Geology of the Crystalline Rocks in the Western Part of the Morrison Quadrangle Jefferson County, Colorado

GEOLOGICAL SURVEY BULLETIN 1251-E

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By D. J. GABLE

CONTRIBUTIONS TO GENERAL GEOLOGY

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A study of the igneous and metamorphic rocks along the mountain front due west of Denver, Colorado

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGY OF THE CRYSTALLINE ROCKS IN THE WESTERN PART OF THE MORRISON QUADRANGLE JEFFERSON COUNTY, COLORADO

By D. J. Gable

ABSTRACT

The Morrison quadrangle lies on the east flank of the Front Range, due west of Denver, Colo. The crystalline basement rocks lie in the western part of the quadrangle and consist of moderately to highly metamorphosed sedimentary and igneous rocks and, less commonly, nonmetamorphosed igneous rocks.

The oldest rocks are interlayered metasedimentary gneisses and are separated as map units on the basis of the relative abundance of each rock type. These units consist principally of microcline gneiss, biotite gneiss, and hornblende gneiss, and of lesser amounts of quartz-plagioclase gneiss, calc-silicate gneiss, quartzite, and marble. This sequence, which is typical of the Idaho Springs Formation, was intruded, in Precambrian time, by gneissic granodiorite and lamprophyre and by small plutons and lenses of granodiorite, quartz diorite, and hornblendite.

The youngest rocks are dikes of diabase and latite and a small stock of shonkinite. These are nonmetamorphosed and probably are Tertiary in age. If this age is correct, the shonkinite is a new rock type for the Tertiary Period in the central part of the Front Range.

The gneisses now reflect metamorphism of high sillimanite grade, but relic staurolite and helicitic structures in garnet indicate an earlier less intense metamorphism. After the gneisses were metamorphosed to the sillimanite grade they were subjected to pervasive plastic and cataclastic deformation. Retrograde metamorphism within the area is greatest in the vicinity of the larger faults where chlorite and muscovite are more abundant.

The rocks were deformed at least twice and locally at least three times during Precambrian time. During the early deformation the sediments were recrystallized and plastically folded into west-northwest-trending folds. Granodiorite, quartz diorite, and hornblendite were emplaced near the end of this period. This deformation is reflected generally by folds in the north half of the mapped area. During later deformation the rocks were again plastically folded into structures having north-northeast trends. This deformation was accompanied by migmatization and emplacement of the gneissic granodiorite. A third period of deformation, recognized principally by muscovitization and cataclasis, obliterated much of the structural detail formed earlier.

Faults, some of large magnitude, were formed during Precambrian and Laramide times. The steeply dipping beds of Paleozoic, Mesozoic, and Cretaceous sedimentary rocks that flank the basement to the east also were folded during the Laramide orogeny.

INTRODUCTION AND ACKNOWLEDGMENTS

The part of the Morrison quadrangle, Jefferson County, Colo., in which Precambrian rocks are exposed comprises about 18 square miles along the east boundary of the Front Range, between Clear Creek and Turkey Creek Canyons, west of Denver (fig. 1). The area is readily accessible by U.S. Highway 40, Colorado Highway 74, and from good side roads leading from U.S. Highways 285, 6, and 40. Relief in the area reaches a maximum of about 1,960 feet, and is greatest along canyons of the larger streams such as Bear, Mount Vernon, and Clear Creeks.

The present study is part of a continuing program of studies of Precambrian rocks in the central part of the Front Range made for the purpose of gaining a detailed geologic section across the range. Such a section is intended to improve the understanding of the composition and structure of the area as well as the understanding of the factors controlling the ore deposits in the Front Range mineral belt, which lies a few miles west of the Morrison quadrangle. Studies of this kind have been completed to the south in the Kassler quadrangle (Scott, 1963) and the Platte Canyon quadrangle (Peterson, 1964), to the north in the Golden quadrangle (Van Horn, 1957) and Eldorado Springs quadrangle (Wells, 1963), and to the west in the Idaho Springs area (Moench, 1964) and the Central City quadrangle (Sims and Gable, 1964).

In the Morrison quadrangle, Precambrian rocks were studied by Anderson (1949), by Boos (1954) as part of a study of Precambrian granitic pegmatites, and by Boos and Boos (1957) in conjunction with a tectonics study of the Front Range. The sedimentary terrane in the eastern part of the quadrangle was mapped by Smith (1964).

In the present study, the geology of the basement rocks was mapped during the summer of 1962 on a topographic base map at a scale of 1:20,000. The contact between the basement rocks and the overlying Pennsylvanian and Permian Fountain Formation was mapped on aerial photographs. This contact, which differs locally from that mapped by Smith (1964), is not everywhere easily located because in most places it is on a grass- and commonly rubble-covered slope. Several colleagues, particularly C. T. Wrucke, assisted in mapping the contact between the basement and the Fountain.

Most geologic units are fairly well exposed, especially along steep canyon walls and roadcuts. Grass and brush cover are common at lower elevations; conifers cover most northern slopes at higher elevations. Rock units that have been described in detail in other reports are discussed only briefly in this report. Other units, such as migmatitic gneissic granodiorite at Mount Morrison, cordierite-bearing

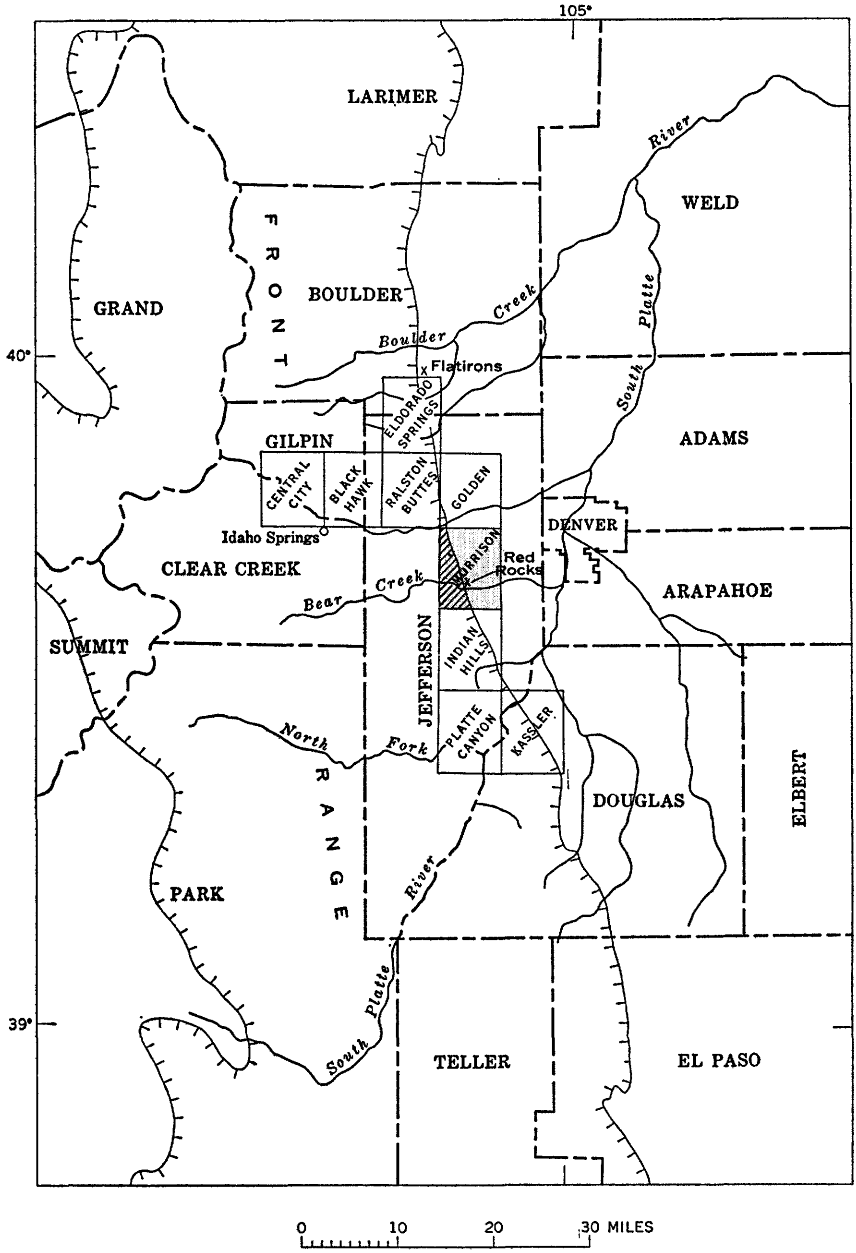

FIGURE. 1.—Map showing location of Morrison quadrangle and nearby mapped quadrangles. Map area crosshatched.

biotite gneiss, and shonkinite, which have not been extensively studied previously, are discussed at greater length.

Numerous X-ray analyses of minerals were made by E. J. Young of the Geological Survey. Chemical analyses of rocks were made in the Survey laboratories in Denver; the analysts are credited where appropriate within the report.

GEOLOGIC SETTING

The area discussed in this report (pl. 1) is on the lower eastern flank of the Front Range, a major mountain range that faces the Interior Plains from southern Wyoming southward for 200 miles to Canon City, Colo. Precambrian crystalline rocks predominate in the core of the range, and Paleozoic and younger sedimentary and volcanic rocks flank the range. The range was formed structurally during the Laramide orogeny in Late Cretaceous and early Tertiary time.

The Precambrian rocks in the core of the Front Range, including those in the Morrison quadrangle, consist of metasedimentary gneisses that were extensively folded and intruded with igneous material during Precambrian time. Among the gneisses are biotitic, hornblendic, and feldspathic units that collectively have been assigned to the Idaho Springs Formation (Spurr and Garrey, 1908) and to the Swandyke Hornblende Gneiss (Lovering and Goddard, 1950). Although some of the hornblendic gneiss may represent volcanic rocks, most of the gneisses probably were sedimentary rocks originally.

Precambrian intrusive rocks in the central part of the Front Range include varieties commonly known as Boulder Creek Granite, Silver Plume Granite, and Pikes Peak Granite. These rocks form batholiths, smaller plutons, and dikes. Other intrusive rocks of Precambrian age, generally in smaller bodies and dikes, include quartz monzonite, quartz diorite, hornblendite, lamprophyre, and gneissic granodiorite. Small bodies and dikes of diabase, latite, and shonkinite appear to be younger than the other intrusive rocks and might be, in part, of post-Precambrian age, although some diabase is known to be Precambrian.

Studies in the central Front Range (Moench and others, 1962; Wells and others, 1964) show that the gneisses were deformed during two or three successive periods. The rocks first were recrystallized and plastically deformed in one or two stages under conditions of high confining pressures and temperatures; later, they were cataclastically deformed perhaps by somewhat lower pressures and temperatures. The gneisses now lie in a complex series of folds, which are broken and displaced by faults ranging in age from Precambrian to Tertiary.

PRECAMBRIAN ROCK UNITS

The metasedimentary rocks in the Morrison quadrangle belong to the Idaho Springs Formation as recognized by Spurr and Garrey (1908, pl. 2), by Lovering and Goddard (1950, pl. 2), and by Boos (1954). In this report the gneisses have been named according to their lithologic characteristics according to the terminology used in the Central City district (Sims and Gable, 1964).

The gneisses include many different lithologic types that are interlayered on scales ranging from laminae less than an inch thick to massive layers hundreds of feet thick. For mapping, various lithologies are grouped into units characterized by some predominant lithology. In the following discussion, emphasis is on these map units rather than on individual rock types.

The metasedimentary map units are: biotite gneiss, garnetiferous biotite gneiss, microcline-quartz-plagioclase-biotite gneiss, hornblende gneiss and amphibolite, cordierite-bearing biotite gneiss, and quartz-plagioclase gneiss. The microcline-bearing gneiss is extremely migmatitic in the southernmost part of the quadrangle, where layers of well-foliated microcline-bearing gneiss alternate with thin to thick layers of poorly foliated granitic gneiss.

The igneous rocks are difficult to correlate with those previously described from other localities in the Front Range because of differences in lithology and in occurrence from those characteristic of the type locations. In this report, the rock called migmatitic gneissic granodiorite and its associated aplite and pegmatite is similar in some respects to the granite gneiss and pegmatite of Harrison and Wells (1956, p. 50) and to granite gneiss and migmatite of Scott (1963, p. 78–80). The rock called granodiorite in this report is generally similar to the gneissic Boulder Creek Granodiorite in the Front Range (Sims and Gable, 1967). Quartz diorite and hornblendite pods and lenses within the area are similar to those in the Kassler quadrangle (Scott, 1963, p. 81).

METASEDIMENTARY ROCKS

BIOTITE GNEISS

The biotite gneiss map unit, which crops out in the northwestern corner of the Morrison quadrangle, consists predominantly of biotite-quartz-plagioclase gneiss. The body of the gneiss in this area is part of a unit called gray gneiss in the Ralston Buttes quadrangle (Sheridan and others, 1958) and is generally similar to the biotite gneiss of the Central City quadrangle which has been described in detail (Sims and Gable, 1967).

The gneiss is a moderate- to dark-gray or pinkish-gray fine- to medium-grained well-foliated rock. The foliation is due to alinement of mineral grains, especially biotite, and to the segregation of minerals into light and dark layers an inch or less thick. Biotite-rich streaks are common. The gneiss is homogeneous except where it contains generally conformable layers and pods of granitic material, and forms migmatite. It also contains pegmatite stringers and dikes a foot or less thick that occur singly or in migmatite swarms and are commonly bright pink, similar to the pegmatite associated with the gneissic granodiorite. Along Lariat Loop Road this gneiss contains lenses of granodiorite and lenses or pods of metamorphosed hornblendite 10–150 feet long. The contact with garnetiferous gneiss on the south is gradational.

Plagioclase, quartz, and biotite make up about 97 percent of the biotite gneiss (table 1), and potassic feldspar, magnetite, muscovite, and other accessory minerals make up the remaining 3 percent. The plagioclase, which is oligoclase (An_{22-27}) with albite twinning, contains many crystals that are zoned and have rims slightly more sodic than the cores. Secondary minerals in and adjacent to plagioclase are muscovite, calcite, kaolinite, and sericite. The potassic feldspars are mainly microperthite, which is of the film-and-vein type, and microcline; antiperthite occurs in irregular patches in plagioclase, and orthoclase occurs locally, especially near hornblendite pods. The potassic feldspars form small grains along the margins of plagioclase crystals and appear to have replaced plagioclase. Biotite is frayed and contains secondary rutile, muscovite, and iron oxide minerals.

GARNETIFEROUS BIOTITE GNEISS

The garnetiferous biotite gneiss map unit, which consists principally of garnetiferous biotite-quartz-plagioclase gneiss, occurs in a belt that lies south of the biotite gneiss unit in the northwest part of the quadrangle. On the south side of this belt, the garnetiferous unit grades into microcline gneiss through a zone several hundred feet wide. Pegmatite and finer grained granitic material constitute nearly half the volume of the garnetiferous unit. The garnetiferous biotite gneiss unit is generally similar to one in the Central City quadrangle (Sims and Gable, 1967).

The principal minerals in the garnetiferous biotite gneiss are quartz, plagioclase, biotite, garnet, and, in lesser amounts, muscovite and potassic feldspar (table 2). The accessory minerals are sillimanite, magnetite and other iron oxides, zircon, and apatite.

The garnetiferous biotite gneiss is more massive and less conspicuously banded than the biotite gneiss. The garnets are generally ¼ to ½ inch in diameter, but near pegmatites some are as much as 3 inches in diameter. Corroded garnet porphyroblasts in the pegmatitic laminae form a hackly weathered surface that is stained dark orange

TABLE 1.—*Modes, in volume percent, of biotite-quartz-plagioclase gneiss*

[Tr., trace, n.d., not determined; —, looked for but not found]

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13
Field No. M–	57	110	236	460	528b	474	621	634	733	753	778	740	913
Potassic feldspar	0.3	4.6	—	0.4	0.5	1.1	1.0	—	1.5	—	—	—	—
Plagioclase	49.8	35.5	46.2	49.4	43.1	45.2	35.5	44.2	32.0	37.9	37.0	40.6	38.0
Quartz	31.1	42.9	42.3	38.4	38.4	38.6	51.5	39.3	52.7	47.0	34.0	46.1	46.9
Biotite	17.3	16.4	11.4	8.1	15.7	14.7	7.1	16.1	13.5	14.5	21.7	10.7	9.6
Muscovite	.6	Tr.	.1	3.1	1.8	.4	3.0	.2	—	.5	—	2.1	4.8
Iron oxides	.1	.6	—	.5	Tr.	Tr.	.5	Tr.	.3	.1	Tr.	.5	—
Zircon	.1	Tr.	Tr.	Tr.	.1	—	—	.2	Tr.	Tr.	.7	Tr.	.5
Chlorite	—	Tr.	—	—	—	—	—	—	—	—	—	—	—
Apatite	.3	—	—	Tr.	—	Tr.	—	—	—	—	—	—	—
Calcite	.4	—	—	.1	.4	—	.6	—	—	—	—	—	—
Hornblende	—	—	—	—	—	—	—	—	—	—	—	—	—
Kaolinite	—	—	—	—	—	—	—	—	—	Tr.	6.6	—	—
Epidote	—	—	—	—	—	—	.1	—	—	—	—	—	—
Garnet	—	—	—	—	—	Tr.	.4	—	—	—	—	—	—
Tourmaline	—	—	—	—	—	—	—	—	—	—	—	—	.1
Allanite	—	—	—	—	—	—	.3	—	—	—	—	—	—
Sillimanite	—	—	—	—	—	—	—	—	—	Tr.	Tr.	—	Tr.
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Composition of plagioclase	An_{22-27}	n.d.	An_{19}	An_{24-27}	An_{19}	An_{21}	An_{25-29}	An_{10}	n.d.	An_{17-22}	An_{12}	An_{12-16}	n.d.

1. From outcrop, south of fork in Chimney Gulch, north of Lookout Mountain.
2. Layer in garnetiferous biotite gneiss 250 ft south of contact with garnetiferous biotite gneiss unit and 75 ft west of contact between basement and base of sedimentary rocks, interlayered with garnetiferous biotite gneiss.
3. Interlayered with hornblende gneiss and amphibolite, just south of Apex Gulch on trail at 7,000-ft elevation.
4. Interlayered with hornblende gneiss and amphibolite, Sawmill Gulch shear zone, from roadcut ½ mile north of Idledale.
5. From lens in gneissic granodiorite, old quarry in Bear Creek Canyon.
6. Lens in microcline gneiss from outcrop northwest of Idledale, 7,100-ft elevation.
7. Garnet-bearing gneiss in microcline gneiss unit from peak at 7,676-ft elevation, due south of Idledale.
8. Migmatitic gneiss in microcline gneiss unit from outcrop adjacent to Falcon Castle ruins.
9. Quartz-rich gneiss interlayered with quartz-plagioclase gneiss from east bank of stream south of old trail leading up from U.S. Highway 285, southwest of Morrison.
10. Interlayered with quartz-plagioclase gneiss from outcrop 300 ft south of old quarry in Bear Creek Canyon.
11. Kaolinite-bearing gneiss interlayered with quartz-plagioclase gneiss from outcrop west of U.S. Highway 285 and 500 ft from south edge of Morrison quadrangle, 6,680-ft elevation.
12. Interlayered with quartz-plagioclase gneiss from outcrop, first main gulch north of Strain Gulch, 6,400-ft elevation.
13. Muscovite-bearing gneiss interlayered with quartz-plagioclase gneiss from outcrop due west of Denver Mountain Parks Emergency Headquarters, 6,040-ft elevation.

TABLE 2.—*Modes, in volume percent, of garnetiferous and sillimanitic biotite-quartz-plagioclase gneiss*

[Tr., trace; n.d., not determined; —, looked for but not found]

	Lookout Mountain area				Bear Creek area				
Sample	1	2	3	4	5	6	7	8	9
Field No. M-	66a	67	74	77	133	487	529	497a	605
Potassic feldspar	0.3	4.7	—	8.1	0.9	—	—	—	—
Microperthite	—	11.3	0.1	—	—	—	—	—	—
Plagioclase	4.0	12.5	41.3	26.6	39.5	34.3	30.8	11.8	16.4
Quartz	69.4	45.3	44.0	45.6	40.6	28.0	44.1	56.6	44.5
Biotite	22.4	18.4	11.2	10.1	14.7	12.1	15.8	25.1	22.7
Muscovite	1.9	7.8	.6	8.3	—	.4	3.2	.6	6.3
Iron oxides	Tr.	Tr.	.6	1.3	.6	1.7	.1	1.1	1.4
Garnet	—	Tr.	2.1	—	3.3	9.8	—	1.1	2.0
Sillimanite	1.7	Tr.	—	—	—	—	5.6	3.2	—
Zircon	Tr.	Tr.	Tr.	Tr.	.3	Tr.	Tr.	Tr.	Tr.
Tourmaline	—	—	—	—	—	—	—	—	.4
Chlorite	.3	—	.1	—	—	13.1	.4	.5	5.1
Staurolite	—	—	—	—	—	—	—	—	Tr.
Andalusite	—	—	—	—	—	—	—	—	.8
Apatite	—	—	Tr.	—	.1	Tr.	—	—	.4
Amphibole(?)	—	—	—	—		.6	—	—	—
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Composition of plagioclase	n.d.	n.d.	An_{19-21}	n.d.	An_{22}	An_{12-14}	An_{6-16}	An_{22}	n.d.

1. From roadcut on Lariat Loop Road, just northeast of Wm. F. Cody (Buffalo Bill) Museum and Grave.
2. From roadcut, 400 ft southwest of sample 1 locality.
3. From outcrop near contact with biotite gneiss unit to north. Outcrop northwest from Wm. F. Cody (Buffalo Bill) Museum and Grave.
4. Microcline-bearing gneiss layer, east side of road, west edge of quadrangle, on Colorow Hill.
5. Lens, south of Deadman Gulch and 500 ft west of Precambrian contact.
6. From roadcut just west of Idledale and adjacent to Foothills mine.
7. From roadcut just west of contact of Precambrian and sedimentary rocks, Bear Creek Canyon.
8. From roadcut, ½ mile east of Idledale in Bear Creek Canyon.
9. Andalusite-bearing gneiss from outcrop in gulch south and slightly east of footbridge in Bear Creek Canyon, 6,800-ft elevation.

brown. Some of the gneiss lacks garnet but is mottled with small elongate white clots consisting of quartz and feldspar surrounding a magnetite core—indication that garnet was once present.

Locally, sillimanitic and sillimanitic garnetiferous biotite-quartz-plagioclase gneiss and amphibolite in pods and lenses are interlayered with the garnetiferous biotite gneiss. Several sillimanitic lenses are located in the roadcuts just below the Wm. F. Cody Museum and Grave on Lariat Loop Road.

The garnetiferous gneiss, as shown by thin-section studies, is richer in quartz, biotite, and potassic feldspar than the biotite gneiss to the north, but it contains considerably less plagioclase. The plagioclase is a slightly zoned oligoclase (An_{19-22}), which is commonly albite twinned and less commonly carlsbad twinned. A striking exsolution antiperthite of long fingerlike blebs or veins locally occurs parallel and normal to the twin lamellae. The potassic feldspars consist of well-twinned microcline and, more predominantly, of film-and-vein types of perthite. Biotite is generally dark brown in most of the rocks but is dark olive green in the sillimanitic varieties.

HORNBLENDE GNEISS AND AMPHIBOLITE

The hornblende gneiss and amphibolite map unit crops out in a large area north and west of Idledale and is similar to the Swandyke Hornblende Gneiss described by Lovering and Goddard (1950, p. 20). The unit consists principally of amphibolite, interlayered with hornblende gneiss, biotite gneiss, microcline gneiss, and numerous small lenses and layers of quartzite and calc-silicate rocks, including traces of impure marble. The layers commonly range in thickness from several feet to several tens of feet, but some are several hundred feet thick; contacts between layers are sharp or gradational. Amphibolite of the same character as that in the map unit forms sparse layers and lenses in the other metasedimentary units in the quadrangle.

The amphibolite is a dark, almost black or greenish-black, foliated rock. Some of it is homogeneous, and some has dark layers separated by paper-thin light-colored plagioclase-rich layers. Hornblende, which is dark olive green, composes 45–69 percent of the amphibolite; plagioclase, which ranges in composition from andesine to bytownite, composes 27–42 percent (table 3). Other minerals, present locally, are diopside partly altered to hornblende, quartz, and traces of biotite. The accessory minerals are sphene, calcite, apatite, zircon, magnetite, ilmenite, and zircon.

Biotite gneiss and microcline gneiss interlayered with the amphibolite constitute 25–35 percent of the hornblende gneiss unit. They are light gray or yellowish gray, and contrast markedly with the

TABLE 3.—*Modes, in volume percent, of amphibolite in hornblende gneiss*

[Tr., trace; —, looked for but not found]

Sample	1	2	3
Field No. M-	247	306	532-C-1
Plagioclase	42. 0	36. 6	27. 4
Quartz	—	Tr.	Tr.
Biotite	Tr.	—	2. 2
Muscovite	—	—	—
Hornblende	58. 0	44. 9	69. 2
Clinopyroxene	—	15. 9	—
Magnetite-ilmenite	Tr.	—	. 8
Apatite	Tr.	. 1	Tr.
Zircon	Tr.	—	Tr.
Sphene	—	. 2	—
Calcite	—	2. 3	. 4
Chlorite	—	—	—
Total	100. 0	100. 0	100. 0
Composition of plagioclase	An_{75}	An_{52}	An_{36-40}

1. From roadcut 500 ft west of contact between Precambrian and Paleozoic rocks at entrance to Mount Vernon Canyon.
2. Speckled amphibolite from outcrop on ridge south of Mount Vernon Canyon and 600 ft northeast of small top with elevation 7,349 ft.
3. From roadcut 1,200 ft west of contact between Precambrian and Paleozoic rocks in Bear Creek Canyon.

greenish black of the amphibolite and yellow green of the calc-silicate rocks.

A conspicuously speckled coarse-grained hornblende gneiss that forms a layer several hundred feet thick south of Mount Vernon Creek owes its distinctive appearance to crystals of diopside that are partly altered to hornblende. Associated with this speckled gneiss are layers of calc-silicate gneiss several feet to several tens of feet wide which grade into amphibolite along strike. A thousand feet east of Mother Cabrini Shrine, lenses of marble and quartzite are finely interlayered with amphibolite and biotite gneiss. These lenses are very pure and have sharp contacts with the enclosing gneiss.

CORDIERITE-BEARING BIOTITE GNEISS

The cordierite-bearing biotite gneiss map unit consists of many interlayered gneisses, namely: biotite-garnet-sillimanite gneiss, cordierite-bearing biotite-garnet sillimanite gneiss, biotite-cordierite-garnet-gedrite gneiss, biotite-cordierite gneiss, and amphibolite. Field exposures are predominantly of biotite-cordierite-garnet-gedrite gneiss.

The gneisses of the unit generally form distinctive layers a fraction of an inch to several tens of feet thick; any one layer may show a great variation in thickness and in composition in short distances along and across strike. A diverse lithology characterizes the map unit along the Bear Creek Canyon road from Idledale eastward to the Paleozoic rocks. South of the canyon, along the mountain front, the unit is more homogeneous and seems to be principally a biotite-cordierite-garnet-gedrite gneiss, except that in southernmost exposures it has a varied lithology and is poorer in gedrite.

The biotite-cordierite-garnet-gedrite gneiss is commonly dark bluish gray medium grained, equigranular, and well foliated. Locally, coarse-grained facies contain radiating clusters of gedrite crystals, 5–6 inches in diameter, and baseball-size garnet porphyroblasts. Most of the gedrite-bearing gneiss closely resembles the associated biotite-cordierite-garnet gneiss, and both of these, along with associated garnet-sillimanite and cordierite-bearing garnet-sillimanite gneisses, resemble rocks in the garnetiferous biotite gneiss unit. Amphibolite is commonly interlayered with the cordierite-bearing gneisses; it occurs in lenses less than a foot to several tens of feet thick, and its contacts are generally gradational. Many of the small pegmatites associated with the cordierite-bearing rocks contain stringers of matted biotite which have clots of sillimanite and scattered grains of garnet along their borders.

Plagioclase occurs only locally in the cordierite-bearing rocks. The plagioclase in the garnetiferous and sillimanitic gneisses in the cordierite-bearing biotite gneiss is oligoclase, An_{14-22}. Zoned crystals with albitic rims as low as An_6 have cores as calcic as An_{16}. Most of the plagioclase is albite twinned, though some grains are only partly twinned and some are untwinned.

Cordierite is a major mineral in the biotite-cordierite gneiss and the gedrite-bearing cordierite-biotite gneiss, but it may be only a local variant in the garnetiferous sillimanitic biotite gneiss (table 4). It ranges from 1 to 60 percent in modal content of the total rock. Cordierite is twinned both simply and by interpenetration twins. Porphyroblasts of cordierite common to most varieties of cordierite-bearing biotite gneiss are "spongelike" and contain many inclusions of unaltered sillimanite and of rounded grains of staurolite, gedrite, and biotite. Hemihedral cordierite, nearly free of inclusions, is found in the coarser grained biotite-cordierite-gedrite gneiss. Magnetite, ilmenite, and, in a few places, spinel are associated with cordierite. Cordierite has a very large optic angle, $80° \pm 5°$, and is biaxial negative; β equals 1.551 ± 0.002, as measured in one crystal. Chemical analysis of the cordierite indicates a ratio of Mg^{++} to Fe^{++} of approximately 3:1.

Garnet, in small clear fractured, disseminated grains or extremely fractured porphyroblasts as large as 4 inches in diameter, is poikilitic with inclusions of quartz, magnetite-ilmenite, and biotite. These frac-

TABLE 4.—*Modes, in volume percent, of cordierite-bearing biotite gneiss and associated rocks*

[Tr., trace; —, looked for but not found]

	Cordierite-bearing garnetiferous, sillimanitic biotite gneiss			Biotite-cordierite gneiss		Gedrite-bearing cordierite-biotite gneiss	
Sample	1	2	3	4	5	6	7
Field No. M-	605a	497b	521	737	788	532b	689
Plagioclase	3. 9	16. 1	0. 1	—	0. 4	—	—
Quartz	42. 2	52. 6	31. 7	50. 6	61. 7	57. 5	. 4
Cordierite	19. 8	17. 8	26. 4	19. 8	16. 1	21. 5	42. 5
Biotite	21. 5	3. 5	32. 6	26. 0	16. 7	16. 3	16. 1
Muscovite	. 2	—	—	—	1. 8	—	—
Gedrite	—	—	—	—	—	4. 3	35. 1
Garnet	. 6	5. 9	6. 3	—	. 1	Tr.	—
Sillimanite	2. 2	3. 9	. 2	. 1	3. 2	—	—
Magnetite and ilmenite	. 7	. 2	2. 1	—	—	Tr.	1. 3
Zircon	. 1	Tr.	Tr.	. 7	Tr.	Tr.	—
Chlorite	2. 6	—	Tr.	2. 8	Tr.	. 3	4. 6
Staurolite	—	Tr.	—	Tr.	—	. 1	—
Apatite	. 7	—	. 6	—	—	—	—
Spinel	—	Tr.	—	—	—	—	—
Andalusite	5. 5	—	—	—	—	—	—
Total	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0

1. From outcrop in gulch south and slightly east of footbridge in Bear Creek Canyon, 6,800-ft elevation.
2. Gneiss interlayered with garnet-sillimanite-biotite gneiss from roadcut ½ mile east of Idledale, Bear Creek Canyon.
3. From roadcut, 1,300 ft east of sample 2 locality.
4. Small lens, north side of drainage ¼ mile due north of Strain Gulch, 6,680-ft elevation.
5. From outcrop 1,600 ft northwest of Falcon Wing building at head of Devils Gulch.
6. From roadcut on curve, 1,400 ft west of contact of Precambrian with Paleozoic rocks in Bear Creek Canyon.
7. From outcrop on ridge just south of footbridge in Bear Creek Canyon, 6,200-ft elevation.

tured grains are coated with iron oxide and are filled with chlorite, biotite, and, locally, quartz and cordierite. Intergrowths of quartz and cordierite and of quartz and biotite rimmed garnet crystals. Garnet, chemically analyzed, consists of 75 mol. percent almandine, 9 mol. percent andradite, 14 mol. percent pyrope, and 2 mol. percent spessartite.

Gedrite ranges in abundance from small scattered laths in rock that is predominantly biotite-cordierite-quartz gneiss to gneissic rocks that are predominantly gedrite with a small percentage of cordierite and biotite. Pleochroism in gedrite ranges from colorless to light brownish yellow or moderate greenish gray. Euhedral gedrite is commonly frayed, feathered against biotite, and corroded by quartz. A large optic angle (80°–85°) is biaxial positive. According to a chemical analysis, gedrite by weight, consists of 12.2 percent Al_2O_3, 23.9 percent FeO, and 13 percent MgO, which means that it actually is a ferrogedrite. Gedrite occurs in layers that contain little plagioclase and no sillimanite.

Biotite and quartz are the only minerals that are consistently abundant in every thin section examined. Biotite in the cordierite-baring rocks is characterized by profuse pleochroic halos surrounding zircon inclusions. Pleochroism in biotite is pale yellow to medium brown or olive green. Secondary minerals in biotite are rutile, magnetite, ilmenite, chlorite, and muscovite.

Sillimanite is lacking in the cordierite-gedrite-bearing rocks but it occurs in other cordierite-bearing rocks as disseminated grains and inclusions in other minerals, and locally it forms conspicuous felted stringers and clots. Muscovite never sheathes sillimanite, even though the two may occur together in the same section. Muscovite is a secondary mineral after biotite.

Andalusite normally forms as an overgrowth on biotite or it penetrates the biotite along cleavage planes. It may also form large crystals that are poikilitic with numerous biotite, sillimanite, magnetite, and quartz inclusions. These large poikilitic crystals have cordierite coronas that in turn may have narrow, well-twinned rims of albite.

Staurolite, a relic mineral, commonly appears as inclusions in quartz and plagioclase. The accessory minerals are magnetite-ilmenite, apatite, and zircon. Zircon is especially abundant in cordierite, biotite, and gedrite.

Chlorite and muscovite as secondary minerals are most abundant in the shear zones.

Textures of the gneiss are predominantly lepidoblastic owing to the alinement of tabular gedrite and plates of biotite. As quartz and cordierite increases, the rocks lose this schistose character and become more granoblastic. Interlayering of the various facies occurs microscopically as well as macroscopically.

Total rock analyses for the three major layers of the gneiss in the unit are presented in table 5 along with analyses of interlayered non-cordierite-bearing associated rocks. The gedrite-bearing rocks are high in ferrous iron, aluminum, and magnesium. The non-gedrite-bearing rocks have more potassium and silica. The distribution of minerals in the modes (table 5) are directly related to the chemical composition. These cordierite-gedrite rocks are similar mineralogically and chemically to gedrite-bearing rocks in the Central City area (Sims and Gable, 1967). The large amount of chlorite and muscovite and accompanying kaolinite shown in the last two analyses in table 5 resulted, in part, from hydrothermal alteration.

TABLE 5.—*Chemical analyses and modes of cordierite-bearing biotite gneisses and associated rocks*

[Tr., trace; —, looked for but not found]

Sample	1	2	3	4	5
Field No. M-	579	532	497	530a	530b
Chemical analyses, in weight percent					
SiO_2	53.44	47.09	72.38	71.22	70.65
Al_2O_3	18.83	18.43	13.26	12.34	12.90
Fe_2O_3	1.00	1.75	.85	1.04	1.08
FeO	9.90	18.99	5.26	5.87	5.02
MgO	10.02	9.36	2.28	2.87	3.10
CaO	.59	.37	.17	.00	.00
Na_2O	.73	.56	1.74	.35	.42
K_2O	1.19	.70	1.63	3.06	3.93
MnO	.18	.21	.10	.12	.05
H_2O+	2.09	1.97	1.57	2.34	2.10
H_2O-	.11	.12	.32	.14	.08
TiO_2	1.45	.33	.20	.30	.31
P_2O_5	.15	.02	.02	.02	.02
CO_2	.01	.04	.02	.00	.00
Cl	.01	.01	.01	.02	.02
F	.12	.16	.09	.13	.14
Total	99.82	100.11	99.90	99.82	99.82
Modes, in volume percent					
Quartz	15	21	52	52	59
Cordierite	60	30	1	—	—
Gedrite	8	18	—	—	—
Biotite	12	14	14	15	20
Garnet	—	14	3	Tr.	—
Sillimanite	—	—	12	4	Tr.
Staurolite	—	Tr.	Tr.	—	—
Plagioclase	2	—	9	Tr.	2
Spinel	Tr.	—	—	—	—
Apatite	1	—	—	—	—
Magnetite and ilmenite	2	1	Tr.	Tr.	—
Tourmaline	—	—	—	—	—
Muscovite	—	—	—	17	12
Chlorite, rutile	Tr.	2	9	[1] 12	[1] 7
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.
Andalusite	—	—	Tr.	—	—
Total accessory minerals	Tr.	Tr.	Tr.	Tr.	Tr.
Total	100.0	100.0	100.0	100.0	100.0

[1] Includes kaolinite.

1. Biotite-cordierite-gedrite-quartz gneiss from outcrop at junction of Bear Creek and Devils Gulch, west of Idledale. Chemical analysis I4194, by C. L. Parker.
2. Cordierite-gedrite-garnet-biotite-quartz gneiss from roadcut on first bend west of Morrison in Bear Creek Canyon. Chemical analysis I4193, by C. L. Parker.
3. Cordierite-bearing garnet-sillimanite-biotite-quartz-plagioclase gneiss from roadcut ½ mile east of Idledale, Bear Creek Canyon. Chemical analysis I4195, by C. L. Parker.

4, 5. Interlayered garnet-sillimanite and sillimanite-bearing biotite gneiss from roadcut just east of sample 2 locality, along strike gradational with cordierite-garnet-gedrite-bearing biotite gneiss. Chemical analyses D101107 and D101108, respectively, by E. S. Daniels.

QUARTZ-PLAGIOCLASE GNEISS

Quartz-plagioclase gneiss as mapped (pl. 1) is a heterogeneous unit consisting of 60 percent or more of quartz-plagioclase gneiss that is interlayered with impure quartzite, biotite gneiss, microcline gneiss, and, locally, hornblende gneiss and amphibolite. Local hydrothermal alteration and faulting and shearing have altered the general appearance of the gneiss along the breadth of outcrop. The gneiss is predominantly an equigranular fine- to medium-grained pale-yellowish-gray to pinkish-gray, thinly foliated homogeneous rock that is best exposed just south of Bear Creek above the cordierite-bearing biotite gneiss unit. The modal composition of the quartz-plagioclase gneiss is shown in table 6. The plagioclase is a sodic oligoclase. Alteration minerals, due primarily to the hydrothermal alteration, consist of muscovite, kaolinite, and chlorite.

MICROCLINE-QUARTZ-PLAGIOCLASE-BIOTITE GNEISS

Microcline-quartz-plagioclase-biotite gneiss, referred to as microcline gneiss hereafter in this report, is a fine- to medium-grained well-foliated rock. The foliation is formed by the segregation of light and dark minerals into distinct layers an eighth of an inch or less thick. Microcline gneiss is typically a quartz-feldspar rock which is granitic

TABLE 6.—*Modes, in volume percent, of quartz-plagioclase gneiss*

[Tr., trace; n.d., not determined; —, looked for but not found]

Sample	1	2	3	4	5
Field No. M-	599	608	747	751	915
Plagioclase	51. 7	51. 0	44. 9	1. 0	59. 4
Quartz	40. 8	42. 3	49. 1	59. 4	35. 9
Biotite	4. 5	3. 0	5. 7	—	3. 1
Muscovite	2. 2	3. 7	—	13. 9	1. 5
Chlorite	—	—	—	Tr.	—
Iron oxides	. 7	—	Tr.	—	. 1
Apatite	Tr.	—	—	—	—
Zircon	. 1	Tr.	. 3	. 1	Tr.
Tourmaline	—	—	—	—	—
Sillimanite	—	—	—	Tr.	—
Kaolinite	—	—	—	25. 6	—
Total	100. 0	100. 0	100. 0	100. 0	100. 0
Composition of plagioclase	An_{14-17}	n.d.	n.d.	n.d.	n.d.

1. From prominent outcrop on northwest side of ridge, west of Denver Mountain Parks Emergency Headquarters.
2. From knob on ridge, northeast of sample 5 locality.
3. From outcrop just south of Strain Gulch, 6,640-ft elevation.
4. Kaolinite-bearing gneiss from outcrop ½ mile due west of BM 6193 on U.S. Highway 285, 6,680-ft elevation.
5. Gneiss interlayered with biotite-quartz-plagioclase gneiss, outcrop due west of Denver Mountain Parks Emergency Headquarters, 6,640-ft elevation.

in appearance and ranges in color on fresh fracture from pinkish gray and yellowish gray to light gray.

Microcline gneiss that crops out in the north-central and southwestern parts of the area contains numerous layers of biotite gneiss and amphibolite. Most of the microcline gneiss south of Bear Creek has a migmatitic aspect, because it contains many layers of granitic material. At Mount Falcon the rock contains so much granitic material that it resembles a well-foliated granodiorite. These more intensely migmatized rocks south of Bear Creek were called migmatite and injection gneiss by Boos (1954, p. 118–119).

The microcline gneiss is granoblastic and its foliation is defined by thin frayed biotite-rich seams. In the more intensely migmatized gneiss and where cataclasis is more noticeable, the quartz forms stringers and clots similar to those found in the gneissic granodiorite.

Microcline gneiss in the Morrison quadrangle ranges from granodiorite to quartz diorite in composition, and is primarily quartz diorite (fig. 2). The modal composition of the gneiss is shown in table 7. Garnet and hornblende occur rarely, and only in layers adjacent to amphibolite, garnet-bearing biotite gneiss, or cordierite-bearing biotite gneiss.

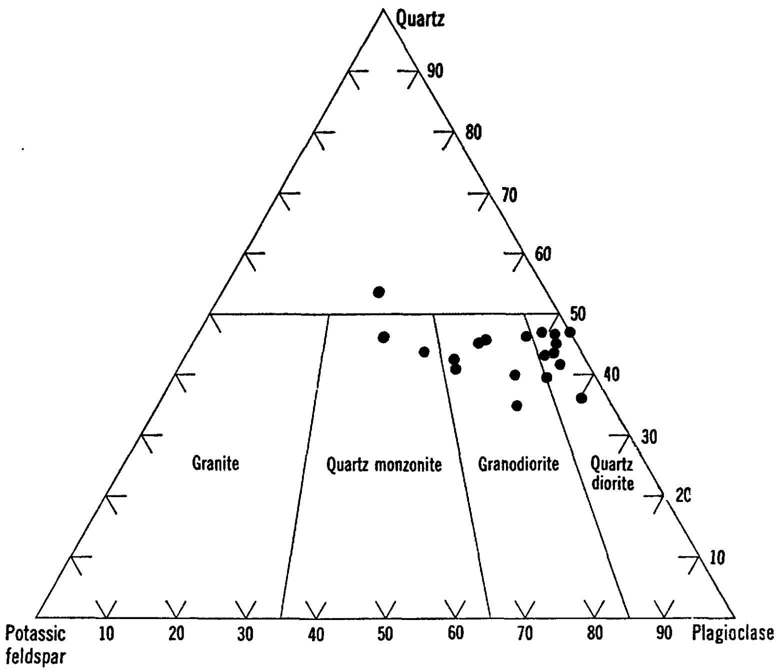

Figure 2.—Diagram showing variation in composition (volume percent) of microcline gneiss.

TABLE 7.—*Modes, in volume percent, of microcline gneiss*

[Tr., trace; n.d., not determined; —, looked for but not found]

	Microcline gneiss from Apex Gulch area						Microcline gneiss interlayered with hornblende gneiss and amphibolite			Microcline gneiss from Bear Creek area						Migmatitic microcline gneiss from Bear Creek area						Microcline gneiss interlayered with garnet-biotite gneiss
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Field No. M–	148	156	172	180	215	229	253	281	468	613	616	769	780a	926	929	923	924	818	830	882	646a	77
Potassic feldspar	12.8	3.9	2.0	9.9	6.4	2.6	11.5	22.4	3.5	4.1	3.6	5.0	16.9	3.8	0.1	23.9	17.6	12.3	5.6	21.7	5.0	8.1
Plagioclase	37.4	49.1	44.0	41.5	49.0	46.2	37.1	20.5	42.5	37.6	45.2	46.3	34.2	56.5	48.3	23.5	35.5	46.9	40.7	31.7	47.3	26.6
Quartz	42.1	38.0	40.5	34.4	36.5	40.5	41.1	50.5	41.4	47.1	38.1	39.3	38.1	34.2	43.1	40.8	37.3	32.3	40.6	42.2	40.2	45.6
Biotite	5.2	5.1	8.2	14.2	5.3	6.1	8.5	4.0	7.3	6.0	12.7	7.9	6.5	1.4	8.5	9.2	8.1	4.6	11.4	3.6	5.0	10.1
Muscovite	.8	.7	1.8	—	.1	.4	1.1	2.4	4.0	1.8	—	1.4	3.2	2.0	Tr.	2.2	.9	.3	1.1	Tr.	1.8	8.3
Iron oxides	1.7	2.4	1.8	Tr.	2.0	2.5	.7	.1	0.8	.5	.2	Tr.	1.0	1.9	Tr.	.3	.6	2.0	.1	.6	.7	1.3
Chlorite	—	.4	Tr.	—	—	.3	—	.1	.1	Tr.	—	—	—	—	Tr.	—	—	—	—	—	Tr.	—
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	.1	Tr.	.1	.1	.1	.2	Tr.	.1	Tr.	Tr.	.1	.1	Tr.	Tr.
Sphene	Tr.	—	—	—	.6	.4	—	—	—	—	Tr.	—	—	—	—	—	—	.2	—	—	—	—
Garnet	—	.4	1.0	—	—	.3	—	—	—	.2	—	—	—	—	—	—	—	—	—	—	—	—
Calcite	—	—	.7	—	—	—	—	—	.3	—	—	—	—	—	—	—	—	—	—	—	—	—
Allanite	—	—	Tr.	—	Tr.	.1	—	—	Tr.	Tr.	Tr.	—	—	—	—	Tr.	—	—	.4	.1	—	—
Apatite	—	—	Tr.	—	.1	Tr.	—	Tr.	Tr.	Tr.	.1	—	—	—	—	Tr.	Tr.	Tr.	Tr.	Tr.	—	—
Hornblende	—	—	—	—	Tr.	.6	—	—	—	1.8	—	—	—	—	—	—	—	.7	—	—	—	—
Epidote	—	—	—	—	Tr.	—	—	—	—	.9	—	—	—	—	—	Tr.	—	.7	—	—	—	—
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Composition of plagioclase	An_{12}	n.d.	n.d.	n.d.	An_{16}	n.d.	An_{14}	n.d.	n.d.	n.d.	n.d.	An_{14}	n.d.	n.d.	n.d.	n.d.	An_{17}	An_{14}	An_{17}	n.d.	An_{14}	n.d

1. Well-foliated gneiss from top of 7,281-ft peak between Deadman Gulch and Apex Gulch.
2. From outcrop adjacent to contact of Precambrian with sedimentary rocks east of sample 1 locality.
3. Well-foliated gneiss from large outcrop north side of Apex Gulch and southeast of sample 1 locality.
4. From south side of Apex Gulch, just below hornblende gneiss contact.
5. From stream bed of Apex Gulch, 6,700-ft elevation.
6. From outcrop near amphibolite lens at head of Apex Gulch.
7. Interlayered with amphibolite, from roadcut 2,000 ft east of Mother Cabrini Shrine entrance, Mount Vernon Canyon.
8. Interlayered with amphibolite, from a roadcut 1,000 ft east of west edge of quadrangle, Mount Vernon Canyon.
9. Lens in amphibolite unit just north of Idledale and east of Grapevine Road.
10. Hornblende-bearing gneiss from tightly folded area from outcrop due south of Idledale, 7,020-ft elevation.
11. From nose of ridge due south of Idledale, 7,080-ft elevation.
12. From outcrop just below migmatite and above amphibolite far southeast edge of quadrangle.
13. From outcrop, 500 ft above contact of Precambrian with Paleozoic sediments along southeast edge of quadrangle.
14. From outcrop on ridge 600 ft west of sample 13 locality.
15. Well-foliated gneiss from outcrop due east of Mount Falcon and just below migmatitic microcline gneiss.
16. Well-foliated migmatitic gneiss from prominent outcrop east of 7,676-ft peak.
17. Migmatitic gneiss from outcrop north of gneissic granodiorite contact, south side of Bear Creek Canyon and just east of Idledale.
18. Migmatitic gneiss from outcrop on north side of small stream, extreme southwest corner of quadrangle, 7,200-ft elevation.
19. Migmatitic gneiss from outcrop on west side of road, due east of sample 18 locality.
20. Migmatitic gneiss from outcrop below aplitic dike, southwest slope of Mount Falcon.
21. Migmatitic gneiss from saddle between top with elevation 7,676 ft south of Idledale, and top 1,000 ft to south.
22. Layer in garnetiferous biotite gneiss on Colorow Hill, east side of road, west edge of quadrangle.

The potassic feldspars are microcline and microperthite. In the northwestern part of the quadrangle the potassic feldspars occur as small interstitial grains, whereas in the large area to the south they are equigranular with other minerals in the gneiss. The amount of potassic feldspar in the microcline gneiss averages about the same in the two areas but varies from outcrop to outcrop. The migmatized gneiss, according to the modes (table 7) is approximately 10 percent richer in potassic feldspar than the adjoining less migmatized microcline gneiss. In the northern unit of microcline gneiss, the small intergranular potassic feldspars that are part of the cataclastic matrix interstitial to the larger crystals may be of metasomatic origin. This metasomatism probably accompanied the mild pervasive cataclasis that is found throughout the area.

The plagioclase is a sodic oligoclase, many grains of which are locally sieved by potassic feldspar to give an antiperthitic texture. Plagioclase is partly altered to sericite, calcite, and muscovite.

CALCIUM-SILICATE GNEISS

Calcium-silicate gneiss, in lenses too small to be mapped separately, crops out within the hornblende gneiss map unit. Lenses 8–10 feet thick and as much as 200 feet long grade through several feet into hornblende gneiss or amphibolite. Fragments of the gneiss can be found also in the talus of microcline gneiss and quartz-plagioclase gneiss. The rock is medium to coarse grained, crudely banded, and mottled dark to light in various shades of bluish green and yellowish green. It contains, in varying proportions, diopside, hornblende, epidote, quartz, plagioclase, and minor amounts of iron oxides and garnet.

IMPURE QUARTZITE

Impure quartzite forms prominent ribbed outcrops as much as several tens of feet thick in the quartz-plagioclase gneiss unit, and it forms thin layers associated with calcium-silicate gneiss in the hornblende gneiss unit. The most persistent lens crops out along the 6,680-foot contour in an intensely sheared area south of Strain Gulch.

The quartzite is grayish white or bluish gray, fine to medium grained, and well layered. Layering within the quartzite is marked by thin bands of plagioclase, muscovite, and biotite. Biotite probably composes 15–20 percent of the quartzite. Other accessory minerals are iron oxides, zircon, and sillimanite. Locally the quartzite contains sinuous stringers of small fibrous crystals of kaolinite, as determined by X-ray.

ORIGIN OF METAMORPHIC ROCKS

Many generalizations have been made regarding the origin of metamorphic rocks in the central Front Range. Authors previously referred to in this report believe, as does the present author, that most of the gneisses are metamorphosed sedimentary rocks.

In the Morrison quadrangle, the gneissic rocks represent interlayered pelites (biotite gneiss), arkoses (microcline gneiss), impure quartzites (quartz-plagioclase gneiss), and impure graywacke interlayered with calcareous and dolomitic sediments (hornblende gneiss). Whether any of the amphibolites originated as basaltic flows or sills cannot be determined. Amphibolites, where well exposed, are conformable with the other gneiss layers.

For a more thorough discussion of the origin of metamorphic rocks in this area, the reader is referred to the report by Sims and Gable (1967).

INTRUSIVE ROCKS

GRANODIORITE

Granodiorite crops out in small lenses and phacolithic bodies in the northern two-thirds of the mapped area. This rock is similar to the gneissic facies of Boulder Creek granodiorite in the Central City quadrangle (Sims and Gable, 1967) and to the more foliated parts of the Boulder Creek batholith (Lovering and Goddard, 1950, p. 25). The rock included in this map unit ranges in composition from quartz diorite to quartz monzonite, but it is mostly granodiorite (table 8); it is gray to buff, medium to coarse grained, virtually homogeneous, and weakly to strongly foliated. Numerous pegmatite bodies and some quartz veins a few inches to several feet wide occur throughout the granodiorite.

Bodies of granodiorite are grossly conformable with the metasedimentary rocks they intruded but are locally disconformable. The body southeast of Lookout Mountain, for example, is phacolithic and its contacts are conformable. The body north and northwest of Cherry Gulch, on the other hand, has a weak to strong foliation that is locally discordant with the foliation of the adjacent hornblende gneiss unit, and its border rocks are gneissic and migmatitic.

The texture of the granodiorite, as seen in thin section, is hypidiomorphic equigranular and is modified by a mild cataclasis in all but the central part of the body northwest of Cherry Gulch. The granodiorite consists principally of quartz, plagioclase, variable amounts of potassic feldspar, and about 12 percent biotite.

The plagioclase ranges in composition from oligoclase to andesine. Most is albite twinned and, more rarely, carlsbad twinned. Where

TABLE 8.—*Modes, in volume percent, of granodiorite*

[Tr., trace; n.d., not determined; —, looked for but not found]

Sample	1	2	3	4	5	6
Field No. M-	84	335	369	386	129	129a
Potassic feldspar	0. 8	Tr.	25. 9	9. 0	6. 4	0. 8
Plagioclase	43. 3	39. 4	21. 3	45. 6	52. 2	57. 6
Quartz	36. 7	42. 7	42. 9	24. 7	24. 5	22. 4
Biotite	18. 3	12. 8	8. 1	10. 1	11. 4	11. 7
Muscovite	. 1	1. 0	. 8	—	Tr.	—
Iron oxides	. 1	3. 8	. 1	Tr.	2. 9	2. 5
Chlorite	Tr.	—	. 8	—	—	—
Allanite	—	—	—	Tr.	. 3	—
Zircon	. 1	. 1	Tr.	. 1	. 1	Tr.
Garnet	. 6	. 1	—	. 1	. 5	. 6
Calcite	—	—	. 1	—	—	. 3
Hornblende	—	—	—	9. 5	. 8	3. 2
Apatite	—	. 1	—	. 4	. 1	. 3
Sphene	—	—	—	. 5	. 8	. 6
Total	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
Composition of plagioclase	An_{17-24}	An_{31}	n.d.	An_{32}	An_{19-22}	An_{2}

1. Quartz diorite facies from roadcut on Lariat Loop Road, about ½ mile south of Golden Reservoir.
2. Quartz diorite facies from peak (elevation 7,521 ft), ¼ mile east of Grapevine Road and ½ mile south of Mount Vernon Canyon.
3. Quartz monzonite facies from dump adjacent to caved mine, 600 ft southwest of sample 2 locality.
4. Hornblende-bearing quartz monzonite facies from outcrop west of diabase dike, head of Cherry Gulch.
5, 6. Hornblende- and garnet-bearing granodiorite, south of Deadman Gulch.

strained by cataclasis the plagioclase is untwinned and turbid looking. Grains in contact with potassic feldspar have thin sodic rims.

Potassic feldspar ranges in content from less than 1 to nearly 26 percent. The potassic feldspars, including microcline and microperthite, embay plagioclase and are in turn embayed by quartz.

Reddish-brown and olive-green biotite occurs as ragged, crushed flakes. Biotite folia in the granodiorite are larger than those in either the microcline gneiss or the gneissic granodiorite.

Accessory minerals include iron oxides, which are concentrated in stringers and clots, and associated biotite, allanite, apatite, and zircon. Hornblende and garnet are contamination minerals in the more gneissic parts of the granodiorite. The secondary minerals are chlorite, muscovite, and clay minerals.

QUARTZ DIORITE AND HORNBLENDITE

Quartz diorite and hornblendite form small massive medium to coarsely crystalline bodies. The rocks are much like the quartz diorite and hornblendite described by Ball (in Spurr and Garrey, 1908) and are similar to the massive facies of quartz diorite and hornblendite described by Scott (1963, p. 81). Quartz diorite and hornblendite are grouped together because their structural relations to the country rocks are similar and because they are closely related in space and time. Both are discordant to the local structure.

Quartz diorite in bodies generally less than 200 feet long and as much as 75 feet thick are recognized at three places in the mapped area. One body, which is the only quartz diorite shown on the map (pl. 1), is north of the Falcon Castle ruins in the southern part of the area. Of the other two bodies, which are too small to map, one is adjacent to the shonkinite in the southwest part of the area and one is west of Sawmill Gulch about 1 mile north of Idledale. Pegmatite lenses, which are generally coarse, occur with the quartz diorite.

The quartz diorite is mottled black and white with biotite and hornblende which commonly form mafic clots in a predominantly felsic groundmass. The quartz diorite north of the Falcon Castle ruins has been metamorphosed and about 40 percent of the hornblende has been replaced by biotite. A fresher diorite just south of the Morrison quadrangle, in Turkey Creek Canyon, contains about 65 percent hornblende and no quartz. The quartz diorites are hypidiomorphic equigranular rocks but they have a xenomorphic texture where they have been metamorphosed. The modal composition of the quartz diorite is shown in table 9.

TABLE 9.—*Modes, in volume percent, of quartz diorite and hornblendite*

[Tr., trace; n. d., not determined; —, looked for but not found]

Sample	1	2	3
Field No. M-	843	13b	834
Plagioclase	32.7	Tr.	Tr.
Quartz	4.6	—	9.5
Hornblende	34.7	88.0	71.8
Orthopyroxene	—	2.6	—
Cummingtonite	—	—	2.6
Iron oxides	Tr.	1.4	5.0
Biotite	24.8	—	.5
Apatite	.6	Tr.	.3
Sphene	1.2	—	—
Epidote	.4	—	—
Muscovite	.1	2.3	4.0
Microperthite	.8	—	—
Allanite	Tr.	.1	.7
Spinel	—	1.8	—
Chlorite	—	3.8	—
Garnet	—	—	5.6
Total	100.0	100.0	100.0
Composition of plagioclase	An_{25-29}	n.d.	n.d.

1. Small body of quartz diorite located halfway between Falcon Castle ruins on the south and Bear Creek Canyon on the north.
2. Hornblendite from lens west of bridge, on Lariat Loop Road, near BM 6477.
3. Hornblendite from pit at head of gulch west of Mount Falcon and just west of abandoned ranchhouse.

Plagioclase, as oligoclase in quartz diorite and as labradorite in the diorite south of the mapped area, has deep myrmekitic rims which extend approximately two-thirds of the way into the plagioclase crystals. Zoned plagioclase crystals have calcic centers. The only potassic feldspar is perthite; it occurs in, and corrodes, plagioclase. The hornblende is predominantly olive green but a small amount of second-generation hornblende, which adjoins biotite, is blue green. Medium-brown biotite occurs in large ragged plates that are sieved by sphene and apatite. Biotite and traces of epidote have partially replaced hornblende and plagioclase.

Hornblendite forms lenticular bodies as much as 75 feet long and 30 feet thick. An irregular-shaped body on Lariat Loop Road in the vicinity of BM 6477 may be associated with an altered intrusive that once was a diorite. Unmapped similar hornblendite bodies occur in a roadcut in gneissic granodiorite one-fourth of a mile east of Idledale, adjacent to unmapped quartz diorite north of Idledale, and just south of the shonkinite outcrop. Many hornblendite bodies contain associated coarse pegmatite. In the mapped area, hornblendite is primarily greenish black, medium to coarse grained, and hypidiomorphic-granular. A thin section of the hornblendite on the Lariat Loop Road (table 9, sample 2) contains approximately 90 percent hornblende. Relic pyroxene cores in this hornblende indicate that before metamorphism more than 25 percent of the rock was pyroxene. In the hornblendite northwest of Mount Falcon (table 9, sample 3), which has been metamorphosed, hornblende has embayed and replaced cummingtonite. The hornblende is dark green and extremely poikilitic with inclusions of quartz, magnetite, and allanite. Large garnet porphyroblasts in turn replace this poikilitic hornblende.

GNEISSIC GRANODIORITE

Gneissic granodiorite and intimately associated aplites and pegmatites crop out in the mapped area, principally at Mount Morrison and vicinity. Boos (1954, p. 118–119) referred to this gneissic granodiorite as the Mount Morrison Formation and defined it as consisting of quartz monzonite, migmatite, and injection gneiss. Later Boos (1957, p. 1859) called it gneissoid granite and migmatite and indicated a metasomatic origin for most of the unit. The gneissic granodiorite in the Morrison quadrangle is similar in field appearance to the so-called granite gneiss and migmatite of the Kassler quadrangle (Scott, 1963, p. 78–79) and to the granite gneiss and pegmatite of the Freeland-Lamartine district, Clear Creek County, Colo. (Harrison and Wells, 1956, p. 50–53).

The gneissic granodiorite consists of quartz, potassic feldspar, plagioclase, and 5–10 percent biotite, magnetite, and other iron oxide minerals (tables 10, 11). It is medium to coarse grained and contains potassic feldspar crystals as much as 4 mm long. Fresh surfaces are pinkish white to light orange; weathered surfaces tend to be a dark pink, or reddish, locally mottled gray and greenish gray. Much of the rock has a heavy iron stain especially in the areas that have been faulted extensively.

The gneissic granodiorite has a rugged topography with cliffs as much as 120 feet high. Characteristic features of the unit are (1) a migmatitic facies with moderate to weak foliation and a massive facies with little or no foliation, (2) well-developed joint sets that are more conspicuous in the massive facies, (3) typical reddish or dark-pink weathered surfaces, and (4) numerous inclusions of metasedimentary rocks. The contact between the gneissic granodiorite and the adjacent rock units is both concordant and discordant. The contact with microcline gneiss on the south is not clear in many places because the rocks have been extensively faulted and sheared, but it appears to be gradational across a zone several hundred feet wide in which migmatite, aplite, and pegmatite occur. In many places structures in the meta-

TABLE 10.—*Modes, in volume percent, of massive gneissic granodiorite*

[Tr., trace; n.d., not determined; —, looked for but not found]

Sample	1	2	3	4	5	6	7	8
Field No. M-	422a	500	502	566	567	693	767	902
Potassic feldspar	34.4	28.5	27.5	22.4	22.4	15.6	11.4	17.3
Plagioclase	29.6	36.0	35.1	41.4	39.6	37.1	43.8	44.8
Quartz	32.0	34.6	33.0	30.6	31.1	36.8	38.4	26.1
Biotite	1.5	.3	2.8	2.1	5.1	5.1	5.1	7.3
Muscovite	1.4	.6	.9	2.1	1.5	4.5	.1	4.0
Iron oxides	1.1	Tr.	.7	1.4	.3	.9	1.1	.4
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	.1	Tr.
Apatite	—	—	Tr.	Tr.	Tr.	—	—	Tr.
Epidote	—	—	—	—	—	—	—	.1
Allanite	—	—	—	—	—	—	—	Tr.
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Composition of plagioclase	n.d.	An_{16}	n.d.	n.d.	An_{17}	n.d.	An_{12}	An_{16}

1. Quartz monzonite from massive outcrop, on old dismantled incline, east side of Mount Morrison, elevation 6,960 ft.
2. Quartz monzonite from outcrop, upslope from Starbuck Park, east of Idledale, elevation 6,760 ft.
3. Quartz monzonite associated with aplite from knob 700 ft northeast of sample 2 locality.
4. Aplitic facies of gneissic granodiorite on long narrow east-west ridge southwest of Mount Morrison, elevation 7,080 ft.
5. Massive brecciated quartz monzonite associated with aplite, 550 ft northeast of sample 4 locality.
6. Gneissic granodiorite from shear zone, on ridge extending from footbridge in Bear Creek Canyon area east of Falcon Castle ruins, elevation 6,680 ft.
7. Gneissic granodiorite from top, southeast of Mount Falcon, elevation 7,720, south edge of quadrangle.
8. Gneissic granodiorite from lens, in gulch southeast of Mount Falcon.

TABLE 11.—*Modes, in volume percent, of migmatitic gneissic granodiorite*

[Tr., trace; n.d., not determined; —, looked for but not found]

Sample	1	2	3	4	5	6	7	8	9
Field No. M-	402	412	419	496	524	528	528a	646a	919
Potassic feldspar	0.6	3.5	2.0	2.8	3.4	3.0	1.8	5.0	1.7
Plagioclase	50.4	50.8	49.5	48.1	45.0	34.6	52.2	47.3	51.6
Quartz	35.9	40.7	37.8	44.1	40.5	56.5	38.8	40.2	38.6
Biotite	12.4	4.5	8.4	3.0	6.8	3.5	5.5	5.0	3.5
Muscovite	.7	.5	2.3	1.4	3.0	2.3	1.1	1.8	4.4
Iron oxides	Tr.	Tr.	—	.5	.3	.1	.4	.7	.2
Apatite	Tr.	—	Tr.	.1	—	Tr.	.1	—	—
Zircon	Tr.	Tr.	Tr.	Tr.	.5	—	.1	Tr.	Tr.
Garnet	Tr.	—	—	—	Tr.	—	—	—	—
Chlorite	—	Tr.	—	Tr.	—	—	—	Tr.	Tr.
Epidote	—	—	—	—	Tr.	—	Tr.	—	—
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Composition of plagioclase	n.d.	An_{19}	n.d.	n.d.	An_{17}	n.d.	n.d.	n.d.	n.d.

1. Quartz diorite from outcrop, north slope of Cherry Gulch.
2. Coarse-grained migmatitic quartz diorite from outcrop, northeast slope of Mount Morrison.
3. Coarse-grained quartz diorite from outcrop along abandoned incline, 650 ft downslope due east from top of Mount Morrison.
4. Quartz diorite near hornblendite from roadcut on large curve, ¼ mile east of Idledale.
5. Quartz diorite from roadcut, ⅛ mile west of Cottonwood Gulch in Bear Creek Canyon.
6, 7. Migmatitic quartz diorite from quarry in Bear Creek Canyon.
8. Quartz diorite in migmatitic microcline gneiss, from west edge of saddle, south of Idledale, about 600 ft southeast of 7,676-ft peak.
9. Migmatitic quartz diorite at elevation 6,490 ft above south parking area of Red Rocks Amphitheater.

morphic rocks can be traced into the migmatites, where they tend to lose their identity. Along the contact with cordierite-bearing biotite gneiss in Red Rocks Park the gneissic granodiorite penetrates the biotite gneiss along foliation planes. In Saw Mill Gulch, where the granodiorite is in fault contact with hornblende gneiss, the foliation within the pluton apparently is conformable locally with gneissic structures in the metasedimentary rocks.

The massive facies, which makes up 15–20 percent of the gneissic granodiorite, crops out predominantly along the west and southwest uppermost flanks of Mount Morrison. The massive facies is a composite of alaskitic aplite, quartz monzonite, granodiorite, quartz diorite, and pegmatite. It is coarser grained than the migmatitic facies and is darker orange pink because it contains a higher percentage of potassic feldspar.

The migmatitic facies is a quartz diorite characterized by discontinuous streaks and wisps of mafic minerals that are predominantly biotite, and by numerous, in places fairly large, inclusions of well-foliated biotite gneiss, amphibolite, and microcline gneiss. These inclusions have both sharp and vaguely defined contacts with the gneissic granodiorite. Potassic feldspar constitutes an average of only 2 percent of the total rock composition of the migmatitic facies, and the iron oxides are less common.

It was stated earlier (p. E22) that the gneissic granodiorite is similar in appearance to the granite gneiss and migmatite of the Kassler quadrangle (Scott, 1963) and to the granite gneiss and pegmatite in the Freeland-Lamartine district (Harrison and Wells, 1956), but compositionally this is not entirely true. In figure 3 it is shown that the granite gneiss in the Freeland-Lamartine district has more potassic feldspar. The granite gneiss in the Kassler quadrangle, however, is very similar modally to the gneissic granodiorite at Morrison. The migmatitic facies of gneissic granodiorite is represented by the cluster of points within the quartz diorite field. The massive facies of gneissic granodiorite has a greater spread in composition, and points representing it occur in the quartz diorite, granodiorite, and quartz monzonite fields.

The texture of the gneissic granodiorite is hypidiomorphic-granular. Fine granular quartz, plagioclase, and potassic feldspar form a mortar texture around larger crystals. This mortar texture and rehealed crystals indicate that after the gneissic granodiorite and associated rocks crystallized, they were deformed by cataclasis. Mortar trains commonly enter plagioclase crystals but few cut through

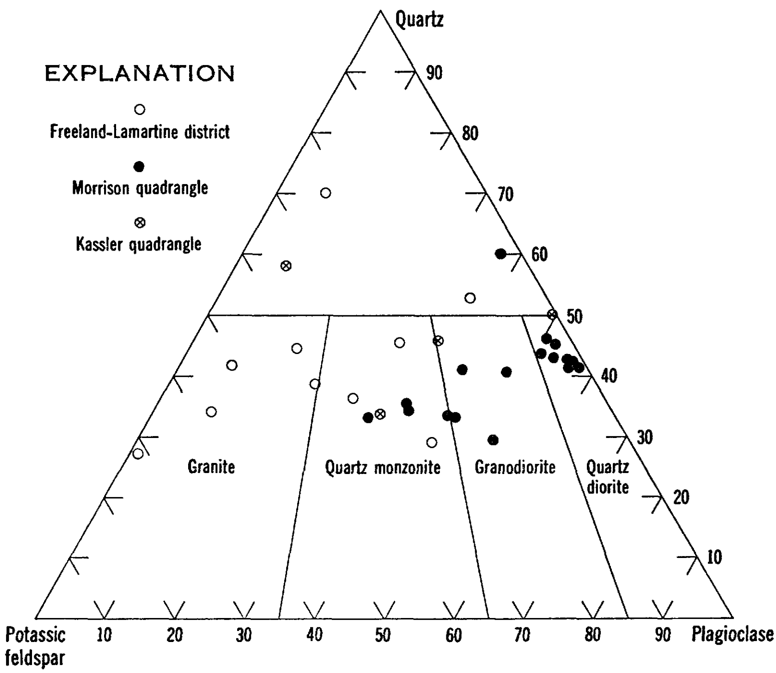

FIGURE 3.—Diagram showing variation in composition (volume percent) of gneissic granodiorite plotted with granite gneiss from Freeland-Lamartine district and Kassler quadrangle.

quartz aggregates. Linear features in the migmatitic facies are due to thin ragged biotite plates that form discontinuous sinuous stringers.

Potassic feldspars of the massive facies of gneissic granodiorite, as shown by thin sections, are complex minerals. A mortar texture formed by small microcline grains that fill fractures in larger microcline crystals and commonly envelop them is most distinctive. Large poikilitic carlsbad-twinned microcline crystals are embayed by plagioclase; in many sections, vein and string perthite is very striking. Within the migmatitic facies, potassic feldspars are equigranular with other minerals, and the distinct mortar texture of the massive facies is lacking.

The plagioclase in both facies is sodic oligoclase. Zoned crystals have calcic cores and thin albitic rims. Much of the plagioclase has a turbid appearance and poor twinning.

The biotite is generally in the form of small frayed plates. Muscovite was derived primarily from the alteration of plagioclase; none of it appears to be primary muscovite.

The chemical composition of the massive facies of gneissic granodiorite, shown in table 10, was calculated by use of an average mode of the typical massive facies. The chemical composition of the plagioclase in the rock was determined by using the anorthite content indicated for the plagioclase in sample M–500, table 10. The anorthite in the plagioclase in solid solution and as exolved blebs in the potassic feldspar was added to the anorthite obtained for plagioclase above. The potassic feldspar was found to be triclinic ($1\bar{3}0$ (CuKa)–130 (CuKo) = 0.80) and to contain 94± percent orthoclase molecule as determined by E. J. Young, of the U.S. Geological Survey, using the method of Bowen and Tuttle (1950). The nonheated feldspar shows a distinct plagioclase peak at 28° 2Θ due to its perthitic nature. After the feldspar was heated for 24 hours at 900°C the plagioclase peak disappeared; this disappearance indicated homogeneity of the feldspar accompanied by a composition change to 87± percent orthoclase molecule. The amount of plagioclase determined to be in solid solution in the potassic feldspar or as blebs was 7±1 percent. Because of the simple mineralogy of the massive facies of gneissic granodiorite, its calculated chemical composition should very nearly reflect its true composition. As shown in table 12, the composition is very close to that of granite-alaskite, as defined by Daly (1933, p. 27).

Pegmatites constitute about 20–25 percent of the gneissic granodiorite. Most of them, however, are not shown on the geologic map because they are generally too small to be shown at a scale of 1:24,000 and because gradational relations between them and the gneissic granodiorite and aplite make the placing of contacts difficult and arbitrary.

TABLE 12.—*Chemical composition, in weight percent, of the massive facies of gneissic granodiorite and of granite-alaskite*

[—, not determined]

Oxide	Gneissic granodiorite [1]	Granite-alaskite [2]
SiO_2	74.33	75.00
TiO_2	—	.30
Al_2O_3	13.96	13.14
Fe_2O_3	.96	.58
FeO	.47	.40
MnO	—	.07
MgO	.65	.30
CaO	1.23	1.13
Na_2O	3.78	3.54
K_2O	4.52	4.80
P_2O_5	—	.03
H_2O	.10	.71

[1] Average calculated chemical composition using five modes of gneissic granodiorite from Mount Morrison pluton.
[2] From Daly (1933, p. 27).

The pegmatite bodies occur singly or they grade into gneissic granite, or, along strike, into aplite. Pegmatites related to the gneissic granodiorite are widespread throughout the other crystalline rocks in the Morrison quadrangle also. These pegmatites are medium to very coarse grained and dark pink or pinkish orange. Most bodies are a few inches to several feet thick, although some near or along the gneissic granodiorite boundary are several hundred feet thick and are intimately associated with aplite. The pegmatites consist almost wholly of quartz, plagioclase, and potassic feldspar, and they contain small amounts of biotite and magnetite. The biotite occurs in the form of books or as disseminated flakes and is unoriented and widely scattered throughout the pegmatite.

Aplite comprises 10–15 percent of the gneissic granodiorite, and it also forms dikes in the metasedimentary rocks of the mapped area. These dikes, which are 10–15 feet wide and are vertical or nearly so, probably are equivalent in age to the aplite associated with the gneissic granodiorite. Within the gneissic granodiorite, aplite commonly grades into pegmatite along strike. The aplite is pink, fine grained, and in places sugary textured. It is generally brighter pink and coarser grained in the gneissic granodiorite than in the dikes in the metasedimentary rocks.

The aplite is alaskitic in composition (table 13). The potassic feldspar is microperthite, and the plagioclase is albite or sodic oligoclase. The mafic minerals are skeletal magnetite altered to hematite, sparse miniature pale-greenish-gray books of biotite, and colorless books of muscovite.

TABLE 13.—*Modes, in volume percent, of aplite*
[—, looked for but not found]

Sample	1	2	3
Field No. M-	384a	411	882a
Perthitic potassic feldspar	40.0	38.3	29.8
Plagioclase	17.9	30.8	33.2
Quartz	38.9	29.2	33.6
Biotite	1.3	—	.4
Muscovite	—	.9	1.7
Iron oxides	1.5	.8	1.3
Zircon	.2	—	—
Apatite	.2	—	—
Total	100.0	100.0	100.0
Composition of plagioclase	An_6	An_{13}	An_{16}
Average grain diameter, millimeters	0.3	1.0	0.1

1. Alaskitic aplite dike at head of Cherry Gulch.
2. Alaskitic aplite associated with gneissic granodiorite, northeast slope of Mount Morrison.
3. Alaskitic aplite, south slope of Mount Falcon.

The origin of the gneissic granodiorite perhaps is complex. The massive facies probably formed as a magma that has been contaminated in part by country rock, and the migmatitic facies probably formed as a result of high-grade regional metamorphism and thermal metamorphism that accompanied the emplacement of the magma. There is no distinct break between facies, but migmatites logically occur here because the grade of regional plus thermal metamorphism is probably within the temperature range where migmatites form. The fact that the massive facies has a weak cataclastic texture, not observed in the migmatitic facies could indicate that the mass was partially crystallized before emplacement. One joint set, and possibly two, labeled P in figure 9, formed when the gneissic granodiorite was emplaced.

LAMPROPHYRE DIKES

Many small lamprophyre dikes cut the crystalline rocks in the mapped area, but only the larger dikes are shown on plate 1. The largest dike is about 1,500 feet long and has a maximum width of 3 feet. These dikes weather more readily than adjoining rocks and are so poorly exposed that most could be traced for no more than a few hundred feet.

The dikes, which are biotitic vogesites and hornblende-bearing minettes (table 14), are fine grained to aphanitic, slightly porphyritic, gray to black, and weakly foliated. Crystals of biotite and hornblende, as much as 0.3 mm across, are visible in the finer grained groundmass and they commonly glisten on freshly broken surfaces. Weathered surfaces are dull brown, pinkish gray, or black.

Feldspar, most of which is potassic feldspar, comprises about 30–45 percent of these rocks. In thin section the potassic feldspar is seen to be a film-and-bleb perthite, which is less altered than plagioclase. The plagioclase is oligoclase and occurs as small anhedral albite-twinned grains that have been greatly altered to sericite. The quartz content is unusually high in some of the lamprophyres; in one sample it is 11 percent of the volume of the rock. Anhedral olivine (fayalite) is partly altered to calcite. Frayed greenish-brown biotite contains profuse inclusions of magnetite, rutile, zircon, and sphene. Accessory minerals are apatite, zircon, and sphene; secondary minerals are calcite, epidote, chlorite, sericite, and clay minerals.

Metamorphism differs noticeably among the lamprophyre dikes; this difference suggests that they probably were intruded during more than one period of deformation.

PEGMATITE

Pegmatites, exclusive of those believed to be associated with gneissic granodiorite, form lenticles and small bodies a few inches to several tens of feet thick and several tens of feet long. Only one pegmatite is shown on the map (pl. 1). It is a large lenslike body with many small inclusions of gneissic granodiorite, quartzite, biotite gneiss, lamprophyre, and hornblendite. This pegmatite apparently is younger than the pegmatite related to the gneissic granodiorite.

Older pegmatites associated with granodiorite and quartz diorite are generally not as coarse grained as the pegmatites in the younger gneissic granodiorite. These pegmatites are gray white or pinkish gray and consist mostly of quartz and plagioclase. Potassic feldspar, biotite, and trace amounts of magnetite are also present. Rarely other minerals are observed in these pegmatites.

INTRUSIVE ROCKS OF TERTIARY(?) AGE

Intrusive rocks which appear younger than the Precambrian rocks previously discussed but which otherwise are of undetermined age consist of shonkinite, in a small pluton, and biotite latite and diabase, in small dikes.

SHONKINITE

Shonkinite occurs in the mapped area in only one small body which forms an irregular-shaped plug about 1,000 feet long and about 500 feet wide. The Falcon Castle Road cuts through the center of the mass. The walls of the shonkinite body, where exposed, are nearly vertical. The south side of the shonkinite is in contact with a quartz diorite body, too small to be shown on the map, which has been altered for as much as 15 feet away from the contact.

The shonkinite is massive, medium grained, and, locally, slightly porphyritic. It is dark brown to black on outcrop and it has a glistening grayish-brown luster on fresh fractures. The rock tends to weather into rounded boulders. It contains bluish-gray feldspar grains which can be recognized only by close scrutiny; biotite and augite are the most prominent minerals in hand specimen.

Emmons, Cross, and Eldridge (1896, p. 310) reported a similar rock, described as augite-mica-bearing syenite in small bodies, in the vicinity of the north fork of Turkey Creek, approximately 4½ miles west of the town of Morrision, but these bodies could not be located for comparison.

The shonkinite contains an average of 48–58 percent sanidine, 20–23 percent clinopyroxene, and 12–23 percent biotite. Accessory minerals are magnetite, apatite, sphene, olivine, nepheline, and hornblende (table 14).

TABLE 14.—*Modes, in volume percent, of shonkinite and mica lamprophyre*

[Tr., trace; —, looked for but not found]

	Shonkinite			Mica lamprophyre	
Sample	1	2	3	4	5
Field No. M-	785a	785b	M-785a-1	158	532a
Sanidine	56.4	57.8	48.4	—	—
Microperthite	—	—	—	36.7	29.4
Plagioclase	—	—	—	10.5	4.2
Quartz	—	—	—	1.1	11.2
Clinopyroxene (diopside-augite)	22.9	20.1	23.3	—	—
Hornblende	.1	.6	.6	30.7	18.1
Iron oxides	6.3	4.7	1.5	.8	1.9
Biotite	11.7	14.9	21.8	18.7	30.8
Sphene	—	—	1.4 }	[1] .6 (Sphene and zircon)	{ .4
Zircon	—	—	— }		{ Tr.
Apatite	1.0	1.9	2.0	.8	1.6
Olivine	1.6	—	—	—	.5
Nepheline(?)	—	—	1.0	—	—
Rutile	—	—	—	Tr.	—
Epidote	—	—	—	.1	1.1
Chlorite	—	—	—	—	Tr.
Calcite	—	—	—	—	.8
Muscovite	—	—	—	Tr.	—
Total	100.0	100.0	100.0	100.0	100.0

[1] Most grains too small to identify further.

1, 3. Dark-gray, almost black, medium-grained massive shonkinite from pit, north of road to Falcon Castle ruins.

2. Shonkinite with brownish cast, massive; sample from bouldery outcrop south of road to Falcon Castle ruins.

4. Lamprophyre (biotitic vogesite) from dike, north of Apex Gulch and west of base of Paleozoic sedimentary rocks.

5. Lamprophyre (hornblende minette), from roadcut, 1,400 ft west of base of Paleozoic sedimentary rocks in Bear Creek Canyon.

Microscopically the shonkinite is a hypidiomorphic-granular rock with prominent euhedral crystals of augite and sanidine. The average grain size is about 1.3 mm in diameter; sparse hemihedral crystals of olivine are as much as 3.2 mm, sanidine laths 3 mm, and euhedral augite crystals 1.6 mm. Zoning formed by concentric bands of reddish-brown, opaque, dust-sized particles is a conspicuous feature of apatite, augite, and sanidine crystals.

The feldspar is sodic sanidine. The rims of zoned sanidine crystals have a 2V of about 40° as measured on the universal stage. The optic angle could not be measured in the central parts of the sanidine crystals because they contain hairlike albitic twin lamella. In oil immersion, β index measured 1.525–1.527 ($\pm$0.002) on the rim of crystals. The centers of the crystals generally have inclusions of pyroxene, magnetite, and biotite that indicate the sanidine formed late.

Olivine forms subhedral to anhedral crystals that are extremely fractured and altered to orangish-brown iddingsite. The olivine contains profuse minute dark opaque particles that are equally scattered throughout the crystal.

The pyroxene is a diopsitic augite. In zoned crystals the outer rim is greener than the core—a probable indication of an increase in iron in the outer rim; 100 twins are common. Augite is embayed by olive-brown hornblende and brown biotite along cleavage and fractures. Centers of augite crystals commonly contain subrounded grains of magnetite and other iron oxide minerals.

The biotite, which is bright reddish orange brown, rims magnetite grains and occurs as distinct plates embaying both pyroxene and sanidine. Long slender euhedral plates of biotite pierce sanidine crystals.

Accessory minerals are apatite, magnetite, nepheline (?), and sphene. The apatite, which is a moderate pink, is often zoned and is commonly included in augite. The iron oxides adjoin augite, biotite, and olivine; commonly they replace the augite or biotite. Nepheline (?) forms very tiny interstitial anhedral grains. Sphene occurs as small generally anhedral grains in biotite or as partial rims on magnetite. Secondary minerals are sericite and traces of chlorite, calcite, and some iron oxide minerals.

The analysis of a representative sample of shonkinite (table 15) is compared with the average analyses of 64 samples of minette and of 30 samples of vogesite as tabulated by Métais and Chayes (1963). The chemical composition of the shonkinite is more nearly that of the average minette. The shonkinite contains more CaO and K_2O than the average minette contains and it is also more anhydrous.

The shonkinite mapped in the Morrison quadrangle has a high content of BaO and SrO (table 16), as does the highly potassic rocks of the Highwood province (Weed and Pirsson, 1901) and potassic basic lavas of other provinces.

BIOTITE LATITE

Two dikes of biotite latite were recognized in the mapped area. One crops out on Lariat Loop Road, has a northwest trend, and was traced as far as tunnel 1 in Clear Creek Canyon. The other dike crops out southwest of Mount Falcon and is several hundred feet long. Both are

TABLE 15.—*Chemical analyses, in weight percent, of shonkinite from the mapped area compared with average chemical analyses of minette and vogesite*

[—, looked for but not found]

	Shonkinite [1]	Average analyses of 64 minette samples [2]	Average analyses of 30 vogesite samples [2]
SiO_2	50.60	51.17	51.13
Al_2O_3	13.61	13.87	14.35
Fe_2O_3	3.20	3.27	3.63
FeO	4.41	4.16	4.74
MgO	6.96	6.91	6.84
CaO	7.84	6.58	7.05
Na_2O	2.05	2.12	3.00
K_2O	6.64	5.49	3.81
MnO	.13	—	—
H_2O+	.59	2.42 (H₂O+ and H₂O−)	2.62 (H₂O+ and H₂O−)
H_2O-	.09		
TiO_2	1.18	1.36	1.44
P_2O_5	1.20	—	—
CO_2	.14	—	—
Cl	.05	—	—
F	.54	—	—
Subtotal	99.23	—	—
Less 0	.24	—	—
Total	98.99	—	—
Powder density	2.91	—	—

[1] Analyst: G. O. Riddle, Lab. No. D100506, Field No. M-785a-1.
[2] From Métais and Chayes (1963, p. 157).

TABLE 16.—*Spectrographic analysis, in parts per million, of shonkinite*

[Analyst, Harriet Neiman. Serial No. D100506; Field No. M-785a-1]

Ba	7,000	Ni	150
Be	5	Pb	50
Ce	150	Sc	100
Co	20	Sr	5,000
Cr	200	V	200
Cu	70	Y	50
Ga	20	Yb	5
La	150	Zr	150
Mo	5	Nd	150

nearly vertical and less than 10 feet thick. The dikes have been intensely fractured and iron stained. The latite is pinkish gray and aphanitic, and it contains phenocrysts of biotite and feldspar.

Similar dikes of latite in the Eldorado Springs quadrangle have been mapped by Wells (1963), and latite in the Boulder County tungsten district has been mapped and described by Lovering and Tweto (1953, p. 22–23).

Modal analyses for the biotite latite averaged: microperthite, 40 percent; plagioclase (oligoclase An_{31}), 36 percent; quartz, 4 percent; biotite, 8 percent; muscovite, 6 percent; iron oxide minerals, 5 percent; apatite, 1 percent; and zircon and sphene, traces.

DIABASE

Several narrow dikes of fine-grained dense gray-black diabase are poorly exposed in the west-central part of the Morrison quadrangle. Joints in the dikes are heavily iron coated.

The diabase consists of labradorite, 55 percent; pyroxene (augite and hypersthene), 25 percent; and magnetite, 5 percent. Accessory minerals are traces of quartz and apatite. Alteration minerals which compose the remaining 15 percent include sericite, epidote, and clay minerals.

The texture of the rock, as shown in thin section, is subophitic, characterized by pyroxene partly enveloped by labradorite. Needle-like locally radiating greenish-yellow pyroxene crystals as much as 1.4 mm long are visible in most sections. Schiller structure is visible only near the centers of the pyroxene crystals.

The plagioclase is labradorite that averages An_{54} and occurs in euhedral carlsbad-twinned laths that have a peculiar discontinuous albite or pericline twinning. Zoned crystals are common.

AGE

Similar dikes of latite and diabase mapped elsewhere in the Front Range have been assigned by various authors to the Cretaceous or Tertiary. Latite dikes that crop out in the Eldorado Springs quadrangle are considered to be Cretaceous or Tertiary (Wells, 1963). Latite dikes in the Boulder County tungsten district are placed in the early Tertiary (Lovering and Tweto, 1953, p. 25–26). Diabase dikes in the Eldorado Springs quadrangle have been assigned a Cretaceous or Tertiary age (Wells, 1963), and to the north in the Gold Hill district a diabase dike called the Iron Dike has been assigned a Paleocene(?) age (Lovering and Tweto, 1953, p. 19). In the mapped area, these latite and diabase dikes are designated Tertiary(?), for lack of direct evidence for dating them as other than post-Precambrian.

The shonkinite body can be dated positively only as younger than the microcline gneiss and quartz diorite that it intruded. The shonkinite has not been extensively metamorphosed, and it evidently is post-Precambrian in age.

METAMORPHISM

Regional metamorphism of the Precambrian rocks in the Morrison quadrangle produced mineral assemblages characteristic of the sillimanite-potassic feldspar grade of metamorphism. These high-grade gneisses occur in a terrane of concordant granitic intrusives and gneissic granodiorite with its related migmatite, pegmatites, and aplite. The assemblages of minerals representative of these high-grade metamorphosed rocks are controlled principally by the composition of the original rock.

Biotite gneiss, which resulted from the metamorphism of pelitic rocks, has been metamorphosed at least to sillimanite-potash feldspar grade as defined by Evans and Guidotti (1966). A representative assemblage in these rocks is sillimanite, potassic feldspars, plagioclase, and quartz plus or minus muscovite. Those rocks that have a lower potassic content are sillimanite-bearing biotite gneisses; those that contain high percentages of iron and magnesium are sillimanite-cordierite or cordierite-gedrite gneisses in the same metamorphic grade. Muscovite is a common mineral in these rocks; however, muscovite generated by the high sillimanite-potassic feldspar grade of metamorphism is very sparse. Most of the muscovite is part of a later retrograde metamorphism.

Metamorphism other than that which produced the sillimanite-potassic feldspar-grade rocks is indicated by other minerals and mineral associations. Relic staurolite in cordierite-bearing gneisses and helicitic structures in garnet from the same gneisses are evidence of an earlier, though it is not known how much earlier, slightly lower grade of metamorphism, or conceivably of a local variation in the intensity of the sillimanite-potassic feldspar grade of regional metamorphism. Muscovite and large andalusite crystals containing unaltered sillimanite inclusions and having cordierite coronas, although sparse, indicate that there was additional metamorphism in the area after the high-grade regional metamorphism.

Slight retrograde metamorphism is evident throughout the Precambrian rocks and is represented chiefly by chlorite, muscovite, and sericite. Chlorite and muscovite form flakes within other minerals or occur as overgrowths. Retrograding due to shearing and faulting, especially in the cordierite-bearing biotite gneiss, has produced much feather-textured chlorite after biotite and pinnite after cordierite.

STRUCTURE

A complex structural history is recorded in the Precambrian rocks in the Morrison quadrangle. Events that formed the structural patterns cannot be dated accurately but the general sequence is as follows: (1) plastic deformation and development of west-northwest-trending folds; this deformation was accompanied by recrystallization and reconstitution of the sedimentary rocks and by intrusion of granodiorite, quartz diorite, and hornblendite sufficiently early for these intrusives to reflect the same deformation pattern as the metasediments; (2) plastic deformation and development of north-northeast lineaments, accompanied by emplacement of gneissic granodiorite, aplite, pegmatite, and migmatite; (3) deformation that produced widespread shearing and faulting, the faults having prominent northwest trends; (4) intrusion of lamprophyres probably at several times during the Precambrian; (5) intrusion of latite, diabase, and shonkinite probably in Tertiary time; (6) faulting, fracturing, and mineralization in Tertiary time.

FOLDS

Two sets of folds are recognized in the western part of the Morrison quadrangle. North of the fault that trends southwest from near Cherry Gulch, the fold axes trend westward; south of this prominent fault, fold trends are north-northwest to north-northeast.

The older folds trend slightly north of west in the northern two-thirds of the quadrangle and decidedly northwest in the lower third of the quadrangle. These folds are isoclinal in the vicinity of Mount Zion and Lookout Mountain, but southward they become more open and slightly asymmetrical with the south limbs steeper than the north ones. Drag folds are common on the limbs of these folds. These west-northwest-trending folds form the structural framework for the area mapped.

The younger and weaker folds trend north to N. 35° E. These folds occur south of Cherry Gulch and continue southward at least as far as the south edge of the quadrangle; most are small open folds slightly overturned to the east, but the fold pattern is difficult to determine in many places because it has been obscured by shearing and faulting. Ptygmatic folds are prominent locally.

FOLIATION AND LINEATION

Foliation is represented by a compositional layering and by a well-defined preferred mineral orientation which probably is parallel to the bedding in the original rocks. The foliation is moderately regular within a single outcrop but differs widely in attitude from outcrop to outcrop. Widespread differences were caused by deformation during intrusion of the many pegmatites and migmatites that warped the metasediments and by extensive faulting and shearing.

In the northwestern part of the quadrangle the foliation strikes mostly west and dips principally to the southwest. In the southwestern part the foliation has two principal trends, the most prominent strikes northwest and dips to the southwest; superimposed on this northwest trend is a weaker foliation that strikes northeast and dips to the southeast. Locally the northeast deformation warps and deflects the older northwest lineaments. This is especially true south of Cherry Creek.

Lineations within the area mapped are nearly parallel to major fold axes (*B* lineations) or nearly normal to them (*A* lineations). These lineations consist of axes of small folds and warps and of mineral alinements, streaks, and slickenside striae. The most conspicuous and widespread linear feature is a mineral alinement formed by parallel alinement of the long dimensions of fibrous and prismatic minerals. The elongate minerals are hornblende in amphibolite and sillimanite and gedrite in biotite gneiss. Streaking is due to the parallel alinement of mineral aggregates that are formed of garnet in biotite gneiss and of feldspar and biotite in microcline gneiss. Lineations are generally well developed in the metasedimentary rocks. Stringers and clots of mafic minerals and inclusions of metasediments define the linear trends in the gneissic granodiorite.

All lineations measured were plotted on the lower hemisphere of Schmidt equal-area nets and are contoured to summarize the data (figs. 4–6).

Lineations that formed during the older period of Precambrian deformation plunge 14° S. 83° W. (fig. 4); they are represented by small folds and mineral alinements. These lineations are nearly parallel to the west-northwest-trending fold axes and are designated the B_o lineation according to the usage of Cloos (1946, p. 5). Lineations in A_o approximately at right angles to the fold axes are represented mostly by small fold axes. In figure 4 the small high at 25° S. 18° E. may represent the A_o lineation.

Lineations that formed during a younger period of Precambrian deformation are represented in figures 5 and 6 by small folds, streaking, and mineral alinements. B_y is here used for lineations approximately parallel to the younger fold axes. The maxima in B_y (figs. 5 and 6) have a bearing of 23° S. 10° W. The A_y direction does not show readily in any of the figures.

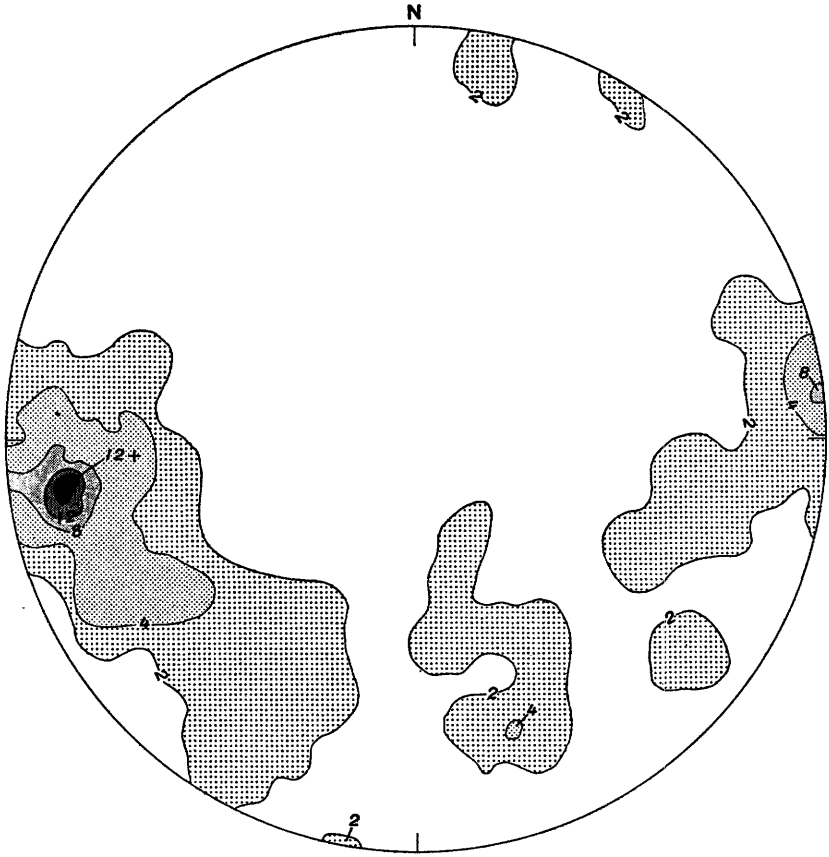

FIGURE 4.—Lineations in Precambrian rocks, excluding gneissic granodiorite. Lower hemisphere plot. Contoured in percent. North edge of quadrangle to Bear Creek, 122 poles.

A strong maxima at 55° S. 30° W. (figs. 5 and 6) may represent a still younger period of metamorphism and cataclasis, similar to the metamorphism and cataclasis in the Idaho Springs-Ralston shear zone, in the Coal Creek area (Wells and others, 1964, p. O15–O21), whose lineations have an average trend of 56° S. 15° W. This younger cataclasis has been superimposed on the older structures, especially south of Bear Creek and at least as far as the south boundary of the quadrangle. The shearing obliterated or modified much of the older structure in the area. The older west-northwest deformation is weakly represented south of Bear Creek, but there it appears to be somewhat changed in that the average trend for the B_o lineations is 42° S. 73° W. and for the A_o maxima it is 38° S. 20° E.

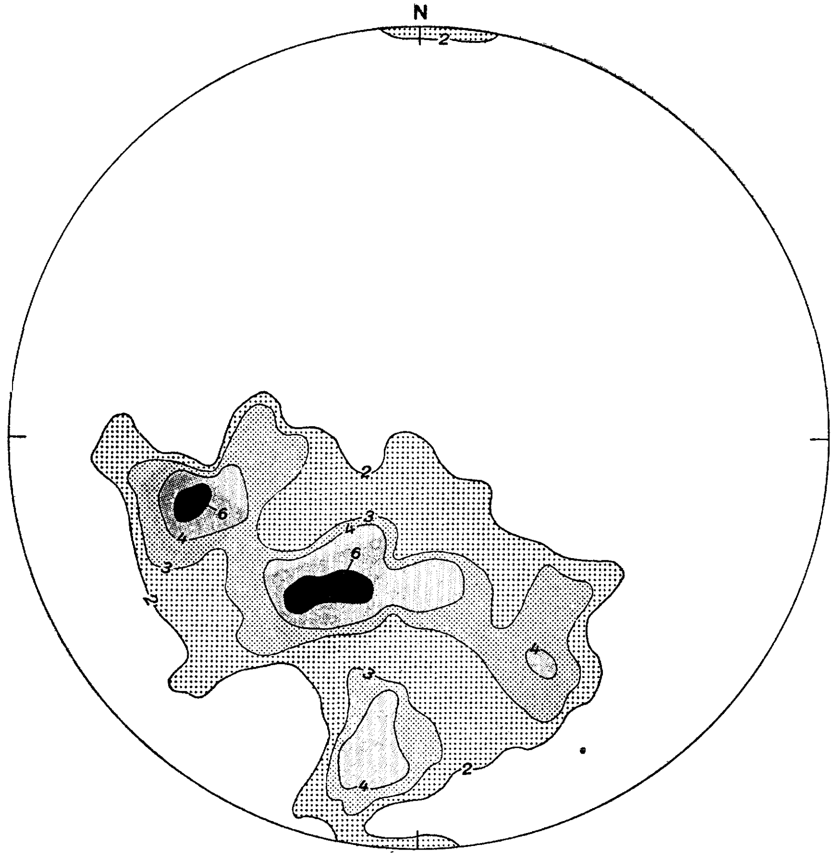

FIGURE 5.—Lineations in Precambrian rocks, excluding gneissic granodiorite. Lower hemisphere plot. Contoured in percent. Bear Creek to south edge of quadrangle, 92 poles.

FAULTS

Except for the fault on the northwest flank of Mount Morrison, which trends northeast, the largest and most persistent faults in the mapped area trend west and northwest and belong to the regional northwest-trending fault system (Lovering and Goddard, 1950).

The west-, north-, and northwest-trending faults characteristically are marked by shear zones that form topographic lows across ridges. Rocks along the faults are intensely fractured and silicified, and are colored by disseminated hematite. Fractures in Mount Vernon Canyon contain calcite locally. The faults generally dip steeply to the southwest, but at several locations in Bear Creek Canyon, small faults are nearly flat lying.

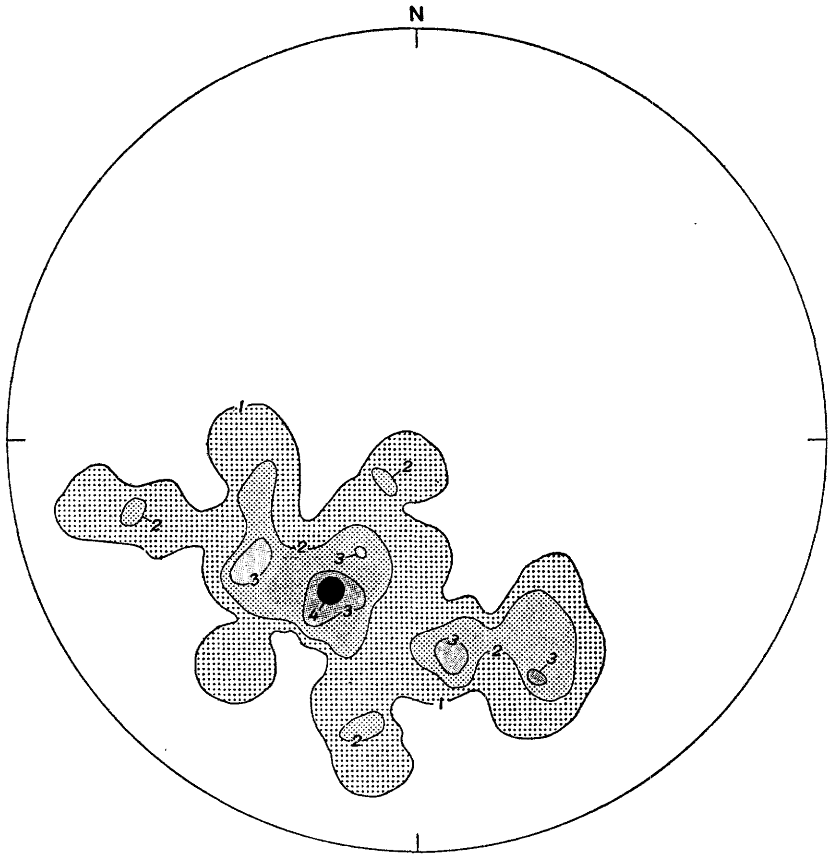

FIGURE 6.—Lineations in gneissic granodiorite. Lower hemisphere plot. Contoured in percent, 26 poles.

The northeast-trending fault on the northwest flank of Mount Morrison is a large fault along which the rocks are intensely sheared and silicified and are stained dark orange brown. This fault is terminated against or displaced by the shear zone at Idledale.

The faults in the mapped area are east of the Colorado mineral belt but are part of the much broader fault pattern of that belt described by Tweto and Sims (1963). The faults appear to have had their origin during Precambrian time, but the distribution of the rock units indicates probable movement on the faults again during Tertiary time. Some of the fracture zones were mineralized during the Tertiary when uranium and traces of copper were deposited.

JOINTS

Joints occur in all Precambrian rocks in the Morrison quadrangle but are most pronounced in the gneissic granodiorite where at least two and locally three joint sets occur in every outcrop. The metasedimentary rocks contain one or two definite sets. The poorest defined joint sets probably formed during Precambrian deformation, and the most consistent and best defined during Laramide deformation.

All joints were plotted on Schmidt equal-area nets, according to the method of Billings (1942, p. 116). Of the two primary joint sets (P) in the gneissic granodiorite (fig. 9), the most conspicuous one strikes N. 70° W. and dips 78° NE.; the other strikes N. 25° E. and dips 35° SE. The most persistent joint set, exclusive of joints in the gneissic granodiorite, generally trends north-south and dips steeply west. It changes in strike from N. 15° W. in the northern part of the mapped area (fig. 7) to about N. 2° E. in the southern part (fig. 8). Most of the other sets strike northeast and dip steeply northwest.

Most of the major joints in the Precambrian rocks in the Morrison quadrangle seem to belong to a regional joint system of probable Laramide age, as set forth by Harrison and Moench (1961, p. B10) for the Central City-Idaho Springs area. Longitudinal joints representative of Precambrian fold axes may be indicated on figures 8 and 9. However, the high concentrations of joints shown on these figures should be interpreted as primarily of the same origin as the related cross joints which do not belong to Precambrian linear trends. A comparison of table 17 of this report with table 1 of Harrison and Moench (1961, p. B10) shows close agreement for the regional joint system in the two areas. In the Central City-Idaho Springs area, longitudinal joints trend N. 12°–22° W. and dip steeply to the northeast or southwest; in the Morrison quadrangle they trend N. 3°–18° W. and dip moderately to steeply to the southwest. Cross joints in the Central City-Idaho Springs area trend N. 69°–83° E. and dip steeply to the northwest; in the Morrison quadrangle they trend N. 67°–74° E. and dip steeply to the northwest. Diagonal joints in the Central City-

TABLE 17.—*Summary of attitudes of joint sets in the Precambrian rocks in the Morrison quadrangle that may be related to a regional joint system*

[Joints measured from Schmidt nets of figs. 7–9]

Figure	Longitudinal joints	Cross joints	Diagonal joint sets	
			Northwest	Northeast
7	N. 15° W., 57° SW	N. 67° E., 87° NW		N. 31° E., 75° NW.
8	N. 18° W., 88° SW	N. 70° E., vertical	N. 87° E., vertical	N. 57° E., 55° NW.
9	N. 3° W., 82° SW	N. 74° E., 83° NW	N. 70° W., 78° NE	N. 27° E., 80° NW.

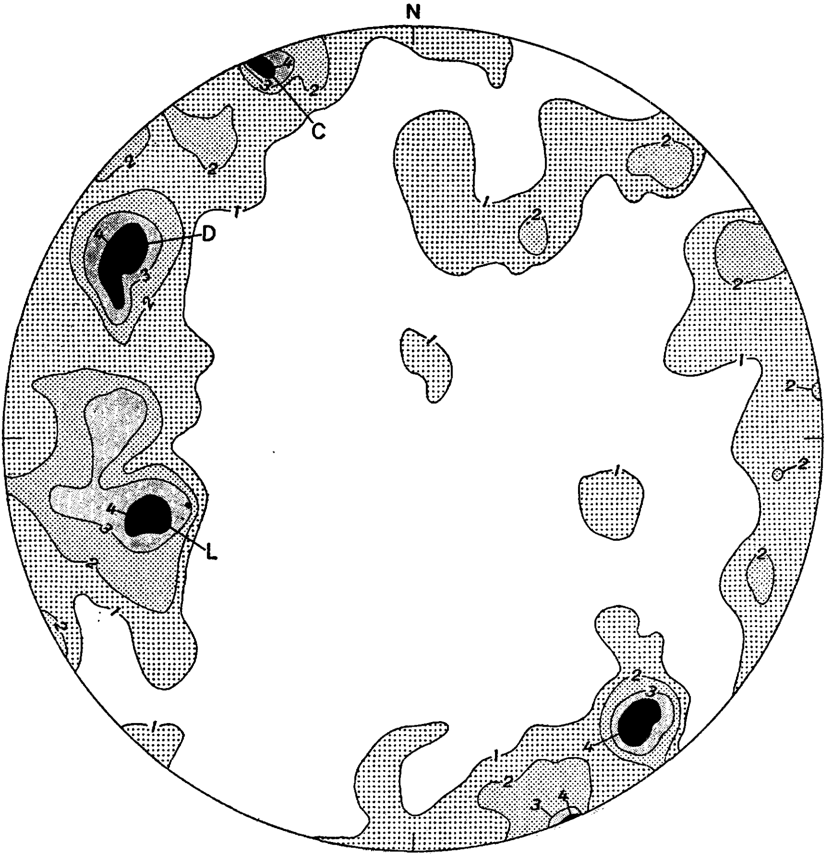

FIGURE 7.—Contour diagram of joints in Precambrian rocks, excluding gneissic granodiorite. Upper hemisphere plot; contoured on percent of poles. L, longitudinal joints; C, cross joints; D, diagonal joints. Northern edge of quadrangle to Bear Creek, 244 poles.

Idaho Springs area trend N. 72°–80° W. and N. 47°–65° E. and dip respectively moderately steeply to the northeast and northwest. In the Morrison area the northwest set is not well defined. In the gneissic granodiorite the set trends N. 70° W. and dips 78° NE., but, possibly due to faulting, the set in the southern part of the Morrison quadrangle trends N. 87° E. and dips vertically. The northeast diagonal joint set in the Morrison bears N. 27°–57° E. and dips moderately steeply to the northwest.

One major joint set (figs. 7 and 8), which trends N. 54° E. and dips 78° SE., does not fit either a Precambrian or Tertiary pattern. Two highs are apparently shown in both figures 7 and 8, one for the longitudinal joints and one for the cross joints, with exactly the same

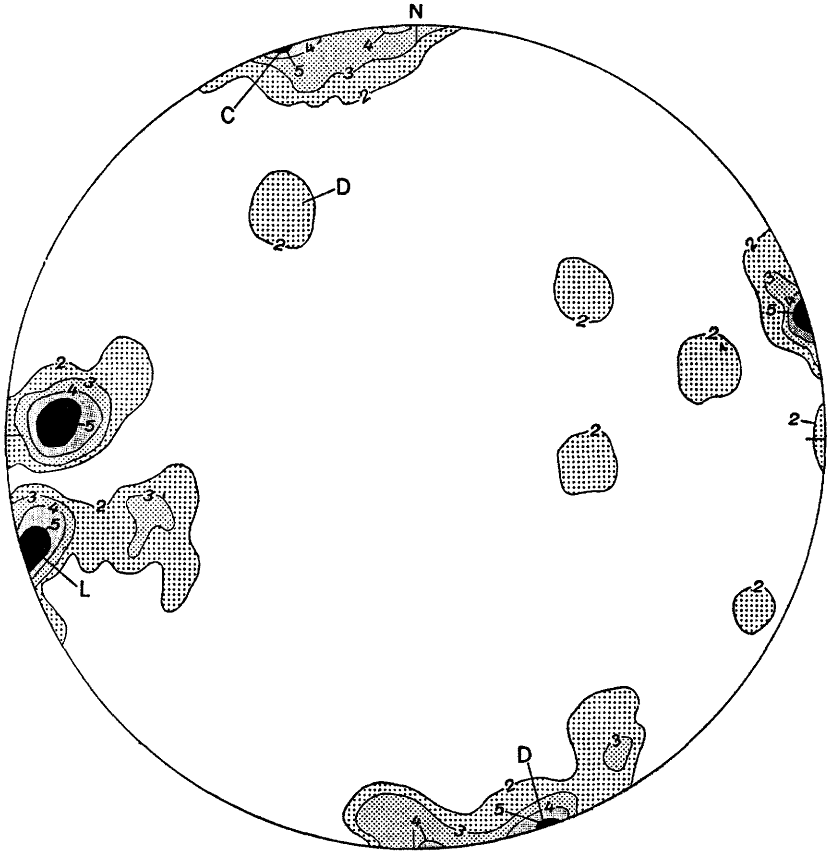

FIGURE 8.—Contour diagram of joints in Precambrian rocks, excluding gneissic granodiorite. Upper hemisphere plot; contoured on percent of poles. L, longitudinal joints; C, cross joints; D, diagonal joints. Bear Creek to south edge of quadrangle; 81 poles.

amount of displacement in each. In figure 9 some displacement is shown along trend, but it is not as great as that shown in figures 7 and 8. About the same difference in dip is shown in figures 7–9. Trend displacement and change in dips are probably due to reactivation of faults in the area during the Tertiary.

ECONOMIC GEOLOGY

The area of this report contains few mineral deposits of economic significance under present conditions. Uranium has been produced from several mines, now idle, in the vicinity of Idledale, stone is quarried in Bear Creek Canyon, and gravel is produced from one Precambrian fault zone along the mountain front.

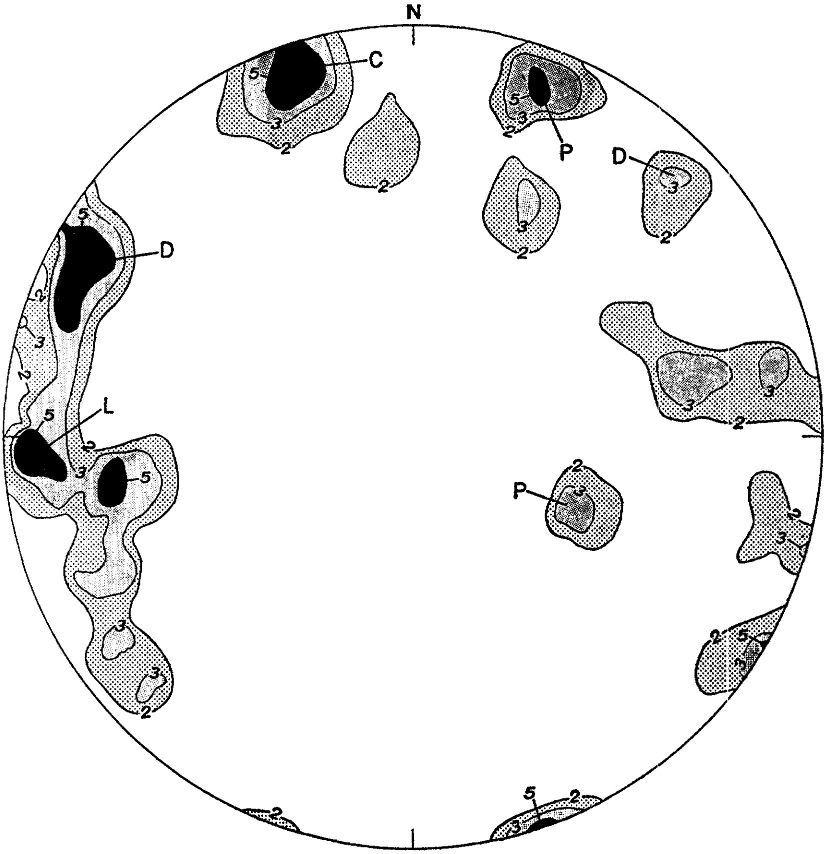

FIGURE 9.—Contour diagram of joints in gneissic granodiorite. Upper hemisphere plot of 83 poles; contoured on percent of poles. P, primary joints; L, longitudinal joints; C, cross joints; D, diagonal joints.

The uranium occurs in shear zones in amphibolite and biotite gneiss of the hornblende gneiss map unit and in gneissic granodiorite, aplite, and pegmatite. The two principal mines, the Foothills mine west of Idledale and the Grapevine mine northeast of Idledale in Sawmill Gulch, have been described by Sims and Sheridan (1964, p. 94–99). The combined total ore shipped from 1955 to 1960 was slightly more than 10,000 short tons, containing 0.26–0.37 percent U_3O_8; most of this production was from the Foothills mine.

Copper minerals occur along fractures in an area just north of Strain Gulch. Prospect pits on several of these mineralized fractures have not exposed minable deposits. Kaolinite associated with muscovite crops out discontinuously at about the 6,680-foot contour in the quartz-plagioclase gneiss map unit just west of the contact between the

Precambrian and sedimentary rocks in the southern part of the area. These kaolinite deposits are too small and too discontinuous to be of commercial interest.

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