

Geologic Setting and Petrochemistry of the Late Cretaceous–Early Tertiary Intrusives in the Northern Front Range Mineral Belt, Colorado

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By DOLORES J. GABLE

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*A mineralogical, geochemical, and trace-element study of
Cretaceous–Tertiary stocks and associated dikes in the
northern Front Range mineral belt*



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GEOLOGIC SETTING AND PETROCHEMISTRY OF THE LATE CRETACEOUS-EARLY TERTIARY INTRUSIVES IN THE FRONT RANGE MINERAL BELT, COLORADO

By DOLORES J. GABLE

ABSTRACT

The Late Cretaceous-early Tertiary intrusive rocks in the northern Front Range mineral belt are predominantly monzonite, granodiorite, or syenite in composition, but compositions of individual stocks vary from pyroxenite to syenite. According to spectrographic analyses, the intrusives have below-average amounts of most base-metal trace elements when compared with published average concentrations of common ore metals in igneous rocks. Uranium, thorium, barium, copper, strontium, vanadium and zirconium are the exception.

In this part of the Front Range, most of the mineable ore deposits, in and associated with the stocks and dikes, may not be directly associated with them, but may be attributable to another origin. Chemical similarities and differences found in the intrusive rocks are presented graphically using 104 chemical and 169 semiquantitative spectrographic analyses.

INTRODUCTION

This report on the Late (uppermost) Cretaceous and early Tertiary intrusive rocks is a product of the Front Range geologic mapping program carried out between the years 1963-76. The area studied covers the northern part of the Colorado mineral belt (fig. 1) and includes many of the Front Range mining districts. The intrusive rocks discussed in this report are shown on the published geologic quadrangle maps (1:24,000) for Nederland (Gable, 1969), Tungsten (Gable, 1972), Ward (Gable and Madole, 1976), and Gold Hill (Gable, 1980). The intrusive rocks on these four maps were delineated in some detail and petrographically studied, and many were chemically analyzed as support work in producing the geologic maps. At that time many of the analyses that have since appeared in the literature (Phair and Jenkins, 1975) were not available. This report is a synthesis of my impressions gained by mapping the intrusives of the area with published information presented by others. New data are presented and, where possible, recommendations for future work have been made.

There is a tremendous amount of information available pertaining to these intrusives, partly because the area is easily accessible and partly because of the associated mineralization. Over the years numerous chemical analyses for some of the intrusive rocks of the area have been published by individuals who used many dif-

ferent laboratories, and although some appear to be accurate analyses, I believed it best to use analyses done by the same laboratory by essentially the same people and using the same methods. In this way variations between stocks, parts of stocks, and stocks and associated dikes could be more accurately compared.

The classification followed for defining the holocrystalline intrusive rock types was primarily done by mode determination where possible, using the classification of Streckeisen (1976). Where it was not possible to determine a mode, as in the porphyritic rocks that have an aphanitic or a trachytic groundmass, a chemical analysis was used to classify the rock. When it was necessary to classify the rock using a chemical analysis, the tables of "average chemical composition of some igneous rocks" presented by Nockolds (1954) were used for comparison. For the many dikes not chemically analyzed, and because of their fine-grained texture, the light minerals were separated from the whole rock and X-rayed in order to ascertain the proportion of quartz, plagioclase, and potassium feldspar. Although not quantitatively accurate, it was at least possible to determine proportions and what minerals were present. Knowing the mafic minerals in the rock and the general proportion of the light minerals, many of the dikes could be tentatively classified.

The chemistry of the feldspars in these intrusive rocks is complex. An attempt to define the oscillatory zoning by use of the electron microprobe was made, but the composition in the zone reversals, sometimes several tens in a single crystal, was so variable that this project was abandoned. Phair and Fisher (1962) studied some feldspars in Colorado Front Range intrusive rocks using X-ray, optical, and chemical techniques, and, in 1981, their data were the most extensive available on the feldspars in these rocks.

LABORATORY TECHNIQUES USED

Whole-rock analyses, commonly known as rapid rock analyses, were performed in the analytical laboratories of the U.S. Geological Survey using a single-solution

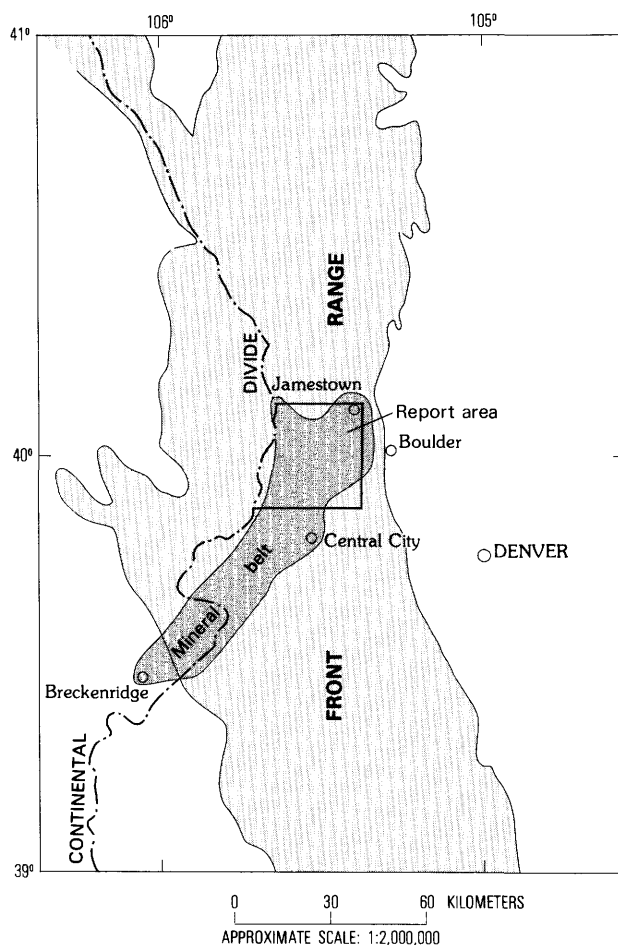


FIGURE 1.—Index map of the Front Range, Colorado, showing the area studied.

procedure described in the following U.S. Geological Survey publications: Shapiro (1967), Shapiro and Brannock (1962), and Shapiro (1975). Analysts responsible for the rapid rock analyses are: Hezekiah Smith, Roosevelt Moore, Sam Botts, Kay Coates, Paul Elmore, James Kelsey, Lowell Artis, John Glenn, and Gilson Chloe. These analysts worked both as a team and individually. Fifty-eight of the analyses were done by team effort; 26 were analyzed by Smith and Coates or Smith and Elmore; 30 analyses were done by Botts. Joseph Budinsky and Roosevelt Moore made the chlorine determinations, and Violet Merritt determined CaO, Na₂O, K₂O, Rb, and Sr for samples footnoted in the tables.

Minor elements were determined by semiquantitative spectrographic methods, and the precision of each result is defined by the standard deviation of any single determination and should be taken as plus 50 percent and minus 33 percent. Analysts are: Harriet Neiman, who did 48 of the analyses; J. L. Harris, 54 analyses; W. B. Crandell, 37 analyses; L. A. Bradley, 18

analyses; Leung Mei, 14 analyses, and Norma Rait, 4 analyses.

Compositional classifications, where possible, are based on modal analyses (generally 800 counts per mode). Modes that have been rounded to nearest percent or half percent are less accurate than those showing a mode to nearest tenth. Plagioclase determinations were done by measuring maximum extinction angles in conjunction with albite twinning.

PREVIOUS WORK

Descriptions of the Cretaceous–Tertiary rocks began with the work of Emmons and others (1896) in the late 1880's. Since then the northern Colorado mineral belt has been studied by many, and will continue to be studied as new concepts and techniques develop. Today we can bracket ages, or we think we can, for most of the stocks and associated dikes, but we still are not certain if magma generation and perhaps mineralization was episodic or continuous or whether there was one magma source or several.

Those who have contributed to the knowledge of the Cretaceous–Tertiary intrusives in this part of the mineral belt include the following, and this list is by no means complete: Goddard (1935, 1938, and 1946) published a series of reports and maps for the Jamestown stock. At about the same time, Lovering and Goddard (1938) described the Laramide igneous sequence for the Colorado Front Range, Smith (1938) published a report on the geology of the Caribou stock, Wahlstrom (1940) reported on the Audubon-Albion stock, and Cree (1948) did a thesis on the Bryan Mountain (Eldora) stock. The southern part of the Apex stock was described in 1954 by C. D. Rinehart (unpub. data). Numerous other reports on the Cretaceous–Tertiary intrusives have been written, including those of Lovering and Goddard (1950), Lovering and Tweto (1953), Phair and Fisher (1962), Phair and Gottfried (1964), and Phair and Jenkins (1975). The reports by Phair and others were prompted by the uranium boom in the 1950's. With the advent of isotopic age dating, Hart (1964) was perhaps the first to date one of the stocks, namely the Bryan Mountain (Eldora) stock. He has been followed over the years by many others (table 1). Thermal studies of the effects of intrusions on country rock evolved along with geochronology: Hart (1964), and Gable, Sims, and Weiblen (1970).

GEOLOGIC SETTING

The Upper Cretaceous–Lower Tertiary intrusive rocks described here are part of a sequence of hypabyssal intrusive rocks in a belt approximately 10 km wide that trends northeast across the Precambrian core of

TABLE 1.—Summary of radiometric dates from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt

Stock or dike and location	Rock type dated	Age* (millions of years)	Time division	Reference
Sunset stock, Gold Hill area---	Syenite-----	-54+	Tertiary-Paleocene(?) or Eocene	C. E. Hedge, early 1970's, oral commun.
Sunset stock, Gold Hill area---	Diorite-monzonite	-44+	Tertiary-Eocene-----	Young (1972).
Small pluton, Boulder quadrangle	Quartz monzonite	Hb-45+1.0 Sp-51+7.1	----do-----	C. T. Wrucke, mid 1960's (Marvin and others, 1974).
Dike, Indian Peaks area-----	Biotite-quartz-plagioclase porphyry.	Zr-53+5.6	Tertiary-Paleocene(?) or Eocene	Pearson and Speltz (1975).
Jamestown stock (north)-----	Syenite porphyry	Zr-45+2.7 Zr-45+3.8	Tertiary-Eocene-----	Cunningham and others (1977).
Do-----	Syenite dike-----	Bi-59+2.0	Tertiary-Paleocene-----	Do.
Dike, Rollinsville-----	Augite latite porphyry.	Hb-54+	Tertiary-Paleocene or Eocene---	C. E. Hedge, early 1970's, oral commun.
Caribou stock-----	Quartz monzonite	Zr-63+6.3	Tertiary-Paleocene-----	G. J. Neuberger, mid 1960's (Marvin and others, 1974).
Dikes, Boulder quadrangle-----	Quartz latite----	Bi-64+2.2	----do-----	C. T. Wrucke, mid 1960's (Marvin and others, 1974).
Do-----	----do-----	Bi-65+2.2	----do-----	Do.
Do-----	----do-----	Bi-65+2.2	----do-----	Do.
Do-----	----do-----	Bi-65+2.4	----do-----	E. E. Larson, 1973 (Marvin and others, 1974).
Bryan Mtn (Eldora) stock-----	Quartz monzonite	Bi-55+ Bi-63+9 Hb, Bi-54+	Tertiary-Paleocene or Eocene(?)	Hart (1964).
Do-----	----do-----	Bi-59+1.8	Tertiary-Paleocene-----	McDowell (1971).
Do-----	----do-----	Ap-73+7 Sp-67+7.5	Late Cretaceous-----	C. W. Naeser, 1969, (Marvin and others, 1974).
Do-----	----do-----	Zr-67+5.5 Zr-62+5.5 Ap-59+8.8	Tertiary (Paleocene)-Late Cretaceous.	Cunningham and others (1977).
Apex stock-----	Granodiorite-----	Zr-62+5.5	Tertiary-Paleocene-----	Do.
Do-----	----do-----	Zr-59+4.4 Ap-67+6.7	Tertiary (Paleocene)-Late Cretaceous.	Do.
Do-----	----do-----	Hb-60+	Tertiary-Paleocene-----	C. E. Hedge, oral commun., early 1970's.
Horseshoe Creek stock-----	Monzonite-----	Hb-70+	Late Cretaceous-----	Do.
Audubon-Albion stock-----	----do-----	-68+	----do-----	C. W. Naeser, 1974, oral commun.
Jamestown stock (south)-----	Quartz monzonite	Hb-78+2.3 Hb-72+2.2	----do-----	McDowell (1971).

* Hb, hornblende; Sp, sphene; Zr, zircon; Bi, biotite; Ap, apatite.

the Colorado Front Range, and is called the Front Range mineral belt. Breckenridge is on the southwest end of the belt, and Jamestown is on the northeast (fig. 1). There are three groups of age dates on Cretaceous-Tertiary intrusives in the Front Range mineral belt. The oldest group is 70-60 m.y., and the youngest group of this report, 54-44 m.y., is between the 70-60 m.y. and 30-10 m.y. old groups. To date, the younger intrusives have not been found in the area of this report. The Precambrian country rock into which these intrusives were emplaced consists of a well-foliated, often migmatitic, metasedimentary and metavolcanic gneiss and schist sequence. Profuse Precambrian intrusives of granodiorite and quartz monzonite pierce this gneiss

and schist sequence and with it form the core of the Colorado Front Range. Precambrian rocks adjacent to the Cretaceous-Tertiary stocks have been thermally altered to varying degree by these younger intrusives (Hart, 1964; Gable and others, 1970).

The oldest stocks in the northern part of the mineral belt, and described in this report, are approximately 72 to 62 m.y. (table 1). These include the southern part of the Jamestown stock, and the Caribou, Horseshoe Creek, Bryan Mountain, and Audubon-Albion stocks. The Apex stock appears to be younger in age, 62-59 m.y. approximately, and the Sunset and adjacent alkali syenite stocks are 59-45 m.y. In addition, several dikes have been dated. Pearson and Speltz (1975) obtained

TABLE 2.—*Chemical and spectrographic analyses for pyroxenite, gabbro-monzogabbro, and limburgite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[G. greater than 10 percent; ---, not found; N.d., not determined; L, detected but below limit of determination]

Sample No.---	174	172	165	194	97	116	114	118	122	99	101
Lab No.-----	W177972	W177970	W177966	D156583	W170211	W170218	W170217	W170220	W170224	D131309	D131310
Rock type---	Pyroxenite										
Intrusive---	Audubon-Albion stock					Caribou stock					
Rapid rock chemical analyses in weight percent											
SiO ₂ -----	35.0	36.3	46.1	*N.d.	32.3	34.7	35.5	37.3	37.5	#10.0	#10.0
Al ₂ O ₃ -----	7.6	9.6	12.1	n.d.	3.6	3.8	4.0	3.8	6.0	3.0	3.0
Fe ₂ O ₃ -----	15.8	11.1	3.1	n.d.	19.5	15.9	18.9	15.4	15.0	N.d.	N.d.
FeO-----	10.6	10.2	7.3	n.d.	13.6	11.7	13.2	10.2	12.0	G	G
MgO-----	7.3	8.6	11.9	n.d.	9.8	10.2	10.6	10.6	8.7	7.0	7.0
CaO-----	17.2	16.8	11.2	17.6	15.5	16.9	14.1	17.4	14.6	G	G
Na ₂ O-----	.89	1.2	1.8	1.22	.20	.24	.18	.33	.73	.2	.5
K ₂ O-----	.41	.92	4.0	2.10	.18	.14	.21	.18	.56	0.0	0.0
H ₂ O+-----	.76	.92	1.3	n.d.	.77	.68	.60	.83	.46	N.d.	N.d.
H ₂ O-----	.03	.00	.17	n.d.	.06	.12	.10	.16	.22	n.d.	n.d.
TiO ₂ -----	2.5	2.1	1.0	n.d.	2.3	2.2	2.2	1.9	2.0	1.0	1.0
P ₂ O ₅ -----	.52	.64	.66	n.d.	1.7	2.1	.14	1.6	1.7	0.0	0.0
MnO-----	.48	.35	.26	n.d.	.30	.36	.27	.31	.36	.2	.2
CO ₂ -----	.04	.02	.02	n.d.	.05	.89	<.05	<.05	<.05	n.d.	n.d.
F-----	.18	.19	.23	n.d.	N.d.	N.d.	N.d.	N.d.	N.d.	n.d.	n.d.
Cl-----	.025	.08	.23	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-----	N.d.	N.d.	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total-----	99	99	101	N.d.	100	100	100	100	100	N.d.	N.d.
Spectrographic analyses in parts per million											
Ba-----	92	200	714	150	20	70	70	70	100	30	150
Be-----	1	---	---	1.5	---	---	---	---	---	---	---
Ce-----	155	---	64	L	---	---	---	---	150	---	---
Co-----	35	55	24	50	70	70	70	70	50	70	70
Cr-----	9	10	396	7	70	50	50	50	7	200	20
Cu-----	87	451	8	50	50	50	70	10	500	150	300
Ga-----	29	27	10	---	20	20	20	20	20	20	20
La-----	67	60	21	150	---	---	---	---	150	---	70
Mo-----	4	5	1	---	5	5	5	5	5	---	---
Nb-----	5	9	---	L	---	5	5	7	5	---	L
Nd-----	50	---	---	150	---	---	---	---	100	---	---
Ni-----	3	20	149	15	70	70	100	50	30	100	50
Pb-----	5	---	2	20	---	---	---	---	15	---	---
Rb-----	N.d.	N.d.	N.d.	20	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Sc-----	36	---	23	70	70	70	70	100	70	150	150
Sn-----	14	---	4	---	---	---	---	---	---	---	---
Sr-----	559	689	720	425	100	100	70	300	700	300	500
V-----	---	---	144	700	1,000	700	500	---	200	1,000	1,500
Y-----	29	31	11	30	20	30	15	30	30	30	100
Yb-----	3	6	3	---	2	3	2	3	3	5	10
Zn-----	289	218	96	---	---	---	---	---	---	200	300
Zr-----	132	97	42	100	50	70	50	70	70	50	100

* CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

Oxides by emission spectroscopy; standard deviation of any single determination shall be taken as plus 50 percent and minus 33 percent.

@ Total iron reported as FeO.

TABLE 2.—Chemical and spectrographic analyses for pyroxenite, gabbro-monzogabbro, and limburgite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt—Continued

Sample No.	110	115	111	119	224	100	178	164	177	136	14	28
Lab No.	D131316	D131318	D131317	D131319	W170221	W170212	W177976	W177965	W177975	W175171	W173012	W173017
Rock type	Pyroxenite		Gabbro-monzogabbro							Limburgite		
Intrusive	Caribou stock						Audubon-Albion stock			Rainbow Lakes plug	Dikes	
	Rapid rock chemical analyses in weight percent											
SiO ₂ -----	#10.0	#10.0	#G	#10.0	38.4	38.6	50.1	50.9	53.0	53.7	41.1	42.4
Al ₂ O ₃ -----	3.0	2.0	G	G	13.3	16.0	14.2	14.4	16.3	15.7	9.0	11.7
Fe ₂ O ₃ -----	N.d.	N.d.	N.d.	N.d.	10.8	9.3	2.7	2.2	3.6	3.7	5.2	4.6
FeO-----	@G	@G	@10.0	@G	9.7	8.6	6.5	6.4	5.4	6.0	4.1	7.0
MgO-----	5.0	5.0	2.0	3.0	7.7	6.6	9.8	8.6	5.5	5.3	10.7	10.8
CaO-----	G	10.0	10.0	10.0	13.1	12.1	8.9	8.3	7.8	7.8	15.2	11.9
Na ₂ O-----	.5	.2	2.	.7	.95	1.5	2.9	3.4	3.2	2.6	1.2	2.0
K ₂ O-----	0.0	0.0	1.5	2.0	1.0	1.5	2.1	3.2	3.2	2.2	2.0	2.1
H ₂ O+ -----	N.d.	N.d.	N.d.	N.d.	1.4	1.7	.06	.04	.00	.05	2.5	2.6
H ₂ O- -----	n.d.	n.d.	n.d.	n.d.	.13	.16	1.0	1.2	.84	.91	1.7	1.0
TiO ₂ -----	1.0	1.0	.5	1.0	2.1	1.6	.97	.88	.93	.99	1.1	2.3
P ₂ O ₅ -----	0.0	0.0	0.0	0.0	1.3	1.5	.54	.53	.48	.48	1.0	.86
MnO-----	.2	.2	.1	.2	.14	.33	.18	.26	.14	.00	.18	.19
CO ₂ -----	n.d.	n.d.	n.d.	n.d.	<.05	<.05	.02	.04	.02	<.05	5.0	.55
F-----	n.d.	n.d.	n.d.	n.d.	N.d.	N.d.	.07	.14	.06	.05	.12	.04
Cl-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.04	.03	.04	.03	.01	.08
S-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	N.d.	N.d.	N.d.	.00	.36	0.0
Total -----	N.d.	N.d.	N.d.	N.d.	100	99	100	100	100	99	100	100
Spectrographic analyses in parts per million												
Ba-----	200	30	1,000	1,000	700	700	420	436	575	1,000	500	500
Be-----	---	---	---	---	---	---	---	---	---	---	3	1
Ce-----	---	---	---	---	---	150	---	---	---	---	500	500
Co-----	70	100	20	50	50	30	26	27	19	30	50	50
Cr-----	70	150	10	15	50	50	346	315	186	150	1,000	300
Cu-----	150	30	100	150	30	10	---	12	---	2	100	100
Ga-----	30	20	30	30	20	20	---	---	---	---	10	15
La-----	---	---	30	70	---	100	---	---	---	---	100	100
Mo-----	---	---	---	---	5	5	2	2	2	7	3	5
Nb-----	---	---	---	---	7	10	---	---	---	---	7	20
Nd-----	---	---	---	---	---	---	---	---	---	---	---	---
Ni-----	70	100	15	20	30	20	128	125	76	20	500	200
Pb-----	---	---	---	---	10	---	3	3	5	7	---	---
Rb-----	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Sc-----	100	100	20	30	70	50	---	---	---	---	50	30
Sn-----	---	---	---	---	---	---	4	5	5	---	---	---
Sr-----	200	200	5,000	2,000	1,000	2,000	857	815	889	1,000	1,500	1,000
V-----	1,000	1,500	500	1,000	200	200	---	---	---	---	200	200
Y-----	20	15	20	30	20	30	---	---	---	---	50	30
Yb-----	5	5	2	5	2	3	---	---	---	---	5	3
Zn-----	200	200	---	200	---	---	80	84	78	---	---	---
Zr-----	150	20	20	30	70	100	---	---	---	---	150	150

* CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

Oxides by emission spectroscopy, standard deviation of any single determination shall be taken as plus 50 percent and minus 33 percent.

Total iron reported as FeO.

TABLE 3.—Chemical and spectrographic analyses for hornblende-pyroxene diorite and monzodiorite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt

[G, greater than 10 percent; N.d., not determined; L, detected but below limit of determination; H, interference, cannot measure; ---, not found]

Sample No.---	175	171	163	170	162	183	107	68	77	67	71	193	196
Lab No.-----	W177973	W177969	W177964	W177968	D156578	D156581	W170214	W170200	D131296	W170199	D131293	W177984	D156585
Rock type---	Hornblende-pyroxene diorite												
Intrusive---	Audubon-Albion stock						Caribou stock				Dike	Monzodiorite Audubon-Albion stock	
Rapid rock chemical analyses in weight percent													
SiO ₂ -----	43.6	45.2	49.1	49.1	*N.d.	*N.d.	44.3	57.6	#G	54.9	@G	39.6	@G
Al ₂ O ₃ -----	18.3	14.2	18.1	16.3	n.d.	n.d.	8.8	17.0	10.0	16.4	10.0	11.3	10.0
Fe ₂ O ₃ -----	7.0	7.8	8.0	5.4	n.d.	n.d.	9.6	3.6	N.d.	3.6	N.d.	9.4	N.d.
FeO-----	6.8	6.4	5.3	5.1	n.d.	n.d.	8.7	4.2	@5.0	5.1	@7.0	5.3	@7.0
MgO-----	4.4	4.2	2.6	3.9	n.d.	n.d.	8.8	2.8	2.0	3.8	7.0	4.8	1.5
CaO-----	11.4	11.9	9.0	10.5	9.80	10.7	14.2	5.8	5.0	6.5	7.0	18.6	6.10
Na ₂ O-----	3.0	2.4	4.5	3.7	3.75	3.0	1.2	3.2	2.0	3.0	2.0	2.1	4.15
K ₂ O-----	.96	3.0	1.0	2.6	1.25	1.55	1.1	3.5	3.0	3.8	2.0	1.3	3.60
H ₂ O+-----	.73	1.5	.70	.87	n.d.	n.d.	.88	.33	n.d.	.89	n.d.	.67	n.d.
H ₂ O- -----	.01	.19	.01	.05	n.d.	n.d.	.12	.16	n.d.	.11	n.d.	.07	n.d.
TiO ₂ -----	2.0	2.0	1.2	1.3	n.d.	n.d.	1.3	.71	.3	.92	.7	1.8	.5
P ₂ O ₅ -----	.46	.53	.59	.67	n.d.	n.d.	.64	.51	0.0	.59	0.0	4.8	L
MnO-----	.31	.48	.31	.35	n.d.	n.d.	.26	.14	.1	.16	.1	.44	.1
CO ₂ -----	.02	.02	.02	.02	n.d.	n.d.	.05	.12	n.d.	<.05	n.d.	.02	n.d.
F-----	.14	.10	.02	.15	n.d.	n.d.	N.d.	N.d.	n.d.	N.d.	n.d.	.41	n.d.
Cl-----	.02	.04	.02	.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.13	n.d.
S-----	N.d.	N.d.	N.d.	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	N.d.	n.d.
Total-----	99	100	100	100	N.d.	N.d.	100	100	N.d.	100	N.d.	101	N.d.
Spectrographic analyses in parts per million													
Ba-----	613	385	242	432	200	500	700	2,000	1,000	2,000	500	396	1,000
Be-----	---	---	1	1	3	2	---	2	1	2	---	---	2
Ce-----	100	127	H	H	---	L	---	15	---	15	---	374	L
Co-----	22	21	15	15	30	30	50	20	20	30	30	18	20
Cr-----	12	---	7	10	7	7	20	15	15	50	150	4	2
Cu-----	187	28	6	30	150	70	30	30	70	50	7	---	70
Ga-----	26	24	23	25	---	---	15	20	20	20	15	5	---
La-----	33	55	28	35	100	100	---	100	50	100	30	168	70
Mo-----	3	3	2	3	---	---	5	3	---	5	---	2	---
Nb-----	4	4	3	---	L	L	7	15	L	20	---	6	15
Nd-----	56	48	H	---	100	150	---	100	---	100	---	100	70
Ni-----	6	2	9	5	7	5	70	10	10	30	20	3	L
Pb-----	4	8	5	6	15	15	---	20	15	20	---	2	30
Rb-----	N.d.	N.d.	N.d.	N.d.	2,475	1,625	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	90
Sc-----	15	11	10	13	20	30	100	20	30	30	50	8	20
Sn-----	10	---	---	---	---	---	---	---	---	---	---	7	---
Sr-----	4,990	1,150	3,600	2,570	2,475	1,625	1,500	2,000	2,000	1,500	500	2,510	1,600
V-----	---	---	---	---	500	500	500	150	200	200	200	---	300
Y-----	18	22	14	12	30	30	20	30	30	30	30	57	20
Yb-----	4	4	4	5	---	---	2	3	3	3	7	5	---
Zn-----	171	230	155	159	---	---	---	---	---	---	---	157	---
Zr-----	39	133	44	69	70	30	50	300	70	150	100	90	100

* CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

Total iron reported as FeO.

@ Oxides by emission spectroscopy; the standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

TABLE 4.—*Chemical and spectrographic analyses for hornblende latite porphyry, augite latite porphyry, and biotitic hornblende-augite latite porphyry from Cretaceous-Tertiary dikes, northern Front Range mineral belt*

(N.d., not determined; G, greater than 10 percent; L, detected but below limit of determination; ---, not found)

Rock type--		Hornblende latite porphyry								Augite latite porphyry				Biotitic hornblende-augite latite porphyry
Sample No.--	61	69	85	93	124	88	73	209	20	33	35	43	87	42
Lab No.----	D131328	W171190	W170207	D131305	D131324	D131301	D131294	W185446	W173013	W185442	W173015	W173016	W131300	W171188
Rapid rock chemical analyses in weight percent														
SiO ₂ -----	*G	56.5	51.4	*G	*G	*G	*G	56.0	47.2	50.1	51.7	51.8	*G	51.4
Al ₂ O ₃ -----	G	15.6	15.3	7.0	10.0	10.0	G	16.3	13.5	13.1	15.6	16.0	7.0	14.5
Fe ₂ O ₃ -----	N.d.	4.3	4.0	N.d.	N.d.	N.d.	N.d.	7.0	3.1	5.1	4.9	4.3	N.d.	8.0
FeO-----	#5.0	3.2	6.6	#2.0	#2.0	#5.0	#5.0	1.8	5.4	5.1	5.4	5.4	#10.0	3.5
MgO-----	2.0	2.8	4.2	.5	.3	1.0	2.0	.98	7.4	7.8	4.1	3.8	3.0	4.1
CaO-----	3.0	7.1	8.0	.5	.5	2.0	5.0	2.7	7.8	9.7	6.3	6.3	5.0	7.8
Na ₂ O-----	3.0	4.3	3.2	2.0	3.0	3.0	3.0	4.3	2.7	1.9	3.2	2.8	2.0	2.8
K ₂ O-----	3.0	3.2	2.6	3.0	3.0	3.0	2.0	4.5	3.4	2.7	3.5	5.3	5.0	3.0
H ₂ O+-----	n.d.	1.0	1.6	N.d.	N.d.	N.d.	N.d.	1.5	2.7	2.3	2.0	1.9	n.d.	1.0
H ₂ O-----	n.d.	.10	.18	n.d.	n.d.	n.d.	n.d.	.25	.55	.48	.36	.33	n.d.	.55
TiO ₂ -----	.5	.92	1.3	.15	.15	.5	.7	.45	.86	.75	1.2	.91	.7	1.3
P ₂ O ₅ -----	0.0	.44	.53	0.0	0.0	0.0	0.0	.29	.60	.48	.54	.64	0.0	.76
MnO-----	.1	.16	.23	.03	.01	.1	.15	.0	.17	.11	.18	.18	.1	.17
CO ₂ -----	n.d.	.34	.60	n.d.	n.d.	n.d.	n.d.	1.7	3.7	.42	.21	.08	n.d.	.49
F-----	n.d.	.07	---	n.d.	n.d.	n.d.	n.d.	.01	.08	.06	.08	.04	n.d.	.12
Cl-----	n.d.	.03	---	n.d.	n.d.	n.d.	n.d.	.01	.012	.02	.027	.014	n.d.	.02
S-----	n.d.	.04	---	n.d.	n.d.	n.d.	n.d.	3.5	.21	.06	.11	0.0	n.d.	.04
Total-----	N.d.	100	100	N.d.	N.d.	N.d.	N.d.	101	99	100	99	100	N.d.	99
Spectrographic analyses in parts per million														
Ba-----	1,500	2,000	3,000	2,000	2,000	1,500	1,000	1,230	1,000	703	700	700	1,500	1,000
Be-----	2	---	1	1	1	1	1	3	---	---	1	1	1	1
Ce-----	---	325	300	---	---	150	L	115	300	---	500	500	---	500
Co-----	15	20	30	7	---	15	15	5	50	32	50	50	30	30
Cr-----	20	50	70	7	2	15	15	3	200	273	20	20	200	30
Cu-----	150	20	100	150	5	30	200	49	200	122	70	150	100	70
Ga-----	20	15	20	20	20	30	30	28	15	23	20	15	20	20
La-----	70	200	200	50	30	100	100	63	100	35	70	100	50	100
Mo-----	---	---	3	---	---	---	---	---	3	---	5	5	---	---
Nb-----	10	50	100	30	30	70	70	12	7	---	7	10	---	10
Nd-----	---	---	200	---	---	70	70	---	---	---	---	---	0	---
Ni-----	15	L	30	7	---	5	15	3	300	71	L	L	70	L
Pb-----	30	3	20	15	50	15	10	19	20	17	30	10	20	20
Sc-----	20	15	30	L	---	10	20	4	30	36	50	30	50	20
Sr-----	1,500	1,500	2,000	1,000	700	2,000	1,500	1,150	1,000	691	1,000	1,000	1,000	1,500
Th-----	---	---	---	---	---	---	---	41	---	---	---	---	---	---
V-----	200	150	150	30	30	150	150	69	200	175	300	200	300	300
Y-----	30	50	50	15	20	30	50	14	30	18	30	30	30	50
Yb-----	3	5	5	1	2	5	7	2	3	4	50	30	3	5
Zn-----	---	---	---	---	---	---	---	---	---	81	---	---	---	---
Zr-----	100	200	150	100	100	150	200	184	150	153	150	150	150	200

* Oxides by emission spectrography; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

Total iron reported as FeO.

a date of $53 \pm$ m.y. on a biotite-quartz-plagioclase porphyry dike (table 1) from the Indian Peaks area. The biotite-quartz-plagioclase porphyry dikes of the Indian Peaks area have counterparts on the eastern slope of the Continental Divide and are shown in the northern part of plate 1. Another dike, an augite latite porphyry near Rollinsville, has been dated at $54 \pm$ m.y., and several quartz latite dikes west of Boulder have been dated at 65–64 m.y. (table 1). The bostonite porphyry of Bald Mountain has not been dated, but it appears to be older

than the 54–44 m.y. old syenite of the Sunset group of rocks.

At least two periods of mineralization appear to be associated with these intrusives; the oldest mineralization is associated with the 72–55 m.y. intrusive sequence and the younger mineralization with the 54–44 m.y. intrusive sequence. Mineralization, however, like the intrusives' history, may not be this clear cut. It may have been continuous; age dating has not proved otherwise.

TABLE 5.—*Modes for pyroxenite, gabbro-monzogabbro, hornblende-pyroxene diorite, and monzodiorite from Cretaceous-Tertiary stocks, northern Front Range mineral belt*

[Chemical and spectrographic analyses in tables 2, 3, and 4. ---, not found; Tr., trace; N.d., not determined]

Sample No.-----	174	172	165	194	116	114	122	101	111	119	100	178
In volume percent												
Potassium feldspar--	Tr.	---	2.3	---	---	---	---	---	4.0	3.0	---	---
Plagioclase-----	4.0	1.0	33.5	2.3	---	---	8.6	---	71.0	50.0	48.0	36.0
Quartz-----	---	---	---	---	---	---	---	---	---	---	---	---
Hornblende-----	17.0	52.0	Tr.	17.1	4.3	1.3	10.7	22.7	3.0	10.0	36.3	12.0
Pyroxene:												
Clinopyroxene-----	60.0	30.0	---	58.4	---	---	---	---	---	---	---	19.0
Undifferentiated--	---	---	26.7	---	67.2	71.2	47.1	52.9	7.0	9.0	2.7	---
Biotite-----	Tr.	1.0	34.3	.9	Tr.	Tr.	3.9	1.3	8.0	18.0	---	30.0
Ores-----	15.0	9.0	2.8	17.1	24.0	*27.5	15.8	18.1	4.0	6.0	9.2	2.0
Apatite-----	4.0	7.0	.4	2.8	4.5	---	5.3	---	1.0	4.0	1.7	1.0
Sphene-----	Tr.	Tr.	---	1.4	---	---	---	3.2	Tr.	---	---	---
Chlorite-----	---	---	---	---	---	---	7.6	---	1.0	---	1.2	---
Epidote-----	---	---	---	---	---	---	1.0	---	1.0	---	.8	---
Muscovite-----	---	---	---	---	---	---	---	#1.8	---	---	.1	---
Total-----	100	100	100	100	100	100	100	100	100	100	100	100
An (percent)-----	N.d.	N.d.	33-51	N.d.	---	---	40+	---	56-69	54-63	58+	50+

* Includes traces of green spinel associated with magnetite.
 # Includes calcite.
 @ Monzodiorite from Jamestown stock, no chemical analysis.

DESCRIPTIONS OF STOCKS

Stock descriptions in this report are intentionally brief. The various publications mentioned earlier give more extensive descriptions. Here only enough information is given to emphasize the mode of emplacement and physical and mineralogical similarities and differences both within and between stocks, in order to provide some background for the discussion on chemical data presented later in this report. More data are presented for several of the stocks simply because their history has not been well documented. Modal and chemical data presented in tables 2 through 19 have been grouped according to mineralogical and chemical composition, for comparison.

Beginning with the Apex and Buckeye Mountain stocks in the southwestern part of the report area (pl. 1) and continuing northward, the Bryan Mountain, Caribou, and Audubon-Albion stocks are discussed. However, the Long Gulch stock, shown in the north-central part of plate 1, has been included with the Apex and Buckeye Mountain stocks because of its similar composition. The Jamestown stock is the easternmost stock, and sandwiched in between the Jamestown stock and the stocks along the western border of the plate 1 area are the Bald Mountain, Sunset, Tuscarora, Sugarloaf, Burnt Mountain, and Grassy Mountain stocks.

APEX AND BUCKEYE MOUNTAIN STOCKS

The Apex and Buckeye Mountain stocks consist mostly of leucocratic monzonite but locally may vary from diorite to granite. The Apex stock is about 10 times larger than the Buckeye Mountain stock (pl. 1); both have an irregular outline, and both are associated with many dikes that are clearly cogenetic with the stocks. An offshoot dike from the Buckeye Mountain stock contains garnet that probably was derived from garnet-bearing schist country rock. Small garnets have also been found in several other Cretaceous-Tertiary dikes in this part of the mineral belt in areas of garnet-bearing country rock.

The stocks are medium to coarse grained and locally porphyritic, and in general the Apex stock at Jumbo Mountain (Nederland quadrangle) and the Buckeye Mountain stock are more coarsely porphyritic than the Apex stock south of Jumbo Mountain. Exposed surfaces of the more coarsely porphyritic rocks are rough and uneven due to weathering out of the groundmass around tabular feldspar crystals that are as long as 3-4 cm. Quartz lenses and veins, although present in the Apex, are particularly abundant in the southern part of the Buckeye Mountain stock.

In thin section, the least porphyritic rocks are generally holocrystalline, have a phaneritic texture, and locally show some cataclasis and recrystallization intersti-

TABLE 5.—*Modes for pyroxenite, gabbro-monzogabbro, hornblende-pyroxene diorite, and monzodiorite from Cretaceous-Tertiary stocks, northern Front Range mineral belt—Continued*

Sample No.-----	164	177	136	175	107	67	68	77	193	196	@219
In volume percent											
Potassium feldspar---	Tr.	19.8	0.4	Tr.	---	3.0	11.0	9.0	1.0	14.4	1.6
Plagioclase-----	20.0	35.3	51.6	59.5	26.0	57.0	54.0	51.0	32.0	49.7	47.1
Quartz-----	---	.8	6.7	---	---	4.0	9.0	1.0	---	---	.3
Hornblende-----	Tr.	27.0	17.5	16.5	11.0	6.0	14.0	3.0	---	23.5	---
Pyroxene:											
Clinopyroxene-----	---	4.6	---	---	---	9.0	---	24.0	26.0	---	29.5
Undifferentiated---	31.0	---	3.6	10.0	39.0	---	1.0	---	---	4.7	---
Biotite-----	47.0	9.0	17.7	2.7	14.0	15.0	9.0	8.0	6.0	.5	14.6
Ores-----	1.0	2.9	1.8	6.8	10.0	6.0	1.0	4.0	6.0	4.0	6.3
Apatite-----	1.0	Tr.	.7	1.5	---	Tr.	.5	Tr.	27.0	1.0	.6
Sphene-----	---	.6	Tr.	3.0	---	---	.5	---	2.0	1.0	---
Chlorite-----	---	---	---	---	---	---	---	---	---	---	---
Epidote-----	---	---	---	---	---	---	---	---	---	1.0	---
Muscovite-----	---	---	---	---	---	---	---	---	---	.2	---
Total-----	100	100	100	100	100	100	100	100	100	100	100
An (percent)-----	27-53	55	50+	28-47	25-37	35-40	33	30-32	N.d.	N.d.	31-40

* Includes traces of green spinel associated with magnetite.
Includes calcite.
@ Monzodiorite from Jamestown stock, no chemical analysis.

tial to the larger crystals. Crystal boundaries, especially of the feldspars, have been eroded and replaced by small, irregular-shaped quartz grains. In the porphyritic parts of the Apex stock the groundmass is aphanitic, and large corroded feldspar and mafic mineral crystals are randomly oriented throughout the section. The plagioclase crystals have deep albitic rims, or patch zoning.

Modal analyses of the less porphyritic parts of the stocks indicate that they vary in composition from monzodiorite to quartz monzonite. Samples 46 and 51, table 16, are from the Apex stock, and sample 58, table 16, is from the Buckeye Mountain stock. Pyroxene, hornblende, biotite, and ores (mainly magnetite) make up only 5 to 10 percent of the rock. Chemical analyses for both the Apex and Buckeye Mountain stocks indicate that their compositions lie in both the quartz monzonite and granodiorite field. It does seem appropriate at this time to keep the name "leucocratic granodiorite" as suggested in Sims and Gable (1967) because of the general lack of mafic minerals in these rocks in comparison with the other monzonites in the area.

The contact zone of the Apex stock contains profuse lenses, stringers, and even some blocks of biotite gneiss and schist country rock, many of which show various stages of assimilation. The Buckeye Mountain stock, however, does not seem to contain the large number of inclusions typical of the Apex. Forcible intrusion of

the Apex stock along its southern border is indicated by shearing, cataclasis, and recrystallization of the country rock at least 300 m from the stock contact. Shearing and cataclasis is not nearly as intense in the country rock along the northern part of the Apex stock or in the aureole of the Buckeye Mountain stock.

LONG GULCH STOCK

The Long Gulch stock is a small porphyritic stock similar in composition to the leucocratic granodiorite of the Apex and Buckeye Mountain stocks. On the map of Lovering and Goddard (1950), this small stock was shown as a dike and was mapped in the group consisting of quartz monzonite, monzonite, and andesite. The Long Gulch stock is a very coarse aphanitic rock, and prominent feldspar crystals 3-4 cm in length cover weathered surfaces. In thin section, the rock has a cryptocrystalline groundmass with orthoclase and plagioclase phenocrysts, both euhedral and anhedral, and rounded quartz. Hornblende has been extensively replaced by biotite, magnetite, minor sphene, and allanite. The plagioclase locally shows oscillatory zoning. Biotite-quartz porphyry dikes (Tgd) on plate 1 are probably related to this stock.

Contacts of the Long Gulch stock with the country rock are nearly vertical, and inclusions of country rock in the stock are few. The intrusive, because of its small size, had little thermal effect on the country rock.

TABLE 6.—*Chemical and spectrographic analyses for monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[N.d., not determined; ---, not found; L, detected but below limit of determination; G, greater than 10 percent]

Sample No.--	32	37	70	223	75	79	82	112	120	121	130	131
Lab No.----	W185441	W185443	W170201	D131307	W170202	W170204	W170206	W170216	W170222	W170223	D131325	W175166
Intrusive--	Dikes		Bryan Mountain stock		Caribou stock		Dikes		Horseshoe Creek stock		Dikes	
Rapid rock chemical analyses in weight percent												
SiO ₂ -----	63.0	61.3	58.5	*G	55.4	54.2	52.2	54.7	60.4	57.1	*G	53.4
Al ₂ O ₃ -----	16.4	15.8	18.2	10.0	17.2	16.5	15.7	17.1	18.0	18.6	7.0	16.4
Fe ₂ O ₃ -----	2.7	3.3	3.6	N.d.	4.3	4.2	4.2	4.1	3.4	4.0	N.d.	4.5
FeO-----	2.6	3.4	2.1	@5.0	4.8	5.1	6.2	4.4	2.0	2.7	@5.0	4.5
MgO-----	1.9	2.4	1.3	1.5	3.4	3.4	4.2	3.0	1.5	2.1	5.0	3.5
CaO-----	3.8	4.4	5.3	5.0	6.6	6.3	7.8	6.9	4.5	5.9	5.0	5.4
Na ₂ O-----	4.5	4.0	5.2	2.0	2.8	3.2	2.7	3.4	3.9	4.5	2.0	3.5
K ₂ O-----	3.4	2.9	3.7	3.0	2.8	4.3	4.2	3.6	4.8	3.0	2.0	4.4
H ₂ O+-----	1.2	1.4	1.0	n.d.	1.1	.66	.79	.82	.47	.07	n.d.	1.7
H ₂ O-----	.20	.25	.06	N.d.	.07	.13	.07	.08	.08	.74	N.d.	.48
TiO ₂ -----	.34	.47	.72	.3	.96	.88	.93	.73	.58	.65	.5	.92
P ₂ O ₅ -----	.32	.47	.24	0.0	.64	.70	.70	.72	.28	.41	0.0	.64
MnO-----	.05	.12	.14	.1	.16	.18	.18	.16	.13	.15	.07	.20
CO ₂ -----	.02	.06	<.05	n.d.	<.05	<.05	<.05	<.05	<.05	<.05	n.d.	<.05
F-----	.01	.08	N.d.	n.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	n.d.	.10
Cl-----	.01	.02	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.004
S-----	.03	.05	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	N.d.
Total--	100	100	100	N.d.	100	100	100	100	100	100	N.d.	100
Spectrographic analyses in parts per million												
Ba-----	987	925	3,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000	1,500	1,500
Be-----	1	1	3	---	1	2	2	1	3	3	1	1
Ce-----	---	84	500	---	150	150	150	150	100	200	---	200
Co-----	7	9	10	20	20	30	30	20	15	10	20	30
Cr-----	17	22	---	2	15	10	20	30	5	10	100	50
Cu-----	24	17	7	70	15	100	100	100	15	5	70	50
Ga-----	24	22	20	20	20	20	20	15	20	20	20	15
La-----	20	51	300	50	100	100	100	100	100	150	50	100
Mo-----	---	---	3	---	5	5	3	3	3	3	---	5
Nb-----	16	20	70	---	15	15	10	7	10	20	---	10
Nd-----	---	---	300	---	100	100	100	100	---	150	---	---
Ni-----	6	9	---	L	10	20	20	20	---	10	50	15
Pb-----	23	33	20	10	20	30	20	30	15	15	15	7
Rb-----	N.d.	N.d.	N.d.	---	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Sc-----	6	13	5	20	30	30	50	20	15	10	30	50
Sn-----	---	---	---	---	---	---	---	---	---	---	---	---
Sr-----	1,040	1,320	3,000	2,000	1,500	2,000	2,000	2,000	2,000	2,000	1,000	1,500
V-----	60	64	100	200	150	200	200	150	150	100	300	200
Y-----	10	23	50	50	30	30	30	30	20	30	30	50
Yb-----	2	4	3	5	3	3	3	3	2	3	3	5
Zn-----	41	80	---	---	---	---	---	---	---	---	---	---
Zr-----	65	187	300	70	150	150	100	150	150	300	70	200

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

BRYAN MOUNTAIN (ELDORA) STOCK

The Bryan Mountain stock, as mapped by Cree (1948), consists mainly of adamellite (quartz monzonite) but varies from granodiorite to granite to syenite or monzonite. The contacts between rock types are grada-

tional and difficult to map. The stock is fairly equigranular and only locally porphyritic, and has feldspar crystals as long as 3-4 cm that are especially prominent just north of Jenny Creek (Nederland quadrangle).

Chemical analyses and modes show the stock to be predominantly quartz monzonite; however, monzonite

TABLE 6.—*Chemical and spectrographic analyses for monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt—Continued*

Sample No.--	188	187	203	173	158	161	140	144	191	176	192	195
Lab No.----	W177981	W177980	W177986	D177971	W177961	D156577	W175175	W175179	W177982	W177974	D177983	D156584
Intrusive--	Audubon-Albion stock											
	Rapid rock chemical analyses in weight percent											
SiO ₂ -----	61.3	60.2	59.9	58.5	58.1	*,#G	56.2	56.2	56.1	53.3	53.0	*,#G
Al ₂ O ₃ -----	17.6	18.9	18.0	18.3	18.2	10.0	19.0	18.0	18.2	18.5	17.9	10.0
Fe ₂ O ₃ -----	3.1	2.7	2.9	2.8	3.2	N.d.	3.4	3.9	3.8	3.3	4.4	N.d.
FeO-----	2.3	2.1	2.2	2.3	2.2	@5.0	2.4	2.8	2.8	3.6	3.4	@3.
MgO-----	1.3	1.3	1.5	1.4	1.5	1.5	1.5	1.9	2.0	2.0	2.4	1.0
CaO-----	4.1	4.0	4.9	5.2	5.7	6.9	6.2	6.1	6.1	6.9	6.7	4.60
Na ₂ O-----	4.3	5.0	4.4	4.7	5.1	4.25	4.7	4.3	4.1	4.1	3.4	4.95
K ₂ O-----	4.6	4.0	4.8	5.4	4.8	3.43	4.3	4.8	5.3	5.3	5.3	2.20
H ₂ O+-----	.55	.73	.58	.52	.70	.3	.66	.33	.42	1.6	1.4	n.d.
H ₂ O-----	.02	.07	.15	.01	.06	n.d.	.20	.07	.07	.20	.41	n.d.
TiO ₂ -----	.72	.62	.62	.76	.82	n.d.	.79	.97	.96	.98	1.0	.3
P ₂ O ₅ -----	.25	.27	.28	.26	.28	L	.30	.40	.44	.45	.55	L
MnO-----	.03	.14	.06	.18	.18	.1	.21	.17	.23	.23	.31	.05
CO ₂ -----	.02	.02	.02	.02	.02	n.d.	<.05	<.05	.02	.02	.02	n.d.
F-----	.08	.06	.05	.10	.04	n.d.	.06	.09	.10	.10	.04	n.d.
Cl-----	.005	.001	.01	.001	<.001	n.d.	.01	.01	.012	.016	.01	n.d.
S-----	N.d.	N.d.	N.d.	N.d.	N.d.	n.d.	.0	.0	N.d.	N.d.	N.d.	n.d.
Total-----	100	100	N.d.	100	101	N.d.	100	100	101	101	100	N.d.
Spectrographic analyses in parts per million												
Ba-----	701	932	652	534	998	1,500	3,000	1,500	1,350	1,160	836	2,000
Be-----	1	1	---	1	1	2	1	1	---	---	---	2
Ce-----	79	68	---	58	88	L	500	500	69	68	53	L
Co-----	6	7	58	4	6	15	10	15	10	10	12	10
Cr-----	19	17	5	3	4	2	7	15	6	5	7	3
Cu-----	13	13	9	58	29	15	15	30	28	50	24	70
Ga-----	22	26	7	28	19	30	15	15	21	27	16	30
La-----	43	21	21	30	35	70	100	150	30	34	32	70
Mo-----	---	1	22	2	2	---	---	3	---	3	2	---
Nb-----	13	9	3	15	14	15	20	20	8	12	---	15
Nd-----	53	---	37	30	46	70	---	---	57	---	---	70
Ni-----	8	5	4	1	2	L	---	3	3	3	3	L
Pb-----	8	9	6	11	8	30	7	7	8	18	14	15
Rb-----	N.d.	N.d.	N.d.	N.d.	N.d.	65	N.d.	N.d.	N.d.	N.d.	N.d.	95
Sc-----	6	3	5	2	4	20	15	20	7	6	7	10
Sn-----	4	---	---	---	5	---	---	---	3	4	---	---
Sr-----	1,890	2,080	1,470	1,430	2,370	2,015	5,000	3,000	3,070	2,990	3,180	1,800
V-----	119	112	86	78	118	300	150	200	165	132	>215	150
Y-----	18	9	9	9	12	30	50	50	9	11	9	30
Yb-----	3	2	2	3	3	3	5	5	2	4	2	3
Zn-----	47	47	48	77	56	---	---	---	60	123	135	---
Zr-----	130	46	56	72	54	70	100	150	121	87	49	100

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

or syenite, depending on the classification used, crops out on the northwest side of the stock, and there are a few dikes of leucocratic granodiorite and (or) rhyodacite within the stock. Representative modal analyses for the stock are: rhyodacite, sample 62, table 18; quartz monzonite, samples 59, 63, 65, and 66, table 9;

and monzonite or possibly syenite, sample 70, table 7.

The southwest contact of the Bryan Mountain stock shows more dynamic emplacement than contacts elsewhere. On the southwest, fault-related breccia zones containing country rock and fragments of intrusive rocks have been cemented by monzonite, indicating

TABLE 7.—*Modes for monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[---, not found; Tr., trace; N.d., not determined]

Sample No.-----	*70	#223	#79	#113	°82	°112	@121	@120	"188	"157	"168	"186	"187	"190	"203	£217	£220
In volume percent																	
Potassium feldspar	39.0	29.0	31.0	18.0	26.0	26.0	49.0	26.2	40.0	51.0	55.0	35.0	42.5	35.0	37.0	31.9	30.0
Plagioclase-----	51.0	34.0	38.0	43.0	32.0	39.0	35.0	49.9	46.0	40.0	38.0	54.0	44.2	53.0	47.0	38.5	46.1
Quartz-----	1.0	---	2.0	1.0	1.0	3.0	1.0	3.8	2.0	---	---	3.0	2.5	4.0	3.0	4.1	4.3
Hornblende-----	1.0	---	3.0	5.0	3.0	3.0	6.0	11.8	4.0	4.0	3.0	1.0	3.2	3.0	6.0	19.0	13.0
Pyroxene:																	
Clinopyroxene----	4.0	---	---	---	---	---	---	---	---	---	2.0	4.0	---	---	---	---	---
Undifferentiated--	---	24.0	15.0	17.0	18.0	17.0	3.0	3.2	3.0	3.0	---	---	4.3	3.0	3.0	---	---
Biotite-----	---	8.0	8.0	9.0	15.0	7.0	---	.4	---	---	tr	---	.4	---	Tr.	---	---
Ores-----	3.0	5.0	3.0	6.0	4.0	5.0	4.0	2.1	2.0	2.0	1.0	2.0	2.2	2.0	2.0	3.9	2.4
Apatite-----	Tr.	Tr.	Tr.	1.0	1.0	Tr.	1.0	1.3	1.0	---	---	Tr.	.6	Tr.	1.0	.1	---
Allanite-----	---	---	---	---	---	---	---	---	Tr.	---	---	---	---	Tr.	---	---	---
Sphene-----	1.0	---	---	Tr.	---	---	1.0	1.3	2.0	---	1.0	1.0	.1	Tr.	1.0	1.1	2.6
Zircon-----	Tr.	---	---	---	---	---	---	Tr.	---	---	---	---	---	---	---	---	---
Calcite-----	---	---	---	---	---	---	---	Tr.	---	---	---	---	---	---	---	.5	.3
Chlorite-----	---	---	---	---	---	Tr.	---	---	---	---	---	---	---	---	---	.6	---
Epidote-----	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	.3	1.3
Total-----	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
An (percent)-----	31	31-37	25-53	N.d.	31-37	24-28	32	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	25-29	N.d.	N.d.	N.d.

- * Bryan Mountain stock.
 # Caribou stock.
 @ Horseshoe Creek stock.
 " From Audubon-Albion stock.
 £ From the southern part of the Jamestown stock.
 ° Dikes, Caribou stock.

movement during emplacement. Evidence for assimilation and piecemeal stoping along the west-northwest contact are observed along glacially scoured outcrops adjacent to Jasper and North Fork Creeks (Nederland quadrangle) where the magma forced its way into and pervasively invaded the country rock. Contacts to the northeast are considerably sharper and more regular, indicating passive emplacement.

CARIBOU STOCK

The Caribou stock is made up of the Caribou stock proper but herein includes the North Fork and Horseshoe Creek stocks. The North Fork and Horseshoe Creek stocks both have dominant rock types not characteristic of the Caribou, but because glacial and more recent sedimentary deposits cover the contact relationships, it is easier to treat them as individual stocks associated with the Caribou stock. The geology and mineralogy of the Caribou stock have been well documented by Smith (1938). Monzonite and quartz monzonite of the Caribou make up half of Bald and Pomeroy Mountains (Nederland quadrangle) and all of Caribou Hill and a large area east and southeast of Caribou Flat. As indicated on plate 1, the Caribou has a variable composition that ranges from titaniferous, magnetite-bearing pyroxenite to quartz monzonite.

Mafic lenses of pyroxenite and gabbro-monzogabbro occur mostly on or near Caribou Hill. Some of the pyroxenites may contain as much as 25 percent titaniferous magnetite, and Smith (1938, p. 177) described magnetite-rich lenses in the centers of these mafic pyroxenite bodies that are 4-6 m thick, extend the length of the pyroxenite body, and are considerably richer in titaniferous magnetite than 25 percent. Modal analyses for rocks in the Caribou stock proper are as follows: pyroxenites, samples 101, 111, and 119, table 5; monzonite, sample 79, table 7; quartz monzonite, samples 106, 108, and 117, table 9; samples 108 and 117 are borderline monzonite-quartz monzonite but, following Streckeisen, they are classified as quartz monzonite.

Twenty-seven chemical analyses define the various rock types of the Caribou stock, and those of the North Fork and Horseshoe Creek intrusives. Pyroxenite and gabbro-monzogabbro are represented by 13 analyses, table 2; hornblende-pyroxene diorite and monzodiorite, four analyses, table 3; monzonite, five analyses, table 6; and quartz monzonite, five analyses, table 8.

The North Fork stock is a small diorite intrusion just west of the Caribou stock. This intrusion lies along North Fork Creek, southwest of the main part of the Caribou stock, and appears to be locally gradational to the northeast into monzonite of the Caribou stock. The

TABLE 8.—Chemical and spectrographic analyses for quartz monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt

[---, not found; L, detected but below limit of determination; G, greater than 10 percent; N.d., not determined]

Sample No.--	59	63	64	65	66	80	52	72	78	83	84	86
Lab No.-----	W170195	W170196	W170197	W170198	D131291	W170205	W170190	D131329	D131330	D131298	D131331	D131299
Intrusive --	Bryan Mountain stock						Dikes					
Rapid rock chemical analyses in weight percent												
SiO ₂ -----	67.4	61.2	66.9	62.3	*G	69.3	71.4	*G	*G	*G	*G	*G
Al ₂ O ₃ -----	16.9	18.1	17.0	17.8	G	15.2	15.8	G	G	10.0	G	10.0
Fe ₂ O ₃ -----	1.7	3.2	2.0	3.1	N.d.	1.7	1.1	N.d	N.d.	N.d.	N.d.	N.d.
FeO-----	.72	2.0	.96	1.9	@2.0	1.3	.60	@5.	@5.	@3.	@3.	@3.0
MgO-----	.28	1.3	.66	1.3	.7	.74	.41	1.0	1.0	1.0	1.0	1.0
CaO-----	1.4	4.7	2.0	4.1	3.0	2.3	1.2	.7	3.0	3.0	2.0	3.0
Na ₂ O-----	5.5	4.7	5.3	4.9	3.0	3.0	4.5	3.0	2.0	3.0	3.0	3.0
K ₂ O-----	4.7	3.2	3.9	3.2	3.0	4.8	3.8	2.0	3.0	2.0	3.0	3.0
H ₂ O+-----	.56	.41	.57	.40	n.d.	.76	.60	n.d.	n.d.	n.d.	n.d.	n.d.
H ₂ O-----	.16	.07	.11	.08	n.d.	.07	.31	n.d.	n.d.	n.d.	n.d.	n.d.
TiO ₂ -----	.29	.54	.24	.53	.3	.36	.14	.2	.3	.2	.2	.2
P ₂ O ₅ -----	.13	.28	.14	.06	0.0	.15	.06	0.0	0.0	0.0	0.0	0.0
MnO-----	.02	.13	.07	.11	.07	.06	.0	.05	.03	.05	.07	.07
CO ₂ -----	.06	<.05	<.05	<.05	n.d.	<.05	<.05	n.d.	n.d.	n.d.	n.d.	n.d.
F-----	N.d.	N.d.	N.d.	N.d.	n.d.	N.d.	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cl-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total----	100	100	100	100	N.d.	100	100	N.d.	N.d.	N.d.	N.d.	N.d.
Spectrographic analyses in parts per million												
Ba-----	2,000	3,000	2,000	3,000	2,000	2,000	3,000	2,000	1,500	1,500	2,000	3,000
Be-----	3	3	5	3	2	3	2	1	1	1	1	1
Bi-----	---	---	50	---	---	---	---	---	---	---	---	---
Ce-----	300	500	500	500	150	200	150	---	---	---	---	---
Co-----	5	10	7	10	5	7	5	7	5	7	5	7
Cr-----	3	7	10	15	3	5	3	20	7	10	10	15
Cu-----	1	3	2	10	2	7	2	200	70	7	7	150
Ga-----	20	20	20	20	30	20	20	20	20	20	20	20
La-----	200	300	300	300	100	150	100	70	50	50	70	70
Mo-----	---	5	3	3	---	3	5	---	---	---	---	---
Nb-----	100	30	200	50	50	30	30	20	---	15	20	15
Nd-----	50	200	200	200	70	150	---	---	---	---	---	---
Ni-----	---	---	---	---	---	---	10	10	L	5	L	10
Pb-----	20	20	15	20	10	30	10	20	15	15	15	15
Rb-----	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Sc-----	3	10	5	7	5	7	3	10	15	10	10	10
Sr-----	2,000	3,000	2,000	3,000	2,000	1,000	2,000	1,500	1,000	2,000	1,500	1,500
V-----	50	100	70	70	70	50	30	70	70	70	100	70
Y-----	20	30	30	30	30	30	15	30	50	20	30	30
Yb-----	2	3	3	3	3	3	1	2	5	2	2	3
Zn-----	---	---	---	---	---	---	---	---	---	---	---	---
Zr-----	150	200	300	150	150	200	150	100	100	100	100	150

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

diorite is a fine- to medium-grained, almost black rock that varies in composition from diorite to monzodiorite to quartz monzodiorite. Mineralogically, it is a biotite-hornblende or biotite-hornblende-pyroxene bearing diorite. Modal analyses are given in table 5, samples 67, 68, and 77; and chemical analyses are given in table 3, samples 67, 68, and 77. The country rock adjacent to the diorite appears to have been pervasively in-

truded; however, much of the contact is covered by glacial till. A multitude of stringers and sills of diorite occur along the foliation and schistosity of the country rock. Schistosity in the schist adjacent to the stock is slightly contorted. For several hundred meters out from the diorite the country rock shows microscopic shearing and recrystallization, and the compositional banding, as seen in the field, appears to have been enhanced due

TABLE 8.—*Chemical and spectrographic analyses for quartz monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt—Continued*

Sample No. -- 94	95	96	98	102	104	105	76	106	108	117	123	109	134	
Lab No. -- W170209	D131306	W170210	D131308	D131311	D131312	D131313	W170203	D131314	W170215	W170219	D131320	D131315	W175169	
Intrusive --	Bryan Mountain dikes						Caribou stock				Dikes		Horseshoe Creek stock	
Rapid rock chemical analyses in weight percent														
SiO ₂ -----	62.9	*G	55.7	*G	*G	*G	*G	59.4	*G	56.6	56.5	*G	*G	59.2
Al ₂ O ₃ -----	17.1	10.0	16.9	7.0	G	G	G	17.1	G	17.0	17.0	10.0	10.0	18.2
Fe ₂ O ₃ -----	2.9	N.d.	4.0	N.d.	N.d.	N.d.	N.d.	3.7	N.d.	3.4	4.1	N.d.	N.d.	3.0
FeO-----	2.7	@2.0	4.6	@5.0	@3.0	@5.0	@2.0	3.0	@5.0	5.2	4.4	@10.0	@1.0	3.3
MgO-----	1.6	.7	3.5	2.0	1.5	3.0	.5	2.3	1.5	3.2	2.6	3.0	.2	2.3
CaO-----	3.2	2.0	6.1	5.0	5.0	5.0	.7	5.9	3.0	6.0	6.1	2.0	2.0	5.8
Na ₂ O-----	3.3	2.0	2.9	2.0	2.0	2.0	3.0	3.4	3.0	2.9	2.9	2.0	2.0	3.2
K ₂ O-----	3.5	3.0	3.7	3.0	3.0	3.0	3.0	2.8	3.0	3.3	3.8	5.0	3.0	2.9
H ₂ O+-----	1.3	n.d.	1.0	n.d.	n.d.	n.d.	n.d.	.68	n.d.	.82	.80	n.d.	n.d.	.82
H ₂ O-----	.23	n.d.	.09	n.d.	n.d.	n.d.	n.d.	.19	n.d.	.06	.08	n.d.	n.d.	.09
TiO ₂ -----	.54	.2	.86	.5	.3	.5	.2	.71	.3	.79	.83	.7	.07	.68
P ₂ O ₅ -----	.36	0.0	.58	0.0	0.0	0.0	0.0	.44	0.0	.48	.63	0.0	0.0	.39
MnO-----	.08	.05	.13	.07	.05	.05	.02	.13	.07	.16	.18	.1	.05	.18
CO ₂ -----	.08	n.d.	<.05	n.d.	n.d.	n.d.	n.d.	.11	n.d.	<.05	<.05	n.d.	n.d.	<.05
F-----	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	N.d.	n.d.	n.d.	N.d.	n.d.	n.d.	.07
Cl-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.04
S-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total----	100	N.d.	100	N.d.	N.d.	N.d.	N.d.	100	N.d.	100	100	N.d.	N.d.	100
Spectrographic analyses in parts per million														
Ba-----	2,000	1,500	2,000	1,000	1,500	1,000	2,000	3,000	1,500	1,500	2,000	1,000	1,500	1,000
Be-----	2	1	1	1	1	1	1	2	1	2	2	1	1	---
Bi-----	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Ce-----	200	---	200	---	---	---	---	200	---	150	150	---	---	---
Co-----	10	7	30	20	15	20	3	15	15	20	20	20	---	10
Cr-----	1	10	15	20	15	100	1	20	5	7	3	20	---	15
Cu-----	30	7	5	50	15	100	1	5	50	30	30	150	2	2
Ga-----	20	20	20	20	20	15	20	20	20	20	20	30	15	15
La-----	150	50	150	70	50	30	50	150	50	100	100	50	---	50
Mo-----	3	---	3	---	---	---	---	3	---	5	3	---	---	---
Nb-----	50	15	10	10	L	L	20	20	15	20	10	10	L	5
Nd-----	150	---	100	---	---	---	---	150	---	100	100	---	---	---
Ni-----	10	5	20	7	7	30	---	10	5	10	---	30	---	---
Pb-----	20	15	15	15	10	100	20	20	20	20	20	20	30	5
Rb-----	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.
Sc-----	10	10	30	30	15	30	---	20	15	20	20	30	---	15
Sr-----	1,000	2,000	1,500	1,000	1,000	1,500	1,000	2,000	1,500	1,500	2,000	1,000	1,000	1,500
V-----	70	70	150	200	150	300	50	100	150	150	150	300	10	70
Y-----	50	20	30	50	20	30	20	30	30	30	30	30	20	50
Yb-----	5	2	3	3	3	2	2	3	2	3	3	5	1	5
Zn-----	---	---	---	---	---	500	---	---	---	---	---	---	---	---
Zr-----	200	100	100	150	70	70	100	150	100	150	150	150	70	200

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

to high temperatures and partial melting and recrystallization associated with the invading rock.

The monzonite-quartz monzonite intrusive north of Horseshoe Creek (Nederland quadrangle), herein called the Horseshoe Creek stock, physically appears to be a part of the monzonite-quartz monzonite in the Caribou stock, except that the monzonite in the southern part of the Horseshoe Creek intrusive is more like the monzonite that occurs on the very west edge of the map area (pl. 1) on Niwot Ridge (Ward quadrangle) in the

Audubon-Albion stock. The mode of feldspar crystallization in both areas is exactly the same, with plagioclase crystals showing the same striking lineation. This lineation is primary and is not as pronounced in the feldspars of the monzonites in the Caribou stock. In the Horseshoe Creek stock the plagioclase crystals are as much as 3 cm in length, whereas those in the area on Niwot Ridge are as long as 30 cm. No cataclasis appears in the rock, and crystal boundaries are sharp and clear. The northern part of the Horseshoe Creek stock is a

TABLE 8.—Chemical and spectrographic analyses for quartz monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt—Continued

Sample No.-----	167	185	198	147	148	152	154	155	189	200	216	218
Lab No.-----	W177967	W177979	D156587	W175181	W177957	D156574	D156576	W177960	D156582	D156589	W194510	W194511
Intrusive-----	Audubon-Albion stock						Dikes				Jamestown stock	
Rapid rock chemical analyses in weight percent												
SiO ₂ -----	63.9	66.2	*,#G	69.6	65.4	*,#G	*,#G	73.6	*,#G	*,#G	63.5	57.9
Al ₂ O ₃ -----	18.0	17.2	7.0	17.4	16.2	7.0	.7	15.7	.7	7.0	16.3	15.8
Fe ₂ O ₃ -----	1.8	1.6	N.d.	1.4	1.9	N.d.	N.d.	1.4	N.d.	N.d.	2.7	3.5
FeO-----	.92	1.4	@1.5	1.0	2.4	@.7	@3.0	.48	2.0	@2.	1.6	3.2
MgO-----	.70	.83	.5	.45	1.5	.1	.7	.64	.5	.5	1.4	2.8
CaO-----	3.0	3.0	2.30	3.7	4.3	1.50	3.10	.28	3.0	2.85	3.4	5.8
Na ₂ O-----	5.8	5.1	5.10	3.2	4.1	3.40	3.90	.19	3.35	2.70	4.2	3.3
K ₂ O-----	5.2	4.4	4.80	1.5	2.5	3.15	2.50	4.3	3.0	3.25	4.3	4.3
H ₂ O+-----	.45	.61	n.d.	1.3	1.4	n.d.	n.d.	2.9	n.d.	n.d.	.57	.49
H ₂ O-----	.08	.01	n.d.	.14	.13	n.d.	n.d.	.29	n.d.	n.d.	.20	.40
TiO ₂ -----	.33	.38	.15	.14	.46	.03	.2	.19	.15	.15	.49	.79
P ₂ O ₅ -----	.13	.17	L	.12	.26	L	L	.12	L	L	.22	.43
MnO-----	.11	.08	.05	.03	.14	.05	.05	.03	.03	.07	.06	.11
CO ₂ -----	.02	.02	n.d.	<.05	.32	n.d.	n.d.	.04	n.d.	n.d.	.05	.00
F-----	.03	.06	n.d.	.01	.05	n.d.	n.d.	.08	n.d.	n.d.	.07	.07
Cl-----	<.001	<.001	n.d.	.01	.01	n.d.	n.d.	<.001	n.d.	n.d.	.02	.03
S-----	N.d.	.0	n.d.	N.d.	N.d.	n.d.	n.d.	N.d.	n.d.	n.d.	N.d.	N.d.
Total-----	100	101	N.d.	100	100	N.d.	N.d.	100	N.d.	N.d.	99	99
Spectrographic analyses in parts per million												
Ba-----	1,110	880	1,500	3,000	488	700	1,500	388	1,000	1,500	590	530
Be-----	2	2	3	1	---	2	2	---	2	2	3	2
Bi-----	---	---	---	---	---	---	---	---	---	---	---	---
Ce-----	50	43	L	100	34	---	L	27	---	L	96	---
Co-----	2	3	5	---	6	---	7	1	L	5	8	13
Cr-----	6	5	5	7	14	---	15	1	5	3	15	15
Cu-----	14	---	7	7	22	20	10	2	3	7	50	77
Ga-----	29	22	30	15	16	15	30	16	20	30	26	25
La-----	32	22	70	50	15	---	L	33	L	L	45	50
Mo-----	1	---	---	---	15	---	---	---	---	---	---	---
Nb-----	7	9	10	15	---	10	L	8	10	10	5	5
Nd-----	15	---	L	---	23	---	L	27	---	L	---	51
Ni-----	2	---	7	7	5	---	10	1	L	L	8	9
Pb-----	16	7	30	15	7	30	30	9	30	20	15	19
Rb-----	N.d.	N.d.	180	N.d	N.d.	N.d.	60	N.d.	95	100	N.d.	N.d.
Sc-----	2	2	L	7	4	---	15	2	7	7	11	17
Sr-----	1,330	1,230	1,065	2,000	1,140	300	700	20	700	640	870	830
V-----	68	62	70	10	44	---	70	8	30	30	88	120
Y-----	7	7	10	30	7	10	15	9	15	15	14	19
Yb-----	2	1	2	3	1	1	2	1	2	2	3	4
Zn-----	42	20	---	---	---	300	---	59	---	---	---	54
Zr-----	164	65	150	200	66	70	70	120	100	100	44	54

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

quartz monzonite, however, and is no different from the quartz monzonite in either the Caribou or the Audubon-Albion stocks. The contact between the monzonite and the quartz monzonite is covered, and the location of the contact is in question. Mineralogically, the stock is represented by the following modes: samples 120 and 121, table 7, are monzonite and sample 134, table 9, is quartz monzonite. Chemical analyses for the monzonite from this stock are a part of table 6, samples 120 and 121; sample 134, table 8, is the quartz monzonite.

Chemically, the monzonites are very similar; modes differentiate monzonite containing less than 5 percent quartz from the quartz monzonites containing 10 percent quartz.

Emplacement of the Caribou stock appears to have been similar to that described for the Bryan Mountain stock. The contact may be sharp against country rock, as on the ridge southeast of the old townsite of Caribou (Nederland quadrangle), or brecciated as seen on the road north of Hessie, or the stock may have stoped

TABLE 9.—*Modes for quartz monzonite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[—, not found; N.d., not determined; Tr., trace]

Sample No.*	59	63	65	66	80	52	96	76	106	108	117	134	167	185	216	218	215
In volume percent																	
Potassium feldspar----	54.0	27.0	30.0	19.0	20.0	29.0	19.0	23.0	31.0	33.0	26.0	19.5	43.0	39.0	26.4	31.5	25.0
Plagioclase-----	28.0	53.0	48.0	56.0	41.0	45.0	44.0	44.0	45.0	36.0	39.0	52.0	44.0	45.0	49.5	37.9	49.5
Quartz-----	15.0	7.0	11.0	15.0	31.0	23.0	8.0	13.0	9.0	5.0	7.0	10.2	5.0	5.0	13.3	8.5	11.2
Hornblende-----	1.0	4.0	5.0	5.0	---	---	1.0	13.0	3.0	Tr.	14.0	5.6	3.0	5.0	7.4	16.6	5.8
Pyroxene:																	
Clinopyroxene-----		5.0	1.0	---	---	---	---	---	---	---	---	---	2.0	---	---	---	---
Undifferentiated---	---	---	---	2.0	---	---	7.0	---	4.0	14.0	5.0	---	---	3.5	---	Tr.	---
Biotite-----	---	---	1.0	---	5.0	1.0	17.0	3.0	7.0	8.0	5.0	9.9	---	---	Tr.	---	2.2
Ores-----	1.0	2.0	2.0	2.0	1.5	1.0	3.0	2.0	1.0	4.0	3.0	1.2	1.0	1.0	.8	2.3	1.5
Apatite-----	---	1.0	1.0	---	---	Tr.	1.0	1.0	---	Tr.	.5	.3	Tr.	.5	1.4	.5	---
Allanite-----	1.0	---	---	---	---	---	---	---	---	---	---	Tr.	---	---	---	---	---
Sphene-----	---	1.0	1.0	1.0	1.5	1.0	---	1.0	---	---	.5	---	2.0	1.0	.8	2.2	1.0
Calcite-----	---	---	---	---	---	---	---	---	---	---	---	.1	---	---	Tr.	---	3.2
Chlorite-----	---	---	---	---	---	---	---	---	---	---	---	.2	---	---	.2	.5	.6
Epidote-----	---	---	---	---	---	---	---	---	---	---	---	.1	---	---	.2	---	Tr.
Fluorite-----	Tr.	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Muscovite-----	---	---	---	---	---	---	---	---	---	---	---	.2	---	---	Tr.	---	---
Sericite-----	---	---	---	---	---	---	---	---	---	---	---	.7	---	---	---	---	---
Total-----	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
An (percent)-----	N.d.	29-30	29-42	N.d.	16-23	32-40	29-45	32-40	N.d.	30-34	26-38	N.d.	N.d.	N.d.	N.d.	N.d.	N.d.

* All samples except 215 have chemical analyses in table 4. Sample 215 is from the Jamestown stock.

its way into its present setting, as indicated by blocks of country rock in the intrusive along the north contact on Bald Mountain (Nederland quadrangle). The stock also has pervasively entered the country rock as indicated by the large number of dikes and reentrants in the country rock on the south slope of Klondike Mountain. Forceful entry, except on the southwest, does not appear to have been a major factor in emplacement of the stock.

RAINBOW LAKES PLUG

The Rainbow Lakes intrusive is a small pluglike mass just north of the Rainbow Lakes (Ward quadrangle). Its appearance and chemical composition are very similar to the monzogabbro of the Audubon-Albion stock found on the northwest side of Lake Isabelle. A mode, sample 136, table 5, indicates the mineralogy of the pluglike mass, but the mode classifies the rock as a hornblende-pyroxene diorite. Quartz, as seen in thin section, unlike the mafic minerals and the feldspars, occurs as featureless crystals, interstitial to all other crystals, and appears to be a late contaminant. A chemical analysis for this rock type is in table 2, sample 136.

AUDUBON-ALBION STOCK

The Audubon-Albion stock is an elongated intrusive that extends from Lake Albion on the south to Mount Audubon on the north (Ward quadrangle). It covers approximately 7 square kilometers, but because of glacial

till, talus debris, and diamicton deposits in the east-central and southern parts of the stock, only about half of the stock is exposed. Its composition varies from pyroxenite to syenite; however, the greater percentage of exposed rock is monzonite. There are many similarities between the Audubon-Albion and Caribou stocks. Both have nearly the same range in composition; the Caribou, however, has lenses of very rich titaniferous magnetite not present in the Audubon-Albion stock, and the Audubon-Albion contains a syenite otherwise only found in stocks to the east in the vicinity of Sunset and Jamestown.

Mineralogy of the Audubon-Albion stock is here defined primarily by modes, beginning with the more mafic rock, and only highlights of the mineralogy and petrology are presented because Wahlstrom (1940) described the rocks and their mineralogy in some detail. The pyroxenites and gabbro-monzogabbros all occur in the stock south and southeast of Lake Isabelle. The pyroxenites are coarse to very coarse grained, massive black rocks containing upwards of 60 percent pyroxene, as much as 15 percent ores (mainly magnetite), 0.4 to 7 percent apatite, and varying amounts of biotite and hornblende. Modes for these rocks are given in table 5, samples 165, 172, and 194. Chemical analyses for these samples are in table 2. Wahlstrom did not consider these rocks as part of the Audubon-Albion stock as I have done here; according to him these were altered hornblende gneisses. Gabbro-monzogabbro (called

TABLE 10.—Chemical and spectrographic analyses for latite, latite porphyry, and plagioclase porphyry from Cretaceous-Tertiary dikes, northern Front Range mineral belt

[---, not found; N.d., not determined; L, detected but below limit of determination; G, greater than 10 percent]

Sample No.----- Lab No.-----	Biotite quartz latite		Plagioclase latite porphyry		Biotite-quartz latite porphyry		Biotite-quartz plagioclase porphyry		
	179 D156580	199 D156588	201 W177985	57 D131288	142 W175177	143 W175178	202 D156590	151 W177959	180 W177977
Rapid rock chemical analyses in weight percent									
SiO ₂ -----	*,#G	*,#G	67.2	*G	69.2	69.0	*,#G	69.8	67.2
Al ₂ O ₃ -----	7.0	5.0	16.8	G	16.3	15.7	10.0	15.2	16.8
Fe ₂ O ₃ -----	N.d.	N.d.	1.6	N.d.	1.6	1.2	N.d.	1.0	1.5
FeO-----	@2.0	@.5	1.5	@.5	1.8	1.8	@2.0	1.7	1.8
MgO-----	.5	.07	1.0	.2	.98	1.0	.5	1.1	1.2
CaO-----	2.90	1.65	2.6	3.0	2.9	2.5	2.85	3.0	3.7
Na ₂ O-----	3.65	3.25	2.9	5.0	3.6	3.3	3.25	4.1	3.4
K ₂ O-----	2.85	4.00	3.6	3.0	3.1	3.9	3.00	2.1	2.6
H ₂ O+-----	n.d.	n.d.	1.6	n.d.	.81	.79	n.d.	1.3	1.4
H ₂ O-----	n.d.	n.d.	.71	n.d.	.19	.13	n.d.	.05	.22
TiO ₂ -----	.15	.01	.31	.15	.25	.30	.15	.32	.36
P ₂ O ₅ -----	L	.0	.21	0.0	.18	.19	L	.20	.18
MnO-----	.05	.03	.11	.07	.05	.09	.03	.00	.00
CO ₂ -----	n.d.	n.d.	.02	n.d.	<.05	<.05	n.d.	.11	.08
F-----	n.d.	n.d.	.02	n.d.	.10	.07	n.d.	.03	.02
Cl-----	n.d.	n.d.	<.001	n.d.	.01	.01	n.d.	.48	.02
S-----	n.d.	n.d.	N.d.	n.d.	.0	.0	n.d.	---	---
Total -----	N.d.	N.d.	100	N.d.	101	100	N.d.	100	100
Spectrographic analyses in parts per million									
Ba-----	1,500	700	515	3,000	3,000	5,000	1,500	551	839
Be-----	2	2	---	2	---	1	2	---	---
Ce-----	L	---	26	300	100	---	---	28	45
Co-----	L	---	2	3	7	---	7	2	4
Cr-----	3	L	5	5	10	20	7	8	16
Cu-----	7	3	---	100	5	---	2	9	18
Ga-----	30	30	12	50	15	15	30	17	25
La-----	50	---	19	150	70	50	L	15	15
Mo-----	---	---	---	---	---	---	---	---	2
Nb-----	L	10	4	70	20	20	10	11	7
Nd-----	---	---	22	150	---	---	L	33	26
Ni-----	L	L	3	5	---	5	L	3	7
Pb-----	30	50	9	15	10	20	30	17	12
Rb-----	90	115	N.d.	N.d.	N.d.	N.d.	90	N.d.	N.d.
Sc-----	7	---	2	---	15	10	7	2	4
Sr-----	10,000	0	646	3,000	2,000	1,500	1,500	800	784
V-----	30	L	24	30	50	50	70	24	35
Y-----	15	L	9	30	30	20	15	4	6
Yb-----	2	L	1	3	3	2	2	1	1
Zn-----	---	---	40	---	---	---	---	59	53
Zr-----	150	30	97	200	200	100	100	116	136

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

TABLE 11.—*Chemical and spectrographic analyses for Cretaceous-Tertiary felsite dikes, northern Front Range mineral belt*

[N.d., not determined; G, greater than 10 percent; L, detected but below limit of determination; ---, not found]

Sample No.-----	48	145	146	197
Lab No.-----	D131285	W175180	W175182	D156586
Rapid rock chemical analyses in weight percent				
SiO ₂ -----	*G	68.6	69.8	*G
Al ₂ O ₃ -----	G	17.2	15.7	7.0
Fe ₂ O ₃ -----	N.d.	1.3	1.4	N.d.
FeO-----	#3.0	.96	.4	#2.0
MgO-----	1.0	.46	.39	.7
CaO-----	.7	2.7	.75	2.75
Na ₂ O ₃ -----	3.0	4.0	3.50	3.30
K ₂ O-----	5.0	3.5	4.80	3.30
H ₂ O+-----	n.d.	.68	1.80	n.d.
H ₂ O-----	n.d.	.21	1.30	n.d.
TiO ₂ -----	.3	.14	.10	.15
P ₂ O ₅ -----	0.0	.12	.11	L
MnO-----	.07	.09	.03	.05
CO ₂ -----	n.d.	.05	.05	n.d.
F-----	n.d.	.01	.06	n.d.
Cl-----	n.d.	.01	.01	n.d.
S-----	n.d.	.0	.0	n.d.
Total-----	N.d.	100	100	N.d.
Spectrographic analyses in parts per million				
Ba-----	1,500	5,000	300	1,500
Be-----	2	1	3	---
Ce-----	L	---	---	---
Co-----	20	---	---	5
Cr-----	1	10	5	7
Cu-----	20	10	---	7
Ga-----	20	10	30	20
La-----	50	50	50	70
Nb-----	20	10	30	10
Nd-----	L	---	---	70
Ni-----	---	3	---	---
Pb-----	20	15	50	30
Sc-----	10	5	3	7
Sr-----	2,000	2,000	200	1,000
V-----	70	10	30	50
Y-----	30	30	15	15
Yb-----	3	3	2	2
Zr-----	150	200	200	100

* Oxides by emission spectroscopy; the standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

Total iron reported as FeO.

syenogabbro by Wahlstrom, 1940) is a medium-grained, rather homogeneous dark rock, and modal analyses are given in table 5, samples 164, 177, and 178. Chemical analyses for these samples are in table 2.

Hornblende-pyroxene diorite, monzodiorite, and mon-

zonite all vary almost as much within their rock types as between rock types. The diorites and, to a certain extent, the monzonites are mixed rocks not only in the Audubon-Albion stock but in the Caribou as well. Examples of mixing and segregation include: (1) a discontinuous lens of apatite-rich rock found in the diorite north of Blue Lake in the Audubon-Albion stock. Here disseminated apatite (sample 193, table 5) makes up as much as 27 percent of the rock; (2) east of Lake Isabelle and north of the Pawnee Pass trail the diorite contains aligned feldspar crystals 4–6 cm in length and is inter-layered with foliated hornblende-pyroxene-rich layers; (3) north of the Pawnee Pass trail, hornblende-pyroxene-rich layers and hornblende-rich diorite lenses are present in the monzonite. Another area where these mixed rocks are exposed is the west-central part of the stock northeast of Lake Isabelle (labeled "Tm" on plate 1). Wahlstrom (1940, p. 1798) also described an area in the monzonite of Albion Valley (Ward quadrangle) that shows these same variations. Modal analyses of hornblende-pyroxene diorite are given in table 5, sample 175; and monzodiorite in table 5, samples 193 and 196. Modal analyses of monzonite are given in table 7, samples 188 and 203. Chemical analyses for these rocks are in tables 3 and 6.

In the Audubon-Albion stock the contacts of monzonite and quartz monzonite appear to be gradational in many places; however, glacial till and solifluction deposits cover much of the contact zone. Modal analyses for quartz monzonite are given in table 9, samples 167 and 185, and chemical analyses are in table 8. The youngest rock associated with the Audubon-Albion stock is syenite. It forms the most leucocratic part of the Audubon-Albion stock except for the granite dikes and thin quartz veins that are present in the syenite. Samples taken from the central part of the larger mass of syenite of the Audubon-Albion stock, north of Long Lake, contain 5–9 percent quartz. Modal analyses of the syenite are in table 13, samples 159, 160, and 166, and grade from quartz monzonite to quartz syenite to syenite. Chemical analyses of the syenite are in table 12.

Thermal metamorphism and shearing of the biotite schist and gneiss country rock, on the south side of Lake Isabelle, is more intense in the vicinity of the pyroxenites than elsewhere along country rock-stock contacts. The sheared zone consists of a brecciated pyroxene rock, biotite schist containing thin pyroxene-hornblende lenses, and monzonite. Within this area, biotite schist is a crudely layered, highly altered, very dark green chloritic rock containing migmatitic quartz lenses that have been oxidized and sheared along a zone several tens of meters wide. Pyroxene knots (some of walnut size) rimmed by hornblende, and pyroxene-

hornblende stringers and lenses occur along the schistosity in the biotite schist at this location. These pyroxene stringers and clots along the foliation of the country rock appear to be forcefully emplaced intrusives and may be offshoots of the pyroxenite that occurs upslope from this area. Quartzite layers in the biotite schist and gneiss are part of the black-and-white compositional banding in the schist emphasized by thermal metamorphism adjacent to the stock contact. This same black-and-white banding may be observed along contacts elsewhere, especially along the road (trail on map) from Lake Albion to the Green Lakes area, southwest of Lake Isabelle.

Both the Caribou and Audubon-Albion stocks seem to have crystallized in a similar way; the pyroxenites in both stocks seem to be the result of a crystal cumulate (Jennings, 1913; Smith, 1938; Mathews, 1970) as in a mantle-derived mafic magma that was injected into the area at nearly the same time that the gabbro-monzogabbro was emplaced. The similarity in chemical analyses between some of the pyroxenites and the gabbro-monzogabbros indicates that this mode of crystallization and emplacement is definitely possible. This idea is directly opposite to the hypothesis, previously presented, that the pyroxenites were derived from the alteration of hornblende, hornblende gneiss, or calc-silicates (Lovering and Goddard, 1938; Wahlstrom, 1940). The Caribou stock does abut several layers of hornblende gneiss that pinch out into biotite gneiss near the intrusive contact, and the Audubon-Albion stock does occur in an area where thin layers of hornblende gneiss and lenses of amphibolite occur, but nowhere are these layers or lenses of the size necessary to provide the calcium, potassium, and magnesium needed to form the massive pyroxenites.

JAMESTOWN STOCK

The Jamestown stock consists of two distinct intrusives: an older one of quartz monzonite (granodiorite of Goddard, 1935, 1938; and Lovering and Goddard, 1950) makes up the southern part of the stock and has been dated at about $70 \pm$ m.y., and a younger one of syenite that makes up the northern part of the stock and has been dated at $45 \pm$ m.y. (table 1). The quartz monzonite of the Jamestown stock is a medium- to coarse-grained, phaneritic, slightly porphyritic rock similar to monzonite-quartz monzonite of the Caribou and Audubon-Albion stock. Modal analyses of the quartz monzonite are in table 9, samples 215, 216, and 218, and chemical analyses for samples 216 and 218 are in table 8. The northern part of the Jamestown stock is a leucocratic quartz-bearing syenite that has a few small aplitic dikes satellitic to the main syenite stock. This younger syenite is a coarse, very porphyritic rock

having an aphanitic groundmass containing large, eroded feldspar crystals. This aphanitic groundmass is sheared in many places; however, large orthoclase crystals that are 50 percent or more albite antiperthite and equally large plagioclase crystals are not. The shearing may be due to movements in the magma as the orthoclase and plagioclase crystals grew. The large semirounded orthoclase and plagioclase crystals are oscillatory zoned and somewhat altered. Accessories in the syenite are very sparse but include small amounts of biotite, opaque minerals, fluorite, and sphene. All accessory minerals except fluorite are so highly altered that only the crystal outline remains. Because of the slightly sheared aphanitic groundmass in the syenite, no modal analyses were possible. Chemical analyses are in table 12, samples 221 and 222.

The contact of the quartz monzonite in the Jamestown stock with the country rock is marked by a slightly finer grained monzonite; the width of the contact zone varies considerably, from several meters to a hundred meters or so. This monzonite locally contains a finer grained dioritic rock that has augite and some biotite. Goddard (1938) suggested that these fine-grained darker lenses in the quartz monzonite that occur northeast of Walker Mountain and in the monzonite along James Creek are digested biotite schist and gneiss. However, the diorite lens 1 km northeast of Walker Mountain, in the quartz monzonite, has a crystallization history that duplicates that of diorite in the Audubon-Albion stock, especially the oscillatory zoning in the plagioclase crystals and the presence of large clear pyroxene crystals in a medium-grained groundmass. The diorite in the Jamestown stock is a foliated rock, and the foliation is defined by prominent pyroxene-rich layers. This diorite lens may be an early crystal cumulate that was rafted into place similar to the monzogabbro near Lake Isabelle. A modal analysis for sample 219, table 5, is from the diorite from this lens.

Emplacement of the quartz monzonite, as suggested by Goddard (1938), is partly due to the pushing aside of the country rock and partly due to stoping and assimilation. Stopping does appear to have been an important process in the emplacement of the intrusive. Goddard suggested that the quartz monzonite was intruded along a zone of weakness where schist, Silver Plume Quartz Monzonite, and a major fault intersect. The syenite in the northern part of the stock appears to have been emplaced along this same zone of weakness.

BALD MOUNTAIN STOCK

The Bald Mountain stock is a quartz-bearing bostonite porphyry that was called a trachyte porphyry by Breed (1899). The main outcrop of the stock is on Bald Mountain (pl. 1). This is the largest mass of bostonite

TABLE 12.—Chemical and spectrographic analyses for syenite from Tertiary stocks and dikes, northern Front Range mineral belt

[---, not found; N.d., not determined; L, detected but below limit of determination; G, greater than 10 percent]

Sample No.-----	141	159	160	166	169	182	211	206	207
Lab No.-----	W175176	W177962	W177963	W177987	D156579	W177978	W185234	W185444	W185445
Intrusive-----	Audubon-Albion stock						Sunset stock		
Rapid rock chemical analyses in weight percent									
SiO ₂ -----	63.9	65.4	68.2	68.6	*,#G	63.4	63.1	63.8	61.8
Al ₂ O ₃ -----	19.6	18.0	17.5	16.0	10.0	19.0	16.8	16.5	16.5
Fe ₂ O ₃ -----	1.1	.72	1.2	1.1	N.d.	1.4	2.4	2.9	3.3
FeO-----	.64	.12	.16	.28	@1.5	.80	1.2	1.3	2.0
MgO-----	.15	.22	.25	.09	.1	.35	.63	.86	1.3
CaO-----	1.6	.83	1.8	.93	.55	2.6	3.2	2.9	2.7
Na ₂ O-----	4.9	4.3	6.8	3.8	6.00	5.6	6.2	5.6	5.4
K ₂ O-----	7.1	9.2	4.0	8.7	6.50	5.4	4.1	4.0	4.6
H ₂ O+-----	.43	.65	.65	.47	n.d.	.58	.54	.11	.70
H ₂ O-----	.06	.15	.15	.03	n.d.	.10	.17	.36	.40
TiO ₂ -----	.13	.53	.14	.10	.03	.32	.37	.41	.61
P ₂ O ₅ -----	.04	.22	.11	.07	L	.10	.20	.36	.38
MnO-----	.04	.05	.08	.18	.05	.08	.14	.0	.0
CO ₂ -----	<.05	.04	.02	.02	n.d.	.06	.07	.05	.05
F-----	.0	.02	.0	.0	n.d.	.02	N.d.	.05	.01
Cl-----	.01	<.001	.021	.01	n.d.	<.001	n.d.	.003	.004
S-----	.0	N.d.	N.d.	N.d.	n.d.	N.d.	n.d.	.03	.01
Total -----	100	100	101	100	N.d.	100	99	99	100
Spectrographic analyses in parts per million									
Ba-----	3,000	654	756	262	1,500	408	1,850	1,330	1,600
Be-----	1	---	1	1	2	---	3	4	2
Ce-----	---	---	33	---	L	---	193	184	81
Co-----	---	---	---	---	L	1	4	6	8
Cr-----	15	9	4	9	L	4	6	9	18
Cu-----	10	22	17	22	50	6	53	429	28
Ga-----	15	26	25	44	50	24	43	36	43
La-----	70	15	16	---	L	---	108	129	53
Mo-----	---	---	---	---	---	---	---	---	---
Nb-----	20	14	9	8	L	4	23	20	13
Nd-----	---	---	26	---	---	27	3	---	---
Ni-----	---	1	2	4	L	2	3	7	7
Pb-----	10	26	7	2	30	24	57	107	59
Rb-----	N.d.	N.d.	N.d.	N.d.	145	N.d.	N.d.	N.d.	N.d.
Sc-----	3	---	---	---	---	---	4	8	7
Sn-----	---	---	---	---	---	---	---	48	---
Sr-----	5,000	298	990	86	625	1,100	3,400	2,940	2,500
Th-----	---	---	---	---	---	---	---	69	76
V-----	50	43	31	55	100	44	69	79	113
Y-----	15	---	5	---	---	---	24	28	15
Yb-----	2	---	1	---	---	---	4	4	3
Zn-----	---	---	---	15	---	44	71	84	69
Zr-----	30	55	90	33	150	60	299	313	165

* Oxides by emission spectroscopy; the standard deviation of any single determination shall be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb, and Sr by atomic absorption.

@ Total iron reported as FeO.

TABLE 12.—Chemical and spectrographic analyses for syenite from Tertiary stocks and dikes, northern Front Range mineral belt—Continued

Sample No.---	210	212	221	222	149	150	153	21	213	214
Lab No.-----	W185234	W185447	W194512	W194513	D156573	W177958	D156575	D131332	W185448	W185449
Intrusive---	Sugarloaf stock	Sunset-Sugarloaf stocks	Jamestown stock			Grassy Mountain stock		Dikes		Tuscarora stock
Rapid rock chemical analyses in weight percent										
SiO ₂ -----	62.7	63.5	66.4	68.2	*,#G	61.1	*,#G	G	64.4	63.7
Al ₂ O ₃ -----	16.5	16.4	17.4	16.4	7.0	17.1	7.0	G	17.0	16.5
Fe ₂ O ₃ -----	3.2	3.3	1.8	1.1	N.d.	2.8	N.d.	N.d.	2.4	2.1
FeO-----	1.3	1.4	.20	.32	@3.0	1.3	@2.0	@5.0	1.3	2.0
MgO-----	1.1	1.4	.15	.18	.3	1.1	.7	3.0	.70	1.4
CaO-----	3.2	2.9	.83	.90	2.40	3.4	2.20	3.0	2.1	3.0
Na ₂ O-----	5.6	4.8	5.6	5.2	5.25	5.4	3.40	2.0	5.8	4.3
K ₂ O-----	3.9	4.3	5.3	5.9	4.05	4.7	3.70	5.0	4.7	3.8
H ₂ O+-----	.71	.79	.51	.09	n.d.	.77	n.d.	n.d.	1.2	1.6
H ₂ O-----	.49	.21	.94	.53	n.d.	.20	n.d.	n.d.	.30	.68
TiO ₂ -----	.47	.39	.17	.20	.2	.51	.2	.5	.33	.32
P ₂ O ₅ -----	.36	.32	.06	.07	L	.26	L	0.0	.24	.34
MnO-----	.12	.02	.01	.04	.03	.16	.03	.07	.02	.05
CO ₂ -----	.07	.02	.01	.01	n.d.	2.3	n.d.	n.d.	.01	.32
F-----	N.d.	.03	.32	.50	n.d.	.06	n.d.	n.d.	.03	.02
Cl-----	n.d.	.01	.03	.01	n.d.	.002	n.d.	n.d.	.01	.004
S-----	n.d.	.05	N.d.	N.d.	n.d.	N.d.	n.d.	n.d.	.01	.03
Total-----	100	100	100	100	N.d.	101	N.d.	N.d.	101	100
Spectrographic analyses in parts per million										
Ba-----	1,590	2,000	670	700	1,500	1,010	700	1,500	2,350	1,280
Be-----	2	2	2	2	2	2	L	1	4	2
Ce-----	159	70	35	63	L	87	L	---	139	---
Co-----	7	8	3	2	7	3	7	20	4	5
Cr-----	18	17	2	2	7	6	15	50	7	17
Cu-----	112	30	81	3	7	7	7	100	162	53
Ga-----	42	36	37	32	30	21	15	20	40	24
La-----	93	42	23	28	70	43	L	50	77	122
Mo-----	---	---	---	---	---	1	---	---	---	---
Nb-----	19	16	12	12	30	18	L	10	34	14
Nd-----	8	---	---	---	100	27	---	---	---	74
Ni-----	9	9	---	---	L	3	L	15	3	6
Pb-----	68	42	25	29	70	94	50	15	60	71
Rb-----	N.d.	N.d.	N.d.	N.d.	105	N.d.	125	N.d.	N.d.	N.d.
Sc-----	7	8	17	2	7	4	7	30	5	7
Sn-----	---	---	---	---	---	---	---	---	20	---
Sr-----	3,070	2,250	1,000	900	1,825	1,610	850	1,500	3,050	2,370
Th-----	---	---	---	---	---	---	---	---	---	---
V-----	85	89	41	33	150	72	70	200	65	44
Y-----	21	14	13	10	20	11	15	30	22	16
Yb-----	4	3	2	2	3	2	2	3	4	2
Zn-----	65	89	22	---	---	119	---	---	53	121
Zr-----	265	161	120	79	150	147	70	70	200	323

* Oxides by emission spectroscopy, the standard deviation of any single determination shall be taken as plus 50 percent and minus 33 percent.

CaO, Na₂O, K₂O, Rb and Sr by atomic absorption.

@ Total iron reported as FeO.

TABLE 13.—*Modes for syenite from Tertiary stocks and dikes, northern Front Range mineral belt*

[Chemical analyses in table 12. —, not found; Tr., trace]

Sample No. -----	159	160	166
In volume percent			
Potassium feldspar--	60.0	33.0	62.0
Plagioclase-----	30.0	55.0	28.0
Quartz-----	5.0	9.1	7.0
Hornblende-----	---	.7	2.5
Biotite-----	---	1.0	---
Ores-----	5.0	---	---
Apatite-----	---	.6	Tr.
Sphene-----	---	.6	.5
Zircon-----	---	Tr.	---
Total-----	100	100	100
An (percent) -----	24-34	8-25	25-30

porphyry east of the Continental Divide and the only major rock type that has not been age dated. Weathering and probable deuteric alteration have deterred those workers who have been dating the Cretaceous-to-Tertiary intrusives. The bostonite appears to be older than the syenite that has intruded the area on the north, but faulting and scree slopes have destroyed or covered contacts. Lovering and Goddard (1950, p. 205) believed the Bald Mountain bostonite to be younger than the Sunset syenite, and it may well be younger.

The rock in outcrop is pink and contains nearly white, rather large orthoclase crystals. In thin section all minerals have been partly to completely replaced except for the accessories, apatite and opaque minerals. Pyroxene crystals are skeletal. Quartz occurs in the groundmass but only in small grains that barely are visible. The first description and chemical analysis of the bostonite in this stock was presented by Breed (1899); Worcester (1921, p. 38) described the rock in greater detail. A new chemical analysis of the stock and new chemical analyses of several bostonite dikes are in table 14.

The mode of emplacement was, perhaps, chiefly by stopping and assimilation. The thermal regime of the stock was not nearly as high as that of the stocks to the west, because garnet and cordierite gneiss assemblages in the country rock appear almost untouched by thermal metamorphism adjacent to the intrusives.

SUNSET, GRASSY MOUNTAIN, BURNT MOUNTAIN, TUSCARORA, AND SUGARLOAF STOCKS

These are alkali syenite stocks that undoubtedly have a common magma source. Field relations of the stocks are similar, but the stocks do vary texturally and in

TABLE 14.—*Chemical and spectrographic analyses for bostonite porphyry from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[N.d., not determined; G, greater than 10 percent; —, not found; L, detected but below limit of determination]

Sample No. ----	22	44	45	55	208
Lab No. -----	W173014	W185440	D131284	W170192	W185233
Intrusive -----	Miscellaneous Dikes				Bald Mountain stock
Rapid rock chemical analyses in weight percent					
SiO ₂ -----	56.4	56.2	*G	70.1	65.4
Al ₂ O ₃ -----	19.0	17.6	G	16.1	16.9
Fe ₂ O ₃ -----	3.1	3.8	N.d.	1.8	1.5
FeO-----	2.6	2.4	#2.0	.16	.32
MgO-----	1.8	2.0	.05	.19	.06
CaO-----	4.5	4.6	.07	.49	1.1
Na ₂ O-----	4.7	4.1	3.0	5.1	5.4
K ₂ O-----	5.0	5.7	3.0	4.7	5.9
H ₂ O+-----	1.4	1.5	n.d.	.83	1.0
H ₂ O-----	.19	.29	n.d.	.27	.34
TiO ₂ -----	.47	.40	.07	.12	.09
P ₂ O ₅ -----	.47	.48	0.0	.04	.07
MnO-----	.14	.0	.01	.0	.08
CO ₂ -----	<.05	.01	n.d.	<.05	.42
F-----	.04	.02	n.d.	N.d.	N.d.
Cl-----	.02	.03	n.d.	n.d.	n.d.
S-----	.00	.03	n.d.	n.d.	n.d.
Total----	100	99	N.d.	100	99

Spectrographic analyses in parts per million					
Ba-----	700	1,240	500	1,000	1,400
Be-----	3	3	15	1	4
Ce-----	500	81	150	200	61
Co-----	20	15	---	---	---
Cr-----	10	20	---	3	6
Cu-----	70	120	3	1	19
Ga-----	20	26	30	20	39
La-----	150	53	150	200	52
Mo-----	3	---	---	3	2
Nb-----	20	13	150	50	20
Nd-----	---	---	70	100	---
Ni-----	L	8	7	---	3
Pb-----	30	45	200	70	91
Sc-----	15	11	---	---	---
Sr-----	1,500	1,750	500	200	432
Th-----	---	49	---	---	---
V-----	100	94	15	30	16
Y-----	30	17	15	20	9
Yb-----	3	3	2	2	2
Zn-----	---	50	---	---	75
Zr-----	150	209	500	200	212

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

Total iron reported as FeO.

degree of alteration. The Sunset stock is the only one in the group that has radiometric age dates. Two dates, 54 and 44 m.y. (table 1), were determined for this intrusive, which place it in a younger group of lower Tertiary intrusive rocks.

The Sugarloaf stock was the first of the group to be described and chemically analyzed. Both were done by Hogarty in 1899, and at that time he called the stock an andesite. The entire group of syenite stocks were first mapped and described by Worcester (1921), who

TABLE 15.—Chemical and spectrographic analyses for granodiorite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt

[N.d., not determined; ---, not found; L, detected but below limit of determination; G, greater than 10 percent]

Sample No.-----	46	49	51	50	56	58	205	41	47	60	81	128	54
Lab No.-----	W170187	W171189	W170189	D131286	W170193	W170194	W185232	W173018	W170188	D131289	D131297	D131326	D131287
Intrusive -----	Apex stock				Buckeye Mountain stock			Long Gulch stock	Dikes				
Rapid rock chemical analyses in weight percent													
SiO ₂ -----	66.9	67.3	65.4	*G	67.5	64.5	65.1	62.0	65.8	*G	*G	*G	*G
Al ₂ O ₃ -----	16.9	16.6	16.7	7.0	16.4	16.7	16.6	16.1	17.5	10.0	10.0	10.0	G
Fe ₂ O ₃ -----	2.6	1.6	2.6	N.d.	1.4	2.0	3.0	1.9	2.3	N.d.	N.d.	N.d.	N.d.
FeO-----	1.1	1.1	1.6	#1.5	.80	1.0	.96	2.6	.64	#1.5	#2.0	#3.0	#2.0
MgO-----	.62	.63	1.3	.015	.73	.62	.93	1.4	.34	.07	.5	.5	.05
CaO-----	2.3	2.4	3.8	.03	2.6	4.0	2.9	3.5	1.2	.05	1.0	3.0	.07
Na ₂ O-----	5.4	5.2	4.1	.05	5.5	6.1	4.8	4.8	6.1	2.0	3.0	3.0	.2
K ₂ O-----	3.1	3.4	3.0	.0	3.8	2.9	3.7	3.5	4.1	5.0	3.0	2.0	5.0
H ₂ O+-----	.47	.25	.60	n.d.	.44	.40	1.0	1.7	.51	n.d.	n.d.	n.d.	n.d.
H ₂ O-----	.12	.20	.18	n.d.	.16	.14	.55	.22	.24	n.d.	n.d.	n.d.	n.d.
TiO ₂ -----	.36	.28	.47	.05	.30	.25	.49	.43	.30	.1	.1	.15	.07
P ₂ O ₅ -----	.20	.14	.25	0.0	.18	.20	.38	.29	.09	0.0	0.0	0.0	0.0
MnO-----	.24	.10	.03	.01	.09	.0	.15	.12	.09	.003	.07	.07	.02
CO ₂ -----	<.05	<.05	<.05	n.d.	<.05	.65	.02	1.3	<.05	n.d.	n.d.	n.d.	n.d.
F-----	N.d.	.06	N.d.	n.d.	N.d.	N.d.	N.d.	.02	N.d.	n.d.	n.d.	n.d.	n.d.
Cl-----	n.d.	.01	n.d.	n.d.	n.d.	n.d.	n.d.	.02	n.d.	n.d.	n.d.	n.d.	n.d.
S-----	n.d.	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.00	n.d.	n.d.	n.d.	n.d.	n.d.
Total-----	100	99	100	N.d.	100	99	101	100	99	N.d.	N.d.	N.d.	N.d.
Spectrographic analyses in parts per million													
Ba-----	2,000	3,000	2,000	30	3,000	2,000	1,380	1,000	2,000	200	2,000	2,000	300
Be-----	3	1	1	---	2	3	2	1	5	1	1	1	1
Ce-----	500	500	300	L	300	200	206	500	500	---	---	---	---
Co-----	7	1	10	---	5	5	5	10	10	---	3	3	---
Cr-----	3	7	7	3	5	5	9	15	5	1	5	10	7
Cu-----	2	7	1	200	1	1	16	20	5	7	100	150	150
Ga-----	20	20	20	15	20	20	39	15	20	20	20	15	30
La-----	300	150	200	70	200	150	119	150	300	---	70	50	70
Mo-----	5	---	7	---	3	3	---	---	3	---	---	---	---
Nb-----	50	50	30	30	30	30	20	50	70	100	20	15	50
Nd-----	200	---	---	---	150	150	---	---	200	---	---	---	---
Ni-----	---	---	10	5	10	---	4	L	10	0	5	7	7
Pb-----	15	3	10	---	10	10	47	50	50	0	30	20	30
Sc-----	5	5	10	---	5	7	8	10	3	0	L	L	---
Sr-----	3,000	2,000	2,000	10	2,000	3,000	2,860	700	3,000	70	1,500	1,500	100
V-----	70	50	100	10	50	70	58	70	150	70	30	30	20
Y-----	30	30	30	---	30	30	20	30	30	0	20	20	20
Yb-----	3	3	3	1	3	3	3	3	3	1	2	2	3
Zn-----	---	---	---	---	---	---	37	---	---	0	---	---	---
Zr-----	150	200	150	---	150	150	302	150	200	100	100	100	200

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.
 # Total iron reported as FeO.

called them monzonite porphyry and diorite porphyry. Lovering and Goddard (1950) indicated that these intrusives belonged to a group consisting of alkali syenite, diorite, monzonite, and sodic granite. Using the classification in this report, the porphyries are mainly alkali syenite and quartz-alkali syenites. The Grassy Mountain stock (a local name) in the Ward quadrangle (Gable and Madole, 1976) was called a monzo-granodiorite; this name should be abandoned in favor of the name "alkali syenite." The Grassy Mountain stock differs from the Sunset stock mainly in the amount of deuteric alteration.

All of the syenite stocks in this immediate area are

strongly porphyritic, and most have a trachytic groundmass. Flow structures are particularly evident along their borders and in dikes adjacent to the stocks. Grassy Mountain, Sugarloaf, and part of the Tuscarora stock, in particular, have a concoidal fracture when broken, which is perhaps related to the fine-crystalline texture due to chilling at the contact. Chilled contacts with country rock may be observed in roadcuts in Lefthand Canyon and Fourmile Canyon, but perhaps the widest chilled contact is found in the Tuscarora stock. In this stock the chilled rocks occur northward from Lefthand Creek, and the contact between chilled and unchilled rock can be drawn along the 8,760-foot

TABLE 16.—*Modes for granodiorite from Cretaceous-Tertiary stocks and dikes, northern Front Range mineral belt*

[Chemical analyses in table 15, except sample 204. Tr., trace; N.d., not determined; ---, not found]

Sample No.-----	46	51	58	*204
In volume percent				
Potassium feldspar--	10.0	11.0	21.0	20.7
Plagioclase-----	78.0	59.0	64.0	36.5
Quartz-----	6.0	17.0	4.0	29.4
Hornblende-----	4.0	6.0	---	4.3
Pyroxene:				
Clinopyroxene----	---	---	8.0	---
Undifferentiated--	.6	---	---	---
Biotite-----	---	2.0	---	6.3
Ores-----	1.0	2.0	1.0	1.0
Apatite-----	.2	.5	1.0	Tr.
Allanite-----	---	.5	---	Tr.
Sphene-----	.2	2.0	1.0	---
Chlorite-----	---	---	---	Tr.
Epidote-----	---	---	---	1.8
Total-----	100	100	100	100
An (percent)-----	N.d.	32-34	20-26	N.d.

* From a small intrusive north of the Audubon-Albion stock.

elevation contour. Chilled rocks are less porphyritic, darker, and better flow layered, and have the composition of monzodiorite and monzosyenite. The variable composition probably is due in part to assimilation of schist and gneiss country rock. Profuse inclusions of schist and gneiss occur at the country rock-stock contact of most of these stocks. The Tuscarora stock bears the greatest number of schist, gneiss, and Silver Plume Quartz Monzonite inclusions. Some of the Silver Plume Quartz Monzonite is in rather large blocks. The number of inclusions in the Tuscarora and adjacent syenite stocks probably indicates that the roof of the intrusives had been breached.

In thin section, there is a difference in degree of vitrification (amount of glass in groundmass) between stocks; the Sunset is the most vitrified. Least vitrified, perhaps, is the small unnamed stock that lies east of the Sunset stock and north of Fourmile Creek (labeled "Tas" on pl. 1). This small body has a very fine crystalline groundmass. Plagioclase in most of these stocks, although zoned, does not normally have the oscillatory zoning observed in feldspar crystals in stocks to the west. The phenocrysts in all the stocks of this group, except Grassy Mountain and Sugarloaf, are oligoclase-andesine. The plagioclase phenocrysts in the Grassy Mountain and Sugarloaf stocks are andesine. Hornblende is both euhedral and unaltered, or almost completely destroyed and replaced by biotite and magnetite and some calcite. Several of the stocks have considerable calcite, including the Grassy Mountain, where the ferromagnesian minerals have been replaced by calcite.

These stocks are classified only by chemical analyses, because modal analyses were impossible to make, due to the fine-grained, trachytic groundmass. Table 12 contains nine chemical analyses of these rocks.

GEOCHEMISTRY

Most of the early reports discussed the major-element chemistry of the Late Cretaceous-Tertiary intrusives, but other than the work of Phair and Gottfried (1964) on uranium and thorium and Neuerberg (1967) on selected trace elements in the Caribou stock, the trace-element chemistry was not studied. Major- and trace-element chemistry are analyzed here for trends both within and between stocks. Semiquantitative spectrographic analyses presented in this report show significant trends between both rock types and stocks.

MAJOR-ELEMENT CHEMISTRY

Major variations in oxide chemistry between similar rocks of the Front Range stocks, and a comparison of Front Range rocks with similar rocks presented by Nockolds (1954), indicate that iron and potassium are higher than normal in the mafic rocks of both the Caribou and Audubon-Albion stocks.

The composition of the pyroxenites of this report (Audubon-Albion and Caribou stocks, table 2) and of those of Nockolds (1954, p. 1022) differ considerably, but the pyroxenites of this report are very much like those of Precambrian potassic biotite peridotites and biotite pyroxenites in southern Greenland (Upton and Thomas, 1973). Both have high total iron, rather high amounts of aluminum and potassium, and very low silica when compared to Nockolds' pyroxenites. It should be noted that the Front Range pyroxenites are very rich in iron, as much as 30 percent FeO. Gabbro-monzogabbro (Audubon-Albion and Caribou stocks and Rainbow Lakes plug, table 2) also has higher potassium and much higher total iron than the gabbros shown by Nockolds; otherwise, the analyses are not too different. Hornblende-pyroxene diorite analyses of this report are higher in total iron, CaO, and K₂O, and lower in MgO than hornblende-pyroxene diorite in Nockolds' tables. No typical monzodiorite was analyzed; the single monzodiorite analysis cannot be used for comparison because it shows 4.8 percent P₂O₅ that represents 27 percent apatite in the rock.

The major-oxide chemistry of the rocks that make up the stocks is shown in the variation diagrams of figure 2. Here the oxides of the stocks have been plotted against SiO₂ using the chemical data in tables 2-9 for the various rock types, excluding the dike rocks. This diagram emphasizes both variations in composition for each rock type and variations between stocks.

TABLE 17.—Chemical and spectrographic analyses for rhyodacite (granodiorite) from Cretaceous-Tertiary dikes, northern Front Range mineral belt

[---, not found; N.d., not determined; L, detected but below limit of determination; G, greater than 10 percent]

Sample No.---	90	91	92	103	124	125	74	89	62	132	133
Lab No.-----	D131303	D131304	W170208	W170213	D131321	D131322	D131295	D131302	D131290	W175167	W175168
Rapid rock chemical analyses in weight percent											
SiO ₂ -----	*G	*G	67.4	62.2	*G	*G	*G	*G	*G	68.9	63.9
Al ₂ O ₃ -----	10.0	10.0	17.8	16.8	10.0	10.0	10.0	7.0	G	17.2	16.9
Fe ₂ O ₃ -----	N.d.	N.d.	2.3	2.7	N.d.	N.d.	N.d.	N.d.	N.d.	1.5	2.3
FeO-----	#3.0	#1.5	.46	2.3	#2.0	#3.0	#5.0	#2.0	#3.0	.64	2.0
MgO-----	.7	.5	.80	1.7	.2	.3	1.5	.2	1.5	.43	1.3
CaO-----	3.0	.3	.63	4.2	.1	.3	3.0	.15	5.0	1.5	3.9
Na ₂ O-----	2.0	2.0	3.3	4.1	2.0	3.0	2.0	2.0	3.0	4.6	2.9
K ₂ O-----	3.0	3.0	3.1	3.0	2.0	2.0	3.0	3.0	2.0	3.1	3.2
H ₂ O+-----	n.d.	n.d.	2.0	.89	n.d.	n.d.	n.d.	n.d.	n.d.	1.5	1.6
H ₂ O-----	n.d.	n.d.	1.0	.11	n.d.	n.d.	n.d.	n.d.	n.d.	.17	.11
TiO ₂ -----	.2	.15	.29	.47	.2	.3	.3	.15	.5	.14	.14
P ₂ O ₅ -----	0.0	0.0	.14	.26	0.0	0.0	0.0	0.0	0.0	.11	.24
MnO-----	.07	.01	.0	.09	.05	.05	.07	.01	.1	.09	.14
CO ₂ -----	n.d.	n.d.	<.05	.74	n.d.	n.d.	n.d.	n.d.	n.d.	<.05	.39
F-----	n.d.	n.d.	N.d.	N.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.05	.05
Cl-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.01	.014
S-----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.0	.0
Total-----	N.d.	N.d.	99	100	N.d.	N.d.	N.d.	N.d.	N.d.	100	99
Spectrographic analyses in parts per million											
Ba-----	1,500	2,000	2,000	2,000	1,000	2,000	1,000	1,000	1,500	1,500	1,500
Be-----	1	1	1	1	1	1	1	1	1	---	---
Ce-----	---	---	100	150	---	---	---	---	L	200	200
Co-----	7	---	---	10	5	10	15	7	15	---	5
Cr-----	30	1	---	30	2	15	7	3	10	15	5
Cu-----	150	20	1	20	3	150	15	70	20	1	2
Ga-----	20	20	10	20	15	15	20	30	30	15	15
La-----	70	30	70	100	30	100	50	30	100	100	100
Mo-----	---	---	---	5	---	---	---	---	---	3	3
Nb-----	15	30	50	30	30	20	10	50	15	10	3
Nd-----	---	---	---	---	---	70	---	---	70	---	---
Ni-----	7	---	---	15	---	7	7	10	7	3	---
Pb-----	10	20	20	30	50	30	15	50	---	10	15
Sc-----	10	L	3	15	---	10	20	---	15	5	10
Sr-----	700	700	700	1,500	150	700	1,000	100	1,500	1,500	1,000
V-----	70	30	30	100	30	100	150	20	100	10	30
Y-----	30	20	20	30	20	30	50	20	50	30	50
Yb-----	3	2	3	3	2	3	3	2	7	3	5
Zn-----	---	---	---	0	---	0	61	---	---	---	---
Zr-----	100	150	150	150	100	100	100	100	150	200	200

* Oxides by emission spectroscopy; standard deviation of any single determination should be taken as plus 50 percent and minus 33 percent.

Total iron reported as FeO.

The pyroxenites have less SiO₂ than any other rock type. Gabbro and monzogabbro vary between 38 and 54 percent SiO₂ and completely overlap the diorites with their 46 to 53 percent SiO₂. Gabbro and diorite are separated by Streckeisen (1976) on the percent An in the plagioclase; therefore, it is not possible to show them separately on this type of diagram. The overlap of monzonite and quartz monzonite fields in figure 2 is due to more calcium and iron and less SiO₂ in the quartz monzonite of the Caribou stock. A similar situation occurs in the syenite field; calcium and sodium are higher than potassium, and SiO₂ and aluminum are

lower in syenite of the Sunset stocks as compared to the syenite in either the Jamestown or Audubon-Albion stocks. The syenite stocks containing the greatest amount of altered minerals, especially mafic minerals, tend to have higher SiO₂, and because of this introduced SiO₂, the rocks assigned to the syenite field overlap the granodiorite field and plot to the right of the syenite field. By modes, the syenite of the Audubon-Albion stock is a quartz syenite, and because the chemical composition of the syenites in the Jamestown and Audubon-Albion stocks are similar, the Jamestown stock is also assumed to be a quartz syenite.

TABLE 18.—*Modes for rhyodacite from a Cretaceous-Tertiary dike, northern Front Range mineral belt*

(Partial chemical analysis in table 17. ---, not found; Tr., trace)

Sample No.-----	62
In volume percent	
Potassium feldspar-----	1.0
Plagioclase-----	56.0
Quartz-----	17.0
Hornblende-----	17.0
Biotite-----	Tr.
Ores-----	7.0
Apatite-----	1.0
Sphene-----	1.0
Total-----	100

Chemical trends are indicated in figure 2 for each of the major stocks; however, because chemical variations between all stocks except the Caribou and Audubon-Albion stocks plot very closely along a straight line, only trends for the Caribou and Audubon stocks are discussed here. According to trends for the various oxides, the Audubon-Albion stock is chemically more variable than the Caribou. Oxides for the Caribou stock from the more mafic to the least mafic rocks plot close to a straight line for each of the oxides in relation to SiO_2 . Exceptions are CaO , Al_2O_3 , and iron in pyroxenites. In the Audubon-Albion stock, the oxides for pyroxenite do not vary from the overall trend of the oxides in the entire stock. There are noticeable variations, however, in oxide trends in the Audubon-Albion rocks for MgO and K_2O , and slight variations in FeO and Al_2O_3 not found in the Caribou stock. For most oxides in the Audubon-Albion stock, the trend of averages of the high and low points nearly match the trends in the Caribou stock.

TRACE-ELEMENT CHEMISTRY

Selected trace elements, especially the ore elements, in the various Cretaceous-Tertiary intrusive rocks of the northern Front Range mineral belt have been plotted in figures 3, 4, and 5 for comparison purposes. Uranium and thorium have not been considered in this study because Phair and Jenkins (1975) and Phair and Gottfried (1964) have described these elements in Front Range Cretaceous-Tertiary intrusives in great detail. Molybdenum, an important ore element associated with similar, but younger, age-group rocks elsewhere in Colorado, barely shows in analyses of this report. At Jamestown, molybdenum shows are associated with quartz-feldspar veins. The abundance of many of the

TABLE 19.—*Chemical and spectrographic analyses for dellinite, alkaline rhyolite, and peralkaline and alkaline granite from Cretaceous-Tertiary dikes, northern Front Range mineral belt*

(N.d., not determined; ---, not found)

Sample No.-----	Dellinite (adamellite) 135	Alkaline rhyolite 137	Peralkaline granite 53	Alkaline granite 138	Alkaline granite 139
Lab No.-----	W175170	W175172	W170191	W175173	W175174
Rapid rock chemical analyses in weight percent					
SiO_2 -----	72.0	71.2	74.5	69.5	70.2
Al_2O_3 -----	16.3	15.8	13.6	16.6	15.7
Fe_2O_3 -----	1.0	1.1	.0	1.5	1.1
FeO -----	.6	.8	1.6	.48	.64
MgO -----	.28	.36	.12	.35	.24
CaO -----	1.8	1.9	.78	.95	1.2
Na_2O -----	3.2	3.6	4.0	5.4	5.6
K_2O -----	3.7	3.8	4.1	4.4	4.0
H_2O^+ -----	.74	.95	.62	.34	.75
H_2O -----	.14	.15	.16	.14	.22
TiO_2 -----	.07	.08	.06	.13	.12
P_2O_5 -----	.07	.08	.02	.07	.05
MnO -----	.08	.06	.11	.07	.07
CO_2 -----	<.05	<.05	<.05	<.05	<.05
F-----	.04	.03	N.d.	N.d.	.04
Cl-----	.01	.004	n.d.	n.d.	.01
S-----	.0	.0	n.d.	n.d.	.0
Total-----	100	100	100	100	100
Spectrographic analyses in parts per million					
Ba-----	2,000	3,000	100	2,000	2,000
Be-----	1	1	5	1	3
Ce-----	---	---	---	200	500
Co-----	---	---	3	---	---
Cr-----	20	5	5	15	200
Cu-----	5	2	100	2	2
Ga-----	15	15	20	15	15
La-----	---	100	---	100	150
Mo-----	3	---	5	---	---
Nb-----	20	20	50	20	20
Ni-----	3	---	10	---	30
Pb-----	20	20	100	30	30
Sc-----	5	5	3	5	3
Sr-----	1,000	2,000	70	2,000	2,000
V-----	1	30	3	30	30
Y-----	20	30	15	30	30
Yb-----	2	2	1	3	3
Zr-----	100	150	100	150	100

trace elements in these rocks is compared with the average concentrations of common ore metals in igneous rocks compiled by Parker (1967).

The major rock types of the stocks are shown in columns 1, 2, 4-7, and 12-14, figure 3, and the various dike rocks mostly found in the country rock adjacent to the stocks are shown in columns 3, 8-11, and 15-17. Barium, copper, strontium, vanadium, and zirconium are consistently the most abundant trace elements found in the stocks and dikes, and strontium, barium, copper, and vanadium are all consistently higher in these rocks than the averages given by Parker (1967).

The mafic and ultramafic rocks do not, in general, contain as much cobalt, chromium, nickel, or vanadium as the averages for similar rocks in table 19 by Parker

(1967), but they bear greater than average amounts of copper, scandium, zinc, and zirconium, and far greater amounts of fluorine (not shown in fig. 3). The monzonites and quartz monzonites are below average in the ore metals nickel, vanadium, zinc, and zirconium, according to Parker (1967). Syenites are richer in copper and lead, and sometimes fluorine. Fluorine in the Jamestown stock is about 15 times greater than in the other syenite stocks. The granodiorites have more copper and less zinc than the averages for published granodiorite analyses (Parker, 1967). The Apex, Buckeye Mountain, and Long Gulch stocks, all called granodiorite but with a composition near that of quartz monzonite, and the monzonite of the Bryan Mountain stock are richer in cerium than the average for granitic or intermediate rocks shown in the table by Parker (1967). The syenite stocks, Jamestown and Sunset, and the bostonite porphyry stock, Bald Mountain, have more copper than average, but lead is above average in only the Sunset and Bald Mountain stocks. Zirconium is higher in the bostonite porphyries than in any of the other rock types.

Variations between similar rocks from each of the stocks are depicted in figure 4. Variations are not discussed here but may be evaluated by comparing the stocks collectively in figure 4.

Semiquantitative spectrographic analyses of the dike rocks, shown graphically in figure 5, indicate that zinc is below average in all dikes except biotite-quartz-plagioclase porphyry, in comparison with averages by Parker (1967) for similar rock types. Barium, cerium, copper, uranium, and thorium (Phair and Jenkins, 1975; Phair and Gottfried, 1964), vanadium, and zirconium, although variable between rock types within the dikes, appear to average higher than the Parker (1967) analyses.

The difference in average trace-element amounts between chemically similar stock rocks and dike rocks can be noted by comparing rocks in figure 3 with similar rocks in figure 5. The augite, hornblende, and biotite-hornblende-augite latite porphyry dikes all compare roughly to hornblende-pyroxene diorite. They differ in that the latite dikes have more cerium, chromium, and copper, whereas the hornblende-pyroxene diorite has more zinc and strontium (strontium from tables 3 and 4, not shown in figure 5). Elements in a monzodiorite dike compared with monzodiorite in the adjacent stock (table 3) are comparable except for chromium; chromium is far greater in the dike. A comparison of the trace elements in monzonite dikes (fig. 5, column 10) and in average monzonite (fig. 3, column 6) shows that amounts are nearly the same. The leucocratic latite porphyry dikes (plagioclase, biotite-quartz, and biotite-quartz-plagioclase latite porphyry), compared to aver-

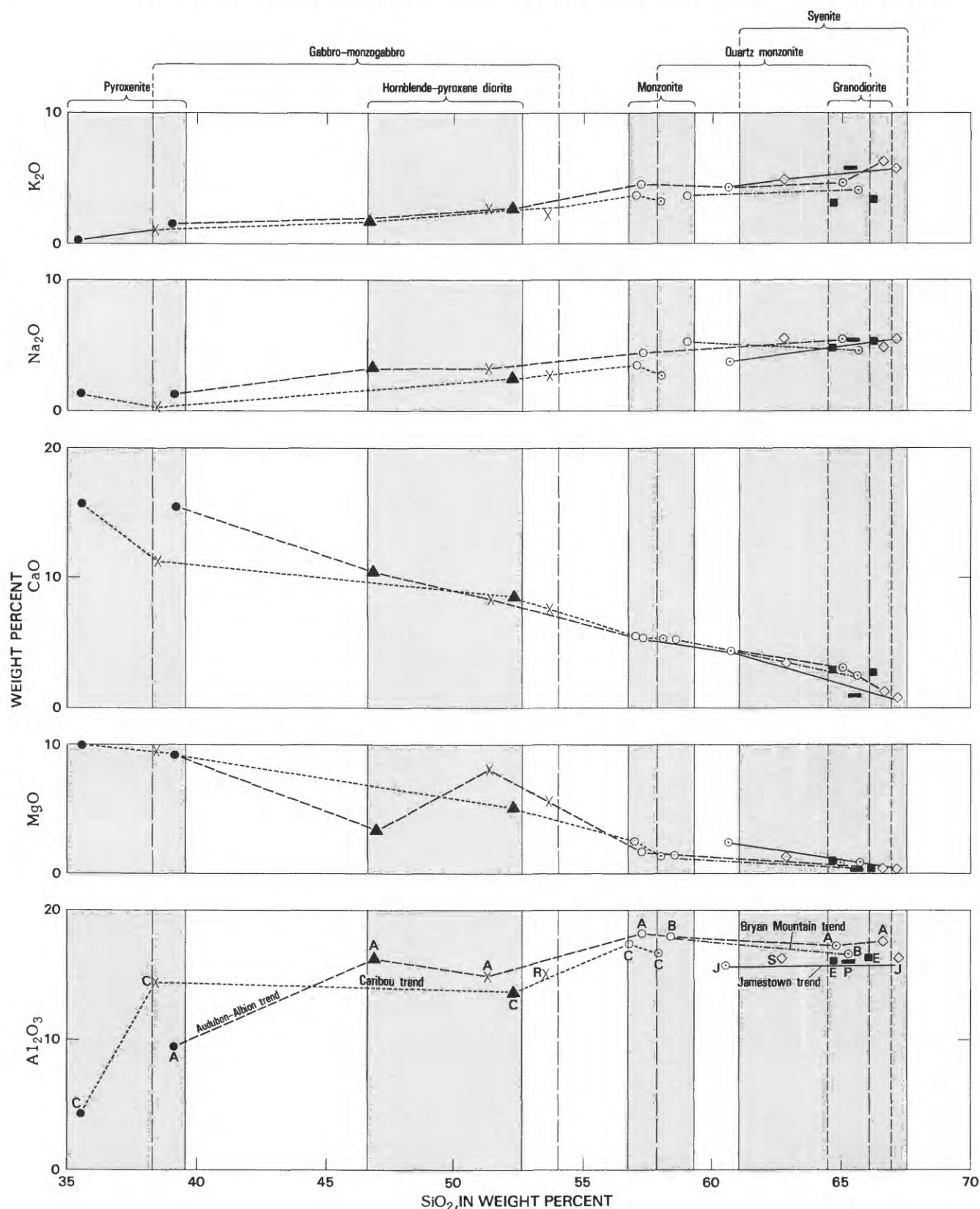
aged quartz monzonite of figure 3, column 7, show more cerium and copper in plagioclase latite porphyry and more zinc in biotite-quartz-plagioclase latite porphyry, whereas chromium is slightly higher in the quartz monzonite; also, quartz monzonite has more cerium and copper than do the felsite dikes. In bostonite porphyry dikes, when compared with averaged syenite (fig. 3, column 13), cerium is the same or greater, but zinc is slightly higher in the average syenite. Zirconium (not shown in fig. 5) also is higher in the dikes. The trace-element amounts in rhyodacite dikes are similar to averaged granodiorite, except that zinc, cerium, and strontium are higher in the granodiorite.

Tin occurs only in the Audubon-Albion and Sunset stocks. Most rock types of the Audubon-Albion stock, except the syenite, contain some tin. The range is 4 to 14 ppm (parts per million). Tin in the Sunset stock and in at least one of its associated dikes is higher than in the Audubon-Albion rocks. One analysis from the stock shows 48 ppm tin and one dike 20 ppm.

MODE OF EMPLACEMENT

Emplacement of many of the Late Cretaceous-Tertiary intrusives in the northern part of the mineral belt has occurred primarily along old Precambrian structures and zones of weakness. Lovering and Goddard (1938, p. 38) recognized that the "basement rocks were chiefly responsible both for the fracture pattern and for the distribution of the intrusives appearing during the Laramide revolution." Recent detailed mapping shows the relationships of intrusives to Precambrian structures. The stocks are directly or indirectly associated with fold axes (pl. 1), faults, and fractures, all of which originated in Precambrian time. Structures in the area of the Bryan Mountain, Caribou, and Sunset stocks strongly suggest that preexisting folds and faults controlled emplacement of these stocks. Faults have not been shown on plate 1 due to its small scale, but the area is cut by numerous broad, continuous, northwest-trending faults and many east-west and northeast-trending faults. Many of the latter I considered cross-breaking faults that occur between the northwest-trending faults. Dike swarms, especially those east of the Caribou and Audubon-Albion stocks, north of Burnt Mountain, and west of the Jamestown stock, seem to occupy some of the old Precambrian fracture zones. Also, in the south-central part of the plate 1 area, dikes of augite latite porphyry and bostonite porphyry trend northwest, as do faults in the same general area.

The mechanics of emplacement for each of the stocks is similar, and variations in stocks and between stocks have resulted mainly from multiple injections of magma. The emplacement of the southern part of the

FIGURE 2.—Variation diagrams showing relationships of major oxides plotted against SiO_2 for each rock type.

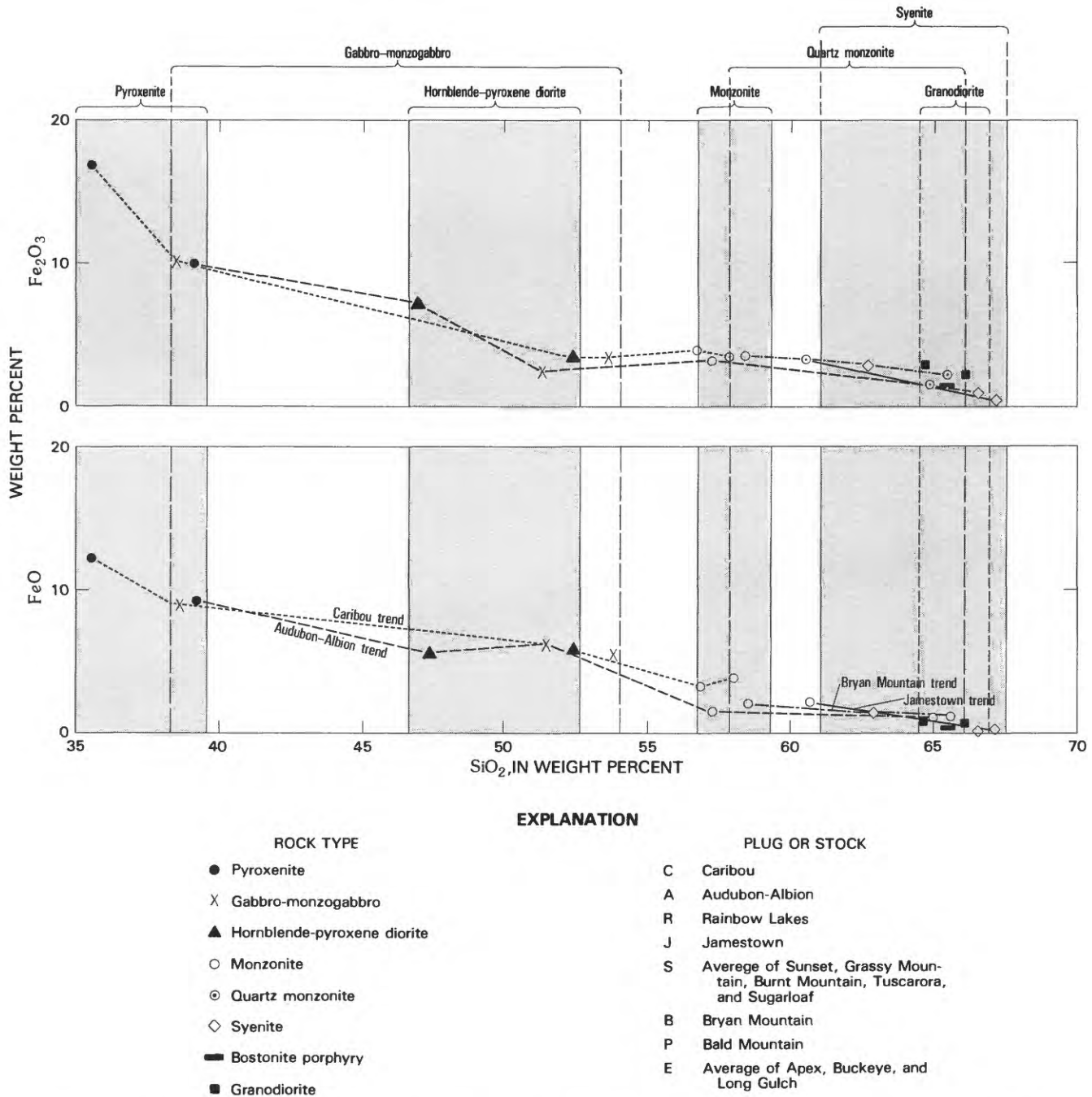


FIGURE 2.—Variation diagrams showing relationships of major oxides plotted against SiO₂ for each rock type.—Continued

Jamestown stock and similar stocks to the west accompanied the uplift of the Front Range that occurred sometime after 69 m.y. ago (Tweto, 1973). These stocks, from their more crystalline or phaneritic appearance, must have been emplaced at some depth. The syenite stocks (Sunset, Grassy Mountain, Tuscarora, and Burnt Mountain) on the east are related to Front Range uplift, faulting, and thrusting that ceased 49–43

m.y. ago (Bryant and others, 1975). The trachytic groundmass in many of the porphyritic stocks indicates that they cooled quickly, much closer to the surface than those on the west. The Bald Mountain stock, which has a trachytic groundmass, could also be related to this younger event. The contact zones of the stocks indicate that the magma was intruded by stoping, assimilation, and forcible intrusion, although the latter process

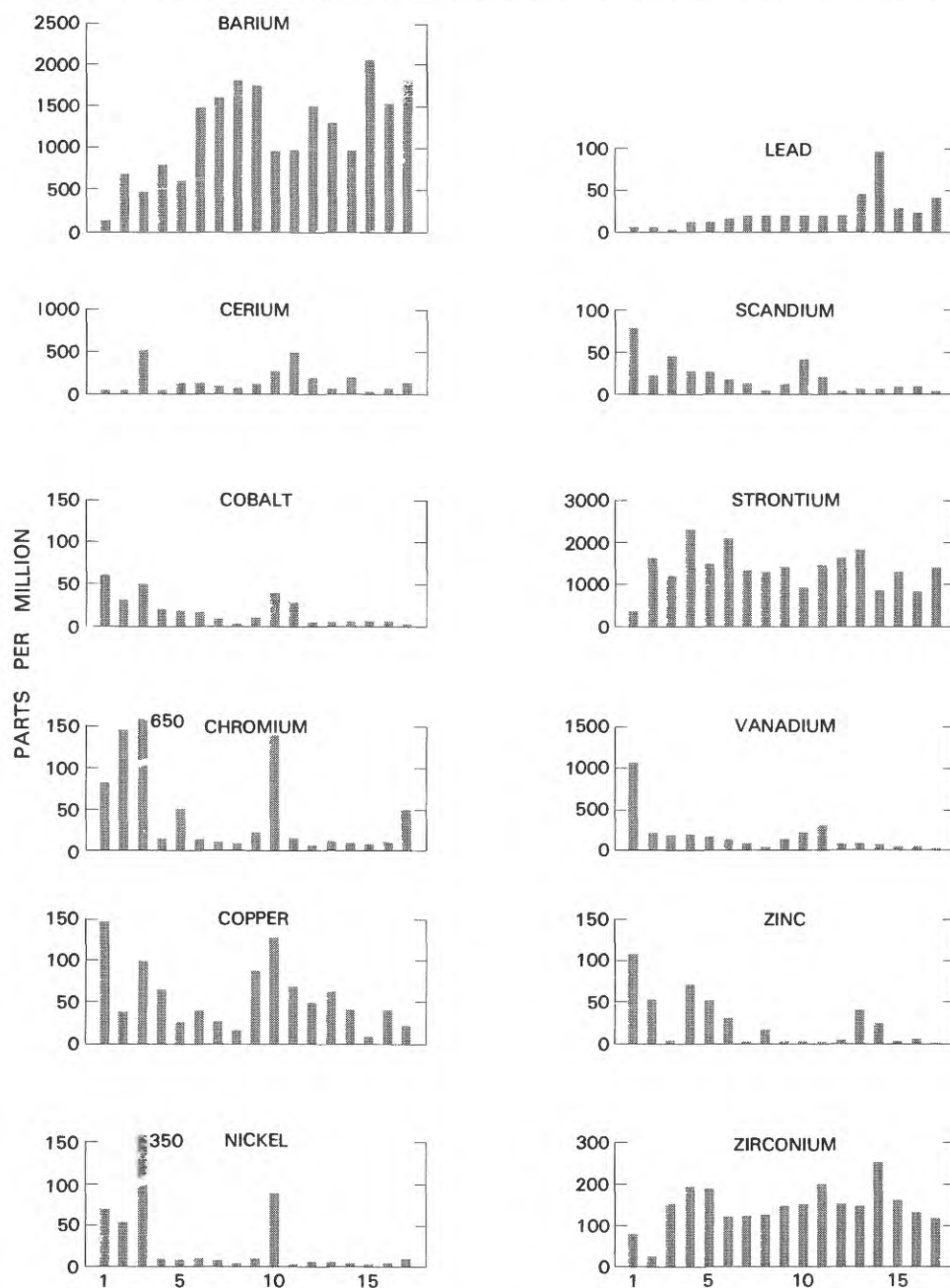


FIGURE 3.—Plots of trace elements in Cretaceous-Tertiary intrusive rocks, central Front Range.

Number of analyses for each rock type are in parentheses (samples averaged): 1, pyroxenite (13); 2, gabbro-monzogabbro (8); 3, limburgite (2); 4, hornblende-pyroxene diorite (13); 5, monzodiorite (3); 6, monzonite (24); 7, quartz monzonite (38); 8, latite, latite porphyry, and plagioclase porphyry from dikes (9); 9, hornblende latite (8); 10, augite latite (5); 11, biotitic hornblende-augite porphyry (1); 12, granodiorite (13); 13, syenite (19); 14, bostonite porphyry (5); 15, felsic dike rocks (4); 16, rhyodacite dike rocks (11); 17, dellonite-granite dike rocks (5).

appears to have been the least common method of emplacement. Breccias and faults along the periphery of some stocks appear to be directly related to the upward movement of the magma. Except for brecciation,

the country rock is not noticeably deformed, except locally, adjacent to the stocks, and this lack of deformation is probably because the magma entered the area along old Precambrian fractures, faults, and folds.

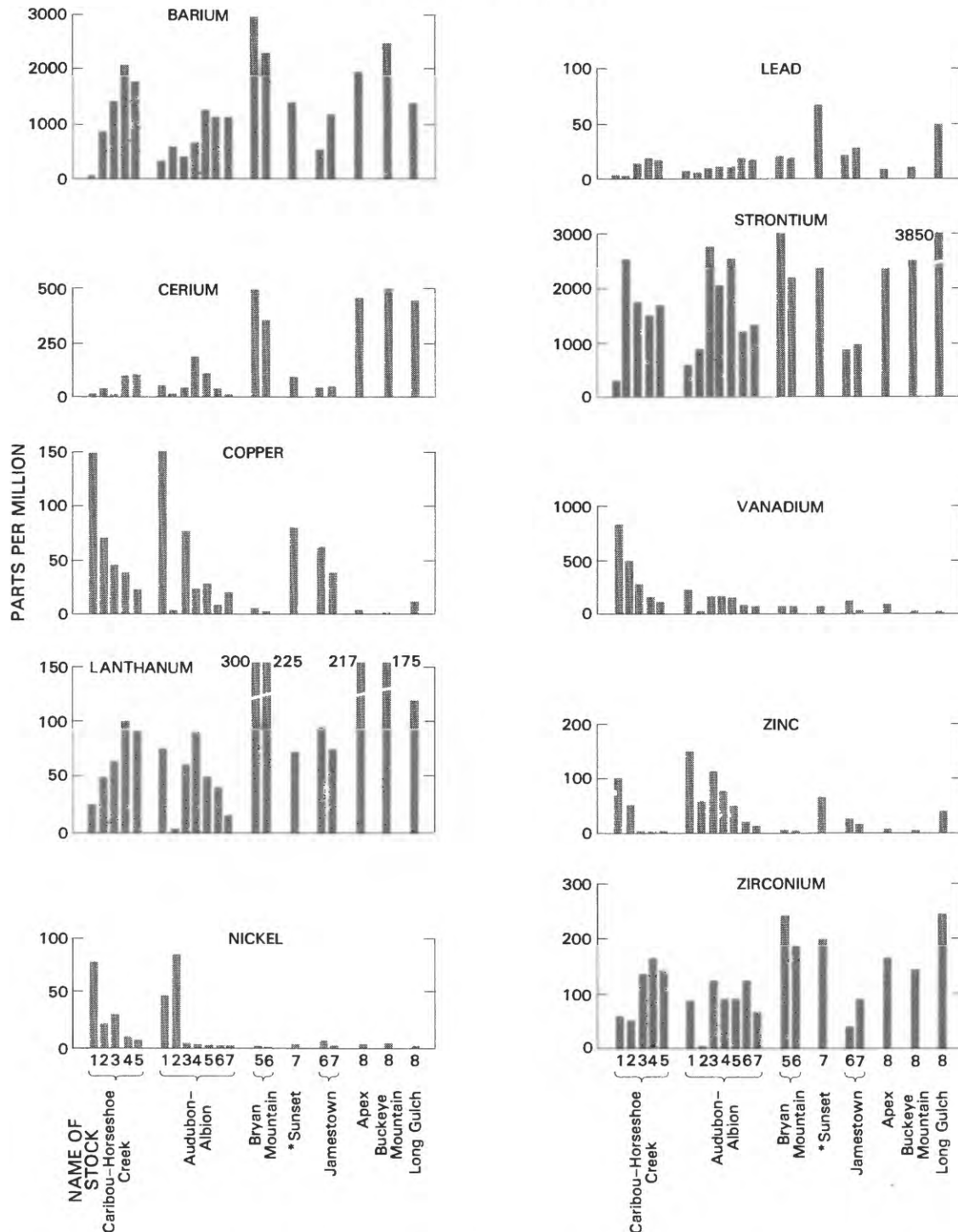


FIGURE 4.—Plots comparing selected trace elements between Cretaceous-Tertiary stocks, central Front Range. 1, pyroxenite; 2, gabbro-monzogabbro; 3, hornblende-pyroxene diorite; 4, monzodiorite; 5, monzonite; 6, quartz monzonite; 7, syenite; 8, granodiorite; *, average for Sunset, Sugarloaf, Grassy Mountain, Burnt Mountain, and Tuscarora stocks.

ADDITIONAL WORK NEEDED

Perhaps the most necessary work that needs to be done is more and better age dating. For example, only

the monzonite has been dated in the Audubon-Albion stock; the associated younger syenite sorely needs dating. There is a remote possibility that the syenite of the Audubon-Albion stock is not of Audubon-Albion age

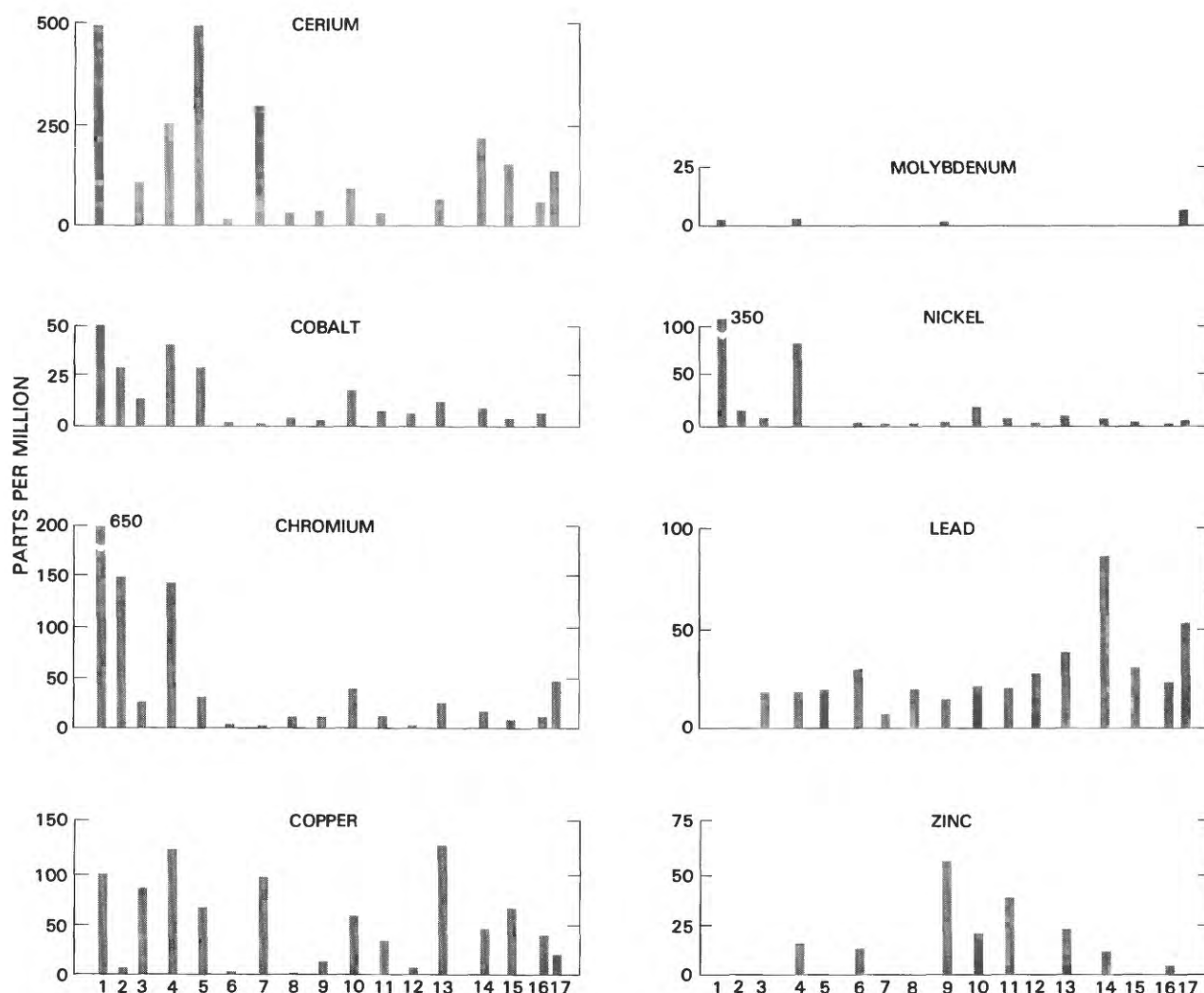


FIGURE 5.—Plots comparing selected trace elements between some Cretaceous-Tertiary dikes, central Front Range. Number of analyses for each rock type are in parentheses: 1, limburgite (2); 2, monzodiorite (1); 3, hornblende latite porphyry (8); 4, augite latite porphyry (5); 5, biotite-hornblende-augite latite porphyry (1); 6, biotite-quartz latite (3); 7, plagioclase latite porphyry (1); 8, biotite-quartz latite porphyry (3); 9, biotite-quartz-plagioclase porphyry (2); 10, monzonite (6); 11, quartz monzonite (24); 12, felsite (4); 13, syenite (2); 14, bostonite porphyry (4); 15, granodiorite (6); 16, rhyodacite (11); 17, alkali granite (5).

but is related to the syenite stocks to the east. The Bald Mountain bostonite porphyry stock also needs age dating. Similar bostonite porphyry to the south has been designated Cretaceous in age (Taylor, 1976), whereas Lovering and Goddard (1950) interpreted the Bald Mountain bostonite porphyry to be younger than the syenite of the Eocene Sunset stock.

The general low ore-metal geochemistry values from trace-element data, especially the base metals in the mafic rocks, has major economic implications. For example, Neuerburg (1967), after a study of the minor-accessory-mineral distribution of the Caribou stock, suggested that the ore deposits in the stock are structurally controlled and not genetically related to the

stock. Perhaps many of the ore deposits here in this part of the mineral belt now considered as derivatives of the intrusives are of another origin—this sets the stage for an interesting investigation.

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