (1957) referred to the Fairview Peak as gneissic granite.

The granodiorite is homogeneous and possesses a foliation defined by thin ribbons of aligned mafic minerals. Minor subhedral plagioclase phenocrysts and anhedral quartz- and plagioclase-rich zones between the ribbons of mafic minerals enhance the foliation. Near contacts with metavolcanic rocks, foliation in the granodiorite tends to parallel the contact and dip from 15 to 50 degrees toward the country rocks; away from the contacts the foliation is less well developed and more randomly oriented. On the east side of the pluton the foliation strikes between northwest and north and dips northeast to east; on the west and south sides the foliation strikes between north and northwest and dips southwest to west. The resulting pattern is a northwest-elongate foliation dome that coincides with the outcrop of the granodiorite.

Table 9. K-Ar analytical data from Middle Proterozoic granite of Taylor River (unit Yt), Fossil Ridge area, Gunnison County, Colorado.

[$^{40}\text{Ar}_R$, radiogenic Ar; constants used $\lambda_b = 4.962 \times 10^{-10}/\text{yr}$, $\lambda_e = 0.581 \times 10^{-10}$ yr, $^{40}\text{K}/\text{Total K} = 1.167$; sample collected by AMAX Exploration, Denver, CO, from dike cutting metasedimentary rocks, Mill Lake cirque; sample analyzed at Geochron Laboratories, Cambridge, MA, Laboratory reference number M-2549]

Sample No., mineral	$^{40}\text{Ar}_R$, ppm	^{40}K , ppm	K (wt. %)	$^{40}\text{Ar}_R/\text{Total } ^{40}\text{Ar}$	Date (Ma)	+/- (Ma)
X-61962, muscovite; trace biotite	1.1825	10.574	8.668	0.988	1326	44

The regional foliation developed in the Early Proterozoic metavolcanic and metasedimentary rocks and older Early Proterozoic plutonic rocks is not the same as the foliation in the Fairview Peak Granodiorite, which is younger and related to emplacement of the granodiorite. Northeast- to north-striking regional foliation is cut, deflected, and warped away from the granodiorite. Foliation in the granodiorite is interpreted to be mostly

related to high-temperature solid state deformation of a crystal-rich mush containing phenocrysts of biotite, plagioclase, and minor amphibole during final emplacement of the Fairview Peak Granodiorite.

The granodiorite is light to medium gray, medium grained, equigranular to very slightly porphyritic, moderately to strongly foliated, and contains biotite as the dominant mafic mineral.

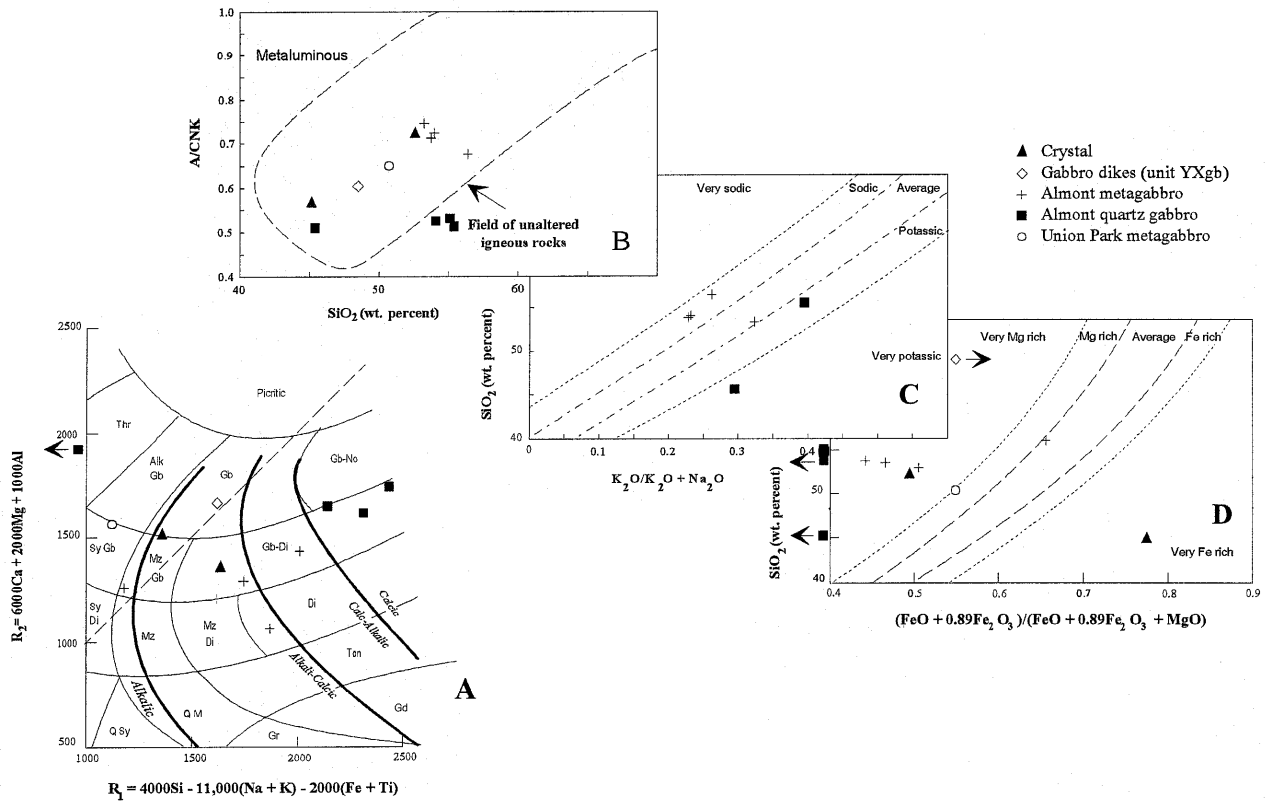


Figure 7. Summary geochemical diagrams for Crystal Creek Gabbro (unit Xc), gabbro dikes (unit YXgb), and gabbroic rocks in the Almont area. Thr, theralite; Alk Gb, alkali gabbro; Ol Gb, olivine gabbro; Gb-No, gabbro-norite; Sy Gb, syenogabbro; Mz Gb, monzogabbro; Gb-Di, gabbro-diorite; Sy Di, syenodiorite; Mz, Monzonite; Mz Di, monzodiorite; Di, diorite; Q Sy, quartz syenite; Q M, quartz monzonite; Ton, tonalite; Gr, granite; Gd, granodiorite. Data from this study and Urbani and Blackburn (1974). Position of samples that plot off the diagrams shown by arrows. Refer to table 10 for analytical data.

(A) R_1/R_2 major element classification diagram (De la Roche and others, 1980. Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).

(B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O .

(C) Alkali classification diagram ($\text{K}_2\text{O}/(\text{K}_2\text{O} + \text{Na}_2\text{O})$ versus SiO_2). Field boundaries from this study.

(D) Iron enrichment classification diagram $(\text{FeO} + 0.89\text{Fe}_2\text{O}_3)/(\text{FeO} + 0.89\text{Fe}_2\text{O}_3 + \text{MgO})$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

Table 10. Major- and minor-element chemistry of Early to Middle Proterozoic gabbroic rocks (units YXgb, Xc, and Xmg) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample 7-2-82-5, 7-1-82-2, and 6-30-82-7 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmachem Exploration, Seattle, WA; Fe₁O₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Urbani and Blackburn (1974) for analytical techniques for gabbro samples in the Almont area beginning with M or G]

Map unit	YXgb	Xc	Xc	Metagabbro in Union Park	Xmg	Xmg	Xmg	Xmg
Sample number	7-10-82-6	7-2-82-5	7-1-82-2	6-30-82-7	MG194	MG246	MG291	MG93A
Major elements								
SiO ₂	48.20	44.94	52.30	50.44	52.94	53.46	53.68	56.08
TiO ₂	1.02	3.07	1.15	0.87	1.45	1.90	1.59	1.43
Al ₂ O ₃	12.20	12.87	14.20	16.24	13.54	13.48	12.58	12.10
Fe ₂ O ₃	1.91	7.70	2.41	2.95	2.74	3.87	4.35	4.56
FeO	6.56	9.63	5.50	5.50	5.33	4.51	4.39	4.19
MnO	0.14	0.25	0.14	0.15	0.19	0.12	0.18	0.16
MgO	12.20	4.83	7.63	6.70	7.65	9.21	10.52	4.36
CaO	7.68	9.63	6.65	8.57	6.08	5.02	6.25	5.76
Na ₂ O	1.30	2.15	2.36	4.18	3.27	4.97	3.04	3.65
K ₂ O	3.74	1.42	3.31	2.15	1.57	1.48	0.92	1.30
P ₂ O ₅	0.81	0.58	0.63	0.33	--	--	--	--
H ₂ O+	2.08	--	--	--	3.63	2.96	1.06	4.12
H ₂ O-	0.04	--	--	--	0.51	0.43	0.20	0.56
CO ₂	0.01	--	--	--	0.56	0.46	0.19	0.63
LOI	--	0.86	1.15	1.32	--	--	--	--
TOTAL	97.89	97.93	97.79	99.40	99.46	101.87	98.95	98.90
Minor elements								
Ba	3780	--	2600	--	880	1919	825	1173
Rb	151	--	106	--	101	96	103	152
Sr	1354	--	1090	--	303	381	159	199
Y	30	--	19	--	--	--	--	--
Zr	257	--	355	--	336	738	223	187
Nb	10	--	11	--	--	--	--	--
U	3.24	--	2.63	--	--	--	--	--
Th	15.00	--	12.80	--	--	--	--	--
Metals								
Cu	89	--	99	--	47	51	59	43
Pb	12	--	23	--	12	14	49	93
Zn	129	--	134	--	--	--	--	--
Ni	504	--	242	--	269	467	407	341
Cr	--	--	--	--	355	390	701	794
Co	--	--	--	--	40	38	45	49
V	--	--	--	--	136	197	292	215
Calculations								
R ₁	1618	1359	1635	1123	1743	1179	2008	1867
R ₂	1666	1522	1368	1568	1296	1258	1437	1070
A/CNK	0.61	0.57	0.73	0.66	0.75	0.71	0.73	0.68
Fe No.	0.40	0.77	0.49	0.55	0.50	0.46	0.44	0.66
K No.	0.74	0.40	0.58	0.34	0.32	0.23	0.23	0.26

Table 10. Major- and minor-element chemistry of Early to Middle Proterozoic gabbroic rocks—*continued*.

Map unit	YXgb?	YXgb?	YXgb?	YXgb?
Sample number	G0078	G0090	G0075	G0074
Major elements				
SiO ₂	45.13	53.79	54.85	55.13
TiO ₂	2.28	0.94	0.78	0.87
Al ₂ O ₃	13.62	10.42	10.42	9.78
Fe ₂ O ₃	2.28	2.32	2.52	2.90
FeO	5.07	4.26	4.79	3.64
MnO	0.10	0.12	0.13	0.36
MgO	12.03	12.47	13.37	12.58
CaO	10.06	7.73	8.21	7.50
Na ₂ O	3.99	2.54	1.74	2.29
K ₂ O	1.68	1.45	1.65	1.50
P ₂ O ₅	--	--	--	--
H ₂ O+	2.10	2.47	0.26	2.71
H ₂ O-	0.44	0.37	0.11	0.40
CO ₂	0.49	0.39	0.07	0.43
LOI	--	--	--	--
TOTAL	99.27	99.27	98.90	100.09
Minor elements				
Ba	514	333	182	123
Rb	33	28	73	117
Sr	860	505	272	117
Y	--	--	--	--
Zr	78	86	76	78
Nb	--	--	--	--
U	--	--	--	--
Th	--	--	--	--
Metals				
Cu	72	76	27	42
Pb	13	19	18	44
Zn	--	--	--	--
Ni	259	515	611	516
Cr	353	861	1398	1158
Co	41	24	31	35
V	152	115	139	107
Calculations				
R ₁	940	2140	2432	2311
R ₂	1940	1650	1746	1618
A/CNK	0.51	0.53	0.53	0.51
Fe No.	0.37	0.34	0.35	0.33
K No.	0.30	0.36	0.49	0.40

Subhedral to anhedral calcic oligoclase phenocrysts (1 x 2 mm) are set in a finer grained groundmass of anhedral calcic oligoclase, perthite, and quartz (average grain size 0.2 mm). Mortar-textured quartz and minor myrmekite are developed around plagioclase phenocrysts. Aligned mafic ribbons and clots (typically 0.5 x 4.0 mm maximum) of euhedral biotite, minor hornblende, allanite rimmed by epidote, sphene, magnetite, and apatite are present, but

individual grains (0.2 x 0.5 mm) of euhedral biotite, sphene, and amphibole are randomly distributed throughout the rock as well. Although the alignment of mafic ribbons and clots and individual grains of biotite in the groundmass define the foliation, many biotite grains within clots and ribbons have random orientations. Minor igneous(?) epidote-group minerals are intergrown with biotite, hornblende, and sphene in some mafic clots. Presence of primary phenocrysts, anhedral nature of most phenocrysts and all groundmass minerals, prominent mortar texture of much quartz, and euhedral nature of early formed phenocrysts such as biotite, hornblende, and sphene is interpreted as evidence of early magmatic flow foliation overprinted by high-temperature, solid-state deformation as summarized by Paterson and others (1989).

Average modal composition of the granodiorite is calcic oligoclase (52%), quartz (24%), biotite (23%), perthite (8%), hornblende (0.5–2.5%), sphene (0.9–2.3%), apatite (0.3%), epidote-group minerals (1.5%), magnetite and ilmenite (0.2%), and trace amounts of allanite and zircon.

The granodiorite is alkali-calcic, metaluminous to strongly peraluminous, and averages Mg rich (fig. 8). The unusual sodic nature, high Sr concentration (> 500 ppm), and low Rb (< 60 ppm; table 11) are features shared by the Kroenke Granodiorite (fig. 8) in the Sawatch Range (Barker and others, 1974; Fridrich and others, 1998), which we correlate with the Fairview Peak.

Early Proterozoic age assignment based on interpretation that high-temperature, solid-state fabric in the granodiorite formed after development of regional fabric and by Rb-Sr geochronology of Kroenke Granodiorite and unpublished U-Th-Pb geochronology by Ed DeWitt and R.E. Zartman. A Rb-Sr whole-rock isochron date of 1670 ± 100 Ma (recalculated by DeWitt using the program of Ludwig, 1990; York Model 1 fit-MSWD = 3.22) was determined for the Kroenke Granodiorite in the Sawatch Range to the northeast of this map by Barker and others (1974). One fraction of zircon from sample #8-7-82-1 from the southeast shoulder of Fairview Peak in T. 51 N., R. 4 E., sec. 16 (southwest part) has a ²⁰⁷Pb/²⁰⁶Pb date of 1640 Ma (Ed DeWitt and R.E. Zartman, unpub. data, 1990)

Xmg Metagabbro near Almont (Early Proterozoic)—

Metagabbro bodies apparently intruded by granodiorite at Almont (Urbani and Blackburn, 1974). Shown only in Almont area. Metagabbro consists of fine-grained intergrowth of plagioclase, actinolite partially replaced by biotite, and epidote.

Metagabbro ranges widely in composition, from calc-alkalic gabbro-diorite to alkalic syenogabbro, is predominantly very Mg rich, and has no preferred alkali enrichment (fig. 7). The very Mg-rich nature of the metagabbro distinguishes it from gabbro

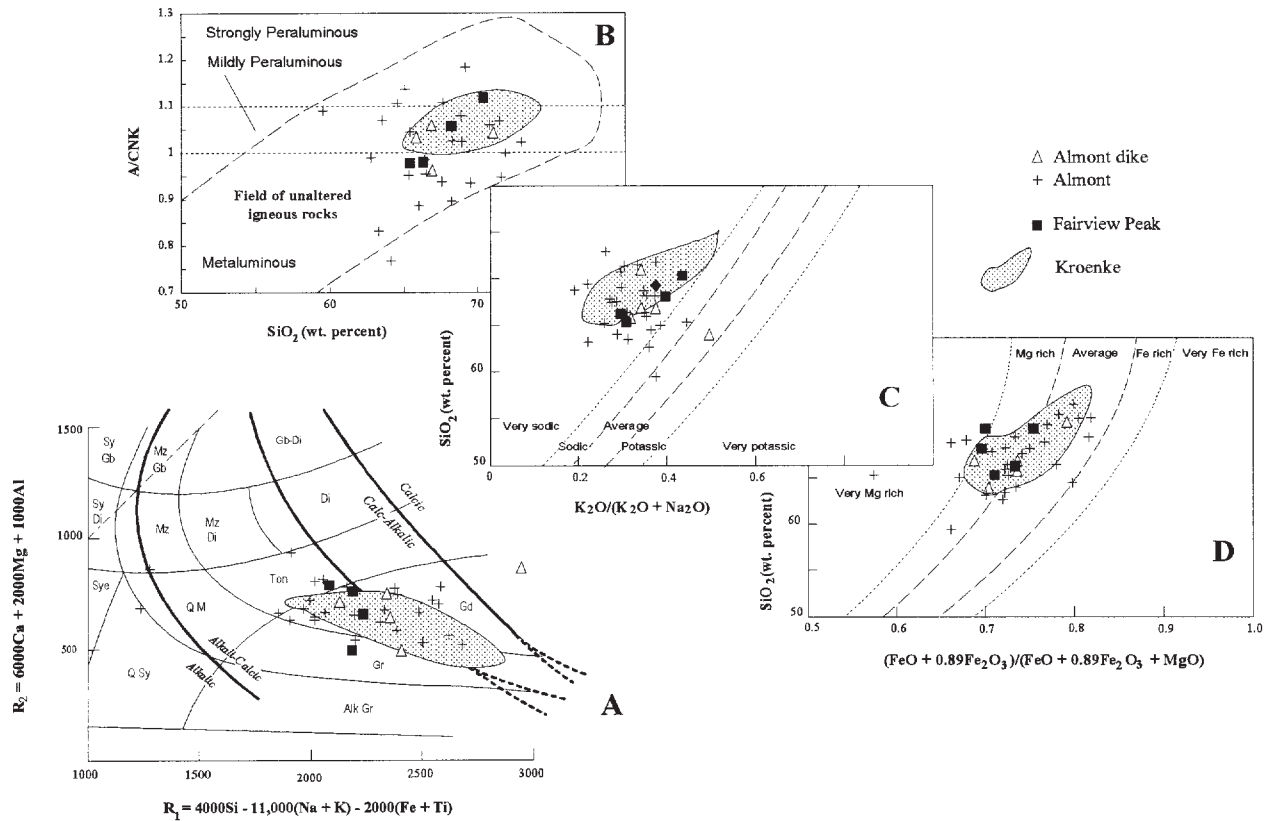


Figure 8. Summary geochemical diagrams for Fairview Peak Granodiorite (unit Xf) and granodiorite in the Almont area. Rock names listed in figure 4. Data from this study and Urbani and Blackburn (1974). Refer to table 11 for analytical data. (A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998). (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O . (C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study. (D) Iron enrichment classification diagram $(FeO + 0.89Fe_2O_3)/(FeO + 0.89Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

bodies (unit Xgb) associated with older metabasaltic rocks (unit Xmv).

Early Proterozoic age based on observation by Urbani and Blackburn (1974) that granodiorite at Almont cuts metagabbro. Age relation to Crystal gabbro unknown

Xh Henry Mountain Granite (Early Proterozoic)—Named herein for exposures at its type area on Henry Mountain (T. 51 N., R. 3 E., secs. 14 and 15) and the mountainous terrane north of Fossil Ridge. Granite intrudes Early Proterozoic metasedimentary and metavolcanic rocks and it is cut by the granite of Taylor River. Granite crops out to north, outside this map area, in the drainage of Spring Creek and in the western part of Taylor Park (Fridrich and others, 1998). In northern Taylor Park the granite (unit pCg) and porphyritic quartz monzonite (unit pCpq) of Bryant (1970) are phases of the Henry Mountain Granite. To the southwest, in the Quartz Creek pegmatite district, Henry Mountain Granite is represented by coarse-grained granite (unit gr, Staatz and Trites, 1955), which was informally

called the Quartz Creek granite by Aldrich and others (1956). Henry Mountain Granite in the Quartz Creek pegmatite district is continuous to the south and equivalent to the granite of Wood Gulch (Olson, 1976). Before emplacement of younger Proterozoic plutons, the batholith containing the Henry Mountain Granite was at least 40 mi north-south by 20 mi east-west. Rocks believed to be equivalent to the Henry Mountain Granite crop out as far northeast as Leadville and as far east as Trout Creek Pass, east of Buena Vista. If all these rocks belong to the Henry Mountain Granite, the entire batholith may have been as large as 1,600 mi^2 .

Most of the granite is homogeneous and undeformed, but possesses a flow foliation that strikes northeast and dips steeply. The foliation is defined by aligned, tabular phenocrysts of perthitic microcline. Only in isolated outcrops in the cirques east of South Lottis Creek and southeast of Cross Mountain is the Henry Mountain Granite tectonically foliated. In those localities the microcline phenocrysts are augen within a matrix of recrystallized plagioclase,

Table 11. Major- and minor-element chemistry of Early Proterozoic Fairview Peak Granodiorite (unit Xf) and granodiorite at Almont (unit Xa) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- and 8- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample S9-30-88-3, 6-30-82-3, S9-30-88-1, 6-30-82-2, and 6-30-82-1A determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmagem Exploration, Seattle, WA; Fe₂O₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Urbani and Blackburn (1974) for analytical techniques for granodiorite and dike samples in the Almont area beginning with T; additional geochemical results from the granodiorite at Almont are present in Urbani and Blackburn (1974)]

Map unit	Xf	Xf	Xf	Xf	Xa	Xa	Xa	Xa
Sample number	7-26-82-1	7-26-82-2	7-12-82-2	8-7-82-1	S9-30-88-3	T294	T190A	6-30-82-3
Major elements								
SiO ₂	65.40	66.30	68.20	70.40	59.51	63.29	63.50	65.07
TiO ₂	0.57	0.46	0.35	0.24	0.46	0.50	0.64	0.38
Al ₂ O ₃	16.40	16.10	16.10	15.70	19.71	15.82	15.88	17.29
Fe ₂ O ₃	1.05	1.09	0.83	0.57	1.36	2.54	2.40	0.30
FeO	2.24	2.00	1.57	0.95	2.95	2.09	3.11	2.55
MnO	0.04	0.04	0.03	0.02	0.05	0.07	0.07	0.04
MgO	1.40	1.09	1.02	0.63	2.15	1.88	2.04	1.39
CaO	3.72	3.66	2.72	1.47	3.45	4.96	2.89	2.57
Na ₂ O	4.72	4.68	4.38	4.61	5.16	5.15	4.50	4.56
K ₂ O	2.10	1.96	2.88	3.53	3.11	1.47	2.05	2.85
P ₂ O ₅	0.24	0.16	0.11	0.08	0.35	--	--	0.28
H ₂ O+	--	0.58	0.67	0.57	--	1.22	1.43	--
H ₂ O-	--	0.01	0.01	0.05	--	0.22	0.25	--
CO ₂	--	0.01	0.10	0.06	--	0.21	0.24	--
LOI	0.45	--	--	--	0.98	--	--	0.70
TOTAL	98.83	98.13	98.97	98.88	99.24	99.42	99.00	97.98
Minor elements								
Ba	710	647	687	695	960	897	984	830
Rb	43	61	59	86	97	52	80	75
Sr	681	491	524	308	680	928	669	655
Y	8	13	9	9	< 5	--	--	< 5
Zr	217	185	133	116	140	165	95	110
Nb	13	16	11	14	14	--	--	10
U	1.50	2.04	1.42	1.82	--	--	--	--
Th	3.60	3.30	4.50	7.20	--	--	--	--
Metals								
Cu	--	8	14	31	--	17	5	--
Pb	--	13	--	10	--	5	6	--
Zn	96	68	74	60	--	--	--	--
Ni	--	88	33	41	--	33	25	--
Cr	--	--	--	--	--	74	35	--
Co	--	--	--	--	--	8	7	--
V	--	--	--	--	--	56	38	--
Calculations								
R ₁	2079	2200	2239	2179	1276	1907	1988	1959
R ₂	789	761	657	497	862	934	722	683
A/CNK	0.98	0.98	1.06	1.12	1.09	0.83	1.07	1.14
Fe No.	0.71	0.73	0.69	0.70	0.66	0.70	0.72	0.67
K No.	0.31	0.30	0.40	0.43	0.38	0.22	0.31	0.38

Table 11. Major- and minor-element chemistry of Early Proterozoic Fairview Peak Granodiorite (unit Xf) and granodiorite at Almont (unit Xa)—*continued*.

Map unit	Xa dike	Xa	Xa	Xa	Xa	Xa
Sample number	T136A	S9-30-88-1	6-30-82-2	6-30-82-1A	T76	T272
Major elements						
SiO ₂	67.57	67.87	68.27	69.14	70.82	71.48
TiO ₂	0.33	0.33	0.33	0.31	0.27	0.34
Al ₂ O ₃	14.98	16.51	16.38	16.79	15.41	14.58
Fe ₂ O ₃	0.22	0.65	2.10	0.56	0.91	1.42
FeO	2.74	2.20	0.75	1.95	1.77	1.50
MnO	0.05	0.03	0.05	0.03	0.04	0.03
MgO	3.19	1.16	1.02	1.17	0.78	0.68
CaO	3.07	2.76	2.57	2.61	2.27	2.28
Na ₂ O	5.07	4.77	5.08	4.51	4.98	4.51
K ₂ O	1.93	1.77	2.77	1.90	2.09	1.96
P ₂ O ₅	--	0.15	0.25	0.27	--	--
H ₂ O+	1.08	--	--	--	0.67	0.82
H ₂ O-	0.20	--	--	--	0.16	0.17
CO ₂	0.19	--	--	--	0.13	0.15
LOI	--	0.74	0.50	0.50	--	--
TOTAL	100.62	98.94	100.07	99.74	100.30	99.92
Minor elements						
Ba	921	640	720	450	2185	713
Rb	82	66	52	80	35	58
Sr	776	610	570	570	584	608
Y	--	< 5	< 5	< 5	--	--
Zr	212	130	120	120	113	73
Nb	--	13	12	12	--	--
U	--	--	--	--	--	--
Th	--	--	--	--	--	--
Metals						
Cu	11	--	--	--	54	4
Pb	8	--	--	--	5	6
Zn	--	--	--	--	--	--
Ni	84	--	--	--	9	9
Cr	109	--	--	--	38	44
Co	11	--	--	--	5	4
V	48	--	--	--	20	21
Calculations						
R ₁	2158	2326	2013	2482	2380	2614
R ₂	781	677	647	667	584	564
A/CNK	0.94	1.12	1.02	1.18	1.06	1.07
Fe No.	0.48	0.71	0.72	0.68	0.77	0.80
K No.	0.28	0.27	0.35	0.30	0.30	0.30

biotite, and muscovite. In the cirques east of South Lottis Creek the tectonically foliated Henry Mountain Granite is cut by undeformed fine-grained granite and aplite dikes related to the granite. Along the southern contact of the granite with metasedimentary and metavolcanic rocks and the Willow Monzonite (newly named) are extensive pegmatite swarms that extend into the Quartz Creek pegmatite district to the southwest. These pegmatites are

genetically related to the Henry Mountain Granite and its late-stage fine-grained granite and aplites (Staatz and Trites, 1955). Pegmatite bodies are biotite- and beryl-rich, but contain anomalously little tourmaline. Significantly, however, fine-grained granite and aplite of the Henry Mountain Granite contain disseminated tourmaline, and metasedimentary rocks along Fossil Ridge from Beaver Creek to Alder Creek are extensively veined

and replaced by tourmaline. Apparently, most tourmaline crystallized in late-stage aplite bodies before final formation of the tourmaline-depleted pegmatite bodies in the Quartz Creek district.

The normal granite is pinkish tan and black, coarse grained, strongly porphyritic (large microcline phenocrysts > smaller quartz phenocrysts), undeformed to moderately flow foliated, and contains both biotite and muscovite. Abundant perthitic microcline phenocrysts as large as 1 × 1.8 cm and less numerous quartz phenocrysts as large as 1 cm are set in a groundmass of albite to sodic oligoclase (3 × 4 mm common, but as large as 4 × 6 mm) and minor myrmekite. All plagioclase is turbid and partially altered to sericite and muscovite, both of which are preferentially aligned along twin planes. Biotite and muscovite constitute most of the interstitial material and are present randomly throughout the granite, but more commonly in mafic clots. The clots are as large as 3 × 5 mm and contain biotite > muscovite >> apatite > ilmenite/magnetite, allanite overgrown by epidote, and zircon.

Average modal compositions of the granite are difficult to estimate because of its coarse grain size and porphyritic texture, but probably average microcline (32%), quartz (28%), albite and sodic oligoclase (18%), biotite (12%), muscovite (8%), magnetite and ilmenite (1.4%), apatite (0.5%), and trace amounts of zircon, allanite, and epidote.

A border phase is preserved locally on the southeast shoulder of Henry Mountain and on the divide that separates Crystal Creek and Beaver Creek in T. 51 N., R. 3 E., sec. 12. Conspicuously lacking in the border phase are the large perthitic microcline phenocrysts. Phenocrysts of unstrained to recrystallized quartz (6 × 10 mm) and plagioclase (3 × 5 mm) replaced by fine-grained muscovite are set in a groundmass of fine-grained (0.11 × 1.2 mm) quartz, albite(?), and microcline. Muscovite is throughout the groundmass as fine-grained, individual grains (0.3 × 0.4 mm), mats of grains, and as larger phenocrysts (1.8 × 3.0 mm). Minor biotite phenocrysts (0.3 × 0.6 mm) are disseminated throughout the granite and are spatially associated with minor apatite and traces of zircon. Pink garnet (0.3 to 0.6 mm) is conspicuous in most border phases.

Average modal composition of the border phase is 40% phenocrysts that consist of quartz (28%), plagioclase (10%), and microcline (2%). The remaining 60% of the rock is groundmass consisting of 35–40% quartz, 25–30% microcline, 25% albite(?), 8% muscovite, 1% biotite, 0.25% garnet, and trace amounts of apatite, zircon, and opaque minerals.

Fine-grained aplitic granite and aplite dikes are light tan, equigranular, leucocratic, and are muscovite-rich. Fine-grained granite and aplite contain quartz and sodic oligoclase to albite and much lesser amounts of microcline. Muscovite is interstitial to

all grains and is present as sparse phenocrysts as large as 1 mm. Biotite is much less abundant than muscovite. Minor apatite is present. Characteristically the fine-grained granite and aplite contain trace amounts of tourmaline.

Fine-grained granite and aplite average quartz (40–50%), albite (15–25%), microcline (8–16%), muscovite (20%), biotite (0.5%), magnetite (0.1%), and traces of chlorite and tourmaline.

Chemically the unit is an alkali-calcic to calc-alkalic granite that is strongly peraluminous, and has no discernible alkali or iron enrichment (fig. 9). Samples described as border phases are not appreciably more mafic than most of the granodiorite. Aplites are strongly calcic because of depletion of alkali elements, peraluminous because of enriched concentrations of muscovite, and Mg rich. For a rock that contains so much potassium feldspar, the granodiorite and granite are characterized by moderate to high concentrations of Y (25–55 ppm) and low concentrations of Ba (many < 550 ppm; table 12). Chemistry of the unit overlaps that of the Henry Mountain Granite in the Sawatch Range (fig. 9) and east of the Arkansas River (Fridrich and others, 1998), but is, on average, more chemically evolved in the Fossil Ridge area.

Early Proterozoic age assignment is based on observation that minor parts of the granite are affected by regional foliation, economically important pegmatite deposits that are genetically related to the granite, and published and unpublished Rb-Sr and U-Th-Pb geochronology studies. In a pioneering study of radioactive minerals from the Quartz Creek pegmatite district, Aldrich and others (1956) analyzed zircon from their Quartz Creek granite at Indian Head (T. 49 N., R. 3 E., sec. 4., north-central part), which is the Henry Mountain Granite of this report, and determined a $^{207}\text{Pb}/^{206}\text{Pb}$ zircon date of 1540 Ma. Numerous Rb-Sr dates of 1600–1800 Ma were determined for lepidolite and microcline from pegmatite bodies in the district and biotite from the Henry Mountain Granite. Sample #CO-20 of Wetherill and Bickford (1965) from the granite at Indian Head has three Rb-Sr whole-rock analyses which defined a minimum age of 1600 Ma if an initial Sr ratio of 0.706 was assumed. Bickford and Boardman (1984) and Bickford and others (1989b) report a U-Pb upper intercept age of 1701 ± 10 Ma for zircon from the granite at Indian Head, which they call the granite of Wood Gulch (M.E. Bickford, oral commun., 1990). This age of 1701 Ma is in agreement with a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 1693 Ma from one fraction of zircon from sample #8-12-82-2 along the Taylor River in T. 15 S., R. 84 W., Sec. 24 (Ed DeWitt and R.E. Zartman, unpub. data, 1990)

Xw Willow Monzonite (Early Proterozoic)—Named herein for exposures at its type area along and northeast of Willow Creek, T. 50 N., R. 3 E., secs. 9 and 10,

Table 12. Major- and minor-element chemistry of Early Proterozoic Henry Mountain Granite (unit Xh) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- and 8- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample 7-2-82-2 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmache Exploration, Seattle, WA; Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot]

Part of unit	main	main	main	main	main	aplite	border	border
Sample number	8-12-82-2	7-15-82-1	7-10-82-5	8-11-82-3	8-8-82-1	7-1-82-3	7-2-82-2	8-11-82-4
Major elements								
SiO ₂	70.20	70.50	70.60	70.90	73.60	78.20	74.70	75.00
TiO ₂	0.46	0.59	0.37	0.32	0.23	0.04	0.07	0.16
Al ₂ O ₃	14.60	14.10	14.50	14.60	13.60	12.90	14.10	13.20
Fe ₂ O ₃	0.80	1.23	0.78	--	0.61	0.56	1.55	--
Fe _t O ₃	--	--	--	2.46	--	--	--	1.42
FeO	2.22	2.44	1.96	--	1.16	0.27	2.17	--
MnO	0.07	0.08	0.06	0.05	0.05	0.06	0.10	0.04
MgO	0.72	0.84	0.73	0.57	0.44	0.42	0.14	0.29
CaO	1.50	2.03	1.34	1.07	1.09	0.96	0.56	0.62
Na ₂ O	2.44	2.37	2.57	2.23	2.48	2.47	3.64	1.78
K ₂ O	4.97	3.79	4.62	5.29	4.40	1.97	4.37	4.71
P ₂ O ₅	0.27	0.32	0.22	0.26	0.23	0.12	0.13	0.26
H ₂ O+	0.91	1.02	0.91	--	0.96	0.95	--	--
H ₂ O-	0.01	0.01	0.02	--	0.01	0.09	--	--
CO ₂	0.03	0.06	0.01	--	0.18	0.01	--	--
LOI	--	--	--	1.16	--	--	0.60	1.11
TOTAL	99.20	99.38	98.69	98.91	99.04	99.02	102.13	98.59
Minor elements								
Ba	829	534	577	690	274	277	--	110
Rb	246	187	227	252	279	116	186	330
Sr	144	129	120	105	70	211	200	55
Y	45	56	36	26	34	16	53	31
Zr	249	290	163	188	131	24	342	89
Nb	21	22	19	23	22	11	24	20
U	0.51	3.05	3.35	1.74	2.69	1.20	--	2.54
Th	2.00	23.40	10.50	9.03	12.10	< 2.1	--	4.80
Metals								
Cu	63	22	38	--	42	--	99	--
Pb	43	15	17	--	32	--	20	--
Zn	81	94	64	--	66	--	102	--
Ni	57	71	34	--	--	--	--	--
Cr	--	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--	--
V	--	--	--	--	--	--	--	--
Calculations								
R ₁	2553	2853	2625	2623	2938	3846	2559	3221
R ₂	483	535	464	429	405	377	343	340
A/CNK	1.21	1.21	1.25	1.29	1.26	1.63	1.20	1.44
Fe No.	0.80	0.81	0.78	0.80	0.80	0.65	0.96	0.82
K No.	0.67	0.62	0.64	0.70	0.64	0.44	0.55	0.73

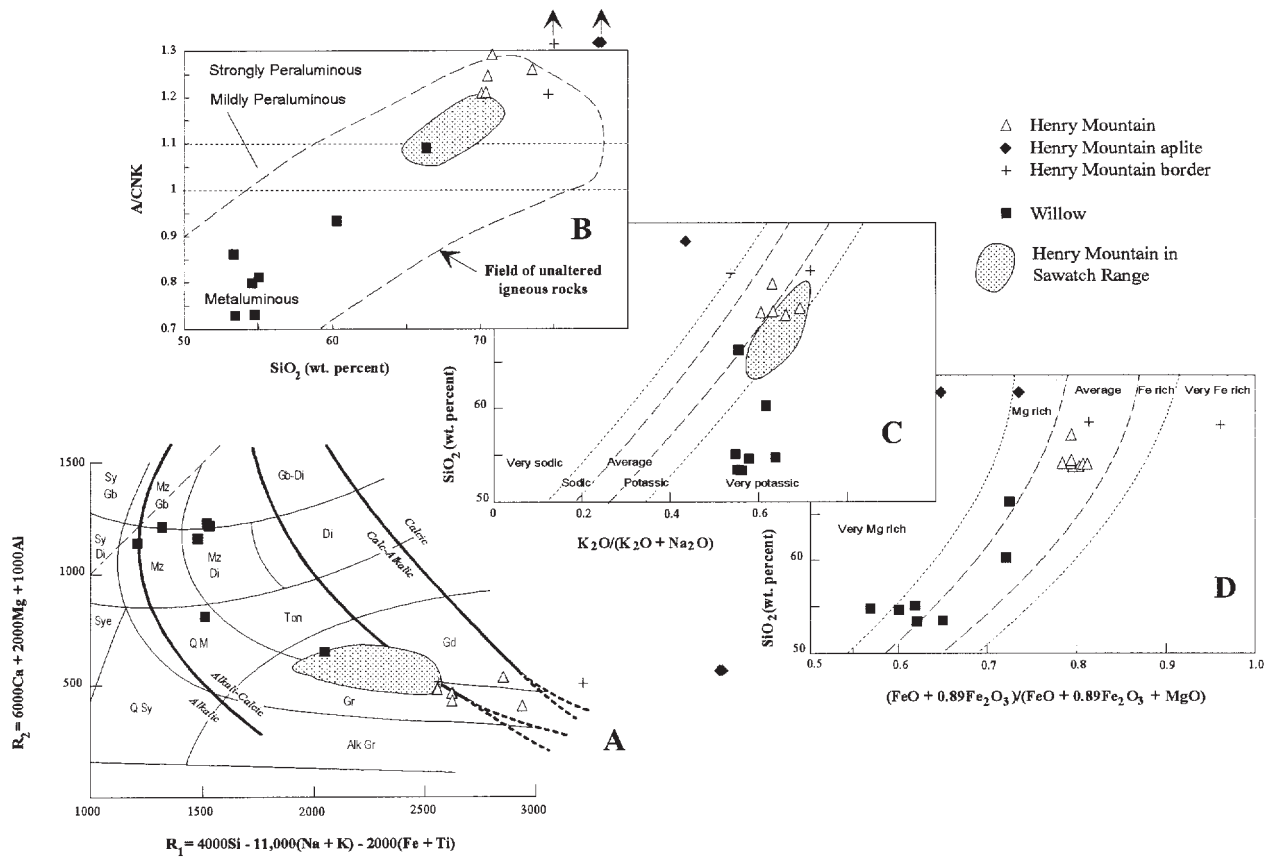


Figure 9. Summary geochemical diagrams for the Henry Mountain Granite (unit Xh) and the Willow Monzonite (unit Xw). Rock names listed in figure 4. Data from this study and from Earley (1987). Position of samples that plot off the diagrams shown by arrows. Refer to tables 12 and 13 for analytical data.

(A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).

(B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O .

(C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study.

(D) Iron enrichment classification diagram $(FeO + 0.89*Fe_2O_3)/(FeO + 0.89*Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

south of Fossil Ridge. Pluton is a northeasterly elongate body, about 4 km wide and 8 km long, that crops out between Alder Creek and Quartz Creek, south of Fossil Ridge. About 75% of the pluton is within the map area; 25% extends to the southwest, into the Quartz Creek pegmatite district where it is cut off by the coarse-grained granite (unit gr of Staatz and Trites, 1955) that is equivalent to the Henry Mountain Granite (unit Xh). Pluton equivalent to the hornblende-biotite syenite and pyroxene monzonite of Crawford and Worcester (1916), to unnamed granite-syenite-monzonite (DeWitt and others, 1985), and to pyroxene monzonite and hornblende monzonite of Earley (1987). Body consists of older, mafic border phase of dark-greenish-gray to black, medium- to coarse-grained, undeformed monzogabbro to gabbro-diorite (stippled on geologic map, unit Xwg) exposed discontinuously on the east, north, and northwest sides of the pluton.

Younger, tan to grayish-green, medium-grained, porphyritic (plagioclase phenocrysts), undeformed felsic core phase of granodiorite (no stippled pattern) cuts off border phase on southeast side of the pluton and isolates a part of the border phase within the core on the northwest side of the pluton, but grades into the border phase to the north and northeast, as originally noted by Crawford and Worcester (1916). Granodiorite phase equivalent and continuous to the southeast with quartz monzonite (unit qm of Staatz and Trites, 1955) in the Quartz Creek pegmatite district. Red, feldspar-rich, iron-stained rocks termed syenite by Crawford and Worcester (1916) are restricted to northeast part of pluton. Feldspar in these iron-stained rocks is predominantly oligoclase, not microcline.

Monzonite to gabbro-diorite consists of subequal amounts of medium- to coarse-grained, turbid oligoclase (5×10 mm) and mafic clots of dark- to

medium-green actinolitic hornblende and poikilitic, brown biotite. Amphibole in mafic clots is a mixture of minor, early-formed hornblende and abundant, large crystals made up of a fine-grained mosaic of light-green to blue-green pleochroic actinolitic hornblende. The turbid nature of oligoclase is caused by fine-grained epidote and biotite grains. Sphene, ilmenite rimmed by sphene, and abundant apatite as much as 1 mm long are associated in the mafic clots. Minor epidote and trace zircon are also associated with the mafic clots. Fine- to medium-grained quartz, microcline, and myrmekite are interstitial to oligoclase and the mafic minerals. Crawford and Worcester (1916) and Earley (1987) noted minor orthopyroxene mantled by clinopyroxene in the most mafic rocks.

Granodiorite is porphyritic and consists of 40–70% phenocrysts of medium- to coarse-grained, turbid oligoclase(?), clots of mafic minerals, and groundmass of oligoclase, quartz, and microcline. The turbid nature of plagioclase is due to very fine grained epidote and biotite. Mafic clots are composed of medium-grained hornblende and biotite that contain and overgrow euhedral sphene, ilmenite rimmed by sphene, abundant apatite, fine-grained epidote, and allanite rimmed by epidote. Groundmass of the most felsic granodiorite is a mosaic of fine- to medium-grained, equigranular microcline, oligoclase, biotite, and quartz.

All rock types are alkali-calcic, metaluminous, sodic to very potassic, and average to very Mg rich (fig. 9). The unit is characterized by high Zr (155–835 ppm) and average to high Ba (1,600–3,800 ppm) concentrations (table 13). No rocks of similar composition are known from the Sawatch Range or other mountain ranges in Central Colorado.

Early Proterozoic age assignment based on observation that pegmatite bodies related to the Henry Mountain Granite cut the pluton in the map area and on the fact that the Henry Mountain Granite in the Quartz Creek pegmatite district (Staatz and Trites, 1955) to the southwest of the map area cuts the felsic core phase of the pluton. The Taylor River Granite cuts the pluton on the north and northeast

Xc Crystal Gabbro (Early Proterozoic)—Named herein for exposures at its type area along the upper reaches of Crystal Creek, both on the western side of the creek and on the southwestern face of Henry Mountain in T. 51 N., R. 3 E., sec. 17, and in T. 51 N., R. 3 E., sec. 15, respectively. In these localities the gabbro is intruded by the Henry Mountain Granite. To the south, on Fossil Ridge, gabbro intrudes Early Proterozoic metasedimentary rocks. Equivalent to quartz diorite of Crawford and Worcester (1916) and unnamed diorite of DeWitt and others (1985). Includes part of quartz diorite of Zech (1988).

Gabbro is dark gray to black and tan, medium grained, equigranular, and massive to poorly

foliated. Minor porphyroblasts of potassium feldspar are present in gabbro where it has been intruded by the Henry Mountain Granite. Distinctive, translucent, light-brown calcic andesine (0.1 × 0.4 mm to 0.4 × 2.0 mm), large (2 × 2 mm) crystals of amphibole composed of mass of finer grained (0.15 × 0.25 mm) actinolitic hornblende and hornblende, and biotite (averages 1 mm across, but as large as 0.6 × 5.0 mm) are set in a matrix of clear calcic andesine and quartz. Darkening of plagioclase grains may be a consequence of submicroscopic, iron-rich colloidal particles. Acicular apatite grains as long as 0.2 mm, sphene as ragged overgrowths on ilmenite(?) and magnetite(?), and allanite overgrown by epidote are trace constituents. Epidote-group minerals and minor calcite are trace components.

Average modal composition of typical gabbro is 35–40% calcic andesine, 25–40% amphibole, 10–15% biotite, 5–8% quartz, 0.2–11% magnetite and ilmenite, 0.8% apatite, 0.4% sphene, and traces of epidote-group minerals, chlorite, and calcite. Potassium feldspar may be present, but was not identified.

The unit ranges from monzogabbro to gabbro-diorite, is alkali-calcic, metaluminous, very potassic, and very Fe to very Mg rich (fig. 7). One sample of gabbro has high concentrations of barium (2,600 ppm), strontium (>1,000 ppm), and zirconium (350 ppm; table 4), similar to olivine gabbro dikes of unit YXgb. Some samples are similar in chemistry to metagabbro bodies in the Almont area (Urbani, 1971, Urbani and Blackburn, 1974), but exact correlation does not appear to be possible.

Early Proterozoic age assignment based on observation that body is intruded by the Henry Mountain Granite

Xb Granodiorite of Broncho Mountain (Early Proterozoic)—Small deformed mass of granodiorite on south and east sides of Broncho Mountain near the headwaters of Gold Creek. Granodiorite intrudes Early Proterozoic metasedimentary rocks and is cut by granite of Taylor River. Equivalent to the now obsolete Broncho Mountain granite of Crawford and Worcester (1916). Included as part of unit YXg by Tweto (1979). May be genetically related to mafic part of Henry Mountain Granite or felsic, pink, plagioclase-rich phase of Willow Monzonite.

Granodiorite is dark gray and pink, medium grained, well foliated, and characteristically biotite rich. Sigmoidal aggregates of strained and recrystallized quartz (as much as 2 × 4 mm) and aggregates of biotite (as much as 1 × 4 mm) define the foliation in the rock. A groundmass of fine-grained (0.1 × 0.2 mm), anhedral quartz, subhedral microcline and biotite, and minor plagioclase phenocrysts(?) (as much as 0.4 × 0.6 mm) is

Table 13. Major- and minor-element chemistry of Early Proterozoic Willow Monzonite (unit Xw) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[major elements for samples 9-2-88-3, 9-2-88-11, 9-2-88-6, 9-2-88-7, and 9-2-88-13 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmchem Exploration, Seattle, WA; Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Earley (1987) for analytical techniques for samples of gabbro beginning with 13 or 66]

Sample number	9-2-88-3	66G	9-2-88-11	13	9-2-88-6	9-2-88-7	9-2-88-13
Major elements							
SiO ₂	53.41	53.50	54.66	54.80	55.13	60.36	66.43
TiO ₂	1.52	1.69	1.33	1.24	1.49	1.11	0.57
Al ₂ O ₃	16.24	15.20	15.61	14.77	16.35	16.24	16.37
Fe ₂ O ₃	3.53	3.20	3.05	2.88	2.57	3.12	1.56
FeO	4.30	5.27	5.15	4.30	5.40	2.30	1.85
MnO	0.11	0.12	0.12	0.10	0.13	0.07	0.07
MgO	4.55	4.37	5.24	5.22	4.74	1.97	1.23
CaO	5.75	6.51	6.07	5.53	6.30	3.66	2.50
Na ₂ O	2.75	3.02	2.70	2.83	2.92	3.14	3.46
K ₂ O	3.65	3.85	3.84	5.18	3.68	5.23	4.46
P ₂ O ₅	0.85	0.64	0.78	0.70	0.77	0.43	0.32
H ₂ O+	--	0.75	--	0.85	--	--	--
H ₂ O-	--	--	--	--	--	--	--
CO ₂	--	0.02	--	0.01	--	--	--
LOI	1.00	--	0.80	--	< 0.01	0.80	0.60
TOTAL	97.66	98.14	99.35	98.41	99.48	98.43	99.42
Minor elements							
Ba	3800	3200	3000	3720	2500	1600	1600
Rb	74	86	87	136	73	200	210
Sr	900	1137	895	1435	900	600	500
Y	16	29	28	31	18	53	30
Zr	155	215	260	470	200	835	255
Nb	10	--	15	--	15	34	31
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
Metals							
Cu	--	132	--	39	--	--	--
Pb	--	--	--	--	--	--	--
Zn	--	99	--	87	--	--	--
Ni	--	116	--	119	--	--	--
Cr	--	128	--	179	--	--	--
Co	--	--	--	--	--	--	--
V	--	195	--	138	--	--	--
Calculations							
R ₁	1481	1321	1530	1211	1522	1512	2048
R ₂	1159	1211	1216	1140	1230	808	650
A/CNK	0.86	0.73	0.80	0.73	0.81	0.93	1.09
Fe No.	0.62	0.65	0.60	0.57	0.62	0.72	0.73
K No.	0.57	0.56	0.59	0.65	0.56	0.62	0.56

between the biotite-rich folia. Within the biotite-rich clusters is abundant allanite rimmed by epidote, minor but conspicuous fine-grained sphene that apparently nucleated preferentially on biotite,

abundant apatite, traces of zircon, and muscovite (0.1 × 0.2 mm) that is concentrated near the margins of biotite-rich clots. Tourmaline crystals were noted in one biotite-rich band. Minerals within the

biotite-rich bands are very similar to those in the Henry Mountain Granite.

Average modal composition is approximately 30% biotite, 2–25% microcline, 20–25% quartz, 10–15% plagioclase, 5% muscovite, 1–2% apatite, 1–2% allanite rimmed by epidote, and traces of sphene, epidote, zircon, and opaque minerals.

The granodiorite is alkali-calcic, mildly peraluminous, average to very potassic, very Mg rich (fig. 10), and has moderately high concentrations of Sr (table 14).

Early Proterozoic age assignment based on pre-tectonic nature of body and chemical similarity to mafic parts of Henry Mountain Granite and felsic, pink, plagioclase-rich phase of Willow Monzonite

Xr Roosevelt Granite (Early Proterozoic)—Named herein for exposures at its type area along Quartz Creek between Pitkin and Ohio City, especially outcrops along Roosevelt Gulch in T. 50 N., R. 4 E., secs. 17 (this map) and 20 (south of this map). Granite forms northwesterly elongate pluton that averages 3 km wide and 10 km long. Contacts with country rocks

are sharp. Minor dikes and sills of granite present in wall rocks as far as 1 km from pluton boundary. Included in granite unit of Crawford and Worcester (1916) and unit Xg of Tweto (1979).

Granite is light tan, fine to medium grained, slightly porphyritic (sodic oligoclase phenocrysts), and massive to well foliated. Intensely foliated granite restricted to discontinuous zones of high strain that strike north to north-northeast, parallel to regional foliation. Emplacement of the granite predates development of regional foliation, but much of granite crops out in a zone of low strain and hence, is relatively unfoliated.

Sodic oligoclase phenocrysts (average 0.7×1.5 mm, but as large as 0.8×2.5 mm) are turbid and partly replaced by sericite and muscovite as much as 0.1 mm in diameter. Groundmass predominated by quartz (0.1–0.2 mm diameter) and minor microcline. Greenish-brown biotite is the only mafic mineral and is randomly distributed throughout the granite. Epidote is locally present as breakdown product of plagioclase and as overgrowths on

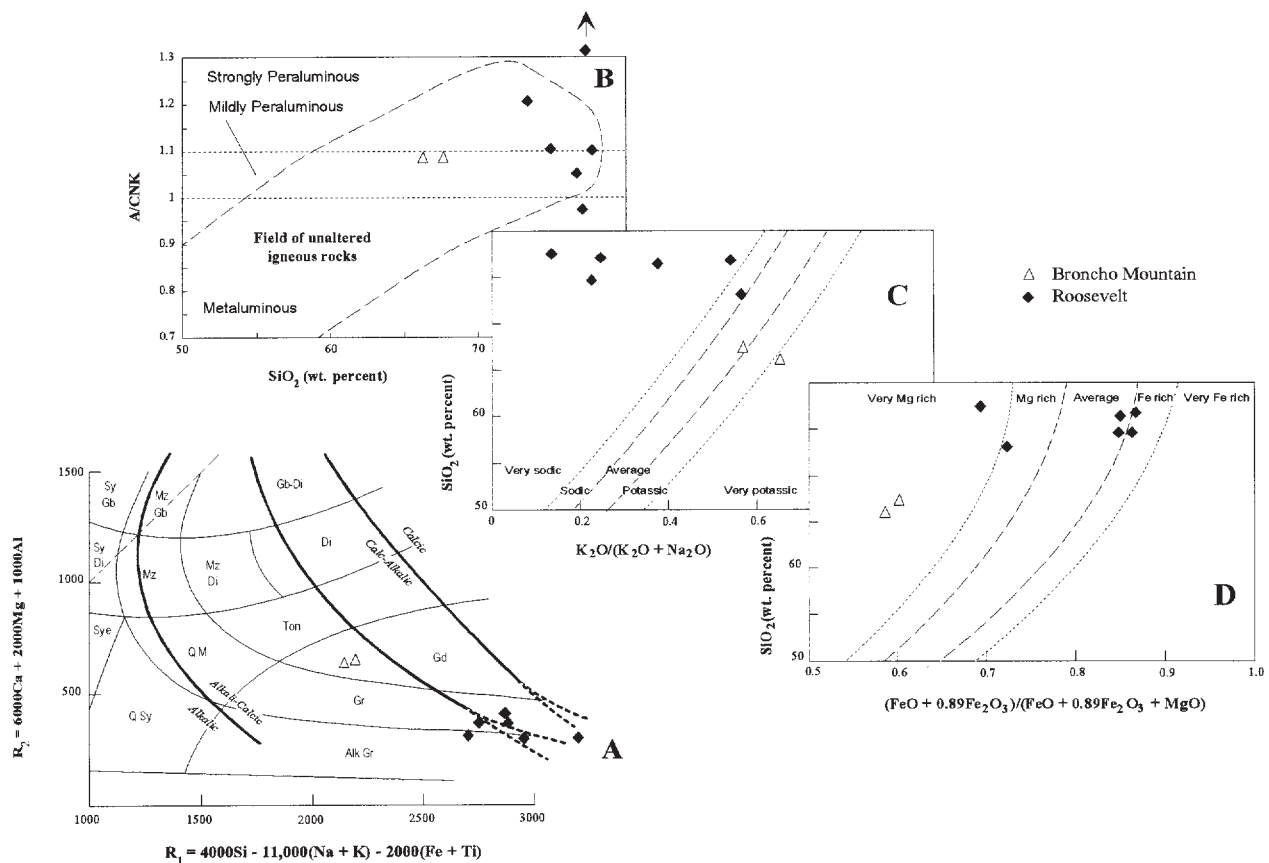


Figure 10. Summary geochemical diagrams for the granodiorite of Broncho Mountain (unit Xb) and the Roosevelt Granite (unit Xr). Rock names listed in figure 4. Data from this study. Refer to table 14 for analytical data.

(A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998).

(B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO; N, molar Na_2O ; K, molar K_2O .

(C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study.

(D) Iron enrichment classification diagram $(FeO + 0.89*Fe_2O_3)/(FeO + 0.89*Fe_2O_3 + MgO)$ versus SiO_2 . Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

Table 14. Major- and minor-element chemistry of Early Proterozoic granodiorite of Broncho Mountain (unit Xb) and Roosevelt Granite (unit Xr) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (8- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O⁺ and H₂O⁻ determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample BM2, BM1, 8-31-83-5, 8-31-83-7, 8-30-83-5, and 8-30-83-6 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmachem Exploration, Seattle, WA; Fe_tO₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot]

Map unit	Xb	Xb	Xr	Xr	Xr	Xr	Xr	Xr
Sample number	BM2	BM1	8-31-83-5	8-13-82-2	8-31-83-7	8-30-83-5 mineralized	8-30-83-6 mineralized	8-30-83-8 mineralized
Major elements								
SiO ₂	66.17	67.54	73.25	74.80	76.54	76.94	77.17	77.60
TiO ₂	0.58	0.51	0.19	0.14	0.16	0.06	0.05	0.05
Al ₂ O ₃	14.98	15.49	13.12	13.20	12.52	12.07	12.21	12.10
Fe ₂ O ₃	1.44	1.42	1.01	0.87	1.23	0.79	0.32	--
Fe _t O ₃	--	--	--	--	--	--	--	0.91
FeO	2.40	2.30	1.20	1.08	0.85	0.15	0.50	--
MnO	0.09	0.10	0.02	0.02	0.03	0.03	0.01	0.02
MgO	2.59	2.35	0.80	0.33	0.34	0.13	0.79	0.36
CaO	2.10	2.24	0.71	1.32	1.03	0.68	0.23	0.44
Na ₂ O	2.70	3.30	3.14	4.86	4.36	3.81	4.45	5.60
K ₂ O	5.09	4.37	4.07	1.42	2.62	4.48	1.46	0.88
P ₂ O ₅	0.47	0.50	0.18	0.05	0.22	0.13	0.11	0.05
H ₂ O ⁺	--	--	--	0.51	--	--	--	--
H ₂ O ⁻	--	--	--	0.02	--	--	--	--
CO ₂	--	--	--	0.10	--	--	--	--
LOI	0.60	0.90	0.90	--	0.60	0.70	0.70	0.60
TOTAL	99.21	101.02	98.59	98.71	100.50	99.97	98.00	98.60
Minor elements								
Ba	2000	1800	1400	766	760	80	< 20	260
Rb	195	160	69	31	63	180	72	38
Sr	690	565	54	131	99	< 5	10	20
Y	18	15	< 5	25	15	145	125	128
Zr	285	280	175	152	170	120	170	156
Nb	33	36	17	13	14	17	41	52
U	--	--	--	2.69	--	--	--	7.51
Th	--	--	--	6.59	--	--	--	14.10
Calculations								
R ₁	2140	2192	2748	2867	2877	2698	3193	2948
R ₂	647	660	373	417	373	316	303	302
A/CNK	1.09	1.09	1.21	1.11	1.06	0.98	1.31	1.11
Fe No.	0.59	0.60	0.72	0.85	0.85	0.87	0.50	0.69
K No.	0.65	0.57	0.56	0.23	0.38	0.54	0.25	0.14

alanite. Ilmenite, zircon, and apatite are trace constituents.

Average modal composition of typical granite is 45% sodic oligoclase, 42% quartz, 8% microcline, 3.7% biotite, 0.2 % ilmenite, 0.1% epidote, and traces of zircon, apatite, allanite, and minor calcite.

Fresh samples of the granite are alkali-calcic to calc-alkalic, strongly peraluminous, very sodic, and

have variable Fe/Mg ratios (fig. 10). Samples least affected by hydrothermal alteration related to gold deposits in the Gold Creek district are the most Fe-rich (fig. 10D). The granite is distinguished from other Early Proterozoic plutonic units by its high Na₂O/K₂O ratio (in unaltered rocks > 2) and Sr concentrations less than 55 ppm (table 14). Very high Y concentrations in samples from the Raymond and

Carter mines (Samples 8-30-83-5, 8-30-83-6, and 8-30-83-8, table 10) reflect hydrothermal alteration related to gold mineralization (Crawford and Worcester, 1916; DeWitt and others, 1985).

Early Proterozoic age based on pre-tectonic structural relations, published Rb-Sr geochronology and unpublished U-Th-Pb geochronology of this study. Sample #CO-61 of Wetherill and Bickford (1965) is from the Roosevelt Granite. Two Rb-Sr whole-rock analyses suggest a minimum age of 1600 Ma if 0.706 is assumed for Sr_1 . One zircon fraction from sample #8-13-82-2 of the Roosevelt Granite (located just south of this map in T. 50 N., R. 4 E., Sec. 20, center) has a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 1720 Ma (Ed DeWitt and R.E. Zartman, unpub. data, 1990).

Xs Metasedimentary rocks (Early Proterozoic)—Quartz-muscovite-plagioclase-chlorite schist, quartz-muscovite-biotite-chlorite schist, quartz-muscovite-cordierite-biotite-chlorite schist, quartz-rich metachert or quartzite, quartz-muscovite-plagioclase-cordierite-sillimanite schist, and quartz-plagioclase-biotite-chlorite-andalusite-staurolite schist (all containing opaque minerals, apatite, and zircon) that crop out predominantly on Fossil Ridge and to the north, west, and southwest. Another, fairly extensive body east of Pitkin. Cordierite-bearing schist most widespread; andalusite- and staurolite-rich schist restricted to small outcrops near Boulder Gulch and Bear Gulch, and area west and south of Ohio City (Usdansky, 1981); sillimanite-rich schist restricted to western Fossil Ridge, near contact with Henry Mountain Granite. Veins and thin replacement lenses of tourmaline cut quartz-muscovite-plagioclase-cordierite schist on western Fossil Ridge.

Protoliths include graywacke, siltstone, Mg-rich shale, and siliceous volcanoclastic rocks. Depositional contact with older mafic metavolcanic rocks well preserved in cirque wall on south side of Lower Lamphier Lake (T. 51 N., R. 3 E., sec. 24); trace of contact is crudely parallel to the Boulder fault to the southwest. Facing indicators such as graded beds and crossbeds show top-to-the-northwest in much of the metasedimentary unit. Metamorphosed graywacke predominates along Fossil Ridge and to the west. Metamorphosed Mg-rich shale and siltstone abundant from Mill Lake to Broncho Mountain. Quartzite or metachert restricted to thin outcrops on west side of Gold Creek, in T. 50 N., R. 3 E., secs. 2 and 14. Metamorphosed siltstone and shale common in area east of Pitkin. Includes quartz-mica schist (Dings and Robinson, 1957), part of quartz-sericite schist and quartzite unit of Earley (1987), and part of unit called gneisses and schist by Crawford and Worcester (1916). Metagraywacke and metamorphosed siltstone similar in mineralogy and composition to metasedimentary units in the Almont area (Navarro, 1971; Navarro and Blackburn, 1974).

Fine-grained quartz (0.3 mm), muscovite (0.05 × 0.3 mm diameter), and plagioclase (0.1 × 0.5 mm) form matrix to porphyroblasts of biotite (0.6 mm diameter), chlorite (0.2–0.8 mm), cordierite (2 × 4 mm to as large as 1 × 4 cm), staurolite and andalusite (0.8 × 1.5 mm to 2 × 3 cm), and feathery, fine-grained mats of sillimanite (0.02 × 0.3 mm across). Cordierite commonly contains abundant inclusions of quartz and muscovite and is normally retrograded to fine-grained masses of quartz and muscovite, medium-grained masses of pale-green chlorite, or single crystals of biotite.

Early Proterozoic age based on unit being intruded by the 1700-Ma Henry Mountain Granite and the approximately 1650-Ma Fairview Peak Granodiorite and on the fact that the unit is depositionally on top of mafic and felsic metavolcanic rocks that have U-Pb zircon dates of 1745 to 1770 Ma (see discussion below in section on felsic metavolcanic rocks)

Xgb Metagabbro (Early Proterozoic)—Sills, hypabyssal intrusive masses, and small plugs(?) that intrude Early Proterozoic metavolcanic and metasedimentary rocks on either side of Gold Creek. Bodies extend south of the map, across Quartz Creek, and into the Revenue mine area (Horlacher, 1987). Equivalent to diorite of Crawford and Worcester (1916). Includes part of hornblende plagioclase amphibolite (unit HPa) and hornblendite amphibolite (unit Ha) of Earley (1987) and hornblende diorite of Zech (1988). Where relations are obscured by vegetation, some metagabbro bodies may be included in mafic metavolcanic rocks (unit Xmv), below. Cumulate-textured bodies most abundant on south slope of Sheep Mountain and extending to Boulder Gulch, and on the eastern side of the valley of the headwaters of Comanche Creek.

Metagabbro is dark greenish black, fine to medium grained, equigranular to slightly porphyritic, and massive to well foliated. Relict phenocrysts of plagioclase, ophitic and cumulate textures, and homogeneous composition indicate gabbro protolith. Discordant intrusive contacts and chemical composition suggests metagabbro is younger, more mafic, and less alkali rich than mafic metavolcanic rocks of unit Xmv.

Non-cumulate metagabbro contains andesine to labradorite relict phenocrysts (0.3–2.0 mm) and hornblende (0.2–0.5 mm) set in a matrix of finer grained andesine and minor quartz. Ilmenite, apatite, and minor biotite and epidote-group minerals are noted, as well as trace amounts of calcite and sphene. Cumulate-textured metagabbro contains actinolite instead of hornblende, fewer plagioclase phenocrysts, and less biotite and much more chlorite. Magnesium-rich varieties are actinolite-chlorite schist.

Average modal composition of metagabbro is 35–45% andesine to labradorite, 35–50%

hornblende, 1–5% quartz, 2–4% ilmenite and minor magnetite, 0–3% biotite, 0.2% apatite, and trace to less than 2% of epidote-group minerals, calcite, and sphene.

Metagabbro ranges from an ultramafic rock to gabbro-norite, to olivine gabbro. The suite is metaluminous, with the most evolved alkalic samples having the highest Al_2O_3 concentrations (table 15), and hence having the highest A/CNK ratio (fig. 11B). The gabbroic rocks have no appreciable alkali enrichment and most are average to very Fe rich (fig. 11D). Most metagabbro bodies are more mafic than most of the mafic metavolcanic strata that they intrude (fig. 11A). The calcic nature of the gabbro-norite bodies is probably related to slight accumulation of calcic plagioclase during crystal settling.

Xfv Felsic metavolcanic rocks (Early Proterozoic)—Quartz-plagioclase-muscovite-biotite-opaque-mineral-chlorite schist that crops out on the south slopes of Sheep Mountain, east of Quartz Creek. Relict phenocrysts of albite and polygonal aggregates of quartz, in addition to possible flattened pumice shards and agglomeratic textures, indicate volcanic protolith, probably rhyolite to rhyodacite tuff. Includes part of quartz-feldspar schist and quartz-microcline schist of Earley (1987).

Matrix of fine-grained quartz (0.06 to 0.1 mm diameter), muscovite (0.3 × 0.5 mm), and minor biotite (0.1 × 0.3 mm), opaque minerals, and chlorite and apatite surround phenocrysts and lenses of albite (0.4 × 0.9 mm) and quartz-rich material.

Average modal composition is 50–65% quartz, 10–20% albite, 8–12% muscovite, 2–4% opaque minerals, 3–5% biotite, and minor amounts of chlorite and apatite. Potassium feldspar was not recognized.

Early Proterozoic age assignment based on observation that map unit is stratigraphically beneath metasedimentary rocks discussed above that are intruded by the Henry Mountain Granite.

Xiv Intermediate-composition metavolcanic and metasedimentary rocks (Early Proterozoic)—Heterogeneous mixture of quartz-plagioclase-biotite-muscovite schist, quartz-plagioclase-biotite-chlorite schist, plagioclase-quartz-biotite-hornblende-epidote schist, quartz-microcline-plagioclase-biotite-epidote schist, quartz-plagioclase-cordierite-anthophyllite schist, and quartz-plagioclase-gedrite-garnet-biotite schist (all containing opaque minerals, apatite, and minor zircon) that crop out extensively on the east side of Quartz Creek and to a lesser extent, on the west side. Cordierite- and orthoamphibole-rich rocks restricted to area along Quartz Creek, especially adjacent to amphibole-bearing rocks in mafic metavolcanic unit. Plagioclase- and microcline-rich units most numerous on southwest flank of Quartz Dome.

Protoliths include dacite flows and tuffs, intermediate-composition volcanoclastic rocks, and

Mg- and Al-rich sediments. Metamorphosed dacitic flows and tuffs abundant on southwest flank of Quartz Dome in T. 50 N., R. 3¹/₂ E., sec. 13, and T. 50 N., R. 3 E., sec. 13, and extend south across Quartz Creek (Horlacher, 1987). Includes part of quartz-feldspar schist of Earley (1987), part of biotite gneiss of Usdansky (1981), and part of unit called gneiss and schist by Crawford and Worcester (1916).

Fine-grained quartz, muscovite, and plagioclase form matrix to relict phenocrysts of oligoclase (1–2 mm diameter) and minor aggregates of quartz (0.2–0.5 mm diameter) and biotite in metamorphosed dacite. Fine-grained quartz, muscovite, and minor biotite form matrix to much coarser grained (3–8 mm diameter), radiating splays of anthophyllite and gedrite and 3–10-mm-diameter porphyroblasts of cordierite in metamorphosed Mg- and Al-rich sediments and tuffaceous volcanoclastic rocks.

Early Proterozoic age assignment based on interbedded nature of these rocks with felsic metavolcanic rocks and by U-Pb zircon dating of similar rocks immediately south of the map area. Sample QCF of Bickford and others (1989b), which has a U-Pb zircon age of 1770 ± 8 Ma, is from T. 50 N., R. 3 E., sec. 30 (approximate location) and is representative of much of the metamorphosed dacite in the unit.

Xmv Mafic metavolcanic rocks (Early Proterozoic)—

Amphibolite, quartz-plagioclase-biotite-hornblende-cummingtonite schist, hornblende-epidote-plagioclase-quartz gneiss, epidote-plagioclase-diopside-hornblende-quartz gneiss, calcite-hornblende-diopside-labradorite-quartz gneiss, diopside-epidote-sphene-calcite gneiss, microcline-biotite-hornblende-epidote gneiss, hornblende-microcline-epidote-gneiss, and quartz-plagioclase-hornblende-biotite-muscovite-calcite-epidote gneiss. Unit is predominantly amphibolite that crops out on both sides of Gold Creek. Smaller exposures of amphibolite in area northeast of Union Park and northeast of Cumberland Pass. Part of unit containing epidote, diopside, and garnet exposed on west side of Gold Creek, from near Sheep Mountain to near Ohio.

Protoliths include pillowed and vesicular basalt, calcareous mafic tuff, calcareous felsic tuff, and minor intrusive gabbro. Virtually unstrained metamorphosed pillowed basalt exposed in Comanche Gulch in T. 50 N., R. 3 E., secs. 2 and 3, in Boulder Gulch in T. 51 N., R. 3 E., sec. 36, and in upper plate of Tincup thrust northeast of Cumberland Pass. Vesicular metamorphosed basalt exposed on southern slopes of Sheep Mountain in T. 51 N., R. 3 E., sec. 28. Includes parts of vesicular basaltic amphibolite, pillowed basaltic amphibolite, and calc-silicate gneiss of Earley (1987), part of banded gneiss and hornblende amphibolite of Usdansky (1981), part of unit called gneisses and schist of Crawford and

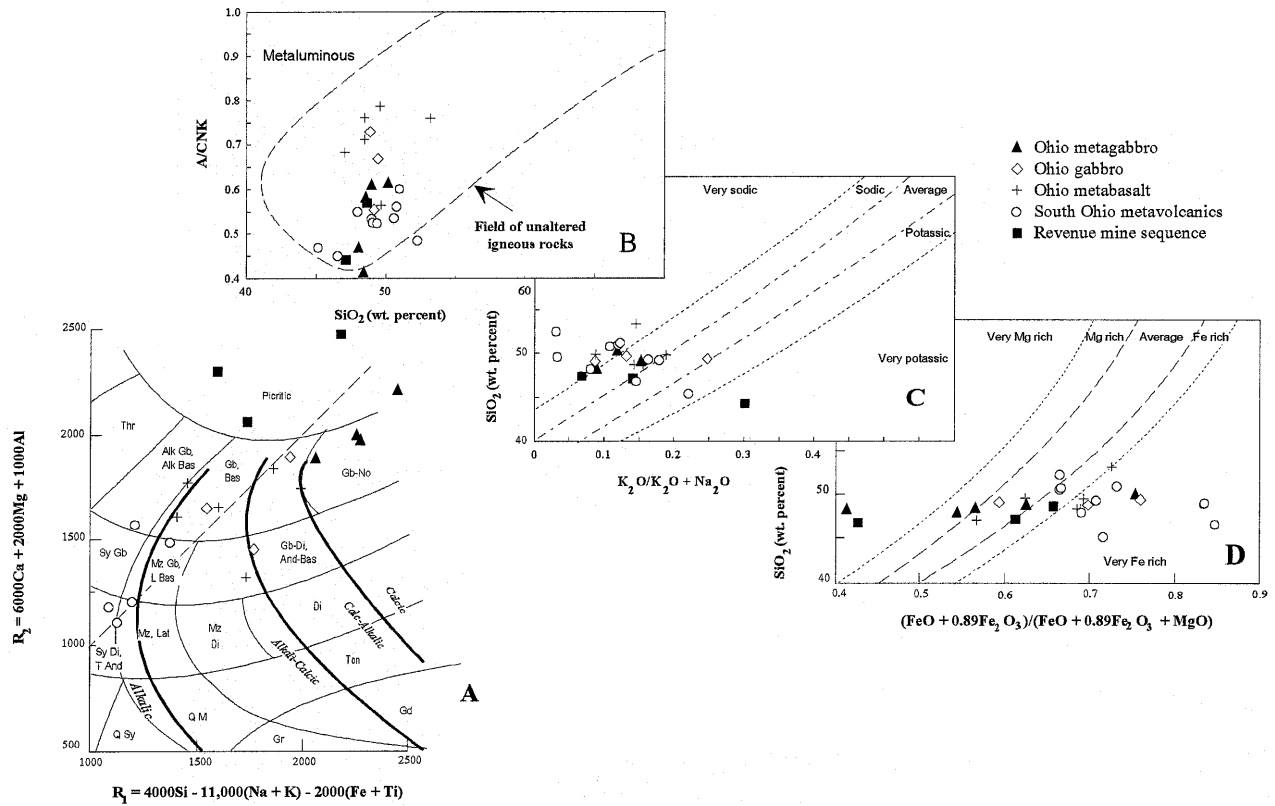


Figure 11. Summary geochemical diagrams for metagabbro and gabbro near Ohio (unit Xgb), mafic metavolcanic rocks near Ohio (Xmv), and mafic metavolcanic rocks south of Ohio, near the Revenue mine. Rock names listed in figure 7, with the addition of Alk Bas, alkali basalt; Ol Bas, olivine basalt; L Bas, lati-basalt; And-Bas, andesitic basalt; Lat, latite; T And, trachyandesite. Data from this study, Earley (1987), and Horlacher (1987). Refer to table 15 for analytical data. (A) R_1R_2 major element classification diagram (De la Roche and others, 1980). Fields of alkalinity modified slightly from those in DeWitt (1989) based on Fridrich and others (1998). (B) Alumina saturation diagram (SiO_2 versus A/CNK). A, molar Al_2O_3 ; C, molar CaO ; N, molar Na_2O ; K, molar K_2O . (C) Alkali classification diagram ($K_2O/(K_2O + Na_2O)$ versus SiO_2). Field boundaries from this study. (D) Iron enrichment classification diagram ($(FeO + 0.89Fe_2O_3)/(FeO + 0.89Fe_2O_3 + MgO)$ versus SiO_2). Field boundaries slightly modified from those in DeWitt (1989) based on Fridrich and others (1998).

Worcester (1916), and quartz-hornblende schist and quartz-hornblende gneiss of Dings and Robinson (1957).

Amphibolite (pillowed and vesicular metabasalt) contains fine-grained (0.2×0.4 mm diameter), untwinned plagioclase and minor quartz, coarser-grained (0.8×2.0 to 1×3 mm) relict phenocrysts of oligoclase to andesine, and hornblende (0.5×1.0 mm). Traces of biotite are noted, as are minor amounts of epidote. Accessories include fine-grained sphene, ilmenite, and apatite.

Average modal composition of amphibolite is 35–60% oligoclase to andesine, 30–50% hornblende, 10–15% quartz, 0.5–2% sphene, minor ilmenite, and traces of biotite, epidote, and chlorite.

Chemically, amphibolite is predominantly an alkali-calcic to calc-alkalic olivine basalt having high Al_2O_3 concentrations (table 15, fig. 11B). The

sequence has no appreciable alkali enrichment and ranges from average to very Fe rich (fig. 11), similar to the metagabbro bodies described above. Metamorphosed mafic rocks of similar major- and minor-element composition, but slightly more evolved (fig. 11A) are noted south of Quartz Creek (Horlacher, 1987), as are their spilitized equivalents. The amphibolite unit is characterized by slightly elevated strontium concentrations (>400 ppm, table 15).

Epidote-, diopside-, orthoamphibole-, garnet-, calcite-, and microcline-rich units (calcareous mafic tuff and felsic tuff protoliths contain 1–4-mm-thick bands of alternating feldspar-rich and feldspar-poor material within otherwise homogeneous amphibolite and amphibole schist. Bands of diopside-microcline-epidote, hornblende-epidote-sphene-diopside, epidote-biotite-muscovite-chlorite-sphene, biotite-

Table 15. Major- and minor-element chemistry of Early Proterozoic metagabbro (unit Xgb) and mafic metavolcanic rocks (unit Xmv) from the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[Major-element oxides (in weight percent) for samples collected in this study (7- series) determined by X-ray fluorescence by A.J. Bartel, K.C. Stewart, and J.E. Taggart; H₂O+ and H₂O- determined by weight loss by H. Neiman and J. Ryder; CO₂ determined by coulometric titration by H. Neiman and J. Ryder; FeO determined by potentiometric titration by H. Neiman and J. Ryder; Minor elements (in ppm) determined by energy-dispersive X-ray fluorescence by Ross Yeoman and Ed DeWitt; U and Th determined by delayed neutron activation by J. Storey, S. Danahey, R.B. Vaughn, and M. Coughlin; major elements for sample 7-22-82-3 determined by X-ray fluorescence by Bondar-Clegg Laboratories, Vancouver, British Columbia, courtesy of Magmagem Exploration, Seattle, WA; Fe₂O₃, total iron as Fe₂O₃; LOI, loss on ignition; --, not determined or calculated; R₁, calculated values for R₁R₂ plot; R₂, calculated values for R₁R₂; A/CNK, calculated values for SiO₂ versus A/CNK plot; Fe No., calculated values for (FeO + 0.89Fe₂O₃)/(FeO + 0.89Fe₂O₃ + MgO) versus SiO₂ plot; K No., calculated values for K₂O/(K₂O + Na₂O) versus SiO₂ plot; see Earley (1987) for analytical techniques for samples of metagabbro and metabasalt not beginning with 7-]

Map unit	Xgb	Xgb	Xgb	Xgb	Xgb	Xgb	Xgb	Xgb
Sample number	37	K	29CM	7-20-82-2	7-22-82-3	7-21-82-1A	6	29CC
Major elements								
SiO ₂	48.00	48.40	48.50	48.80	49.10	49.40	48.90	50.10
TiO ₂	0.71	0.38	0.46	1.25	0.79	1.75	0.97	2.01
Al ₂ O ₃	10.28	10.20	14.36	17.50	13.97	13.90	15.40	12.79
Fe ₂ O ₃	3.60	2.70	2.70	2.91	2.75	--	3.20	4.40
Fe _t O ₃	--	--	--	--	--	16.80	--	--
FeO	11.40	7.30	9.00	9.18	9.21	--	8.30	11.80
MnO	0.25	0.21	0.20	0.19	0.22	0.24	0.20	0.30
MgO	12.37	13.92	8.86	5.16	8.07	4.84	6.75	5.21
CaO	10.78	12.30	11.88	9.75	11.34	8.74	11.65	9.08
Na ₂ O	1.31	0.97	1.70	3.56	2.28	2.70	2.16	2.36
K ₂ O	0.13	0.63	0.16	0.34	0.75	0.41	0.39	0.32
P ₂ O ₅	0.09	0.20	0.06	0.18	0.15	0.30	0.14	0.28
H ₂ O+	1.97	2.32	1.67	1.23	--	--	1.38	1.33
H ₂ O-	--	--	--	0.01	--	--	--	--
CO ₂	0.01	0.01	0.09	0.01	--	--	0.01	0.01
LOI	--	--	--	--	0.78	0.54	--	--
TOTAL	100.90	99.54	99.64	100.06	99.41	99.62	99.45	99.99
Minor elements								
Ba	37	273	25	139	--	110	86	41
Rb	1	6	6	2	--	3	5	3
Sr	236	318	96	322	--	324	297	292
Y	12	11	14	21	--	26	19	30
Zr	37	29	17	56	--	84	50	76
Nb	--	--	--	6	--	7	--	--
U	--	--	--	2.38	--	0.48	--	--
Th	--	--	--	12.50	--	< 1.2	--	--
Metals								
Cu	60	5	162	134	--	146	131	1
Pb	--	--	--	--	--	--	--	--
Zn	82	171	82	110	--	--	80	130
Ni	99	296	128	138	--	171	46	3
Cr	254	1330	218	--	--	--	86	--
Co	--	--	--	--	--	--	--	--
V	309	216	264	--	--	--	322	451
Calculations								
R ₁	2275	2450	2258	1546	1939	1770	2062	1934
R ₂	1968	2206	1992	1642	1888	1448	1883	1481
A/CNK	0.47	0.41	0.59	0.73	0.56	0.67	0.61	0.62
Fe No.	0.54	0.41	0.56	0.70	0.59	0.76	0.62	0.75
K No.	0.09	0.39	0.09	0.09	0.25	0.13	0.15	0.12

Table 15. Major- and minor-element chemistry of Early Proterozoic metagabbro and metabasalt—*continued*.

Map unit	Xmv	Xmv	Xmv	Xmv	Xmv	Xmv
Sample number	42	51G	53G	48G	42G	52G
Major elements						
SiO ₂	47.00	48.40	48.40	49.50	49.60	53.10
TiO ₂	0.98	1.13	1.07	1.59	0.54	1.32
Al ₂ O ₃	16.40	17.00	18.21	18.54	14.20	15.30
Fe ₂ O ₃	2.70	2.50	2.90	3.20	3.20	5.20
Fe _t O ₃	--	--	--	--	--	--
FeO	8.10	9.30	8.00	8.30	9.40	7.20
MnO	0.15	0.20	0.18	0.17	0.23	0.23
MgO	8.09	5.36	4.84	4.99	7.45	4.54
CaO	9.72	9.36	9.83	10.51	11.05	7.38
Na ₂ O	2.71	3.72	3.26	2.33	2.88	3.64
K ₂ O	1.68	0.62	0.60	0.54	0.28	0.62
P ₂ O ₅	0.13	0.13	0.13	0.13	0.06	0.30
H ₂ O+	1.73	1.79	1.54	1.42	1.32	1.24
H ₂ O-	--	--	--	--	--	--
CO ₂	0.01	0.74	0.54	0.16	0.01	0.01
LOI	--	--	--	--	--	--
TOTAL	99.40	100.25	99.50	101.38	100.22	100.08
Minor elements						
Ba	230	77	127	61	53	201
Rb	20	5	11	8	3	13
Sr	98	516	485	289	172	432
Y	19	24	20	24	15	24
Zr	46	66	65	66	19	139
Nb	--	--	--	--	--	--
U	--	--	--	--	--	--
Th	--	--	--	--	--	--
Metals						
Cu	140	60	134	114	109	147
Pb	--	--	--	--	--	--
Zn	77	93	85	96	78	125
Ni	325	38	35	33	75	24
Cr	403	43	41	46	60	25
Co	--	--	--	--	--	--
V	366	286	274	298	331	276
Calculations						
R ₁	1457	1407	1602	1991	1859	1734
R ₂	1763	1601	1649	1736	1830	1315
A/CNK	0.69	0.72	0.76	0.79	0.57	0.76
Fe No.	0.57	0.68	0.69	0.69	0.62	0.72
K No.	0.38	0.14	0.16	0.19	0.09	0.15

muscovite-microcline, plagioclase-hornblende-biotite-epidote, nearly pure diopside altered to actinolite and quartz, microcline-sphene-epidote-actinolite-muscovite-hornblende, hornblende-quartz-biotite-plagioclase-cummingtonite, cummingtonite-

gedrite-quartz-biotite, and calcite-diopside-hornblende-labradorite-quartz are locally abundant. Diopside and epidote in layers are coarser grained (4 to 10 mm diameter) than all other minerals (0.1–0.4 mm). Modal compositions vary tremendously,

from nearly monomineralic bands of epidote or diopside, to bands containing 40% microcline or 30% biotite.

Aeromagnetic Survey

In December 1981, High Life QEB covered the Fossil Ridge and surrounding area of this map with an airborne magnetic survey. East-west flight lines at a nominal spacing of one-half mile were tied with north-south lines spaced 4.5 mi apart. The survey was draped at an average elevation of 1,000 ft above the ground surface. A Geometrics 803 magnetometer having a sensitivity of 0.25 gammas was used for data acquisition at a sampling rate of one second. Data were reduced by the U.S. Geological Survey in Denver, Colo., and the reduced data were gridded at a spacing of 150 meters. Terrain corrections were applied where flight line elevations deviated significantly from 1,000 ft above ground. A total intensity magnetic field map and residual magnetic intensity map were produced from the data (U.S. Geological Survey, 1982). The total intensity map is used in this study.

Magnetic susceptibility measurements of rock units in the area were made using a Geoinstruments JH-8 meter (table 16). Natural outcrops, hand specimens, and slabbed rocks were measured, with no appreciable differences among the same rock collected from various sample localities. Paleozoic, Mesozoic, and Tertiary stratified rocks do not contain significant concentrations of magnetic minerals. The principal effect of such rocks is to slightly reduce the total magnetic intensity in proportion to the thickness of the rock units. All significant anomalies on the magnetic map are attributed to crystalline rocks.

Magnetic susceptibility measurements, in SI units, can be converted, approximately, to volume percent magnetite-equivalent by multiplying the SI measurements in table 16 by 100. Magnetite-equivalent units assume that magnetite is the only magnetic substance in the rock. A measurement of 2000×10^{-5} SI units is equivalent to 2 volume percent magnetite. An average magnetite concentration in most upper crustal rocks is between 1 and 2 volume percent. In simple terms, rocks with less than 1–2 volume percent magnetite will create magnetic lows; rocks with greater than 2 volume percent magnetite will create magnetic highs. Other features, such as magnetic inclination, dipoles, and orientation with respect to the earth's magnetic field will cause variations from these generalizations.

Tertiary and Cretaceous Igneous Rocks

Rhyolite (unit Tr) and the porphyry of Green Mountain (unit Tgm) average less than 400×10^{-5} SI units (equivalent to less than 0.4 volume percent magnetite; table 16). Compared to many Proterozoic units, the rhyolitic rocks could be expected to cause magnetic lows. But, most bodies of rhyolite are too small to affect the magnetic field at the scale of this map. Also, many bodies have magnetite concentrations very similar to the Early Proterozoic Fairview Peak Granodiorite or Roosevelt Granite. A detailed, ground-based

magnetic survey of the Cumberland Pass area (Rosenlund, 1984, plate 8) shows a 1,500-gamma positive magnetic anomaly coincident with the southwestern edge of the porphyry of Green Mountain (unit Tgm) southwest of Cumberland Pass in T. 51 N., R. 4 E., sec. 14. That anomaly is coincident with the -870 gamma closed contour of this map. Increased magnetite in the porphyry of Green Mountain is believed related to early stages of hydrothermal alteration (Rosenlund, 1984). The amount of magnetite in hydrothermally altered samples is indistinguishable from that in the Fairview Park Granodiorite (0.3 percent). Therefore, the porphyry cannot be readily distinguished from the Fairview Peak although the east-striking prong defined by the -850 to -900 gamma contour is roughly coincident with the surface exposure of the porphyry.

No magnetic susceptibility measurements were made on the tonalitic rocks (unit Tkt), but the magnetite concentrations of 2–4 percent described by Rosenlund (1984) should contrast strongly with the surrounding Paleozoic strata and underlying Fairview Peak Granodiorite. No positive anomalies are noted over either the stock or sill. A detailed, ground-based magnetic survey of the Cumberland Pass area (Rosenlund, 1984, plate 8) also failed to reveal any positive magnetic anomalies associated with the stock, although adjacent skarn deposits rich in magnetite caused 700–1,000-gamma positive anomalies. If reversely polarized, the stock should have caused a magnetic low, but it did not (Rosenlund, 1984; plate 8). Perhaps the tonalitic rock is not stock-like in cross-section, but, rather, is a slightly inflated sill-like body.

The stock at Tincup (Jefferson, 1985), which has a slightly more mafic composition than the above tonalite stock and sill, contains only 2–3 volume percent magnetite, but surface outcrop of the stock is coincident with the -540 gamma contour of the steep-sided anomaly in the far northeastern part of map. The steep, southern gradient to the magnetic field suggests a steep-sided, magnetic intrusive rock at depth. A longer wavelength in the magnetic field to the northeast may also be enhanced by lack of nonmagnetic Fairview Peak Granodiorite to the northeast.

The Fossil Ridge Latite (unit Kf) has twice the magnetic susceptibility as the younger felsic rocks (table 16). The latite contains much more magnetite than any of the Paleozoic rocks that it intrudes, but less magnetite than the underlying Early Proterozoic metasedimentary rocks (unit Xs). Therefore, magnetic anomalies related to the latite are difficult to assess. The magnetic high at about the -500 gamma contour on Fossil Ridge in T. 51 N., R. 3 E., sec. 28 could be related to the mass of latite which intrudes the Belden Formation, but the two positive anomalies of similar intensity to the northeast do not coincide with surface expressions of the latite. More likely, the positive magnetic anomalies are related to magnetic parts of unit Xs. A detailed, helicopter-based aeromagnetic survey of the area between South Lottis Creek and Crystal Creek (Rocky Mountain Energy Corp., unpub. data, 1985) shows a north-trending, 50-gamma positive magnetic anomaly centered over the north-trending outcrop of latite that intrudes the granite of Taylor River near the confluence of South Lottis Creek and the Taylor River. Possibly, this discontinuous, dike-like mass on the surface may coalesce into a thin dike-like pluton at depth.

Table 16. Summary of magnetic susceptibility data for rock units in the Fossil Ridge and surrounding area, Gunnison County, Colorado.

[magnetic measurements range, mean, and standard deviation in SI units $\times 10^{-5}$; N, number of samples; 1σ standard deviation calculated if $N > 8$; data acquired with Geoinstruments JH-8 magnetic susceptibility meter; --, not calculated]

Rock name	Map unit	N	Range	Mean	Standard deviation	Comments
Tertiary and Cretaceous igneous rocks						
Rhyolite	Tr	5 fresh 2 altered	5-1500 5-400	350 200	--	None
Green Mountain porphyry	Tgm	2	200-800	500	--	None
Fossil Ridge Latite	Kf	5	400-1600	820	--	None
Proterozoic igneous rocks						
Taylor River Granite	Yt	22	5-400	30	15	Least magnetic igneous rock
Gabbro dike	YXgb	1		250	--	None
Fairview Peak Granodiorite	Xf	8	20-1400	360	160	None
Granodiorite at Almont	Xa	7	20-400	115	--	None
Henry Mountain Granite	Xh	16 granite 7 aplite	70-2700 5-140	890 25	200	Aplite component negligible
Crystal Gabbro	Xc	4	250-11,000	4200	--	Large range
Willow Monzonite	Xw	11	700-4000	2380	310	Most magnetic major igneous rock
Granodiorite of Broncho Mountain	Xb	2	800-150	115	--	None
Roosevelt Granite	Xr	8 fresh 3 altered	5-1100 5	170 5	125	Most < 10
Proterozoic metamorphic rocks						
Metasedimentary units	Xs	7 cordierite schist 4 quartzite	200-2200 1300-6000	880 3525	--	Most magnetic major rock type
Metagabbro, gabbro	Xgb	8	20-2600	575	--	Most < 60
Metavolcanic rocks	Xiv, Xmv	5	20-1500	690	--	None

Proterozoic Igneous Rocks

The granite of Taylor River has the second lowest magnetic susceptibility of any major rock unit in the area (table 16). Areas underlain by the magnetite-poor granite have the lowest magnetic values on the map, from the -850 to the -1100 gamma contour. The magnetic low (-1000 gamma contour) immediately southwest of Henry Mountain in T. 51 N., R. 3 E., secs. 15 and 21 may not indicate granite of Taylor River in the subsurface, but may be an artifact of steep topography on the northwest side of Fossil Ridge.

Only one measurement from gabbro dikes of uncertain age (unit YXgb) was made. The measured dike has very little magnetite. The thin, discontinuous nature of the dikes suggests that they can not be responsible for any major magnetic anomalies.

The large expanse of Fairview Peak Granodiorite in the northeastern part of the map has a uniform and low magnetic

susceptibility (table 16). That area, and its inferred continuation to the southeast, past Pitkin, where Fairview Peak Granodiorite crops out, has a weak (-810 to -950 gamma contours) and homogeneous magnetic signature that dominates the eastern half of the map.

The Henry Mountain Granite (unit Xh), although containing small aplite bodies having very little magnetite, has an average magnetite-equivalent of 0.9 ± 0.2 percent (table 16). Areas underlain by the coarse-grained granite range from the -650 to -850 gamma contours and are characterized by a convoluted pattern of the magnetic contours, which is indicative of the variability of the magnetite concentrations in samples of the granite. The size of outcrops of the fine-grained granite and aplite are insignificant at the scale of this map. The pronounced magnetic low (-1020 gamma contour) in T. 51 N., R. 3 E., secs. 30 and 31, and T. 51 N., R. 2 E., secs. 25 and 36 is underlain by Henry Mountain Granite. The intensity of the low may be an

artifact caused by the steep topography on the northwestern side of Fossil Ridge.

The Willow Monzonite is the most magnetic igneous rock in the area (table 16), averaging 2.4 percent magnetite-equivalent. The most mafic, northeastern part of the pluton averages 3.5 volume percent magnetite and is coincident with the prominent -210 gamma contour associated with the magnetic high in T. 50 N., R. 3 E., sec. 4. The southeastern margin of the pluton coincides, roughly, with the -670 gamma magnetic contour.

The Crystal Gabbro has the highest average susceptibility ($4,200 \times 10^{-5}$ SI units), but most samples have values less than $3,000 \times 10^{-5}$. The amount of magnetite in a single body of the gabbro is highly variable, from less than 0.25 percent to 11 percent. The prominent magnetic high (-210 gamma contour) in the upper reaches of Crystal Creek in T. 51 N., R. 3 E., sec. 17, coincides with outcrop of Crystal Gabbro. A sample of gabbro to the northwest (#7-2-82-5) contains 11 percent magnetite; the body centered in sec. 17 must also be magnetite-rich. The steep-sided pattern of the magnetic high suggests that the gabbro is not cut off at a shallow depth by the Henry Mountain Granite. A large magnetic high at the +240 gamma contour in T. 50 N., R. 2 E., sec. 2, is probably due to a body of gabbro covered by Paleozoic sedimentary rocks. The larger (in surface area) magnetic high defined by the -240 gamma contour that encompasses much of T. 50 N., R. 2 E., secs. 2 and 12, and extends into T. 50 N., R. 3 E., secs. 6 and 7, could be due to a much larger, unexposed body of gabbro, or could be related to an unexposed body of Willow Monzonite.

Small outcrops of the granodiorite of Broncho Mountain (unit Xb) do not affect the magnetic signature of the surrounding granite of Taylor River and metasedimentary sequence.

The least magnetic unit in the map area is the Roosevelt Granite, which averages 0.2 percent magnetite-equivalent, but for which most samples are less than 0.1 percent (table 16). The outcrop area of the granite is characterized by a magnetically quiet signature (-850 to -950 gamma contours) that is very similar to that of the region underlain by the Fairview Peak Granodiorite.

Proterozoic Metamorphic Rocks

Parts of the metasedimentary unit in the Fossil Ridge area have the highest magnetic susceptibility of any rock units except the Crystal Gabbro (table 16). Quartzite is the most magnetic; cordierite schist is less magnetic. The prominent series of magnetic highs along Fossil Ridge are coincident with quartzite and quartz-rich schist. The small, northwest-trending high (-790 gamma contour) north of Henry Mountain in T. 15 S., R. 83 W., sec. 36, is probably related to magnetic protoliths. A detailed, helicopter-based aeromagnetic survey (Rocky Mountain Energy Corp., unpub. data, 1985) suggests Quaternary cover in the cirque in T. 15 S., R. 83 W., unsurveyed sec. 26, may be underlain by similar magnetic siliceous schist or Henry Mountain Granite. Metasedimentary units east of Pitkin, which lack quartz-rich schist, do not have associated magnetic highs.

Metagabbro and gabbro bodies along either side of Quartz Creek have magnetic susceptibilities similar to mafic metavolcanic rocks (table 16). Although the average for 8 metagabbro and gabbro bodies is 575×10^{-5} SI units, all but one sample are less than 60×10^{-5} SI units. Therefore, the metagabbro bodies in this general area may have magnetic susceptibilities slightly less than the metavolcanic rocks they are associated with. The one anomalously magnetite-rich sample (#7-21-82-1A) is slightly east of the -330 gamma maximum magnetic high over Comanche Gulch in T. 51 N., R. 3 E., secs. 35, and may indicate a mass of the magnetite-rich metagabbro at depth beneath the anomaly.

One sample of metarhyolite from the south slope of Sheep Mountain has about 1.5 percent magnetite-equivalent. This amount of magnetite, coupled with the proximity of the small plug of Fossil Ridge Latite to the north, could account for the small, -620 gamma maximum magnetic high centered over Sheep Mountain.

Limited magnetic susceptibility measurements indicate that most amphibolite contains little magnetite, about 0.6 percent. The area underlain by amphibolite that does not contain many plutonic rocks averages less than -400 gammas, the approximate average for the entire Fossil Ridge and surrounding area. Banded amphibolitic units contain about 0.03 volume percent magnetite, but some banded units may contain as much as 1.0 percent magnetite. These compositionally diverse units are too small to affect the magnetic signature of the associated amphibolite units to any notable degree.

Mineral Deposits

As part of a continuing effort to improve the ability to estimate mineral resource potential of Federal lands, the major effort of this study was to summarize existing knowledge of metallic mineral deposits and provide an updated classification of metallic mineralized districts in the Fossil Ridge and surrounding area. These new mineralized districts (table and figure on geologic map) are different from classical mining districts, because they group deposits by genesis and age instead of by geographic position. As an example, many mines in the area between Ohio and Pitkin were grouped in the Gold Brick mining district by Crawford and Worcester (1916) because of their geographic position. We subdivide mines in that area into two groups: (1) those related to Tertiary igneous rocks are now in the Gold Creek mineralized district; and (2) those related to Early Proterozoic deformation and quartz vein formation are now in the Gold Brick mineralized district. In most cases we retained mining district names for many of the new metallic mineral districts. In some cases, new names were introduced in order to avoid confusion with other metallic mineral districts.

Gold Placer Mineralized Districts

The Willow Creek placer district is centered about the town of Tincup, just to the northeast of the map area. Placer

deposits worked in the early part of the 1900's are in Pleistocene glacial deposits and Quaternary alluvium, and extend northward into Taylor Park (Hill, 1909). Insufficient water during summer months inhibited full development of the placer deposits. Gold was probably derived from weathering of precious-metal-bearing veins in the Tincup mineralized district to the south.

Gold placer deposits in the Union Park district are contained in Quaternary alluvial deposits, Pleistocene glacial deposits, and in Tertiary(?) sedimentary deposits that may be equivalent to the Dry Union Formation. Although the deposits had a more reliable source of water year-round (Hill, 1909), the grade of gold is quite low (Kluender and McColly, 1983; DeWitt and others, 1985). Gold in the Tertiary(?) sedimentary deposits may have been derived from the vein deposits in the Tincup mineralized district to the southeast.

Base- and Precious-Metal Districts containing Deposits of Tertiary to Cretaceous Age and Older(?)

Much of the mineralization in the Fossil Ridge area is related to emplacement of Oligocene to Late Cretaceous igneous rocks (Hill, 1909; Goddard, 1935; Tweto, 1943; Dings and Robinson, 1957; Rosenlund, 1984; Jefferson, 1985; Kuender and others, 1983; DeWitt and others, 1985; Zech, 1988). Deposits include Au-Ag veins cutting Early Proterozoic basement rocks, Pb-Au-Ag-Cu replacement bodies in Paleozoic strata, and W- and Mo-bearing veins in Oligocene porphyries.

Vein deposits in the Gold Creek mineralized district (part of the Gold Brick mining district) are spatially associated with the rhyolite stock along Gold Creek (Crawford and Worcester, 1916; DeWitt and others, 1985; Neff, 1988). Some veins cut rhyolite dikes; others are localized along rhyolite dikes. Veins are Pb-rich, consisting of quartz, galena, electrum, minor tetrahedrite, limonite, and pyrite in a gangue of quartz, calcite, dolomite and ankerite, and minor barite (Crawford and Worcester, 1916; Ed DeWitt, unpublished mapping, 1984; Neff, 1988). Open-space fillings are common. Fluids responsible for mineralization were of low salinity. Temperature of mineralization was about 290° C (Neff, 1988). The exact southern boundary of the Tertiary veins is difficult to establish, in part because Early Proterozoic quartz veins in the Gold Brick mineralized district to the south have a somewhat similar mineralogy.

Vein deposits in the central part of the Cumberland Pass mineralized district (part of the Tincup mining district) are W and Mo rich and probably are related to emplacement of an evolved Oligocene porphyry system beneath and slightly west of Cumberland Pass (Tweto, 1943; DeWitt and others, 1985). Many veins strike northeast and dip steeply (Dings and Robinson, 1957; Rosenlund, 1984). Precious-metal-bearing veins having a similar orientation cut the Fairview Peak Granodiorite to the northeast and also cut Paleozoic rocks in the Tincup mineralized district to the northeast. The entire vein system is probably related to the Oligocene porphyry system (Rosenlund, 1984), and represents mineral zonation away from an igneous center.

Replacement and manto deposits in Paleozoic strata typify the Tincup mineralized district, which extends from Cumberland Pass to north of Tincup. Veins having a northeast strike and steep dip also cut the Paleozoic strata, but are less numerous than the replacement deposits (Hill, 1909; Goddard, 1935; Dings and Robinson, 1957). Replacement bodies are most numerous in the Leadville Limestone and rocks of the Chaffee Group (Rosenlund, 1984; Jefferson, 1985). These oxidized deposits consist of friable mixtures of quartz, carbonate minerals, electrum, and secondary silver and lead minerals. Protore probably consisted of pyrite-poor, galena-rich material. We assume that the replacement deposits are related to emplacement of Oligocene and older igneous rocks, but some bodies could be pre-Cretaceous, as direct links to igneous rocks are not apparent in all cases. Skarn deposits are found locally along contacts with Oligocene and Cretaceous(?) plutonic rocks (Rosenlund, 1984; Jefferson, 1985). These small, high-temperature, Fe-rich deposits contain minor amounts of copper and gold. Conceivably, the skarn deposits could all be Cretaceous and unrelated to Oligocene plutonism.

The new Pitkin mineralized district was created from parts of the old Quartz Creek mining district and parts of the Tincup mining district. Because of the existence of the Quartz Creek pegmatite district to the southwest, the new name Pitkin replaces Quartz Creek. Small replacement deposits in Paleozoic limestone, similar to those in the Tincup mineralized district, are most common (Hill, 1909; Herald, 1981; Daly, 1983). Deposits do not appear to be genetically and spatially related to Oligocene porphyries, as the intrusive mass in Chicago Park does not host any deposits nor do the deposits appear to be more common near the rhyolite. Deposits in the northern part of the district, such as the Fairview Peak, could be distally related to the porphyry on Green Mountain. Conversely, deposits in this district may not be related to Oligocene plutonic activity, and conceivably could be much older, even pre-Cretaceous.

The Cross Mountain mineralized district is similar to the Pitkin district because it contains highly oxidized replacement deposits and minor vein deposits in Paleozoic carbonate rocks (Hill, 1909; Zech, 1988) that do not appear to be genetically related to Oligocene intrusive rocks. Rhyolitic rocks are unknown in the area; only sills and dikes of the Cretaceous Fossil Ridge Latite are abundant in the district. In other areas, particularly along the crest of Fossil Ridge, the latite and surrounding rocks are not mineralized and replacement deposits are not known. Perhaps the mineralization in the Cross Mountain district could be pre-Cretaceous in age.

High-Calcium Limestone District

The Leadville Limestone, along the crest of Fossil Ridge, constitutes a high-calcium limestone resource (Kluender and others, 1983; DeWitt and others, 1985; Zech, 1988). Although the limestone has not been mined in the past, we include it in the Fossil Ridge mineralized district because of its potential importance and because of the numerous prospect pits from which high-calcium limestone has been substantiated (DeWitt and others, 1985).

Precious-Metal District containing Early Proterozoic Veins in Basement Rocks

The Gold Brick mineralized district contains precious-metal-rich veins localized along zones of high strain in the Roosevelt Granite and adjacent rock units (Crawford and Worcester, 1916; DeWitt and others, 1985; Neff, 1988). Deposits extend south of the mapped area, to the vicinity of the Revenue mine, south of Ohio (Horlacher, 1987). Vein mineralogy is simple and consists of quartz, limonite, galena, minor pyrite and sphalerite, electrum, minor arsenopyrite, and minor calcite and ankerite. Many deposits are extensively oxidized. Even those deposits that contain noticeable galena are pyrite-poor. Underground mapping of the Carter mine reveals that Oligocene rhyolite dikes discordantly intrude and truncate a major vein hosted by the Roosevelt Granite just west of the inferred Volunteer vein (Ed DeWitt, unpub. data, 1987; Rugg, 1956). Although most veins have not been deformed or metamorphosed, they are most abundant along zones of high strain in the Roosevelt Granite and wall rocks to the west that are related to regional metamorphism (pre-1.7 Ga) that pre-dates the Henry Mountain Granite. Although Neff (1988) considered most mineralization in the district to be Oligocene in age, we believe the above relationships indicate the majority of mineralization took place in the Early Proterozoic.

Pegmatite District

The Quartz Creek pegmatite district (Eckel, 1933; Aldrich and others, 1956) hosts numerous massive to simply zoned pegmatite bodies and minor layered pegmatite bodies related to the Henry Mountain Granite. Principal among the deposits is the Brown Derby, south of the map area. The pegmatites contain feldspar, beryl, muscovite, lepidolite, columbite-tantalite, and other minor mineral commodities (Staatz and Trites, 1955).

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