Biotite, Gould Creek, Colorado B65GC

	reported	probe, av	σ (N=5)
SiO_2	34.26	32.95	(0.55)
Al_2O_3	12.76	12.13	(0.27)
Fe_2O_3	(3.41)		
FeO	34.97 (31.90)	32.56	(0.22)
MnO	0.67	0.67	(0.11)
MgO	1.05	1.09	(0.32)
CaO	0.17	0.06	(–)
Na_2O	0.46	0.07	(0.04)
K_2O	8.57	8.70	(0.08)
TiO_2	3.45	3.54	(0.11)
P_2O_5	0.05	0.06	
H_2O^-	0.08		
H_2O^+	2.50	3.01	(0.04)
Cl	0.35	0.39	(0.03)
F	0.82	0.80	(0.23)
BaO		0.12	(0.03)
SrO		0.04	
Li_2O			
	100.50	96.17	
O=F+Cl	0.43	0.42	
	100.07	95.75	

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THE PIKES PEAK BATHOLITH, COLORADO FRONT RANGE, AND A MODEL FOR THE ORIGIN OF THE GABBRO—ANORTHOSITE—SYENITE—POTASSIC GRANITE SUITE

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ABSTRACT

Barker, F., Wones, D.R., Sharp, W.N. and Desborough, G.A., 1975. The Pikes Peak batholith, Colorado Front Range, and a model for the origin of the gabbro—anorthosite—syenite—potassic granite suite. Precambrian Res., 2: 97—160.

This study of the Pikes Peak batholith includes the mineralogy and petrology of quartz syenite at West Creek and of fayalite-bearing and fayalite free biotite granite near Mount Rosa; major element chemistry of the batholith; comparisons with similar postorogenic, intracratonic, sodic to potassic intrusives; and genesis of the batholith.

The batholith is elongate in plan, 50 by 100 km, composite, and generally subalkalic. It was emplaced at shallow depth 1,040 m. y. ago, sharply transects its walls and may have breached its roof. Biotite granite and biotite—hornblende granite are predominant; quartz syenite, fayalite granite and riebeckite granite are present in minor amounts.

Fayalite-bearing and fayalite-free quartz syenite, fayalite-biotite granite and riebeckite granite show a well-defined sodic differentiation trend; the less sodic fayalite-free granites exhibit a broader compositional range and no sharp trends.

Crystallization was largely at $P_{H_2O} < P_{total}$; P_{H_2O} approached P_{total} only at late stages. Aplite residual to fayalite-free biotite granite in the north formed at about 1,500 bars, or 5 km depth. Feldspar assemblages indicate late stages of crystallization at about 720°C. In the south ilmenite and manganian fayalite indicate f_{O_2} of 10^{-17} or 10^{-18} bars. Biotite and fayalite compositions and the 'granite minimum' imply completion of crystallization at about 700°C and 1,500 bars. Nearby fayalite-free biotite granite crystallized at higher water fugacity.

All types of syenite and granite contain 5—6% K_2O through a range of SiO_2 of 63—76%. Average Na_2O percentages in quartz syenite are 6.2, fayalite granite 4.2, and fayalite-free granite 3.3 MgO contents are low, 0.03—0.4%; FeO averages 1.9—2.5%. FeO/Fe_2O_3 ratios are high. Fluorine ranges from 0.3 to 0.6%.

The Pikes Peak intrusives are similar in mode of emplacement, composition, and probably genesis to rapakivi intrusives of Finland, the Younger Granites of Nigeria, Cape Ann Granite and Beverly Syenite, Mass., and syenite of Kungnat, Greenland, among others — allowing for different levels of erosion. A suite that includes gabbro or basalt, anorthosite, quartz syenite, fayalite granite, riebeckite granite, and biotite and/or hornblende granites is of worldwide occurrence.

A model is proposed in which mantle-derived, convecting alkali olivine basaltic magma first reacts with K_2O-poor lower crust of granulite facies to produce magma of quartz syenitic composition. The syenitic liquid in turn reacts with granodioritic to granitic intermediate crust of amphibolite facies to produce the predominant fayalite-free biotite

TABLE VIII

Chemical analyses of biotites (specimen numbers and locations as in Table II and Fig.7)

Field no.:	Fairview B65F*[1]	Gould Creek B65GC*[1]	Devils Slide B65DS*[1]	West Creek B65D*[2]
SiO_2	34.42	34.26	33.96	36.23
Al_2O_3	11.78	12.76	13.10	11.16
Fe_2O_3	2.49	3.41	3.06	3.41
FeO	32.95	31.90	32.04	33.55
MgO	1.25	1.05	0.97	0.48
CaO	0.17	0.17	0.42	0.21
Na_2O	0.42	0.46	0.49	0.20
K_2O	8.79	8.57	8.47	8.25
H_2O^+	2.45	2.50	2.44	2.79
H_2O^-	0.03	0.08	0.06	0.14
TiO_2	3.86	3.45	3.55	3.02
P_2O_5	0.05	0.05	0.06	0.05
MnO	0.64	0.67	0.65	0.77
Cl	0.32	0.35	0.34	0.20
F	0.69	0.82	0.82	0.45
Subtotal	100.31	100.50	100.43	100.91
Less O	0.36	0.43	0.43	0.24
Total	99.95	100.07	100.00	100.67
*Structural formulas (half cell)**[3]				
Si(IV)	2.87	2.84	2.81	2.98
Al(IV)	1.13	1.16	1.19	1.02
Al(VI)	0.03	0.09	0.09	0.06
Ti(III)	0.24	0.22	0.22	0.19
Fe(II)	0.16	0.21	0.19	0.21
Fe	2.30	2.21	2.22	2.31
Mg	0.16	0.13	0.12	0.06
Mn	0.05	0.05	0.05	0.05
Ca	0.02	0.02	0.04	0.02
Na	0.07	0.07	0.08	0.03
K	0.93	0.91	0.90	0.87
OH	1.36	1.38	1.38	1.53
F	0.18	0.22	0.22	0.12
Cl	0.05	0.05	0.05	0.03
O	10.41	10.35	10.35	10.32
Σalk	1.02	1.00	1.02	0.92
Σoct cations	2.94	2.91	2.89	2.88

*[1] Analyst: V.C. Smith.
*[2] Analyst: Ellen Lillie.
*[3] Calculated on a basis of (O + OH + Cl + F) = 12.

TABLE IX

Biotite analyses by electron microprobe (analyst: G.A. Desborough; n.d., not determined)

Field no.:	West Creek B65D (2 grains)			Devils Slide B65DS (1 grain)			
	C	D	mean	no.2, margin	no.3, margin	no.4, margin	no.5, center
SiO_2	34.7	34.8	34.8	34.4	34.5	34.5	34.4
Al_2O_3	9.6	9.8	9.7	11.3	11.1	11.5	11.1
Fe_2O_3 *1	3.4	3.4	3.4	3.0	3.0	3.0	3.0
FeO *1	35.5	35.7	35.6	31.5	31.9	31.6	31.4
MgO	0.41	0.40	0.40	1.46	1.31	1.41	1.31
CaO	0.07	0.17	0.12	0.20	0.17	0.14	0.25
Na_2O	0.31	0.66	0.49	0.12	0.12	0.10	0.14
K_2O	8.8	8.8	8.8	8.5	8.8	8.7	8.5
H_2O	n.d.	n.d.	—	n.d.	n.d.	n.d.	n.d.
TiO_2	3.1	3.2	3.1	3.4	3.5	3.5	3.4
MnO	0.48	0.43	0.46	0.52	0.47	0.40	0.49
Cl	n.d.	n.d.	—	n.d.	n.d.	n.d.	n.d.
F	n.d.	n.d.	—	n.d.	n.d.	n.d.	n.d.
Total	96.4	97.5	97.0	94.4	95.0	95.0	94.0
Fe (analytical)	30.0	30.2	30.1	26.6	26.9	26.6	26.5

*1 As an approximation, Fe_2O_3 and FeO are calculated in the ratio $FeO/Fe_2O_3 = 10.54$, which is the mean value obtained from the wet-chemical analyses presented in Table VIII.

Iddingsitic alteration is very common, and analyses of iddingsite formed from fayalite are given in Table VII. Magnetite is often associated with the iddingsite. All of the textural and compositional evidence suggests that the olivine is magmatic, and that it was not compositionally affected by deuteric reactions.

Biotites

Four biotites were analysed by wet chemistry in order to establish values for FeO, Fe_2O_3, H_2O, and F (Table VIII). They are rich in FeO, so much so that it is appropriate to refer to them as annite. The structural formulas all calculate out to 2.80 or more octahedral positions filled. They are very slightly titaniferous and contain only small proportions of octahedral alumina. Hazen and Wones (1972) have demonstrated that ideal annite $KFe_3^{2+}AlSi_3O_{10}(OH)_2$ is physically impossible to achieve, so that any natural iron-rich biotite should contain finite amounts of Fe^{3+} as well as octahedral Al and excess Al in the tetrahedral layer. Hazen and Burnham (1973) have determined the structure of B65DS biotite. Table IX gives biotite analyses determined on the electron microprobe and demonstrates the homogeneous nature of these biotites, undoubtedly a result of the low MgO content of the rocks.

The biotites all contain 0.45–0.82% F (Table VIII). Thus a problem arises in the procedure used to calculate normative computations. Biotite and amphibole, of course,

		Gould Creek B65GC (1 grain)				Cripple Creek Road SPD-1 (3 grains)			
no.1, halfway from center to margin	mean	no.2, margin	no.3, margin	no.1, near center	mean	A	B	C	mean
34.4	34.5	34.4	34.9	34.5	34.6	34.6	34.4	34.3	34.4
11.7	11.4	11.9	11.8	12.1	11.9	11.4	12.1	12.5	12.0
3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
31.5	31.6	31.9	31.9	31.8	31.9	31.4	31.4	31.5	31.4
1.40	1.38	0.98	0.98	0.98	0.98	1.14	1.16	1.11	1.14
0.19	0.19	0.22	0.18	0.16	0.19	0.09	0.17	0.18	0.15
0.09	0.11	0.34	0.09	0.11	0.18	0.18	0.09	0.02	0.10
8.7	8.6	8.3	8.7	8.6	8.5	8.8	7.6	8.1	8.2
n.d.	—		n.d.	n.d.	—	n.d.	n.d.	n.d.	—
3.4	3.5	3.0	3.0	3.1	3.0	3.2	3.3	3.1	3.2
0.49	0.47	0.62	0.65	0.65	0.64	0.65	0.65	0.65	0.65
n.d.	—		n.d.	n.d.	—	n.d.	n.d.	n.d.	—
n.d.	—		n.d.	n.d.	—	n.d.	n.d.	n.d.	—
94.9	94.6	94.7	95.2	95.2	95.0	94.5	94.0	94.5	94.3
26.6	26.6	26.9	26.9	26.9	26.9	26.5	26.5	26.5	26.5

are not included in the CIPW norm, yet these minerals contain most of the F in these rocks. In the norm calculation the fluorine of these two minerals is paired with Ca and calculated as normative fluorite; thus the values for normative anorthite are less than they would be if the biotite and amphibole were fluorine-free. Similarly, chlorine in biotite and amphibole is calculated as normative halite, and slightly lowers the expected amount of normative albite.

Feldspars

Plagioclase

Plagioclase compositions were estimated from measurement of extinction angles in thin sections. Much of the plagioclase occurs in exsolution textures coexisting with alkali feldspar. Some discrete grains of plagioclase with concentric zoning were assumed to be magmatic plagioclase. Plagioclase of the quartz syenite is typically An_{5-8}, of fayalite granite An_{7-9}, and of fayalite-free biotite granite (SPD-1) An_{5-7}.

Alkali feldspars

Concentrations of perthitic alkali feldspars were prepared by heavy liquid separations of the −35, +120-mesh fraction. This process tends to give a powder enriched in orthoclase, and thus to concentrate Or component. Nearly all the material X-rayed had exsolved into albite and orthoclase. This material was then sanidinized at 1 atm pressure, 800°C, for 250 h. Only one run produced homogeneous feldspar. Longer heating periods did not alter the results (Table X). Determination of Or content was established by the position