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Analytical data on the crystalline rocks of the Strawberry Lake area, Grand County, Colorado

by

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ABSTRACT

The map area of this report lies between the Continental Divide and Granby in Grand County, Colorado, and occupies at least 160 km^2. Most of the map area is composed of a pluton of Boulder Creek Granodiorite (1.7 b.y.) that is about 80 km^2. A pluton of Silver Plume Granite (1.5 b.y.) and a biotite gneiss unit are roughly equal in area, totaling about 60 km^2. Numerous enclaves of fine-grained granitic rock are found in the Boulder Creek Granodiorite and in the biotite gneiss, but the Silver Plume Granite contains fewer. Lamprophyric enclaves and Tertiary andesite porphyry dikes make up less than 1 percent of the map area.

A long, northwest-trending fault which separates the Silver Plume Granite from the biotite gneiss unit is the northwest extension of the Arapahoe fault.

The chemical, physical, and petrographic properties of each rock unit are listed for comparison in a set of 18 tables. Biotite lamprophyre is the most uraniferous rock, followed by the Silver Plume Granite. Biotite lamprophyre is also most enriched in elements of mafic affinity such as Ti, Mg, Ca, P, Y, Sr, Sc, Cr, Ni, V, and Co and, surprisingly in elements of felsic affinity also, such as K, U, Th, La, Ce, Nd, Ba, Zr, Be, and Pb. All of the granitic rocks are enriched in the light rare earth elements and Th. Monazite is a diagnostic accessory mineral for both the Silver Plume Granite and the biotite gneiss, whereas apatite and sphene are diagnostic of the Boulder Creek Granodiorite.

INTRODUCTION

The rocks described in this report come from the area shown in figure 1, which occupies the Strawberry Lake quadrangle and smaller portions of the surrounding quadrangles in the western part of the Front Range. The map area is about 160 km^2, within which the largest pluton of approximately 80 km^2 is composed of tonalite and granodiorite of the Boulder Creek Granodiorite (~ 1.7 b.y., Tweto, 1977). The other pluton of about 30 km^2 is that of Silver Plume Granite (~ 1.4 b.y., Tweto, 1977). In this map area, however, a Rb-Sr age of 1.5 b.y. was obtained by C. E. Hedge (written commun., 1982). Biotite gneiss (pre-1.7 b.y. metamorphic complex, Tweto, 1977), with minor granite gneiss, amphibolite, and pegmatite is the third major rock type occupying about 30 km^2. Finally, various granitic enclaves from small (<50 m) to large (1/2 km or more), and lamprophyric enclaves are found within the major rock units. Tertiary andesite porphyry dikes are scarce.

Enclave is a good term to use when the origin of a body of rock enclosed within a host rock is not known with certainty. Didier (1973, p. 1) addressed this problem when he stated "One of the aims of this book is to create a simple descriptive terminology devoid of genetic implication, and to this end the French words "enclave" and "inclusion" are used consistently to refer respectively to bodies of material enclosed within a host rock and within individual crystals." It is in this sense that enclave is used in this report, but even when one knows, with some certainty, the origin of a certain enclave, it is good practice to use the term because of its strictly descriptive connotation.

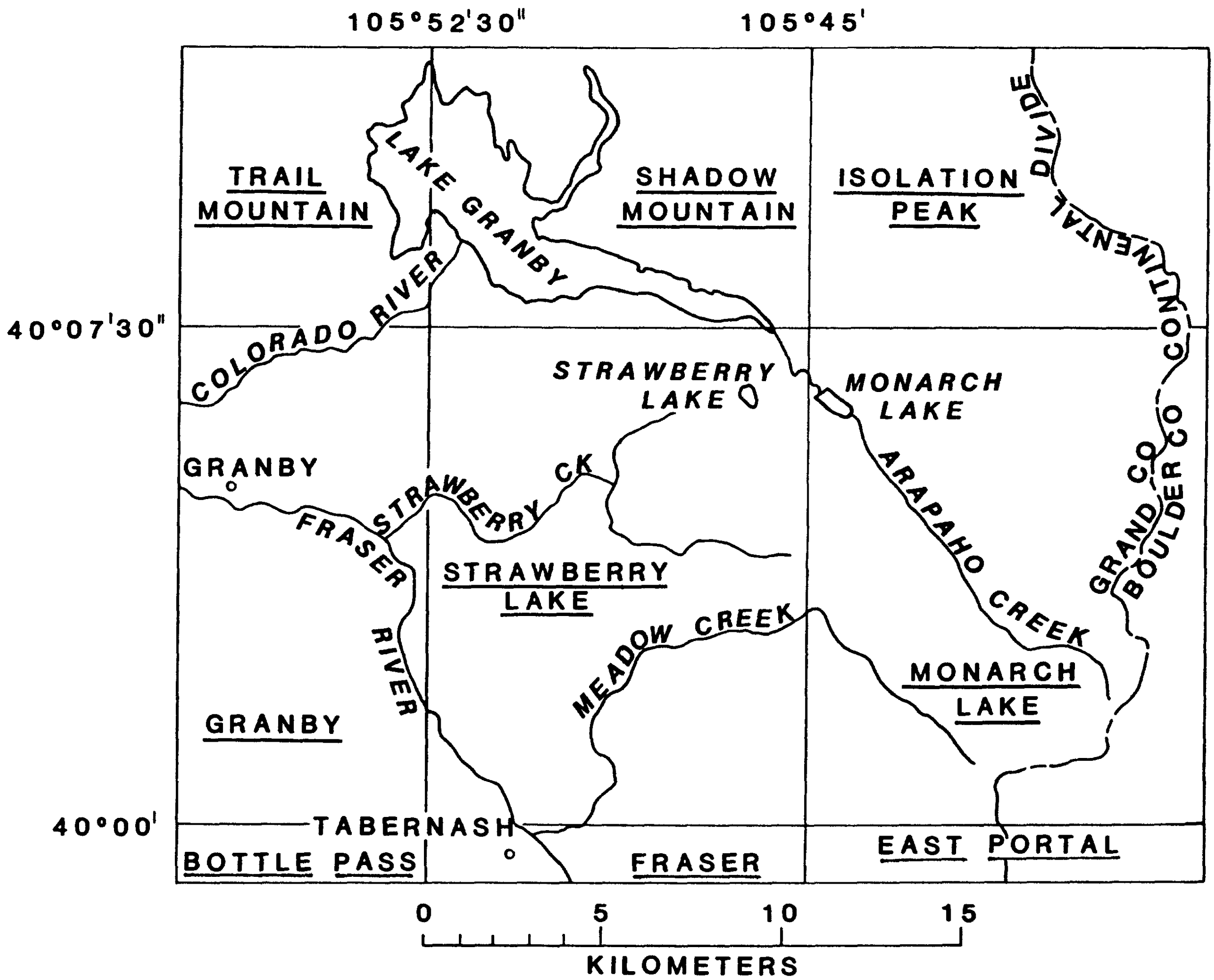


FIGURE 1.--Location of the Strawberry Lake area--7½ -minute quadrangles underlined.

GEOLOGIC SETTING

A geological sketch map of the Strawberry Lake area with sampling localities is shown in plate 1 (in pocket). Most of the map area is in the Strawberry Lake quadrangle, mapped by Schroeder (oral commun., 1982). Smaller portions of the map area are found in the Trail Mountain quadrangle, mapped by Izett (1974), in the Granby quadrangle, mapped by Schroeder (oral commun., 1982), and in the Bottle Pass quadrangle, mapped by Taylor (1975). Portions of the map area that are in the Mountain Shadows and Monarch lake quadrangles have been mapped by the author.

The largest portion of the map area (~50 percent) consists of Boulder Creek Granodiorite, but the Silver Plume Granite and the biotite gneiss unit, with subordinate granite gneiss, amphibolite, and pegmatite each comprise about 20 percent of the map area. Enclaves of fine-grained granitic rock occur in the tonalite, granite, and biotite gneiss, aggregating about 5 percent. Lamprophyric enclaves and a Tertiary andesite porphyry dike, both confined to the Boulder Creek Granodiorite, make up less than 1 percent of the map area.

Regional foliations in the biotite gneiss unit, in biotite gneiss enclaves within the Silver Plume Granite, and in the Boulder Creek Granodiorite generally strike northeast with steep dips. Divergences from this pattern are found in the biotite gneiss enclaves in the Silver Plume Granite and in the biotite gneiss, near the northwest-trending fault, where many strikes are to the northwest.

The northwest-trending fault between the Silver Plume Granite and the biotite gneiss unit is the northwest extension of the Arapahoe Pass fault shown by Pearson and Johnson (1980). There is good evidence for extending the Arapahoe Pass fault northwest into the Shadow Mountain and Trail Mountain quadrangles because the quartz monzonite of Stillwater Creek (Izett, 1974) is on the northeast side of the fault, where it should be, if it is correlative with the Silver Plume Granite.

A small north-south fault is found in the west central part of the Strawberry Lake quadrangle, where the faulting has preserved a small inlier of Mesozoic sediments within the pluton of Boulder Creek Granodiorite.

CHEMICAL, PHYSICAL, AND PETROGRAPHIC PARAMETERS

Table 1 lists the parameters used in the description of nine rock units of the Strawberry Lake area and the number of analyses or measurements made on each rock unit. The table shows, for instance, that 27 chemical analyses were made, 61 spectrographic analyses, etc. It also indicates that most work was done on the two principal plutonic rocks, the Boulder Creek Granodiorite and the Silver Plume Granite.

Of the nine chemical parameters only peraluminous index needs an explanation. The peraluminous index (Clarke, 1981) is equal to the ratio (in molecular proportions) of $\frac{Al_2O_3}{CaO + Na_2O + K_2O}$. Crystalline rocks with a peraluminous index greater than 1.00 are said to be peraluminous.

TABLE 1.--Parameters used in description of rocks of the Strawberry Lake area and number of analyses or measurements for each rock unit

[See text for explanation of parameters]

		Boulder Creek Granodiorite	Silver Plume Granite	biotite gneiss	granitic enclaves in biotite gneiss	granitic enclaves in Boulder Creek Granodiorite	biotite lamprophyre	granitic enclaves in Silver Plume Granite	small mafic enclaves in Boulder Creek Granodiorite	andesite porphyry dike	totals
Areal percentage of rock unit in map area		50	20	20	5	near 1	<1	<<1	<1?	<1	100
Chemical parameters	Chemical analysis, K_2O/Na_2O, Peraluminous index	6	7	3	1	4	2	2	1	1	27
	Spectrographic analysis, La/Ni, U, Th, Th/U	12	25	5	7	5	3	2	1	1	61
	Rb/Sr	3	5	3	3	4	1	2	1	1	23
Physical parameters	Radioactivity	26	33	8	8	13	4	2	0	1	95
	Magnetic property	26	34	9	8	13	5	2	2	1	100
	Specific gravity	25	31	7	7	13	5	2	1	1	92
Petrographic parameters	Modal analysis, Color index	24	32	8	8	12	5	2	1	1	93
	Grain size	26	34	9	8	12	5	2	2	1	99
Total number of parameters, analyzed for, or measured, for each rock unit		232	347	86	88	116	51	30	16	15	

Of the physical parameters, radioactivity has been measured in counts per second (cps) on the outcrop with a Mount Sopris scintillometer, Model SC-132. The designation m for magnetic means that a rock hand specimen reacts positively to a large hand magnet; the designation nm means that a rock hand specimen does not react positively to the same magnet. These data suggest that the black opaque mineral in rocks designated m is wholly or mostly magnetite. Rocks designated nm probably contain black opaque minerals that are hematite and/or ilmenite. Specific gravity has been determined with an air pycnometer, described by McIntyre, Welday, and Baird (1965). An average of three determinations for each rock specimen yields a specific gravity with a $\pm$0.008 g/cc maximum deviation.

Modal analysis was done by point counting (generally 550 to 800 points per thin section). Plagioclase determinations were done by a combination of maximum extinction angles to the 010 trace, optic sign, and refractive index comparisons against quartz. The color index of a rock is the sum of the colored (melanocratic) minerals expressed in percentages. The colored minerals in the rocks described in this report are: biotite, amphibole, pyroxene, chlorite, scapolite, all opaque minerals, garnet, allanite, zircon, sphene, tourmaline, epidote, and monazite. The light (leucocratic) minerals are: quartz, feldspar, muscovite, cordierite, calcite, fluorite, apatite, sillimanite, and clinozoisite.

CRYSTALLINE ROCKS

Data on the chemical, physical, and petrographic parameters of the rocks of the Strawberry Lake area are found in Tables 2 to 18. In general, the rocks are described in order of their volumetric importance.

BOULDER CREEK GRANODIORITE

The Boulder Creek Granodiorite is a massive to foliated, medium grained, light to dark gray, hypautomorphic granular, granitoid rock of granodioritic to tonalitic composition. Biotite and hornblende commonly cluster, giving the appearance of a coarser grain size. Essential minerals are quartz, plagioclase (generally andesine, locally labradorite), and biotite. The plagioclase is commonly myrmekitic and antiperthitic, but not zoned. Microcline, hornblende, muscovite/sericite, chlorite, epidote, clinozoisite, and allanite occur sporadically. Apatite and sphene, black opaque minerals, and zircon (commonly showing overgrowths) are common accessory minerals (tables 2, 3, 4, and 5).

Using Streckeisen's (1976) classification, which is based on modal analysis, 13 samples are granodiorite, 10 are tonalite, and 1 is a granite.

Much of the Boulder Creek Granodiorite is homogeneous, but within its borders many structural and textural differences occur. The largest structural anomalies are granitic enclaves, from less than 2 m to over 1/2 km in size. In some cases, the granitic phase contains remnant(?) enclaves of granodiorite (approximately 1 m). Wisps of biotite gneiss and larger enclaves of biotite gneiss are not uncommon. Three enigmatic biotite lamprophyre enclaves, described below, occur in the granodiorite. Small (1-30 cm) mafic enclaves (gabbroic to dioritic) that are probably restites are common locally. Large pink porphyroblasts, as much as 10 cm long, are common near contacts with the biotite gneiss unit.

TABLE 2.--U, Th, chemical, and spectrographic analyses of the Boulder Creek Granodiorite

[Delayed neutron activation analyses for U ahd Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, W. Stang, R. Bies, B. Keaten, and S. Lasater. Rapid rock chemical analyses of SL-35 by K. Coates and SL-51 by N. Skinner and D. Kobilis. Chemical (X-ray spectrographic) analyses of SL-57, 66, 67, and 70 by J. S. Wahlberg, J. Taggart, and J. Baker. Semiquantitative spectrographic analyses of SL-35 by G. Kaczanowski, SL-51 by T. Fries, and SL-57, 66, 67, and 70 by N. M. Conklin. Significant trace elements (2 x crustal abundance, or more) are underlined. n.d., not determined.]

Boulder Creek Granodiorite

	SL-35	SL-51	SL-57	SL-66	SL-67	SL-70
U..........	1.67 ppm	0.81	2.32	0.84	0.87	1.24
Th.........	3.7 "	5.5	8.8	7.7	10.4	16.8
Th/U.......	2.2	6.8	3.8	9.2	12.0	13.5
Chemical analyses, in weight percent						
SiO_2......	60.6	58.1	60.3	61.6	64.7	66.1
Al_2O_3......	16.1	16.5	16.9	16.7	15.5	15.3
Fe_2O_3......	2.4	2.0	6.03[1]	5.78[1]	6.05[1]	5.66[1]
FeO........	3.8	4.3	n.d.	n.d.	n.d.	n.d.
MgO........	3.5	3.7	3.1	2.7	2.3	2.0
CaO........	4.9	5.3	5.16	4.91	3.53	3.49
Na_2O.......	3.2	3.2	3.5	3.3	2.8	3.0
K_2O........	3.4	3.2	2.32	2.61	3.10	2.83
H_2O+.......	.73	1.0				
....			.78[2]	.70[2]	.80[2]	.60[2]
H_2O-.......	.33	.21				
TiO_2.......	.78	.84	.94	.73	.74	.70
P_2O_5.......	.34	.41	.40	.30	.20	.20
MnO........	.08	.11	.07	.06	.07	.05
CO_2........	.01	.01	n.d.	n.d.	n.d.	n.d.
Total......	100	99	100	99	100	100
K_2O/Na_2O...	1.1	1.0	.66	.79	1.1	.94
Peraluminous index...	.90	.90	.96	.97	1.08	1.07
Spectrographic analyses, in parts per million						
B..........	20	<10	<10	<10	<10	<10
Ba.........	690	1000	300	700	700	500
Be.........	3.3	3.3	1.5	1.5	1.0	1.0
Ce........	<100	<100	<100	<100	<100	100
Co.........	22	24	15	15	15	15
Cr.........	78	98	70	70	30	30
Cu.........	28	39	70	15	15	15
Ga.........	24	24	15	15	15	15
La.........	41	43	30	50	30	70
Nb.........	<25	<25	<10	<10	<10	<10
Nd.........	n.d.	n.d.	<70	70	<70	<70
Ni.........	56	60	50	30	15	15
Pb.........	<10	<10	<10	10	10	10
Sc.........	20	22	7	20	15	7
Sr.........	480	720	700	700	500	500
V..........	140	150	70	70	70	70
Y..........	33	30	20	30	15	15
Yb.........	n.d.	n.d.	3	3	1.5	1.5
Zn.........	87	64	<300	<300	<300	<300
Zr.........	120	150	150	200	150	150
La/Ni......	.73	.72	.60	1.7	2.0	4.7

[1]Total iron reported as Fe_2O_3

[2]LOI at 900°C

TABLE 3.--Modal analyses and descriptive parameters of the Boulder Creek Granodiorite

[Same rock samples as in table 2. Diagnostic accessory minerals are underlined. tr, trace; -, not found.]

Boulder Creek Granodiorite

	SL-35	SL-51	SL-57	SL-66	SL-67	SL-70
Modal analyses, in volume percent						
Quartz	16.9	20.7	19.0	21.9	25.4	31.3
Microcline	10.8	9.4	-	2.6	3.3	5.5
Plagioclase	42.5	37.5	59.0	55.7	52.4	37.1
(An)	(35)	(43)	(38)	(36)	(32)	(32)
Biotite	16.9	11.3	11.7	12.6	16.6	23.3
Muscovite/sericite	-	4.0	-	-	-	.3
Chlorite	-	-	-	.1	-	.3
Hornblende	9.4	13.7	7.5	5.4	.5	-
Black opaque mineral	.2	.1	.4	.1	.5	.9
<u>Apatite</u>	.7	.5	.8	.7	.8	1.0
<u>Sphene</u>	2.4	1.2	1.3	.9	.2	.3
Zircon	tr	tr	tr	tr	.1	tr
Epidote	.2	1.6	.3	tr	-	-
Allanite	tr	-	-	tr	.2	tr
Total	100	100	100	100	100	100
Points counted	801	826	710	684	610	690
Color index	29.1	27.9	21.2	19.1	18.1	24.8
Average grain size (mm)	2.5	2.5	3	3	2.5	2.5
Magnetic, m or nonmagnetic, nm	m	m	nm	m	m	m
Radioactivity (cps)	110	150	125	105	120	165
Specific gravity	2.770	2.830	2.814	2.795	2.745	2.750
Rock name (Streckeisen, 1976)	granodiorite	granodiorite	tonalite	tonalite	tonalite	granodiorite

TABLE 4.--U, Th, spectrographic, and modal analyses and descriptive parameters of the Boulder Creek granodiorite

[Delayed neutron activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, W. Stang, R. Bies, B. Keaten, and S. Lasater. Semiquantitative spectrographic analyses of SL-B by L. Castillo, SL-50 and 52 by T. Fries, and SL-53, 54, and 61 by N. M. Conklin. Significant trace elements (2 x crustal abundance, or more) are underlined. Diagnostic accessory minerals are underlined. tr, trace; -, not found; n.d., not determined; n.a., not applicable.]

Boulder Creek Granodiorite

	SL-8	SL-50	SL-52	SL-53	SL-54	SL-61
U......................	1.83 ppm	1.38	1.18	1.62	2.52	1.24
Th.....................	6.78 "	14.0	8.64	18.5	11.6	9.74
Th/U...................	3.7	10.1	7.3	11.4	4.6	7.9
Spectrographic analyses, in parts per million						
B......................	<10	<10	<10	<10	<10	<10
Ba.....................	840	890	1300	700	1000	700
Be.....................	3.1	4.2	2.7	1	1	1
Ce.....................	110	<100	<100	200	100	100
Co.....................	23	23	15	15	15	15
Cr.....................	55	97	58	70	70	70
Cu.....................	21	56	9.4	30	15	30
Ga.....................	27	25	19	15	15	15
La.....................	68	56	36	150	70	70
Li.....................	96	<50	<50	<100	<100	<100
Mn.....................	790	1100	710	700	700	500
Nb.....................	<25	<25	<25	<10	<10	<10
Nd.....................	n.d.	n.d.	n.d.	100	100	70
Ni.....................	47	57	40	30	30	30
P......................	1500	2900	1500	<2000	<2000	<2000
Pb.....................	3.7	<10	<10	15	10	10
Sc.....................	<10	23	13	7	15	7
Sr.....................	550	610	550	700	700	700
Ti.....................	6300	5400	4200	3000	3000	3000
V......................	150	150	92	70	70	70
Y......................	23	36	21	20	30	10
Yb.....................	n.d.	n.d.	n.d.	2	3	1.5
Zn.....................	52	71	55	<300	<300	<300
Zr.....................	100	140	67	200	150	150
La/Ni..................	1.4	1.0	.9	5.0	2.3	2.3
Modal analyses, in volume percent						
Quartz.................	16.8		16.6	25.3	23.4	
Microcline.............	10.2	no	27.6	11.3	5.3	no
Plagioclase............	32.6		29.5	39.3	36.3	
(An)...................	(30)		(31)	(38)	(35)	
Biotite................	32.2		15.3	22.4	20.9	
Muscovite/Sericite.....	--	thin	3.8	.6	--	thin
Chlorite...............	.1		.3	.1	--	
Hornblende.............	--		3.9	--	11.6	
Black opaque mineral...	2.4	section	1.0	.1	.1	section
Apatite................	2.0		.7	.5	.5	
Sphene.................	1.4		.7	.4	1.1	
Zircon.................	--		.1	tr	tr	
Epidote................	--	available	.1	--	.4	available
Clinozoisite...........	--		--	tr	.4	
Allanite...............	2.3		--	--	--	
Calcite................	--		.4	--	--	
Total..................	100.0		100.0	100.0	100.0	
Points counted.........	651		767	835	786	
Color index............	38.4	n.a.	21.4	23.0	34.5	n.a.
Average grain size (mm)................	3.5	~3	3	2	2.5	~3
Magnetic, m or nonmagnetic, nm...	m	m	nm	m	nm	m
Radioactivity (cps)...............	165	150	170	120	130	140
Specific gravity.......	2.720	2.812	2.759	2.807	2.789	2.850
Rock name (Streckeisen, 1976)	granodiorite	n.a.	granite	granodiorite	granodiorite	n.a.

TABLE 5.--Modal analyses and descriptive parameters of the Boulder Creek Granodiorite

[Diagnostic accessory minerals are underlined, tr, trace; -, not found]

Boulder Creek Granodiorite	SL-84	SL-86	SL-93	SL-94	SL-96	SL-97	SL-98
Modal analyses, in volume percent							
Quartz	29.4	21.3	18.8	20.8	28.9	30.7	27.1
Microcline	18.1	.5	2.8	12.4	--	17.8	.4
Plagioclase	35.1	41.1	36.7	44.4	53.5	38.1	42.2
(An)	(32)	(32)	(28)	(32)	(32)	(32)	(30)
Biotite	11.9	29.4	31.8	14.7	17.0	11.5	27.7
Muscovite/Sericite	.6	--	.4	--	--	tr	--
Chlorite	tr	--	--	--	tr	1.0	--
Hornblende	1.4	1.3	5.8	6.3	--	--	--
Black opaque mineral	tr	.3	tr	.1	tr	--	.9
Apatite	.3	.8	.4	.6	.5	.2	.3
Sphene	.3	1.8	1.0	.6	--	.7	.9
Zircon	--	tr	tr	tr	tr	tr	tr
Epidote	2.8	2.4	2.3	.1	--	tr	.4
Allanite	--	--	tr	--	--	tr	.1
Calcite	.1	--	--	--	--	--	--
Total	100	100	100	100	100	100	100
Points counted	725	615	702	712	647	583	669
Color index	16.4	36.3	40.9	21.8	17.0	13.2	30.0
Average grain size (mm)	2.5	2.5	2.5	2.5	3	2.5	2.5
Magnetic, m or nonmagnetic, nm	nm	nm	nm	nm	nm	nm	m
Radioactivity (cps)	130	110	120	100	160	175	125
Specific gravity	2.727	2.812	2.786	2.803	2.756	2.685	--
Rock name (Streckeisen, 1976)	granodiorite	tonalite	tonalite	granodiorite	tonalite	granodiorite	tonalite

	SL-109A	SL-110	SL-111A	SL-112	SL-113	SL-114	SL-117
Modal analyses, in volume percent							
Quartz	28.0	18.7	20.1	16.5	16.8	27.6	20.3
Microcline	12.8	13.8	2.0	12.7	9.0	--	1.6
Plagioclase	35.7	43.7	59.8	48.6	46.1	44.2	47.3
(An)	(33)	(35)	(35)	(35)	(32)	(35)	(32)
Biotite	18.4	20.6	17.4	15.8	13.1	23.6	25.7
Muscovite/Sericite	4.1	.1	--	--	.2	.7	.2
Chlorite	--	.6	--	--	.3	--	--
Hornblende	--	--	--	4.9	8.6	--	--
Black opaque mineral	.5	.6	tr	.2	.2	2.5	2.7
Apatite	.5	.8	.2	.5	.7	.8	.6
Sphene	--	tr	tr	.5	.7	.5	.6
Zircon	tr	tr	tr	tr	tr	tr	tr
Epidote	tr	.8	.5	.3	1.6	.1	tr
Clinozoisite	--	.3	tr	--	1.4	--	--
Allanite	tr	tr	tr	tr	1.3	tr	1.0
Total	100	100	100	100	100	100	100
Points counted	592	647	596	612	579	601	630
Color index	18.9	22.6	17.9	21.7	25.8	26.7	30.0
Average grain size (mm)	1.5	2.5	2.5	2.5	2	2	2
Magnetic, m or nonmagnetic, nm	m	m	nm	nm	nm	m	m
Radioactivity (cps)	120	120	100	100	100	90	90
Specific gravity	2.762	2.774	2.770	2.767	2.773	2.811	2.787
Rock name (Streckeisen, 1976)	granodiorite	granodiorite	tonalite	granodiorite	granodiorite	tonalite	tonalite

SILVER PLUME GRANITE

The Silver Plume Granite is a generally-massive, pale-gray to buff, hypautomorphic granular, medium grained, peraluminous granite which forms an almost homogeneous mass. Essential minerals are quartz, microcline (locally perthitic), oligoclase (unzoned, locally myrmekitic or containing quartz blebs), biotite and muscovite. Monazite is ubiquitous, having been found in every sample, and zircon (locally showing overgrowths), apatite, and black opaque minerals are present in most samples. Chlorite and sillimanite occur locally, and epidote and allanite are rare. Pyrite and fluorite were only found in one sample (tables 6, 7, 8, and 9).

By Streckeisen's (1976) classification 22 samples are monzogranite, 8 are syenogranite, 1 is a granodiorite, and 1 is a quartz monzonite.

Foliation symbols shown in the Silver Plume Granite in plate 1 were read on small enclaves of biotite gneiss within the granite. Pegmatites in the Silver Plume Granite are uncommon and small, but several, too small to show in plate 1, along Lake Granby are notable for small amounts of tourmaline (black schorl).

Several small (less than 50 m in greatest dimension), but more radioactive, granitic enclaves occur in the silver Plume Granite and are described further on.

Locally, but not commonly, the Silver Plume Granite, shows alignment of microcline laths as often described (Pearson and Johnson, 1980, p. 16). Locally, thin, parallel, biotite schlieren show evidence of relict structures.

Whole-rock sample SM-4 has been dated by C. E. Hedge (written commun., 1982) using the Rb-Sr method. Assuming an initial Sr^{87}/Sr^{86} of 0.7036, which previous suites of Silver Plume Granite have yielded, gives an apparent age of about 1500 m.y., an age closer to the Silver Plume grouping (1400 m.y.) than to the Boulder Creek grouping (1700 m.y.).

BIOTITE GNEISS

The biotite gneiss unit is predominantly a fine- to medium-grained biotite gneiss (tables 10, 11, and 12), but includes lesser amounts of granite gneiss, amphibolite, quartzite, pegmatite, and cordiorite-garnet-sillimanite-biotite gneiss and schist. The biotite gneiss unit is also host to fine-grained granitic enclaves of variable size that are described further on.

Grain size of the biotite gneiss is variable, from less than 1 mm to 10 mm, but much, if not most of the unit is fine-grained. Foliation is everywhere present and the rock becomes schistose as biotite and muscovite increase. Essential minerals are quartz, biotite, muscovite or chlorite. Microcline and plagioclase (oligoclase, andesine, rarely labradorite) are generally present. Hornblende, garnet, sillimanite, and cordierite occur locally. Monazite and zircon are very common, apatite less so. Black opaque minerals are normally present, epidote and allanite are uncommon, and sphene is rare.

The biotite gneiss unit is very peraluminous, and has a high K_2O/Na_2O ratio.

TABLE 6.--U, Th, chemical, and spectrographic analyses of the Silver Plume Granite.

[Delayed neturon activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, W. Stang, R. Bies, B. Keaton, S. Lasater, J. Storey, and S. Danahey. Rapid rock chemical analyses of SM-3 and SL-34 by K. Coates, of SL-40 by N. Skinner and D. Kobilis. Chemical (X-ray spectrographic) analyses of SM-4 and 43A by A. J. Bartel, of SL-64 and 65 by J. S. Wahlberg, J. Taggart, and J. Baker. Semi-quantitative spectrographic analyses of SM-3 and SL-34 by G. Kaczanowski, of SM-4 by L. Bradley, of SL-40 by T. Fries, and of SM-43A, SL-64, and 65 by N. M. Conklin. Significant elements (2 x crustal abundance, or more) are underlined. n.d., not determined]

	Silver Plume Granite						
	SM-3	SM-4	SM-43A	SL-34	SL-40	SL-64	SL-65
U................	8.79 ppm	3.65	6.8	6.77	7.44	6.57	8.27
Th................	37.0 "	30.0	41.0	48.0	27.1	38.2	52.8
Th/U.............	4.2	8.5	6.0	7.1	3.6	5.8	6.4
	Chemical analyses, in weight percent						
SiO_2..............	72.8	71.0	71.0	71.4	72.0	73.0	71.8
Al_2O_3............	14.5	14.7	14.8	14.5	14.3	14.7	14.7
Fe_2O_3............	1.2	2.36[1]	1.82[1]	1.4	.83	1.38[1]	1.37[1]
FeO..............	.68	n.d.	n.d.	1.0	.68	n.d.	n.d.
MgO..............	.36	.67	.48	.65	.34	.40	.40
CaO..............	1.0	.99	1.27	1.80	.96	.92	1.05
Na_2O..............	3.0	2.74	2.82	2.80	3.30	2.80	3.1
K_2O..............	6.0	5.49	5.63	6.00	5.00	5.66	5.49
H_2O^+.............	.59	.94[2]	.76[2]	.51	.53	.71[2]	.58[2]
H_2O^-.............	.24			.26	.23		
TiO_2..............	.27	.32	.28	.33	.17	.19	.23
P_2O_5..............	.13	.15	.14	.18	.14	<.10	.10
MnO..............	.02	<.02	<.02	.04	.04	<.02	<.02
CO_2..............	.03	n.d.	n.d.	.01	.01	n.d.	n.d.
Total............	101	99	99	101	99	100	99
K_2O/Na_2O..........	2.0	2.0	2.0	2.1	1.5	2.0	1.8
Peraluminous index	1.09	1.20	1.13	1.01	1.14	1.19	1.13
	Spectrographic analyses, in parts per million						
B................	<10	<10	<20	<10	<10	<10	<10
Ba................	850	500	700	610	430	300	500
Be................	1.6	<1.5	<1	1.3	1.7	<1.0	<1
Ce................	<100	<100	150	170	<100	150	200
Co................	2.4	<5	<3	1.5	1.4	<3	<3
Cr................	<10	5	3	<10	<10	1.5	7
Cu................	6.2	15	30	23	12	7	30
Ga................	17	30	30	20	21	15	15
La................	54	70	70	100	31	70	150
Nb................	<25	10	15	<25	<25	<10	<10
Nd................	n.d.	150	n.d.	n.d.	n.d.	70	150
Ni................	4.9	<5	<3	4.4	2.7	<2	2
Pb................	53	50	30	36	21	30	30
Sc................	<10	<10	5	<10	<10	<10	<10
Sr................	200	200	200	120	81	150	150
V................	17	30	30	21	11	15	30
Y................	13	<10	10	18	<10	10	15
Yb................	n.d.	<1	n.d.	n.d.	n.d.	1	1
Zn................	<50	<300	<300	61	<50	<50	<50
Zr................	160	70	150	120	62	70	150
La/Ni............	11	>14	>23	23	12	>35	75

[1]Total iron reported as Fe_2O_3

[2]LOI at 900°C

TABLE 7.--Modal analyses and descriptive parameters of the Silver Plume Granite

[Same rock samples as in table 6. Diagnostic accessory minerals are underlined. tr, trace; -, not found]

	Silver Plume Granite						
	SM-3	SM-4	SM-43A	SL-34	SL-40	S1-64	SL-65
	Modal analyses, in volume percent						
Quartz..................	23.6	28.6	28.1	23.5	35.1	32.3	24.7
Microcline.............	43.1	39.0	43.2	43.0	31.3	28.1	28.3
Plagioclase............	20.7	22.8	20.7	23.5	26.5	33.3	40.0
(An)....................	(12)	(15)	(15)	(25)	(12)	(13)	(15)
Biotite................	7.1	.9	3.3	4.5	2.8	4.1	4.9
Muscovite..............	3.6	3.7	3.5	3.1	3.2	1.3	1.3
Chlorite...............	--	3.1	.6	.8	.3	--	tr
Black opaque mineral...	1.5	.9	.1	.9	tr	.1	.6
Apatite................	.2	.6	.4	.3	tr	--	.1
Monazite...............	.2	tr	tr	.4	tr	tr	tr
Zircon.................	tr	tr	tr	tr	tr	tr	tr
Sphene.................	--	.3	--	--	--	--	--
Epidote................	--	tr	--	--	--	--	--
Sillimanite............	--	--	--	tr	.8	.B	.1
Allanite...............	--	--	--	--	--	tr	--
Fluorite...............	--	tr	--	--	--	--	--
Pyrite.................	--	tr	--	--	--	--	--
Calcite................	--	.1	.1	--	--	--	--
Total..................	100	100	100	100	100	100	100
Points counted.........	813	703	691	800	713	716	750
Color index............	B.8	5.2	4.0	6.6	3.1	4.2	5.5
Average grain size (mm).................	1.5	3.0	2.5	2.5	1.5	2.5	3.5
Magnetic, m or nonmagnetic, nm...	nm	m	m	m	nm	nm	nm
Radioactivity (cps)................	350	460	335	450	390	320	360
Specific gravity.......	2.630	2.668	2.662	2.660	2.643	2.647	2.664
Rock name (Streckeisen, 1976)...	granite (*syenogranite*)	granite (*monzogranite*)	granite (*syenogranite*)	granite (*monzogranite*)	granite (*monzogranite*)	granite (*monzogranite*)	granite (*monzogranite*)

TABLE 8.--U, Th, spectrographic, and modal analyses and descriptive parameters of the Silver Plume Granite

[Delayed neutron activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, W. Stang, R. Bies, B. Keaten, and S. Lasater. Semiquantitative spectrographic analyses of ML-1, 2, and 4, and SL-29, 30, and 31 by G. Kaczanowski, SL-37, 39, 41,42,44,45,46,47,48, and 49 by T. Frias, and SL-62 and 63 by N. M. Conklin. Significant trace elements (2 x crustal abundance, or more) are underlined. Diagnostic accessory minerals are underlined. tr, trace; --, not found; n.d., not determined; n.a., not applicable]

	Silver Plume Granite								
	ML-1	ML-2	ML-4	SL-29	SL-30	SL-31	SL-37	SL-39	SL-41
U	2.23 ppm	2.78	5.80	3.33	5.00	4.42	4.39	6.08	5.59
Th	71.5	71.2	45.2	70.7	33.8	38.7	21.6	33.6	31.9
Th/U	32.1	25.3	7.8	21.2	6.8	8.8	4.9	5.5	5.8
Spectrographic analyses, in parts per million									
B	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ba	1300	1500	700	720	470	590	470	620	580
Be	1.2	1.4	2.4	<1	2.1	2	3.6	2.9	1.8
Ce	200	280	200	270	<100	140	140	150	150
Co	3.4	3.9	3.0	4.7	1.1	2.8	2.3	2.3	2.2
Cr	11	11	<10	<10	<10	<10	<10	<10	<10
Cu	24	19	14	22	5.8	18	11	25	6.6
Ga	21	22	26	20	20	23	23	24	18
La	85	170	120	150	45	80	60	75	69
Mn	<200	<200	230	290	<200	260	230	<200	<200
Nb	<25	<25	<25	<25	<25	<25	<25	<25	<25
Nd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	7.6	7.0	5.5	8.5	2.5	3.7	3.2	3.5	3.0
P	900	1000	900	900	1100	900	1600	1500	1000
Pb	31	61	46	46	34	35	23	26	20
Sc	<10	<10	<10	<10	<10	<10	<10	<10	<10
Sr	160	210	130	180	82	120	100	120	140
Ti	2200	2300	1300	2100	1200	1700	1200	1400	1000
V	39	41	38	23	<10	23	14	19	16
Y	16	21	14	33	12	21	16	13	12
Yb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Zn	68	89	57	<50	<50	<50	<50	<50	<50
Zr	150	130	170	230	64	91	33	96	98
La/Ni	11	24	22	18	18	22	19	21	23
Modal analyses, in volume percent									
Quartz	23.7	31.7	46.6	33.7	29.6	26.2	35.7	29.1	33.3
Microcline	35.1	38.0	17.7	41.1	42.8	26.7	34.8	31.3	33.1
Plagioclase	31.8	19.7	32.5	17.7	18.1	35.7	22.9	28.0	27.0
(An)	(15)	(15)	(15)	(12)	(14)	(15)	(13)	(23)	(25)
Biotite	3.8	4.1	.2	2.7	2.8	.9	3.2	4.1	4.2
Muscovite	4.7	4.1	1.7	2.3	6.2	6.3	3.4	6.6	1.1
Chlorite	tr	1.5	.6	1.0	--	3.4	--	--	--
Black opaque mineral	.7	.3	.6	1.4	.5	.3	tr	.1	.8[1]
Apatite	tr	.3	tr	--	--	.5	tr	.1	--
Monazite	tr	.2	tr	.1	tr	tr	tr	tr	tr
Zircon	tr	tr	.1	tr	tr	tr	tr	tr	tr
Epidote	.2	.1	--	--	--	--	--	--	--
Sillimanite	tr	tr	tr	--	--	--	tr	.7	.5
Allanite	--	--	tr	--	--	--	--	--	--
Calcite	--	tr	--	--	--	--	--	--	--
Total	100	100	100	100	100	100	100	100	100
Points counted	553	604	661	824	794	587	682	740	644
Color index	4.7	6.2	1.5	5.2	3.2	4.6	3.2	4.2	5.0
Average grain size (mm)	1.5	1.5	5	<1	1.5	3	1.5	3	2.5
Magnetic, m or nonmagnetic, nm	nm	m	nm	nm	nm	nm	nm	nm	nm
Radioactivity (cps)	420	410	280	240	300	330	255	350	390
Specific gravity	2.660	2.650	2.630	2.640	2.630	2.670	--	2.655	2.651
Rock name (Streckeisen, 1976)	granite (monzogranite)	granite (syenogranite)	granite (monzogranite)	granite (syenogranite)	granite (syenogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)

[1] About one half of the opaque mineral is secondary in grain interstices.

TABLE 8.--U, Th, spectrographic, and modal analyses and descriptive parameters of the Silver Plume Granite--Continued

	SL-42	SL-44	SL-45	SL-46	SL-47	SL-48	SL-49	SL-62	SL-63
U	9.03 ppm	3.36	5.83	3.04	5.42	5.91	7.35	5.60	5.76
Th	61.7	41.1	60.0	32.8	64.0	50.1	71.2	31.9	26.4
Th/U	6.8	12.2	10.3	10.8	11.8	8.5	9.7	5.7	4.6
Spectrographic analyses, in parts per million									
B	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ba	720	890	1000	1200	830	810	730	500	300
Be	1.8	1.6	2.2	1.9	1.6	1.4	<1	<1	<1
Ce	190	140	190	130	230	200	280	100	200
Co	4.1	2.6	6.0	4.9	3.1	3.1	4.6	<3	<3
Cr	<10	11	<15	13	<10	<10	11	3	1
Cu	51	17	9.9	5.1	24	19	9.6	7	15
Ga	22	20	24	20	16	22	19	15	15
La	100	72	130	58	140	120	160	70	150
Mn	230	<200	270	250	<200	210	<200	100	70
Nb	<25	<25	<25	<25	<25	<25	<25	<10	<10
Nd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	70	150
Ni	5.1	4.8	7.7	6.6	4.1	4.0	5.9	2	<2
P	2100	1400	1600	1400	1100	1500	900	<2000	<2000
Pb	49	52	25	25	41	31	32	30	30
Sc	<10	<10	<10	<10	<10	<10	<10	<7	<7
Sr	120	170	180	210	160	160	150	150	150
Ti	1900	1800	3000	2100	2400	1900	2100	1500	700
V	30	21	48	37	27	26	32	15	15
Y	21	11	12	16	15	15	24	10	15
Yb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1	1
Zn	84	61	86	50	54	66	63	<300	<300
Zr	210	170	280	170	130	110	160	100	70
La/Ni	20	15	17	9	34	30	27	35	>75
Modal analyses, in volume percent									
Quartz	19.8	34.0	21.0	17.2	22.4	18.6		22.4	
Microcline	37.0	33.4	20.5	38.8	47.8	48.3	no	36.2	no
Plagioclase	31.6	24.3	46.1	34.0	20.4	23.0		33.7	
(An)	(18)	(20)	(17)	(15)	(15)	(17)		(12)	
Biotite	4.0	3.7	10.0	.8	4.1	4.6		2.9	
Muscovite	4.4	1.1	1.3	1.8	3.9	2.5	thin	3.8	thin
Chlorite	.5	--	.2	6.3	--	1.2		--	
Black opaque mineral	2.3[1]	3.4[1]	.6	1.1	1.2	1.2		.6	
Apatite	tr	.1	.3	tr	tr	tr	section	.3	section
Monazite	.2	tr	tr	tr	.2	tr		tr	
Zircon	tr	tr	tr	tr	tr	tr		tr	
Epidote	--	--	--	--	--	--	available	--	available
Sillimanite	.2	tr	--	--	--	.6		.1	
Allanite	--	--	--	tr	--	--		--	
Calcite	--	--	--	--	--	--		--	
Total	100	100	100	100	100	100		100	
Points counted	1210	618	629	652	608	679		662	
Color index	7.0	7.1	10.8	8.2	5.5	7.0	n.a.	3.5	n.a.
Average grain size (mm)	3	2	1.5	1.5	2	2.5	2	3	3
Magnetic, m or nonmagnetic, nm.	nm	nm	nm	m	nm	nm	nm	nm	nm
Radioactivity (cps)	505	380	390	360	350	430	300	330	305
Specific gravity	2.659	2.655	2.683	2.641	2.679	2.664	--	2.660	--
Rock name* (Streckeisen, 1976)	granite (monzogranite)	granite (monzogranite)	granodiorite	quartz monzonite	granite (syenogranite)	granite (syenogranite)	n.a.	granite (monzogranite)	n.a.

[1]About one half of the opaque mineral is secondary in grain interstices.

TABLE 9.--Modal analyses and descriptive parameters of the Silver Plume Granite

[Diagnostic accessory minerals are underlined. tr, trace; --, not found]

	Silver Plume Granite								
	SL-75	SL-81	SL-91	SL-92	SM-35	SM-52	SM-55	SM-72	SM-73
	Modal analyses, in volume percent								
Quartz	36.1	29.8	36.7	36.0	27.3	28.4	34.0	33.7	32.2
Microcline	30.1	37.8	40.9	36.2	30.7	30.6	39.6	27.6	33.1
Plagioclase	23.5	29.0	12.7	20.7	30.4	32.7	21.8	24.6	24.2
(An)	(18)	(17)	(25)	(15)	(15)	(15)	(13)	(12)	(13)
Biotite	3.2	2.2	8.6	4.7	5.2	6.1	1.8	2.0	4.8
Muscovite	5.7	.9	.3	1.9	2.4	1.2	2.7	11.2	3.8
Chlorite	.5	--	--	.5	2.0	--	--	--	.6
Black opaque mineral	.5	.3	.3	--	1.5	.6	.1	.1	.3
Apatite	.2	tr	tr	--	.4	.4	tr	.1	.1
<u>Monazite</u>	tr	tr	.5	tr	tr	tr	tr	tr	.1
<u>Zircon</u>	tr	tr	--	tr	tr	tr	tr	tr	.1
Epidote	--	--	--	--	--	--	--	--	--
Sillimanite	.2	--	--	tr	--	--	--	.7	.7
Allanite	--	--	--	tr	tr	--	--	--	--
Pyrite	--	--	--	--	tr	--	--	--	--
Calcite	--	--	--	--	--	--	--	--	--
Total	100	100	100	100	100	100	100	100	100
Points counted	631	1273	640	580	735	668	670	802	715
Color index	4.2	2.5	9.4	5.2	8.8	6.7	1.9	2.1	5.9
Average grain size (mm)	2.5	3	3	1	2	1.5	2	2.5	2.5
Magnetic, m or nonmagnetic, nm	m	nm	nm	nm	m	m	nm	nm	m
Radioactivity (cps)	450	400	370	260	--	280	380	290	300
Specific gravity	2.660	2.642	2.635	2.643	2.668	2.668	2.652	2.654	2.662
Rock name (Streckeisen, 1976)	granite (monzogranite)	granite (monzogranite)	granite (syenogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)

TABLE 10.--U, Th, chemical, and spectrographic analyses of the biotite gneiss, biotite lamprophyre enclaves, a small mafic enclave in the Boulder Creek Granodiorite, and an andesite porphyry dike

[Delayed neutron activation analyses for U and Th by H. J. Millard, Jr., B. A. Keaten, F. M. Luman, J. Storey, S. Danahey, B. Vaughn, and M. Couglin. Chemical (X-ray spectrographic) analyses of SL-88, 101B, 139, 142, and SM-152 by A. Bartel and of SL-69 and 71 by J. S. Wahlberg, J. Taggart, and J. Baker. Semiquantitative spectrographic analyses of SL-69 and 71 by N. M. Conklin and of SL-88, 101B, 139, 142, and SM-152 by L. Bradley. Significant elements (2X crustal abundance, or more) are underlined. n.d., not determined]

	biotite gneiss			biotite lamprophyre enclaves		small mafic enclave	andesite prophyry dike
	SL-69	SL-71	SM-152	SL-88	SL-142	SL-101B	SL-139
U	2.02 ppm	2.69	5.33	8.31	9.52	2.15	3.38
Th	24.7 "	23.4	22.2	51.6	62.6	<2.7	22.9
Th/U	12.2	8.7	4.2	6.2	6.6	<1.3	6.8
SiO_2	52.4	66.5	62.0	50.0	47.7	46.8	52.2
Al_2O_3	26.5	17.0	21.5	11.2	11.7	16.5	15.0
Fe_2O_3	12.4[1]	7.15[1]	8.89[1]	7.77[1]	7.84[1]	13.4[1]	8.51[1]
FeO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MgO	2.6	2.6	2.23	9.20	9.04	6.07	6.01
CaO	.27	.82	.38	7.01	7.43	8.54	6.41
Na_2O	.6	1.0	.58	.71	.78	2.76	2.80
K_2O	3.84	2.47	2.59	7.67	7.84	2.38	3.51
H_2O+ H_2O-	.94[2]	1.20[2]	.45[2]	.57[2]	.75[2]	1.21[2]	1.29[2]
TiO_2	1.07	.76	1.09	1.39	1.12	1.25	1.02
P_2O_5	<.1	<.1	.08	1.53	1.79	.42	1.06
MnO	.1	.08	.11	.13	.11	.23	.12
CO_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	101	100	100	97	96	100	98
K_2O/Na_2O	6.40	2.47	4.47	10.8	10.1	.86	1.25
Peraluminous index	4.64	2.95	4.81	.50	.50	.73	.75

Spectrographic analyses, in parts per million

	SL-69	SL-71	SM-152	SL-88	SL-142	SL-101B	SL-139
B	<10	<10	<10	<10	<10	<10	<10
Ba	700	500	300	5000	15000	300	5000
Be	1	<1	<1	3	5	2	1.5
Ce	100	100	<100	500	700	<100	300
Co	30	15	20	20	20	20	20
Cr	150	70	100	500	300	300	300
Cu	3	70	10	15	50	30	30
Ga	30	15	30	20	20	30	20
La	70	70	50	300	300	<50	200
Nb	<10	10	10	<10	<10	<10	<10
Nd	70	70	70	300	700	100	200
Ni	70	20	30	150	150	30	70
Pb	15	10	15	30	50	15	50
Sc	30	15	20	30	20	50	15
Sr	150	150	50	1500	3000	500	3000
V	70	70	150	200	150	200	150
Y	50	70	15	50	70	70	30
Yb	7	7	n.d.	3	3	5	3
Zn	<300	<300	<300	<300	<300	<300	<300
Zr	150	300	150	150	150	70	100
La/Ni	1.0	3.5	1.7	2.0	2.0	<1.7	2.9

1 Total iron reported as Fe_2O_3
2 LOI at 900°C

TABLE 11.--Modal analyses and descriptive parameters of the biotite gneiss, biotite lamprophyre enclaves, a small mafic enclave in the Boulder Creek Granodiorite, and an andesite porphyry dike

[Same rock samples as in table 10. Diagnostic accessory minerals are underlined. tr, trace; --, not found; n.a., not applicable]

	biotite gneiss			biotite lamprophyre enclaves		small mafic enclave	prophyry dike
	SL-69	SL-71	SM-152	SL-88	SL-142	SL-101B	SL-139
Modal analyses, in volume percent							
Quartz	12.0	31.1		--	--	5.7	1.9
Microcline	7.5	4.4		45.8	24.9	tr	10.4
Plagioclase	--	16.5	no	1.6	--	37.9	39.1
(An)	--	(35)		(05)	--	(32)	(30)
Biotite	21.5	16.5		23.6	38.1	28.0	20.7
Chlorite	2.5	1.8		--	--	--	--
Hornblende	--	--	thin	20.8	15.6	20.7	17.3
Monoclinic pyroxene	--	--		--	5.7	--	2.9
Garnet	42.1	6.2		--	--	--	--
Cordierite	6.8	12.8		--	--	--	--
Scapolite (meionite)	--	--		--	--	--	2.1
Sillimanite	6.2	10.1	section	--	--	--	--
Black opaque mineral	1.3	.6		1.3	.5	.9	2.7
Apatite	--	--		2.3	4.2	1.0	1.9
Sphene	--	--		2.6	4.8	1.0	.3
Monazite	.1	tr	available	--	--	--	--
Zircon	tr	tr		--	--	tr	--
Epidote	.1	--		2.0	5.9	4.8	.7
Allanite	--	--		tr	.3	tr	--
Rutile	--	--		tr	tr	--	--
Total	100	100		100	100	100	100
Points counted	601	662		696	598	690	701
Color index	67.4	25.1	n.a.	50.3	70.9	55.4	46.7
Average grain size (mm)	3	2.5	2	<1	<1	<1	<1
Magnetic, m or nonmagnetic, nm	nm	nm	m	nm	nm	m	m
Radioactivity (cps)	210	155	--	295	--	--	160
Specific gravity	2.920	2.872	--	2.899	2.932	--	2.852
Rock name (Streckeisen, 1976, 1979)	n.a.	n.a.	n.a.	minette-vogesite	minette-vogesite	diorite	monzogabbro

TABLE 12.--U, Th, spectrographic, and modal analyses and descriptive parameters of the biotite gneiss and biotite lamprophyre enclaves in the Boulder Creek Granodiorite

[Delayed neutron activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, and W. Stang. Semiquantitative spectrographic analyses of SL-1 and SL-10 by L. Castillo and of SL-36 by T. Fries. Significant elements (2 x crustal abundance, or more) are underlined. Diagnostic accessory minerals are underlined. tr, trace; --, not found; n.d., not determined; n.a., not applicable]

	biotite gneiss						biotite lamprophyre enclaves		
	SL-1	SL-36	SL-76	SL-79	SL-80	SL-89	SL-10	SL-82	SL-83
U	3.04 ppm	2.65	n.d.	n.d.	n.d.	n.d.	7.68	n.d.	n.d.
Th	12.6 "	7.6	n.d.	n.d.	n.d.	n.d.	43.9	n.d.	n.d.
Th/U	3.7	2.9	n.d.	n.d.	n.d.	n.d.	5.7	n.d.	n.d.
Spectrographic analyses, in parts per million									
B	15	15					<10		
Ba	890	1300					4100		
Be	3	3.1					11		
Ce	<100	<100					440		
Co	16	9.9					38		
Cr	84	<10					420		
Cu	8.9	4.5					36		
Ga	24	22					25		
La	54	39					230		
Li	170	<50					130		
Mn	600	1200					1400		
Nb	<25	<25					<25		
Nd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	34	6.5					220		
P	600	2000					>4500		
Pb	<10	<10					<10		
Sc	17	21					29		
Sr	130	180					1700		
Ti	5200	4100					9600		
V	92	52					240		
Y	43	59					64		
Yb	n.d.	n.d.					n.d.		
Zn	91	90					<50		
Zr	190	240					510		
La/Ni	1.6	6.0					1.0		
Modal analyses, in volume percent									
Quartz	51.9	41.6	58.8	47.3	33.3	25.5	--	0.4	--
Microcline	--	.6	4.2	.3	13.2	4.5	37.6	37.4	37.7
Plagioclase	13.3	23.2	24.6	32.2	36.9	20.0	.5	12.3	2.8
(An)	(28)	(68)	(15)	(17)	(28)	(28)	(08)	(20)	(08)
Biotite	16.4	27.8	9.9	18.9	14.7	36.9	20.7	12.1	20.5
Muscovite	17.9	3.1	1.7	.5	.3	.8	--	--	--
Chlorite	--	.1	.1	.2	--	--	--	--	--
Hornblende	--	.9	--	--	--	--	34.2	30.5	29.3
Garnet	--	--	--	--	.2	1.8	--	--	--
Sillimanite	--	.1	.1	--	.2	10.3	--	--	--
Black opaque mineral	.5	--	.6	.5	.7	.2	.5	1.9	.1
Apatite	--	.4	--	--	.5	tr	2.1	.8	3.7
Sphene	tr	--	--	--	tr	--	4.3	4.4	5.8
Monazite	tr	tr	tr	.1	--	tr	--	--	--
Zircon	tr	--	tr	tr	tr	--	--	--	.1
Epidote	--	2.2	--	--	--	--	.1	.2	tr
Allanite	--	--	tr	tr	--	--	--	--	tr
Rutile	--	--	--	--	--	--	tr	tr	tr
Calcite	--	--	--	--	--	--	--	tr	--
Total	100	100	100	100	100	100	100	100	100
Points counted	801	681	710	640	1314	514	807	571	711
Color index	16.9	31.0	10.6	19.7	15.6	38.9	59.8	49.1	55.8
Average grain size (mm)	<1	<1	<1	1	1	1	<1	<1	1
Magnetic, m or nonmagnetic, nm	nm	nm	m	nm	m	nm	nm	nm	nm
Radioactivity (cps)	180	170	230	240	185	165	250	280	310
Specific gravity	2.760	2.807	2.719	2.718	2.749	--	2.890	2.896	2.899
Rock name (Streckeisen, 1979)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	minette-vogesite	minette-vogesite	minette-vogesite

GRANITIC ENCLAVES IN THE BIOTITE GNEISS

Granitic enclaves in the biotite gneiss range from 1 m in greatest dimension to over 0.5 km in greatest dimension. The long, narrow enclave in the northwest part of the map area is mapped as Silver Plume Granite by Schroeder (oral commun., 1982) and as quartz monzonite by Izett (1974). My interpretation of this elongate body as being different from the Silver Plume Granite is based on its finer grain size, lower U content, and other parameters. These generally fine-grained granitic rocks are gray to buff and have hypautomorphic granular texture (tables 13, 14, 15, and 16).

Essential minerals are quartz, microcline, oligoclase (rarely andesine), and biotite. Muscovite is generally present; chlorite occurs sporadically. Zircon is very common; apatite and monazite are slightly less so. Black opaque minerals are generally present; garnet, epidote, allanite, sillimanite, and tourmaline are rarely present.

One chemical analysis of a granitic enclave (SL-3, table 13) indicates that the rock is a peraluminous and very potassic granite. Using the Streckeisen (1976) modal classification 6 samples are monzogranites, 1 is a syenogranite, and 1 is a granodiorite.

GRANITIC ENCLAVES IN THE BOULDER CREEK GRANODIORITE

Granitic enclaves in the Boulder Creek Granodiorite range from 1 m to greater than 0.5 km in greatest dimension and are not uncommon. The smaller enclaves are generally fine grained, but the larger enclaves are slightly coarser. All are gray to buff and have hypautomorphic granular texture (tables 13, 14, 15, and 16).

Essential minerals are quartz, microcline, oligoclase (rarely, albite), and biotite. Muscovite or sericite and black opaque minerals are generally present. Apatite and zircon were found in all of the smaller enclaves, and in most of the larger enclaves. Chlorite, epidote, allanite, monazite and sphene occur locally.

All four chemically analyzed samples are peraluminous (table 13). According to the Streckeisen (1976) modal classification 8 samples are syenogranite, 3 are monzogranite, and 1 is a granodiorite.

BIOTITE LAMPROPHYRE ENCLAVES IN THE BOULDER CREEK GRANODIORITE

Enclaves of biotite lamprophyre, tens of meters in length, tend to cluster in the south central portion of the map area (figure 2 and tables 10, 11, and 12). A single enclave, similar in size, is found in the south-west central part of the map area, and another one in the east central part of the map area has been mapped by Schroeder (oral commun., 1982). The biotite lamprophyre is dark gray, fine grained, and is holocrystalline. Most specimens are massive, but SL-10 showed a pronounced foliation. Essential minerals are biotite and hornblende set in a matrix of microcline, naturally stained inhomogeneously light brown. Monoclinic pyroxene occurs in SL-142, and quartz was found in one out of five samples. Apatite, sphene, a black opaque mineral, epidote, and triangular inclusions of rutile in biotite were found in all samples. Zircon and allanite occur locally.

TABLE 13.--U, Th, chemical, and spectrographic analyses of granitic enclaves in the Boulder Creek Granodiorite, in the Silver Plume Granite, and in the biotite gneiss

[Delayed neutron activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, R. Bies, B. Keaten, S. Lasater, J. Storey, and S. Danahey. Rapid rock chemical analyses of SL-3 and SL-11 by V. Smith and J. Reid, and of SL-20 by K. Coates. Chemical (X-ray spectrographic) analyses of SL-147, SM-43B and SM-48 by A. Bartel and of SL-58 by J. S. Wahlberg, J. Taggart, and J. Baker. Semiquantitative spectrographic analyses of SL-58, SM-43B, and SM-48 by N. M. Conklin, of SL-3, 11, and 20 by G. Kaczanowski, and of SL-147 by L. Bradley. Significant elements (2 x crustal abundance, or more) are underlined. n.d., not determined]

	Granitic enclaves in the Boulder Creek Granodiorite				Granitic enclaves in the Silver Plume Granite		Granitic enclave in the biotite gneiss
	Small - 1 to 5 m		Large - 1/2 km or more		Small - less than 50 m		Large - 1/2 km or more
	SL-11	SL-20	SL-58	SL-147	SM-43B	SM-48	SL-3
U	1.96 ppm	1.77	1.55	1.87	3.4	5.0	4.50
Th	86.2 "	33.9	55.1	8.65	75.9	123.0	53.1
Th/U	44.0	19.2	35.5	4.63	22.3	24.6	11.8
Chemical analyses, in weight percent							
SiO_2	69.3	71.2	71.B	63.8	70.2	70.7	72.4
Al_2O_3	14.7	13.4	15.4	14.7	14.6	14.4	14.5
Fe_2O_3	2.0	1.9	1.86[1]	6.94[1]	3.24[1]	2.84[1]	1.6
FeO	1.0	.96	n.d.	n.d.	n.d.	n.d.	.52
MgO	.64	.78	.68	1.09	.86	.69	.29
CaO	.98	1.1	2.19	2.51	1.14	.85	.66
Na_2O	2.4	1.9	3.4	3.20	2.33	2.23	2.7
K_2O	7.5	7.4	3.75	4.41	5.33	5.83	6.3
H_2O^+	.42	.64					
....			.70[2]	.51[2]	.91[2]	.79[2]	.03
H_2O^-	.21	.32					
TiO_2	.55	.51	.28	1.02	.44	.41	.29
P_2O_5	.23	.09	<.1	.50	.12	.16	.12
MnO	.02	.04	<.02	.D7	<.02	<.02	.00
CO_2	.03	.02	n.d.	n.d.	n.d.	n.d.	.08
Total	100	100	100	99	99	99	100
K_2O/Na_2O	3.13	3.90	1.10	1.38	2.29	2.61	2.33
Peraluminous index	1.16	1.05	1.02	1.13	1.25	1.25	1.16
Spectrographic analyses, in parts per million							
B	<10	<10	<10	<10	<20	<20	<10
Ba	2400	1500	700	3000	1000	700	1100
Be	1.1	1.1	<1	1.5	<1	<1	2.4
Ce	420	<100	150	300	200	300	210
Co	5.3	6.0	3	7	<3	7	1.8
Cr	<10	<10	7	5	15	15	<10
Cu	7	12	1	10	30	7	27
Ga	20	14	15	30	30	30	19
La	230	67	150	150	150	150	130
Nb	<25	<25	<10	15	10	10	<25
Nd	n.d.	n.d.	70	150	150	150	n.d.
Ni	5.3	8.4	3	<10	7	7	4
Pb	38	38	30	30	30	30	23
Sc	<10	<10	7	15	7	5	<10
Sr	270	240	700	1000	300	150	120
V	42	33	15	70	30	30	14
Y	15	12	10	50	15	15	17
Yb	n.d.	n.d.	1	3	1.5	1.5	n.d.
Zn	57	<50	<300	<300	<300	<300	<50
Zr	340	380	150	200	150	150	170
La/Ni	43	8.0	50	>15	21	21	33

[1]Total iron reported as Fe_2O_3

[2]LOI at 900°C

TABLE 14.--Modal analyses and descriptive parameters of granitic enclaves in the Boulder Creek Granodiorite, in the Silver Plume Granite, and in the biotite gneiss

[Same rock samples as in table 13. Diagnostic accessory minerals are underlined. tr, trace; --, not found]

	Granitic enclaves in the Boulder Creek Granodiorite				Granitic enclaves in the Silver Plume Granite		Granitic enclave in the biotite gneiss
	Small - 1 to 5 m		Large - 1/2 km or more		Small - less than 50 m		Large - 1/2 km or more
	SL-11	SL-20	SL-58	SL-147	SM-43B	SM-48	SL-3
	Modal analyses, in volume percent						
Quartz	23.2	27.9	32.9	22.6	29.9	29.7	32.7
Microcline	54.3	41.8	30.5	27.8	29.8	34.3	27.6
Plagioclase	11.6	17.6	29.1	35.3	25.2	24.2	27.2
(An)	(14)	(05)	(12)	(24)	(27)	(27)	(14)
Biotite	8.5	8.4	3.4	8.4	9.6	5.9	4.8
Muscovite	.5	--	2.7	--	3.0	4.3	6.5
Sericite	--	.2	tr	2.5	--	--	--
Chlorite	--	.5	.3	tr	1.0	.1	--
Black opaque mineral	1.0	2.1	.9	1.9	1.1	.9	.6
Apatite	.7	.3	tr	1.4	tr	tr	.1
Monazite	--	--	tr	--	.1	.1	.5
Sphene	--	.8	tr	.1	--	--	--
Zircon	.2	.3	tr	tr	tr	tr	tr
Epidote	--	tr	.2	--	--	--	--
Allanite	--	.1	--	--	--	--	--
Sillimanite	--	--	--	--	.3	.5	--
Total	100	100	100	100	100	100	100
Points counted	801	1803	584	B06	1769	1036	805
Color index	9.7	12.2	4.8	10.4	11.8	7.0	5.9
Average grain size (mm)	<1	<1	1.5	<1	1.5	1.5	1.5
Magnetic, m or nonmagnetic, nm	m	m	nm	m	m	m	nm
Radioactivity (cps)	490	525	220	150	500	550	345
Specific gravity	2.650	2.630	2.677	2.758	2.673	2.675	2.650
Rock name (Streckeisen, 1976)	granite (syenogranite)	granite (syenogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)

TABLE 15.--U,Th, spectrographic, and modal analyses and descriptive parameters of granitic enclaves in the biotite gneiss and in the Boulder Creek Granodiorite

[Delayed neutron activation analyses for U and Th by H. T. Millard, Jr., M. Solt, M. Coughlin, B. Vaughn, M. Schneider, W. Stang, B. Keaten, and F. Luman. Semiquantitative spectrographic analyses of SL-4 and SL-17 by L. Castillo, of TM-2 and SL-25 by G. Kaczanowski, of SL-38 and SL-43 by T. Fries, and of SL-59 by N. M. Conklin. Significant elements (2 x crustal abundance, or more) are underlined. Diagnostic accessory minerals are underlined. tr, trace; -, not found; n.d., not determined]

	Granitic enclaves in the biotite gneiss						Granitic enclave in the Boulder Creek Granodiorite
	Small - less than 50 m			Large - 1/2 km or more			Large - 1/2 km or more
	SL-25	SL-38	SL-43	SL-4	SL-17	TM-2	SL-59
U	6.97 ppm	2.73	1.36	2.78	3.89	3.99	2.08
Th	26.4 "	29.9	30.4	75.2	75.6	26.2	23.7
Th/U	3.8	11.0	22.0	27.1	19.4	6.6	11.4
Spectrographic analyses, in parts per million							
B	<10	<10	17	<10	<10	<10	<10
Ba	340	220	1700	2000	1100	370	700
Be	1.9	2.8	3.6	1.4	1.5	3.2	<1
Ce	<100	<100	310	390	320	110	150
Co	1.1	1.5	10	4.3	4.2	1.8	3
Cr	<10	<10	13	<10	<10	<10	15
Cu	<1	8.7	30	11	6.5	12	2
Ga	18	18	25	25	21	22	15
La	44	<20	190	230	160	54	100
Li	<50	<50	<50	<50	<50	55	<50
Mn	<200	260	860	<200	230	<200	70
Nb	<25	<25	<25	<25	<25	<25	<10
Nd	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	70
Ni	2.4	4.3	11	6.2	4.7	2.3	3
P	600	1000	>4500	700	500	900	<2000
Pb	51	14	<10	43	50	31	30
Sc	<10	<10	11	<10	<10	<10	7
Sr	170	73	290	190	150	61	700
Ti	900	900	6300	3100	2200	1300	1500
V	<10	<10	77	41	27	<10	30
Y	<10	17	43	17	16	20	15
Yb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.5
Zn	<50	<50	170	54	55	<50	<300
Zr	<20	43	420	280	220	130	150
La/Ni	18	<5	17	37	34	23	33
Modal analyses, in volume percent							
Quartz	31.1	28.3	28.7	29.2	30.1	35.3	28.5
Microcline	34.1	38.6	20.8	30.8	39.5	23.9	13.3
Plagioclase	32.8	29.1	32.3	27.0	20.8	29.1	50.7
(An)	(13)	(12)	(32)	(13)	(12)	(16)	(15)
Biotite	2.0	3.2	13.8	7.3	7.1	1.7	5.0
Muscovite	--	.8	1.1	2.8	2.5	8.8	2.1
Chlorite	tr	--	.1	.6	--	--	.1
Black opaque mineral	tr	--	2.5	1.5	tr	.8	.3
Apatite	--	tr	.6	.4	tr	.4	--
Monazite	.1	tr	--	.4	tr	tr	tr
Zircon	tr	tr	.1	tr	tr	tr	tr
Allanite	--	--	tr	--	--	--	--
Sillimanite	tr	--	--	--	tr	--	--
Tourmaline	--	tr	--	--	--	--	--
Total	100	100	100	100	100	100	100
Points counted	549	622	832	800	552	809	701
Color index	2.1	3.2	16.5	9.8	7.1	2.5	5.4
Average grain size (mm)	1	1.5	2	<1	<1	1	2.5
Magnetic, m or nonmagnetic, nm	nm	nm	m	nm	nm	nm	nm
Radioactivity (cps)	330	165	325	385	325	280	200
Specific gravity	2.620	2.649	2.776	2.630	2.640	2.640	2.689
Rock name (Streckeisen, 1976)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (monzogranite)	granite (syenogranite)	granite (monzogranite)	granodiorite

TABLE 16.--Modal analyses and descriptive parameters of granitic enclaves in the Boulder Creek Granodiorite and in the biotite gneiss

[Diagnostic accessory minerals are underlined. tr, trace; --, not found]

	Granitic enclaves in the Boulder Creek Granodiorite							Granitic enclave in the biotite gneiss
	Small - 1 to 5 m			Large - 100 to 400 m				Small 1 to 5 m
	SL-95	SL-109B	SL-111B	SL-85	SL-99	SL-115	SL-116	SL-103
	Modal analyses, in volume percent							
Quartz	31.8	33.0	35.5	33.0	25.3	24.3	25.2	32.2
Microcline	41.8	32.6	36.2	55.8	45.4	48.8	44.2	11.7
Plagioclase	19.5	21.6	18.8	7.4	20.2	15.1	18.9	36.2
(An)	(28)	(20)	(26)	(13)	(13)	(27)	(25)	(33)
Biotite	5.0	5.7	6.4	1.6	5.1	7.1	4.6	15.1
Muscovite	--	6.1	tr	2.1	2.0	2.1	4.1	3.6
Chlorite	.5	tr	.7	--	tr	.1	.8	--
Black opaque mineral	.5	1.0	1.2	--	1.0	1.8	1.0	.3
Apatite	tr	tr	.5	.1	.5	.3	.5	.7
Monazite	--	tr	--	tr	--	tr	--	tr
Sphene	.2	--	tr	--	.5	--	--	--
Zircon	tr	tr	tr	--	tr	.4	.1	tr
Epidote	.7	tr	.7	--	--	--	.3	tr
Allanite	--	tr	--	--	tr	--	.3	tr
Garnet	--	--	--	--	--	--	--	.2
Total	100	100	100	100	100	100	100	100
Points counted	559	592	563	578	605	708	608	583
Color index	6.9	6.7	9.0	1.6	6.6	9.4	7.1	15.6
Average grain size (mm)	1	<1	1.5	1	1	<1	<1	<1
Magnetic, m or nonmagnetic, nm	m	m	m	nm	m	m	m	nm
Radioactivity (cps)	180	480	365	165	270	470	400	50
Specific gravity	2.666	2.666	2.665	2.625	2.670	2.674	2.675	--
Rock name (Streckeisen, 1976)	granite (syenogranite)	granite (monzogranite)	granite (syenogranite)	granite (syenogranite)	granite (syenogranite)	granite (syenogranite)	granite (syenogranite)	granodiorite

According to the Streckeisen (1979) classification for lamprophyres, minette-vogesite is an appropriate name. The narrow range of specific gravities indicates the homogeneity of the lamprophyres; five specimens average 2.903 with maximum deviations not exceeding ±0.029 (tables 11 and 12).

Chemically, the biotite lamprophyre is the most unusual of all the rock units. Both U and Th are high, but the Th/U ratio is close to normal (5.2). Mg and K, incompatible major elements, are unusually high, as well as the elements Ba, Sr, P, LREE, Y, Cr, Ni, Sc, and V.

GRANITIC ENCLAVES IN THE SILVER PLUME GRANITE

These granitic enclaves are mappable only where exposure is very good. They are slightly more radioactive, more melanocratic, and slightly finer grained than the Silver Plume Granite, and show a subtle porphyritic texture. Contact relations between the granitic enclaves and the Silver Plume Granite are generally sharp, but there is no semblance of a chilled border in the enclaves.

Quartz, microcline, oligoclase, biotite, and muscovite are essential minerals. Chlorite, a black opaque mineral, monazite, apatite, zircon, and sillimanite, are common accessories (tables 13 and 14).

The enclaves are peraluminous, and according to the Streckeisen (1976) classification they are monzogranites.

Th is much more abundant than U in the enclaves, as compared with the Silver Plume Granite. The LREE are also very abundant.

The origin of these granitic enclaves may be due to local melting within the Silver Plume Granite.

SMALL MAFIC ENCLAVES (RESTITES) IN THE BOULDER CREEK GRANODIORITE

These small (generally 1 to 20 cm), mafic, fine-grained, roundish or discoid enclaves (restites) in the Boulder Creek Granodiorite are abundant locally. They are too homogeneous to be xenoliths; moreover, no country rock fits their description. Hence they are interpreted to be restites or unassimilable constituents of the Boulder Creek Granodiorite.

Their essential minerals (tables 10 and 11) are andesine, biotite, and hornblende. Small amounts of quartz and muscovite are present in some samples. Accessory minerals consist of a black opaque mineral, apatite, sphene, epidote, zircon, and allanite. According to the Streckeisen (1976) classification sample SL-101B is a diorite.

Abundant elements in the mafic enclaves are Fe, P, Cr, Nd, Sc, V, and Y. Th is notably deficient.

ANDESITE PORPHYRY DIKE

The Tertiary andesite porphyry dike in the southwest part of the map area is approximately 9 m wide and at least 150 m long. It is dark and fine grained. Essential minerals are plagioclase (An_{30}), biotite, hornblende, monoclinic pyroxene, microcline, and a very little quartz. A black opaque mineral, apatite, sphene, and epidote are accessory minerals. An unusual mineral found in this dike is scapolite (meionite) occurring as phenocrysts as much as 2.5 x 3.5 mm in size. Microprobe analyses on the phenocrysts by Isabelle Brownfield (written commun., 1984) indicate the CaO/Na_2O ratio to be about 4.4 (tables 10 and 11).

According to the Streckeisen (1976) classification, sample SL-139 is a monzogabbro. U, P, Ba, Cr, Sr, and the LREE are unusually high.

COMPARISON OF ROCK UNITS

Table 17 lists Rb/Sr for some samples from each of the rock units. Table 18 summarizes and gives averages and ranges of chemical, physical, and petrographic parameters of each of the rock units.

TABLE 17.--Rb/Sr ratios of rocks from the Strawberry Lake area

[X-ray fluorescence analysis of SM-4 by C. E. Hedge, of SM-43A, SM-43B, SM-48, SL-76, SL-84, and SL-89 by Z. E. Peterman, of SL-3, SL-10, SL-11, SL-20,SL-25, SL-72, SL-96, SL-100, SL-116, SL-139, SL-147, SL-151, SL-152, SL-153, SL-155, and TM-2 by G. N. Green]

	Boulder Creek Granodiorite	Silver Plume Granite	biotite gneiss	granitic enclaves in biotite gneiss	granitic enclaves in Boulder Creek Granodiorite	biotite lamprophyre	granitic enclaves in Silver Plume Granite	small mafic enclaves in Boulder Creek Granodiorite	andesite porphyry dike
Rb/Sr	SL-84 - 0.095 SL-96 - .41 SL-100 - .13	SM-4 - 2.47 SM-43A - 1.94 SL-72 - 3.98 SL-151 - .92 SL-153 - 4.70	SL-76 - 0.49 SL-89 - .27 SL-152 - 1.30	SL-3 - 1.92 SL-25 - .80 TM-2 - 5.02	SL-11 - 0.72 SL-20 - .61 SL-116 - 1.03 SL-147 - .08	SL-10 - 0.18	SM-43B - 1.57 SM-48 - 2.51	SL-155 - 0.02	SL-139 - 0.03
Average Rb/Sr	0.21	2.80	0.69	2.58	0.61	0.18	2.04	0.02	0.03

TABLE 18.--Averages and ranges of chemical, physical, and petrographic parameters of rock units in the Strawberry Lake area.

[Key to system: 25 ----------Number of samples contributing to average; 7 ----------Average; (3 to 10) ----------Range; - no data]

	Boulder Creek Granodiorite	Silver Plume Granite	biotite gneiss	granitic enclaves in biotite gneiss, small - < 50m	granitic enclaves in biotite gneiss, large - > ½ km	granitic enclaves in Boulder Creek Granodiorite, small - 1 to 5m	granitic enclaves in Boulder Creek Granodiorite, large, 100m to > ½ km	biotite lamprophyre	granitic enclaves in Silver Plume Granite, small - < 50m	small mafic enclaves in Boulder Creek Granodiorite	andesite porphyry dike
K_2O/Na_2O	6 0.93 (0.66 to 1.10)	7 1.9 (1.5 to 2.1)	3 4.45 (2.47 to 6.40)	-	1 2.33	2 3.52 (3.13 to 3.90)	2 1.24 (1.10 to 1.38)	2 10.5 (10.1 to 10.8)	2 2.45 (2.29 to 2.61)	1 0.86	1 1.25
Peraluminous index	6 0.98 (0.90 to 1.10)	7 1.13 (1.01 to 1.20)	3 4.13 (2.95 to 4.81)	-	1 1.16	2 1.11 (1.05 to 1.16)	2 1.08 (1.02 to 1.13)	2 0.50 (0.5 to 0.5)	2 1.25 (1.25 to 1.25)	1 0.73	1 0.75
U	12 1.46 (0.81 to 2.52)	25 5.57 (2.23 to 9.03)	5 3.15 (2.02 to 5.33)	3 3.89 (1.36 to 6.97)	4 3.79 (2.78 to 4.50)	2 1.87 (1.77 to 1.96)	3 1.83 (1.55 to 2.08)	3 8.50 (7.68 to 9.52)	2 4.2 (3.4 to 5.0)	1 2.15	1 3.38
Th	12 10.2 (3.7 to 18.5)	25 45.3 (21.6 to 70.5)	5 18.1 (7.6 to 24.7)	3 28.9 (26.4 to 30.4)	4 57.5 (26.2 to 75.6)	2 60.1 (33.9 to 86.2)	3 29.2 (8.65 to 55.1)	3 52.7 (43.9 to 62.6)	2 99.5 (75.9 to 123)	1 <2.7	1 22.9
Th/U	12 7.0 (2.2 to 12.0)	25 8.13 (3.6 to 32.1)	5 5.75 (2.9 to 12.2)	3 7.4 (3.8 to 22.0)	4 15.2 (6.6 to 27.1)	2 32.1 (19.2 to 44.0)	3 16.0 (4.6 to 35.5)	3 6.2 (5.7 to 6.6)	2 23.7 (22.3 to 24.6)	1 <1.3	1 6.8
La/Ni	12 1.9 (0.6 to 5.0)	25 25 (9 to >75)	5 2.8 (1 to 6)	3 ~13 (<5 to 18)	4 32 (23 to 37)	2 26 (8 to 43)	3 >33 (>15 to 50)	3 1.7 (1 to 2)	2 21 (21 to 21)	1 <1.7	1 2.9
Radioactivity (cps)	26 127 (90 to 175)	33 355 (240 to 505)	8 192 (155 to 240)	4 218 (50 to 330)	4 334 (280 to 385)	5 408 (180 to 525)	7 268 (150 to 470)	4 284 (250 to 310)	2 525 (500 to 550)	-	1 160
Magnetic, m or nonmagnetic, nm	26 (14m, 12nm)	34 (9m, 25nm)	9 (3m, 6nm)	4 (1m, 3nm)	4 (0m, 4nm)	5 (5m, 0nm)	7 (4m, 3nm)	5 (0m, 5nm)	2 (2m, 0nm)	2 (2m, 0nm)	1 m
Specific gravity	25 2.778 (2.685 to 2.850)	31 2.654 (2.630 to 2.683)	7 2.792 (2.718 to 2.920)	3 2.682 (2.620 to 2.776)	4 2.640 (2.630 to 2.650)	5 2.655 (2.630 to 2.666)	7 2.681 (2.625 to 2.758)	5 2.903 (2.890 to 2.932	2 2.674 (2.673 to 2.674)	-	1 2.852
Color index	24 24.9 (13.2 to 40.9)	32 5.0 (1.5 to 10.8)	8 28.2 (10.6 to 67.4)	4 9.4 (2.1 to 16.5)	4 6.3 (2.5 to 9.8)	5 8.9 (6.7 to 12.2)	7 6.5 (1.6 to 10.4)	5 57.2 (49.1 to 70.9)	2 9.4 (7.0 to 11.8)	1 55.4	1 46.7
Average grain size (mm)	26 2.5 (1.5 to 3.0)	34 2.3 (<1 to 5.0)	9 <1.5 (<1 to 3)	4 ~1.2 (<1 to 2)	4 ~1 (<1 to 1.5)	5 <1 (<1 to 1.5)	7 ~1 (<1 to 2.5)	5 <1 (<1 to 1)	2 1.5 (1.5 to 1.5)	2 <1	1 <1

Significant elements - Key to system: 618(1.8) — 618: Average; (1.8): Enrichment factor = Average/crustal abundance

-, less than 1.4 enrichment factor; n.d., no determination

	Element (crustal abundance)	Boulder Creek Granodiorite	Silver Plume Granite	biotite gneiss	granitic enclaves in biotite gneiss, small	granitic enclaves in biotite gneiss, large	granitic enclaves in Boulder Creek Granodiorite, small	granitic enclaves in Boulder Creek Granodiorite, large	biotite lamprophyre	granitic enclaves in Silver Plume Granite, small	small mafic enclaves in Boulder Creek Granodiorite	andesite porphyry dike
Weight percent	Fe (4.65)	-	-	6.64 (1.4)	-	-	-	-	-	-	9.38 (2)	-
	Ti (0.45)	-	-	-	-	-	-	-	0.76 (1.7)	-	0.75 (1.7)	0.61 (1.4)
	Mg (1.87)	-	-	-	-	-	-	-	5.47 (2.9)	-	3.64 (1.9)	3.61 (1.9)
	Ca (2.96)	-	-	-	-	-	-	-	5.16 (1.7)	-	6.10 (2.1)	4.58 (1.5)
	K (2.5)	-	4.66 (1.9)	-	-	5.23 (2.1)	6.18 (2.5)	-	6.44 (2.6)	4.63 (1.9)	-	-
	P (0.093)	-	-	-	~0.22 (2.4)	-	-	-	0.72 (7.7)	-	0.18 (1.9)	0.46 (4.9)
ppm	U (2.5)	-	5.57 (2.2)	-	3.89 (1.6)	3.79 (1.5)	-	-	8.50 (3.4)	4.2 (1.7)	-	3.38 (1.4)
	Th (13)	-	45.3 (3.5)	18.1 (1.4)	26.9 (2.2)	57.5 (4.4)	60.1 (4.6)	29.2 (2.2)	52.7 (4.1)	99.5 (7.7)	-	22.9 (1.8)
	La (29)	60 (2.1)	96 (3.3)	57 (2)	~80 (2.8)	144 (5)	149 (5.1)	133 (4.6)	277 (9.6)	150 (5.2)	-	200 (6.9)
	Ce (70)	-	166 (2.4)	-	~150 (2.1)	258 (3.7)	~245 (3.5)	200 (2.9)	547 (7.8)	250 (3.6)	-	300 (4.3)
	Nd (37)	-	118 (3.2)	70 (1.9)	n.d.	n.d.	n.d.	97 (2.6)	500 (13.5)	150 (4.1)	100 (2.7)	200 (5.4)
	Y (29)	-	-	47 (1.6)	-	-	-	-	61 (2.1)	-	70 (2.4)	-
	Yb (3)	-	-	7 (2.3)	n.d.	n.d.	n.d.	-	-	-	5 (1.7)	-
	Ba (650)	-	-	-	-	1143 (1.8)	1950 (3)	1467 (2.3)	8033 (12.4)	-	-	5000 (7.7)
	Sr (340)	618 (1.8)	-	-	-	-	-	800 (2.4)	2067 (6.1)	-	500 (1.5)	3000 (8.8)
	Zr (170)	-	-	-	-	-	360 (2.1)	-	270 (1.6)	-	-	-
	Be (3.8)	-	-	-	-	-	-	-	6.3 (1.7)	-	-	-
	Pb (16)	-	35 (2.2)	-	-	37 (2.3)	38 (2.4)	30 (1.9)	28 (1.8)	30 (1.9)	-	50 (3.1)
	Sc (10)	-	-	21 (2.1)	-	-	-	-	26 (2.6)	-	50 (5)	-
	Cr (83)	-	-	-	-	-	-	-	407 (4.9)	-	300 (3.6)	300 (3.6)
	Ni (58)	-	-	-	-	-	-	-	173 (3)	-	-	-
	V (90)	-	-	-	-	-	-	-	197 (2.2)	-	200 (2.2)	150 (1.7)
	Co (18)	-	-	-	-	-	-	-	26 (1.4)	-	-	-

Accessory minerals, computed as averages (volume percentage) - trace counted as 0.01%

	Boulder Creek Granodiorite	Silver Plume Granite	biotite gneiss	granitic enclaves in biotite gneiss, small	granitic enclaves in biotite gneiss, large	granitic enclaves in Boulder Creek Granodiorite, small	granitic enclaves in Boulder Creek Granodiorite, large	biotite lamprophyre	granitic enclaves in Silver Plume Granite, small	small mafic enclaves in Boulder Creek Granodiorite	andesite porphyry dike
Black opaque mineral	0.58	0.71	0.55	0.71	0.73	1.16	0.98	0.86	1.0	0.9	2.7
Pyrite	0	0.0006	0	0	0	0	0	0	0	0	0
Sphene	0.73	0.009	0.0025	0	0	0.20	0.09	4.4	0	1.0	0.3
Apatite	0.64	0.14	0.11	0.33	0.23	0.30	0.40	2.6	0.01	1.0	1.9
Monazite	0	0.067	0.03	0.008	0.23	0.002	0.006	0	0.1	0	0
Zircon	0.017	0.015	0.0075	0.033	0.01	0.11	0.08	0.02	0.01	0.01	0
Rutile	0	0	0	0	0	0	0	0.01	0	0	0
Epidote	0.58	0.01	0.29	0.003	0	0.28	0.07	1.6	0	4.8	0.7
Clinozoisite	0.09	0	0	0	0	0	0	0	0	0	0
Allanite	0.21	0.0016	0.0025	0.005	0	0.02	0.04	0.06	0	0.01	0
Fluorite	0	0.0003	0	0	0	0	0	0	0	0	0
Tourmaline	0	0	0	0.003	0	0	0	0	0	0	0
Garnet	0	0	6.0	0.05	0	0	0	0	0	0	0
Cordierite	0	0	2.5	0	0	0	0	0	0	0	0
Sillimanite	0	0.17	3.4	0.003	0.003	0	0	0	0.4	0	0

REFERENCES CITED

Clarke, D. B., 1981, The mineralogy of peraluminous granites: A review: Canadian Mineralogist, v. 19, p. 3-17.

Didier, J., 1973, Granites and their enclaves: Elsevier Scientific Publishing Company, Amsterdam, London, New York, 393 p.

Izett, G. A., 1974, Geologic map of the Trail Mountain quadrangle, Grand County, Colorado: U.S. Geological Survey Map GQ-1156.

McIntyre, D. B., Welday, E. E., and Baird, A. K., 1965, Geologic application of the air pycnometer-A study of the precision of measurement: Geological Society of America Bulletin, v. 76, no. 9, p. 1055-1060.

Pearson, R. C., and Johnson, Gordon, 1980, Mineral Resources of the Indian Peaks Study Area, Boulder and Grand Counties, Colorado: U.S. Geological Survey Bulletin 1463, 109 p.

Streckeisen, A. L., 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, no. 1, p. 1-33.

______, 1979, classification and nomenclature of volcanic rocks, lamprophyres, carbonatites, and melilitic rocks: Recommendations and suggestions of the IUGS subcommission on the systematics of igneous rocks: Geology, v. 7, p. 331-335.

Taylor, R. B., 1975, Geologic map of the Bottle Pass Quadrangle, Grand County, Colorado: U.S. Geological Survey Map GQ-1224.

Tweto, Ogden, 1977, Nomenclature of Precambrian rocks in Colorado: U.S. Geological Survey Bulletin 1422-D, 22 p.

DESCRIPTION OF MAP UNITS

Q — UNDIFFERENTIATED ALLUVIUM (HOLOCENE), COLLUVIUM (HOLOCENE), AND GLACIAL TILL (PLEISTOCENE)

Tt — TROUBLESOME FORMATION (MIOCENE)--Gray tuffaceous mudstone and sandstone

Tb — BASALT FLOWS (MIOCENE)--Dark-gray to black aphanitic basalt; contains clinopyroxene and altered olivine phenocrysts

Ta — ANDESITE PORPHYRY DIKE (TERTIARY?)--Brownish-gray andesite porphyry dike; contains biotite, hornblende, and monoclinic pyroxene phenocrysts; dike in southwest corner of Strawberry Lake quadrangle also contains scapolite (meionite) phenocrysts

Mz — UNDIFFERENTIATED MESOZOIC SEDIMENTARY ROCKS INCLUDING THE TRIASSIC CHUGWATER FORMATION, JURASSIC MORRISON AND SUNDANCE FORMATIONS AND THE CRETACEOUS BENTON SHALE AND DAKOTA SANDSTONE

Ygsp — GRANITIC ENCLAVES IN SILVER PLUME GRANITE (PRECAMBRIAN Y)--Slightly porphyritic, more melanocratic, and finer grained than typical Silver Plume Granite; largest dimension of enclave less than 50 m

Ysp — SILVER PLUME GRANITE (PRECAMBRIAN Y)--Buff to gray medium-grained biotite-muscovite granite; includes some enclaves of biotite gneiss and very minor pegmatite; whole rock Rb-Sr age determination on SM-4 is approximately 1500 m.y. (C. E. Hedge, written commun., 1982)

Xp — PEGMATITE (PRECAMBRIAN X?)--Pinkish-gray coarse-grained microcline-quartz-plagioclase pegmatite; contains small variable amounts of biotite and muscovite.

Xgbc — GRANITIC ENCLAVES IN BOULDER CREEK GRANODIORITE (PRECAMBRIAN X)--Pale yellowish brown, fine-grained granite to granodiorite in enclaves from a few meters to 1 1/2 km in greatest dimension

Xla — LAMPROPHYRE ENCLAVES IN BOULDER CREEK GRANODIORITE (PRECAMBRIAN X)--Dark gray fine-grained, minette-vogesite lamprophyre; contains microcline, biotite and hornblende, and 1-5 percent each of sphene and apatite; greatest dimension of enclave is less than 100 m

Xbc — BOULDER CREEK GRANODIORITE (PRECAMBRIAN X)--Gray medium-grained granodiorite to tonalite; contains biotite everywhere, commonly hornblende; contains granitic and lamprophyric enclaves

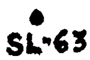
Xggn GRANITIC ENCLAVES IN BIOTITE GNEISS (PRECAMBRIAN X?)--Generally fine-grained buff to gray granite, locally more mafic; as much as 6 km in greatest dimension; locally containing enclaves of biotite gneiss

Xbgn BIOTITE GNEISS (PRECAMBRIAN X)--Gray fine- to medium-grained gneissose and schistose rock, commonly banded or migmatized; locally contains varying amounts of sillimanite, garnet, or cordierite; contains local enclaves of pegmatite, granite gneiss, or hornblendite

FAULT

STRIKE AND DIP OF FOLIATION

STRIKE AND DIP OF VERTICAL FOLIATION



SAMPLE SITE