Geology of the Eldorado Springs Quadrangle Boulder and Jefferson Counties, Colorado

By JOHN D. WELLS

CONTRIBUTIONS TO GENERAL GEOLOGY

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Petrography, stratigraphy, and structural geology of the Precambrian metamorphic and igneous rocks, Paleozoic and Mesozoic sedimentary rocks, and Cenozoic surficial deposits

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By John D. Wells

ABSTRACT

The Eldorado Springs quadrangle lies across the eastern margin of the Front Range immediately south of Boulder and about 25 miles northwest of Denver. The western two-thirds of the quadrangle is mountainous and is underlain by Precambrian metamorphic and igneous rocks. The upturned Paleozoic and Mesozoic rocks form The Flatirons and the hogback ridges to the east. The eastern part of the quadrangle is a plain covered by Pleistocene gravels. The valleys of Coal Creek, South Boulder Creek, and their tributaries, and the tributaries of Boulder Creek dissect these rocks and form steep-walled canyons as much as 2,000 feet deep.

The Precambrian rocks are a folded and sheared layered sequence of high-grade metasedimentary quartzite, schist, hornblende gneiss, and biotite gneiss. These rocks were intruded by Precambrian igneous rocks—Boulder Creek Granodiorite, quartz monzonite, Silver Plume Granite, aplite, and pegmatite. Cataclastic gneisses were formed in the Idaho Springs–Ralston shear zone.

The hornblende gneiss consists mostly of hornblende and plagioclase. The biotite gneiss is well foliated and is largely biotite, quartz, and plagioclase. Locally the gneiss contains sillimanite in contact with microcline; this feature indicates high-grade metamorphism. The quartzite and schist commonly contain andalusite and locally contain cordierite, garnet, and sillimanite.

The Paleozoic rocks are Pennsylvanian and Permian in age and consist of sandstone, shale, and conglomerate, generally red, in the Fountain, the Lyons, and the lower part of the Lykins Formations. The Mesozoic rocks consist of gray and varicolored shale, sandstone, and limestone in the upper part of the Lykins Formation, Ralston Creek and Morrison Formations, Dakota Group, Benton Shale, Niobrara Formation, and Pierre Shale.

A small remnant of a Tertiary gravel deposit occupies a high level in the mountains. Four pre-Wisconsin Pleistocene gravels—the pre-Rocky Flats, Rocky Flats, Verdos, and Slocum alluviums—form veneers on successive pediment surfaces east of the mountains. Wisconsin alluvial deposits occur immediately above modern stream terraces. Recent alluvial deposits occur in the streams, and colluvial deposits occur on the slopes of the mountains and hills.

Three periods of Precambrian metamorphism and structural deformation have been recognized in the area. Evidence of the oldest period, which was one of plastic deformation, is found as relict staurolite grains and warped lineation of the rocks. The second deformation was also plastic; it formed the Coal

Creek syncline and the Scar Top anticline and was accompanied by the intrusion of the Boulder Creek Granodiorite and the quartz monzonite. The third deformation, characterized by shearing, formed the relatively restricted Idaho Springs–Ralson shear zone and certain minor structures. The Silver Plume Granite and associated aplite and pegmatite were intruded relatively late in the Precambrian, after the structural framework had been established.

The Laramide orogeny rotated the area by folding and faulting so that the sedimentary rocks now strike north or northwest and in general dip 40°–60° E. Locally, beds are vertical or overturned in fault zones. The main faults in the area strike northwest and dip steeply; they show offsets of a few thousand feet near the mountain front and commonly die out to the southeast. Many minor east- and northeast-striking faults connect the main faults. Most of these also dip steeply. The faults are commonly cemented by quartz and carbonate and locally by hematite, barite, fluorite, and copper minerals

Economic materials are virtually restricted to clay products, water, and construction materials. Gold and silver have been produced in the past in the Magnolia area, but only in small amounts since 1942 There are potential resources of several nonmetallic minerals in the quadrangle.

INTRODUCTION

The Eldorado Springs quadrangle is one of a series that lie in a north-south line along the mountain front west of Denver; these quadrangles have been or are being studied geologically because of their bearing on problems of urbanization, engineering, and water supply. Studies in these quadrangles also support and extend detailed studies made or being made in the metal-mining areas immediately to the west. In this report, the character, distribution, structure, history, and economic mineral potential of the rock units and the surficial deposits of the Eldorado Springs quadrangle are described. Although the present discussion is limited to the quadrangle and its immediate environs, these data contribute to solution of general and regional problems in many fields of geology.

LOCATION AND GEOLOGIC SETTING

The Eldorado Springs quadrangle lies at the eastern edge of the Front Range about 25 miles northwest of Denver, Colo. (fig. 1). The western two-thirds of the quadrangle is underlain by Precambrian igneous and metamorphic rocks; the eastern one-third is underlain by upturned Paleozoic and Mesozoic rocks that are partly covered with a veneer of Quaternary surficial deposits (pl. 1). The Mesozoic rocks form the low-lying eastern plains; the Paleozoic rocks form The Flatirons at the eastern mountain front; and the Precambrian rocks form the western mountainous area. The valleys of Coal Creek, South Boulder Creek, and their tributaries, and the tributaries of Boulder Creek (fig. 1) dissect these rocks and form steep-walled canyons as much as 2,000 feet deep in the Paleozoic and Precambrian rocks.

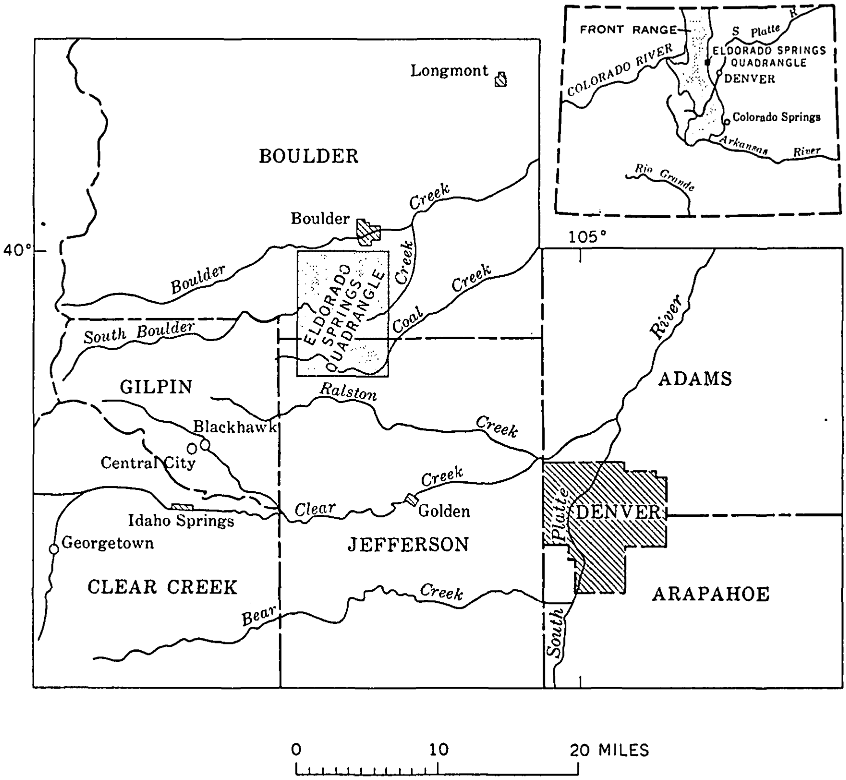

FIGURE 1.—Location of the Eldorado Springs quadrangle, Colorado.

The Front Range is the easternmost range of the Southern Rocky Mountains. It is 30–60 miles wide and about 250 miles long and consists largely of Precambrian gneiss and schist and granitic intrusive rocks. These rocks are bordered by Paleozoic and Mesozoic sedimentary rocks that were upturned during the Laramide orogeny. Porphyritic igneous rocks and metalliferous deposits lie in the central part of the range, and faults are distributed through the length of the range.

The gneiss and schist consist of widespread biotitic, feldspathic, and hornblendic units that were previously mapped as the Idaho Springs and Swandyke Formations (Ball, 1908; Lovering and Goddard, 1950). These rocks have been repeatedly deformed and now lie in a series of complex folds. Precambrian intrusive rocks are widespread in the Front Range and consist of Boulder Creek Granodiorite, Silver Plume Granite, and Pikes Peak Granite, all of which occur as batholiths, plutons, and dikes.

The sedimentary rocks consists of sandstone, shale, limestone, and conglomerate. They are of late Paleozoic and Mesozoic age in the central and northern parts of the range, including the Eldorado Springs area but include rocks of early Paleozoic age farther south. The Tertiary rocks consist mostly of conglomerate, sandstone, and shale. The Pleistocene and Recent deposits consist of glacial material in the high mountains, and gravel veneers on pediments and along streams east of the range.

PREVIOUS AND PRESENT WORK AND ACKNOWLEDGMENTS

The general geologic framework of the area has been known since the early surveys of Cross (1894), Emmons, Cross, and Eldridge (1896), Fenneman (1905), and Gilbert (1897). Since then, many reports have been made on various aspects of the geology of the Front Range. Regional summaries have been made by Lovering and Goddard (1950) on the Front Range mineral belt and by C. M. and M. F. Boos (1957) on the eastern flank of the Front Range.

This investigation is part of a program of detailed mapping in the central part of the Front Range by the U.S. Geological Survey. Mapping is in progress in some areas, and reports are also in preparation. Reports and maps have been published on the following areas:

- Trail Creek and Chicago Creek areas, west of Idaho Springs (Harrison and Wells, 1956, 1959)
- Central City area (Sims and others, 1963; Sims, 1964)
- Idaho Springs area (Moench, 1964; Moench and Drake, 1966)
- Ralston Buttes quadrangle, immediately to the south of the Eldorado Springs quadrangle (Sheridan and others, 1967)
- Golden quadrangle, immediately to the southeast (Van Horn, 1957a)
- Louisville quadrangle, to the east (Malde, 1955)
- Platte Canyon quadrangle (Peterson, 1964)
- Kassler and Littleton quadrangles, about 30 miles to the southeast (Scott, 1962, 1963 a, c).

A detailed report has been published on the structural and metamorphic geology of the entire body of quartzite and schist along Coal Creek, and on the relation of these rocks to the Idaho Springs Formation (Wells and others, 1964). The Eldorado Springs quadrangle includes a part of this quartzite and schist, and therefore the earlier report will be cited freely to avoid duplication.

The mapping of the Eldorado Springs quadrangle, at a scale of 1:20,000, was started in July 1957 and was continued through the summers of 1958, 1959, and 1961 by J. D. Wells. J. W. Adams did preliminary work in the Magnolia area in 1957; in 1959 John J. Halbert assisted in the mapping. W. A. Cobban and G. R. Scott identified fossil collections.

It is a pleasure to acknowledge the generous and courteous cooperation of the ranchers and property owners of the area who, without exception, allowed access to their lands.

DESCRIPTION OF ROCKS

The rocks in the Eldorado Springs quadrangle range in age from Precambrian to Recent. The Precambrian rocks consist of folded and sheared metasedimentary quartzite, schist, hornblende and biotite gneisses, and intrusive into these, Boulder Creek Granodiorite and a quartz monzonite. After the intrusion of these Precambrian igneous rocks, cataclastic gneisses were formed in the Idaho Springs–Ralston shear zone—the eastern part of a narrow northeast-trending shear zone that extends about 150 miles across central Colorado—and along some northwest-trending faults. Younger Precambrian igneous rocks—Silver Plume Granite, aplite, and pegmatite—were intruded after the shearing.

The Paleozoic and Mesozoic sedimentary rocks consist of a bedded sequence of conglomerate, arkose, sandstone, shale, and limestone that was folded and faulted during the Laramide orogeny and now dips about 50° E. Dikes of diabase and latite porphyry that cut the Precambrian and Paleozoic rocks were intruded during the Laramide orogeny.

Tertiary gravel deposits occupy a high level in the mountain area. Four levels of Pleistocene pre-Wisconsin gravel deposits were laid down on pediment surfaces east of the mountains. Wisconsin alluvial deposits occur in stream terraces.

Recent alluvial deposits are present in modern streams, and Recent colluvial deposits occur on the sides of the mountains and hills.

PRECAMBRIAN ROCKS

METASEDIMENTARY ROCKS

The Precambrian metasedimentary rocks in the Eldorado Springs quadrangle are hornblende gneiss, biotite gneiss, quartzite, and schist. The schist occurs as three separate layers in the quartzite. Small unmapped layers and pods of calc-silicate gneiss are present in the schist.

The rocks are folded and generally well foliated and lineated. The foliation is shown by oriented platy minerals, color or compositional layering, and surfaces of cataclastic shear. The foliation formed by platy minerals is almost everywhere parallel to compositional layering. The units are deformed into a series of complex folds ranging from broad mappable folds to minute crinkles. The schist and biotite gneiss, because of their lack of competency, are more intensely deformed than the other rocks. The lineations include mineral alinements and mineral streaking, fold axes, crinkle axes, slickensides, and boudinage.

The metamorphic history of the metasedimentary rocks along Coal Creek has been described by Wells, Sheridan, and Albee (1964), who recognized three periods of Precambrian metamorphism, probably reflecting three periods of structural deformation. According to these writers, the first period of metamorphism is represented by relict staurolite grains and relict microfolds, which probably formed at the same time. These are now included in andalusite and cordierite grains that were crystallized during the second period of metamorphism. Other components of high metamorphic grade—sillimanite with muscovite and locally microcline—were also formed at this time. This second metamorphism took place during folding of the Coal Creek syncline and intrusion of the Boulder Creek Granodiorite and the quartz monzonite. The third period of metamorphism is represented by shearing and recrytallization that took place during cataclastic deformation along the Idaho Springs–Ralston shear zone; there is only minor evidence of retrogressive metamorphism.

The lithologic units of this report are lithologic equivalents of units mapped by Lovering and Goddard (1950), Harrison and Wells (1956, 1959), Ball (1908), and Wells, Sheridan, and Albee (1964). Various names have been applied to the units in these reports. The tabulation below shows the names used in this report and the names given to equivalent units in earlier reports.

This report	Wells, Sheridan, and Albee (1964)	Lovering and Goddard (1950)	Harrison and Wells (1956, 1959)	Ball (1908)
Biotite gneiss	Biotite-quartz-plagioclase-gneiss and mica schist (biotite gneiss and mica schist).	Idaho Springs formation.	Biotite-quartz-plagioclase and biotite-quartz gneiss.	Idaho Springs formation.
Quartzite	Quartzite	Quartzite at Coal Creek.		
Schist layers in quartzite.	Schist in quartzite	Schist layers in quartzite.		
Hornblende gneiss and augen gneiss.	Augen gneiss and hornblende gneiss.	Included in the Idaho Springs formation and Swandyke hornblende gneiss.		
Cataclastic gneiss	Cataclastic gneiss			
Boulder Creek Granodiorite.	Boulder Creek granite.	Boulder Creek granite and quartz monzonite.	Granodiorite	Quartz monzonite.
Quartz monzonite	Quartz monzonite	Granite gneiss and gneissic aplite.		
Silver Plume Granite.		Silver Plume granite.	Biotite-muscovite granite.	Silver Plume granite.
Pegmatite and aplite.	Pegmatite and aplite.	Pegmatite	Pegmatite	Pegmatite.

Wells, Sheridan, and Albee (1964) showed that the quartzite and schist of the Coal Creek area grade into and are interlayered with gneiss typical of the Idaho Springs Formation, and that they have the same structural history and metamorphic grade as the Idaho

Springs. These writers therefore concluded that the quartzite and schist are a local facies of the Idaho Springs Formation.

HORNBLENDE GNEISS

The hornblende gneiss unit consists of an interlayered conformable sequence of hornblendic and biotitic gneisses. The layers range from a few feet to a few tens of feet in thickness, and most of them are hornblendic. These rocks are limited to the southeastern part of the area of Precambrian rocks, where they occur in northeast-trending bodies several hundred feet wide, interlayered conformably with cataclastic rocks (pl. 1). The hornblende gneiss itself shows extreme cataclasis. It is cut by thin highly sheared dikes that are probably part of the quartz monzonite unit.

In detail, some of the hornblende gneiss is massive and some is banded or finely layered. The massive variety is medium to fine grained and dark colored, although in detail it is finely mottled black and white. A specimen from 4,500 feet S. 6° E. of Coal Creek Peak contains 6 percent microcline, 36 percent plagioclase, 8 percent biotite, 49 percent hornblende, and 1.6 percent accessory minerals. The layered variety is fine grained and light colored, mostly white to pink, with black layers. The average composition is estimated to be about 60 percent feldspar (mostly plagioclase), 10 percent quartz, and 30 percent hornblende.

The hornblendic rocks within the hornblende gneiss unit grade into the biotitic rocks of the unit. These biotitic rocks are dark colored and layered black and white, and most specimens are corrugated in small folds. Some specimens show a conspicuous shear foliation. Modal analyses of two of the biotitic rocks from the hornblende gneiss unit are shown in table 1.

In thin sections the felsic minerals from the hornblende gneiss unit are generally broken and distorted, and the biotite is shredded and bent. The hornblende shows little effect of shearing. The plagioclase is oligoclase in the biotitic rocks and andesine in the hornblendic rocks. Microcline is absent from the biotitic rocks but present in hornblendic rocks. In the areas of intense shearing the plagioclase is poorly twinned.

BIOTITE GNEISS

The biotite gneiss crops out in the southeastern part of the area of Precambrian rocks, where it forms a northeast-trending layer that lies between the quartzite to the northwest and the cataclastic gneiss to the southeast (fig. 2). It is continuous with the biotite gneiss and mica schist unit of the Ralston Buttes quadrangle (Sheridan and others, 1967; Wells and others, 1964).

The biotite gneiss is a fine-grained layered black and white rock that consists predominantly of biotite, quartz, and plagioclase, and locally contains muscovite. The unit is well foliated and is highly folded or sheared in the intensely deformed parts of the Idaho Springs–Ralston shear zone. The mineral content of the biotite gneiss is shown in table 1. In these specimens the quartz is in grains that range from rounded to irregular anhedral. The plagioclase (calcic oligoclase) is mostly anhedral and occurs as small poorly twinned or untwinned grains in aggregates formed by the crushing of larger grains. A few residual well-twinned grains remain. Where muscovite is present, it is interlaminated with the biotite. Accessory minerals are zircon, apatite, and opaque minerals. Where they are abundant, the opaque minerals occur in layered concentrations parallel to the foliation.

TABLE 1.—*Modes (volume percent) of biotite gneiss*

	H-16D	H-33	H-36	H-98B	H-112
Quartz	36	27	16	14	34
Plagioclase	13	38	54	15	35
Biotite	28	29	29	69	27
Muscovite	22	--------	Tr.	Tr.	--------
Accessory minerals	Tr.	[1] 6	Tr.	1.4	4

[1] Includes 4.6 percent black metallic opaque minerals.

NOTES ON SPECIMENS

H-16D. From 5,000 ft S. 39° W. of Coal Creek Peak, NE¼ sec. 14, T. 2 S., R. 71 W.
H-33. From 4,300 ft S. 30° W. of Coal Creek Peak, NE¼ sec. 14, T. 2 S., R. 71 W.
H-36. Sheared; from 3,400 ft S. 6° W. of Coal Creek Peak, NW¼ sec. 13, T. 2 S., R. 71 W.
H-98B. Sheared; from hornblende gneiss unit from 4,000 ft S. 40° E. of Coal Creek Peak, NW¼ sec. 13, T. 2 S., R. 71 W.
H-112. Sheared; from hornblende gneiss unit from 4,800 ft S. 9° E. of Coal Creek Peak, SW¼ sec. 13, T. 2 S., R. 71 W.

To the southwest, in the Ralston Buttes quarangle, where muscovite schist forms a significant part of the unit, the occurrence of sillimanite and microcline together indicates that this part of the sillimanite zone of regional metamorphism is of higher grade.

QUARTZITE

Quartzite is exposed in the south-central part of the area (fig. 2), where this resistant rock forms Blue Mountain, Crescent Mountain, and Coal Creek Peak. The most extensive readily accessible exposures are along the steep walls of Coal Creek Canyon.

The main mass of the quartzite is in a syncline whose northeast-plunging axis extends from Coal Creek Peak southwestward for about 6 miles. Here the quartzite consists of four layers separated in most places by schist layers; the uppermost layer is conglomeratic on Coal Creek Peak, and the other layers are conglomeratic locally. The quartzite is intruded by quartz monzonite and rocks of the Boulder Creek batholith. Several large and small quartzite bodies lie within these igneous rocks west and north of the main synclinal body. Foliations and lineations in the outlying bodies of quartzite are parallel to those in the nearby main mass and indicate that the isolated bodies are probably roof pendants. The generally sharp contact between the quartzite and the igneous rocks is marked by a micaceous selvage. Although the quartz monzonite and Boulder Creek Granodiorite broadly outline the syncline, the contact is discordant in detail. The igneous rocks make up nine-tenths of the rock in contact with the quartzite; the remainder of the contact is with biotite gneiss in the southeastern part of the area.

The quartzite unit consists of interlayered generally well foliated fine- to coarse-grained quartzite and conglomeratic quartzite, all of which are rather micaceous. Mica flakes are generally oriented parallel to compositional layering, although foliations crossing compositional layering are known. Bedding in the quartzite unit is shown by layers having variations in color, grain size, and mineral composition. The layers, which are white, pale red, gray, and black, are a fraction of an inch to several hundred feet thick.

The conglomerate layers are discontinuous and are less than a foot to several tens of feet thick. The boundaries are sharp, and no graded bedding is evident. The pebbles, which are almost exclusively quartzite, are generally rounded and equidimensional to oval, although some are flat. Most pebbles are less than a inch across, but some are as much as several inches across; although most lie parallel to the bedding, a few groups are inclined as much as 20°, in a manner suggesting imbricate structure.

All the conglomerate and most of the quartzite is even bedded. In crossbedded layers noted locally, the bedding sets are lenticular, a few inches thick, and only slightly curved, and they transect other sets at angles generally less than 20°.

As mentioned earlier, four stratigraphic layers, separated through most of their extent by layers of schist, may be recognized. In ascending order, these are here referred to as layers A, B, C, and D. Layers A and B are generally white, light gray or pink, fine grained to locally conglomeratic, and locally micaceous. Layer C is generally gray and fine grained and has inconspicuous bedding; pink and white layers are also present. Almost all the specimens that contain andalusite are from this layer. Layer D is white to pink; it is fine grained and contains abundant lenses of conglomerate, some of which are arkosic.

The thickness of the quartzite layers varies from place to place. On the northern flank of the Coal Creek syncline, layer A is at least 400 feet thick, and if the outliers to the northwest are in true position with respect to the main body, the layer may be as much as 2,000 feet thick. Layer B is about 1,800 feet thick on Blue Mountain, but it thins to about 500 feet south of the mountain. Layer C is about 1,700 feet thick on Blue Mountain and 3,600 feet thick on Crescent Mountain, but only about 500 feet thick a mile southwest of Coal Creek Peak. Layer D is nowhere entirely exposed, but about 2,000 feet of it is present on Coal Creek Peak.

The structure of individual outcrops of the unit varies depending on lithology and location. Layers of massive quartzite commonly do not show small folds, but the micaceous varieties may show warps and folds that range from open to tight. Folding is commonly disharmonic, the micaceous layers being highly distorted. Locally, a cross-cutting foliation has formed parallel to the axial planes of tight drag folds, as a result of shearing by overstretching during the folding. Where cataclastic zones cross the quartzite, the effects range from minor breakage of mineral grains to formation of cataclastic foliation planes that obliterate all older structures.

The quartzite, on the average, is about 78 percent quartz and 12 percent muscovite. The remaining 10 percent of the rock consists of local concentrations of andalusite, plagioclase, microcline, tourmaline, or chlorite. Modal analyses (table 2) show the range of values. The andalusite occurs principally in layer C, and the specimens that contain feldspar are all from layer D. Accessory minerals are opaque minerals, zircon, apatite, epidote, and sphene.

TABLE 2.—*Modes (volume percent) of quartzite*

	H-41	H-54	H-87	G-1	H-7A	H-10	H-24	H-75	H-94	F-56	G-26	H-58
Quartz	88	78	70	84	60	64	56	93	80	87	91	82
Muscovite	10	20	22	6	Tr.	16	22	1.3	18	13	5	10
Biotite								Tr.				Tr.
Plagioclase		1	3									7
Microcline		Tr.	3									
Andalusite	Tr.			9			18	5			1.5	Tr.
Sillimanite								Tr.			Tr.	
Chlorite	Tr.		Tr.	Tr.		20		Tr.				
Tourmaline	Tr.	1	Tr.	Tr.	38	Tr.	Tr.		Tr.			
Accessory minerals	1	Tr.	1.6	Tr.	2.1	Tr.	4	Tr.	2	Tr.	2.1	Tr.

H-41. Conglomeratic, A layer; from south slope of Coal Creek Peak, SW¼ sec. 12, T. 2 S., R. 71 W.
H-54. Fine grained, A layer; from southwest slope of Coal Creek Peak, SE¼ sec. 11, T. 2 S., R. 71 W.
H-87. Arkosic coarse grained, A layer; from northeast slope of Coal Creek Peak, NW¼ sec. 12, T. 2 S., R. 71 W.
G-1. Banded gray and pale-red fine grained, B layer; from knob south of Coal Creek, NE¼ sec. 15, T. 2 S., R. 71 W.
H-7A. Layered black and white, rich in tourmaline, B layer; from east slope of ridge, NW¼ sec. 14, T. 2 S., R. 71 W.
H-10. Dark gray fine grained chloritic, B layer; from west slope of ridge, NW¼ sec. 14, T. 2 S., R. 71 W.
H-24. Pale red sheared, B layer; from a roadcut, NW¼ sec. 14, T. 2 S., R. 71 W.
H-75. Gray well jointed, B layer; from east slope of Crescent Mountain, SW¼ sec. 11, T. 2 S., R. 71 W.
H-94. Light gray, B layer; from ridge northwest of Crescent Mountain, NW¼ sec. 11, T. 2 S., R. 71 W.
F-56. White sugar textured, D layer; from stream level of South Draw 2,800 ft northeast of Quartz railroad siding.
G-26. Banded gray and white, C layer; from near quartz monzonite contact on west slope of Crescent Mountain, SE¼ sec. 10, T. 2 S., R. 71 W.
H-58. Arkosic conglomerate, A layer; from southwest slope of Coal Creek Peak, SE¼ sec. 11, T. 2 S., R. 71 W.

The quartz grains in the quartzite are anhedral and irregular to equant. The equant grains are virtually undeformed. In the cataclastically deformed rocks, the grains are strained and have irregular sutured boundaries. In thin section the boundaries of the pebbles are obscured by granulation but are faintly defined by opaque dust, mica, and andalusite in the cement or matrix. The fine grain of at least some of the quartzite is due to granulation.

Muscovite occurs in thin layers of flakes and books and as scrattered flakes between and parallel to these layers. Most of the muscovite is clear, but some contains minute opaque grains along cleavages. Much of it is shredded and bent, and in stringers along surfaces of intense shear it is very fine grained. Flakes of muscovite cut across individual lamellae of the biotite and also replace them. In some intensely deformed rocks, the muscovite is undeformed and has apparently recrystallized.

Plagioclase (oligoclase) and microcline occur as small anhedral grains that are broken and bent. They are apparently original detrital grains.

Andalusite occurs as scattered grains and layered concentrations and as granular aggregates, generally accompanied by opaque minerals. In conglomerate, it occurs as scattered fine grains between the pebbles. Poikiloblastic grains are uncommon in the quartzite, although they are abundant in the interlayered schist. The fact that some shear surfaces wrap around andalusite grains indicates that the andalusite was formed before the cataclastic deformation.

Several trace minerals are found in the quartzite. Sillimanite occurs as radiating needles around muscovite grains in specimens containing andalusite. Tourmaline is black in hand specimen, but in thin section most of the crystals are yellow in the center and green on the margin. Chlorite is an alteration product of biotite. Magnetite-ilmenite, hematite, and leucoxene occur in irregular aggregates, in individual grains, and as dust. The dust and concentrations of the opaque minerals cause the gray color of many of the rocks.

CONTACT EFFECTS WITH IGNEOUS ROCKS

A micaceous selvage exists along the contact between quartzite and the igneous rocks. Along some of the contact the selvage is only a few inches thick or is absent; however, it may be a few tens of feet thick. Where the selvage is well formed, typical quartzite grades into muscovite-rich schistose quartzite near the contact, which in turn grades through muscovite-rich igneous rock into typical quartz monzonite or Boulder Creek Granodiorite. The quartzite in the selvage zones differs from the normal quartzite only in an abundance of muscovite, which occurs in flakes and aggregates and cuts the biotite flakes. In the micaceous quartz monzonite, the micas occur as flakes and alined aggregates, and in some specimens they cut the feldspar grains. The plagioclase is oligoclase much like that in the typical

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quartz monzonite, but in some specimens the plagioclase is better twinned than is usual in the quartz monzonite. Some of the potassic feldspar in the micaceous quartz monzonite is microperthitic.

The modes of suites of specimens taken from the selvage zones in three localities are shown in table 3, where they are arranged so that the variations in mineralogy across the contact can be seen. For each suite, the far-left-hand column represents typical quartzite, and the far-right-hand column, typical quartz monzonite.

In each suite the quartz content gradually diminishes in the progression from quartzite to quartz monzonite. The muscovite content increases in the selvage and then diminishes in the vicinity of the quartz monzonite. Potassic feldspar and plagioclase are absent from the quartzite and from two of the selvage samples; only a small amount is present in the selvage specimen from Coal Creek. The potassic feldspar and plagioclase content increases from the selvage zone into the typical quartz monzonite. The biotite content is variable, but it generally increases toward the quartz monzonite.

The chemical composition of each of the specimens has been calculated (table 4) by use of the values for the composition of the minerals given by Wahlstrom (1947a, table 5). Average compositions have been computed for each part of the selvage zone: the quartzite, muscovite-rich quartzite from the selvage, micaceous quartz monzonite, and quartz monzonite.

From the table, it is evident that the chemical compounds are present in varying proportions and in different minerals, depending on the source of the specimens. The SiO_2 content decreases with the decrease in modal quartz. The Na_2O and CaO content increases with the increase in plagioclase into the quartz monzonite. The Al_2O_3 and K_2O increase sharply from the quartzite into the selvage; the Al_2O_3 decreases slightly from the selvage into the quartz monzonite, whereas the K_2O remains relatively constant. In the selvage zone the K_2O and Al_2O_3 are contained mostly in muscovite. As the muscovite in the micaceous quartz monzonite and quartz monzonite decreases progressively, more K_2O is contained in the potassic feldspar, and the Al_2O_3 is contained in the potassic feldspar and the plagioclase. The variations in H_2O reflect variations in the mica content, and the variations in Fe_2O_3, FeO, and MgO reflect variations in biotite and opaque minerals (mostly magnetite).

The chemical contact between the quartz monzonite and the quartzite is sharp at the quartzite-selvage contact except that there are variations in the Na_2O and CaO content. These are reflected in variations in mineralogy across the contact zone. The presence of these oxides led to the formation of abundant plagioclase in the quartz monzonite. The formation of the plagioclase used up Al_2O_3, so that the proportion of Al_2O_3 to K_2O was lowered; as a result, much potassic feldspar was

TABLE 3.—*Modes (volume percent) of specimens taken across the selvage zone at the contact of quartzite and quartz monzonite*

	South Boulder Creek suite				Quartz railroad siding suite				Coal Creek suite			
	F-118C	F-118A	F-118B	F-120	F-56	E-10A	E-10B	E-10C	G-26	G-53E	G-53F	G-53A
Quartz	(1)	44	42	30	87	57	49	32	91	43	30	27
Muscovite		40	33	7	13	42	24	5	5	46	11	5
Potassic feldspar			18	23			19	29		2.1	22	29
Plagioclase			5	30			4.7	30		4.4	34	33
Biotite		13		9		Tr.	2.2	Tr.		3.9	2.6	5
Andalusite						Tr.			1.5			
Sillimanite									Tr.			
Calcite			Tr.									
Tourmaline						Tr.						
Accessory minerals		2.4	1.7	Tr.	Tr.	Tr.	Tr.	3.3	2.1	Tr.	Tr.	Tr.

[1] Specimen is virtually pure quartz; no modal count made.

NOTES ON SPECIMENS

F-118C. White quartzite; from 50 ft from the west contact of the quartzite, South Boulder Creek canyon.

F-118A. Muscovite-rich quartzite from selvage, 10 ft from the west contact of the quartzite, South Boulder Creek canyon.

F-118B. Micaceous quartz monzonite; from 20 ft from the west contact of the quartzite, South Boulder Creek canyon.

F-120. Quartz monzonite; from about 200 ft from the west contact of the quartzite, South Boulder Creek canyon.

F-56. White sugar-textured quartzite; from stream level of South Draw 2,800 ft northeast of Quartz railroad siding.

E-10A. Muscovite-rich quartzite from selvage, about 10 ft from west contact of quartzite about 2,000 ft south of Quartz railroad siding.

E-10B. Micaceous quartz monzonite; from about 20 ft from locality E-10A.

E-10C. Typical quartz monzonite; from about 50 ft from quartzite contact, same locality as E-10A.

G-26. White quartzite from near contact 8,300 ft southeast of Coal Creek store, SW¼SW¼SE¼ sec. 10, T. 2 S., R. 71 W.

G-53E. Muscovite-rich quartzite from selvage, a few feet from contact 6,400 ft southeast of Coal Creek store, SE¼NW¼SW¼ sec. 10, T. 2 S., R. 71 W.

G-53F. Micaceous quartz monzonite from a few feet from the quartzite at same locality as G-53E.

G-53A. Typical quartz monzonite; from several feet from the quartzite at same locality as G-53E.

TABLE 4.—*Chemical composition of specimens taken across selvage zone (calculated from modal analyses shown in table 3)*

	SiO_2	Al_2O_3	Fe_2O_3+ FeO+ MgO	CaO	Na_2O	K_2O	H_2O
Quartzite:							
F–118C	100. 0	------	------	------	------	------	------
F–56	92. 3	5. 4	------	------	------	1. 6	0. 6
G–26	92. 2	3. 1	3. 8	------	------	. 6	. 2
Average	94. 8	2. 8	1. 3	------	------	. 7	. 3
Muscovite-rich quartzite from selvage:							
F–118A	65. 7	18. 0	8. 4	------	------	6. 1	2. 0
E–10A	75. 8	16. 9	------	------	------	5. 2	2. 0
G–53E	69. 0	20. 5	1. 3	0. 2	0. 4	6. 3	2. 3
Average	70. 1	18. 5	3. 2	. 1	. 1	5. 9	2. 1
Micaceous quartz monzonite:							
F–118B	70. 2	17. 4	3. 4	. 2	. 4	7. 0	1. 5
E–10B	76. 3	14. 8	. 7	. 2	. 4	6. 4	1. 2
G–53F	71. 4	17. 1	. 8	1. 7	3. 0	5. 3	. 5
Average	72. 6	16. 4	1. 6	. 7	1. 3	6. 2	1. 1
Quartz monzonite:							
F–120	70. 8	15. 9	3. 0	1. 5	2. 7	5. 6	. 4
E–10C	70. 1	14. 1	6. 1	1. 5	2. 6	5. 3	. 2
G–53A	71. 0	16. 2	1. 7	1. 6	2. 9	5. 9	. 4
Average	70. 6	15. 4	3. 6	1. 5	2. 7	5. 6	. 3

formed in the quartz monzonite. In the selvage, Na_2O and CaO are lacking and little plagioclase is present, and muscovite, a more aluminous mineral than potassic feldspar, appears in quantity.

SCHIST LAYERS IN QUARTZITE

Three major layers of schist alternate with the four layers of quartzite along the Coal Creek syncline. The lower layer crops out in the southwestern part of the area (sec. 17, T. 2 S., R. 71 W.) and extends into the Ralston Buttes quadrangle to the south (Wells and others, 1964, pl. 1). On the south limb of the syncline, the layer thins and is cut off at a small angle by the quartz monzonite; similar relations probably exist on the north limb, but the critical area is covered by surficial deposits. The middle layer extends from about 1 mile southwest of Coal Creek Peak (secs. 14 and 15, T. 2 S., R. 71 W.) southwestward around Blue Mountain and pinches out on the north side of the mountain (secs. 9 and 16, T. 2 S., R. 71 W.). It reappears along the northwest side of Crescent Mountain and extends northeastward to Eldorado Mountain, interrupted only by faults. The upper schist layer outlines the syncline around Coal Creek Peak and also atop Blue Mountain. The schist layers are in gradational contact with those of the quartzite, and the lower and middle layers contain many thin layers and lenses of quartzite.

The schist is well foliated, and most of it shows conspicuous mineral lineation. Crinkling of the foliation planes is common, and where this is intense, there may be a slip cleavage parallel to the axial planes of the crinkles. Locally the schist has been slightly to intensely deformed by cataclasis.

The schist layers in quartzite consist predominantly of muscovite, biotite, and quartz, with local occurrences of andalusite, cordierite, garnet, plagioclase, and staurolite (table 5). Opaque minerals are common and locally abundant. Muscovite and quartz are present in all specimens, but the quantities vary widely; muscovite ranges from 4 to 93 percent, and quartz ranges from a trace to 79 percent. Several specimens contain no biotite, although others contain as much as 43 percent. Andalusite is absent from the upper schist layer but is present in about half of the specimens from the middle and lower layers, where it makes up as much as 38 percent of the rock. Some specimens from the upper schist layer contain 3 percent plagioclase (oligoclase). Garnet is present in some specimens in amounts ranging from a trace to 4 percent, and cordierite is present in others, in amounts from 1 to 8 percent. Staurolite occurs sparsely in the middle schist layer. The accessory minerals are opaque minerals, which may constitute as much as 6 percent of the rock, and tourmaline, zircon, apatite, chlorite, and epidote.

Relict staurolite and microfolds visible in thin sections from the middle schist layer are useful for interpretation of the metamorphic and structural history of this area. The staurolite occurs only as inclusions in andalusite, where it forms irregular grains with rounded corners (Wells, and others, 1964, fig. 2). The staurolite grains within an andalusite crystal generally have a uniform extinction position and are regarded as evidence that staurolite has been replaced by andalusite.

The relict microfolds are defined by folded trains of elongate opaque mineral particles in andalusite poikiloblasts, and similar trains of quartz, opaque minerals, muscovite, biotite, and tourmaline in cordierite poikiloblasts (Wells and others, 1964, fig. 3). In both occurrences the microfolds are restricted to poikiloblasts. Since the poikiloblasts are undeformed, the microfolds must predate them.

Biotite and muscovite are intimately mixed in several different ways. About one-third of the specimens contain biotite books that are porphyroblastic subhedral to euhedral and as much as 3 mm across. The books are variously oriented at large angles to the compositional layering of the rocks, but elongate quartz inclusions within them are parallel to the layering. Seams of muscovite that contain lines of minute opaque grains along cleavage lamellae cut

TABLE 5.—*Modes (volume percent) of schist layers in quartzite*

	G-128A	G-128B	G-128C	H-20	H-28	H-50A	H-50B	H-51A	H-124	F-2	G-48	G-91B	H-7B	H-9	H-150
Quartz	44	30	Tr.	39	46	42	Tr.	18	47	39	32	79	45	31	42
Muscovite	51	65	93	52	4	21	50	56	23	30	5	6	35	11	6
Biotite					41	27	43	25	21	17	35	15	18	17	30
Plagioclase					3	3									
Andalusite										8	28		Tr.	38	20
Garnet					4										Tr.
Cordierite				1					8						
Staurolite										Tr.					1
Opaque minerals	5	5	6	6	1	6	6	Tr.	1	4	1	Tr.	1.6	1	Tr.
Tourmaline	Tr.			Tr.	Tr.	1	1	1	Tr.	Tr.			Tr.	Tr.	
Chlorite				1	Tr.					1				1	
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.		Tr.	Tr.	Tr.
Apatite				Tr.	Tr.				Tr.				Tr.		
Epidote	Tr.	Tr.	Tr.												

G-128A. Fine grained, upper layer; from Blue Mountain, NW¼ sec. 15, T. 2 S., R. 71 W.
G-128B. Isoclinally folded, fine grained, upper layer; from some locality as G-128A.
G-128C. Crinkled, upper layer; from some locality as G-128A.
H-20. Porphyroblastic, upper layer; from roadside southwest of Coal Creek Peak, SE¼ sec. 11, T. 2 S., R. 71 W.
H-28. Fine grained, gray, upper layer; from slope south of road southwest of Coal Creek Peak, NE¼ sec. 14, T. 2 S., R. 71 W.
H-50A. Interlayered quartz-rich and quartz-poor schist, upper layer; from west slope of Coal Creek Peak, SE¼ sec. 11, T. 2 S., R. 71 W.
H-50B. Same as H-50A.
H-51A. Fine grained, gray, upper layer; from near H-50A.
H-124. Porphyroblastic, upper layer; from south slope of Coal Creek Peak, NW¼ sec. 13, T. 2 S., R. 71 W.
F-2. Contains staurolite, middle layer; from the ridge north of Crescent Mountain, SW¼ sec. 2, T. 2 S., R. 71 W.
G-48. Rich in andalusite, middle layer; from the ridge west of Crescent Mountain, NE¼ sec. 10, T. 2 S., R. 71 W.
G-91B. Rich in quartz, lower layer; from northwest slope of Blue Mountain in the NE¼ sec. 17, T. 2 S., R. 71 W.
H-7B. Middle layer; from ridge southwest of Coal Creek Peak, NE¼ sec. 14, T. 2 S., R. 71 W.
H-9. Middle layer; from small body on northwest slope of the ridge at locality of H-7B.
H-150. Contains staurolite, middle layer; from 300 ft southwest of locality of H-7B.

through some of the large biotite grains and are deflected around others. Both the muscovite and biotite are deformed by crinkling.

Other specimens show an intimate mixture of interlaminated muscovite and biotite in which some muscovite flakes cut biotite grains and others grade into the biotite along the length of the lamellae. Some of the muscovite contains minute opaque minerals along cleavage surfaces. All the specimens shows crinkling, and in some the presence of shredded mica indicates cataclasis. Specimens that are only slightly deformed generally contain little muscovite.

Anhedral to euhedral garnet porphyroblasts, from 0.1 to 2.0 mm across, are present in two specimens. The garnet contains poikilitic inclusions of quartz; some biotite flakes are deflected around the crystals. The unit cell edge, a_0 is 11.596±0.003 A, and the refractive index is 1.798±0.004, according to determinations made by E. J. Young.

Magnetite-ilmenite and hematite are everywhere present and are locally abundant in the schist. Leucoxene is formed locally. These minerals occur as poikilitic inclusions in andalusite, cordierite, and quartz, lens-shaped grains between mica flakes, euhedral diamond-shaped crystals cutting through mica, and irregularly distributed grains scattered through the rock. The dark color of the andalusite and of some outcrops of schist is due to the opaque minerals.

Chlorite is commonly present in the rock as an alteration product of biotite, garnet, and cordierite. Locally, chlorite flakes are oriented across the foliation of biotite flakes. Tourmaline occurs as small euhedral zoned grains.

CALC-SILICATE ROCKS IN SCHIST

Quartz-rich calc-silicate rocks occur in pods or thin layers in the schist of the quartzite-schist sequence on the south slope of Coal Creek near the upper contact of the upper schist layer. The rock is layered and shows a well-developed foliation with subsequent folding and cataclastic deformation of moderate degree. It is fine grained and is green, gray, or white, depending on composition. The content of a representative sample, by modal analysis, is quartz, 57 percent; epidote, 23 percent; microcline, 13 percent; plagioclase (oligoclase-andesine), 1.3 percent; tremolite, 4 percent; sphene, 1.3 percent, and biotite, chlorite, opaque minerals, tourmaline, zircon, and apatite, trace amounts. Some layers are rich in epidote, tremolite, and sphene, and others are rich in quartz and microcline. Most of the grains are subhedral to anhedral.

Biotite occurs as anhedral flakes as much as 0.3 mm long scattered through quartz layers and as flakes as much as 0.5 mm long in epidote layers. Small anhedral grains of potassic feldspar occur as individual grains and aggregates largely concentrated in layers with quartz. There is some grid twinning, but it is usually poorly developed. Some of the grains are altered to clay minerals. Plagioclase (oligoclase-andesine, about An_{30}) is anhedral and shows poorly developed polysynthetic twinning. Tremolite laths as much as 1.5 mm long are oriented parallel to the compositional layers and occur largely in layered concentrations with epidote. Chlorite occurs as an alteration product in irregular patches, scattered blades, and radiating aggregates. Sphene in large anhedral to subhedral grains up to 0.5 mm long is scattered through the rock, mostly in the epidote-rich layers. The apatite occurs in euhedral crystals, some of which are as much as 1 mm across. Opaque minerals are in scattered patches up to 1 mm across. Tourmaline and zircon occur as scattered small crystals.

OLDER IGNEOUS ROCKS

The older Precambrian igneous rocks in the quadrangle, all of which are younger than the metasedimentary rocks, include part of the Boulder Creek batholith (Lovering and Goddard, 1950) and the quartz monzonite associated with the batholith. These Precambrian igneous rocks underlie the western two-thirds of the quadrangle except for the southern part, where the metasedimentary rocks are exposed (pl. 1). The Boulder Creek Granodiorite of the batholith predominates, and except for scattered dikes, the quartz monzonite occurs only in the southern part of the quadrangle, where it forms an irregular margin of the batholith and generally lies between the batholith and the metasedimentary rocks. In the southern part of the quadrangle the quartz monzonite has invaded the Boulder Creek batholith in an intricate way, and inclusions of the batholithic rocks occur in a wide variety of sizes and shapes in the quartz monzonite, clearly showing that the quartz monzonite is younger. These features can be seen in individual outcrops, such as that near the diversion dam 2 miles west of Eldorado Springs, as well as on the geologic map (pl. 1). Apparently the quartz monzonite is closely related to the batholith of Boulder Creek Granodiorite but slightly younger.

The contacts between the granodiorite and the quartz monzonite are sharp, but they are not obvious everywhere because these rocks have a similar aspect in outcrop and because the effects of minor cataclasis have obscured the characteristic differences between the two units. The structural similarities of the two rocks indicate a close genetic relation. The attitudes of foliation planes and lineations are continuous across the contacts, as is well shown in an outcrop 2 miles west of Eldorado Springs, on the geologic map (pl. 1), and by statistical plots, which show the same lineation trends in the Boulder Creek Granodiorite and the quartz monzonite.

BOULDER CREEK GRANODIORITE

The name Boulder Creek Granodiorite is applied to granitic to granodioritic rocks which are part of a batholith exposed along Boulder Creek west of Boulder (Lovering and Goddard, 1950). The Eldorado Springs quadrangle covers a part of this same batholith, and the name is applied also to smaller bodies of similar-appearing rock. The rock is gray, speckled black and white, medium to fine grained, and locally porphyritic. It consists mainly of biotite, potassic feldspar, plagioclase, and quartz, and hornblende is commonly present. The biotite occurs in aggregates and the feldspar grains are white or pinkish. Phenocrysts of potassic feldspar up to an inch long are common in the porphyritic varieties.

The foliation, which is generally weak, commonly takes the form of parallel orientation of elongate aggregates of quartz and feldspar and clusters of biotite in rocks with slight cataclasis. In rocks that show no cataclasis, foliation may consist of oriented feldspar phenocrysts most of which have small inclusions in parallel arrangement. In areas where both these types are present, no appreciable difference in the attitude of the foliation has been seen. In zones of intense cataclasis, the foliation in the zone may lie at a small angle, generally less than 45°, to the regional foliation, and the foliation surfaces may be crinkled. The cataclastic zones range from narrow zones a few feet in width, shown by symbol on the geologic map, to broad zones shown by pattern on the map. The boundaries are broadly gradational although locally they are abrupt. Mylonitic rocks occur in the Idaho Springs–Ralston shear zone in the southern part of the quadrangle and in thin discontinuous zones a few inches to several feet wide in the north.

Lineations consisting of rods of quartz and feldspar aggregates and elongate biotite clusters are present but poorly defined in the least deformed rocks, and absent in most of the undeformed rocks. In the Idaho Springs–Ralston shear zone and the small mylonitic zones, mineral streaking forms a conspicuous lineation. The lineations in the undeformed and the cataclasized granodiorite are generally parallel.

The composition of the Boulder Creek rocks in this area ranges from quartz monzonite to quartz diorite, and the average composition is granodiorite, as shown by the modes (table 6) and the plot of the modes on a triangular diagram (fig. 2*A*).

The mineral content is as follows: Quartz, 12–39 percent; microcline, absent to 41 percent; plagioclase, 23–68 percent; biotite, a trace to 33 percent; muscovite, absent to 7 percent; and hornblende, absent to 13 percent. Common accessory minerals are apatite, zircon, sphene, allanite, opaque minerals, and chlorite. Opaque minerals, epidote, and chlorite locally constitute a few percent of the rock.

TABLE 6.—*Mode (volume percent) of Boulder Creek Granodiorite*

	Quartz monzonite																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Quartz	34	16	26	25	22	24	25	32	33	25	12	38	27	35	23	23	29	39	24	31	31	26
Microcline	34	41	35	34	36	5	30	29	29	29	35	24	28	25	31	30	28	19	30	25	22	23
Plagioclase	26	35	30	29	33	51	33	32	32	32	40	27	32	30	38	37	35	25	34	35	35	40
Biotite	4	5	4	8	9	14	10	7	3	12	11	5	9	7	6	9	5	9	9	8	11	9
Muscovite	1.8	Tr.	3	----	----	----	----	1.0	1.9	Tr.	----	7	2.0	----	----	----	1.7	7	2.3	Tr.	Tr.	----
Hornblende	----	----	----	2.4	----	2.5	1.9	----	----	Tr.	1.7	----	----	2.0	1.0	----	----	----	----	----	----	Tr.
Accessory minerals	1.0	2.5	1.3	Tr.	Tr.	4	Tr.	Tr.	Tr.	2.0	Tr.	Tr.	1.5	Tr.	Tr.	1.4	Tr.	Tr.	Tr.	Tr.	Tr.	1.2

	Granodiorite																			Quartz diorite			
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Quartz	28	32	18	35	17	27	20	20	18	26	39	39	39	32	23	20	31	17	26	27	20	16	34
Microcline	20	16	22	16	20	17	16	15	14	13	9	5	8	8	8	8	5	5	4	Tr.	Tr.	Tr.	----
Plagioclase	40	35	49	37	46	44	43	43	41	43	37	23	45	47	54	55	50	56	47	44	50	68	49
Biotite	9	13	9	9	9	9	15	14	21	18	14	33	6	10	Tr.	12	11	17	21	29	21	14	17
Muscovite	2.3	3	----	----	----	1.7	----	----	----	Tr.	----	----	----	1.4	----	----	2.1	----	Tr.	Tr.	----	----	Tr.
Hornblende	----	----	1.6	1.3	7	----	4	Tr.	2.2	----	----	----	1.4	----	13	2.5	----	4	----	----	7	----	----
Accessory minerals	Tr.	Tr.	1.2	Tr.	1.3	Tr.	1.9	6.9	3.5	Tr.	1.3	Tr.	Tr.	1.6	1.9	2.1	Tr.	1.1	1.4	Tr.	2.0	Tr.	Tr.

NOTES ON SPECIMENS

1. From 2,900 ft S. 8° W. of Miramonte.
2. Highly porphyritic from 5,200 ft S. 39° E. of Miramonte.
3. Crushed; from 1,500 ft S. 26° W. of Scar Top Mountain on the west boundary of sec. 3, T. 2 S., R. 71 W.
4. Cataclastically deformed, porphyritic, from 6,200 ft N. 16° W. of Green Mountain, NE¼ sec. 2, T. 1 S., R. 71 W.
5. Sheared; from 4,600 ft N. 72° W. of Coal Creek store, SE¼ sec. 5, T. 2 S., R. 71 W.
6. From 2,000 ft S. 80° W. of Crescent railroad siding.
7. Porphyritic; from 4,700 ft N. 43° E. of Castle Rock.
8. From 2,200 ft N. 55° W. of Scar Top Mountain.
9. Cataclastically deformed, from 3,000 ft S. 35° E. of Quartz railroad siding, NW¼ sec. 2, T. 2 S., R. 71 W.
10. Cataclastically deformed; from knob near north boundary of sec. 17, T. 1 S., R. 71 W.
11. Porphyritic; from 1,000 ft S. 38° W. of South Boulder Peak, NW¼ sec. 24, T. 1 S., R. 71 W.
12. Cataclastically deformed; from 6,400 ft S. 50° E. of Coal Creek store, SW¼ sec. 10, T. 2 S., R. 71 W.
13. Cataclastically deformed; from SE¼ sec. 7, T. 2 S., R. 71 W., 3,100 ft north and 1,000 ft east of the quadrangle boundaries.
14. From 1,500 ft N. 58° W. of Bear Peak, SW¼ sec. 13, T. 1 S., R. 71 W.
15. From 3,200 ft S. 55° W. of South Boulder Peak, SE¼ sec. 23, T. 1 S., R. 71 W.
16. Cataclastically deformed; from 2,000 ft N. 50° W. of Shirt Tail Peak.
17. Cataclastically deformed; from 3,500 ft due south of Coal Creek store, NW¼ sec. 9, T. 2 S., R. 71 W.
18. Cataclastically deformed; from 2,200 ft N. 52° W. of southwest point of Crescent Mountain, NW¼ sec. 10, T. 2 S., R. 71 W.
19. Cataclastically deformed; from NW¼ sec. 8, T. 2 S., R. 71 W., 6,200 ft north and 3,200 ft east of the quadrangle boundaries.
20. From 2,500 ft S. 60° W. of Coal Creek store on west boundary of sec. 9, T. 2 S., R. 71 W.
21. Sheared; from 6,100 ft due west of Shirt Tail Peak.
22. From 1,400 ft due east of Tram Hill, NE¼ sec. 3, T. 1 S., R. 71 W.
23. From SE¼ sec. 7, T. 2 S., R. 71 W., 5,200 ft north and 800 ft east of the quadrangle boundaries.
24. Cataclastically deformed; from 2,000 ft N. 58° W. of Eldorado Mountain.
25. Porphyritic; from 3,000 ft S. 75° E. of Castle Rock.
26. From 6,900 ft N. 86° W. of Shirt Tail Peak.
27. From 2,300 ft S. 60° W. of Kossler Lake, SW¼ sec. 10, T. 1 S., R. 71 W.
28. Cataclastically deformed; NE¼ sec. 7, T. 2 S., R. 71 W., 7,500 ft north and 800 ft east of the quadrangle boundaries.
29. From 2,800 ft N. 85° W. of Tram Hill, NE¼ sec. 4, T. 1 S., R. 71 W.
30. From Winiger Ridge in west central part of quadrangle, 1,500 ft from west boundary.
31. From 5,200 ft N. 43° W. of Bear Peak, NE¼ sec. 14, T. 1 S., R. 71 W.
32. Sheared; from 500 ft N. 45° E. of Quartz railroad siding.
33. Cataclastically deformed; from 2,700 ft N. 55° W. of Bear Peak, SW¼ sec. 13, T. 1 S., R. 71 W.
34. Cataclastically deformed; from 6,600 ft S. 50° W. of Coal Creek Peak, NW¼ sec. 14, T. 2 S., R. 71 W.
35. From 6,900 ft S. 60° W. of South Boulder Peak.
36. From 2,000 ft N. 65° W. of Quartz railroad siding.
37. From Magnolia, 1,800 ft south and 1,500 ft east of quadrangle boundaries.
38. Cataclastically deformed; from near Magnolia, 1,700 ft south and 3,500 ft east of the quadrangle boundaries.
39. From 3,800 ft N. 7° W. of Bear Peak, NW¼ sec. 13, T. 1 S., R. 71 W.
40. From Magnolia area, 300 ft south and 1,100 ft east of quadrangle boundaries.
41. Crushed; from knob marked with the elevation of 8,436 ft, sec. 7, T. 1 S., R. 71 W.
42. Sheared and crinkled; from 5,500 ft N. 35° E. of Kossler Lake, SW¼ sec. 2, T. 1 S., R. 71 W.
43. From Magnolia area, 6,800 ft south and 250 ft east of quadrangle boundaries.
44. From Magnolia shear zone, 1,100 ft south and 3,400 ft east of quadrangle boundaries.
45. From near quartzite contact on Eldorado Mountain.

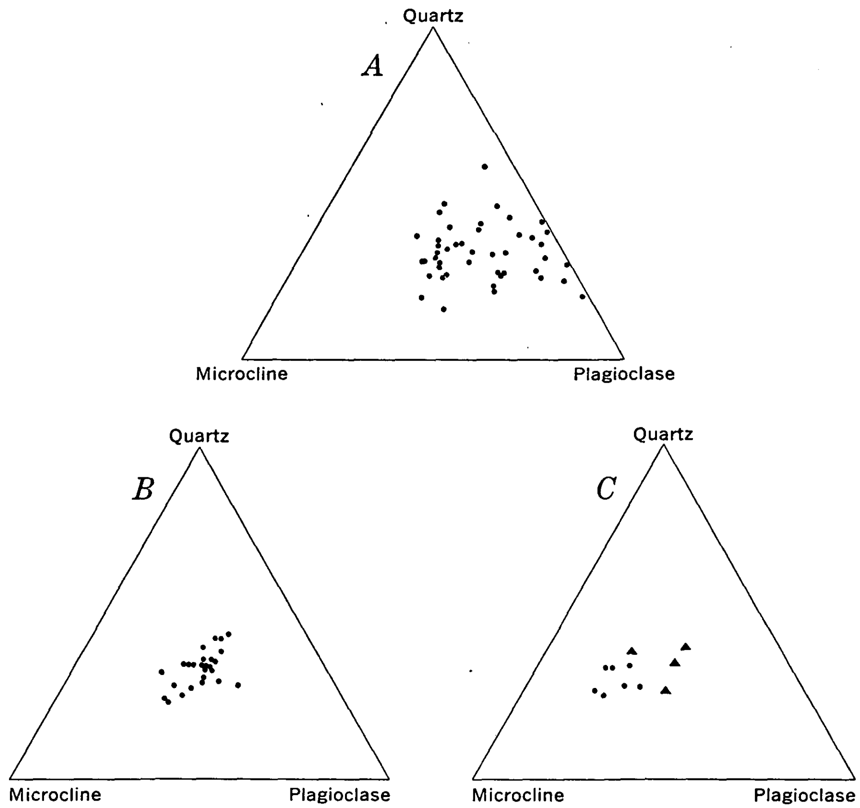

FIGURE 2.—Variations in mineralogical composition (volume percent). *A*, Boulder Creek Granodiorite; *B*, quartz monzonite; and *C*, Silver Plume Granite (●) and associated aplite (▲).

Hornblende and muscovite were found together in only one specimen, which contains each in trace amounts. The combination does not represent a rock type, but merely reflects the propinquity of the quartz monzonite unit. Of 21 specimens collected from the quartz monzonite in the southern part of the area, 18 contain muscovite and none contains hornblende. Of 25 specimens collected in the north, only 4 contain muscovite, but 20 contain hornblende.

The geographic distribution of the various rock types is not well defined. Rocks of similar composition are grouped into several crude northwest-trending belts. No attempt is made here to interpret this feature because data from the entire batholith are lacking.

Quartz occurs as small rounded anhedral grains and aggregates in the least deformed rocks. In mortar zones in cataclastic rocks, the grains are as small as 0.01 mm and have sutured boundaries. Vermicular intergrowths with plagioclase are present locally.

Potassic feldspar occurs as anhedral to subhedral grains and stringers. Phenocrysts generally show combination Carlsbad and grid twinning. Many contain inclusions of biotite, quartz, and plagioclase that may be zonally arranged; these minerals also fill fractures and form replacement trains along fractures in the potassic feldspar. The phenocrysts in the most deformed rocks are only partially twinned and are commonly changed in shape to augen or crushed to an aggregate of smaller grains. The medium-grained crystals are anhedral, generally twinned, and locally perthitic. In the cataclastic zones, thin stringers and fine grains of potassic feldspar fill interstitial areas between quartz and plagioclase grains.

The plagioclase (oligoclase-andesine) varies in its characteristics with degree of cataclasis. In seams in which cataclasis is intense, the plagioclase is in very fine anhedral grains with sutured boundaries and there is little twinning. In moderately deformed rocks, it is in rounded aggregates of rounded fine grains that show only faint or weak twinning; some grains are bent. In undeformed or slightly deformed rocks, it is in large subhedral grains that show well-developed polysynthetic twinning and Carlsbad twinning. The plagioclase is locally myrmekitic, and in the southwestern part of the area some of the grains have albitic borders along their contact with microcline.

Biotite, the principal mica, is in aggregates and individual flakes imperfectly alined to form a foliation, and muscovite, if present, is generally associated with it. The biotite and muscovite show the same deformational effects, although locally the biotite is bent, whereas the muscovite is undeformed. These features indicate that the muscovite is the younger and that deformation intervened between formation of these two micas. Large muscovite flakes up to 2 mm long cut through the other minerals locally and include them poikilitically. In the undeformed parts of the rock the flakes are 0.1–2 mm long and form aggregates as much as 5 mm across. In rocks showing slight to moderate cataclasis, some small mica flakes, predominantly biotite, occur between the feldspar and quartz grains, but most of the mica occurs in undeformed flakes that are larger than quartz and feldspar grains. These flakes have at least partly recrystallized after some cataclasis.

The hornblende occurs in subhedral to anhedral grains which are generally 1–4 mm across and are associated with the biotite. Many of the anhedral crystals are poikilitic with inclusions of quartz and plagioclase.

Opaque minerals are mainly magnetite-ilmenite but include leucoxene in irregular fine grains. In some of the intensely deformed rocks, sphene forms rims around the irregular opaque minerals. Sphene also occurs as individual crystals. Epidote replaces biotite and hornblende and forms layers in some of the cataclastic seams. Chlorite occurs mostly as an alteration product of biotite. Apatite, zircon, and allanite occur as scattered individual grains.

INCLUSIONS IN THE BOULDER CREEK GRANODIORITE

Many small thin inclusions of dark-colored fine-grained hornblendic rocks, generally less than a foot long, are present in the granodiorite of the northern part of the area. The boundaries are sharp except where areas of abundant inclusions are bordered by irregular, gradational reaction zones several tens of feet across.

Modal analyses of two inclusions and one specimen of contaminated granodiorite from a reaction zone are shown in table 7. Both inclusions contain abundant hornblende, biotite, and plagioclase, but they differ markedly in quartz and microcline content. The plagioclase (andesine) shows Carlsbad, pericline, and albite twinning. The hornblende and biotite grains are anhedral to euhedral and occur together without apparent replacement textures. The accessory minerals are apatite, zircon, sphene, and allanite.

In the specimen of contaminated Boulder Creek Granodiorite, replacement textures are common; microcline and hornblende show poikilitic inclusions. The inclusions in the microcline are grains of all the other minerals, and the inclusions in the hornblende are quartz.

TABLE 7.—*Modes (volume percent) of inclusions in the Boulder Creek Granodiorite*

	A-98B	C-1A	C-1B
Quartz	6	Tr.	2.2
Microcline	Tr.	21	18
Plagioclase	54	24	32
Biotite	14	12	13
Hornblende	23	40	31
Accessory minerals	3	3	4

NOTES ON SPECIMENS

A-98B. From Magnolia area, 6,800 ft south and 250 ft east of the quadrangle boundaries.
C-1A. From 3,200 ft west of Castle Rock.
C-1B. Contaminated Boulder Creek Granodiorite; from same locality as C-1A.

QUARTZ MONZONITE

The quartz monzonite is a gray fine- and medium-grained igneous rock that weathers pinkish gray. The rock consists mainly of quartz, potassic feldspar, plagioclase, muscovite, and biotite. Although locally the contact between fine- and medium-grained rock phases is sharp enough to be mapped, it is typically gradational and the two varieties are not distinguished on the geologic map. Along South Boulder Creek, angular fragments of the medium-grained rock are included in the fine-grained variety, which shows that the fine-grained rock is the younger. The medium-grained rock phase is locally porphyritic in areas where cataclasis is lacking. Most of the rock shows a weak foliation and lineation formed by moderate to slight cataclasis. The lineation is evident in alinement and streaking of biotite flakes.

The quartz monzonite in the report area has been called granite gneiss and gneissic aplite by Lovering and Goddard (1950), but the quartz monzonite is not equivalent to all the rocks shown by them to be part of the granite gneiss and gneissic aplite elsewhere in the Front Range.

The modes (table 8) and a triangular diagram (fig. 2*B*) show that the rock ranges in composition from quartz monzonite to granodiorite and that the average composition is quartz monzonite. No consistent variation can be correlated with grain size, degree of cataclasis, or location, although the specimens with least plagioclase are among the most intensely deformed rocks. The rock contains 21–42 percent quartz, 17–44 percent microcline, and 23–43 percent plagioclase. The mica content varies, ranging from trace amounts to 14 percent biotite, and from trace amounts to 14 percent muscovite. Accessory minerals zircon and apatite are commonly present; opaque minerals and sphene are locally abundant. Chlorite is absent from most specimens but is abundant in a few.

Quartz occurs as fine anhedral rounded to sutured grains in undeformed rocks, and in grains as small as 0.01 mm in cataclastic seams. The grains are scattered through the rock, are grouped as medium-grained aggregates, and fill fractures in microcline.

Microcline is in subhedral to anhedral fine and medium grains in the least deformed rocks. The larger grains are commonly broken, and the fractures are filled with biotite, quartz, and plagioclase. The least deformed crystals show pronounced grid twinning, commonly in combination with Carlsbad twinning. In the intensely deformed specimens, twinning is sparse or absent. Film perthite is locally present.

Plagioclase has the composition of oligoclase and occurs as subhedral to anhedral grains that are fine to medium grained. Most of the larger grains in slightly deformed or undeformed rocks show strong albite twinning that is locally combined with pericline twinning. In the slightly and moderately deformed rocks, the large grains are partly or completely broken to form an aggregate of untwinned or partly twinned grains about 0.2 mm in diameter. Plagioclase in the intensely deformed rocks is almost totally untwinned and generally less than 0.1 mm across. Many of the plagioclase grains have albitic rims where they are in contact with microcline. In most such grains, twinning is continuous from the core into the albitic border. In general, the border is clear whereas the core is cloudy.

Biotite and muscovite are closely associated in the quartz monzonite and occur as fine flakes and aggregates in an imperfect alinement. In rocks showing slight or moderate cataclasis, the mica, predominantly biotite, occurs as undeformed, possibly recrystallized, flakes in a granulated matrix of quartz and plagioclase that is finer grained

TABLE 8.—*Modes (volume percent) of quartz monzonite*

	Quartz monzonite																									Grano-diorite
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Quartz	30	21	23	28	28	24	31	30	34	32	30	29	33	36	25	29	34	30	29	37	35	36	35	42	28	38
Microcline	40	42	44	41	29	36	28	28	25	29	25	30	30	29	29	27	32	23	29	22	20	23	20	19	24	17
Plagioclase	23	26	29	28	23	28	35	26	25	30	26	32	33	33	33	33	27	30	39	30	28	34	34	34	43	32
Biotite	3	11	3	1.1	5	7	3	13	7	Tr.	14	7	1.5	Tr.	12	10	4	9	2.2	5	8	3	1.6	1.6	2.9	7
Muscovite	4	Tr.	Tr.	2.0	14	3	Tr.	1.9	7	5	4	1.3	1.4	1.9	-----	.7	2.2	7	Tr.	4	9	3	9	2.1	1.3	4
Accessory minerals	Tr.	Tr.	Tr.	Tr.	Tr.	1.5	3.5	Tr.	1.3	3.3	Tr.	Tr.	Tr.	Tr.	1.2	Tr.	Tr.	Tr.	Tr.	1.5	Tr.	Tr.	Tr.	1.4	Tr.	1.6

NOTES ON SPECIMENS

1. From hill marked with the elevation 8,436 ft, east-central part of sec. 7, T. 1 S., R. 71 W.
2. From 2,000 ft south of the north boundary of quadrangle, near north-south center-line of sec. 5, T. 1 S., R. 71 W.
3. Medium-grained rock phase; from 500 ft N. 45° E. of Quartz railroad siding.
4. From SW cor. sec. 8, T. 2 S., R. 71 W.
5. From 3,600 ft S. 53° E. of Coal Creek store.
6. From knob 6,300 ft S. 66° W. of Castle Rock.
7. From South Draw near contact with Boulder Creek rocks, 4,200 ft northwest of Eldorado Mountain.
8. Porphyritic, medium-grained rock phase; from 5,200 ft N. 75° W. of Shirt Tail Peak.
9. From near Coal Creek 2,100 ft west of southwest ridge of Cresent Mountain, SE¼SW¼ sec. 10, T. 2 S., R. 71 W.
10. From about 50 ft from quartzite contact about 2,000 ft south of Quartz railroad siding, NE¼ sec. 3, T. 2 S., R. 71 W.
11. Cataclastically deformed; from 5,500 ft west of Shirt Tail Peak.
12. From 3,500 ft west of Blue Mountain, SW¼SW¼ sec. 17, T. 2 S., R. 71 W.
13. From 2,600 ft N. 73° W. of Scenic railroad siding.
14. From 3,700 ft N. 30° W. of Eldorado Mountain.
15. Sheared; 6,100 ft west of Shirt Tail Peak.
16. From near South Boulder Creek 5,300 ft N. 87° W. of Shirt Tail Peak.
17. From 9,500 ft N. 67° W. of Coal Creek store, NE¼ sec. 6, T. 2 S., R. 71 W.
18. From 200 ft from the west quartzite contact, 2,900 ft S. 70° W. of Shirt Tail Peak, South Boulder Creek canyon.
19. From 3,000 ft S. 88° W. of Castle Rock.
20. From 2,200 ft S. 65° E. of Coal Creek store, NE¼NE¼ sec. 9, T. 2 S., R. 71 W.
21. Porphyritic, medium-grained rock phase; from ridge 3,700 ft N. 73° W. of Shirt Tail Peak.
22. From 1,600 ft west of Shirt Tail Peak.
23. From 6,400 ft S. 49° E. of Coal Creek store, SW¼ sec. 10, T. 2 S., R. 71 W.
24. From near quartzite contact 5,900 ft S. 47° W. of Eldorado Mountain, SW¼SW¼ sec. 2, T. 2 S., R. 71 W.
25. From 3,800 ft S. 71° W. of Shirt Tail Peak.
26. From same location as 23.

than the mica. Some of the muscovite flakes seem to be younger than the biotite because they cut or replace biotite; where muscovite replaces biotite, it contains minute opaque grains along the cleavage planes. Locally the biotite is altered to chlorite.

Most of the accessory minerals occur as scattered grains. In some of the most deformed specimens, sphene crystals rim irregular opaque minerals, and epidote is aggregated in layers parallel to the shear directions.

CATACLASTIC ROCKS

The Idaho Springs-Ralston shear zone in the southeastern part of the mapped area (pl. 1) contains many varieties of intensely deformed rock. Correlation of some of these rocks with the parent material can be made from less deformed rocks into which they grade, or from their distinctive composition. Those rocks which cannot be identified have been mapped separately as either augen gneiss or cataclastic gneiss. The augen gneiss characteristically contains prominent small pink feldspar clasts or augen in a well-foliated biotitic matrix; the cataclastic gneiss is mostly a granular poorly foliated quartz-feldspar rock accompanied by a small amount of well-foliated biotitic rock. As map units, each contains small bodies of the other, and contacts between the two units are generally gradational.

AUGEN GNEISS

The augen gneiss crops out near the southern border of the quadrangle in two northeast-trending layers separated by hornblende gneiss (pl. 1), and there are small lenses of hornblende gneiss within the augen gneiss unit.

The augen gneiss is a fine-grained well-foliated rock ranging from pinkish gray to pink. It is characterized by white to pink porphyroclasts of feldspar, 0.2–2.5 mm in diameter, in a fine-grained matrix. The rock is mostly quartz, plagioclase, and potassic feldspar, but it contains lesser amounts of biotite, muscovite, epidote, and pennine (chlorite). Accessory minerals are sphene, zircon, apatite and opaque minerals. Modal analyses of two specimens are shown in table 9. The pennine occurs in veins with epidote and appears to replace biotite elsewhere in the specimen. The epidote occurs as a mass of crystals filling fractures. Both the epidote and pennine are apparently products of some late period of recrystallization. Most thin sections of augen gneiss show prominent mortar structure and a succession of parallel granulated zones. In some of the granulated areas, there is unbroken quartz and mica which may have recrystallized.

CATACLASTIC GNEISS

The cataclastic gneiss unit forms a northeast-trending belt between biotite gneiss and augen gneiss units in the southeastern part of

TABLE 9.—*Modes (volume percent) of augen gneiss*

	H-35C	H-100
Quartz	24	36
Microcline	4	28
Plagioclase	49	26
Biotite	----------	8
Pennine	8	----------
Muscovite	1.1	3
Epidote	12	----------
Accessory minerals	1.2	Tr.

NOTES ON SPECIMENS

H-35C. From the SE¼SE¼NE¼ sec. 14, T. 2 S., R. 71 W.
H-100. From the NE¼NE¼ sec. 13, T. 2 S., R. 71 W.

the area (pl. 1). The belt is 400–900 feet wide and thins to the southwest in the Ralston Buttes quadrangle, where it is much better exposed and has been described by Sheridan, Maxwell and Albee (1967).

The cataclastic gneiss consists principally of layers or zones of poorly foliated fine-grained light-colored quartz-feldspar rock alternating with thinner layers of slightly coarser dark-colored biotitic gneiss that contains feldspar augen. Northeastward the light-colored quartz-feldspar fraction grades into a mottled green and pink poorly foliated epidote-quartz rock. A specimen of the dark-colored gneiss contains 34 percent quartz, 2 percent potassic feldspar, 37 percent plagioclase (andesine), 22 percent biotite, 2 percent epidote-clinozoisite, 2 percent opaque minerals, and a trace of sphene, zircon, apatite, allanite, and sericite. A specimen of the light-colored gneiss contains 48 percent quartz, 27 percent potassic feldspar, 12 percent plagioclase (oligoclase), 2 percent biotite, 8 percent muscovite, 2 percent epidote-clinozoisite, and a trace of opaque minerals, apatite, allanite, and sericite. A specimen of the quartz-epidote rock contains 25 percent quartz, 74 percent epidote, and a trace of opaque minerals, sphene, and sericite (Sheridan and others, 1967, table 16). Thin sections of these rocks show pervasive crushing and many parallel or anastomosing granulated zones. These zones locally contain younger and undeformed epidote or muscovite.

YOUNGER IGNEOUS ROCKS

Silver Plume Granite, aplite, and pegmatite are closely associated in space, time, mode of occurrence, and origin. Exposures of Silver Plume Granite are concentrated in two areas in the northern part of the quadrangle. One in the Magnolia area consists of irregular bodies with extending dikes; the other, southeast of the first, near Green Mountain, consists of an irregular body with many irregular inclusions of Boulder Creek Granodiorite. Many dikes, only the larger and more continuous of which have been mapped, are scattered through the intervening area and southward nearly to South Boulder Creek.

Dikes of aplite and pegmatite, which cut Silver Plume Granite, are scattered over much the same area as the Silver Plume Granite dikes but are concentrated near Green Mountain and on South Boulder Creek. Small discontinuous dikes of pegmatite or aplite are scattered sparsely throughout the igneous terrane. The dikes are virtually absent from the metasedimentary rocks; only one example of pegmatite intruding the quartzite is known.

The close association of the aplite and pegmatite with the Silver Plume Granite is well illustrated by a dike (too small to be shown on the geologic map) that extends from a body of Silver Plume and grades from granite into aplite and pegmatite. Aplite and pegmatite occur together in many dikes, and irregular bodies of pegmatite occur in the large bodies of aplite near South Boulder Creek northwest of Quartz railroad siding.

Silver Plume Granite, aplite, and pegmatite lack the cataclastic structure characteristic of the rocks they intrude. Silver Plume Granite that cuts the zone of intense cataclasis in the Magnolia area is undeformed, as are the Silver Plume Granite, aplite, and pegmatite that cut the moderately or slightly deformed Boulder Creek Granodiorite and the quartz monzonite in many areas. In the area south of the Coal Creek syncline, undeformed pegmatite cuts the Idaho Springs-Ralston shear zone (Wells and others, 1964).

The radioactivity of the Silver Plume Granite is about 2–3 times as high as that of the older igneous rocks, and the radioactivity of the pegmatite and aplite is intermediate.

SILVER PLUME GRANITE

The Silver Plume Granite is a tan medium-grained seriate porphyritic rock consisting mostly of quartz, microcline, plagioclase, and biotite with small amounts of muscovite and accessory minerals. The phenocrysts are tabular microcline crystals; commonly, they are imperfectly alined and delineate a vague foliation that is represented by symbols on the geologic map (pl. 1).

The composition of the Silver Plume Granite is shown by modal analyses (table 10) and by a triangular diagram (fig. 2*C*).

The quartz occurs in the granite as anhedral grains that characteristically contain many hairlike inclusions of rutile(?). The microcline occurs as euhedral to subhedral tabular crystals that are commonly zoned and show grid and Carlsbad twinning. In some crystals there is zoning marked by minute inclusions. The plagioclase is in subhedral to anhedral grains; most show pericline and albite twinning, and some show Carlsbad twinning. The plagioclase, which is calcic oligoclase, has an albitic border where the grains are in contact with

TABLE 10.—*Modes (volume percent) of Silver Plume Granite*

	Granite					Quartz monzonite	
	1	2	3	4	5	6	7
Quartz	25	31	23	31	26	30	27
Microcline	52	47	49	45	44	39	39
Plagioclase	18	18	20	19	25	23	28
Biotite	2.9	4	4	4	3	6	4
Muscovite	Tr.	Tr.	1.7	1.1	1.5	1.1	1.2
Accessory minerals	1.4	Tr.	2.8	Tr.	Tr.	Tr.	1.4

NOTES ON SPECIMENS

1. From 6,000 ft N. 19° W. of Castle Rock, SW¼ sec. 16, T. 1 S., R. 71 W.
2. From SW cor. sec. 4, T. 1 S., R. 71 W., in Magnolia area.
3. From 5,200 ft S. 75° W. of Green Mountain, SW¼ sec. 11, T. 1 S., R. 71 W.
4. From 2,700 ft S. 38° W. of Kossler Lake, NW¼ sec. 15, T. 1 S., R. 71 W.
5. From 700 ft N. 62° E. of Green Mountain, NE¼ sec. 10, T. 1 S., R. 71 W.
6. From hill marked with elevation 8,436 ft in east-central part of sec. 7, T. 1 S., R. 71 W.
7. From 5,200 ft N. 50° W. of Green Mountain, SW¼ sec. 2, T. 1 S., R. 71 W.

microcline. The biotite occurs as randomly oriented flakes, some of which show pleochroic halos. Some of the muscovite is apparently primary and some replaces biotite and feldspar. The accessory minerals consist of zircon, apatite, and opaque minerals, which are locally abundant; allanite, chlorite, and sphene are present in some places.

APLITE AND PEGMATITE

The aplite and pegmatite occur mostly as steep-walled dikes a few inches to a few tens of feet wide and a few hundred to a few thousand feet long. The aplite dikes are generally longer than those of pegmatite; one west of Green Mountain extends about 2.5 miles. In the south-central part of the quadrangle, aplite also occurs in two large irregular bodies.

The aplite is a fine-grained pale-red rock consisting of quartz, plagioclase, microcline, muscovite, and locally, biotite. In hand specimen the rock may be distinguished from other fine-grained rocks, in particular from the finer grained phase of the quartz monzonite unit, by the characteristic red-flecked appearance resulting from concentrations of red iron oxide along grain boundaries, especially around the mica.

The mineralogy of the aplite is shown by modal analyses (table 11) and on a triangular diagram (fig. 2*C*). The ratio of microcline to plagioclase indicates a quartz monzonite composition, but the plagioclase is albite-oligoclase and the rock is therefore alkalic. The plagioclase has albitic borders adjacent to the microcline and has poorly developed twinning. The mica flakes occur as small aggregates and as scattered individual flakes, most of which are less than a millimeter long. Some skeletal muscovite replacing plagioclase is present.

TABLE 11.—*Modes (volume percent) of aplite*

	C-70	D-7	D-86	E-31
Quartz	26	35	35	33
Microcline	34	32	36	29
Plagioclase	35	22	20	33
Biotite	------	------	1.9	------
Muscovite	5	11	7	5
Accessory minerals	Tr.	Tr.	Tr.	Tr.

C-70. From 600 ft N. 70° E. of Walker Ranch.
D-7. From small dike 3,800 ft N. 36° W. of Shirt Tail Peak on south boundary of sec. 24, T. 1 S., R. 71 W.
D-86. From 3,000 ft S. 77° W. of Bear Peak, SE¼ sec. 14, T. 1 S., R. 71 W.
E-31. From 8,400 ft N. 62° W. of Eldorado Mountain.

Locally the mica flakes are bent. The accessory minerals are zircon, opaque minerals, apatite, and locally epidote.

Most of the pegmatite is white and has quartz and microcline crystals as much as a few inches across; perthite is a common constituent in the northern part of the quadrangle. Muscovite is generally present and biotite occurs locally. Magnetite is sparse. The dikes are zoned and unzoned and most are intimately mixed with aplite. A typical zoned pegmatite in the Magnolia area is about 15 feet wide and has a 2-foot-wide wall zone of perthite, quartz, and magnetite, and a core of quartz. Some small dikes consist only of white quartz. Allanite in crystals as much as 2 inches long occurs in a few dikes in the Magnolia area.

CHEMICAL COMPOSITION OF PRECAMBRIAN IGNEOUS ROCKS

In table 12, chemical analyses of 14 Precambrian igneous rock samples from the Eldorado Springs quadrangle are presented. (Samples were supplied by George Phair and David Gottfried, and the analyses were made for investigations of uranium and thorium in igneous rocks.)

All the Boulder Creek rock samples were taken from the northern part of the quadrangle in the area where hornblende is commonly present. One sample of quartz monzonite is from the coarser grained rock phase and two are from the finer grained rock phase. The Silver Plume Granite samples are typical of the unit in this area.

The triangular diagram (fig. 3) shows the Na_2O–CaO–K_2O ratio of the samples. The igneous rock sequence has a regular chemical variation; the oldest rocks are most calcic and youngest rocks most potassic. The SiO_2 content of these samples increases in general with increase of K_2O; it ranges from 61 to 73 percent.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

The eastern third of the quadrangle is underlain by sedimentary rocks that range in age from Pennsylvanian to Cretaceous and include the following mapped units: Fountain Formation, Lyons Sand-

TABLE 12.—*Chemical analyses of Precambrian igneous rocks*

[Method of analysis similar to that described by Shapiro and Brannock (1956)]

	Boulder Creek Granodiorite									Quartz monzonite			Silver Plume Granite	
										Coarse grained	Fine grained			
	P-55 [1]	P-62 [1]	P-80 [2]	P-81 [1]	P-89 [2]	P-92 [2]	P-95 [1]	P-98 [1]	P-208 [2]	P-57 [2]	P-63 [2]	P-73 [2]	P-100 [1]	P-207 [2]
SiO_2	66.5	67.9	67.2	64.8	68.5	64.2	67.2	65.4	61.0	69.1	69.6	72.6	71.0	70.6
Al_2O_3	15.4	15.2	15.4	16.2	14.4	16.0	15.5	16.1	16.8	15.0	15.6	14.5	14.2	13.7
Fe_2O_3	1.8	1.6	1.5	1.8	1.6	1.5	2.1	1.9	1.8	1.3	.9	.8	1.5	1.5
FeO	2.2	2.4	2.3	2.6	2.2	3.2	1.5	2.2	3.6	2.0	1.4	1.4	2.0	1.8
MgO	1.8	1.6	1.8	2.2	1.7	2.8	1.9	2.0	2.9	1.0	.63	.38	.68	.66
CaO	2.7	2.8	2.7	3.5	2.0	3.6	2.8	3.3	4.8	1.8	1.8	1.4	1.3	1.3
Na_2O	3.4	3.2	3.2	3.6	2.9	3.2	3.2	3.2	3.5	3.0	3.4	3.8	2.8	2.2
K_2O	4.0	3.6	4.2	4.5	4.6	3.2	4.6	4.5	3.2	5.1	5.6	4.2	6.2	6.8
TiO_2	.44	.42	.42	.65	.36	.54	.40	.53	.64	.44	.30	.23	.36	.47
P_2O_5	.16	.19	.16	.34	.16	.24	.16	.21	.31	.18	.11	.07	.15	.20
MnO	.06	.06	.08	.05	.06	.09	.05	.06	.10	.06	.05	.08	.04	.06
H_2O	.85	.77	1.0	.70	1.1	1.0	.93	.54	.87	.61	.58	.57	.69	.63
CO_2	.22	.10	.14	.11	.16	.16	<.05	.14	.13	.13	.18	.22	.15	.11
	99.53	99.84	100.10	101.05	99.74	99.73	100.38	100.08	99.65	99.72	100.15	100.25	100.07	100.03

[1] Analyzed by Paul L. D. Elmore, Samuel D. Botts, and Katrine E. White.
[2] Analyzed by Paul L. D. Elmore, Ivan H. Barlow, Samuel D. Botts, and Herman H. Thomas.

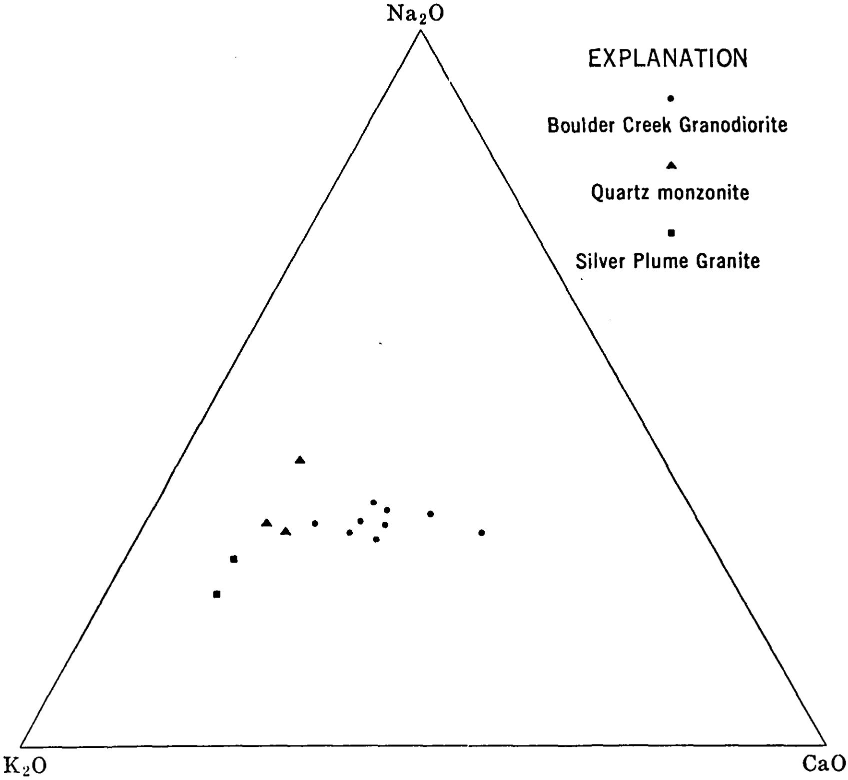

FIGURE 3.—Variations in chemical composition of Precambrian igneous rocks.

stone, Lykins Formation, Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Fort Hays Limestone and Smoky Hill Shale Members of the Niobrara Formation, the Pierre Shale, and the Hygiene Sandstone Member of the Pierre Shale. All these units were turned up along the eastern flank of the Front Range during the Laramide orogeny, so that most of the beds strike N. 5°–15° W. and dip 40°–60° E.; locally in areas of faulting the beds are vertical. Differential erosion has caused the resistant units—the Fountain Formation, the Lyons Sandstone, and the sandstone beds of the Dakota Group—to form prominent hogbacks and flatirons, and the nonresistant units to form low-lying intervening areas. Pedimentation of the nonresistant beds east of the hogbacks has formed broad flat areas.

PALEOZOIC ROCKS

FOUNTAIN FORMATION

The Fountain Formation is generally well exposed; it forms hogbacks and the prominent Flatirons south of Boulder. It is almost continuously exposed the full length of the quadrangle except in the southern part where faulting has removed the rock from surface exposure. Faults have repeated the lower part of the formation in the northern and southern parts of the quadrangle and offset it in the central part.

The Fountain Formation is predominantly a layered sequence of coarse-grained locally conglomeratic locally crossbedded arkosic sandstone in various shades of red and gray; it includes lenses and layers of siltstone and fine-grained sandstone. (See strat. sections 1 and 2.) The measured sections are 1,051 and 1,003 feet thick at South Boulder Creek canyon and Bear Canyon, respectively. The formation is only about 800 feet thick near the northern boundary of the quadrangle and northwest of Plainview. Thinning is probably related to the faults in these areas.

The unit is poorly sorted and consists of rounded to angular locally derived rock fragments of quartzite and granitic rock, and mineral grains of quartz, plagioclase, microcline, muscovite, and clay. These rocks are porous, but generally they are firmly cemented by clay, quartz, and feldspar. Thin rims of authigenic quartz occur on quartz grains, authigenic plagioclase on plagioclase, and authigenic microcline on microcline. Several samples taken near Eldorado Springs show the pore spaces partly filled with a zeolite that probably is stilbite. Mica flakes that have been bent between other grains are probably primary sedimentary grains that were deformed during compaction. Some of the feldspar grains are clouded, and others are completely replaced by clay. This condition suggests postdepositional alteration, because clay aggregates probably could not have survived as detrital grains.

Much of the gray sandstone is adjacent to or surrounds red siltstone lenses or pods. According to Hubert (1960), the gray sandstone was once red and has been bleached partly by the removal of iron and partly by the reduction of ferric iron to ferrous iron. Hubert suggested that the iron was removed by carbonate waters after being reduced by hydrogen sulfide in a syngenetic environment.

The basal contact of the Fountain is in profound angular unconformity with the underlying Precambrian rocks. This contact is generally concealed by talus, but where exposed it is sharp. The underlying quartzite is not weathered, but granitic rocks are locally weathered to depths of as much as 15 feet, although more commonly to depths of only a few feet. The weathered zone is characterized by iron oxide stain, silicification, altered biotite, and the alteration of the feldspars, especially plagioclase, to clay. Wahlstrom (1948) reported an 80-foot-thick weathered zone on Flagstaff Mountain west of Boulder, where he studied the chemical and physical properties of the zone in detail. He pointed out that the thickness of the zone here is nearly maximum and that in places the Fountain Formation rests on fresh rock.

Upper and lower parts of the formation were recognized by Maughan and Wilson (1960). The division is placed at the lowermost bed of fine-grained sandstone that has laminations of coarse grains. The lower part contains lenticular red siltstone beds.

The Fountain Formation was originally named for exposures on Fountain Creek near Colorado Springs, Colo., by Cross (1894). The formation in the Eldorado Springs quadrangle is continuous with the type locality and has virtually the same characteristics. Recent studies by Maughan and Wilson (1960) in northern Colorado and southern Wyoming have established that the Fountain Formation of the central Front Range is equivalent to the Casper Formation of the southern Laramie Range, and that the uppermost part of the Fountain is equivalent to the Ingleside Formation of the northern Front Range. By this correlation the Permian-Pensylvanian boundary is placed below the top of the Fountain Formation in the Eldorado Springs quadrangle because the base of the Ingleside marks the base of the Permian.

LYONS SANDSTONE

The Lyons Sandstone is generally well exposed at the base of the flatirons formed by the Fountain Formation (pl. 1). The Lyons consists of fine-grained to very fine grained sandstone showing very coarse grains along some lamination planes. The color ranges through various shades of pale red and pale pink. (See strat. sections 1 and 2.) The thickness of the formation at South Boulder Creek and Bear Canyon is 233 and 250 feet, respectively. The formation is thinner in the northern and southern parts of the quadrangle, possibly as a result of faulting or folding. Crossbedding is prominent in the sandstone in the northern part of the area but is inconspicuous in the southern part.

The mineral grains are well sorted, rounded, and frosted; they are mostly quartz but include trace amounts of plagioclase, microcline, and muscovite. The rock is firmly cemented by authigenic quartz overgrowths and can be classed as an orthoquartzite. The original grains are coated with iron oxide. Some specimens of the rock show white flecks which are feldspar grains altered to clay.

The basal contact is transitional in that coarse-grained arkosic beds of the Fountain Formation are interlayered with sandstone typical of the Lyons. The contact was placed at the top of the uppermost coarse-grained arkosic bed.

The name Lyons Sandstone was applied by Fenneman (1905) to strata consisting of fine-grained quartzose white or light-reddish sandstone overlying the Fountain Formation near Lyons, Colo. The strata in the Eldorado Springs quadrangle are continuous with the type locality. North of the type locality near the Wyoming State line, the upper part of the Lyons Sandstone is intertongued with the Permian Satanka Shale; this relation establishes a Permian age for the Lyons (Maughan and Wilson, 1960). South of the Eldorado Springs quadrangle, in the Kassler quadrangle, the Lyons Sandstone becomes friable, and its cement is carbonate (Scott, 1963a) rather than silica.

The Lyons Sandstone has been described in detail by Thompson (1949) and Hubert (1960).

LYKINS FORMATION

The Lykins Formation is generally covered by surficial deposits and is nowhere completely exposed in the quadrangle. The most extensive exposures are found in Bear Canyon and on South Boulder Creek. A clay pit in the formation west of Plainview exposes the unit where it has been folded adjacent to a fault (pl. 1). Topographically the unit forms rounded slopes and lies in the low area between The Flatirons and the Dakota hogback.

Only the boundaries of the formation are shown on the geologic map, although some of the members—the Harriman Shale, Falcon Limestone, Bergen Shale, Glennon Limestone, and Strain Shale Members of LeRoy (1946)—can be recognized locally.

The unit consists of about 533–565 feet of calcareous siltstone and fine-grained sandstone in various shades of red brown and light green, and an 8-foot-thick limestone—the Glennon Limestone Member—about 100 feet above the base. (See strat. section 1.) Rounded frosted quartz grains occur in the lower part of the formation. Most of the sandstone and siltstone rocks are massive or show thin horizontal laminations, but some show wavy bedding, ripple marks, and small-scale crossbedding. Typically the rock is cemented by calcite, but in the area of folding exposed in the clay pit near Plainview, the Lykins is noncalcareous. Results of X-ray analysis of samples from the clay pit (specimen H–133) and from typical exposures near Eldorado Springs are shown in table 14.

The Glennon Limestone Member of LeRoy (1946) consists principally of very fine grained calcite with minor amounts of dolomite in layers and stringers. Small quartz grains and traces of muscovite are scattered through the rock. This unit is commonly referred to as the "crinkly" member because of its wavy, curled, and offset bedding. Such bedding structures are probably the result of solution and collapse during deposition or lithification.

The basal contact of the formation is sharp against the Lyons Sandstone and is marked by the obvious difference in lithology and erosion characteristics. The contact is generally not exposed but may be closely located at the foot of the Lyons flatirons.

The Lykins Formation was named by Fenneman (1905) for exposures in Lykins Gulch about 9 miles north of Boulder, Colo. The beds in the Eldorado Springs quadrangle are continuous with those at the type locality, and the rocks are virtually the same in lithology. Farther north, in the northern part of the Front Range the Lykins below the Glennon is equivalent to the upper part of the Satanka; the Glennon is equivalent to the Forelle Limestone (Maughan and Wilson, 1960). The upper part of the formation is believed by Oriel and Craig (1960) to be equivalent to the Chugwater Formation of the northern Front Range and Wyoming. The lower part of the formation is Permian(?) and the upper part Triassic(?); according to Mudge (1959), the boundary is placed 90 feet above the Glennon Limestone Member.

MESOZOIC ROCKS

RALSTON CREEK FORMATION

The Ralston Creek Formation lies at the base of the west slope of the Dakota hogback. It is generally covered, but two outcrops are known: one on the ridge north of Bear Canyon, the other about half a mile south of Eldorado Springs (pl. 1).

The unit consists of about 34 feet of calcareous sandstone and siltstone in various shades of red and gray. (See strat. section 1.) In other parts of eastern Colorado the Ralston Creek Formation contains limestone and gypsum beds as well (LeRoy, 1946). Frosted rounded quartz grains occur in layers and scattered grains throughout the unit. The formation is distinctive because it contains thin layers and nodules of red and white chert. A thin section of the chert shows coarse-grained clear and stained granular quartz, clear granular chalcedony, clear radiating aggregates of chalcedony, radiating aggregates of chalcedony with growth lines, and fine- and coarse-grained calcite. The staining and growth lines are from iron oxide. No consistent age relations are shown between these minerals, but in general coarse-grained clear granular quartz is rimmed by radiating aggregates of chalcedony with growth lines outlined by progressively increasing staining outward. The radiating aggregates replace fine-grained calcite, and fracture fillings of coarse-grained calcite cut the entire mass.

The basal beds of the formation are much the same color as the underlying Lykins Formation, although they are somewhat paler. The boundary between the two formations is placed at the base of the layers containing scattered grains of rounded frosted quartz sand.

The name Ralston Creek was applied by Van Horn (1957b) as an amendment of the name Ralston originally proposed by Le Roy (1946) for exposures on Ralston Creek about 5 miles north of Golden. The zone of red chalcedonic quartz (chert) is widespread, extending from southern Wyoming to northern New Mexico and from central Utah to western Kansas (McKee and others, 1956; Oriel and Craig, 1960). The Ralston Creek Formation is Late Jurassic in age and is in part equivalent to the Sundance Formation of Wyoming, the Wanakah Formation of southwestern Colorado, and the Curtis Formation of northwestern Colorado (Oriel and Craig, 1960). It is assigned to the Oxfordian Stage by Oriel and Craig, but at least part of it is younger, Kimmeridgian age, as indicated by fossils from the chalcedonic zone in the Kassler quadrangle south of Denver (Scott, 1963a) and by stratigraphic relations to the Sundance Formation (G. N. Pipiringos, oral commun., 1964).

MORRISON FORMATION

The Morrison Formation forms the west slope of the Dakota hogback; the upper part is exposed in many places, but a complete section may be seen only on the ridge north of Bear Canyon. These exposures form rounded slopes which have projecting limestone and sandstone ledges.

As exposed at Bear Canyon, the formation consists of a lower sandy member about 105 feet thick and an upper silty member about 240 feet thick. The lower member consists of interlayered light-colored sandstone, varicolored calcareous, clayey siltstone, and thin light-colored limestone. The upper member consists of varicolored clayey calcareous siltstone, thin brown sandstone, and light-colored limestone near the base. (See strat. sections 1 and 3.) Near Eldorado Springs, where only the upper part is well exposed, the formation is 325 feet thick and consists of siltstone, varicolored claystone, and light-colored limestone.

A thin section of the sandstone unit 21 in the Bear Canyon section (strat. section 1) shows the rock to be mostly quartz with trace amounts of microcline, plagioclase, and chalcedony. The rock is cemented by clay and small amounts of chalcedony. The sandstone in the middle of the formation, unit 31, consists of rounded quartz grains, some angular chalcedony grains, and a few fragments of volcanic rock. The chalcedony is both granular and spherulitic. The limestone beds are very fine grained and have a conchoidal fracture whose surface is generally colored with iron oxide. Clear calcite fills fractures in the rock. Ostracodes and charophytes are locally present but are too poorly preserved to be identified.

The composition of the claystone in the upper part of the formation at the clay pit about one-half mile north of Plainview is indicated in table 14.

The basal contact is placed at the base of the sandstone that overlies the chalcedony-bearing beds of the Ralston Creek Formation. This contact is disconformable, and Van Horn (1957) reported that part of the basal sandstone was deposited in a channel that cut into the Ralston Creek Formation at Ralston Creek in the Golden quadrangle.

The Morrison Formation was named by Emmons, Cross, and Eldridge (1896) for exposures near Morrison, Colo. The formation is of Late Jurassic age and extends across the western interior of the United States from northern Arizona and New Mexico to the Canadian border (McKee and others, 1956).

DAKOTA GROUP

The resistant sandstone beds of the Dakota Group dip about 45° E. and form prominent hogbacks along the mountain front and immediately west of the flat pediment surfaces of the plains. All or part of the Dakota has been removed from surface exposure by faulting near the north and south boundaries of the quadrangle, and the hogbacks consequently are absent there. Exposure of the sandstone parts of the group is generally good, but the shaly parts are poorly exposed except in natural and artificial cuts.

The Dakota Group includes the Lytle and South Platte Formations as defined by Waagé (1955), who also recognized three members and two unnamed units in the South Platte Formation. In ascending order these members are Plainview Sandstone Member, unnamed unit, Kassler Sandstone Member, Van Bibber Shale Member, and an unnamed unit. The Dakota Group was mapped as a unit in this report because of the small map scale and general lack of exposure of the contacts. The Dakota Group is Early Cretaceous in age. The upper boundary of the Lower Cretaceous was placed at the top of the Mowry Shale by Cobban and Reeside (1952); the Mowry interfingers with the upper part of the Dakota Group in northern Colorado. The Cretaceous-Jurassic boundary has been extensively debated but was placed in the Morrison Formation by Haun and Weimer (1960, p. 59).

Detailed reports on the regional stratigraphy, lithology, paleontology, and correlation of the various units and horizons of the Dakota Group have been made by Waagé (1955, 1959, 1961). No attempt will be made in this report to enlarge upon these papers except to comment upon some of the features and to point out local variations in these features as they occur in the Eldorado Springs quadrangle.

A measured section and a photograph of the exposure at the railroad cut one-fourth mile north of Plainview, and a photograph of an exposure one-eighth mile south of Eldorado Springs are on pages 29 and 27, respectively, in the report of Waagé (1955). A measured section of the exposures near Eldorado Springs and at Plainview was described by Waagé (1961) and was presented in tabular form by Waagé (1959).

The Dakota Group varies in thickness and lithology across the quadrangle. The thickness ranges from about 350 feet near Plainview to 314 feet near Eldorado Springs to 296 feet at Bear Canyon. The lower part of the Dakota Group, the Lytle Formation, consists of gray to tan coarse-grained conglomeratic crossbedded sandstone and conglomerate interlayered with varicolored shale. The upper part of the group, the South Platte Formation, consists of well-sorted medium- to fine-grained sandstone interlayered with dark-gray carbonaceous siltstone and clayey shale. The lower half of the formation is mostly sandstone that forms the main part of the hogback. The upper half is mostly shale in the southern part of the quadrangle, but sandstone layers become more abundant in it northward. This sandstone is commonly ripple marked, and along the South Boulder Creek water diversion canal, south of Eldorado Springs, it contains dinosaur tracks.

The sand grains in the sandstones consist of quartz, chalcedony, some rock and claystone fragments, and traces of microcline. These are cemented by chalcedony, authigenic quartz, and a clay binder. The authigenic quartz crystallized only on quartz grains and commonly formed euhedral bipyramidal quartz crystals.

The minerals in six samples of the shale have been identified by X-ray diffraction; the results and the sources of the samples are shown in table 14.

Waagé (1955) pointed out that regionally the lithology of the basal part of the group varies. Large lithologic variations exist locally as well. The base of the group is marked by a sandstone at the railroad cut north of Plainview (pl. 1). Northward this sandstone thins rapidly and most of the basal part is shale at Doudy Draw. At Bull Gulch, about one-third mile farther north, about 50 feet of chalcedony-pebble conglomerate, firmly cemented by chalcedony and quartz, forms the base. This conglomerate thins to the north and south; it extends from a short distance south of Bull Gulch northward to Spring Brook. North of Spring Brook as far as Shadow Canyon, the basal unit is coarse- to medium-grained sandstone, which is locally quartzitic where it is very finely cemented with silica cement.

BENTON SHALE

The Benton Shale is exposed at a few places near Eldorado Springs east of the Dakota hogback, where it forms rounded slopes commonly covered with colluvial or alluvial material. Near Coal Creek and between Bear Canyon Creek and the north boundary of the quadrangle, the Benton is only partly exposed, owing to faulting. The poor exposure and the lack of distinctive lithologic horizon markers precluded separate mapping of the units of the Benton equivalent to the Carlile Shale, Greenhorn Limestone, and Graneros Shale.

These units consist of interlayered dark- to light-gray shale and thin dark-gray earthy to crystalline limestone. They are about 450 feet thick at Eldorado Springs and apparently thicken southward, as the thickness in the Golden quadrangle is about 500 feet (Van Horn, 1957a) and in the Kassler quadrangle about 600 feet (Scott, 1963a). The exposure at Eldorado Springs is mostly Greenhorn Limestone equivalent, which contains *Inoceramus labiatus* near the top of the exposure. (See strat. section 4.) Microfossils occur at the base of the exposure. In the faulted exposure in Bluebell Canyon, G. R. Scott (oral commun., 1965) identified *Inoceramus pictus* and heteromorphic ammonites from the lower part of the Greenhorn Limestone equivalent.

Johnson (1930) reported that the contact of the Graneros with the Dakota is transitional. Dane, Pierce, and Reeside (1937, p. 210) reported fish scales in the lower part of the Graneros equivalent in the Morrison quadrangle that indicate equivalence to the Mowry Shale, which is Early Cretaceous in age. The Mowry has been recognized in the Boulder quadrangle north of Eldorado Springs by R. F. Wilson (oral commun., 1961).

NIOBRARA FORMATION

Incomplete exposures of the Niobrara Formation are present 700–1,000 feet east of the Dakota hogback. Locally the basal limestone, the Fort Hays Limestone Member, forms small discontinuous hogbacks, but the overlying Smoky Hill Shale Member is almost totally covered. Near Bear Canyon Creek both members are well exposed, but faults cut the exposure and the unit is not complete. Because the Fort Hays and Smoky Hill Members are not included in the measured stratigraphic sections, detailed rock descriptions are given here. The color designations are from the Rock Color Chart (Goddard and others, 1951).

The Fort Hays Limestone Member is about 30 feet thick, and its basal contact is disconformable. The following is a description of an exposure of the Fort Hays near Eldorado Springs, in the NW¼SE¼SW¼ sec. 30, T. 1 S., R. 70 W.:

Limestone, yellowish-gray (5*Y* 8/1), irregular medium-gray (*N*6) patches in upper part; very light gray (*N*8) mottled with yellowish gray in lower part; medium crystalline, dense, thick bedded, weathers slabby and rounded. *Inoceramus deformis* and foraminifera are common.

The Smoky Hill Shale Member is about 215 feet thick at a weathered exposure on Doudy Draw. Near Bear Canyon Creek in the NE¼SE¼SE¼ sec. 12, T. 1 S., R. 71 W., most of the lithologic types are exposed although the thickness of the member cannot be determined. In the following description the general order is from top to bottom of the exposure.

Limestone, pale-yellowish-brown (10*YR* 6/2); weathers very pale orange (10*YR* 8/2); made up of rounded to elongate grains, massive; weathers slabby; abundant foraminifera.

Shale, olive-gray (5*YR* 4/1); weathers light gray (*N*7); clayey, very calcareous, thin bedded to very thin bedded; weathers very thin bedded. weathers very thin bedded.

Limestone, medium-gray (*N*5); weathers very light gray (*N*8), massive to thin bedded; weathers slabby to very thin bedded. Coquina bed that contains mollusks and foraminifera forms gradational upper contact.

Shale, medium-dark-gray (*N*4); weathers light gray; clayey, calcareous, thin bedded to very thin bedded, weathers to rounded slope.

The Niobrara Formation, which extends throughout the western interior region, is Late Cretaceous in age. According to Scott and Cobban (1964, p. L–23), the names Timpas Limestone Member and Apishapa Shale Member have erroneously been used interchangeably for the Fort Hays Limestone and Smoky Hill Shale Members by various authors of earlier reports.

PIERRE SHALE

The Pierre Shale underlies the eastern one-fourth of the quadrangle, where it is exposed in scattered outcrops. Faults in the northern and southern parts of the quadrangle have eliminated some of the lower part from surface exposure. Most of the Pierre is overlain by gravelly alluvium on pediment surfaces and colluvial deposits on the slopes marginal to the pediment gravels.

The formation consists of about 7,545 feet of greenish-gray shale and poorly cemented sandstone with ironstone and limestone concretions. The Hygiene Sandstone Member is about 535–565 feet thick; its base lies about 1,725 feet above the base of the formation. Although the upper contact of the Pierre Shale lies east of the quadrangle boundary, the entire formation is described in this report.

A section measured along Community Ditch by planetable methods with graphical corrections for dip (see strat. section 5) is typical of the lithology of the upper part of the formation. A sample collected for clay determination (table 14), taken from a point about 750 feet below the top of the Pierre Shale in the NE¼NE¼NE¼ sec. 5, T. 2 S., R. 70 W., shows the clay to be mostly montmorillonite with mica and chlorite. The basal part of the formation below the Hygiene is not exposed along Community Ditch, but exposures along Bear Canyon Creek are described as follows:

Mudstone, dark-gray (*N*3); weathers dusky yellow (5*Y* 6/4); silty, very slightly calcareous, bentonitic, massive to thin bedded; weathers very thin bedded to blocky; few siltstone layers 0.1 ft thick are moderate brown (5*YR* 4/4), fine grained, and noncalcareous.

The base of the formation lies where the gray mudstone is in contact with the tan limestone of the Niobrara Formation.

The Hygiene Sandstone Member is mostly sandstone and sandy siltstone. (See strat. section 5.) The sand grains are principally quartz and chalcedony but include small amounts of plagioclase and microcline, and flakes of muscovite. Large carbonate grains with poikilitic inclusions of the detrital grains form the cement.

Through regional studies of many fossil collections from the Pierre Shale, Scott and Cobban (1965) have been able to establish fossil zones restricted to specific stratigraphic horizons. The stratigraphic control is within a few hundred feet. The zones allow relatively close stratigraphic and structural control in this thick sequence of nearly homogeneous rock.

The zone lines shown on plate 1 are keyed to guide fossils, mostly *Baculites* but also other ammonites, collected from the numbered localities. The approximate stratigraphic interval above the base of the formation for each of the zone areas follows: *Baculites obtusus*, 950 feet; *Baculites scotti*, 2,250 feet; *Didymoceras nebrascense*, 2,800 feet; *Didymoceras cheyenense*, 3,375 feet; *Baculites reesidei*, 3,975 feet; *Baculites eliasi*, 4,325 feet; *Baculites baculus*, 4,700 feet; and *Baculites grandis*, 5,100 feet.

CENOZOIC ROCKS

The Cenozoic rocks include Tertiary diabase and latite porphyry and surficial deposits ranging in age from Tertiary to Recent. The igneous rocks form dikes that intrude the Precambrian and Paleozoic rocks. The surficial deposits occur on high-level surfaces, on pediment surfaces, and along modern valleys.

TERTIARY INTRUSIVE ROCKS

Diabase and latite porphyry dikes of Tertiary age (Lovering and Goddard, 1950, p. 47) crop out in the quadrangle. The diabase occurs as several small dikes and as the southern end of the Iron dike described by Lovering and Tweto (1953, p. 18) and Wahlstrom (1956). The Iron dike extends more than 30 miles northwest of the quadrangle boundary. The latite porphyry occurs as a short segment of a dike that extends a short distance north of the quadrangle boundary.

DIABASE

The diabase dikes trend northwestward and extend in discontinuous exposure from the northwest corner of the quadrangle to South Boulder Creek. The dike in the Magnolia area is about 30 feet wide; the short dikes are narrower and locally are less than 1 foot thick. In most places the dikes dip less than 70° SW., and a dike in Martin Gulch near South Boulder Creek dips 14° NE. (pl. 1). In fresh outcrops the diabase is black; where weathered it is reddish brown due to limonite staining. Weathered areas are blocky.

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The fabric of the dikes in this area is diabasic except in thin chilled margins. Wahlstrom (1956) pointed out that the grain size and fabric of the dike varies with distance from its margin. Lovering and Tweto (1953) classified the Iron dike as a gabbro, but it is here called diabase. The diabase consists of augite, plagioclase (labradorite), bladed opaque minerals (magnetite-ilmenite), chlorite, biotite, and nontronite (determination of the nontronite was by X-ray techniques by A. J. Gude, 3d). The nontronite occurs as pseudomorphs of euhedral crystals that were probably olivine, and as irregular masses mixed with chlorite and interspersed with the other mineral constituents. The Iron dike was described in detail by Wahlstrom (1956).

LATITE PORPHYRY

The latite porphyry crops out as a 300-foot segment of dike at the northern boundary of the quadrangle (pl. 1), where it cuts the basal part of the Fountain Formation. The dike dips about 60° E., is about 20 feet wide, and has a chilled margin about 1 foot thick.

The rock consists of euhedral phenocrysts of biotite and feldspar, generally less than 2 mm in width, in a light-gray aphanitic groundmass; a few anhedral quartz phenocrysts are present. The feldspar phenocrysts, now completely altered to clay minerals, were probably plagioclase.

TERTIARY OR QUATERNARY DEPOSITS

HIGH-LEVEL ALLUVIUM

One deposit of high-level alluvium caps a knob about 2,000 feet northwest of Castle Rock in the western part of the quadrangle (pl. 1). The deposit is about 3 feet thick and consists of well-rounded pebbles, cobbles, and boulders of pegmatite, Tertiary porphyry (diabase, quartz monzonite, and bostonite), and other resistant rocks. The boulders have a maximum size of about 3 feet.

The deposit is about 2 miles east of deposits shown by Lovering and Goddard (1950, pl. 2) as post-Eocene in age and considered by them to be possibly as young as Pleistocene (p. 41). Wahlstrom (1947b) identified these deposits as early Pleistocene glacial till. Lovering and Tweto (1953, p. 26) considered them to be of undetermined origin and age—either Tertiary alluvial or early Pleistocene glacial. The deposits are certainly older than the pediment gravels east of the mountains; when projected to the mountain front, the surface upon which the deposits lie is about 600 feet above the highest pediment. In accepting the age of the pediment deposits as spanning the entire Pleistocene (as described later), one must also conclude that the high-level deposits are most likely Tertiary and, in accordance with the reasoning of Lovering and Tweto, probably alluvial in origin.

PRE-ROCKY FLATS ALLUVIUM

The pre-Rocky Flats alluvium occurs in the southeastern part of the quadrangle, where it occupies the highest pediment level (pl. 1). The thickness ranges from 10 feet near the east border of the quadrangle to 30 feet west of Plainview. The alluvium consists of bouldery gravel in a sand matrix (strat. section 6). Quartzite boulders are conspicuous on the surface of the alluvium.

The pediment surface has in general a conical shape, obscured, however, by erosion. The pediment lies about 40–100 feet above the Rocky Flats pediment in the eastern part of the quadrangle where the slope is about 200 feet per mile; the slope steepens to about 1,400 feet per mile at its apex west of Plainview. This pediment beveled the Dakota hogback, whereas the younger pediments abut the Dakota.

The position of the pre-Rocky Flats alluvium above the Rocky Flats Alluvium indicates that it is older; it apparently represents the first in the series of pediment deposits. Malde (1955) suggested that this pediment deposit may be as old as Pliocene, but Scott (1963b; oral commun. 1965) considered it to be earliest Pleistocene and possibly correlative with the Nussbaum Alluvium of the Pueblo area. Pending more certain correlation, the deposit is here referred to simply as pre-Rocky Flats alluvium, and following Scott (1963b), is classed as Pleistocene(?) in age.

QUATERNARY DEPOSITS

The Quaternary deposits in the area consist of unconsolidated alluvium and colluvium of Pleistocene and Recent age. The Pleistocene deposits are alluvial veneers on pediment surfaces that have been beveled on the upturned sedimentary rocks at five different stages. The Recent alluvial deposits are restricted to stream valleys. The colluvial deposits are Recent talus, solifluction debris, and landslides.

The Pleistocene and Recent deposits along the east side of the central Front Range have been described and named by Hunt (1954), who mapped the Denver area, by Malde (1955), who mapped the Louisville quadrangle immediately east of the Eldorado Springs quadrangle, and by Scott (1960, 1962, 1963c), who mapped the Littleton and Kassler quadrangles. Table 13 correlates the terms used for alluvial deposits by Malde and Scott with those used in this report. The separation and correlation of these deposits were made on the basis of physiographic expression, vertebrate and invertebrate paleontology, archaeology, and C^{14} dates.

PLEISTOCENE DEPOSITS

ROCKY FLATS ALLUVIUM

The Rocky Flats Alluvium was named for exposures on Rocky Flats (Scott, 1960) 2 miles east and 1 mile south of the southeast corner of

TABLE 13.—*Correlation of terms used for Quaternary alluvial deposits described by Malde (1955), Scott (1960), and this report*

Malde (1955)			Scott (1960)			This report		
Series	Stage	Map unit	Series	Stage or substage	Formation	Series	Geologic climate unit	Map unit
Recent		Post-Piney Creek alluvium	Recent	Late	Post-Piney Creek alluvium	Recent		Valley alluvium (includes post-Piney Creek alluvium, Piney Creek Alluvium, and alluvial fans)
		Piney Creek alluvium			Piney Creek alluvium			
				Early	Pre-Piney Creek alluvium			
Pleistocene	Wisconsin	Gravel fill	Pleistocene	Wisconsin: Late	Broadway alluvium	Pleistocene	Wisconsin	Terrace Alluvium
		Alluvial fill		Wisconsin: Early	Louviers alluvium			
		Undifferentiated upland deposits		Illinoian or Sangamon	Slocum alluvium		Illinoian or Sangamon	Slocum Alluvium
		Cobble gravel Terrace gravel Upland gravel		Kansan or Yarmouth	Verdos alluvium		Kansan or Yarmouth	Verdos Alluvium
Pliocene(?) or Pleistocene		Gravel on Rocky Flats		Nebraskan or Aftonian	Rocky Flats alluvium		Nebraskan or Aftonian	Rocky Flats Alluvium
		Old gravels				Pleistocene(?)		Pre-Rocky Flats alluvium

the Eldorado Springs quadrangle (pl. 1). This alluvium is the most extensive and most prominently displayed of the pediment alluvial deposits. It once mantled the surface of an extensive plain, but it is now dissected; one of the largest remnants covers part of the Eldorado Springs, Louisville, and Golden quadrangles. This surface is strewn with quartzite boulders and is aptly called Rocky Flats. Scott (1960) interpreted this alluvium to be of Nebraskan or Aftonian age because it is next older than the Verdos Alluvium, which is dated Kansan or Yarmouth.

The Rocky Flats Alluvium consists generally of yellowish-brown bouldery gravel about 15–35 feet thick, with layers of clay, silt, and sand (strat. section 7). Malde (1955) reported thicknesses ranging from 1 to 50 feet. In the southern part of the quadrangle the pediment surface has the form of a fan with its apex at the mouth of Coal Creek Canyon. The slope near the apex and within a mile of the hogbacks north of Plainview (pl. 1) is about 325 feet per mile; the gradient flattens to about 70 feet per mile in the eastern part of the Louisville quadrangle (Malde, 1955). This slope projects uniformly north, parallel to the mountain front across South Boulder and Bear Canyon Creeks, without appreciable interruption. Near the north boundary of the quadrangle the pediment slopes northward toward Boulder Creek; this fact suggests that Boulder Creek flowed in a valley lower than the pediment surface, in contrast with Coal Creek, which flowed over the surface of the cone. Whatever drainage issued from South Boulder and Bear Canyon Creeks had little if any influence on the form of the pediment.

Near the mountain front the boulders in the alluvium are larger and include a greater proportion of Paleozoic and younger sedimentary rocks than farther to the east, where the boulders are mostly Precambrian quartzite and are relatively small. As exposed about a mile south of Boulder, the basal 15 feet of the alluvium is silty clay, which apparently is reworked Pierre Shale.

VERDOS ALLUVIUM

The Verdos Alluvium was named for exposures in the Littleton quadrangle south of Denver (Scott, 1960, p. 1541–1542). There the alluvium consists of 16–35 feet of gravelly well-stratified coarse sand and a volcanic ash bed, and it lies about 100 feet below the Rocky Flats Alluvium. The volcanic ash bed and others at similar horizons have been correlated with the Pearlette Ash Member of the Sappa Formation, of Kansan or Yarmouth age, by Scott (1960, p. 1542), who thus established the age of the alluvium. In the Eldorado Springs quadrangle the pediment gravel that generally lies 50–100 feet below the Rocky Flats is correlated with the Verdos Alluvium because it contains Pearlette in the Golden quadrangle (Richard Van Horn, oral commun., 1960).

This pediment capped by the Verdos is less extensive and less uniform than the Rocky Flats surface. It slopes into the South Boulder and Bear Canyon Creek drainages and has a gradient of about 450 feet per mile near the mountain front but flattens to about 200 feet per mile to the east.

The Verdos Alluvium is generally less than 35 feet thick but is not well exposed in the quadrangle. On its surface the Verdos Alluvium appears much like the Rocky Flats. Malde (1955, p. 231) described terrace gravel that is roughly equivalent to part of the Verdos Alluvium (table 13). His description indicated that the deposits are reddish brown and contain clay, silt, sand, and cobbles commonly 5 inches across. About 85 percent of the cobbles are quartzite, 12 percent granitic rock, and 3 percent sandstone.

SLOCUM ALLUVIUM

The Slocum Alluvium was named for exposures on the pediment surface immediately below the Verdos in the Kassler quadrangle south of Denver (Scott, 1960, p. 1542). At that location the Slocum lies 150 feet below the Verdos Alluvium and consists of 10–90 feet of moderate-reddish-brown well-stratified clayey coarse sand with lenticular beds of pebbles and silt. Scott considered the Slocum to be Illinoian or Sangamon in age because it is the youngest pre-Wisconsin alluvium.

The Slocum Alluvium generally lies 50–100 feet below the Verdos in the Eldorado Springs quadrangle, is generally less than 25 feet thick, and mantles surfaces that are related to the present drainage system in much the same way as the Verdos. The Slocum is not as extensive as the Rocky Flats and Verdos and is restricted to the area east of the Dakota hogbacks. The typically irregular and rilled surface of the Slocum Alluvium suggests an alluvial fan or low-gradient mudflow. The slope of the pediment surface is about 500 feet per mile near the mountains and about 200 feet per mile near the east edge of the quadrangle.

The Slocum Alluvium consists of reddish-brown clay, silt, sand, pebbles, and boulders. About 50 feet of alluvium is exposed in a roadcut one-fourth mile east of Eldorado Springs in the NW¼NE¼ SW¼ sec. 30, T. 1 S., R. 70 W. The basal contact is irregular, with a relief of a few feet, and slopes to the east. The basal few feet consists principally of reworked shale from the underlying bedrock, but there are lenses of gravel as much as 3 feet thick and some of sand as much as 1 foot thick. The gravel consists of well-rounded ¼–1-inch pebbles, mostly granitic rocks but including some sedimentary rocks, in a matrix of grayish-orange (10*YR* 7/4) sand. Above these basal units the alluvium is light brown (5*YR* 5/6) and consists of a mixture of clay, silt, sand, pebbles, and boulders up to several feet across. The largest boulders in the alluvium are angular blocks as much as 15 feet on a side, derived from the Fountain Formation. The pebbles and boulders are a mixture of angular pieces of sedimentary rocks and rounded pieces of igneous and metamorphic rocks.

The alluvium 1.5 miles south of the northeast corner of the quadrangle is about 8 feet thick. It is similar to that previously described except that the boulders are mostly less than 1 foot across.

TERRACE ALLUVIUM

The material mapped as terrace alluvium is continuous with the gravel fill and alluvial fill mapped by Malde (1955), who reported that on South Boulder Creek the maximum thickness is about 14 feet and that these deposits have been subject to reworking by floodwaters. In most places alluvium consists principally of well-rounded stones that are 2–7 inches in diameter. The stones are mostly granite, gneiss, and quartzite. In the northeast corner of the quadrangle the alluvium is continuous with what Malde described as clayey silt and silty sand, containing only a few pebbles and cobbles.

These deposits are interpreted to be Wisconsin in age by Malde for several reasons. They contain relatively unweathered rock fragments; in general, their soils show an earlier stage of development than those of the pediment alluvial deposits; and their topographic position is lower.

RECENT DEPOSITS

COLLUVIAL DEPOSITS

The colluvial deposits in the quadrangle are talus, colluvium (solifluction debris), and landslides. The talus is restricted to areas below cliffs of the Fountain Formation and the Lyons Sandstone. It is an accumulation, 10–20 feet thick, of large angular boulders from these rock units. In the mountains the solifluction debris is a heterogeneous mixture of boulders, gravel, sand, silt, and clay that has accumulated at the base of steep slopes as a result of slope wash and frost action. The solifluction debris is as much as 30 feet thick and supports a forest vegetation. On the plains the solifluction debris consists of gravel from the pediment alluvial deposits and debris from the underlying bedrock. Since the bedrock is most commonly shale, the solifluction debris is most commonly clay with silt, sand, and gravel. Thicknesses are generally less than 10 feet.

Only one small area of landslide deposits, south of Boulder, is shown; there the Pierre Shale has slumped 10–15 feet with a rotational motion so that the beds dip into the original bank.

VALLEY ALLUVIUM

Valley alluvium consists of deposits in the channels of the present streams and on low terraces along them. These deposits are equivalent to the pre-Piney Creek, Piney Creek, and post-Piney Creek alluviums of Malde (1955), Scott (1960), and Hunt (1954). Alluvial fans that have been deposited over the terrace alluvium are also included.

The aspect of the valley alluvium is variable; it depends on the topography on which it was deposited, the size of the stream that deposited it, and its source area. The large streams in the mountains and on the plains have deposits of sand and large boulders. In the mountains the deposits are mainly at or near stream level, but on the plains, some are in terraces formed by downward erosion and the migration of meanders. The highest terrace is about 15 feet above the stream, as along Coal and South Boulder Creeks. The alluvium is generally sandy and humic except in the quartzite terrane, where quartzite gravel is common. High-level basins are filled with colluvium and alluvium deposited by small streams and slope wash. The valleys of small streams on the plains contain sand and gravel from the older alluvial deposits and clay and sand from the underlying bedrock. Here stream gradients are generally less than in the mountains; in the mountains the alluvial deposits tend to be in hanging valleys because tributary streams erode less rapidly than the major streams. Alluvial fans are formed also where these hanging valleys joint the main streams.

STRUCTURAL GEOLOGY

The rocks of the Eldorado Springs quadrangle consist of a generally conformable sequence of high-grade metamorphic rocks that have been folded into a series of complex anticlines and synclines, intruded by igneous rock, cataclastically deformed, and faulted during Precambrian time. Three periods of Precambrian deformation occurred, each accompanied by a period of metamorphism (Wells and others, 1964, p. 8). During the earliest period, plastic folding formed a southwest-plunging mineral lineation. During the second period, similar plastic folding formed the Coal Creek syncline and was accompanied by the intrusion of the Boulder Creek Granodiorite and the quartz monzonite. During the last period, cataclastic deformation resulted in the northeast-trending Idaho Springs–Ralston shear zone and northwest-trending faults. Laramide mountain-building processes folded the Paleozoic and Mesozoic sedimentary rocks and formed the upturned eastern flank of the Front Range. Rotation of some of the Precambrian rocks and renewed displacements on a system of faults accompanied the orogeny. All these rocks show prominent joints.

PRECAMBRIAN STRUCTURAL GEOLOGY

In the following pages the lineations and foliations that mark the structures will be described first. Then the geographic position, geometric attitude, and geologic relations of the structures will be discussed.

LINEATION AND FOLIATION

Almost every outcrop of Precambrian rocks in the area is foliated, and most show one or more lineations. These structural features are the result of folding, shearing, and igneous flowage, or some combination of these.

In the metasedimentary rocks, foliation is evident in the parallel arrangement of platy minerals, mostly muscovite and biotite, and in layering defined by color, textural variations, or composition. The foliation surfaces are parallel to the layering except where crosscutting foliation has been formed locally by shearing in drag folds, slip cleavage, or axial-plane shear. Lineations are represented in these rocks by fold axes, boudinage, and mineral alinements on the foliation surfaces. The mineral lineations are expressed by alinements of two general types: (1) elongate minerals such as sillimanite and hornblende, and (2) elongate aggregates of platy or equidimensional minerals such as biotite, muscovite, or quartz.

Foliations formed by igneous flowage are evident in the parallel orientation of tabular feldspar crystals, xenoliths, and mineral aggregates. In the Boulder Creek Granodiorite the flow foliation may occur either alone or accompanied by a weak cataclastic foliation. In the Silver Plume Granite, tabular feldspar crystals form the foliation.

Two rather distinct types of foliation formed by the shearing occur in the rocks of this quadrangle. One is the result of relatively minor widespread cataclasis associated with the intrusion of the Boulder Creek batholith and the quartz monzonite in a syntectonic environment at the time the Coal Creek syncline was formed. The other consists of surfaces of intense shearing or mylonitization in restricted throughgoing zones that transect all Precambrian rock types. The lineation in both types is formed by mineral rods and streaks.

The cataclasis in the Boulder Creek Granodiorite varies in intensity. It grades from very weak and indistinct, where it might best be considered as igneous flow structure, to intense, where the mineral grains have been broken and recrystallized and now form a distinct foliation and lineation.

The rocks in the area where both the quartz monzonite and Boulder Creek Granodiorite are exposed near the quartzite have undergone moderate to weak cataclasis. The cataclasis is pervasive, and the foliation planes pass uninterruptedly from one igneous rock type into the other.

More restricted zones of shearing are represented by the Idaho Springs–Ralston shear zone and by local shear surfaces outside this zone which have modified or obliterated preexisting planar and linear structures. In such places, the minerals have been reoriented mechanically and by recrystallization to define new foliation and lineation.

FOLDS

The Coal Creek syncline is the principal fold in the Precambrian rocks of the area (pl. 1). The syncline has a plunge and bearing of about 30° N. 65° E. To the southwest in the Blackhawk quadrangle, the plunge and bearing are about 10° N. 60° E. (Wells and others, 1964, pl. 1). Within the Coal Creek syncline are minor folds whose amplitudes and wavelengths are a few tens of feet and whose bearing is N. 80° E. These folds have been mapped in the Coal Creek Peak area and have been observed, although not mapped, elsewhere.

The Coal Creek syncline varies from open to nearly isoclinal and overturned; the north limb is moderately steep, and the south limb is nearly vertical. The minor N. 80° E. folds are open to isoclinal, and their axial planes are nearly vertical. Drag folds and minor warps and crinkles are parallel and at right angles to both N. 65° E. and N. 80° E. folds. The folding is disharmonic, owing to the flowage of the less competent beds. As a result, the schistose units are thickened in the crests of folds and are more intensely folded than the quartzite and feldspathic units. This is shown on Coal Creek west of Coal Creek Peak (pl. 1).

The foliations in the Boulder Creek Granodiorite and the quartz monzonite unit outline an anticline whose axial trace lies on the northwest flank of Scar Top Mountain about a mile northwest of the northwest margin of the quartzite and parallel to it. A plot of the foliations (fig. 4) shows the statistical axis of this fold, the Scar Top anticline, to have a plunge and bearing of 50° N. 67° E. This axis is parallel with the axis of the Coal Creek syncline but plunges more steeply.

SHEAR ZONES AND FAULTS

The Idaho Springs–Ralston shear zone (Tweto and Sims, 1963) is characterized by intense shear deformation south of the Coal Creek syncline. The shear zone, which is only partly exposed in the quadrangle, ranges from about 0.5 mile to 1.5 miles in width immediately south of the quadrangle (Wells and others, 1964). The shear zone trends about N. 50° E. and dips steeply. Within it, the intensity of cataclasis varies widely, and bodies of intensely deformed rock enclose and grade into bodies of virtually undeformed rock. Therefore the boundaries are gradational and cannot be located exactly.

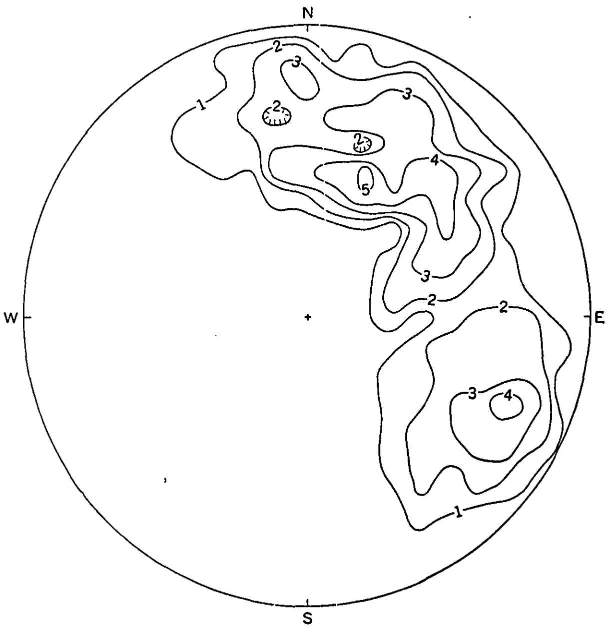

FIGURE 4.—Foliations in the quartz monzonite and Boulder Creek Granodiorite. Upper hemisphere plot of 436 poles. Contoured in percent.

Where cataclasis was intense, a new foliation, parallel to shear planes, cuts and commonly destroys earlier structures, and mineral streaking and slickensides on the new foliation surfaces form a conspicuous lineation. In such places, the rocks have been finely ground but contain remnants of the original material in augen, pods, and lenses of virtually undisturbed rock. Micaceous rocks do not show shear zones as readily as feldspathic rocks but generally have been converted to highly contorted or crinkled rocks.

Several noncontinuous shear zones of moderate intensity have been mapped in the central and northern parts of the quadrangle (pl. 1). These are similar and parallel to the Idaho Springs–Ralston shear zone and probably are related to it in time and origin. Supporting evidence is lacking, however.

Thin mylonitic shear zones occur in the northern part of the quadrangle; most are less than 20 feet wide, have sharp boundaries, and cannot be traced very far. These are not large enough to be shown on the map (pl. 1) except by symbol.

The Idaho Springs–Ralston shear zone was formed during the late Precambrian and is part of a series of northeast-trending zones traced about 150 miles across central Colorado (Tweto and Sims, 1963). Northwest-trending faults, long known as "breccia reefs" or "breccia dikes" (Lovering, 1932), were also formed during this period of deformation. Tweto and Sims (1963, p. 1001) presented strong evidence that the northwest-trending faults or breccia reefs are of Precambrian origin and were reactivated during the Laramide. Scott (1963a, p. 85–88) described sandstone dikes along the breccia reef system. He considered these to be the result of the injection of sand into preexisting Precambrian faults while the Cambrian Sawatch Quartzite was being deposited. Scott recognized a sandstone dike on the Rogers reef near Boulder Canyon, north of the report area, and similar material was found in the fault on the south slope of Scar Top Mountain in the Eldorado Springs quadrangle. All other features that provide evidence of a Precambrian ancestry of the northwest-trending faults in the Eldorado Springs quadrangle were apparently obliterated during the Laramide orogeny. Inasmuch as nearly all the features now apparent were formed during the Laramide, detailed description of these faults is given in the section on Laramide structure.

ORIENTATION OF LINEATIONS

The linear elements in the rocks of the Coal Creek area have a wide range in attitude but show several statistical concentrations. Some of these linear elements are known from field observations to be products of one of the three periods of Precambrian deformation; the relation of the others to these deformations may be inferred.

A statistical study of the lineations in the Coal Creek area was made by Wells, Sheridan, and Albee (1964). Following is a summary of the results. The lineations formed by the first period of deformation are restricted to the metasedimentary rocks and have a varied south-southwest (45° S. 20° W.) plunge and bearing. The "b" lineations are subparallel to both the major and minor axes in the Coal Creek syncline; they range in plunge and bearing from about 18° N. 58° E. to 34° N. 62° E. for the major axes and about 20° N. 80° E. to 45° N. 85° E. for the minor axes (fig. 5). Mineral lineations plunging about 30° S. 25° W. and 25° S. 3° W. occur in both the metasedimentary rocks and the igneous rocks in a position nearly at right angles to the axis of the Coal Creek syncline. These appear to form the "a" lineation of the Coal Creek syncline. Lineations in the Idaho Springs–Ralston shear zone plunge about 56° S. 15° W.

Statistical plots of lineations in the quartz monzonite and Boulder Creek Granodiorite in the quadrangle show two conspicuous concentrations. One concentration has a plunge and bearing of about 30° S. 15° W. (fig. 9*B*); the other, about 45° N. 40° W. (fig. 6*A*). The north-plunging lineation is restricted to the north limb of the Scar Top anticline and the south-plunging lineation to the south limb. The south-plunging lineations are nearly at right angles to the axis of the Scar

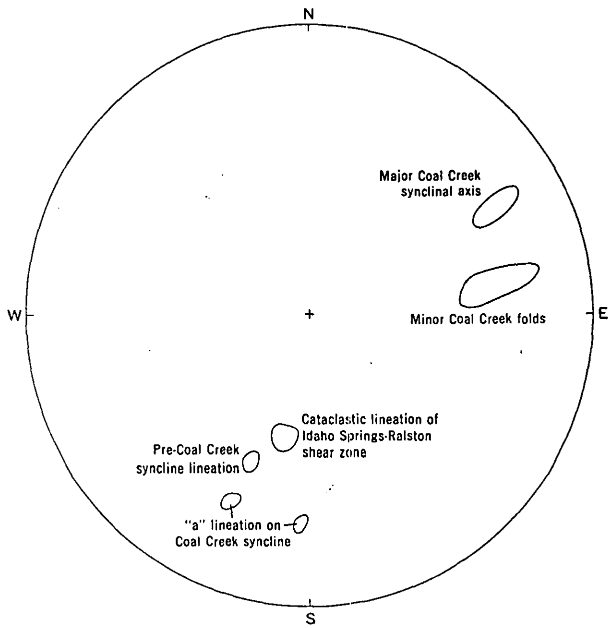

FIGURE 5.—Summary of attitudes of lineations in the metasedimentary rocks along the Coal Creek syncline. Lower hemisphere. From Wells, Sheridan, and Albee (1964).

Top anticline, and the north-plunging lineation is at an angle of about 70° from this axis. These major concentrations occupy the position that would be expected for the "a" lineation of the Scar Top anticline. The coincidence of the attitude of south-plunging lineations in the metasedimentary rocks and the igneous rocks has been pointed out (Wells and others, 1964). These were interpreted as "a" lineations formed on the Coal Creek syncline. The parallelism of the axes of the Scar Top anticline and Coal Creek syncline and of the lineations within these folds indicates that both were formed synchronously under similar stress conditions.

Two less conspicuous concentrations of lineations occur on a plot of the southern flank of the Scar Top anticline (fig. 9*B*). The one with a moderate plunge to the northeast occurs in the quartz monzonite unit, and the one with a moderate plunge east-southeast is restricted to the Boulder Creek Granodiorite. These probably represent dip-slip motion on the foliation planes.

SEQUENCE OF STRUCTURAL EVENTS

The earliest recognized period of Precambrian deformation formed mineral lineations which plunge south-southwestward in this area (Wells and others, 1964). These lineations are present only in the

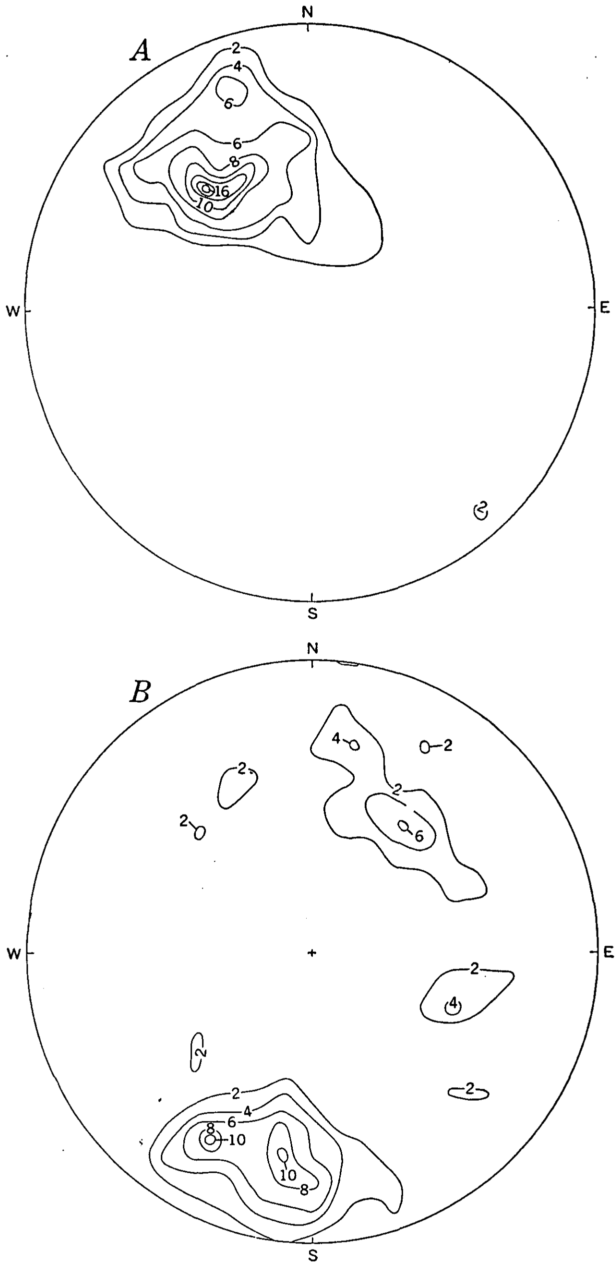

FIGURE 6.—Lineations in the quartz monzonite and Boulder Creek Granodiorite. Lower hemisphere plots. Contoured in percent. *A*, Northwest of the axis of the Scar Top anticline; 91 poles. *B*, Southeast of the axis of Scar Top anticline, 97 poles.

metasedimentary rocks and were probably formed by plastic folding at a time of deep burial. During the second period the Coal Creek syncline and probably the Scar Top anticline were formed. The Boulder Creek Granodiorite and the quartz monzonite were intruded during this deformation and were deformed by it. The second deformation in the Eldorado Springs area is probably equivalent to the first deformation described in the Idaho Springs-Central City area by Moench, Harrison, and Sims (1962) ; in both areas the Boulder Creek rocks are syntectonic and the major folds were formed at that time. During the third period of deformation, the Idaho Springs-Ralston shear zone, and probably the small zones in the central and northern part of the quadrangle, as well as northwest-trending faults, were formed. The Idaho Springs-Ralston shear zone was considered by Harrison and Wells (1959, p. 32) to have been formed in a deep environment because of the plastic deformation associated with it. In the Coal Creek area the shear zone was probably formed at a shallower depth but deep enough to prevent destruction of high-grade minerals.

LARAMIDE STRUCTURAL GEOLOGY

During the Laramide orogeny the sedimentary rocks were tilted to the east, and they now dip about 50°, on the average. Many faults cross the area and displace the rocks as much as several thousand feet. Most of the faults trend northwest and dip steeply; others trend east and northeast.

FOLDS

Most of the sedimentary rocks folded by uplift of the Front Range dip 40°–60° E. Some beds are vertical to slightly overturned in fault zones. The dominant strike of the beds is north, but on the southwest side of major faults the strike is deflected to about N. 15° W. Minor folds have been formed by drag near faults or along the strike of faults where they pass into folds.

FAULTS

The northwest-trending faults called breccia reefs presumably originated during the Precambrian and were reactivated during the Laramide (Tweto and Sims, 1963). The presence of brecciated and gouge material, the absence of sheared rock along the faults, and the displacement of Cretaceous rocks, however, show that most of the features seen on the faults were formed during the Laramide.

The breccia reef fault system shows a varied composition, determined by the country rock and the fracture fillings.

In the southern part of the quadrangle where the reefs cut the quartzite units, the breccia fragments are cemented by hematite-rich red quartz and by layers of white comb quartz. The type of fracture filling also is present in the granitic rocks a mile northwest of the quartzite contact. To the northwest the reefs are of two types: (1) zones of silicified iron oxide-stained breccia, and (2) zones of iron oxide-stained gouge. The silicified zones tend to form ridges, whereas the gouge zones tend to weather down and form depressions. Near the north boundary of the quadrangle, dolomitic cement is also found. In sedimentary rocks, the breccia reefs consist of both gouge and silicified breccia.

Local concentrations of other minerals are distributed in the fractured zones. Fluorite occurs in the reefs from one-half to three-fourths mile south and southeast of the Coal Creek store. The copper minerals chalcocite, malachite, and azurite occur along the Rogers reef from one-half mile south to one-fourth mile northwest of the Coal Creek store. Gold and silver tellurides and ferberite occur in the Magnolia mining district, and ferberite is present along the Copeland fault to the south. Barite veins occur on the east peak of Blue Mountain and on the ridge north of Quartz railroad siding. Material resembling sandstone dikes is present on the southeast slope of Scar Top Mountain.

The Boulder fault, which strikes about N. 30° W. where it occurs in the quadrangle, consists of a steeply dipping zone that is 400–800 feet wide, fault strands, and minor cross faults. The east side has moved down so that about 2,000 feet of stratigraphic section is cut out near the quadrangle boundary. The fault passes into a small monoclinal fold in the plastic beds of the Pierre Shale south of Bear Canyon Creek.

The Maxwell fault or breccia reef generally consists of a few feet to 50 feet of breccia that is locally accompanied by poorly defined limonite-stained zones a few hundred feet wide. It is nearly parallel to the Boulder fault except at its southern end, where it trends south, and dips from nearly vertical to about 70° E. On Green Mountain, rocks on the west side of the fault have moved down about 1,600 feet; the fault dies out 1½ miles to the south. The true movement on the fault is mainly dip slip, as shown by the steep slickensides and the nearly horizontal axis of a small drag fold on Green Mountain.

The Hoosier fault or breccia reef consists of a zone of branching and subparallel fractures. The individual fractures range from a few feet to a few hundred feet in width and are partly cemented by silica or carbonate. The fault zone is steep and trends about N. 30° W. in its northwestern part and about N. 50° W. in its southeastern part. On South Boulder Peak the main fracture has an apparent vertical displacement of about 2,500 feet, and the west side is downthrown. The displacement diminishes along the fault to the southeast; it does not exist east of the Dakota hogback 1½ miles away. The displacement also diminishes to the northwest on this fracture but is apparently taken up on another subparallel fracture where the displacement is significant but unknown.

The Livingston fault or reef is the most conspicuous in the quadrangle, and it is probably one of the longest in the region. Recent mapping by Van Horn in the Ralston Buttes (*in* Sheridan and others, 1967) and Golden quadrangles (1957) indicates that the Livingston fault is continuous southward with the Golden fault.

In the Eldorado Springs quadrangle the Livingston fault is a zone of branching and subparallel faults that trends about N. 33° W. Near the south boundary of the quadrangle the sedimentary layers within the zone have been displaced and overturned along a complex set of faults, only the largest of which are shown on plate 1. Between Eldorado and Crescent Mountains, according to the interpretation made in this report, a folded and faulted graben occurs between two branches of the fault. The movement was left lateral west of the graben and right lateral east of it. The drag folds shown on plate 1 near Plainview indicate the right-lateral displacement. Apparently the left-lateral displacement in the fault zone was the larger; the net displacement is left lateral. Along the fault southwest of Plainview, where both displacements must have occurred, the net apparent displacement is roughly 5,000 feet strike slip or 2,300 feet vertical displacement. According to a contrasting interpretation of C. M. and M. F. Boos (1957, p. 2560 and fig. 7), the Livingston fault ends against a curving thrust fault at the graben. The displacement on the Livingston fault diminishes northwestward to less than 100 feet at South Boulder Creek. In the Magnolia district a subparallel fault displaces a diabase dike.

The Copeland fault, in the west-central part of the quadrangle, is a west-trending fracture that joins the Livingston fault from the west. Near the juncture it is a prominent silicified breccia reef known as the Langridge Dyke, 100–150 feet wide.

The Rogers fault is expressed in this quadrangle as a group of subparallel branching and cross faults in a zone 1–1½ miles wide that trends about N. 30° W. Most of the faults are steep and consist of thin cemented breccia zones except for some broad poorly cemented breccia zones northwest of Coal Creek store. The faults show very little displacement northwest of the quartzite. Along the east branch of the fault zone, which passes along the valley of Coal Creek east of Blue Mountain, a discontinuous schist layer is apparently offset horizontally about 4,000 feet. On the south limb of the syncline in the Ralston Buttes quadrangle (Sheridan, and others, 1967) the same schist layer has an apparent horizontal offset of about 450 feet. By graphical calculation, the Coal Creek syncline west of the fault would have to have been displaced about 4,000 feet vertically downward and 1,600 feet horizontally to the north to cause the apparent offset. The fault that passes through Blue Mountain shows only a small displacement where it crosses the schist layer, yet there is an apparent horizontal offset of about 4,000 feet at the northern contact of the quartzite. This relation suggests that the apparent fault offset there is actually the result of igneous stoping during Precambrian time, especially since a part of the quartzite sequence is missing east of the fault.

The Hurricane Hill fault trends about N. 50° W. across the southwest corner of the quadrangle. The fault is 10–20 feet wide and shows very little offset.

Many east- or northeast-trending faults, most of which are steep and have small offsets, extend from or connect with the major fault zones just described. In addition, a series of east trending moderately dipping faults with dips as low as 32° connect the Rogers and Livingston fault zones one-fourth mile north of Crescent. The northeast-trending fault that passes through Scenic offsets the base of the Fountain Formation; the north side moved down about 500 feet in relation to the south side.

The mineralized faults represented by the veins in the Magnolia area trend from west to northwest. They dip steeply, are generally less than 10 feet wide, and have small offsets.

SUMMARY OF GEOLOGIC HISTORY

The geologic history recorded in the rocks of the quadrangle started in the Precambrian and continued to the present. The probable sequence of events may be summarized as follows:

1. Clastic sedimentary rocks were deposited in a sea at an unknown time in the Precambrian.
2. The rocks were deformed by plastic folding and metamorphosed to staurolite grade in the earliest Precambrian tectonic event recorded in this region.
3. The rocks were deformed again by plastic folding and metamorphosed to sillimanite grade. The Coal Creek syncline was formed at this time, and the Boulder Creek Granodiorite and the quartz monzonite were intruded syntectonically.
4. The rocks were deformed a third time in the Precambrian, this time by cataclasis and shearing. The northeast-trending Idaho Springs-Ralston shear zone and some minor shear zones were formed, and probably most of the northwest-trending faults occurred.
5. The Silver Plume Granite and the aplite and pegmatite were intruded as the final event in the record of Precambrian history.

6. In the Pennsylvanian the conglomeratic arkose of the Fountain Formation was deposited on the Precambrian rocks. (No geologic record remains within the area from the Precambrian to the Pennsylvanian.) Deposition of marine and nonmarine sediments continued during the late Paleozoic and the Mesozoic, interrupted periodically by uplift and erosion.
7. Uplift accompanied by folding and faulting occurred during the Laramide orogeny and formed the Rocky Mountains. The old Precambrian faults were reactivated and in many places their gouge was silicified or otherwise altered to form the breccia reefs. The sedimentary rocks were rotated to their upturned position by the folding. The orogeny was accompanied by intrusion of Tertiary igneous rocks followed by emplacement of the metallic vein deposits.
8. After long erosion that followed the Laramide orogeny, gravel was deposited upon a high-level erosion surface in the late Tertiary.
9. Erosion continued and successive pediments were cut and veneered by gravel east of the mountain front during the pre-Wisconsin Pleistocene glaciations.
10. Erosion accompanied by deposition of alluvium on stream terraces continued until the present.

ECONOMIC GEOLOGY

The economic resources of the Eldorado Springs quadrangle that have been or are being exploited are gold and tungsten from the Magnolia district, clay products from the sedimentary rocks, construction material from local sites in the area, and water. Other metallic and nonmetallic resources are present; some of these may prove to be ore in the future.

METALLIC RESOURCES

The Magnolia mining district occupies an area of less than a square mile in the northwest corner of the quadrangle and extends a short distance west of the quadrangle. The mines are along veins that have yielded gold and silver in the form of tellurides, and tungsten in the form of ferberite.

Most of the production came soon after the discovery of gold in 1875; since then, the quantity and tenor of the ore have generally decreased. Between 1875 and 1905 gold and silver production was valued at $2,815,000; between 1905 and 1936, at about $200,000 (Lovering and Goddard, 1950, p. 227). During 1936–48, gold and silver ore worth $198,877 was produced, most of it before 1942; no ore has been produced since 1948 (U.S. Bur. Mines, 1936–48). Early mining centered on the "rusty" gold ore concentrated near the surface by residual enrichment, whereas the later mining was generally in primary ore. The general decease in values is shown by the change in the tenor of ore from the Magnolia mine in the western part of the district. Output from this mine averaged 4.5 ounces of gold and 2 ounces of silver per ton in 1881–92 but later decreased to less than one-half ounce of gold per ton (Lovering and Goddard, 1950, p. 234). Most of the workings in the district are now caved and inaccessible, although a few have been maintained in a fair state of repair, to judge by their outward appearance.

The ore in the district occurs in small shoots along steep narrow fissure veins that trend from east-northeast to west-northwest (pl. 1). The ore shoots, which are notably discontinuous, are concentrated near vein intersections and at irregularities in the attitude of the vein where openings occurred (Wilkerson, 1939 a, b). Most gold shoots are less than 100 feet in length, 6–10 feet in width, and 250 feet in pitch length. The shoots containing tungsten are generally smaller than those containing gold. Most of the tungsten deposits are found in the east-trending veins near the major faults of the breccia reef system, whereas most of the gold was found in northwest-trending veins. Total tungsten output has been small, and there has been none since World War II.

South of the Magnolia district tungsten occurs in the Copeland and Rogers breccia reefs. The Copeland mine (now inundated by Gross Reservoir) was for a time during World I one of the leading tungsten mines in Boulder County, although the ore was fine grained, relatively low grade, siliceous, and refractory (Lovering and Tweto, 1953, p. 185–187). It yielded about 15,000 units of WO_3, mostly in 1917–18. The Rogers reef is mineralized at several places on the ridge west of Nineteen Gulch and north of the railroad by small amounts of high-grade coarsely crystalline ferberite in small veins within and alongside the reef (Lovering and Tweto, 1953, p. 57).

Uranium has been found in small amounts on the Rogers and Hurricane Hill faults or reefs in the southern part of the quadrangle. These are the same faults along which uranium mines have been established in the Ralston Buttes quadrangle to the south (Sheridan and others, 1958; Sims and Sheridan, 1964). Samples submitted by F. A. McKeown in 1951 from a prospect on the Hurricane Hill fault in the west-central part of sec. 17, T. 2 S., R. 71 W., contained 0.001–0.005 percent uranium. Two samples from a prospect on the Rogers fault in the SE¼NW¼ sec. 9, T. 2 S., R. 71 W. (R. U. King, J. W. Adams, and D. M. Sheridan, written commun., 1954) contained 0.017–0.11 percent uranium. An extensive search for uranium was conducted by King and others in the quadrangle between 1950 and 1955, but no other mineralization was found.

The copper minerals chalcocite, malachite, and azurite occur along the Rogers reef from one-half mile south to one-fourth mile northwest of the Coal Creek store. Two samples taken from a prospect in the NW¼SW¼ sec. 17, T. 2 S., R. 71 W., contain 0.15 and 0.016 percent copper (R. U. King, J. W. Adams, and D. M. Sheridan, written commun., 1954). None of the sites of copper mineralization in the quadrangle have proved economic.

NONMETALLIC RESOURCES

Clay is mined in or near the Eldorado Springs quadrangle from four stratigraphic units: the Lykins Formation, Morrison Formation, Dakota Group, and Pierre Shale. Most of the mines are in the Dakota Group, but the Lykins and Morrison Formations have one mine each, and a plant has been established just east of the quadrangle to manufacture lightweight aggregate from the Pierre Shale.

The main source of clay in the area is the Dakota Group. The Van Bibber Shale Member of the South Platte Formation (Waagé, 1961) is the only source of refractory clay in the area; other beds, generally in the uppermost part of the group in the Eldorado Springs quadrangle, yield clay suitable for brick and tile. Waagé (1961) described in detail the clay resources of the Dakota Group in the northern Front Range. He found that the lithology of the Dakota changes from north to south, and that this change is accompanied by a reduction in the amount of refractory clay to the north, so that the chances of discovering extensive deposits of refractory clay north of Eldorado Springs are diminished (Waagé, 1961, p. 18). Resources of clay suitable for brick and tile are extensive.

Most of the present mining in the Dakota Group is from the upper part; locally the middle and lower parts are also being mined. Table 14 shows the mineral content of these beds to be uniform except in specimen F–177B, which contains a large amount of kaolinite and is therefore a refractory clay.

The mine in the Lykins Formation is near the center of the N½ sec. 12, T. 2 S., R. 71 W., where beds have been deformed by folding near the Livingston fault. Analyses (table 14) show that the clay from this locality lacks the calcite characteristic of most clay in the Lykins Formation. Apparently the calcite has been removed near the fault and the Lykins Formation here has been rendered a suitable source for clay.

The clay mineral in the Morrison Formation is mixed layer mica-montmorillonite (table 14). Clay resources in the Morrison Formation are large, but in the Lykins they are limited to those areas where calcite is absent.

TABLE 14.—*Mineralogy of clay deposits determined from X-ray diffractometer patterns*

[Estimated amount of mineral (parts in 10). Tr, trace; query (?) indicates mineral may not be present. John C. Hathaway, analyst]

	Typical Lykins Formation	Lykins Formation from clay mine	Morrison Formation	Lower part of Dakota Group		Middle part of Dakota Group		Upper part of Dakota Group		Pierre Shale
	F-159	H-133	F-176A	F-176B	S1-15	F-177B	S1-16	F-177A	S1-18	F-148E
Quartz	2	3	4	7	7	5	7	4	7	4
Feldspar	Tr.	2		?Tr.						1
Calcite	4									
Dolomite										Tr.
Mica	2	2						1	Tr.	1
Chlorite			?Tr.							1
Mixed layer mica-montmorillonite			[1] 5	[2] 2	[1] 1		[3] 1	[4] 2	[5] 1	
Mixed layer chlorite montmorillonite	1	[4] 3								
Montmorillonite										3
Kaolinite	?Tr.		?Tr.	1	2	5	2	2	2	
Hematite	1									
Unidentified iron-bearing mineral								<1		

[1] Contains about 10 percent montmorillonite.
[2] Contains about 20 percent montmorillonite.
[3] Contains 10–20 percent montmorillonite.
[4] Contains about 50 percent montmorillonite.
[5] Contains 40–50 percent montmorillonite.

The Pierre Shale, which is a source of bloating clay, contains large amounts of montmorillonite. The resources of bloating clay in the Pierre Shale appear to be very large.

In his appraisal of the clay deposits of the Denver-Golden area, Waagé (1952) pointed out that reserves of refractory clay are dwindling rapidly and that no new deposits have been discovered, although reserves of clay suitable for brick and tile are plentiful. In the Eldorado Springs quadrangle clay mining has increased generally as deposits nearer the kilns have been exhausted. This trend will probably continue, although the chances of finding large deposits of refractory clay in the Dakota Group, particularly north of Eldorado Springs, do not seem to be promising. The utilization of these clay resources depends to a large extent upon the economic factors within the clay-products industry as well as the economic factors of land use in general in this growing metropolitan area.

Sand and gravel are abundant in the pediment and stream alluvial deposits of the quadrangle. Gravel pits are operating or have operated in the Rocky Flats Alluvium a few miles east of the southern part of the quadrangle and in the stream alluvial deposits along South Boulder Creek east of the quadrangle. Any of the alluvial deposits in the area, except possibly the pre-Rocky Flats, may constitute additional resources. The granitic boulders in the oldest deposits have weathered since their deposition and are not now sound. Road metal for local use is taken from the fault zone west of the Coal Creek store and near Flagstaff Mountain.

Limestone and shale units that may be resources of cement materials are limited to the Niobrara Formation. Rocks of this formation near Pueblo and Fort Collins are being used for cement (Vanderwilt, 1947, p. 231; Argall, 1949, p. 78–88). Although the Niobrara is present the full length of the Eldorado Springs quadrangle, it dips steeply and is mostly covered with surficial deposits; therefore only a limited volume of material is available for economic quarrying.

Barite occurs locally as fracture fillings in the breccia reefs, generally in the southern part of the quadrangle near the eastern peak of Blue Mountain and Quartz railroad siding. On Blue Mountain the breccia cuts quartzite and is several feet wide; individual stringers of barite are as much as 1 foot wide. In a prospect pit about one-fourth mile northwest of Quartz siding, the breccia is a few feet wide and contains individual stringers about 6 inches wide; the wallrock is quartz monzonite. These deposits appear to be too small to be economic at this time.

Several of the rock units are potential sources of building and construction stone, although only a small amount of rock has been quarried and no quarries are now in operation (1965). A small amount of building stone has been quarried from the Lyons Sandstone between Skunk and Bluebell Canyons. A large quantity of Lyons Sandstone is available, but the demand for this type of rock has been met by several quarries that have operated for many years in the Lyons, Colo., area (Argall, 1949). The stone in the Lyons area has a more desirable brighter pink color and a better splitting quality than the stone in the Eldorado Springs quadrangle.

Granite quarries have not been established in the Eldorado Springs quadrangle. Although a large supply of stone exists in the western part of the quadrangle, it is not of commercial quality because joints are so closely spaced that large single blocks suitable for monuments are generally lacking and the stone is not particularly beautiful. Quarrying, except for limited local needs, is not likely to develop in this area.

Pegmatite prospects are not known in the quadrangle, although pegmatites containing feldspar, mica, beryl, and rare earths have been mined and prospected about 10 miles north of the quadrangle in the Lefthand Creek area and about 10 miles to the southwest in the Idaho Springs–Golden area (Argall, 1949, p. 48–69, 153–178, 298–314; Hanley, 1947, p. 466–470). These deposits were described in detail by Hanley, Heinrich, and Page (1950). The pegmatites in the Eldorado Springs quadrangle are generally too small and too fine grained to be of potential economic importance.

Andalusite is a common mineral in the quartzite and schist in the southern part of the quadrangle and may be a source of aluminum silicate for ceramic manufacture. In layered concentrations, andalusite constitutes as much as 18 percent of the quartzite and 38 percent of the schist (tables 2, 5). The mineral is fine grained in the quartzite and poikiloblastic in the schist. These characteristics would seem to make pure andalusite in quantity difficult to obtain. If, however, 10 percent mineral content qualifies the rock as ore, as suggested by Foster (1960, p. 784), milling might prove successful, provided that detailed sampling proved the extence of a large enough reserve of ore.

Quartz of potential economic significance occurs in the breccia reefs, quartzite, and sandstone. The breccia reefs in and near the Precambrian quartzite in the southern part of the quadrangle are commonly cemented with quartz. In most of these the brecciated wallrock predominates, but locally, as along the breccia reef 4,500 feet southwest of Twin Spruce in the southwest corner of the quadrangle, individual veins of massive quartz as much as 5 feet wide are present. Quartz is abundant along this reef for about one-half mile. Almost all the quartzite contains mica, andalusite, or iron minerals, and it is generally unsuitable as a source of silica sand.

Silica sand has been mined from the sandstone in the Dakota Group in the Golden and Kassler areas (Vanderwilt, 1947, p. 263–264; Argall, 1949, p. 357). No silica sand is known to have been extracted from this sandstone unit in the Eldorado Springs quadrangle, but the unit is a potential source of silica.

Fluorite occurs as fracture filling in the breccia reefs from ½ to ¾ mile south and southwest of the Coal Creek store. The fractures are small, and the fluorite is closely intermixed with wallrock. Because of this contamination the deposits have not proved economic.

Spectrographic analyses were made of 13 specimens of material from the breccia reefs previously described, but the analyses showed no unusual concentrations of any element that could not be anticipated from inspection of the hand specimen.

GROUND-WATER RESOURCES

Ground water is an important economic commodity in this quadrangle because of the development of the quadrangle as a residential area. Jenkins has described the ground-water potential of the quadrangle in his report on the Boulder area, from which the following is summarized (E. D. Jenkins, written commun., 1963). The principal sources of ground water are in the crystalline rocks in the western part of the area and in the sandstone units along the mountain front, the pediment alluvium east of the front, and the valley alluvium. Wells in the crystalline rocks and pediment alluvium generally yield 1–5 gpm (gallons per minute), the sandstone units yield 5–15 gpm, and the valley alluvium 5–25 gpm. This is sufficient for individual homes, small groups of homes, and small industry. The quality of water from these rock units is generally good, although water from the valley alluvium is hard. Small amounts of water that may be highly mineralized are available from the sandstone units in the Pierre Shale.

The availability of ground water is largely controlled by the permeability of the rock. The permeability of the crystalline rocks and sandstone units is controlled by the extent of jointing and the degree of brecciation along the breccia reef faults; therefore, the probability of finding an adequate water supply is greatest when breccia reefs or areas of closely spaced joints are penetrated. The major breccia reef faults are shown on pl. 1. In the alluvial deposits the better areas for large water supplies are those where the alluvium is coarse and thick and where there are natural depressions at the base of the alluvium.

STRATIGRAPHIC SECTIONS

1. Section in Bear Canyon at the south end of The Flatirons, about 1½ miles south of Boulder, SE¼; sec. 12, T. 1 S., R. 71 W.

[Measured by J. D. Wells and R. F. Wilson]

	Thickness (feet)
Benton Shale (unmeasured and undescribed).	
Dakota Group (undifferentiated):	
40. Covered. Top of unit is probably top of Dakota Group	20.0
39. Sandstone, light-gray (*N* 7), very light gray (*N* 8), and yellowish-gray (5*Y* 8/1); weathers to same colors; fine to very fine grained, well sorted, well cemented, very slightly calcareous in part; composed of subround to round colorless to reddish quartz and dark accessory mineral. Horizontal and cuspate ripple laminae, and trough sets of low-angle small- to medium-scale cross laminae. Some clay pellets in base of unit; discontinuous wavy laminae in upper part. Forms easternmost hogback of Dakota Group	19.0
38. Sandstone (50 percent) and siltstone (50 percent). Sandstone is white (*N* 9), moderate orange pink (5*YR* 8/4), and light olive gray (5*Y* 6/1); weathers to same colors; very fine grained, silty in part, well sorted, well cemented, calcareous in part; composed of subround to round colorless and reddish quartz and dark accessory mineral; horizontally laminted to very thin bedded. Siltstone is medium gray (*N* 5), weathers to same color; composed of medium silt, firmly cemented, noncalcareous-bound with clay. Stratification is concealed; siltstone is interstratified with sandstone in thin to thick sets. Unit as whole forms ledgy slope	55.0
37. Mostly covered. Poor exposures of medium-gray (*N* 5) silty claystone; weathers to same color; finely micaceous, carbonaceous, firmly cemented, noncalcareous, bound with clay. Stratification is concealed	35.0
36. Sandstone, very light gray (*N* 8), yellowish-gray (5*Y* 8/1), and grayish-orange (10*YR* 7/4); weathers to same colors; fine grained to very fine grained, well sorted, well cemented, calcareous in part; composed of subround to round colorless and orange-stained quartz, dark accessory mineral, and limonite spots. Horizontally laminated to thick bedded; forms ledgy interval. A unit 12–25 ft thick contains several thin sandy siltstone sets like unit 35	38.0
35. Mostly covered. Exposures in top half of unit are medium-dark-gray (*N* 4) to very light gray (*N* 8) siltstone to sandy siltstone, which weathers to same colors; rock is very fine grained sandy in part, firmly to well cemented, noncalcareous. Common dark accessory mineral occurs in coarser beds. Siltstone is horizontally very thick bedded; sandy siltstone, at top of unit, is horizontally laminated. Forms partly covered slope	19.0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Dakota Group—Continued	
34. Sandstone, yellowish-gray (5*Y* 8/1) and light-brown (5*YR* 6/4); weathers to same colors; fine to medium grained, well sorted, well cemented, noncalcareous; composed of subround to round colorless and reddish quartz and dark accessory mineral. Thin to thick tabular and lenticular cosets of trough sets of small- to medium-scale cross laminae and some thin horizontal laminae. Forms crest of hogback	60.0
33. Sandstone, very pale orange (10*YR* 8/2) and yellowish-gray (5*Y* 7/2); weathers to same colors and light gray (*N* 7); medium to coarse grained, well sorted, firmly to well cemented, noncalcareous; composed of subround to round clear and frosted colorless quartz, with dark accessory mineral and limonite stains. Horizontally laminated to very thick bedded, with some planar and trough sets of low-angle medium-scale cross strata. Forms first ridge of hogback of Dakota Group	50.0
Total Dakota Group (undifferentiated)	296.0
Morrison Formation:	
Upper silty member:	
32. Siltstone, light-greenish-gray (5*GY* 8/1) and light-olive-gray (5*Y* 6/1) in basal 40 ft, greenish-gray (5*GY* 6/1) and grayish-red (10*R* 4/2) above; weathers to same colors; composed of fine to medium silt; firmly to well cemented, noncalcareous to slightly calcareous, bound with clay; stratification concealed. Forms partly covered slope. Limonite common in basal 40 ft; 40–43-ft interval above base of unit is dark-yellowish-orange (10*YR* 6/6) calcareous coarse siltstone that forms indistinct ledge	88.0
31. Sandstone, light-brown (5*YR* 6/4); weathers to same color; very fine grained to medium grained, fairly well sorted to well sorted, well cemented, calcareous; may be siliceous locally; composed of rounded reddish-stained quartz and accessory dark mineral and abundant limonite; numerous stringers of chert in basal part. Forms ledge	2.0
30. Claystone, silty (70 percent), and silty limestone (30 percent). Claystone is greenish gray (5*GY* 6/1), weathers to light greenish gray (5*GY* 8/1); firmly cemented, slightly calcareous; bound with clay; stratification concealed. Limestone is pale yellowish orange (10*YR* 8/6), weathers to same color; aphanitic, silty, well cemented, horizontally stratified; some may be brecciated; interstratified in thin sets with claystone; weathers to form ledges. Unit as whole forms partly covered ledgy slope	15.0
29. Claystone, silty, like unit 30. Forms partly covered slope	16.0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Morrison Formation—Continued	
Upper silty member—Continued	
28. Sandstone, grayish-orange-pink (5*YR* 7/2) to dark-yellowish-orange (10*YR* 6/6); weathers to very pale orange (10*YR* 8/2); fine to medium grained, well sorted, firmly cemented, calcareous; composed of round clear and orange-stained quartz and abundant accessory limonite. Trough sets of low- and high-angle medium-scale cross laminae. Forms ledge. Base is sharp and fairly even	9. 0
27. Mostly covered. About 30 percent of unit is exposed and consists of several thin sets of limestone that is light olive gray (5*Y* 6/1), medium light gray (*N* 6), and grayish orange (10*YR* 7/4), weathers to same colors and yellowish gray (5*Y* 8/1); rock is aphanitic, with minor more coarsely crystalline parts; well cemented, dense; horizontally very thin to thick bedded. Locally contains ostracodes and charophytes(?) about 8 ft below top. Forms ledges	33. 0
26. Mostly covered. At 25 ft above base unit contains a thin light-gray (*N* 7) sandy siltstone to silty sandstone that weathers to same color and is very fine grained, well cemented, and calcareous; rock is composed of colorless quartz and dark accessory mineral; contains limonite spots. Horizontal and cuspate ripple laminae. Forms thin ledge	80. 0
Total upper silty member	243. 0
Lower sandy member:	
25. Sandstone, yellowish-gray (5*Y* 8/1) and very light gray (*N* 8); weathers to same colors; fine grained to very fine grained, well sorted, firmly cemented, calcareous; composed of subround to round clear and frosted colorless quartz and dark, reddish, and green claystone fragments; bedding dominantly trough and minor planar sets of low-angle small- to medium-scale cross laminae. Lower few feet of unit contains several lenses of clay-pellet conglomerate. Forms prominent whitish ledge. Base of unit sharp and irregular with relief of as much as 2 ft	27. 0
24. Claystone, silty, to clayey siltstone, greenish-gray (5*GY* 6/1) and light-olive-gray (5*Y* 6/1); contains small amounts of moderate-reddish-brown (10*R* 4/6) and grayish-red (10*R* 4/2) rock in upper few feet; some swelling clay; firmly cemented, calcareous, bound with clay; stratification concealed. Forms greenish slope	20. 0
23. Limestone, medium-light-gray (*N* 6); weathers to light olive gray (5*Y* 6/1); aphanitic, dense, well cemented. Contains some greenish-gray claystone seams and fragments of darker material; horizontally thin bedded. Forms indistinct ledge	. 7

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Morrison Formation—Continued	
Lower sandy member—Continued	
22. Clayey siltstone to silty claystone, greenish-gray (5*GY* 6/1), grayish-red (5*R* 4/2), pale-reddish-brown (10*R* 5/4), and pale-yellowish-brown (10*YR* 6/2); weathers to same colors; firmly cemented, calcareous, bound with clay; stratification concealed; varies from silty claystone to clayey siltstone; may contain swelling clay. Forms reddish slope. Upper 15 ft of unit contains several sets of horizontal- to ripple-laminated light-greenish-gray (5*GY* 8/1) sandy siltstone	50.0
21. Sandstone, white (*N* 9) yellowish-gray (5*Y* 8/1) and pinkish-gray (5*YR* 8/1); weathers to same colors; very fine grained to medium grained, well sorted, firmly cemented, slightly calcareous in part; composed of subround to round frosted colorless quartz and common dark, reddish, and green accessory minerals; greenish-gray clay pellets common. Horizontal and cuspate ripple laminae. Forms ledge at crest of hogback. Base of unit sharp and even	7.5
Total of lower sandy member	105.2
Total of Morrison Formation	348.2
Ralston Creek Formation:	
20. Siltstone, yellowish-gray (5*Y* 8/1), light-greenish-gray (5*GY* 8/1), greenish-gray (5*GY* 6/1), and grayish-yellow (5*Y* 8/4); well-sorted to fairly well sorted, nonmicaceous, poorly to firmly cemented, calcareous. Grades from fine siltstone to very fine sandy siltstone, with scattered round coarse sand grains along some horizons in lower 6 ft. Stratification concealed. Forms greenish slope. Thin reddish chert lenses in siltstone 4.5 ft above base. Lower 4.5 ft of unit contains white chert nodules; upper 6 ft includes a few very thin lenses of moderate-reddish-brown (10*R* 4/6) claystone which may contain swelling clay and which grades laterally into siltstone	12.0
19. Siltstone and sandstone. Siltstone is sandy, mottled pale reddish-brown (10*R* 5/4) and greenish-gray (5*GY* 6/1), and weathers to same colors; consists of coarse silt to very fine sand; contains scattered rounded medium to coarse sand grains, fairly well sorted; poorly to firmly cemented, calcareous; stratification concealed. Composed of subround to round greenish- and reddish-stained quartz. Sandstone is yellowish gray (5*Y* 8/1) and weathers to same color; it is very fine grained, well sorted, firmly to well cemented, and calcareous. Composed of subround clear quartz and dark accessory mineral; horizontally laminated, forms sets 4–4½ ft and 15–17 ft above base of unit. Contains some calcite-filled vugs. Unit as whole forms whitish slope	22.0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Ralston Creek Formation—Continued	
18. Sandstone, light-brown (5*YR* 6/4); weathers to same colors; fine grained to very fine grained, firmly cemented, calcareous, stratification concealed; scattered round medium to coarse grains common; composed of subround to round clear and frosted reddish-stained quartz and minor white accessory mineral. Forms indistinct ledge. Base is concealed	.4
Total Ralston Creek Formation	34.4
Lykins Formation:	
Ledge-forming member:	
17. Siltstone to sandstone, pale-reddish-brown (10*R* 5/4) to light-brown (5*YR* 6/4); weathers to same colors; well sorted, firmly cemented to well cemented, calcareous; grades from coarse sandy siltstone to very fine grained sandstone; composed of reddish quartz and rare dark accessory mineral; horizontal cuspate, and parallel ripple laminae, and minor small-scale cross laminae. Forms ledgy slope. Unit contains a few thin to thick horizontally laminated medium siltstone sets	71.0
Total ledge-forming member	71.0
Upper slope-forming member:	
16. Siltstone to sandy siltstone, grayish-red (10*R* 4/2) to pale-reddish-brown (10*R* 5/4); mottled to light greenish gray (5*GY* 8/1) in spots, weathers to same colors, medium to coarse silt, very fine grained sandy in places, well sorted, firmly cemented, calcareous, clay binding; composed of reddish quartz and minor accessory mica in places. Stratification largely concealed but where exposed consists of horizontal laminae to very thick beds. Forms reddish, mostly covered, slope. Near top, unit contains a few thin sets of horizontally laminated sandy siltstone like unit 17	147.0
15. Covered	210.0
Total upper slope-forming member	357.0
Glennon Limestone Member of LeRoy (1946):	
14. Limestone, silty, or dolomite, moderate orange-pink (10*R* 7/4); weathers to same color and pinkish-gray (5*YR* 8/1); silty, finely crystalline, well cemented; thin wavy laminae. Forms thin ledge. Abundant slump structures	8.0
Total Glennon Limestone Member	8.0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Lykins Formation—Continued	
Lower slope-forming member:	
13. Siltstone, sandy, light-brown (5*YR* 6/4) to pale reddish-brown (10*R* 5/4); weathers to same colors; coarse silt, very fine grained sand, scattered fine to medium grains, fairly well sorted, firmly cemented, slightly calcareous; grades to silty sandstone in places; composed of subround reddish-stained quartz and accessory white mineral. Stratification largely concealed, but where exposed, member consists of discontinuous wavy laminae to structureless very thick beds. Forms reddish slope. Base concealed	97.0
Total lower slope-forming member	97.0
Total Lykins Formation	533.0
Lyons Sandstone:	
12. Sandstone, grayish-orange-pink (5*YR* 7/2) in lower half, very pale orange (10*YR* 5/2) in upper half; weathers to same colors; fine grained to very fine grained, well cemented, noncalcareous, well sorted to fairly well sorted; some concentrations of medium to very coarse grains along some lamination planes; composed of subround to round frosted colorless and reddish quartz and accessory white feldspar and minor dark mineral. Lower part covered along line of section, but away from section appears to be composed of horizontal laminae and tabular planar sets of low-angle medium-scale cross laminae; upper part composed of wedge-planar sets of medium- to large-scale low- and high-angle thin cross laminae. Forms covered slope and prominent hogback ridge. Base of unit sharp and fairly even, contains some thin lenses of conglomeratic sandstone like unit 11; may be an interformational conglomerate	250.0
Total Lyons Sandstone	250.0
Fountain Formation:	
11. Sandstone to conglomeratic sandstone and sandstone. Sandstone to conglomeratic sandstone is like that in unit 9 except that it is medium to very coarse grained. Sandstone is grayish orange pink (5*YR* 7/2) and very pale orange (10*YR* 8/2), weathers to same colors; fine to medium grained, some scattered coarse grains, fairly well sorted to well sorted, well cemented, noncalcareous; composed of subround to round clear and frosted(?) quartz and minor dark accessory mineral and white feldspar; stratification concealed, forms sets 25–30 ft and 60–65 ft above base of unit. Unit forms partly covered slope	70.0
10. Covered	30.0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Fountain Formation—Continued	
9. Sandstone to conglomeratic sandstone, very pale orange (10*YR* 8/2) to grayish-orange-pink (10*R* 8/2); weathers to light brown (5*YR* 6/4); coarse grained to very coarse grained with scattered granules to pebbles as much as 1 in. in diameter, poorly sorted, like unit 8. Horizontally laminated to thin bedded; mud-cracked surfaces; 0–8 ft above base, unit is composed of moderate reddish-brown (10*R* 4/6) very fine grained slightly micaceous sandstone containing scattered medium to coarse grains. At 55 ft above base, there are several thin lenses of siltstone like unit 5 and thin to thick sets of pale-reddish-brown (10*R* 5/4) very fine grained sandstone containing rounded medium grains to granules. Unit forms ledgy slope	110. 0
8. Sandstone to conglomeratic sandstone, pale-red (5*R* 6/2 and 10*R* 6/2), and grayish-orange-pink (5*YR* 7/2); small amounts of grayish-red (10*R* 4/2) sandstone near base, weathers to pale brown (5*YR* 5/2); medium grained to very coarse grained, fairly well sorted to poorly sorted, well cemented, noncalcareous; granules to pebbles as much as 4 in. in diameter. Composed of dominantly subround reddish quartz, pink feldspar, and accessory light mica and dark mineral; trough sets of low-angle medium-scale cross laminae to crossbeds and some horizontal strata. A few very thin lenses of sandy siltstone like that in unit 5 in lower part; several lenses of pale-reddish-brown (10*R* 5/4) very fine grained slightly micaceous sandstone 250 ft above base; a 3-ft set of pale-reddish-brown (10*R* 5/4) fine- to medium-grained horizontally laminated sandstone like rest of unit 360 ft above base. Unit forms irregular hogbacks and slopes	385. 0
7. Mostly covered. Exposures in top 15 ft are sandstone like unit 6 and a few very thin sets of siltstone like that in unit 5. Float includes siltstone containing scattered coarse grains to granules. Forms covered slope	65. 0
6. Sandstone to conglomeratic sandstone, grayish-red (10*R* 4/2); mottled to yellowish-gray (5*Y* 8/1) in places; medium grained to very coarse grained with scattered granules to small pebbles; poorly sorted, well cemented, slightly calcareous in part; horizontally laminated to thick bedded with some very low angle cross laminae. Forms hogback ridge	45. 0
5. Sandstone to conglomeratic sandstone, pale-red (5*R* 6/2) to pale-reddish-brown (10*R* 5/4); weathers to same colors; medium grained to very coarse grained, poorly sorted, firmly cemented to well cemented, noncalcareous; abundant fine matrix in places, granules to pebbles as much as 3 in. in diameter. Composition like unit 3; stratification obscured, but probably like unit 3. 60- to 85-ft interval covered 2-ft set of sandy siltstone, like unit 4, 30 ft above base; several very thin siltstone sets in top 15 ft	100. 0

1. Section in Bear Canyon at the south end of The Flatirons—Continued

	Thickness (feet)
Fountain Formation—Continued	
4. Mostly covered. Exposures in top 6 ft are sandy siltstone that is grayish red (5*R* 4/2), weathers to same color, and contains scattered fine to medium sand grains; firmly cemented, very slightly calcareous, structureless; abundant large mica plates	44. 0
3. Sandstone to conglomeratic sandstone, grayish-red (5*R* 4/2) to pale-red (5*R* 6/2); weathers to same colors and yellowish gray (5*G* 7/2); medium grained to very coarse grained with granules to pebbles as much as 4 in. in diameter, poorly sorted, grades locally to conglomerate; firmly cemented to well cemented, noncalcareous; pebbles are milky and clear quartz, feldspar, and quartzite. Composition like unit 2 except contains minor dark accessory mineral; horizontal very thin to thick beds and trough sets of very low angle medium-scale crossbeds. Forms lowest prominent hogback ridge	60. 0
2. Sandstone to conglomeratic sandstone, dark-reddish-brown (10*R* 3/4) to grayish-red (5*R* 4/2); weathers to same colors; coarse grained to very coarse grained with lenses of granules to pebbles as much as 4 in. in diameter, abundant silty to very fine grained sandy matrix, poorly sorted, firmly cemented to well cemented, noncalcareous; composed of subangular to subround clear, milky, and reddish quartz, pink feldspar, and abundant accessory light mica. Stratification largely concealed, but some trough sets of low-angle medium-scale crossbeds were noted. Sets of grayish-red (5*R* 4/2) silty sandstone to sandy siltstone containing scattered fine sand to pebbles and abundant mica. Silty sets are 0–5 ft, 64–66 ft, 74–78 ft, and 93–94 ft above base. Unit forms ledgy slope	94. 0
Total Fountain Formation	1, 003. 0
Boulder Creek Granodiorite:	
1. Igneous rock, light-brownish-gray (5*YR* 6/1) to grayish-red (10*R* 4/2), medium-grained. Dikes of Silver Plume Granite. Altered to depth of about 15 ft. Forms partly covered knobby slope	Unmeasured

2. Section on hillside along South Boulder Creek canyon, from one-half mile west of Eldorado Springs to Eldorado Springs

[Measured by J. D. Wells]

	Thickness (feet)
Lykins Formation, poorly exposed.	
Lyons Formation:	
16. Sandstone, moderate-reddish-orange (10*R* 6/6) to pale-red (10*R* 6/2) in upper part, with white flecks; medium to fine grained, well sorted to moderately well sorted, well rounded, well cemented, massive to thin bedded, large crossbeds upper 50 ft. Lower contact gradational through a few feet with less than 1-in.-thick interfingers of fine- and coarse-grained sandstone. Upper contact sharp and undulatory	233

2. *Section on hillside along South Boulder Creek Canyon, from one-half mile west of Eldorado Springs to Eldorado Springs*—Continued

	Thickness (feet)
Fountain Formation:	
15. Sandstone, grayish-pink (5*R* 8/2) to pale-red (5*R* 6/2); very coarse grained, locally conglomeratic, angular to rounded grains, poorly sorted, arkosic, massive to thick-bedded to crossbedded. Thin lenses of dark-reddish-brown (10*R* 3/4) siltstone and 1–3-ft bed like unit 14. Lower contact irregular with scour and fill	46
14. Sandstone, pale-red (10*R* 6/2), fine-grained, well sorted, well cemented, massive; coarse round quartz and angular white and moderate-orange-pink (10*R* 7/4) feldspar; closely spaced jounts	15
13. Sandstone, predominantly moderate-red (5*R* 5/4), fine grained to very coarse grained, round to angular grains, fairly well sorted to poorly sorted, noncalcareous. 100-ft interval 250 ft below top is micaceous, well cemented, massive to thick bedded with faint crossbedding locally and discontinuous lenses, stringers, and patches of siltstone like unit 10, sandstone like the middle of unit 6, and conglomeratic sandstone that is white with abundant moderate-orange-pink (10*R* 7/4) feldspar grains	480
12. Siltstone like unit 10, but thick bedded and less jointed	23
11. Sandstone, like unit 9	31
10. Siltstone, dark-reddish-brown (10*R* 3/4), dense, noncalcareous, thin- to thick-bedded; clear and grayish-pink (5*R* 8/2) round to angular granules. Small amount of pinkish-gray (5*R* 8/2) coarse-grained poorly sorted noncalcareous well-cemented massive sandstone, round to angular granules. Closely spaced joints	55
9. Sandstone similar to unit 5 with small lenses and irregular beds of red siltstone and grayish-pink sandstone as in unit 6; 2-ft-thick red siltstone bed 42 ft above base; upper 160 ft poorly exposed	208
8. Sandstone and siltstone similar to unit 6 except siltstone more micaceous	10
7. Sandstone very similar to unit 5 but with irregular stringers, beds, and crossbeds of very coarse to conglomeratic sandstone; micaceous	30
6. Siltstone, dark-reddish-brown (10*R* 3/4), fine-grained, noncalcareous, dense, massive. Middle third of unit is sandstone that is grayish pink (5*R* 8/2), coarse grained with rounded to angular grains, arkosic, noncalcareous, well cemented, massive. Lower contact of unit and contacts of middle bed are irregular over a few inches	8
5. Sandstone, moderate-red (5*R* 5/4) and grayish-pink (5*R* 8/2), coarse-grained with rounded to angular grains, fairly well sorted, arkosic, noncalcareous, well-cemented; faint bedding with minor crossbedding	28
4. Covered interval	62
3. Sandstone, moderate-reddish-brown (10*R* 4/6) with grayish-pink (5*R* 8/2) angular grains, very coarse grained, poorly sorted, clayey, noncalcareous, well-cemented, massive. Few well-rounded quartzite pebbles and cobbles (2–6 in.)	45

2. Section on hillside along South Boulder Creek Canyon, from one-half mile west of Eldorado Springs to Eldorado Springs—Continued

	Thickness (feet)
Fountain Formation—Continued	
2. Conglomerate, moderate-red (5*R* 5/4) and grayish-pink (5*R* 8/2), grayish-orange-pink at or near base, coarse-grained, poorly sorted, noncalcareous, well-cemented, massive, lenticular; well-rounded to angular quartzite gravel ranging from coarse sand to 8-in. boulders. Discontinuous interlenses of sandstone that is pale red (10*R* 6/2) and black (*N* 1), medium grained, angular to subrounded, noncalcareous, micaceous, and well cemented, and sandstone that is dark reddish brown (10*R* 3/4) with white specks, fine grained, subrounded, fairly well sorted, porous, and massive	10
Total Fountain Formation	1,051
1. Boulder Creek Granodiorite, grayish-red (5*R* 4/2); color is result of pre-Fountain Formation weathering, but texture and firmness of the rock are retained. Sharp unconformity with undulations of less than 1 ft on top	Unmeasured

3. Section southeast of Eldorado Springs in a roadcut and hillside in the SW¼SW¼SW¼ sec. 30, T. 1 S., R. 70 W.

[Measured by J. D. Wells and J. J. Halbert]

	Thickness (feet)
Dakota Group:	
Basal conglomeratic sandstone	Unmeasured
Morrison Formation:	
13. Claystone, yellowish-gray (5*Y* 7/2) lower half, grayish-green (5*G* 6/1) upper half; slightly silty, noncalcareous. Thin dark-yellowish-orange (10*YR* 6/6) clayey noncalcareous sandstone layers in middle of unit	15.0
12. Claystone, grayish-red (5*R* 4/2), very silty, noncalcareous; lower 2-ft-thick ledge mottled pale red purple (5*R* 6/2) and grayish yellow green (5*GY* 7/2); upper part of unit contains limestone similar to that in unit 5	12.4
11. Claystone, olive-gray (5*Y* 4/1) in lower 8.6 ft; grayish-red (5*R* 4/2) siltstone in upper 3.1 ft. Noncalcareous	11.7
10. Sandstone and siltstone, interlayered. Sandstone is mottled moderate yellowish brown (10*YR* 5/4) and light olive gray (5*Y* 6/1), fine grained, well sorted, clayey, calcareous, firmly cemented, and weathers to dark yellowish orange (10*YR* 6/6). Siltstone is pale greenish yellow (10*Y* 8/2), fine grained, noncalcareous, clayey, and weathers grayish yellow (5*Y* 8/4). Iron-stained joint surfaces and thin layers of greenish-gray (5*GY* 6/1) silty noncalcareous claystone. Claystone near top and bottom of unit is locally mottled with pale red (10*R* 6/2). Sandstone 3 ft from top is cemented with stringers of chalcedony	27.1
9. Limestone and mudstone interbedded in 1- to 3-ft-thick layers. Limestone is light brown (5*Y* 6/4), moderately thick bedded, finely crystalline, clayey, and weathers to dark yellowish orange (10*YR* 6/6). Mudstone is greenish gray (5*GY* 6/1), silty, and noncalcareous. A few 1-in.-thick transition zones between the limestone and mudstone are pale-yellowish-brown (10*YR* 6/2) noncalcareous hard mudstone	11.2

3. Section southeast of Eldorado Springs in a roadcut and hillside in the SW¼ SW¼SW¼ Sec. 30, T. 1 S., R. 70 W.—Continued

	Thickness (feet)
Morrison Formation—Continued	
8. Shale like unit 2	2.0
7. Limestone like unit 5	4.0
6. Shale like unit 2; at 4 ft above base is a 0.5-ft limestone bed, like unit 5	6.8
5. Limestone, interstringered and mottled, light-olive-gray (5*Y* 6/1); finely crystalline to dense, conchoidal fracture; weathers to yellowish gray (5*Y* 8/1) and moderate yellowish brown (10*YR* 5/4); clayey part weathers dark yellowish orange (10*YR* 6/6); few lenticular greenish-gray (5*GY* 6/1) shale layers less than 0.5 ft thick. Unit weathers rounded to nodular	17.2
4. Limestone, dark-yellowish-brown (10*YR* 4/2), light-olive-gray (5*YR* 5/2), and pale-yellowish-brown (10*YR* 6/2); moderate-yellowish-brown (10*YR* 5/4) flecks, finely crystalline, dense to earthy, medium- to thick-bedded. Interbedded with greenish-gray (5*GY* 6/1) silty calcareous thin-bedded to blocky lenticular shale, generally less than 1 ft thick. Upper limestone contains prominent secondary calcite in irregular stringers. Limestone weathers yellowish gray (5*Y* 8/1), rounded and nodular to shaly	16.7
3. Covered	5.5
2. Shale, greenish-gray (5*GY* 6/1), silty, thin-bedded to blocky, noncalcareous. Interbedded with pale-yellowish-brown (10*YR* 6/2) to grayish-orange-pink (5*YR* 7/2) finely crystalline to dense medium-bedded limestone. Shale in 3- to 4-ft-thick layers and limestone in 1- to 2-ft-thick layers; poorly exposed	8.0
1. Limestone, pale-yellowish-brown (10*YR* 6/2), finely crystalline, dense; conchoidal fracture; poorly exposed in road	4.5
Base covered.	
Total thickness of incomplete section	142.1

4. Section in roadcut one-fourth mile east of Eldorado Springs in the NE¼ SW¼ sec. 30, T. 1 S., R. 70 W.

[Measured by J. D. Wells]

	Thickness (feet)
Benton Shale:	
Upper part not exposed.	
21. Shale, dark-gray (*N* 3), calcareous clayey, mostly massive- to thin-bedded, fossiliferous. Weathers to light-gray (*N* 7) blocky to very thin bedded shale. Medium-light-gray (*N* 6), yellowish-gray-weathering (5*Y* 8/1) limestone layer 0.2 ft thick is 11 ft from base and 0.8-ft-thick layer is 23 ft from base. Fossils 28 ft above base; fish scales	35.0
20. Shale, dark-gray (*N* 3) and olive-gray (5*Y* 4/1); interbedded in thick and very thin beds, clayey, calcareous thick-bedded to very thin bedded. Weathers to light-gray (*N* 7) somewhat blocky to very thin bedded shale	48.0
19. Limestone, medium-dark-gray (*N*4) earthy, blocky. Weathers yellowish gray (5*Y* 7/2)	1.5

4. Section in roadcut one-fourth mile east of Eldorado Springs in the NE¼ SW¼; Sec. 30, T. 1 S., R. 70 W.—Continued

Benton Shale—Continued	*Thickness (feet)*
18. Shale, thinly interlayered dark-gray (*N* 4) and light-olive-gray (5*Y* 6/1), calcareous, clayey, thin-bedded to very thin bedded; contains thin olive-gray (5*Y* 4/1) limestone and thin bentonite. Unit weathers to light-gray (*N* 7) very thin beds	14. 5
17. Shale like unit 15, with thin bentonite	2. 0
16. Covered	20. 0
15. Shale like unit 11 with interbedded 1-in.-thick limestone layers like unit 9; 2-ft-thick bentonite layer 1.4 ft above base, 0.3-ft layer 7.6 ft above base	7. 9
14. Limestone like unit 9	. 6
13. Shale like unit 11 but without rounded mineral aggregates	1. 6
12. Bentonite like unit 7	. 4
11. Shale, light-olive-gray (5*Y* 6/1); has grayish-black (*N* 2) stringers; thin-bedded, clayey, very calcareous; weathers light gray (*N* 7); rounded mineral aggregates with beds deformed around them	1. 8
10. Shale like unit 2	1. 0
9. Limestone, medium-gray (*N* 5), finely crystalline, somewhat earthy, thin-bedded, petroliferous; contains fine-grained iron sulfide	. 3
8. Shale like unit 2, with 0.5-ft-thick zone of thin limestone layers 2.5 ft below top and a 0.2-ft bentonite layer as in unit 7, 1.2 ft below top. Upper part has poorly preserved fossils	12. 3
7. Bentonite, very pale orange (10*YR* 8/2) to dark-yellowish-orange (10*YR* 6/6), calcareous, massive, plastic	. 5
6. Shale like unit 2; top 1 ft is a zone of thin-bedded limestone like unit 3 interbedded with the shale	10. 0
5. Limestone like unit 3	. 5
4. Shale like unit 2 with bentonite as in unit 2, 0.5 ft from base	8. 7
3. Limestone, dark-gray (*N* 3), with very thin beds of light-gray (*N* 7) finely crystalline to massive lenses that contain iron sulfide; weathers light gray (*N* 7) and yellowish gray (5*Y* 8/1)	. 3
2. Shale, dark-gray (*N* 3), clayey, calcareous, thin-bedded to very thin bedded; weathers to light-gray (*N* 7) very thin beds. Light-brown (5*YR* 5/6) thin beds of bentonite. Microfossils common	5. 0
1. Covered	4. 5
Total incomplete section	176. 4

5. Section along Community Ditch from 0.5 to 1.8 miles east of Eldorado Springs

[Measured by J. D. Wells]

	Thickness (feet)
Fox Hills Sandstone, basal contact sharp.	
Pierre Shale (upper part):	
17. Claystone, dusky-yellow (5*Y* 6/4) and light-olive-gray (5*Y* 5/2), fine-grained, calcareous, bentonitic, clayey, massive; splits blocky. Thin dusky-yellow (5*Y* 6/4) beds mottled with moderate-brown (5*Y* 4/4) fine-grained calcareous sandstone; some grayish-yellow (5*Y* 8/4) to very pale orange (10YR 8/2) sandstone	85
16. Covered	675
15. Claystone, dusky-yellow (5*Y* 6/4); has thin light-olive-gray (5*Y* 6/1) layers; silty, calcareous, bentonitic, thin-bedded; splits blocky. Thin dusky-yellow (5*Y* 6/4) siltstone layers like unit 12, and layers of bentonite as in unit 13. Weathers dusky yellow (5*Y* 6/4) and forms rounded frothy slope	145
14. Siltstone, mostly dusky-yellow (5*Y* 6/4); some mottled with medium gray (*N* 5) as in unit 12; thin bedded; splits blocky. Thin sandstone like unit 13, otherwise like unit 12. Few bentonite layers	120
13. Sandstone, dusky-yellow (5*Y* 6/4), medium- to fine-grained, rounded grains, well-sorted; contains black mineral grains; micaceous, calcareous, poorly cemented, thin-bedded; splits blocky. Contains beds of mottled dusky-yellow (5*Y* 6/4) and medium-gray (*N* 5) fine-grained clayey slightly calcareous thin-bedded siltstone. Seams of white very calcareous bentonite. Lower contact gradational	40
12. Siltstone, dusky-yellow (5*Y* 6/4), and mottled dusky-yellow and medium-gray (*N* 5), fine- to coarse-grained, clayey, noncalcareous, micaceous, massive; splits blocky; weathers dusky yellow (5*Y* 6/4); forms rounded slope; contains black mineral grains. Seams of white very calcareous bentonite; few thin fine-grained calcareous sandstone layers. Gradational lower contact	95
11. Siltstone, mottled medium-gray (*N* 5) and dusky-yellow (5*Y* 6/4), clayey, noncalcareous to slightly calcareous, micaceous, bentonitic, massive; splits blocky. Less than 0.3-ft-thick dusky-yellow (5*Y* 6/4) fine-grained well-sorted rounded calcareous fairly well cemented sandstone. Few limestone concretions that are light olive gray (5*Y* 6/1) and weather dark yellowish orange (10*YR* 6/6). Thin layers of dark-yellowish-orange (10*YR* 6/6) and very pale orange (10*YR* 8/2) bentonite that weathers dark yellowish orange (10*YR* 6/6). Unit weathers dusky yellow (5*Y* 6/4); forms rounded slopes	155
10. Covered	130
9. Claystone, light-olive-gray (5*Y* 5/2), silty, micaceous bentonitic, calcareous, massive, blocky. Thin seams of dark-yellowish-orange (10*YR* 6/6) and pale-greenish-yellow (10*Y* 8/2) bentonite. Unit weathers yellowish gray (5*Y* 7/2); forms rounded slopes	120
8. Covered	955

5. Section along Community Ditch from 0.5 to 1.8 miles east of Eldorado Springs—Continued

	Thickness (feet)
Pierre Shale (upper part)—Continued	
7. Shale, olive-gray (5*Y* 4/1), silty, bentonitic, micaceous, calcareous, massive- to thin-bedded, blocky. Thin dark-yellowish-orange (10*YR* 6/6) bentonite seams; 32 ft above base is 0.4-ft greenish-gray (5*GY* 6/10) and dark-yellowish-orange (10*YR* 6/6) very fine and round grained well-sorted sandstone that has dark mica grains and carbonaceous chips. Near bottom and about 25 ft below top are limestone concretions as much as 0.8 ft across that are medium gray (*N* 5) and weather dark yellowish orange (10*YR* 6/6). Unit weathers yellowish gray (5*Y* 7/2)	372
6. Covered interval	1, 923
5. Siltstone, dark-gray (*N* 3) (except for a few thin dark-yellowish-orange (10*YR* 6/6) layers), fine-grained, clayey, micaceous, calcareous, massive blocky. Unit weathers dusky yellow (5*Y* 6/4). In lower 50 ft are ellipsoidal limestone concretions that are as much as 2 ft across, medium dark gray, finely crystalline, dense, and weather dark yellowish orange (10*YR* 6/6)	470
Total Pierre Shale, upper part	5, 285
Pierre Shale:	
Hygiene Sandstone Member:	
4. Sandstone, dusky-yellow (5*Y* 6/4), fine-grained, rounded grains, well-sorted, micaceous, calcareous, fairly well cemented, massive to thinly laminated, some dark-green grains	8
3. Sandstone, mottled interbedded and interlensed on a fine scale, light-gray (*N* 7) and medium-gray (*N* 5), fine-grained, with subrounded to rounded grains, well-sorted; slightly calcareous to calcareous, poorly cemented to firmly lime cemented, thin to medium bedded; black and green grains, flakes of carbonaceous material. Few thin bentonite seams throughout. Layers of dark-gray (*N* 3) silty very slightly calcareous very thin bedded mudstone near base. Unit weathers dusky yellow (5*Y* 6/4); forms rounded ledgy slope. Contains *Baculites scotti* 42 ft below top	157
2. Siltstone, dark-gray (*N* 3), fine-grained, clayey, micaceous, calcareous, fairly well cemented. Few 0.2-ft-thick dark-gray (*N* 3) dense to finely crystalline micaceous lenticular limestone beds that contain concentrically formed dark-yellowish-orange (10*YR* 6/6) siltstone concretions; main part is massive blocky with minor part thin bedded. Weathers yellowish gray (5*Y* 7/2) and granular; forms rounded slopes	110
1. Siltstone, pale-olive (10*Y* 6/2), medium-grained, well-sorted, rounded grains, clayey, slightly calcareous, slightly micaceous, fairly well cemented, thin-bedded; contains thin yellowish-gray (5*Y* 7/2) and 0.1- to 0.2-ft-thick dark-yellowish-orange (10*YR* 6/6) layers, few carbonaceous chips; massive upper part. Weathers pale olive (10*Y* 6/2) and granular; forms rounded slope	185
Base of formation covered.	
Total incomplete Hygiene Sandstone Member	460
Total incomplete Pierre Shale	5, 745

6. Section in cut on the diversion canal in the SW¼NE¼SW¼ sec. 5, T. 2 S., R. 70 W., Jefferson County

[Measured by J. D. Wells]

	Thickness (feet)
Pre-Rocky Flats alluvium:	
1. Gravel, moderate-reddish-brown (10*R* 4/6) matrix with boulders as large as 1.5 ft across; uncemented. Matrix is silty sand with clay binder, rounded to subangular, noncalcareous. Coarser fraction ranges from very coarse sand to boulders; stones are subangular to rounded and of metamorphic, igneous, and sedimentary rocks; those of granitic composition are decomposed	10.3

7. Section in roadcut in the NW¼NE¼SW¼ sec. 28, T. 1 S., R. 70 W., Boulder County

[Measured by J. D. Wells]

	Thickness (feet)
Rocky Flats Alluvium:	
3. Gravel, yellowish-brown (10*YR* 5/4); 0.1 ft at base coated by black manganese oxide(?); fine sand to boulders as large as 2 ft across; rounded to angular, poorly sorted; most resistant grains are of sedimentary, metamorphic, and igneous rocks; noncalcareous; minor silt and clay; granitic boulders are rotted	20
2. Sand, moderate-yellowish-brown (10*YR* 5/4) in lower 0.6 ft, dusky-yellow (5*Y* 6/4) in upper part, medium-grained, angular to subround, well-sorted, micaceous, minor clay, noncalcareous, noncemented, massive	1.7
1. Gravel, round to subangular, as large as 2 in. across in a matrix of sand like unit 2	.4
Total Rocky Flats Alluvium	22.1

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