Geology and Uranium Deposits of the Ralston Buttes District Jefferson County, Colorado

By DOUGLAS M. SHERIDAN, CHARLES H. MAXWELL, *and* ARDEN L. ALBEE

With sections on PALEOZOIC AND YOUNGER SEDIMENTARY ROCKS

By RICHARD VAN HORN

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Comprehensive study of the geology of a major district of productive uranium veins on the east flank of the Front Range west of Denver

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By Douglas M. Sheridan, Charles H. Maxwell, and Arden L. Albee

ABSTRACT

The Ralston Buttes uranium mining district in Jefferson County is the richest in Colorado east of the Continental Divide. It is southeast of the Front Range mineral belt along the eastern front of the range. From November 1953 through 1960 a total of about 82,200 tons of uranium ore having a value of at least \$5½ million was shipped from five mines in the district. The average grade of all ore shipped during this period was 0.74 percent U_3O_8. The only other mining activity in the district in past years has been a sporadic production of beryl, feldspar, scrap mica, dimension stone, limestone, and clay.

The bedrock is Precambrian in 90 percent of the district. It consists of a thick apparently conformable succession of complexly folded and metamorphosed sedimentary and volcanic(?) rocks, which were intruded by less abundant Precambrian igneous rocks, some of which have also been metamorphosed. Rocks in the metasedimentary and metavolcanic(?) succession contain mineral assemblages of high-grade metamorphic facies. These rocks include biotite-quartz-plagioclase gneiss, mica schist, microcline-quartz-plagioclase-biotite gneiss, amphibolite, hornblende gneiss, layered calc-silicate gneiss, quartzite, conglomeratic quartzite, quartz gneiss, impure marble, and lenses of calc-silicate rock. Each of seven main units used in mapping this succession contains two or more of these rock types but is characterized by one major rock type or by a characteristic association of rock types. Some of these main units are subdivided further on the geologic map. The Precambrian igneous rocks consist of large bodies of quartz monzonite and Boulder Creek Granodiorite, small bodies of hornblende diorite and associated hornblendite, minor dikes and sills of hornblende-biotite lamprophyre, and numerous bodies of pegmatite and aplite. Two other Precambrian map units consist mostly of cataclastically deformed rocks of uncertain correlation and origin.

In the northeastern part of the district the Precambrian rocks are overlain unconformably by Paleozoic and Mesozoic sedimentary rocks, including, from oldest to youngest, the Fountain Formation, Lyons Sandstone, Lykins Formation, Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, and Pierre Shale. A few dikes and sills of Laramide age intrude the Precambrian rocks and the younger sedimentary rocks. Surficial deposits of Pleistocene and Recent age include talus, landslide, alluvial fans, colluvium, and terrace deposits of nine levels.

The major structural features include east- to northeast-trending folds in the Precambrian rocks, a northeast-trending zone characterized by Precambrian cataclastic deformation, a sharply upturned sequence of Paleozoic and Mesozoic sedimentary rocks, and northwest-trending systems of faults and fracture zones, some of which cut both the Precambrian rocks and the younger sedimentary formations. The general sequence of major structural events is: (1) An early period of plastic folding of Precambrian sedimentary and volcanic(?) rocks, accompanied by regional metamorphism; (2) a second Precambrian period of plastic folding and regional metamorphism, accompanied by intrusion and partial metamorphism of major Precambrian igneous rocks; (3) cataclastic deformation in a zone as much as 1.5 miles wide during a third period of Precambrian deformation; (4) probable movements of late Precambrian age forming the ancestral equivalents of some or all of the presently recognized northwest-trending systems of faults and fracture zones; (5) uplift during the Laramide orogeny, accompanied by upturning and folding of Paleozoic and younger formations along the mountain front and by complex movements along the northwest-trending fault systems in both the Precambrian rocks and the younger formations. The faulting yielded four major northwest-trending systems of breccia-reef faults and fracture zones that traverse the district and persist for many miles northwestward into the Front Range mineral belt. These are, respectively from west to east, the Junction Ranch, Hurricane Hill, Rogers, and Livingston fault systems.

The uranium deposits are in two main areas within the district. Deposits in the Ralston Creek area are along the Rogers fault system and include those in the famous Schwartzwalder mine; those in the Golden Gate Canyon area are along the southeastern extension of the Hurricane Hill fault system.

The typical uranium deposits in the Ralston Buttes district are hydrothermal veins occupying openings in fault breccias and fractures that cut the Precambrian rocks. Ore shoots range from tens of tons to several thousand tons. Pitchblende and lesser amounts of secondary uranium minerals are associated with generally sparse base-metal sulfide minerals in a gangue of carbonate minerals, potassic feldspar, and, in some veins, quartz; coffinite has been identified in one of the largest deposits. Less common deposits of pitchblende and secondary uranium minerals occupy fractures cutting pegmatites and quartz veins. Pitchblende was deposited early in the paragenetic sequence, and base-metal sulfides were deposited later. The age of a pitchblende sample from one of the vein deposits was found to be 73 $\pm$ 5 million years by lead-uranium age determination.

Some of the uranium deposits have the structural, textural, and mineralogic features of epithermal deposits. Others appear to be transitional between mesothermal and epithermal.

The uranium deposits were localized by (1) a favorable structural environment, and (2) favorable host rocks. Deposits in

each of the two major areas formed where a northwest-trending fault system splits into a complex network of faults and fractures. Also, most of the deposits seem to be localized where the faults cut Precambrian rocks rich in hornblende, biotite, or garnet and biotite.

Features observed in the Ralston Buttes district that may be useful as guides to undiscovered deposits include: (1) Association of the deposits with breccia-reef fault systems, (2) localization of deposits in certain favorable Precambrian rocks, such as amphibolite, hornblende gneiss, biotite-quartz-plagioclase gneiss, layered calc-silicate gneiss, and garnetiferous biotite-quartz gneiss, (3) common association of pitchblende with copper minerals and other base-metal sulfides, and (4) abnormal radioactivity at the outcrop and the presence of secondary uranium minerals.

Two great angular unconformities are recorded in the post-Precambrian history of the area. The earliest is marked by the contact between the Precambrian rocks and the terrestrial deposits of the Fountain Formation. Marine sediments were deposited in late Paleozoic and late Mesozoic seas. Terrestrial sediments were deposited in early Mesozoic time. The last sea retreated from the area near the end of the Mesozoic Era, during uplift that accompanied the Laramide orogeny. The second great angular unconformity resulted from the deposition of Pleistocene and Recent materials on the eroded surface of the steeply dipping bedrock.

INTRODUCTION

The Ralston Buttes district is the principal source of uranium in the Front Range and one of the leading sources in Colorado. In this district uranium occurs as pitchblende in veins that follow faults in Precambrian rocks. The uranium mineralization occurred during the Laramide orogeny and accompanied renewed movements along the faults, some or all of which probably originated in Precambrian time. Study of the uranium deposits, made on behalf of the Division of Raw Materials, U.S. Atomic Energy Commission, was integrated with studies of Precambrian and younger rocks as part of a larger program of U.S. Geological Survey investigations in the central Front Range.

LOCATION AND GEOGRAPHY

The Ralston Buttes district covers about 57 square miles of northwestern Jefferson County, Colo. (fig. 1), and coincides with the Ralston Buttes 7½-minute quadrangle. It is about 12 miles west of Denver on the eastern flank of the Front Range and southeast of the Front Range mineral belt (fig. 2). The district was named for a topographic feature, actually a hogback, east of Ralston Creek (pl. 1).

The Ralston Buttes district lies between Clear Creek to the south and Coal Creek to the north (fig. 1). Ralston Creek crosses the northern part of the district. All three streams are a part of the watershed of the South Platte River. Ralston Reservoir, part of the municipal water system of the city of Denver, is on Ralston Creek, at the eastern edge of the district.

The highest points in the district are Centralia Mountain (9,738 ft) and Mount Tom (9,736 ft), both of which are in the west-central part. The crest of Douglas Mountain (9,665 ft) is only about 400 feet west of the western boundary of the district. The lowest point, 5,750 feet above sea level, is on Clear Creek, a short segment of which is shown, but not named, on the southeastern corner of the geologic map (pl. 1). The maximum relief is 3,988 feet, and the average relief is about 1,000 feet. The relief along Ralston Creek and Guy Gulch ranges locally from 500 to 2,000 feet.

Livestock and mining are the principal industries in the district. Lumbering is conducted intermittently. The Ralston Creek Ranch, in the northwestern part, is a teenagers' summer camp.

PREVIOUS GEOLOGIC STUDIES

Early geologic investigations that included parts of the Ralston Buttes district were made by Marvine

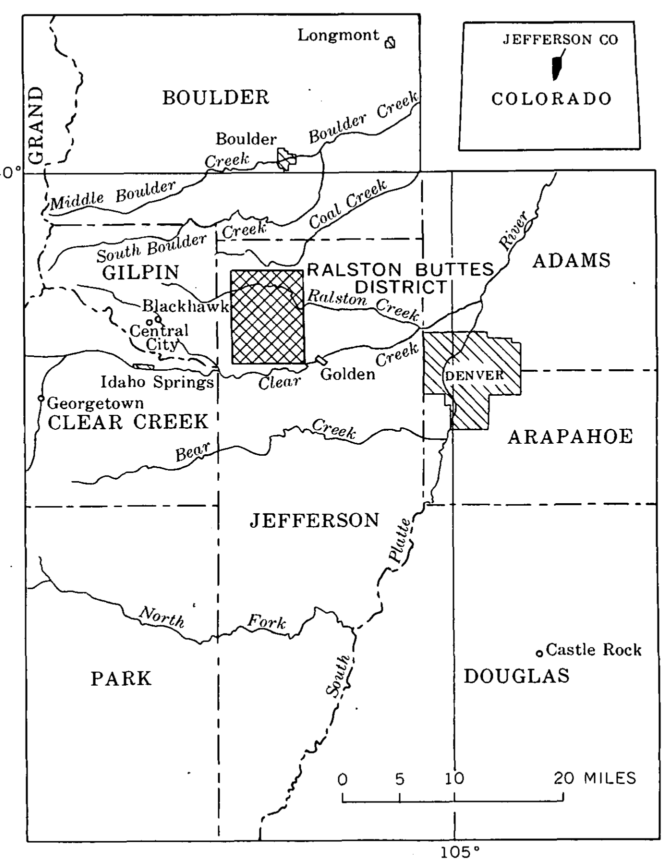

FIGURE 1.—Location of Ralston Buttes district, Jefferson County, Colo.

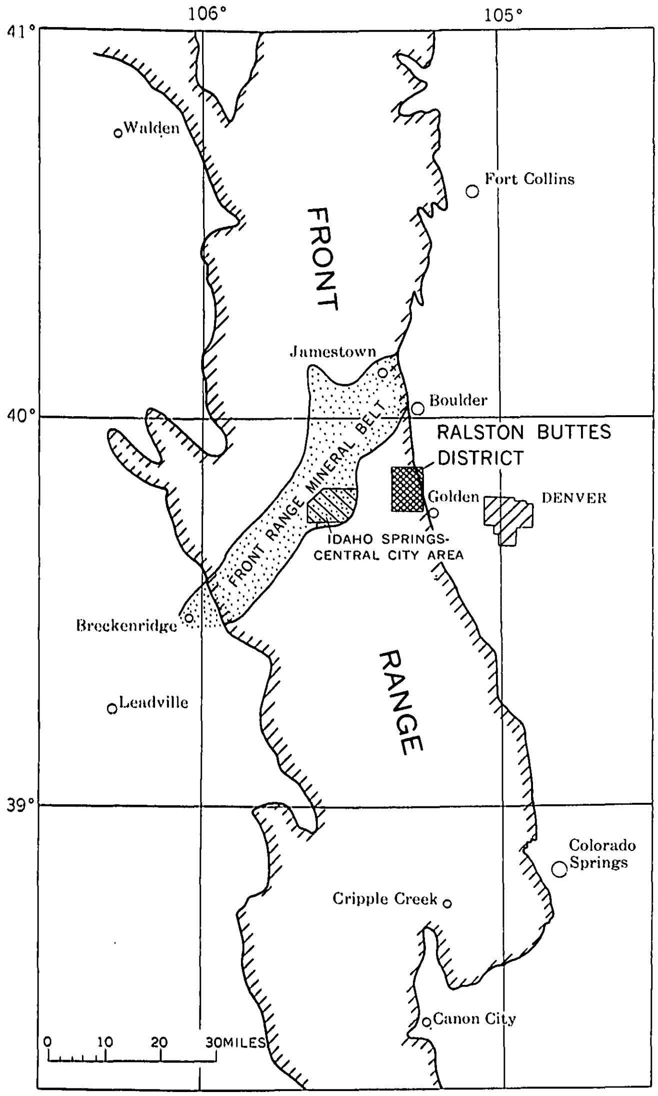

FIGURE 2.—Outline of the Front Range, Colo., and location of the Ralston Buttes district and the Front Range mineral belt. Areal extent of Front Range and Front Range mineral belt from Sims, Drake, and Tooker (1963, fig. 1).

(1874), Underhill (1906), Emmons, Cross, and Eldridge (1896), and Van Hise and Leith (1909, p. 804–808, 825–827). A comprehensive study of the geology of the entire Front Range was made more recently by Lovering and Goddard (1950). Their geologic map of the Front Range mineral belt (pl. 2, scale 1:62,500) includes the northwest corner of the Ralston Buttes district. C. M. and M. F. Boos (1957) interpreted tectonic features of the eastern flank and foothills of the Front Range, and one of their maps (fig. 7) includes the Ralston Buttes district. The metamorphism and structure of quartzitic Precambrian rocks in the Coal Creek area—the northern part of the Ralston Buttes district and parts of the Eldorado Springs and Blackhawk quadrangles—were discussed by Wells, Sheridan, and Albee (1961, 1964).

Geologic studies of the Precambrian rocks in parts of the Ralston Buttes district and adjacent areas were made by Fraser (1949), Adler (1930), Bozbag (1943), and Gabelman (1948). Pegmatites in the district were described by Waldschmidt and Gaines (1939), Waldschmidt and Adams (1942), and Hanley, Heinrich, and Page (1950). Uranium deposits in the district were discussed by Bird and Stafford (1955), Bird (1956, 1957a,b), R. C. Derzay and A. G. Bird (written commun., 1957), J. D. Schlottmann and A. V. Green (written commun., 1957), and Wright and Everhart (1960). The geology of post-Precambrian rocks in the district and adjacent areas was described by Johnson (1925, 1930a, 1934), Van Tuyl and others (1938), Waldschmidt (1939), LeRoy (1946), Waagé (1955, 1959), and Van Horn (1957).

Adams, Gude, and Beroni (1953) described the results of preliminary studies of the uranium deposits. Studies of wallrock control of certain pitchblende deposits in the district were made by Adams and Stugard (1956). Summaries of the uranium deposits in the Front Range, including those in the Ralston Buttes district, were made by Sims (1956) and Sims and Sheridan (1964).

FIELDWORK AND ACKNOWLEDGMENTS

The geologic investigation of the Ralston Buttes district included areal mapping, detailed mapping and related studies of uranium deposits, and laboratory studies of rocks and ores. The Precambrian geology was mapped and the uranium deposits were studied by Sheridan during 16 months from 1953 to 1958, by Maxwell during 9 months from 1953 to 1956, and by Albee during 6 months in 1955 and 1956. W. E. Willging and K. R. Everett assisted in 1955. The geology of the Paleozoic and Mesozoic sedimentary rocks in the northeastern part of the district and of Quaternary deposits throughout the district was mapped by Van Horn during 6 months in 1955 and 1956. Laboratory work included the examination of 322 thin sections of rocks and ores, and 52 polished sections of ores.

Areal geology shown on plate 1 was mapped in the field on U.S. Forest Service aerial photographs at a scale of approximately 1:23,000. The data were then transferred by vertical sketchmaster to an enlarged compilation base (1:20,000) of the 1948 edition of the Ralston Buttes 7½-minute quadrangle. The map was then reduced to a scale of 1:24,000 for publication in this report.

Base maps for underground mine workings were prepared partly by transit-and-tape methods and partly by compass and tape. Underground mapping at the Schwartzwalder mine was on a scale of 1:120; at the Ascension mine and the Aubrey Ladwig mine, on a scale of 1:240; and at the Mena mine, on a scale of 1:600. The scale of some of the mine maps has been reduced for publication in this report. The surface areas were mapped by planetable methods on a scale of 1:1,200 at the Schwartzwalder mine and on a scale of 1:600 at the Ascension mine and the Aubrey Ladwig mine.

The Ralston Buttes district was described in preliminary reports (Sheridan, 1956; Sheridan and others, 1958). The present report contains a more comprehensive discussion of geology than the earlier ones. The descriptions of Paleozoic and Mesozoic sedimentary rocks and of Cenozoic sedimentary deposits were written by Van Horn, who also contributed to the sections on structural, historical, and economic geology.

Many of our colleagues in the U.S. Geological Survey rendered assistance. J. D. Wells helped to correlate geologic features along the northern boundary of the Ralston Buttes district with those in the adjoining Eldorado Springs quadrangle and also made 16 modal analyses of Precambrian rocks from the northern part of the Ralston Buttes district. J. W. Adams and Frederick Stugard, Jr., provided mineralogic data from their previous study of the uranium deposits. We are grateful to B. F. Leonard and J. W. Adams for their very helpful advice during our petrographic studies of polished sections of ore. R. U. King assisted in mapping the Mena mine, and L. R. Stieff and T. W. Stern determined the age of a sample of pitchblende from this mine. E. J. Young contributed to the mineralogic studies, and many analysts of the U.S. Geological Survey provided chemical and spectrographic data. All photomicrographs included in this report were made by R. B. Taylor and R. C. Bucknam. Permian and Cretaceous fossils were identified by Richard Rezak and W. A. Cobban, respectively. G. E. Lewis of the U. S. Geological Survey, in collaboration with C. B. Schultz and L. G. Tanner of the University of Nebraska State Museum, identified the Pleistocene and Recent vertebrate fossils. We are indebted to our U.S. Geological Survey colleagues P. K. Sims, J. D. Wells, Ogden Tweto, C. T. Wrucke, R. B. Taylor, J. E. Harrison, D. E. Lee, and J. C. Ratté for constructive comments and advice during the preparation of this report.

We gratefully acknowledge the generous and courteous cooperation given by the many ranchers and property owners in the district; by officials, geologists, and miners of the Denver-Golden Oil & Uranium Co. and the Yellow Queen Uranium Co.; by geologists of the Union Pacific Railroad Co.; by Fred Schwartzwalder, J. W. Walsh, A. G. Bird, G. W. H. Norman; and by many miners and prospectors. We thank Richard Hamburger, E. L. Grossman, J. D. Schlottmann, and R. C. Derzay, all of the Denver Exploration Branch of the U.S. Atomic Energy Commission, for their cooperation during the field and office work on uranium geology.

GEOLOGIC SETTING

The Front Range, easternmost of the major ranges of the Southern Rocky Mountains, trends northward from the vicinity of Canon City, Colo. (fig. 2), to Wyoming, where it passes into the Laramie Range. The principal rocks of the range are gneisses, schists, and several types of granitic rocks of Precambrian age. Sedimentary rocks of Paleozoic and younger age border the Precambrian rocks on the eastern and western flanks of the range. Trending northeastward across the central part of the range is the Front Range mineral belt, the northeastern segment of the Colorado mineral belt. Most of the major mining districts of Colorado are located in the Colorado mineral belt, which is characterized by porphyritic igneous rocks and associated metalliferous deposits formed during the Laramide orogeny (Late Cretaceous and early Tertiary).

The Ralston Buttes district, on the eastern flank of the central part of the Front Range (fig. 2), is southeast of the Front Range mineral belt. The Precambrian rocks in this part of the range are predominantly a thick succession of metasedimentary rocks, possibly partly metavolcanic, intruded by stocks and small batholiths of granitic rocks. In the area including the Ralston Buttes district and extending 10 miles westward and 25 miles southward, the metasedimentary rocks are principally biotitic gneisses, feldspathic gneisses, and mica schist; in the eastern part of this area amphibolite, hornblende gneiss, and calc-silicate gneiss are relatively abundant, and in the northeastern part, quartzite, conglomeratic quartzite, and schist are abundant. Batholiths and stocks of Precambrian intrusive rocks occur mainly to the north of the Ralston Buttes district and west and south of the Idaho Springs–Central City area (Lovering and Goddard, 1950, pl. 1). The axial planes of Precambrian folds in the east-central part of the Front Range show a diversity of trends. In general, those in the Idaho Springs–Central City area trend north-northeast or northeast, whereas those in the Ralston Buttes district and vicinity trend east-northeast and northwest. A major Precambrian structural feature in this part of the Front Range is a northeast-trending zone characterized by cataclastically deformed rocks and, along part of its length, by younger folds superposed on an older fold system. Tweto and Sims (1960, 1963) called this the Idaho Springs–Ralston shear zone. The general location of this zone is shown as a Precambrian fault zone by Lovering and Goddard (1950, pl. 2). Equally conspicuous are numerous persistent northwest-trending breccia reefs and related faults which cut the Precambrian rocks and extend for short distances southeastward into the bordering Paleozoic and Mesozoic rocks.

ROCKS OF THE DISTRICT

Precambrian metamorphic and igneous rocks, which form the bedrock in 90 percent of the Ralston Buttes district (pl. 1), are overlain unconformably in the northeastern part by sedimentary rocks of Paleozoic and Mesozoic age. A few small bodies of igneous rocks of Laramide age intrude the Precambrian and younger rocks but are much less abundant than in the mineral belt. Quaternary surficial deposits include thick deposits of gravel, which mantle pediments in the northeastern part of the district, and thin deposits of alluvium, which mask the bedrock in most of the valleys.

During a complex early history involving two periods of Precambrian plastic deformation, ancient sedimentary and volcanic(?) rocks were folded, recrystallized to mineral assemblages indicating regional metamorphism of high grade, and intruded syntectonically by igneous rocks. Subsequently, a third Precambrian deformation, characterized by cataclasis, was superimposed on the metamorphic and igneous rocks in a zone trending northeastward across the northern part of the district. Some or all of the northwest-trending fault systems in the district were probably formed originally during late Precambrian time.

During the Laramide orogeny, which extended from Late Cretaceous to early Tertiary time, the Paleozoic and Mesozoic rocks were upturned along the mountain front and were faulted by renewed movements along the northwest-trending fault systems. During this same time, uranium was deposited in hydrothermal veins along some of the faults in the Precambrian rocks.

PRECAMBRIAN ROCKS

The Precambrian rocks of the Ralston Buttes district consist predominantly of complexly folded metamorphosed rocks, most of which probably were originally sedimentary, although some may have been volcanic (pl. 1). Less abundant are Precambrian intrusive igneous rocks, some of which have also been metamorphosed.

In this report lithologic names are used for the Precambrian metasedimentary and metavolcanic(?) rocks. Mineralogic modifiers are used to denote the composition of various types of gneiss and schist, and, in some names, several hyphenated modifiers are used for the sake of clarity. The full names are used in map explanations and for the headings of rock descriptions, but for readability, shortened names are used in much of the text.

Each of the map units of metasedimentary and metavolcanic(?) rocks consists of more than one rock type but is named according to a prominent or characterizing rock type or an association of types. More detailed mapping of individual rocks is possible but was not deemed necessary; such mapping would be difficult because of intimate interlayering and the presence of a widespread cover of colluvium.

Certain names used for the metamorphic rocks warrant special attention. We use the term amphibolite for crystalloblastic rocks consisting of hornblende and plagioclase with very minor amounts of other minerals. Calc-silicate gneiss is characteristically much more varied and complex in mineralogy than amphibolite; it consists of layers containing different proportions of clinopyroxene, hornblende, plagioclase, quartz, epidote, and other minerals. Rocks to which we have applied the term "hornblende gneiss" are gradational in mineralogy either from true amphibolite to biotite-quartz-plagioclase gneiss or from true amphibolite to layered calc-silicate gneiss. We also use the term "hornblende gneiss" in a more general sense as the name of a map unit which is characterized by hornblende-bearing rocks of several types—amphibolite, calc-silicate gneiss, and hornblende gneiss.

Terms used for igneous rocks generally follow the classification devised by Grout (1932). Although some of the igneous rocks have been affected to varying degrees by one or more periods of Precambrian deformation, the igneous rock terms are used as names of map units because it was found impractical to map separately the many metamorphic varieties.

The general distribution of cataclastically deformed rocks is indicated by shading on plate 1. The shaded area includes sheared but recognizable facies of the regular map units and, also, two map units that consist principally of cataclasized rocks of unrecognizable parentage.

The names used for Precambrian rock units in this report differ from those used by Lovering and Goddard (1950, pl. 2) in the northwestern part of the Ralston Buttes district and the nearby Front Range mineral belt. Relations between the two sets of names are shown in the following table.

Probable equivalent Precambrian rock units as mapped by Lovering and Goddard and by Sheridan, Maxwell, and Albee

Lovering and Goddard (1950, pl. 2)	Sheridan, Maxwell, and Albee (pl. 1, this report)
Granite gneiss and gneissic aplite (gn)	Microcline-quartz-plagioclase-biotite gneiss unit (gm) and quartz monzonite (qm)
Boulder Creek granite and quartz monzonite (bcg)	Boulder Creek Granodiorite (bcg) and, in part, quartz monzonite (qm)
Quartzite at Coal Creek (qt)	Quartzite unit (q)
Schist layers in quartzite (sch)	Schist layers in quartzite unit (qs)
Swandyke hornblende gneiss (sg)	Undivided hornblende gneiss unit (h), and, in part, interlayered biotite-quartz-plagioclase gneiss and mica schist (bs), cataclastic gneisses and associated rocks (cg), and quartz-feldspar cataclastic gneiss and associated rocks (qf, hb, qfhb)
Idaho Springs formation (is)	Mica schist unit (s), interlayered biotite-quartz-plagioclase gneiss and mica schist (bs), and cataclastic gneisses and associated rocks (cg)

The compositions of plagioclase reported in the various rock descriptions were determined principally by the Michel-Levy method of maximum symmetrical extinction of albite twins in sections normal to 010, using the curve in figure 219 of Rogers and Kerr (1942). All determinations were made from thin sections on the microscope stage without the use of the universal stage. Composition of poorly twinned plagioclase was determined by estimation of refractive index as compared with quartz and the mounting cement, and by extinction angles in sections perpendicular to the bisectrix, utilizing Tröger's curves for low temperature plagioclase (1952, p. 101).

The modes reported in the descriptions of Precambrian rocks are given in volume percent and represent determinations made on individual thin sections cut at right angles to the foliation. All modes were determined by the point-count method. Because many of the rocks are layered and nonuniform in character, it is difficult to obtain a truly representative thin section. To cope with this problem and to avoid giving the impression that the modes can be more precise than the sampling or the method of analysis, the following system was adopted:

1. Values of 3 percent or more are reported to the nearest percent.
2. Values from 0.5 to 2.9 percent are reported to the nearest tenth of a percent.
3. Values of less than 0.5 percent are reported as trace amounts. Because of these conventions, the mode figures commonly do not total 100 percent, but most totals are between 99 and 101 percent.

METAMORPHOSED SEDIMENTARY AND VOLCANIC(?) ROCKS

The Precambrian metamorphosed sedimentary and volcanic(?) rocks were grouped for mapping (pl. 1) and descriptive purposes into seven main units: (1) mica schist unit, (2) hornblende gneiss unit, (3) microcline-quartz-plagioclase-biotite gneiss unit, (4) microcline-quartz-plagioclase-biotite gneiss complexly interlayered with other rocks, (5) interlayered gneisses, (6) interlayered biotite-quartz-plagioclase gneiss and mica schist, and (7) quartzite unit. Some of these main units have been subdivided further on the geologic map (pl. 1), and mapping at larger scales in the vicinity of some of the uranium mines permitted additional subdivision of some of the units (pls. 2, 6, 8).

Ideally, the study of any metamorphic region should be based on stratigraphy, as emphasized by Billings (1950). According to Billings, such studies should include the assignment of rocks to formations on the basis of their inferred lithology prior to metamorphism. In the present investigation we attempted to follow this principle wherever possible in the grouping of rock types into lithologic map units, but a complete stratigraphic evaluation of these rocks could not be made within the relatively small area this district covers. Our map units, therefore, are largely lithologic rather than stratigraphic in character. The assignment of valid formational names must await the accumulation of stratigraphic and structural data from a much larger area.

It has not been possible to define an age sequence in the metamorphosed sedimentary and volcanic(?) rocks—or, in other words, to recognize the "tops"—in the Ralston Buttes district. The arrangement of the map units in the explanation of plate 1 and the order in which they are described in this report are based primarily on the assumption that the youngest units are in the cores of major synclines, but this is not proved. Thus the arrangement of map units should be considered tentative and does not constitute a stratigraphic column. Our tentative conclusions concerning possible correlation and age relations among the metasedimentary and metavolcanic(?) rocks are discussed in a following section.

MICA SCHIST UNIT

The mica schist unit crops out over a wide area in the east-central and central parts of the district. Extensions of it trend westward from the central area: one between Centennial Cone and Douglas Mountain and the other north of Centralia Mountain near Ralston Creek (pl. 1). The unit is conformable with the adjacent hornblende gneiss unit and in the eastern part of the district is overlain unconformably by the Fountain Formation of Middle and Late Pennsylvanian and Early Permian age. The contact with the hornblende gneiss unit is transitional.

Most of the rocks in the mica schist unit can be classified as schist, but some have a conspicuous compositional layering and are feldspathic or locally migmatitic, and hence are gradational toward gneiss. The unit contains lenses of conglomeratic schist, some of which are shown on plate 1, and lenses of calc-silicate rock, which, although abundant in some areas, are too small and poorly exposed to be shown on the map. The rocks of the mica schist unit commonly weather to brown gray or rusty brown. Except in roadcuts and on the steeper slopes of valleys, outcrops are scattered and many are sharply angular in form.

The compositional layering that is a conspicuous feature in some exposures is generally expressed by alternating quartz-rich and mica-rich layers but locally by alternating porphyroblastic and nonporphyroblastic layers. The quartz-rich layers are lighter in color and more massive in appearance than the mica-rich layers. The layers generally range in thickness from 1 mm to 20 feet, but some are several hundred feet thick.

A foliation imparted by a parallel planar arrangement of muscovite and biotite flakes is very noticeable in the mica schist. Many exposures show conspicuous lineations caused by alinement of minerals or mineral aggregates, and by crinkles, crenulations, and minor folds.

MICA SCHIST

The mica schist unit consists predominantly of silver-gray to dark-gray fine- to medium-grained schist composed principally of quartz, muscovite, and biotite. The proportions of these principal minerals vary widely: quartz, 26–76 percent; muscovite, trace to 42 percent; biotite, 4–37 percent (table 1). The porphyroblastic varieties contain sillimanite, andalusite, or garnet. Some layers of schist contain as much as

TABLE 1.—*Modes (volume percent) of rocks in the mica schist unit*

	Nonporphyroblastic schist					Porphyroblastic schist														Conglomeratic schist
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Field No.	DS-53-21	SW-83	DS-53-30	DS-55-22	RA-19	DS-53-39	DS-55-15	DS-55-16	RA-20	RA-175	DS-53-29	RA-172a	DS-55-17	DS-55-28	DS-55-21	DS-55-40	DS-53-40	RA-578	DS-58-R28	RA-611
Quartz	26	40	42	69	38	41	50	45	61	29	44	47	76	43	43	57	49	34	54	67
Biotite	32	16	24	19	23	22	30	33	25	37	28	17	14	29	29	27	34	4	16	7
Muscovite	42	36	21	11	37	32	4	12	3	28	2	34	Trace	Trace	16	2	1.6	40	4	1.4
Plagioclase	......	1.6	......	......	1.8	3	Trace	2.2	Trace	......	......	1.1	8	17	......	......	1.9	......	20	13
Microcline	......	2.2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	21	1.3	10
Garnet	......	......	......	......	......	......	......	......	......	......	......	Trace	1.0	9	......	......	6	......	......	......
Sillimanite	......	......	......	......	Trace	......	14	7	10	4	25	......	......	......	......	......	4	......	4	......
Andalusite	......	......	......	......	......	......	......	......	......	......	......	......	......	......	11	13	3	......	......	......
Magnetite-ilmenite	Trace	[1] 3	13	Trace	......	1.1	1.0	Trace	Trace	......	.8	Trace	Trace	1.1	Trace	Trace	Trace	......	1.0	.6
Tourmaline	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	1.9	......	Trace	......	......	Trace	......	Trace	Trace	......	......
Apatite	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	.6
Zircon	......	Trace	Trace	Trace	Trace	Trace	Trace	Trace	......	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	......	Trace	......
Chlorite	......	......	......	......	......	......	......	......	......	......	......	......	Trace	......	......	......	Trace	......	......	......
Hematite	......	1.0	......	......	Trace	......	Trace	......	......	Trace	......	......	......	Trace	......	......	Trace	......	......	......
Allanite	......	......	......	......	......	......	......	......	Trace	......	......	......	......	......	......	......	......	......	......	......

[1] Percentage includes undetermined amounts of pyrite and other sulfide minerals.

1. Mica-rich schist showing slip cleavage, NW¼NE¼ sec. 15, T.3S., R.71W.
2. Mica-rich schist, Schwartzwalder mine, Minnesota level, near heading of southeast drift on Nebraska vein.
3. Mica schist with color layering (magnetite) transected by foliation, float in SW¼ sec. 25, T.2S., R.71W.
4. Quartzose schist showing slip cleavage; interlayered with andalusite-bearing schist (mode 15); N½SW¼ sec. 35, T.2S., R.71W.
5. Mica-rich schist, SE¼SW¼ sec. 14, T.3S., R.71W.
6. Schist containing muscovite-biotite aggregates pseudomorphous after staurolite(?) and andalusite, NW¼SE¼ sec. 36, T.2S., R.71W.
7. Sillimanitic schist near Drew Hill road in NE¼ sec. 33, T.2S., R.71W.
8. Sillimanitic schist, SE¼NW¼ sec. 27, T.2S., R.71W.
9. Sillimanitic schist, W½SE¼ sec. 14, T.3S, R.71W.
10. Sillimanitic schist, NW¼ sec. 18, T.3S., R.70W.
11. Sillimanitic schist, SW¼NW¼ sec. 16, T.3S., R.71W.
12. Mica schist (slightly garnetiferous) showing slip cleavage, SW¼SE¼ sec. 7, T.3S., R.70W.
13. Garnetiferous feldspathic schist; interlayered with sillimanitic schist (mode 8); SE¼NW¼ sec. 27, T.2S., R.71W.
14. Garnetiferous feldspathic schist, NW¼SW¼ sec. 2, T.3S., R.71W.
15. Schist containing large porphyroblasts of andalusite; interlayered with quartzose schist (mode 4); N½SW¼ sec. 35, T.2S., R.71W.
16. Schist containing porphyroblasts of andalusite, NE¼SW¼ sec. 35, T.2S., R.71W.
17. Garnetiferous schist containing both sillimanite and andalusite, SE¼SW¼ sec. 25, T.2S., R.71W.
18. Muscovite-rich schist containing porphyroblasts of microcline, NE¼NW¼ sec. 14, T.3S., R.71W.
19. Sillimanitic feldspathic schist, from ridge south of Ralston Creek near center of sec. 29, T.2S., R.71W.
20. Matrix of conglomeratic feldspathic schist; contains pebbles of white quartzite and dark-gray quartz-tourmaline rock; NE¼SE¼ sec. 10, T.3S., R.71W.

20 percent plagioclase (An_{23}–An_{45}), but in many layers the mineral is entirely absent or present only in minor amounts. Microcline is sparse in the mica schist. It occurs locally as blocky porphyroblasts (mode 18, table 1), as a minor constituent of one sillimanitic layer (mode 19) and a layer of nonporphyroblastic schist (mode 2), and in conglomeratic schist (mode 20). Accessory minerals common to both the nonporphyroblastic and porphyroblastic varieties of schist are magnetite-ilmenite, apatite, zircon, and tourmaline. The shape of porphyroblastic aggregates of muscovite and biotite in the specimen of mode 6 (table 1) suggests pseudomorphous replacement after staurolite, but no relict staurolite was found in thin section. Only one small grain of staurolite was observed in all the petrographic study of the mica schist, and this in a thin section not reported in table 1.

Quartz-rich facies of the schist are represented in both the nonporphyroblastic variety (mode 4, table 1) and the porphyroblastic varieties (modes 9, 13). Such quartz-rich rocks might also be called micaceous quartzite, but for purposes of this report they are simply considered to be a quartz-rich variety of schist. Quartz-rich schist is particularly abundant on the slopes adjacent to Van Bibber Creek in the eastern part of the district and also in the southern parts of secs. 10 and 11 west of Crawford Gulch.

Although porphyroblasts and glomeroporphyroblasts occur in both the highly micaceous and the quartzose varieties of the schist, they are more abundant in the mica-rich varieties. Elliptical to elongate aggregates of fine needles of sillimanite are common as glomeroporphyroblasts and are most abundant in the western half of the mica schist unit. The elliptical aggregates are ½–¾ inch long, but pencil-like aggregates as much as 4 inches long occur in several areas. The elongation of the sillimanite glomeroporphyroblasts accentuates a lineation formed by the alinement of aggregates of biotite and muscovite grains in the plane of the foliation. Andalusite, in prismatic porphyroblasts as long as 10 inches, is most abundant in the northeastern part of the mica schist unit and was not observed in the western most part. In contrast to the sillimanite aggregates, the porphyroblasts of andalusite generally show no preferred linear orientation but form radial aggregates or are diversely oriented in the plane of the foliation. Garnet (sample 12 and 13, table 32) in grains 1/16–⅛ inch in diameter is locally present but is not as conspicuous as the sillimanite and andalusite. Poikiloblastic textures are characteristic of the garnetiferous and andalusite-bearing varieties of schist. Microcline porphyroblasts occur in several places, generally in the vicinity of schist that contains tourmaline porphyroblasts.

In the sillimanitic variety of mica schist, textural relations suggest that sillimanite and muscovite generally formed at about the same time, together with quartz and biotite. The micaceous foliation formed by parallel planar arrangement of muscovite and biotite flakes commonly bends around glomeroporphyroblasts of sillimanite. Where muscovite is in contact with sillimanite (fig. 3) these minerals seem to be in equilibrium, because the contacts are sharp and clear and there is no evidence of replacement of one mineral by the other. Although some grains of muscovite transect grains of biotite, other grains of muscovite are interleaved with biotite in a manner suggesting mutual growth. We observed no evidence in most specimens that microcline had existed previously. In one specimen (mode 19, table 1) microcline contains needles of sillimanite but no intervening sheath of muscovite. Elsewhere in the same thin section, however, sillimanite and muscovite occur together as an apparently stable pair, and some grains of microcline and aggregates of sillimanite are locally altered to very fine grained muscovite.

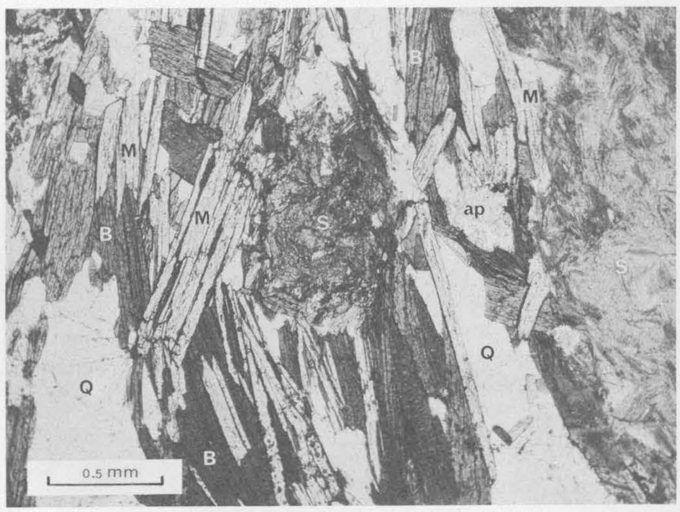

FIGURE 3.—Sillimanitic mica schist from mica schist unit. Quartz (Q), biotite (B), muscovite (M), apatite (ap), and glomeroporphyroblasts of sillimanite (S). Sharp contacts between minerals suggest simultaneous growth. Plane-polarized light.

In parts of the mica schist the glomeroporphyroblasts of sillimanite have been partially or completely altered to fine-grained aggregates of muscovite and some biotite and quartz. In figure 4, the outer edge of a glomeroporphyroblast of sillimanite has been

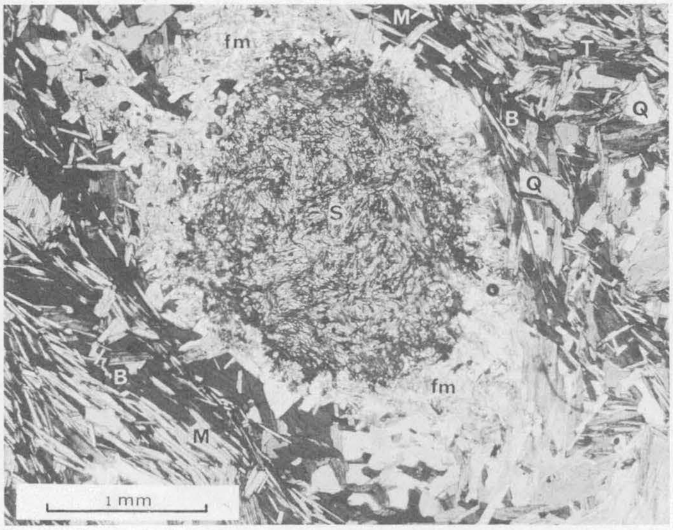

FIGURE 4.—Sillimanitic mica schist from the mica schist unit. Outer part of a glomeroporphyroblast of sillimanite (S) has been altered to very fine grained muscovite (fm), presumably by retrograde metamorphism. Coarser grained muscovite (M) and biotite (B) define a foliation that bends around the glomeroporphyroblast. Other minerals are quartz (Q) and tourmaline (T). Plane-polarized light.

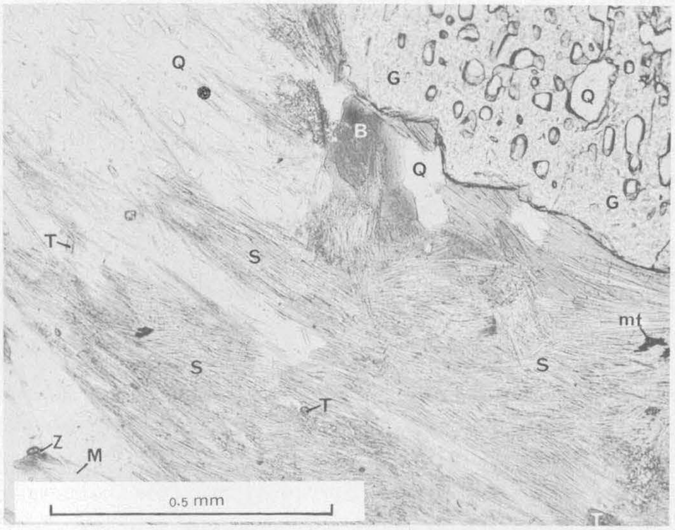

FIGURE 6.—Porphyroblastic mica schist from the mica schist unit, showing part of a glomeroporphyroblast composed of needles of sillimanite (S) and part of a grain of typically poikiloblastic garnet (G). Other minerals are quartz (Q), biotite (B), muscovite (M), tourmaline (T), zircon (Z), and magnetite-ilmenite (mt). Plane-polarized light.

replaced by very fine grained muscovite. This is presumably a retrograde alteration that affected only parts of the mica schist unit.

Andalusite and sillimanite are seldom both present in samples from the mica schist unit, so their age relations are poorly known. The thin section of one garnetiferous specimen (mode 17, table 1) contains a poikiloblastic porphyroblast of andalusite (fig. 5), porphyroblastic aggregates of sillimanite needles (fig. 6), and a porphyroblast of andalusite transected by needles of sillimanite (fig. 7). The textural relations shown in this thin section suggest that at least some

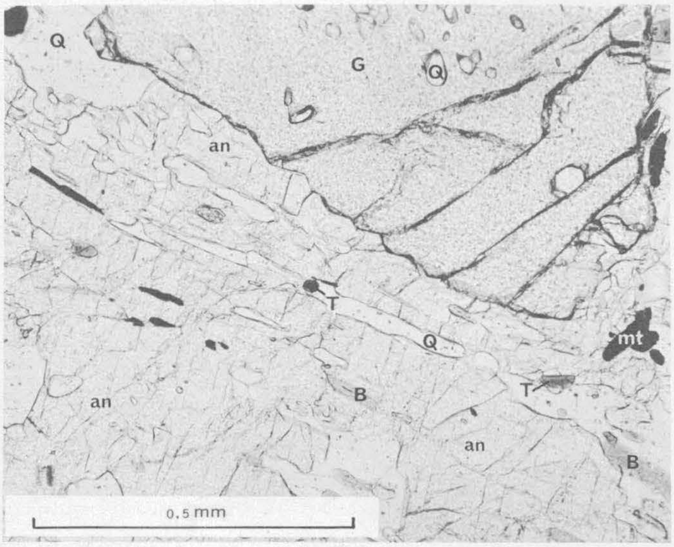

FIGURE 5.—Porphyroblastic mica schist from the mica schist unit, showing part of a very poikiloblastic grain of andalusite (an) adjacent to poikiloblastic garnet (G). Other minerals are quartz (Q), biotite (B), tourmaline (T), and magnetite-ilmenite (mt). Plane-polarized light.

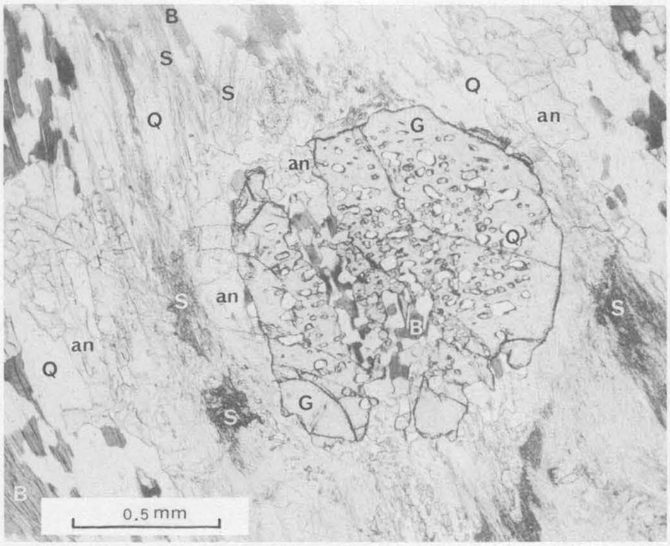

FIGURE 7.—Porphyroblastic mica schist from the mica schist unit. Sillimanite (S) transects a poikiloblastic grain of andalusite (an) to the left of the extremely poikiloblastic grain of garnet (G). Other minerals are quartz (Q) and biotite (B). Plane-polarized light.

of the andalusite formed before some of the sillimanite.

In parts of the andalusite-bearing schist the andalusite is unaltered, although extremely poikiloblastic (fig. 5), but in other parts it is largely altered to fine muscovite and biotite.

Representative samples of white mica from the mica schist unit and from schist layers in the quartzite unit were determined by X-ray methods to be muscovite. The X-ray data are summarized in table 33.

CONGLOMERATIC SCHIST

Conglomeratic schist is shown on plate 1 as lenses in the southern part of the mica schist unit south of Van Bibber Creek and also west of Crawford Gulch. Its matrix is similar to the quartzose types of mica schist. The detrital fragments are generally less than 30 mm in diameter, but locally as large as cobbles. The coarser pebbles are mostly white quartzite or dark-gray quartz-tourmaline rock. The mode of the matrix of a feldspathic sample of conglomeratic schist (mode 20) is shown in table 1. A pronounced elongation of the larger pebbles in the lenses of conglomeratic schist is common. In the southern part of sec. 12, T. 3 S., R. 71 W., for example, the axial ratios measured in one outcrop are about 0.5:1:10. Some outcrops, however, show very little flattening of the cross-sectional shape of the pebbles. The matrix of some of the conglomeratic schist contains light-colored granular aggregates of quartz and feldspar in lenses.

LENSES OF CALC-SILICATE ROCK

Float of calc-silicate rock is common in the mica schist unit, but exposures are rare. In the few exposures found, the rock forms lenses as much as 1 foot thick and 3–10 feet long which are conformable to the layering of the schist. The calc-silicate rock is mineralogically similar to the layered calc-silicate gneiss of the hornblende gneiss unit but differs in some textural and structural characteristics. The lenses are commonly zoned: a dark-colored border surrounds a lighter inner zone. Those that are not zoned consist entirely of the dark-colored material.

Modes of calc-silicate rock from the mica schist unit are shown in table 2. Generally, the dark-colored margins contain abundant hornblende, crystals of which commonly show a preferred planar orientation. The inner light-colored parts contain clinopyroxene and epidote and generally show little preferred mineral orientation. Garnet, quartz, and plagioclase occur in both kinds of rocks, although plagioclase is not always present. Plagioclase in several samples was found to be calcic andesine (An_{45}). Physical properties of garnet from a lens of the calc-silicate rock are shown in table 32 (sample 11).

TABLE 2.—*Modes (volume percent) of calc-silicate rock from lenses in the mica schist unit*

	1	2	3	4
Field No.	DS-53-38a	DS-53-38b	DS-53-38b	DS-53-36
Quartz	34	34	35	55
Hornblende	Trace	1.1	15	20
Plagioclase	28	28	37	12
Clinopyroxene	17	22	2.0	----
Epidote-clinozoisite	14	10	4	----
Garnet	5	2.1	5	4
Apatite	.5	1.0	.6	.5
Sphene	1.0	1.7	1.2	----
Zircon	----	----	----	Trace
Allanite(?)	----	----	----	Trace
Sulfide mineral	----	Trace	Trace	----
Magnetite-ilmenite	----	----	----	1.2
Sericite [1]	----	----	----	7

[1] Alteration product of plagioclase; percentage probably includes some clay minerals.

1. Float from lens in E½ sec. 36, T. 2 S., R. 71 W.
2. Light inner part of lens, float in E½ sec. 36, T. 2 S., R. 71 W.
3. Dark outer part of lens, float in E½ sec. 36, T. 2 S., R. 71 W.
4. Dark outer part of lens, float in SW¼ sec. 36, T. 2 S., R. 71 W.

Mineralogic zoning of the kind in the calc-silicate lenses has been attributed by Turner (1948, p. 141) to the metamorphic exchange of materials between the outer parts of an original calcareous concretion and the adjoining rocks.

HORNBLENDE GNEISS UNIT

The hornblende gneiss unit crops out in west-trending belts in the northern and southern parts of the district and in a semicircular belt in the western part (pl. 1). Thus it almost surrounds the large central area of mica schist except on the east and, in general, lies between the schist and the microcline-quartz-plagioclase-biotite gneiss (microcline gneiss) unit and between the schist and the microcline gneiss interlayered with other rocks. The hornblende gneiss unit comprises several kinds of hornblende-bearing rocks in an interlayered succession. Many of the layers are calc-silicate gneiss, amphibolite, or intermediate rocks; others are hornblende gneisses gradational in composition between biotite-quartz-plagioclase gneiss and amphibolite. Biotite-quartz-plagioclase gneiss is widespread in the unit, and mica schist and quartz gneiss are more localized.

In the southern half of the district the unit was divided into two subunits: (1) layered calc-silicate gneiss and associated rocks, and (2) interlayered hornblende gneiss, amphibolite, and biotite-quartz-plagioclase gneiss. In parts of this southern area, the unit was further divided to show layers and lenses of mica schist and quartz gneiss in the layered calc-silicate gneiss. In the southeastern and south-central parts of the district the total outcrop width of the hornblende gneiss unit (pl. 1) ranges from 5,000 to 7,000 feet. In the southwestern part of the district the main subdivisions of the unit are symmetrically repeated on the flanks of the mica schist unit.

Northward in the west-central part of the district, the contrast between subdivisions of the hornblende gneiss unit becomes less distinct, and in the northern half of the district the unit was mapped as undivided hornblende gneiss. In the northwestern part of the mapped area, the unit thins westward on both sides of the mica schist unit, which also thins westward. As discussed in the section "Correlation and Age Relations," the hornblende gneiss north of the mica schist unit may not be the same stratigraphic unit as the one on the south, but no distinction was made in mapping because the rocks on the two sides are similar.

The contacts of the hornblende gneiss unit with adjacent metasedimentary units seem to be conformable, as do the contacts between subdivisions of the unit. The contact between the hornblende gneiss unit and the mica schist unit is transitional across a zone generaly 50 feet thick that contains garnetiferous biotite-quartz gneiss interlayered with lesser amounts of other rocks.

The hornblende gneiss unit is important to the economic geology of the Ralston Buttes district because most of the uranium deposits are along faults within the unit or at its contact with the mica schist. Because of their economic importance, the rocks of the transition zone between hornblende gneiss and mica schist are discussed in detail.

TRANSITION ZONE AT CONTACT WITH MICA SCHIST UNIT

The contact between rocks of the hornblende gneiss unit and the mica schist unit is commonly marked by a transition zone containing garnetiferous biotite-quartz gneiss interlayered with lesser amounts of quartz gneiss, mica schist, amphibolite, amphibole-quartz gneiss, and gradational rock types. The transition zone is somewhat irregular in thickness and continuity; it is apparently absent in some areas and as much as several hundred feet thick in others, but in most places it is no more than 50 feet thick. It has not been shown as a separate unit on plate 1 but is shown on the more detailed maps (pls. 2, 8). Where thick enough to affect the location of a contact, the zone was mapped as part of the hornblende gneiss unit on the district map (pl. 1). The transition zone commonly weathers rusty brown owing to the presence of disseminated iron sulfides. The zone thus has the appearance of gossan, and many prospect pits have been dug on it.

Studies of the transition zone were made in conjunction with the detailed mapping and investigations of economic geology at the Schwartzwalder mine. In the mine area (pl. 2) garnetiferous biotite-quartz gneiss and associated rocks form a transition zone of variable width along the folded contact between the mica schist unit and the undivided hornblende gneiss unit. In the west-central part of the mine area the garnetiferous biotite-quartz gneiss is only 22 feet thick and is bordered on the north side by 23 feet of fine-grained mica schist. Near the portal of the Charlie adit and southeastward to the edge of the mine area (pl. 2), the transition zone is about 300 feet thick and consists of 250 feet of garnetiferous gneiss and schist containing a central lens of biotitic hornblende gneiss. Between the lens of biotitic hornblende gneiss and the undivided hornblende gneiss unit, the rock of the transition zone is predominantly garnetiferous biotite-quartz gneiss; between the biotitic hornblende gneiss and the mica schist unit it is garnetiferous biotite-quartz gneiss, garnetiferous mica schist, and biotite-rich schist in layers 1–12 inches thick. Near Ralston Creek two small lenses of quartz gneiss occur in the garnetiferous biotite-quartz gneiss, and to the southwest others occur along and near the contact between the fine-grained mica schist and the undivided hornblende gneiss unit. The lens of fine-grained mica schist disappears northward along the west side of the Illinois vein-fissure (pl. 2). Workings of the Schwartzwalder mine are largely in rocks of the transition zone (pls. 3–5), and a summary of the distribution and variations of these rocks underground is given in the description of the mine.

The garnetiferous biotite-quartz gneiss at the Schwartzwalder mine is dark, fine to medium grained, and generally rather massive and less well foliated than the mica schist and the fine-grained schist. It weathers brown, purple brown, or black; the dark colors are stains due to various iron and manganese oxides. Relative amounts of quartz, biotite, and garnet vary from layer to layer in some exposures. Garnet content of individual layers ranges from 1 to about 50 percent. The garnet is commonly very poikiloblastic (fig. 8). The modes of five representative samples of garnetiferous biotite-quartz gneiss from the Schwartzwalder mine area are shown in table 3. An amphibole that is probably grunerite forms as much as 21 percent of some parts of the gneiss (fig. 9; mode 1, table 3). Pyrite and pyrrhotite locally form 5–10 percent of the garnetiferous biotite-quartz gneiss in the mine area.

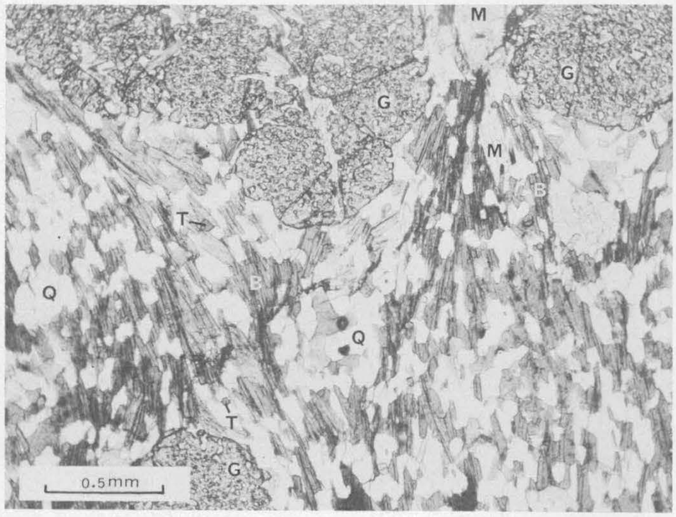

FIGURE 8.—Garnetiferous biotite-quartz gneiss from the transition zone at the contact between the mica schist unit and the hornblende gneiss unit, Schwartzwalder mine. Extremely poikiloblastic grains of garnet (G); other minerals are quartz (Q), biotite (B), muscovite (M), and tourmaline (T). Plane-polarized light.

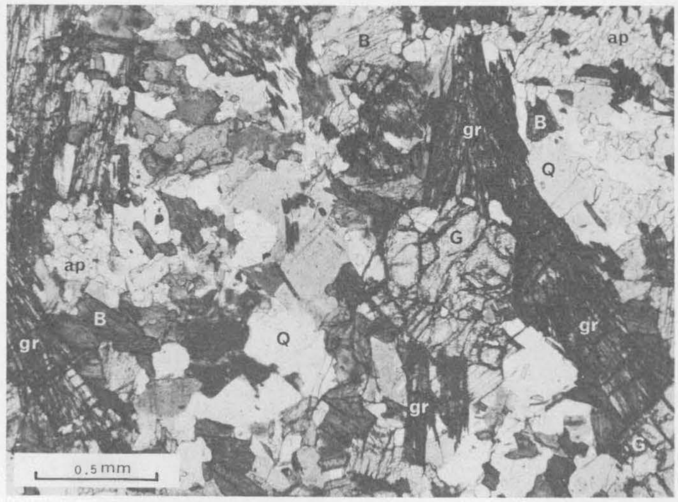

FIGURE 9.—Amphibole-bearing garnetiferous biotite-quartz gneiss from the transition zone at the contact between the mica schist unit and the hornblende gneiss unit, Schwartzwalder mine. Grunerite (gr), garnet (G), biotite (B), quartz (Q), and apatite (ap). The grunerite shows characteristic multiple twinning with narrow twin lamellae. Nicols partly crossed.

TABLE 3.—*Modes (volume percent) of garnetiferous biotite-quartz gneiss in transition zone at contact between hornblende gneiss unit and mica schist unit, Schwartzwalder mine*

	1	2	3	4	5
Field No	SW-31	SW-85	RC-11-580	RC-13-151	FF-2-5
Biotite	41	43	29	31	43
Quartz	17	27	29	18	14
Garnet	10	17	34	29	37
Hornblende	----	----	----	4	Trace
Other amphibole [1]	21	----	----	10	6
Muscovite	----	11	----	----	----
Apatite	7	----	----	.6	----
Tourmaline	----	1.7	----	----	----
Zircon	Trace	Trace	Trace	Trace	Trace
Magnetite-ilmenite	----	----	----	----	Trace
Pyrite	Trace	----	8	6	----
Carbonate mineral [2]	2.7	----	Trace	Trace	----
Chlorite [2]	1.1	----	Trace	.9	Trace

[1] Optical data suggest that the amphibole is probably grunerite in the cummingtonite-grunerite series.
[2] Alteration mineral, chiefly replacing grunerite.

1. Amphibole-bearing variety from crosscut on Upper level.
2. From east wall of southeast drift on Nebraska vein, Minnesota level.
3. From drill hole.
4, 5. Amphibole-bearing variety. From drill holes.

TABLE 4.—*Modes (volume percent) of minor rocks in garnetiferous biotite-quartz gneiss in transition zone at contact between hornblende gneiss unit and mica schist unit, Schwartzwalder mine*

	1	2
Field No	SW-87	SW-130
Hornblende	2.4	58
Grunerite	32	----
Quartz	23	5
Biotite	Trace	7
Plagioclase	----	[1] 24
Garnet	35	----
Apatite	Trace	1.5
Magnetite-ilmenite	Trace	4
Carbonate mineral [2]	6	----
Chlorite [2]	1.4	----

[1] Andesine (An_{41}).
[2] Alteration mineral, chiefly replacing grunerite.

1. Garnetiferous amphibole-quartz gneiss, layer in garnetiferous biotite-quartz gneiss, west wall of northwest drift on Kansas vein, Minnesota level.
2. Biotitic hornblende gneiss, lens in garnetiferous biotite-quartz gneiss; specimen taken from outcrop approximately 250 ft N. 5° E. from the portal of the Charlie level.

Physical properties of six garnet fractions recovered from garnetiferous biotite-quartz gneiss at the Schwartzwalder mine (samples 1–6, table 32) indicate that garnet varies appreciably in composition there. A semiquantitative spectrographic analysis of one of these garnet fractions (sample 3, table 31) indicates that almandite and spessartite are the main end members represented and that the sample contains 0.015 percent each of zirconium and titanium, and 0.007 percent each of cobalt, copper, and germanium.

Locally the garnetiferous biotite-quartz gneiss contains other rocks in small layers or lenses. Modes of garnetiferous amphibole-quartz gneiss and biotitic hornblende gneiss are shown in table 4. Parts of the garnetiferous biotite-quartz gneiss contain thin layers of quartz gneiss and of garnetiferous mica schist, intermediate in composition between mica schist and the garnetiferous gneiss. Parts of the rock mapped as quartz gneiss resemble gray bull quartz, but many of the exposures contain layers less than an inch thick rich in amphibole, biotite, or magnetite-ilmenite.

Rocks similar to those at the Schwartzwalder mine occur at the Aubrey Ladwig mine (pl. 8; fig. 33) and are predominantly garnetiferous biotite-quartz gneiss with lesser amounts of mica schist and biotite schist. The thickness of the transition zone here is not known exactly but is probably 200-300 feet. The hornblende-epidote-garnet gneiss and quartz gneiss shown in the southern and southeastern parts of the Aubrey Ladwig mine area (pl. 8) form part of the main sequence of layered calc-silicate gneiss of plate 1. Metamorphic rocks northwest of the hornblende-epidote-garnet gneiss comprise the transition zone in the mine area (pl. 8). Physical properties of garnet from the garnetiferous biotite-quartz gneiss in this area are shown in table 32 (sample 15).

LAYERED CALC-SILICATE GNEISS AND ASSOCIATED ROCKS

Layered calc-silicate gneiss and associated lenses of mica schist and quartz gneiss were mapped as subdivisions of the hornblende gneiss unit in the southern part of the district (pl. 1). These rocks lie between the mica schist unit and the interlayered hornblende gneiss, amphibolite, and biotite-quartz-plagioclase gneiss subunit of the hornblende gneiss unit. Minor amounts of amphibolite, hornblende gneiss, and biotite-quartz-plagioclase gneiss (biotite gneiss) are interlayered with the layered calc-silicate gneiss but are not shown.

The contact of the layered calc-silicate gneiss with the large central mass of mica schist is transitional over much of its extent, as discussed previously. The opposite contact, with the interlayered hornblende gneiss, amphibolite, and biotite gneiss, is even more subtly gradational. In general, however, the layered calc-silicate gneiss contains more felsic material and has a more pronounced compositional layering than do amphibolite, hornblende gneiss, and biotite gneiss. East of Guy Gulch the southern contact of the layered calc-silicate gneiss is marked by a thin layer of medium-grained amphibolite with a spotted texture. The spotted amphibolite crops out over a distance of about 1 mile along the contact but was not delineated separately on plate 1. Similar spotted amphibiolite was observed in less continuous outcrops elsewhere along this contact, as near the Ascension mine.

In the southern part of the district east of Guy Gulch, the layered calc-silicate gneiss is divided into two parts by a belt of mica schist, which narrows in outcrop width toward the west. The map pattern of this schist suggests that it is a very long lens or tongue within the layered calc-silicate gneiss rather than a part of the main mica schist unit repeated by infolding. This interpretation of interlensing is supported by the presence of a discrete lens of layered calc-silicate gneiss within the long belt of schist in the southeastern part of the district (pl. 1), and by the presence elsewhere in the layered calc-silicate gneiss of lenses of mica schist too small to be shown on the map. The relations thus suggest a complex intertonguing and interlensing of the calc-silicate gneiss and mica schist, which makes structural interpretation much more difficult.

Layered calc-silicate gneiss

The calc-silicate gneiss of the Ralston Buttes district is characterized by a well-developed compositional layering. Individual layers range in thickness from 0.1 inch to several feet. Layers rich in hornblende are dark green whereas layers rich in felsic minerals are white, gray, or pinkish. Other layers are light green, pink, or black; their color varies with the concentrations of epidote and clinopyroxene, garnet, and magnetite-ilmenite. Foliation caused by a parallel arrangement of tabular mineral grains is well developed in the more hornblendic layers and is generally parallel to the compositional layering. The texture of rock samples taken from some individual layers is granoblastic in thin section, although the pronounced compositional layering gives outcrops of the rock a highly foliated appearance. The gneiss ranges from fine to coarse grained.

The principal minerals in most of the layered calc-silicate gneiss are hornblende, plagioclase (andesine, An_{30}–An_{46}), clinopyroxene, and members of the epidote group. Quartz, microline, garnet, magnetite-ilmenite, cummingtonite, tremolite, calcite, and scapolite are also common constituents, and one or several of these minerals may predominate in individual layers. Lenses and pods of coarse-grained epidote and quartz are fairly common. Microcline, vesuvianite, clinopyroxene, hornblende, and plagioclase occur as coarse crystals in the coarse-grained parts of the gneiss. Sphene and apatite are common accessory minerals, and tourmaline was noted in some thin sections.

The wide variation in the thickness and mineralogic composition of individual layers in the calc-silicate gneiss makes it almost impossible to obtain quantitative mineralogic data representative of the unit. Included in table 5, however, are modes of three samples of layered calc-silicate gneiss that illustrate some of the variation in mineralogic content.

Striated crystals of brown vesuvianite (idocrase) as large as 2 inches across occur locally in the more massive skarnlike parts of the calc-silicate gneiss west of Guy Gulch in the southwestern part of the district.

TABLE 5.—*Modes (volume percent) of layered calc-silicate gneiss and associated rocks in the hornblende gneiss unit*

	1	2	3	4	5
Field No	DS-53-10	DS-53-28	RA-150	DS-53-17	RA-178
Hornblende	32	11	10	63	56
Clinopyroxene	33	21	11		
Plagioclase	21	21	28	31	
Clinozoisite-epidote	6		10		
Epidote		8			
Microcline	2.2	4	17		
Quartz		Trace	10		1.8
Sphene	2.0	4	1.5		
Apatite	.7	.9	Trace	.8	
Calcite	.6	17			
Magnetite-ilmenite		Trace	Trace	2.3	Trace
Scapolite		12			
Tourmaline		Trace			
Garnet					37
Biotite				Trace	
Sericite [1]	2.4	.9	12	2.7	
Hematite-limonite					5

[1] Alteration product of plagioclase; percentages probably include some clay minerals.

1. Layered calc-silicate gneiss, SW¼SW¼ sec. 20, T. 3 S., R. 71 W.
2. Layered calc-silicate gneiss, NE¼ sec. 21, T. 3 S.. R. 71 W.
3. Layered calc-silicate gneiss, SE¼SW¼ sec. 18, T. 3 S., R. 70 W.
4. Amphibolite with spotted texture, layer at southern contact of layered calc-silicate gneiss, NW¼SW¼ sec. 22, T. 3 S., R. 71 W.
5. Garnet-hornblende rock, NE¼SE¼ sec. 18, T. 3 S., R. 70 W.

The refractive indices of the vesuvianite are $n_e = 1.717 \pm 0.005$ and $n_o = 1.723 \pm 0.005$.

Minor layers of amphibolite, hornblende gneiss, and biotite gneiss in the layered calc-silicate gneiss are similar in composition and texture to rocks in the interlayered hornblende gneiss, amphibolite, and biotite gneiss subunit. Modes of specimens from layers of spotted amphibolite and garnet-hornblende rock are shown in table 5.

In the vicinity of the Ascension mine (pl. 6), the layered calc-silicate gneiss contains layers of garnetiferous biotite-quartz gneiss 3–17 feet thick, a layer of sillimanitic mica schist 20 feet thick, and a lens of feldspar-quartz gneiss ranging in exposed thickness from 5 to 20 feet. The garnetiferous gneiss is similar to that in the transition zone at the contact between the hornblende gneiss unit and the mica schist unit. The feldspar-quartz gneiss occurs at the contact between layered calc-silicate gneiss and mica schist, and splits eastward into two branches separated by a tongue of schist. It probably pinches out westward, but detailed relations are obscured by surficial deposits and faulting. The feldspar-quartz gneiss consists predominantly of microcline, quartz, and plagioclase, with minor amounts of muscovite and biotite.

Quartz gneiss

Several elongate lenses of quartz gneiss are exposed on Guy Hill (pl. 1), and other smaller lenses occur in the layered calc-silicate gneiss west of Guy Gulch. Similar lenslike exposures of quartz gneiss, too small to be mapped, are common elsewhere in the layered calc-silicate gneiss and in the undivided hornblende gneiss unit in the northern part of the district. Such rock commonly occurs with garnetiferous biotite-quartz gneiss along the transitional contact with the mica schist unit.

The quartz gneiss is fine grained, predominantly gray but locally white, black, or reddish gray in irregular color bands, and commonly layered. It consists predominantly of quartz but contains abundant layers of magnetite-ilmenite ranging in thickness from a millimeter to several centimeters, and less abundant layers of garnet or hornblende. Layers of white quartz commonly parallel but locally transect the other layers. Some small outcrops of the quartz gneiss are similar in general appearance to bull quartz veins but differ from them in containing small grains of magnetite-ilmenite in crude layers.

Mica schist

The long belt of mica schist delineated within the layered calc-silicate gneiss in the south-central and southeastern parts of the district probably represents an elongate lens stratigraphically distinct from the main mica schist unit and hence has been designated separately on the map (pl. 1). Other thin layers and lenses of schist are present in the layered calc-silicate gneiss but are too small to be shown on the geologic map. The schist is lithologically similar to the dominant rock in the main mica schist unit. It consists principally of quartz, muscovite, and biotite, and commonly contains glomeroporphyroblasts of sillimanite.

INTERLAYERED HORNBLENDE GNEISS, AMPHIBOLITE, AND BIOTITE-QUARTZ-PLAGIOCLASE GNEISS

Interlayered hornblende gneiss, amphibolite, and biotite-quartz-plagioclase gneiss (biotite gneiss) constitute a major subdivision of the hornblende gneiss unit in the west-central and southern parts of the district. These rocks lie between the microcline-quartz-plagioclase-biotite gneiss unit and the layered calc-silicate gneiss subunit of the hornblende gneiss unit. The layers of amphibolite and hornblende gneiss are somewhat more resistant to erosion than the biotite gneiss and in most areas crop out more commonly.

The rocks are similar general appearance. Most of them are gray to black and fine grained. They are generally equigranular and on fresh surfaces have a "salt and pepper" appearance, but locally the amphibolite is fine to medium grained, and its megascopic texture is speckled or spotted. Some varieties of the hornblende and biotite gneisses are relatively rich in plagioclase and quartz and consequently are lighter in color than most rocks of the subunit.

TABLE 6.—*Modes (volume percent) of amphibolite and hornblende gneiss from the interlayered hornblende gneiss, amphibolite, and biotite gneiss subunit of the hornblende gneiss unit*

	Amphibolite						Hornblende gneiss					
	1	2	3	4	5	6	7	8	9	10	11	12
Field No.	RA-29d	DS-53-25	DS-53-23	JWA-18-53	JWA-108-53	DS-53-22	JWA-1-53	JWA-4-53	JWA-10-53	JWA-105-53	JWA-14-53	JWA-16-53
Hornblende	52	69	62	42	75	57	50	24	29	22	48	18
Plagioclase	44	22	26	44	(1)	34	23	37	51	33	28	34
Quartz		6	3	7			23	27	13	14	2.0	14
Clinopyroxene			2.3			3					13	Trace
Clinozoisite-epidote			.9		Trace	.9				Trace	1.6	
Biotite						Trace		2.5	1.9	.7		29
Cummingtonite										7		
Apatite	.5	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	1.8	.8	1.4
Sphene			.8		1.7	.7					2.3	Trace
Zircon												Trace
Magnetite-ilmenite	1.4	2.3	.5	1.9	Trace		1.5	3	1.9	[2] 2.4		2.7
Carbonate mineral												Trace
Garnet										Trace		
Hematite				Trace		Trace		Trace	2.6		Trace	
Sericite [3]	1.8	.5	4	5	23	4	2.1	6	.5	19	4	Trace

[1] Plagioclase completely altered to sericite.
[2] Percentage includes some sulfide minerals and limonite.
[3] Alteration product of plagioclase; percentages probably include some clay minerals.

SAMPLED LOCALITIES

1. SW¼SE¼ sec. 23, T. 3 S., R. 71 W.
2. NW¼SW¼ sec. 22, T. 3 S., R. 71 W.
3. NW¼NE¼ sec. 17, T. 3 S., R. 71 W.
4. SW¼ sec. 20, T. 3 S., R. 70 W.
5. SE¼ sec. 24, T. 3 S., R. 71 W.
6. Spotted variety, NW¼NE¼ sec. 17, T. 3 S., R. 71 W.
7, 8. SW¼ sec. 20, T. 3 S., R. 70 W.
9. SE¼ sec. 19, T. 3 S., R. 70 W.
10. NE¼NE¼ sec. 25, T. 3 S., R. 71 W.
11. SW¼ sec. 20, T. 3 S., R. 70 W.
12. Biotite-rich variety, SW¼ sec. 20, T. 3 S., R. 70 W.

Modes of six specimens of amphibolite and six specimens of hornblende gneiss from this map unit are shown in table 6. The amphibolite consists of hornblende and plagioclase and, by our definition, less than 15 percent of other minerals. If the total percentage of other minerals, such as quartz, biotite, clinopyroxene, and cummingtonite, is 15 percent or more of a hornblende-plagioclase rock, we call it hornblende gneiss instead of amphibolite. In some of the amphibolite and hornblende gneiss the hornblende is porphyroblastic. The plagioclase ranges in composition from calcic oligoclase (An_{28}) to calcic andesine (An_{49}). Coarse-grained lenticular aggregates of hornblende and plagioclase occur locally, some parallel to the foliation, and some transverse to it. Apatite and magnetite-ilmenite are common accessory minerals; sphene, clinozoisite-epidote, zircon, and garnet are less common. Light-green needles of cummingtonite randomly oriented in parallel planes were found in a yellow-brown layer of hornblende gneiss that crops out in several places in the southeastern part of the district near the contact with microcline-quartz-plagioclase-biotite gneiss.

Modes of seven specimens of biotite-quartz-plagioclase gneiss are shown in table 7. The first three are typical of this gneiss, and the others represent less common microcline-bearing layers. The principal minerals in all the specimens are plagioclase, quartz, and biotite, but microcline forms 3 percent or more of two specimens. Apatite and zircon are common accessory minerals; other accessory minerals are hornblende, magnetite-ilmenite, muscovite, clinozoisite-epidote, allanite, and garnet. In general the biotite gneiss contains more felsic minerals than the amphibolite. Locally it contains tiny elongate lenses of quartz, plagioclase, and muscovite oriented parallel to the foliation; such lenses average about 6 mm in length and 1–3 mm in cross section. Other exposures of the biotite gneiss exhibit white spots about 5 mm in diameter composed of plagioclase and quartz surrounding a euhedral magnetite crystal.

TABLE 7.—*Modes (volume percent) of biotite-quartz-plagioclase gneiss from the interlayered hornblende gneiss, amphibolite, and biotite gneiss subunit of the hornblende gneiss unit*

	Biotite-quartz-plagioclase gneiss			Microcline-bearing biotite-quartz-plagioclase gneiss			
	1	2	3	4	5	6	7
Field No.	RA-31	JWA-5-53	JWA-3-53	RA-154	RA-43	RA-29b	RA-67
Biotite	22	16	12	19	15	36	31
Quartz	34	42	38	42	31	30	22
Plagioclase	42	40	49	34	50	29	29
Hornblende	Trace	Trace	.5	1.5			
Microcline				1.5	1.3	3	16
Muscovite		1.0			1.5	.7	.9
Apatite	.5	Trace	Trace	Trace	Trace	Trace	Trace
Magnetite-ilmenite	1.2	Trace		.7	.9		
Zircon		Trace	Trace	Trace	Trace	Trace	Trace
Allanite	Trace				Trace	Trace	Trace
Clinozoisite-epidote	Trace			1.2			Trace
Garnet						1.0	.5
Chlorite			Trace			Trace	

SAMPLED LOCALITIES

1. NE¼NW¼ sec. 26, T. 3 S., R. 71 W.
2, 3. SW¼ sec. 20, T. 3 S., R. 70 W.
4. SE¼NW¼ sec. 20, T. 3 S., R. 70 W.
5. SW¼SE¼ sec. 24, T. 3 S., R. 71 W.
6. NW¼SE¼ sec. 23, T. 3 S., R. 71 W.
7. SW¼ sec. 22, T. 3 S., R. 71 W.

A discontinuous layer of medium-grained amphibolite east of Guy Gulch in the southern part of the district has a spotted appearance caused by dark hornblende grains in a lighter matrix consisting principally of plagioclase. Similar spotted rocks occur in thin layers or lenses in this and other parts of the hornblende gneiss unit but are not shown separately on the map. The mode of a specimen from one of these (mode 6) is shown in table 6.

UNDIVIDED HORNBLENDE GNEISS UNIT

The hornblende gneiss unit is not subdivided in the northern half of the district, but it includes rocks megascopically identical with the previously described layered calc-silicate gneiss and associated rocks and with the interlayered hornblende gneiss, amphibolite, and biotite gneiss. Small lenses of quartz gneiss are also common, but lenses or layers of mica schist are few. In the wide area of exposure south of the Mena mine (pl. 1), layered calc-silicate gneiss and interlayered hornblende gneiss, amphibolite, and biotite gneiss appear to be repeated several times across the breadth of the unit by complex folding, but some of this apparent repetition could be due to facies changes within the unit.

The contact with the mica schist unit is commonly marked, as in the southern half of the district, by a transition zone that contains garnetiferous biotite-quartz gneiss interlayered with lesser amounts of quartz gneiss and mica schist. In the northeastern part of the district the contact with the unit consisting of microcline-quartz-plagioclase-biotite gneiss (microcline gneiss) complexly interlayered with other rocks is also gradational and is marked by a zone 200–400 feet wide that consists of alternating layers of microcline gneiss and amphibolite or hornblende gneiss. It is further complicated by faulting along the Rogers breccia-reef system (pl. 1).

Detailed descriptions of all the rocks in the undivided hornblende gneiss unit are not included here, because most of the rocks are the same as in the subdivisions of the unit, described in preceding pages. Modes of rocks typical of the unit are shown in table 8. The unit contains a layer of mottled greenish to buff-brown tremolite marble (mode 6, table 8) about 5 feet thick in the SE¼ sec. 26. A layer of impure marble (mode 5), about 4 feet thick, was noted in core from a drill hole at the Schwartzwalder mine. Rocks intermediate between such highly calcareous rocks and the layered calc-silicate gneiss are common in the hornblende gneiss unit, in both the southern and northern halves of the district. Mode 4 (table 8), calcareous layered calc-silicate gneiss from the Mena mine, is representative of such intermediate rocks. Rocks that contain a higher percentage of silicate minerals than of calcite are much more common than marble.

TABLE 8.—*Modes (volume percent) of specimens from the undivided hornblende gneiss unit*

	1	2	3	4	5	6	7
Field No.	RC-10-78	DS-53-33	SW-52	RC-9-147	FF-2-10	DS-55-31	SW-61
Hornblende	54	53	53	35	6		[1] 11
Plagioclase	[2] 32	44	([3])	[4] 25	Trace		
Biotite			21		23	Trace	
Quartz							85
Clinopyroxene				5	[5] 21		
Epidote-clinozoisite	2.2	1.5		8	1.5		
Tremolite						23	
Calcite				16	46	77	Trace
Opaque minerals	3	1.2	2.9	1.1		Trace	4
Microcline					2.2		
Muscovite					Trace		
Sphene			.6	1.5	Trace		
Zircon			Trace		Trace		
Apatite	.5			Trace	Trace		Trace
Sericite [6]	8	([7])	22	8			

[1] Hornblende in this specimen is partly altered to chlorite, epidote, and carbonate mineral.
[2] Andesine (An_{31}).
[3] Plagioclase completely altered to sericite.
[4] Andesine (An_{40}).
[5] Clinopyroxene in this specimen is partly altered to chlorite, clay minerals, and carbonate mineral.
[6] Alteration product of plagioclase; percentages probably include some clay minerals.
[7] The sericitic alteration of plagioclase in this specimen was not counted separately because the plagioclase is very fine grained.

1. Fine-grained amphibolite from drill hole, Mena mine.
2. Fine-grained amphibolite from slope west of Ralston Creek in NW¼SE¼ sec. 25, T. 2 S., R. 71 W.
3. Hornblende gneiss, breast of first northwest drift, Minnesota level, Schwartzwalder mine.
4. Layered calc-silicate gneiss from drill hole, Mena mine.
5. Impure marble, layer in calc-silicate gneiss, from drill hole, Schwartzwalder mine.
6. Tremolite marble from ridge near southern boundary of SE¼SE¼ sec. 26, T. 2 S., R. 71 W.
7. Quartz gneiss, layer in calc-silicate gneiss of hornblende gneiss unit, west wall of first northwest drift, Minnesota level, Schwartzwalder mine.

In the Schwartzwalder mine area the hornblende gneiss unit consists predominantly of layered calc-silicate gneiss, amphibolite, and hornblende gneiss with minor thin layers of quartz gneiss, impure marble, and garnetiferous biotite-quartz gneiss (pl. 2). The modes of hornblende gneiss (mode 3) and quartz gneiss (mode 7) associated with typical layered calc-silicate gneiss underground in the mine are shown in table 8.

MICROCLINE-QUARTZ-PLAGIOCLASE-BIOTITE GNEISS UNIT

The microcline-quartz-plagioclase-biotite gneiss unit (microcline gneiss unit) forms a westward-trending belt across the southern part of the district and an arcuate belt in the west-central part (pl. 1). In both areas it lies between the hornblende gneiss unit and the unit of interlayered gneisses. The outcrop width of the southern belt ranges from 1,500 feet near Guy Gulch to more than 5,000 feet at the eastern and western boundaries of the district. Discontinuous dark-colored layers of amphibolite and biotite gneiss occur within the unit near the eastern and western extremities of the southern belt, as shown on plate 1, and as small layers or lenses in other places. In many outcrops these rocks occur in layers half an inch to several feet thick, but they constitute only a small fraction of the exposures. Microcline gneiss also occurs in the northeastern part of the district, where it is complexly interlayered with other rocks, forming a separate map unit.

The contact of the microcline gneiss unit with the interlayered gneisses is sharply defined over most of its extent by a garnetiferous schist layer in the interlayered gneisses. The opposite contact—with the hornblende gneiss unit—is also sharp over much of its extent, but east of Guy Gulch it is gradational through a zone 100–200 feet wide. In this area, the contact was drawn along the north side of a layer of fine-grained white plagioclase-quartz gneiss in the central part of the gradational zone. The white gneiss contains thin layers of phlogopite(?), hornblende, and chlorite. A discontinuous layer of garnetiferous biotite gneiss occurs about 20 feet south of the white gneiss. The gradational contact of the microcline gneiss unit is well exposed in several places in sec. 19 and 20, T. 3 S., R. 70 W.

The microcline gneiss is a fine- to medium-grained biotitic rock characterized by a conspicuous foliation and a granitic appearance. It ranges in color from light orange pink and pinkish gray to a darker gray. The color is determined by the biotite and microcline contents. Closely spaced foliation is caused by thin discontinuous aggregates of biotite having a preferred planar orientation. A wider spaced compositional layering parallel to the foliation is evident in some of the rock and is due to variations in the proportion of biotite. The gneiss commonly forms rounded outcrops and weathers reddish.

The principal minerals of the gneiss are microcline, quartz, plagioclase, and biotite. The composition varies greatly. In eight specimens studied in thin sections (table 9), microcline ranges from 5 to 47 percent; biotite, from 1.6 to 16 percent. The plagioclase ranges in composition from sodic oligoclase (An_{12}) to sodic andesine (An_{35}). Accessory minerals include hornblende, muscovite, apatite, zircon, magnetite-ilmenite, garnet, sphene, allanite, and minerals of the epidote group.

Modes of amphibolite, biotite gneiss, and garnetiferous biotite gneiss that occur within the microcline gneiss are shown in table 10. These rocks are similar to those in adjacent map units. Physical properties of garnet (mainly almandite?) from a layer of garnetiferous biotite gneiss in the microcline gneiss are shown in table 32 (sample 9).

TABLE 9.—*Modes (volume percent) of microcline-quartz-plagioclase-biotite gneiss unit (microcline gneiss)*

	1	2	3	4	5	6	7	8
Field No.	RA-32	RA-290	RA-198A	RA-53	CM-55-11	DS-53-24	DS-58-R26	RA-197
Microcline	47	16	14	16	21	26	17	5
Quartz	34	41	48	36	37	40	39	48
Plagioclase [1]	15	25	29	38	30	26	26	31
Biotite	1.6	16	5	8	11	6	16	14
Muscovite	1.7	.8	-------	-------	-------	1.3	1.4	Trace
Hornblende	-------	-------	1.3	1.2	-------	-------	-------	.8
Clinozoisite-epidote	-------	Trace	Trace	.5	-------	-------	-------	.5
Zoisite-clinozoisite	-------	.8	-------	-------	-------	-------	-------	-------
Apatite	-------	Trace	Trace	Trace	Trace	-------	Trace	Trace
Magnetite-ilmenite	Trace	-------	2.2	Trace	-------	-------	Trace	Trace
Zircon	-------	-------	-------	Trace	Trace	Trace	Trace	-------
Garnet	-------	-------	-------	-------	-------	-------	-------	.5
Sphene	-------	-------	Trace	Trace	-------	-------	-------	-------
Allanite	-------	-------	Trace	-------	-------	-------	-------	-------
Hematite	Trace	-------	-------	-------	Trace	-------	-------	-------
Chlorite	-------	-------	-------	Trace	-------	-------	-------	-------

[1] Oligoclase-andesine.

1. Medium-grained gneiss, SE¼NW¼ sec. 26, T. 3 S., R. 71 W.
2. Fine-grained gneiss, SW¼SW¼ sec. 28, T. 2 S., R. 71 W.
3. Fine- to medium-grained gneiss, Douglas Mountain, SE¼ sec. 18, T. 3 S., R. 71 W.
4. Medium-grained gneiss, SE¼NW¼ sec. 25, T. 3 S., R. 71 W.
5. Fine-grained gneiss, SW¼ sec. 29, T. 3 S., R. 70 W.
6. Fine-grained gneiss, south of Mount Tom, SE¼ sec. 8, T. 3 S., R. 71 W.
7. Fine- to medium-grained gneiss, SW¼ sec. 29, T. 2 S., R. 71 W.
8. Fine-grained gneiss, Douglas Mountain, SE¼ sec. 18, T. 3 S., R. 71 W.

TABLE 10.—*Modes (volume percent) of minor rocks in the microcline-quartz-plagioclase-biotite gneiss unit*

	1	2	3
Field No.	CM-55-8	DS-53-18	RA-163
Quartz	1.0	39	28
Plagioclase [1]	21	49	32
Biotite	Trace	9	19
Hornblende	66	.5	-------
Garnet	-------	.7	13
Magnetite-ilmenite	-------	1.1	2.2
Apatite	Trace	Trace	.6
Sphene	1.7	-------	-------
Clinozoisite-epidote	Trace	-------	-------
Microcline	Trace	Trace	-------
Rutile	-------	-------	Trace
Zircon(?) or allanite(?)	-------	Trace	Trace
Chlorite	-------	-------	4
Sericite [2]	10	.5	.7
Hematite	Trace	-------	-------

[1] Oligoclase-andesine.
[2] Alteration product of plagioclase; percentages probably include some clay minerals.

1. Fine-grained amphibolite, lens in microcline gneiss, NW¼SW¼ sec. 29, T. 3S., R. 70 W.
2. Fine- to medium-grained biotite-quartz-plagioclase gneiss, lens in microcline gneiss, SW¼ sec. 28, T. 3S., R. 71 W.
3. Garnetiferous biotite-quartz-plagioclase gneiss, layer in microcline gneiss near contact with hornblende gneiss unit, SE¼SW¼ sec. 19, T. 3S., R. 70 W.

MICROCLINE-QUARTZ-PLAGIOCLASE-BIOTITE GNEISS COMPLEXLY INTERLAYERED WITH OTHER ROCKS

A map unit composed of microcline gneiss complexly interlayered with varying amounts of amphibolite, hornblende gneiss, layered calc-silicate gneiss, biotite gneiss, and, locally, quartz gneiss was distinguished in the northeastern part of the district. The distribution of rock types in this unit is complex and poorly known. Accordingly the rocks are shown on plate 1 in two generalized subunits: one in which microcline gneiss constitutes more than a third of the succession, and one in which it constitutes less than a third. The first named subunit lies north of and adjacent to the undivided hornblende gneiss unit and in a smaller area within that unit, and the second lies farther north.

The microcline gneiss and other interlayered rocks from this unit were not studied in detail because they have the same megascopic characteristics as the rocks of other units discussed above. Modes of several specimens from the units are shown in table 11.

TABLE 11.—*Modes (volume percent) of microcline-quartz-plagioclase-biotite gneiss and other rocks that are complexly interlayered in the northeastern part of the Ralston Buttes district*

	1	2	3	4
Field No	RA-515	RA-486	RA-511b	DS-57-7b
Microcline	31	6		Trace
Plagioclase	22	28	2.6	15
Quartz	35	43	65	
Biotite	6	15	28	10
Hornblende		1.9		69
Andalusite			2.4	
Clinozoisite-epidote		3		
Muscovite	.8			
Zircon			Trace	Trace
Apatite	Trace	Trace		Trace
Magnetite-ilmenite		Trace	1.7	.6
Garnet	Trace			
Sericite [1]	5	2.9	Trace	5
Chlorite	Trace			

[1] Alteration product of plagioclase; percentages probably include some clay minerals.

1. Microcline-quartz-plagioclase-biotite gneiss, SW¼ sec. 24, T. 2 S., R. 71 W.
2. Microcline-quartz-plagioclase-biotite gneiss, SW¼ sec. 13, T. 2 S., R. 71 W.
3. Andalusite-bearing biotite-quartz gneiss, NW¼SE¼ sec. 23, T. 2 S., R. 71 W.
4. Biotitic amphibolite with spotted texture, NW¼ sec. 24, T. 2 S., R. 71 W.

Some amphibolites in the northern exposures of this unit (pl. 1) have a spotted texture. They resemble some hornblende diorite and hornblendite, but because no discordant relations were found, they are considered to be part of the complex interlayered sequence. In this same area, some of the gneisses grade toward cataclastically deformed gneisses.

INTERLAYERED GNEISSES

A unit of interlayered gneisses exposed in the southernmost and west-central parts of the district (pl. 1) consists predominantly of biotite gneiss, amphibolite, hornblende gneiss, and layered calc-silicate gneiss, with less abundant impure marble and quartz gneiss. A layer of garnetiferous quartz-biotite schist separates the interlayered gneisses from the adjacent microcline gneiss in most places but is locally absent.

The unit of interlayered gneisses has been divided into subunits in the west-central part of the district, where a partial concentric pattern is apparent. In addition to the garnetiferous schist, these subunits include: (1) Biotite gneiss with lesser amounts of amphibolite and hornblende gneiss, and (2) layered calc-silicate gneiss, amphibolite, and hornblende gneiss, with less abundant biotite gneiss, quartz gneiss, and impure marble.

In the southernmost part of the district, the unit of interlayered gneisses has not been subdivided; however, the layer of garnetiferous schist is recognized.

For convenience, the following descriptions of the rocks in the unit are based on the subdivisions recognized in the west-central part of the district, but they also apply in large measure to the rocks of the southern belt.

GARNETIFEROUS QUARTZ-BIOTITE SCHIST

Garnetiferous quartz-biotite schist occurs in a layer as much as 400 feet thick along the contact of the interlayered gneiss unit with the microcline gneiss unit (pl. 1). The layer thins and pinches out westward in the southern belt and northwestward in the west-central area. Porphyroblasts of dark-red garnet that are as much as 25 mm in diameter locally constitute 75 percent of the schist, but in most places the garnet is finer grained and forms about 15 percent of the schist. The principal minerals of the schist are quartz, biotite, and garnet, but feldspathic and sillimanitic varieties are not uncommon (modes 4 and 5, table 12). The biotite content of the garnetiferous layer varies considerably and in some exposures is as low as 5 percent. Physical properties of three garnet fractions recovered from this schist (samples 7, 8, and 10, table 32) and semiquantitative spectrographic analyses (table 31) of two of these suggest that each consists predominantly of almandite.

TABLE 12.—*Modes (volume percent) of some of the rocks in the unit of interlayered gneisses*

	1	2	3	4	5
Field No	RA-222	RA-84b	CM-55-5	DS-53-45	RA-209C
Plagioclase [1]	37	20	29	25	5
Quartz	47	19		42	48
Biotite	13	16	1.0	11	19
Microcline	Trace				
Hornblende		43	58		
Muscovite	.5			Trace	
Clinozoisite-epidote	.7				
Magnetite-ilmenite	1.3	1.7		1.2	.7
Apatite	Trace	Trace	Trace		
Garnet				20	24
Sillimanite					3
Zircon		Trace	Trace	Trace	
Tourmaline				Trace	
Sphene			Trace		
Sericite [2]			12		
Chlorite				Trace	

[1] Oligoclase-andesine.
[2] Alteration product of plagioclase; percentage probably includes some clay minerals.

1. Gray biotite-quartz-plagioclase gneiss, NE¼NW¼ sec. 8, T. 3 S., R. 71 W.
2. Hornblende gneiss, NW¼ sec. 34, T. 3 S., R. 71 W.
3. Fine-grained amphibolite, SW¼SE¼ sec. 30, T. 3 S., R. 70 W.
4. Feldspathic variety of garnetiferous quartz-biotite schist, SE¼SW¼ sec. 8, T. 3 S., R. 71 W.
5. Sillimanitic variety of garnetiferous quartz-biotite schist, NE¼ sec. 18, T. 3 S., R. 71 W.

BIOTITE-QUARTZ-PLAGIOCLASE GNEISS SUBUNIT

Biotite gneiss, the predominant constitutent of this subunit of the interlayered gneisses, is fine grained, gray, and moderately well foliated and contains segregations of light and dark minerals that produce a compositional layering generally parallel to the planar arrangement of the biotite flakes. The principal minerals, in order of decreasing abundance, are quartz, plagioclase (oligoclase-andesine), and biotite. Accessory minerals are magnetite-ilmenite, clinozoisite-epidote, muscovite, microcline, and apatite. The mode of a typical specimen of the biotite gneiss (mode 1) is given in table 12.

Interlayered with the biotite gneiss are lesser amounts of amphibolite and hornblende gneiss, and rocks intermediate between these and biotite gneiss. The modes of amphibolite (mode 3) and hornblende gneiss (mode 2) from the southern belt are shown in table 12. The amphibolite and hornblende gneiss are, in general, darker and more massive than the biotite gneiss, but locally some hornblende gneiss contains more plagioclase and quartz than hornblende and is relatively light colored. No structural discordance was observed between any of the rocks.

Some of the biotite gneiss, particularly in the southern belt of interlayered gneisses, contains abundant granitic material in concordant layers generally an inch or less thick similar to migmatite described by Harrison and Wells (1956, p. 49) in the Freeland-Lamartine district near Idaho Springs, Colo. Similar migmatite also occurs locally in parts of the hornblende gneiss and mica schist units but, in general, migmatitic rocks in the Ralston Buttes district occupy areas too small, irregular, and ill defined to warrant mapping.

LAYERED CALC-SILICATE GNEISS, AMPHIBOLITE, AND HORNBLENDE GNEISS SUBUNIT

Rocks mapped as the layered calc-silicate gneiss, amphibolite, and hornblende gneiss subunit of the interlayered gneisses in the west-central part of the district (pl. 1) contain minor biotite gneiss, quartz gneiss, and impure marble. Rocks similar to those in this subunit are recognizable in the interlayered gneisses near the southern boundary of the district but were not mapped separately on plate 1.

The layered calc-silicate gneiss varies widely in composition and color from layer to layer. The more mafic layers are green, black, or dark gray, and the more felsic layers are light gray or white. The layers range in thickness from several millimeters to several meters. Dominant minerals include quartz, hornblende, epidote-clinozoisite, garnet, plagioclase (oligoclase-andesine), magnetite-ilmenite, and microcline. Clinopyroxene, calcite, sphene, apatite, and tourmaline are also present in some layers.

Much of the amphibolite interlayered with the calc-silicate gneiss is fine grained and rather poorly foliated, but some layers have a distinctive spotted texture, caused by dark hornblende grains in a matrix of light plagioclase. The layers of amphibolite and hornblende gneiss are mineralogically similar to those described in the hornblende gneiss unit. Modes of hornblende gneiss (mode 2) and amphibolite (mode 3) are shown in table 12.

Layers of quartz gneiss are predominantly quartz with lesser amounts of magnetite-ilmenite and garnet. Locally the quartz gneiss contains epidote, grunerite, and clinopyroxene.

Medium-grained impure calcite marble was noted in layers and small lenses interlayered with the calc-silicate gneiss, amphibolite, and hornblende gneiss. Probably all gradations exist between the impure marble and the more abundant layered calc-silicate gneiss. An impure marble in sec. 35, T. 3 S., R. 71 W., in the southern part of Guy Gulch, closely resembles a biotitic granite in general appearance.

Biotite gneiss is similar in appearance and mineralogy to that in the other subdivision of the interlayered gneisses.

INTERLAYERED BIOTITE-QUARTZ-PLAGIOCLASE GNEISS AND MICA SCHIST

A unit consisting of interlayered biotite-quartz-plagioclase gneiss (biotite gneiss) and mica schist trends northeastward across the northern part of the district (pl. 1). It is only about 250 feet wide at the western boundary of the district but widens toward the northeast and contains a central belt consisting of cataclastic gneisses and associated rocks. The unit is bounded on the north by Boulder Creek Granodiorite and quartz monzonite, except near the northern boundary of the district, where it is in contact with the quartzite unit. To the south it is bounded by quartz-feldspar cataclastic gneiss and associated rocks.

Because of the cataclastic deformation in the Idaho Springs–Ralston shear zone (pl. 1), the contact relations of the unit are poorly known. The contacts with the quartzite unit and hornblendic and biotitic gneisses appear to be conformable. Boulder Creek Granodiorite in sec. 14, T. 2 S., R. 71 W., cuts across the quartzite unit and, presumably, in part across interlayered gneiss and schist as well. Elsewhere the contact between the interlayered gneiss and schist and the intrusive rocks appears generally concordant.

Although the unit consists principally of biotite gneiss and mica schist showing little cataclasis, it also contains numerous irregular poorly defined zones of cataclastically deformed rocks. Some of the rocks in these zones are similar to those in the central belt composed of cataclastic gneisses, but many are less intensely deformed. Except for the central belt, which is described in a following section, these zones of cataclastically deformed rocks have not been shown on the map.

The interlayered gneiss and schist are silvery- to dark-gray fine- to medium-grained rocks composed principally of quartz, plagioclase, biotite, and muscovite, in varied proportions. Pronounced compositional layering is characteristic of the unit, and in general, layers of biotite gneiss alternate with layers of mica schist. The layers range in thickness from a fraction of an inch to several feet. Thin layers or lenses of amphibolite, hornblende gneiss, and calc-silicate gneiss are locally present. Foliation due to mineral orientation is parallel to the layering, and in many places foliation caused by shearing is nearly parallel to the older foliation and layering.

As shown by the modes in table 13, the rocks classified as schist (modes 5 and 6) contain relatively large amounts of mica and small amounts of plagioclase in comparison to the gneiss (modes 1–4), but many rocks of the unit are intermediate between schist and gneiss (modes 7–10). Sillimanite forms as much as 16 percent of some rocks, and potassic feldspar forms as much as 9 percent of others, but the two are not present together in most rocks. Common accessory minerals are zircon, magnetite-ilmenite, and apatite; less common are hornblende, clinozoisite-epidote, sphene, and andalusite.

TABLE 13.—*Modes (volume percent) of specimens from the unit of interlayered biotite-quartz-plagioclase gneiss and mica schist*

	1	2	3	4	5	6	7	8	9	10
Field No.	RA-449b	RA-544a	RA-454b	DS-58-R19	RA-454c	RA-491	RA-454a	CHM-16-54	DS-59-R2	DS-58-R18
Quartz	50	24	30	71	53	41	68	66	31	34
Biotite	28	38	23	13	17	38	11	14	31	22
Muscovite	Trace		Trace	4	27	1.7	12	6	14	10
Plagioclase [1]	20	28	44	10	2.4	.8	7	13	16	18
Potassic feldspar [2]			2.0	Trace		Trace				9
Sillimanite						16			6	6
Andalusite									Trace	
Hornblende		3								
Clinozoisite-epidote		2.3					Trace			
Magnetite-ilmenite	1.6	1.4	.7	1.0	.8	1.7	2.0	1.0	1.2	.6
Apatite	Trace	Trace	Trace	Trace	Trace	Trace	Trace			
Zircon	Trace		Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Sphene		3								
Chlorite										Trace

[1] Oligoclase-andesine.
[2] Term includes microcline, microperthite, and potassic feldspar showing little or no gridiron twinning.

1. Biotite-quartz-plagioclase gneiss, along Deer Creek in SW¼ sec. 21, T. 2S., R. 71 W.
2. Biotite-quartz-plagioclase gneiss, SE¼ sec. 14, T. 2S., R. 71 W.
3. Biotite-quartz-plagioclase gneiss, from ridge in SW¼NE¼ sec. 22, T. 2S., R. 71 W.
4. Biotite-quartz-plagioclase gneiss, south of Ralston Creek and west of Ralston Creek Ranch in SE¼ sec. 30, T. 2S., R. 71 W.
5. Mica schist, from ridge in SW¼NE¼ sec. 22, T. 2S., R. 71 W.
6. Sillimanitic mica schist, SE¼SE¼ sec. 21, T. 2S., R. 71 W.
7. Rock intermediate in character between biotite gneiss and mica schist, from ridge in NE¼ sec. 22, T. 2S., R. 71 W.
8. Rock intermediate in character between biotite gneiss and mica schist, from west flank of ridge, SW¼NE¼ sec. 22, T. 2S., R. 71 W.
9. Sillimanitic rock intermediate in character between biotite gneiss and mica schist, from ridge in SW¼ sec. 14, T. 2S., R. 71 W.
10. Sillimanitic rock intermediate in character between biotite gneiss and mica schist, south of Ralston Creek and west of Ralston Creek Ranch in SE¼ sec. 30, T. 2S., R. 71 W.

Except in granulated rocks, quartz and the feldspars occur in anhedral grains 0.1–1 mm in diameter, and micas in grains or aggregates as much as 2 mm in diameter. The plagioclase (An_{24}–An_{37}) shows both albite and pericline twinning in some grains but is untwinned or poorly twinned in others. Potassic feldspar shows a similar range in the degree of twinning and appears to be concentrated in distinct layers. Glomeroporphyroblasts of sillimanite are as much as 7 mm long, and some are sharply folded. In two specimens (modes 6 and 10, table 13), sillimanite occurs as fine needles in grains of microcline without an intervening sheath of muscovite. In other parts of the same two thin sections, however, sillimanite and muscovite occur together. Sillimanite and microcline are locally altered to a relatively fine grained muscovite. A little andalusite occurs in poikiloblastic grains as much as 1 mm long in one specimen (mode 9, table 13).

QUARTZITE UNIT

The quartzite unit crops out in the northwestern and northcentral parts of the district (pl. 1), where it forms a complex synclinal fold that plunges gently northeast. The unit extends about 5 miles northeastward into the Eldorado Springs quadrangle and discontinuously about three-fourths of a mile southwestward into the Blackhawk quadrangle. Smaller bodies of the quartzite are separated from the main body by quartz monzonite or Boulder Creek Granodiorite. Such bodies occur in the SW¼ sec. 14, NE¼ sec. 19, and SE¼ sec. 15, T. 2 S., R. 71 W. In most places the quartzite unit is in contact with quartz monzonite, but in sec. 14 it is in contact with Boulder Creek Granodiorite and with the unit of interlayered biotite gneiss and mica schist. In the western part of the district two bodies of Boulder Creek Granodiorite occur within the quartzite unit. As described more fully in the discussion of igneous rocks, the contacts with igneous rocks are discordant in several places. The contact between the quartzite unit and the unit of interlayered gneiss and schist is believed to be conformable, but the relations are obscured by intense cataclastic deformation.

The predominant rocks in the quartzite unit are quartzite and conglomeratic quartzite; less abundant is schist containing sparse lenses of calc-silicate rock. Although not shown as a separate map unit, conglomeratic quartzite occurs in numerous layers and lenses ranging in thickness from about one-half foot to 20 feet. The schist occurs in several layers and lenses, each of which is generally less than 150 feet thick. Two stratigraphic layers of the schist are well defined in most of the quartzite unit, and smaller lenses lie northeast of the long fault in secs. 14 and 15 (pl. 1). A third layer of schist is conspicuous northeast of the map area in the Eldorado Springs quadrangle (Wells, 1963). Lenses of calc-silicate rock occur in the schist on Blue Mountain in the SW¼ sec. 16 but are too small to be shown on the map. The thickened part of a schist layer near the western boundary of the district contains two lenses of quartzite.

Much of the quartzite unit is closely jointed and consists of a mass of small blocky fragments, but in places it is relatively massive and is broken only by widely spaced joints. Intense folding is evident in the schist layers and in quartzite containing abundant laminae of muscovite. Locally the layering in the quartzite is cut by a transverse cleavage.

The metamorphism and structure of the quartzite unit have been described in detail by Wells, Sheridan, and Albee (1964).

QUARTZITE AND CONGLOMERATIC QUARTZITE

Quartzite and conglomeratic quartzite form a succession of fine- to coarse-grained rocks which are mostly gray to white, but less commonly black or pale red. The color layering commonly conforms to the compositional layering, and the unit has a general bedded appearance, especially where mica-rich laminae are abundant.

The quartzite is composed predominantly of quartz in grains less than 1 mm in diameter, but in some layers the grains are as much as 2 mm across. Modes of four quartzite specimens are shown in table 14. Most of the quartzite contains very fine muscovite, the planar orientation of which imparts a foliation that is generally parallel to the layering of the rock. Laminae composed of muscovite, fine-grained andalusite, or, rarely, rutile and hematite (mode 4, table 14) impart a fine-scale layering to the rock. Accessory minerals in the quartzite are tourmaline, zircon, rutile, apatite, magnetite-ilmenite, and hematite. The quartz in some thin sections shows strain shadows and intense suturing of grain boundaries. The quartzite locally contains a cleavage that transects the layering and micaceous foliation. This cleavage together with the presence in some thin sections of bent and shredded grains of muscovite and thin zones of extremely fine quartz suggests that parts of the quartzite have been deformed cataclastically.

Conglomeratic quartzite is common as discontinuous thin layers or lenses throughout the quartzite unit. Most pebbles are quartzite, but a few are quartz-muscovite-magnetite schist. Conglomeratic quartzite consisting of white quartzite pebbles in a darker matrix is well exposed in several areas in the SW¼ sec. 16, T. 2 S., R. 71 W. The matrix contains about 90 percent quartz and lesser amounts of muscovite, hematite, andalusite, magnetite-ilmenite, zircon, and tourmaline. Elongation of the pebbles is approximately parallel to northeast-plunging fold axes. One pebble is $1\frac{1}{2}\times2\frac{1}{2}\times7$ inches; its axial ratio is 0.6:1:3. Suturing at the margins of quartzite pebbles is commonly so intense that it is difficult to distinguish the pebbles from the matrix in thin sections, except where the matrix contains abundant muscovite, andalusite, and opaque minerals. Discontinuous thin layers of muscovite form a foliation that wraps around many of the pebbles. The modes of two specimens of conglomeratic quartzite are shown in table 14.

SCHIST LAYERS IN QUARTZITE UNIT

The layers of schist in the quartzite unit are very fine to medium grained, locally porphyroblastic, and silvery gray, and are composed predominantly of quartz and micas. Pronounced foliation is due to preferred planar orientation of muscovite. Compositional layering, shown by differences in relative amounts of quartz and mica, or by porphyroblasts, is parallel to the micaceous foliation. The foliation

TABLE 14.—*Modes (volume percent) of rocks in the quartzite unit*

	Quartzite				Conglomeratic quartzite		Schist							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Field No	RA-392B	CHM-8-54	RA-384A	CHM-10-54	RA-376	RA-558	DS-59-R1B	RA-384B	RA-375A	RA-385B	RA-446	RA-559C	DS-58-R3	RA-385
Quartz	68	84	85	88	91	90	42	67	46	10	16	24	48	30
Muscovite	[1] 28	[1] 15	[1] 9	[1] 10	[1] .6	8	41	29	17	56	18	[1] 59	--------	49
Biotite	--------	--------	--------	--------	--------	--------	15	Trace	23	--------	1.2	8	41	18
Andalusite	--------	--------	5	--------	2.2	1.1	--------	--------	13	19	49	--------	--------	--------
Cordierite	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	6	--------	--------
Garnet	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	10	2.0
Tourmaline	--------	Trace	Trace	--------	Trace	Trace	--------	Trace	Trace	Trace	--------	Trace	Trace	Trace
Opaque minerals	4	.5	.6	1.7	6	.7	2.2	4	Trace	15	16	2.0	Trace	Trace
Rutile	--------	Trace	--------	Trace	--------	--------	--------	--------	Trace(?)	--------	--------	--------	--------	--------
Zircon	Trace	Trace	Trace	--------	--------	Trace	Trace	--------	Trace	--------	Trace	Trace	Trace	Trace
Apatite	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	Trace	--------	--------
Chlorite	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	Trace	1	--------

[1] Very fine grained.

1. Fine-grained gray micaceous quartzite, south slope of Blue Mountain in SW¼ sec. 16, T. 2S., R. 71 W.
2. Fine-grained quartzite, NW¼SE¼ sec. 15, T. 2S., R. 71 W.
3. Fine-grained quartzite with fine layering, NE¼SE¼ sec. 19, T. 2S., R. 71 W.
4. Very fine grained quartzite with fine layering, SW¼ sec. 14, T. 2S., R. 71 W.
5. Conglomeratic quartzite containing rounded quartzite pebbles, 15 mm in diameter, NE¼NE¼ sec. 20, T. 2S., R. 71 W.
6. White conglomeratic quartzite containing rounded quartzite pebbles, 15 mm in diameter, SW¼ sec. 16, T. 2S., R. 71 W.
7. Fine-grained mica schist from thin layer on ridge in SW¼ sec. 14, T. 2S., R. 71 W.
8. Fine-grained quartz-rich mica schist with fine layering, NE¼SE¼ sec. 19, T.2S., R. 71 W.
9. Fine-grained mica schist containing porphyroblasts of biotite and andalusite, SE¼NE¼ sec. 20, T. 2S., R. 71 W.
10. Mica schist containing porphyroblasts of andalusite, NE¼SE¼ sec. 19, T. 2S., R. 71 W.
11. Knotty schist containing abundant porphyroblasts of andalusite, NW¼ sec. 20, T. 2S., R. 71 W.
12. Very fine grained mica schist containing extremely poikiloblastic porphyroblasts of cordierite, SW¼ sec. 16, T. 2S., R. 71W.
13. Fine-grained garnetiferous mica schist, south slope of Blue Mountain, SW¼ sec. 16, T. 2S., R. 71 W.
14. Garnetiferous mica schist from top of hill northwest of Ralston Creek Ranch, NE¼SE¼ sec. 19, T. 2S., R. 71 W.

planes are commonly folded, and, locally, a slip cleavage parallel or subparallel to the axial planes of tiny crinkles transects the foliation.

The coarser varieties of schist are comparable in grain size and appearance to most of the rock in the mica schist unit, farther south in the district, but the quartzite unit also contains abundant schist of distinctly finer grain. Some geologists have described the fine-grained rocks as phyllites (Lovering and Tweto, 1953, p. 5) or as phyllitic schist (Lovering and Goddard, 1950, p. 73), and in a preliminary report on the Ralston Buttes quadrangle (Sheridan and others, 1958) these rocks were called sericite-quartz phyllite and schist. We have grouped both the finer and the coarser rocks together under the general term "schist," although we recognize that the grain size varies greatly. In general, very fine to fine-grained types predominate, and they occur in alternation with the coarser varieties. Either kind may be porphyroblastic.

The relative proportions of the principal minerals—quartz, muscovite, and biotite—vary widely in the schist. Some parts are very rich in quartz (mode 8, table 14) and are gradational to micaceous quartzite. Interlayered with such rock and also apparently gradational to it along strike are muscovite-rich schists (modes 7 and 10), some of which also contain biotite. In some layers (mode 9) biotite occurs in porphyroblastic plates that transect the schistosity and constitute as much as 23 percent of the rock. Other minerals that occur as porphyroblasts are garnet, andalusite, and cordierite (table 14). Accessory minerals are tourmaline, magnetite-ilmenite, rutile, zircon, apatite, and hematite.

Garnet generally occurs in grains less than 1 mm in diameter that cut across the foliation. Blocky porphyroblasts of andalusite as much as 30 mm long locally form 30–50 percent of the schist and form knotty protuberances on weathered surfaces. Inclusions of magnetite-ilmenite are abundant in the andalusite and give some of it a dark color. J. D. Wells (oral commun., 1959) has found staurolite cores in andalusite porphyroblasts in two samples of schist from the quartzite unit in the Eldorado Springs quadrangle; he also has noted sparse sillimanite needles in the schist.

Very fine grained schist in the upper part of the schist layer on Blue Mountain, in the western part of sec. 16, T. 2 S., R. 71 W., contains cordierite[1] porphyroblasts ¼×¾ inch in size. The porphyroblasts are extremely poikiloblastic and contain muscovite, biotite, quartz, apatite, tourmaline, and minor chlorite. Fine-grained schist below the porphyroblastic rock contains greenish-gray to white calc-silicate lenses, as much as 10 inches thick and 4 feet long, which are megascopically similar to calc-silicate lenses in the large unit of mica schist in the central part of the district. The calc-silicate lenses on Blue Mountain are composed principally of quartz and epidote; they con-

[1] Identification of the cordierite was verified by X-ray methods by E. J. Young, U.S. Geol. Survey (written commun., 1958).

tain 1–5 percent each of hornblende, biotite, tremolite, and garnet, and trace amounts of zircon, apatite, opaque minerals, potassic feldspar, and chlorite. Clay minerals formed from feldspar make up about 4 percent of one sample of the rock.

Physical properties of garnet from fine-grained garnetiferous schist in the lower part of the schist layer on Blue Mountain are shown in table 32 (sample 16).

Optical and X-ray data for two samples of white mica from the schist of the quartzite unit are included in table 33. The X-ray determinations showed that the white mica in these samples is muscovite rather than paragonite.

Evidence of late cataclastic effects is difficult to detect in much of the schist. However, some thin sections contain shredded grains of mica and broken and dislocated grains of andalusite. The movements that produced intense cataclasis in other rocks in the northern part of the quadrangle were evidently taken up by crinkling and interlaminar slippage in the schist.

ORIGIN

The classification of the foliated rocks discussed above as metamorphosed sedimentary and volcanic(?) rocks is necessarily interpretive because deformation and recrystallization have obliterated or greatly modified many of the original features. The interpretation of origin is based on field relations, lithologic character, and, in a few rocks, relict sedimentary features such as pebbles. Throughout the succession, the individual rock units appear to be conformable with one another. The close interlayering, lenticularity, and gradations between some of the rocks are similar to features found in many rocks of known sedimentary origin. The variations in mineralogy and lithology of this succession of metamorphic rocks are believed to reflect primarily the original differences in composition of varied sedimentary and volcanic(?) material.

Most of the rocks are believed to be metasedimentary, but some may be metavolcanic. Perhaps the most definitely metasedimentary are the quartzite unit and the mica schist unit, each of which contains conglomeratic lenses or facies showing relict pebbles. The quartzite unit probably represents original quartz-rich sandstone, and the mica schist unit, interlayered shale and sandy shale. Layered calc-silicate gneiss, which commonly contains calcite and locally grades to impure marble, was probably derived from argillaceous limestone and calcareous shale. Although the microcline gneiss resembles a metamorphosed igneous rock of the composition of quartz monzonite, the absence of discordant contacts and the presence of numerous conformable layers of amphibolite and biotite gneiss within the unit suggest that the microcline gneiss is of metasedimentary origin. Amphibolite, hornblende gneiss, and biotite gneiss in various parts of the succession are also conformable; they contain mineral assemblages that could have been derived from original calcareous and shaly beds or from mafic tuffaceous sediments, volcanic flows, or sills.

Within the mica schist unit, some of the tourmaline-rich rock seems to be areally and genetically related to pegmatites, whereas other concentrations of tourmaline, particularly in quartz-rich schist, are probably the metamorphic product of original sedimentary constituents. Similarly, microcline porphyroblasts in some of the schist may be an additive mineral from nearby pegmatites, but in other parts of the schist these porphyroblasts probably represent recrystallization of the original constituents of sedimentary rocks. Granular lenses of quartz and feldspar in conglomeratic schist may represent granulated fragments or former sandy to arkosic lenses. The lenticular occurrence and mineralogic composition of calc-silicate rocks in the mica schist unit suggest that they were derived by metamorphism of lenses of impure calcareous, argillaceous sandstone, or calcareous siltstone. Metamorphosed lenticular to concretionary rocks of similar composition and zonal structure have been reported from Precambrian schist in the southern Black Hills, S. Dak. (Runner and Hamilton, 1934; Sheridan, 1955, p. 65–66), and elsewhere (Emmons and Laney, 1926, p. 19–21).

The origin of spotted amphibolite is uncertain. Such rock, commonly conformable discontinuous layers and fragmentary exposures in the hornblende gneiss unit and the unit of interlayered gneisses, may represent a textural variety of metamorphosed calcareous sedimentary rocks or metamorphosed volcanic(?) rocks. It is also possible that this rock represents greatly metamorphosed sills of hornblende diorite of the same age or even older than the hornblende diorite and hornblendite mapped in the northeastern part of the district. Although generally resembling the hornblende diorite, the spotted amphibolite appears somewhat less massive; moreover, discordant relations have not been observed along contacts of spotted amphibolite.

The origin of feldspar-quartz gneiss, mapped as a minor subdivision of the layered calc-silicate gneiss at the Ascension mine (pl. 6), is uncertain. Although somewhat similar to microcline gneiss in composition, the feldspar-quartz gneiss has less biotite, and its gneissic foliation is not as pronounced.

CORRELATION AND AGE RELATIONS

This section presents our tentative conclusions concerning stratigraphic correlation and age relations among the Precambrian metamorphosed sedimentary and volcanic(?) rocks of the Ralston Buttes district. These stratigraphic interpretations and some of our structural interpretations discussed on later pages are closely interdependent. A more definitive analysis of Precambrian stratigraphy and structural history will probably not be possible until the detailed geology of more of the east-central Front Range becomes known.

We interpret the symmetrical distribution of lithologic units on each side of the mica schist unit in the southern half of the district (pl. 1) as a repetition due to folding. According to this interpretation, the mica schist unit is the oldest unit in this part of the district. It forms the core of a major anticline that plunges gently west-southwest. Successively younger units on the opposite limbs of the anticline are correlative. The microcline gneiss unit in the west-central part of the district, for example, is thus presumed to be correlative with the west-trending belt of microcline gneiss south of the mica schist unit.

Farther northwest, in the area south of Ralston Creek, the westward thinning of the mica schist and adjacent units is interpreted as stratigraphic lensing (pinching out). The pattern formed by the converging of these units might also be considered to be a repetition by folding, similar to that in the southern part of the district. Unlike the symmetrical pattern in the southern area, however, the pattern here is incomplete, and diversely oriented minor structural features do not provide strong support for a major axial plane. Although we have no conclusive proof for the hypothesis of stratigraphic lensing, the predominant southward dip of foliation in lithologic units near the Drew Hill road (pl. 1) suggests that the northern belt of the hornblende gneiss unit is older than and distinct from the hornblende gneiss unit south of the mica schist. Because the stratigraphy and age relations are uncertain, however, both bodies of hornblende gneiss are shown as parts of the same lithologic map unit.

The quartzite unit is older than the areally associated Precambrian igneous rocks and contains mineralogic and structural features which indicate that it has undergone the same structural and metamorphic history as other metasedimentary and metavolcanic(?) rocks in its vicinity. For these reasons, which are discussed at greater length in another report (Wells and others, 1964), we consider the quartzite unit to be a local facies of the general succession of metasedimentary and metavolcanic(?) rocks of the Ralston Buttes district and adjacent areas, rather than a younger stratigraphic unit as previously described (Van Hise and Leith, 1909, p. 827; Lovering and Goddard, 1950, p. 23).

CATACLASTIC ROCKS

The northeastern part of the Idaho Springs-Ralston shear zone crosses the northern part of the Ralston Buttes district (pl. 1), where it forms a broad zone of cataclastically deformed rocks. The zone includes rocks of two general kinds: (1) sheared but recognizable facies of map units of this report, and (2) rocks so thoroughly sheared, granulated, and recrystallized that the parent materials cannot be specified. Where the parent rocks can be identified, we include the cataclasized facies in our regular map units. Where the parent rocks cannot be identified, as along and near the southeastern margin of the shear zone, we have mapped two cataclastic units: (1) quartz-feldspar cataclastic gneiss and associated rocks, and (2) cataclastic gneisses and associated rocks. The quartz-feldspar cataclastic gneiss was derived from unidentified rocks, but the associated rocks, generally less affected by cataclasis, were derived from metasedimentary and metavolcanic(?) rocks. Part of the first unit is poorly exposed and undivided. The second unit consists of numerous individual zones of cataclastic gneisses together with less abundant rocks similar to those in the adjacent unit of interlayered gneiss and schist.

QUARTZ-FELDSPAR CATACLASTIC GNEISS AND ASSOCIATED ROCKS

The unit characterized by quartz-feldspar cataclastic gneiss marks the southeastern boundary of the Idaho Springs-Ralston shear zone in the Ralston Buttes district (pl. 1). Over most of its extent, the unit lies between the hornblende gneiss and the interlayered gneiss and schist units. Farther northeast, the southeastern margin lies adjacent to the unit of microcline gneiss complexly interlayered with other rocks. To the north, an area of quartz-feldspar cataclastic gneiss was mapped within the interlayered gneiss and schist.

The quartz-feldspar cataclastic gneiss is fine grained and pinkish gray to pink. It is characterized by small white to pink porphyroclasts of feldspars, which commonly range from 0.2 to 2.5 mm in diameter and average about 1 mm. The foliation—produced by cataclasis—is moderately well formed and is most conspicuous in the lighter parts of the rock, where it is commonly expressed by somewhat discontinuous dark laminae, 0.25 mm thick, between lighter laminae, 1–6 mm thick.

The quartz-feldspar cataclastic gneiss is composed principally of quartz, plagioclase, and potassic feldspar, and lesser amounts of biotite, muscovite, and, locally, microantiperthite (table 15). Porphyroclasts of plagioclase, potassic feldspar, and microantiperthite larger than 0. 2mm in size make up 11–22 percent of the rock and are enclosed by a generally fine-grained matrix that contains a few larger grains of opaque minerals and strained quartz. The plagioclase is sodic oligoclase (An_{14}–An_{16}). Some of the plagioclase grains are polysynthetically twinned, whereas others are untwinned. The microantiperthite contains 20–45 percent potassic feldspar, which is commonly elongate parallel to the 010 plane of the plagioclase (An_{17}), although some is irregular and patchy. Gridiron twinning is poorly to well developed. Potassic feldspar also occurs as microcline and in untwinned form both in porphyroclasts and in the fine matrix. Where it is interstitial in the matrix, it appears to vein and embay plagioclase. Some of the potassic feldspar is microperthitic. Garnet occurs locally in grains as large as 0.4 mm. Zircon in one specimen is as large as 0.24 mm and shows zonal growth.

TABLE 15.—*Modes (volume percent) of quartz-feldspar cataclastic gneiss and associated rocks*

	Quartz-feldspar cataclastic gneiss					Associated rocks			
	1	2	3	4	5	6	7	8	9
Field No.	DS-57-9	DS-57-12a	DS-57-12b	RA-371	DS-58-R21	DS-57-11	DS-57-10	DS-57-8	RA-477
Quartz	43	40	41	48	43	0.8	Trace(?)	52	39
Potassic feldspar [1]	17	12	30	5	14			5	2.0
Plagioclase	30	32	19	33	17	38	35	19	42
Microantiperthite				Trace	12			Trace	
Biotite	4	7	3	10	6			21	13
Muscovite	2.3	5	6	Trace	2.5				
Hornblende						56	45		.5
Clinopyroxene							16		
Clinozoisite-epidote	.5	2.0	.8	1.6	2.0	Trace	Trace	1.4	2.8
Apatite	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Garnet			Trace	Trace	Trace				
Zircon	Trace				Trace			Trace	Trace
Sphene		Trace				1.0	.8	Trace	Trace
Opaque minerals	2.6	1.4	Trace	1.9	3	Trace	Trace	1.1	.5
Allanite									Trace
Tourmaline									Trace
Sericite [2]		Trace	Trace	Trace		4	2.4	Trace	Trace
Chlorite	Trace			Trace	Trace				

[1] Term includes microcline, microperthite, and potassic feldspar showing little or no gridiron twinning.
[2] Alteration product of plagioclase; percentages probably include some clay minerals.

1. Topographic saddle in NW¼NE¼ sec 23, T. 2S., R. 71 W.
2. Dark colored variety, ridge in SE¼SE¼ sec. 14, T. 2S., R. 71 W.
3. Light colored variety, from same locality as specimen for mode 2.
4. South of Ralston Creek 0.4 mile northeast of Ralston Creek Ranch in SE¼NE¼ sec. 29, T. 2S., R. 71 W.
5. South of Ralston Creek 0.8 mile southwest of Ralston Creek Ranch in SE¼ sec. 30, T. 2S., R. 71 W.
6. Spotted amphibolite, on ridge in SE¼SE¼ sec. 14, T. 2S., R. 71 W.
7. Layered calc-silicate gneiss, 200 ft. northeast of topographic saddle in S½SE¼ sec. 14, T. 2S., R. 71 W.
8. Catacastically deformed biotite-quartz-plagioclase gneiss, in topographic saddle in NW¼NE¼ sec. 23, T. 2S., R. 71 W.
9. Catacastically deformed dark-gray gneiss containing fine plagioclase porphyroclasts, NE¼SE¼ sec. 14, T. 2S., R. 71 W.

Viewed in thin section the quartz-feldspar cataclastic gneiss shows mortar structure and many subparallel granulated zones that define the foliation. Very fine micas in parallel arrangement and clinozoisite-epidote are abundant in many of the granulated zones and contribute to the color lamination noted megascopically. In detail, many of the granulated zones anastamose around elongate lenses of less deformed material. In some specimens lenticles of very fine grained and intensely sutured quartz are parallel to the granulated zones. Although the texture is dominantly cataclastic, some recrystallization occurred, as shown by textural features of quartz and some micas and interstitial potassic feldspar. The material of the granulated zones was probably never comminuted as finely as in true mylonites (Waters and Campbell, 1935).

The rocks associated with quartz-feldspar cataclastic gneiss as a map subunit include amphibolite, hornblende gneiss, layered calc-silicate gneiss, and biotite gneiss. These rocks are slightly to intensely cataclasized. Modes of four of the rocks are shown in table 15. The specimen of amphibolite (mode 6) is medium grained and moderately well foliated. It has a spotted texture similar to that of amphibolite reported in some of the other map units. The plagioclase is calcic andesine (An_{49}); some of it shows both albite and pericline twinning. The specimen of layered calc-silicate gneiss (mode 7, table 15) is fine to medium grained and consists of greenish-gray and dark-gray to black minerals in alternating layers 2.5–6 mm thick. The mode reported in table 15 is the average for the entire thin section. The modes (volume percent) of light and dark layers are shown below:

	5 dark layers	*4 light layers*
Hornblende	67	6.5
Clinopyroxene	2.6	44
Plagioclase	26	45
Sphene	.7	1.8
Apatite	Trace	Trace
Opaque minerals	.2	Trace
Clinozoisite-epidote	Trace	Trace
Sericite (alteration product of plagioclase)	2.8	2.1

Most of the hornblende seems to have formed contemporaneously with the clinopyroxene, but a small amount probably formed at the expense of clinopyroxene. The plagioclase is calcic andesine (An_{47}). Sphene, in grains as much as 0.2 mm long, is most abundant in the light-colored clinopyroxene-rich layers. Clinozoisite and epidote occur as fine grains between plagioclase and hornblende.

The specimen of cataclastically deformed biotite gneiss (mode 8, table 15) differs from normal biotite gneiss principally in texture and structure. Alternate light and dark layers are not as uniform as the compositional layering in the normal gneiss but are distinctly more lenticular. Dark biotite-rich layers anastamose around light lenses in typical flaser structure. Shearing and cataclasis have destroyed the original foliation and formed a new one. Most biotite flakes are less than 0.2 mm long in the light parts of the rock but as much as 0.6 mm long in the dark parts. Quartz occurs in intensely sheared thin lenses as much as 5 mm long. Twinning in much of the plagioclase is poorly developed or absent. Relative refringence tests suggest that the plagioclase is oligoclase. Gridiron twinning is very poorly developed or absent in most of the potassic feldspar. Microantiperthite occurs sparingly in lenses of relatively undeformed material. It contains less than 25 percent potassic feldspar, which forms patches in the predominant oligoclase (An_{17}). Sphene occurs in small grains associated with biotite and as thin rims on magnetite-ilmenite.

The specimen of cataclastically deformed dark-gray gneiss (mode 9, table 15) contains many small pink to white porphyroclasts of feldspar, which average about 0.6 mm in size and are mostly calcic oligoclase (An_{26}). The thin section shows mortar structure, elongate granulated lenses or zones, and sutured and strained quartz. Biotite shows preferred orientation along the granulated zones. Before cataclasis the rock may have been a somewhat migmatitic biotite gneiss. Rocks of similar appearance form part of the complex succession of cataclastic gneisses farther north.

Although the quartz-feldspar cataclastic gneiss has been so thoroughly reconstituted that the parent rock cannot be specified with certainty, it was presumably derived in large part from one or more of the gneisses described in the preceding section of this report. Part of it may have been derived from microcline gneiss, as suggested by its composition and, in places, its appearance and its association with amphibolite. In composition, the quartz-feldspar cataclastic gneiss could also represent original quartz monzonite, although no quartz monzonite is in contact with it.

CATACLASTIC GNEISSES AND ASSOCIATED ROCKS

Cataclastic gneisses and associated rocks form a central northeast-trending unit within the wide northeastern part of the unit of interlayered biotite gneiss and mica schist (pl. 1). On a preliminary map of the Ralston Buttes quadrangle (Sheridan and others, 1958), the cataclastic gneisses are shown as "granulite," a term we have now abandoned.

The unit consists principally of intensely deformed rocks of undetermined parentage. It is characterized by a light cataclastic gneiss and a dark cataclastic gneiss, among which are interspersed lenses and layers of relatively uncrushed biotite gneiss and mica schist. In general, the light cataclastic gneiss forms the central part of much of the unit, and the dark cataclastic gneiss forms border zones of variable width. Near the western and eastern extremities of the unit, the two varieties of cataclastic gneiss alternate with biotite gneiss and mica schist in layers several feet to several tens of feet thick. Toward the northeast the light cataclastic gneiss grades to a mottled green and pink epidote-bearing rock, and the associated rocks include some light calc-silicate gneiss.

The cataclastic rocks exhibit a foliation caused by granulation and shearing. This foliation is imparted by closely spaced planes of very fine oriented mica flakes separated by quartz- and feldspar-rich lenses and layers. Some of the micaceous granulated zones anastamose around elongate lenses of less deformed rock, in flaser arrangement.

In the associated rocks, such as biotite gneiss, which have been less affected by cataclasis, much of the foliation is identical with the normal foliation in such rocks outside the Idaho Springs-Ralston shear zone. Wherever relict early foliation is recognizable in the cataclastic gneisses, it seems to have the same general trend as the cataclastic foliation, and no markedly discordant relations were observed.

The light cataclastic gneiss is light gray to pinkish gray and fine grained. Poorly foliated parts resemble a massive feldspathic quartzite in overall appearance. Moderately well foliated parts resemble some cataclastically deformed parts of the quartz monzonite. The foliation consists of thin parallel granulated zones about 0.1 mm thick. Between these granulated zones are layers and lenses of relatively less deformed rock, commonly 0.3–1 mm thick, in which the average grain size is about 0.1 mm. Small feldspar porphyroclasts are recognizable only in thin section and are much less abundant than in the dark cataclastic gneiss.

The principal minerals of the light cataclastic gneiss, in order of decreasing abundance, are quartz, potassic feldspar, plagioclase, and muscovite (mode 1, table 16). The quartz grains are commonly strained and sutured. Potassic feldspar occurs in grains ranging in size from 0.02 to 1.4 mm; some of it is interstitial filling in granulated zones. Gridiron twinning is present in some potassic feldspar grains but is absent or only poorly developed in others. Some grains are slightly perthitic. Twinning is only poorly developed or absent in the plagioclase, which by its relative refringence is oligoclase. The microscopic granulated zones in the gneiss contain parallel muscovite and biotite flakes 0.1–0.2 mm long, quartz and feldspar grains generally less than 0.05 mm in diameter, and tiny lenses of epidote-clinozoisite.

TABLE 16.—*Modes (volume percent) of cataclastic gneisses and associated rocks*

	1	2	3	4
Field No.	RA-424C	RA-424B	RA-5441	DS-59-R3B
Quartz	48	34	25	41
Potassic feldspar [1]	27	1.9	-	-
Plagioclase	12	37	Trace (?)	42
Biotite	1.5	22	-	-
Muscovite	8	-	-	-
Hornblende	-	-	-	6
Epidote-clinozoisite	2.1	2.4	[2] 74	[2] 9
Opaque minerals	.9	2.4	Trace	1.5
Sphene	-	Trace	Trace	Trace
Zircon	-	Trace	-	-
Apatite	Trace	Trace	-	Trace
Allanite	Trace	Trace	-	-
Sericite and clay minerals	Trace	Trace	Trace	Trace

[1] Term includes microcline, microperthite, and potassic feldspar showing little or no gridiron twinning.
[2] Predominantly epidote.

1, 2. Light (1) and dark (2) cataclastic gneiss, from ridge in NE¼SW¼ sec. 22, T. 2 S., R. 71 W.
3. Epidote-quartz rock, NW¼SE¼ sec. 14, T. 2 S., R. 71 W.
4. Calc-silicate gneiss, SE¼SW¼ sec. 14, T. 2 S., R. 71 W.

In the northeastern part of the map unit, the light cataclastic gneiss seems to grade into a fine-grained rock showing wavy irregular color banding and mottling in various shades of green, pink, and pinkish gray. One specimen of this rock (mode 3, table 16) consists almost entirely of granoblastic grains of epidote and quartz less than 0.25 mm in diameter. Very fine grained quartz lenses about 0.3 mm thick create a crude layered structure.

The dark cataclastic gneiss is dark gray and consists of a fine-grained biotite-rich matrix enclosing white to pinkish-white porphyroclasts of plagioclase. It differs from the light cataclastic gneiss in being biotite rich and in containing many more small porphyroclasts. Granulated zones that give rise to the foliation anastamose around porphyroclasts and lenses of relatively less deformed rock. A mode of a specimen of the gneiss (mode 2) is shown in table 16. The porphyroclasts are plagioclase (An_{37}) and are mostly about 2 mm in diameter; some are as large as 20 mm. The biotite and quartz grains are mostly about 0.2 mm in diameter in the granulated zones, and as much as 1 mm in the intervening coarser grained lenses. Most of the potassic feldspar is untwinned. Allanite occurs as a core in aggregates of epidote or clinozoisite.

A light calc-silicate gneiss occurs locally in the northeastern part of the unit. A mode of a specimen of this fine-grained grayish to pinkish-white rock (mode 4) is shown in table 16. Quartz grains commonly show strain shadows parallel to the foliation, and plagioclase (An_{30}) occurs in grains showing both albite and pericline twinning as well as in grains devoid of twinning.

IGNEOUS ROCKS

The Precambrian rocks of igneous origin in the Ralston Buttes district (pl. 1) include relatively large bodies mapped as Boulder Creek Granodiorite and as quartz monzonite, smaller bodies of hornblende diorite and associated hornblendite, and minor dikes and sills of hornblende-biotite lamprophyre. In addition, granitic pegmatite, which occurs in numerous bodies, and aplite are probably igneous. Only the larger and more conspicuous pegmatites are shown on the map (pl. 1). The felsic material in migmatitic rocks may have been derived from magmatic material, or it may be metamorphic in origin.

As indicated by discordant relations along their contacts, all the igneous rocks are younger than the metamorphosed sedimentary and volcanic(?) rocks with which they occur, but they were not all intruded at the same time. For reasons discussed in the section "Structural Geology," we believe that the major igneous rocks, including Boulder Creek Granodiorite, quartz monzonite, and hornblende diorite and associated hornblendite, were intruded syntectonically during the second of two early periods of deformation. The hornblende-biotite lamprophyre, although metamorphosed, does not exhibit metamorphic features as pronounced as those of the major igneous rocks and was probably intruded well after the peak of regional metamorphism. Of the larger pegmatites, at least some are clearly younger than the major folding and

239-740-O—67——3

some are younger than the cataclasis that is characteristic of the third period of Precambrian deformation.

The age sequence denoted by the arrangement of Precambrian igneous rocks in the explanation of plate 1 is based partly on structural and textural characteristics and partly on correlations with igneous rocks elsewhere in the Front Range. The Boulder Creek Granodiorite is probably the oldest of the intrusive igneous rocks. It is correlative with the Boulder Creek Granite (Lovering and Goddard, 1950, p. 25–27) and is probably correlative with the granodiorite near Idaho Springs described by Harrison and Wells (1956, p. 53–54; 1959, p. 12–15) and Moench, Harrison, and Sims (1962, p. 38). The bodies of Boulder Creek Granodiorite in the Ralston Buttes district seem to be satellites of the batholith of Boulder Creek Granite and quartz monzonite mapped by Lovering and Goddard (1950, pl. 2) in the region west of Boulder, Colo. Although no evidence of a difference in age between the Boulder Creek Granodiorite and the quartz monzonite has been found in the Ralston Buttes district, J. D. Wells has found that Boulder Creek Granite (the Boulder Creek Granodiorite of this report) occurs as inclusions in quartz monzonite in exposures along South Boulder Creek in the Eldorado Springs quadrangle (Wells and others, 1964). These relations indicate that the Boulder Creek Granodiorite is at least partly older than the quartz monzonite. The age of hornblende diorite and associated hornblendite relative to the Boulder Creek Granodiorite and the quartz monzonite could not be directly observed because the rocks do not occur together. The hornblende diorite and hornblendite, if correlative with the quartz diorite and associated hornblendite in the Chicago Creek area (Harrison and Wells, 1959, p. 4), may be somewhat younger than the Boulder Creek Granodiorite. Although the hornblende-biotite lamprophyre was not observed in contact with other igneous rocks, structural and textural characteristics of the lamprophyre suggest that it is somewhat younger than the principal igneous rocks but older than the larger pegmatites.

BOULDER CREEK GRANODIORITE

Boulder Creek Granodiorite occurs in several areas in the western and northern parts of the Ralston Buttes district (pl. 1). A large body, between Ralston Creek and the crests of Mount Tom and Centralia Mountain, and a smaller body, to the south on the eastern slope of Douglas Mountain, lie within the microcline gneiss unit. Several elongate bodies are associated with quartz monzonite in a northeast-trending belt between the quartzite unit and the unit of interlayered biotite gneiss and mica schist. Farther northeast, a small body of Boulder Creek Granodiorite, which is also associated with quartz monzonite, cuts discordantly across the quartzite unit. Small bodies of Boulder Creek Granodiorite occur within the quartzite unit in secs. 19 and 20, T. 2 S., R. 71 W., and in the interlayered gneiss and schist in sec. 14. A thin sill-like body of the rock occurs in the interlayered gneiss and schist mainly in sec. 29. Small bodies of the relatively fine grained quartz monzonite occur in the Boulder Creek Granodiorite in the northern part of the district, and the reverse relation seems just as common; many of these occurrences are too small to be shown on the map.

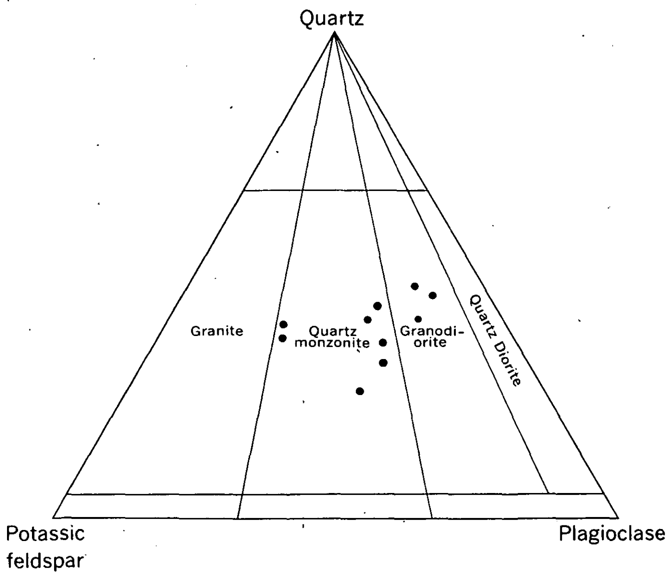

FIGURE 10.—Variations in composition of the Boulder Creek Granodiorite, in volume percent.

Samples of the Boulder Creek Granodiorite studied by modal analysis have a rather wide range in mineralogic composition (fig. 10 and table 17). On a preliminary map (Sheridan and others, 1958) the rock was simply called granodiorite. As shown by detailed petrographic study, however, the average composition of 10 specimens (table 17) is that of quartz monzonite, in which 40 percent of the total feldspar is potassic feldspar. This average is close to the boundary between granodiorite and quartz monzonite, as classified by Grout (1932, p. 50). However, north of the Ralston Buttes district, in the Eldorado Springs quadrangle, Wells (1967) has found that correlative rock forming a significant part of the main batholith has an average composition of granodiorite. For this reason and because other geologists have mapped similar rock in nearby areas of the Front Range as granodiorite (Moench and others, 1962, pl. 1), we have chosen to use the name Boulder Creek Granodiorite rather than the more general name, Boulder Creek Granite.

The contacts between Boulder Creek Granodiorite and adjacent metasedimentary units are concordant in many places but discordant in secs. 14 and 19, T. 2 S., R. 71 W. (pl. 1). The body within the quartzite unit in sec. 20 lies in the trough of a syncline in the structural position of a phacolith. Detailed studies of the contacts of Boulder Creek Granodiorite with interlayered gneiss and schist and with quartz monzonite in the northern part of the district are hampered by the masking effects of the cataclastic deformation which modified most of the rocks in that area. In general, the trend of elongate bodies of Boulder Creek Granodiorite in this northern area is approximately parallel to the trend of folds in nearby metasedimentary units.

Wherever it has not been cataclastically deformed, the Boulder Creek Granodiorite has a somewhat irregular foliation formed by planar parallelism of biotite flakes and elongate biotite-rich aggregates alternating with quartz- and feldspar-rich aggregates. In most places the orientation of this foliation appears to be similar to the trend of foliation and layering in nearby folded metasedimentary units. Similarly, linear features related to this foliation, though seldom visible, seem to have the same trends as the linear elements in the metasedimentary rocks.

Where the Boulder Creek Granodiorite has been cataclastically deformed, as in the northern part of the district, the earlier biotitic foliation is greatly modified, and the only recognizable foliation is commonly that which was formed by intense shearing. Although this relatively late foliation also has a micaceous planar parallelism, the micas are much finer grained than those forming the early foliation. In most of the area, the cataclastic foliation appears to be almost parallel to the early foliation, but it transects the early foliation locally.

The Boulder Creek Granodiorite is gray and has a mottled black and white appearance. Most of it is medium grained, but locally parts are coarse grained. It is principally equigranular in the west-central and southwestern parts of the district but is characterized by abundant prominent phenocrysts in most of the area north of Ralston Creek. Where the rock has been cataclastically deformed, the original porphyritic texture is modified, and where intensely cataclasized, the porphyritic rock is changed to an augen and flaser gneiss.

The Boulder Creek Granodiorite varies widely in composition; the quartz content ranges from 24 to 44 percent, potassic feldspar from 8 to 36 percent, plagioclase from 18 to 39 percent, and biotite from 0.6 to 12 percent (table 17). The proportion of potassic feldspar ranges from as little as 18 percent of the total feldspar to as much as 65 percent. Seven of the specimens (modes 1–7) have the composition of quartz monzonite, and three (modes 8–10) have the composition of granodiorite. Accessory minerals are muscovite, apatite, magnetite-ilmenite, clinozoisite-epidote, hornblende, zircon, sphene, allanite, hematite, leucoxene, and chlorite.

TABLE 17.—*Modes (volume percent) of Boulder Creek Granodiorite*

	1	2	3	4	5	6	7	8	9	10	Average mineralogic composition of 10 specimens
Field No.	RA-399	DS-58-R7	DS-55-6	RA-555A	RA-395C	RA-551	RA-388	RA-306	RA-303b	RA-395B	
Quartz	33	34	24	35	27	31	39	36	44	38	34
Potassic feldspar[1]	36	34	29	20	23	20	18	13	11	8	21
Plagioclase	19	[2] 18	37	30	37	34	31	39	37	37	32
Biotite	4	12	7	11	10	7	9	7	7	.6	7.5
Muscovite	2.9	1.5	1.7	1.3	1.8	2.8	----------	----------	Trace	5	1.7
Hornblende	----------	----------	----------	----------	----------	----------	----------	2.0	----------	----------	Trace
Clinozoisite-epidote	1.3	Trace	Trace	1.5	Trace	3	.8	1.8	Trace	1.7	1.1
Apatite	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Opaque minerals	.7	Trace	.8	.7	1.1	1.0	.9	.8	Trace	2.4	.9
Zircon	----------	----------	Trace	Trace	Trace	----------	Trace	----------	----------	----------	Trace
Sphene	.6	----------	----------	Trace	----------	----------	----------	Trace	----------	Trace	Trace
Allanite	Trace	----------	----------	----------	----------	----------	Trace	----------	Trace	.6	Trace
Chlorite	2.2	Trace	Trace	Trace	Trace	.6	1.1	----------	----------	.6	1.0

[1] Term includes microcline, potassic feldspar showing little or no gridiron twinning, and microperthite.
[2] Percentage includes a small amount of microantiperthite.

1. Quartz monzonite from north side of Ralston Creek 0.85 mile west of Ralston Creek Ranch in NW¼SE¼ sec. 30, T. 2 S., R. 71 W.
2. Quartz monzonite from body of Boulder Creek Granodiorite within quartzite unit northeast of Deer Creek in SE¼NW¼ sec. 20, T. 2 S., R. 71 W.
3. Quartz monzonite from area where trail crosses low ridge in SW¼SW¼ sec. 15, T. 2 S., R. 71 W.
4. Quartz monzonite from small valley near western boundary of NW¼NW¼ sec. 22, T. 2 S., R. 71 W.
5. Quartz monzonite from knob (alt., 8,236 ft) on south flank of Blue Mountain in center of W½NE¼ sec. 21, T. 2 S., R. 71 W.
6. Quartz monzonite from north side of small knob in N½SW¼ sec. 14, T. 2 S., R. 71 W.
7. Quartz monzonite from north side of Ralston Creek 0.7 mile west of Ralston Creek Ranch in NE¼SE¼ sec. 30, T. 2 S., R. 71 W.
8. Granodiorite from knob 0.6 mile south of Ralston Creek Ranch in NE¼NW¼ sec. 32, T. 2 S., R. 71 W.
9. Granodiorite from northern knob (alt. 9,714 ft) of Centralia Mountain in SE¼SE¼ sec. 31, T. 2 S., R. 71 W.
10. Granodiorite from knob (alt. 8,236 ft) on south flank of Blue Mountain in center of W½NE¼ sec. 21, T. 2 S., R. 71 W.

The potassic feldspar occurs as microcline, microperthite, and grains that are not certainly identified as to species. Some grains show well-defined polysynthetic gridiron twinning, and others show twinning only at one end; still others are completely devoid of gridiron twinning. Although many of the grains are definitely microcline, whether the untwinned grains are actually common orthoclase or whether they represent some gradational type of feldspar is unknown. Some of the phenocrysts and porphyroclastic augen also show Carlsbad twinning. The phenocrysts commonly range in length from 5 to 25 mm, but smaller grains are also common. Many of the phenocrysts and smaller grains are actually porphyroclastic augen showing mortar structure in various degrees. In the intensely cataclasized rocks, potassic feldspar occurs both as porphyroclastic remnants and as very fine stringers and irregular grains, 0.02–0.5 mm thick, filling the interstices between very fine grains of quartz and feldspar in granulated zones. Microperthite is apparently more abundant in the more intensely cataclasized parts of the rock and generally has little or no gridiron twinning. A small amount of microantiperthite was detected in one thin section.

The plagioclase in the Boulder Creek Granodiorite is oligoclase-andesine. Most of the specimens range from An_{25} to An_{35} in composition. In the specimen of mode 2 (table 17), however, the plagioclase is sodic oligoclase (An_{15}). Although plagioclase forms phenocrysts in much of the rock, these are generally smaller than those of potassic feldspar. In the cataclasized rocks, plagioclase grains in granulated zones are commonly less than 0.1 mm across, and in the intervening coarser layers, commonly less than 1 mm across, although plagioclase also occurs in larger aggregates or porphyroclasts. Polysynthetic twinning is generally very poorly developed in the plagioclase of most of the specimens studied, and in some of the most deformed specimens the plagioclase is almost devoid of such twinning. Vermicular intergrowths of plagioclase and quartz embay some of the grains of potassic feldspar.

Biotite and muscovite occur in a wide range of sizes —from less than 0.1 mm to several millimeters in length. Much of the finer mica occurs in the more intensely cataclasized rocks. In such rocks the mica grains show preferred orientation along granulated zones and, though smaller than mica grains in relatively undeformed rock, are mostly undeformed and larger than the very fine grains of quartz and feldspar in the granulated zones. In some specimens undeformed muscovite cuts biotite; this suggests that some or all of the muscovite may be younger than the biotite.

Sphene occurs as individual grains and as rims on magnetite-ilmenite. Apatite, allanite, and zircon occur as scattered individual grains. Several allanite grains have rims of epidote. Clinozoisite-epidote and chlorite are concentrated principally in the thin granulated zones in the cataclastically deformed rocks.

Thin sections of Boulder Creek Granodiorite unaffected or only slightly affected by cataclasis show a granular texture modified by an apparent segregation of biotite, epidote, hornblende, and magnetite-ilmenite in elongate aggregates interstitial to coarser grained quartz-feldspar aggregates. Intensely cataclasized rocks have pronounced mortar structure, porphyroclasts, augen, and thin anastamosing subparallel zones of granulated and partly recrystallized minerals.

QUARTZ MONZONITE

Quartz monzonite crops out in the northwestern and north-central parts of the Ralston Buttes district, where it makes up most of the rock adjacent to the quartzite unit (pl. 1). Southeast of the quartzite unit, quartz monzonite and elongate bodies of Boulder Creek Granodiorite form a northeast-trending belt as much as 4,000 feet wide. The quartz monzonite contains a long tabular inclusion or roof pendant of quartzite in the NE¼ sec. 19, T. 2 S., R. 71 W., and a smaller inclusion of quartzite in the SE¼ sec. 15.

The preliminary map of the Ralston Buttes quadrangle (Sheridan and others, 1958) shows the rock now designated as quartz monzonite as a cataclastically deformed variety of microcline gneiss, for at that time it was thought to be conformable with the quartzite unit. J. D. Wells' studies (1958, oral commun.) in the Eldorado Springs quadrangle have indicated that the rock is of igneous origin. Wells' evidence is: (1) The consistent association of the quartz monzonite with Boulder Creek Granodiorite, (2) inclusions of quartzite in the quartz monzonite and discordant relations with quartzite, and (3) inclusions of Boulder Creek Granodiorite in the quartz monzonite.

The igneous origin of the quartz monzonite is also supported by data obtained during more detailed mapping of the northern part of the Ralston Buttes district in 1958. Discordant relations between the quartz monzonite and the quartzite unit constitute the most compelling evidence. Quartz monzonite and Boulder Creek Granodiorite cut across the quartzite unit in the SW¼ sec. 14, T. 2 S., R. 71 W., and separate a small part of the quartzite unit from the main body (pl. 1). Low angle discordance was found near the boundary of secs. 16 and 21, where a schist layer in the quartzite unit is cut off by the quartz monzonite.

From there the contact extends northeastward subparallel to a stratigraphically higher layer of schist.

The quartz monzonite contains bodies of Boulder Creek Granodiorite that are shown on the map (pl. 1) and also many too small to be shown. Similarly, small bodies of quartz monzonite occur in the Boulder Creek Granodiorite. The contacts between the two igneous rocks are generally not sharply defined in the Ralston Buttes district because both rocks have been modified considerably by cataclastic deformation in the Idaho Springs–Ralston shear zone.

Two types of foliation have been recognized in the quartz monzonite. An early foliation, characteristic of those parts of the rock that have been least affected by cataclasis, is caused by the planar parallelism of biotite flakes. A later foliation, conspicuous in the cataclasized parts of the rock, is related to granulation and shearing; although biotite and muscovite show preferred orientation along the late foliation planes, these micas are very fine grained and are generally visible only under a hand lens or in thin section. Although the early foliation is locally transected by the late foliation, few exposures show the two types together. Where they do occur together, they are commonly parallel or subparallel. This general parallelism suggests that the foliation in many of the exposures of quartz monzonite is actually a combination of the two types, in which the early foliation was presumably modified by granulation and shearing along or subparallel to it during the cataclastic deformation. These planar structural features are generally similar in attitude to the foliation in adjacent metasedimentary rocks.

The quartz monzonite is gray to pinkish gray and fine to medium grained; it commonly weathers reddish tan or grayish tan. Parts of the rock that contain

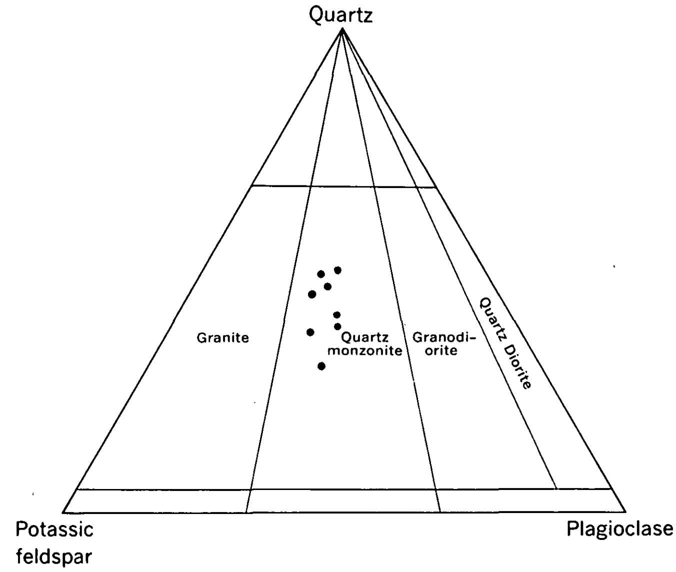

FIGURE 11.—Variations in composition of the quartz monzonite, in volume percent.

abundant porphyroclasts of feldspars may represent original porphyritic phases. Where least deformed by cataclasis the rock generally resembles the more leucocratic varieties of microcline gneiss, but the biotitic foliation is less regular. Where highly deformed by cataclasis the quartz monzonite has become cataclastic gneiss and flaser gneiss, which in some places is difficult to distinguish from intensely deformed Boulder Creek Granodiorite.

The quartz monzonite consists chiefly of quartz, potassic feldspar, and plagioclase, and less abundant biotite and muscovite (table 18); the relative proportions of quartz, potassic feldspar, and plagioclase are shown in the triangular diagram (fig. 11). Quartz ranges from 30 to 45 percent, potassic feldspar from

TABLE 18.—*Modes (volume percent) of quartz monzonite*

	1	2	3	4	5	6	7	8	Average mineralogic composition of 8 specimens
Field No.	DS-57-5	RA-395D	RA-394	RA-377	RA-383A	RA-566B	RA-575	RA-382	
Quartz	40	36	43	30	43	36	34	45	38
Potassic feldspar [1]	29	36	26	35	26	28	28	23	29
Plagioclase	20	25	19	29	22	24	26	22	23
Biotite	9	.6	6	3	5	5	3	8	5
Muscovite	1.5	1.0	4	2.8	3	5	4	1.7	2.9
Apatite	Trace	------	Trace	------	------	Trace	Trace	Trace	Trace
Opaque minerals	Trace	.6	1.6	Trace	.6	1.7	Trace	Trace	.6
Clinozoisite-epidote	Trace	.7	------	Trace	------	------	4	Trace	.6
Zircon	Trace	------	Trace	------	------	------	------	------	Trace
Sphene	------	------	------	------	------	------	------	Trace	Trace
Chlorite	------	------	------	------	------	------	Trace	------	Trace

[1] Term includes microcline, potassic feldspar showing little or no gridiron twinning, and microperthite.

SAMPLED LOCALITIES

1. South flank of ridge near north boundary of NW¼NE¼ sec. 19, T. 2 S., R. 71 W.
2. Saddle north of the knob (labeled with alt. 8,236 ft) in NW¼NE¼ sec. 21, T. 2 S., R. 71 W.
3. Near contact with quartzite unit in SE¼SW¼ sec. 16, T. 2 S., R. 71 W.
4. Near contact with quartzite unit in SW¼SW¼ sec. 17, T. 2 S., R. 71 W.
5. Knob 300 ft south of contact with quartzite unit in SE¼SE¼ sec. 19, T. 2 S., R. 71 W.
6. 350 ft south of road and 400 ft east of small valley in NW¼SE¼ sec. 15, T. 2 S., R. 71 W.
7. Area between northeast-trending noses of body of granodiorite-quartz monzonite in NE¼NW¼ sec. 21, T. 2 S., R. 71 W.
8. Midway between Deer Creek and Nott Creek in the center of S½SW¼ sec. 20 T. 2 S., R. 71 W.

23 to 36 percent, and plagioclase (oligoclase-andesine) from 19 to 29 percent. Potassic feldspar comprises 51–59 percent of the total feldspar, and all the samples fall within the range cited by Grout (1932, p. 50) for quartz monzonite. Biotite commonly forms about 5 percent of the rock but ranges from 0.6 to 9 percent. Muscovite is somewhat less abundant but forms as much as 5 percent of one specimen. Accessory minerals are apatite, magnetite-ilmenite, zircon, sphene, hematite, clinozoisite-epidote, and leucoxene. Chlorite is present in small amounts in one specimen.

Potassic feldspar occurs in grains generally ranging in size from 0.05 to 3 mm. The smaller grains occur in granulated zones, and the larger grains are porphyroclasts. Like the potassic feldspar in the Boulder Creek Granodiorite, it shows various degrees of development of gridiron twinning and microperthite, depending in part on the degree of cataclasis. In relatively undeformed quartz monzonite, most grains are twinned, but in the cataclasized varieties many of the grains are devoid of gridiron twinning or are twinned asymmetrically at one end of the grain. Although the well-twinned grains are certainly microcline, the poorly twinned and untwinned grains are not certainly identifiable as to species. Whereas fine film perthite is present in the grains in most of the specimens, vein perthite is more abundant in the untwinned or poorly twinned grains. In thin sections of some of the most intensely cataclasized rocks, some of the potassic feldspar appears to vein and embay plagioclase.

Plagioclase in the quartz monzonite ranges in size from 0.02 mm in very finely granulated zones to 2 mm in porphyroclasts. The plagioclase is in the oligoclase-andesine range (An_{18}–An_{32}); in most of the specimens it is calcic oligoclase (An_{22}–An_{30}). Polysynthetic twinning, exhibited by some grains in the less deformed rocks, is poorly developed in most specimens, and in the most intensely cataclasized rocks many of the grains are completely devoid of twinning. In contrast with the potassic feldspar, which is generally fresh and unaltered, many of the plagioclase grains are partly altered to fine-grained sericite and clay minerals; these alteration products are not reported as separate minerals in the modes. Locally, vermicular aggregates of plagioclase and quartz embay potassic feldspar.

Biotite and muscovite occur in grains ranging from 0.02 to 1 mm in size. The two micas are commonly associated, and some of the muscovite flakes seem to have formed at the expense of biotite. Muscovite appears to be of greater abundance in the more intensely cataclasized rocks. Some of the larger mica plates are bent, crinkled, and sheared. In some thin sections granulated zones contain grains of biotite and muscovite, generally 0.1 mm or less in size, which show preferred planar orientation along these zones. Although such mica flakes are smaller than some of those in the relatively less deformed parts of the rock, they are commonly larger than the adjacent fine grains of quartz and feldspars in the granulated zones.

Zircon, apatite, sphene, and the opaque minerals occur as scattered grains. Clinozoisite and epidote occur as interstitial aggregates with biotite and muscovite and, in some specimens, appear to be concentrated in or along granulated zones that comprise planes of intense shearing.

Most thin sections of the quartz monzonite show some cataclastic deformation. Some sections show only mortar structure, but others show both mortar structure and thin subparallel granulated zones. Granulation in some sections is so intense that original texture is largely obliterated; such intensely sheared rocks are actually forms of flaser gneiss and finely porphyroclastic gneiss in which small porphyroclasts and lenticles of partly granulated minerals or aggregates of minerals occur in a more intensely granulated matrix. Part of the matrix probably consists of recrystallized material, although the amount of such recrystallization is difficult to establish. Sutured boundaries of fine quartz grains, the preferred orientation of micas which are larger and less deformed than the accompanying quartz and feldspar grains in granulated zones, and the local presence of late potassic feldspar all suggest some recrystallization.

HORNBLENDE DIORITE AND HORNBLENDITE

Hornblende diorite and minor associated hornblendite crop out in the northeastern part of the Precambrian terrane in the Ralston Buttes district (pl. 1). The largest body, entirely hornblende diorite, trends north-northeast a distance of 2,700 feet, and a thin irregular dikelike body extends northwestward from it. Smaller bodies of hornblende diorite and associated hornblendite are crescent shaped to dikelike in plan. All the bodies of hornblende diorite and hornblendite occur within the unit consisting of microcline gneiss complexly interlayered with other rocks.

The hornblende diorite and hornblendite are classified as intrusive igneous rocks on the basis of the apparent discordance shown by the largest body (pl. 1) and its dikelike protuberance. This body appears to cut across the general trend of the compositional layering in the adjacent rocks along part of the eastern contact and across several minor folds in the northwestern part. The rocks in all these bodies closely resemble the foliated varieties of quartz diorite and associated hornblendite described by Harrison and Wells (1956, p. 45–48; 1959, p. 15–17) in the Freeland-Lamartine district and Chicago Creek area near Idaho Springs and, like those rocks, are characterized by complexly twinned plagioclase. Turner (1951, p. 583, 585) noted that the plagioclase of amphibolites of igneous origin tends to be complexly twinned in contrast with the simple twinning of plagioclase in schists and hornfels.

The foregoing evidence strongly suggests an igneous origin; however, the hornblende diorite and hornblendite are foliated, have metamorphic textures in thin section, and closely resemble spotted amphibolites which have been included as parts of various metasedimentary units in the Ralston Buttes district. The distinction is primarily structural; bodies mapped as hornblende diorite and hornblendite show discordant relations, and those mapped as components of the metasedimentary-metavolcanic(?) gneisses are concordant.

The hornblende diorite is mottled black and pale gray and is fine to coarse grained. Some of the rock is rather poorly foliated and consists of large black grains of hornblende, commonly 5–20 mm long, in a fine- to medium-grained matrix of plagioclase and hornblende. Much of the rock, however, is moderately well foliated, and hornblende grains 5–10 mm long as well as smaller ones are alined along the foliation planes. Such rock resembles a hornblende gneiss or the previously discussed spotted amphibolite. The spots are large grains of hornblende. In weathered outcrops they are conspicuous against the plagioclase, which is whiter and provides a stronger color contrast than the pale-grayish plagioclase in the fresh rock. The foliation in parts of the hornblende diorite appears to be oriented parallel to the foliation in the adjacent sequence of metasedimentary and metavolcanic(?) rocks. Furthermore, the lineation formed by the alinement of hornblende grains is oriented similarly to mineral alinement in the adjacent rocks.

The hornblende diorite consists principally of hornblende and plagioclase in varying proportions (table 19). Accessory minerals are biotite, apatite, magnetite-ilmenite, rutile, and sphene. Chlorite and sericite occur as alteration products.

Plagioclase grains (An_{51}) are subhedral and mostly about 0.5 mm across, although they range from 0.1 to 1.5 mm. Sharply defined albite and pericline twinning is characteristic, and many grains show both types of twinning. The plagioclase is generally partly altered to very fine grained material consisting of sericite, minerals of the epidote group, and probably clay minerals.

TABLE 19.—*Modes (volume percent) of hornblende diorite and hornblendite*

	Hornblende diorite		Hornblendite	
	1	2	3	4
Field No.	DS-57-15	DS-57-16	DS-57-1	DS-57-7a
Hornblende	38	36	90	96
Plagioclase	58	63	Trace	Trace
Biotite	.5	Trace	----------	Trace
Apatite	Trace	Trace	Trace	Trace
Opaque minerals	Trace	Trace	.5	.5
Rutile	----------	Trace	----------	----------
Sphene	----------	Trace	----------	----------
Chlorite	.5	Trace	9	----------
Sericite [1]	2.3	Trace	----------	3

[1] Alteration product of plagioclase; percentages probably include some clay minerals and minerals of epidote group.

SAMPLED LOCALITIES

1. East-central part of largest body (250 ft northeast of old quarry) in NW¼NE¼ sec. 24, T. 2 S., R. 71 W.
2. Old quarry in NW¼NE¼ sec. 24, T. 2 S., R. 71 W.
3. Crescent-shaped body, SE¼NE¼ sec. 23, T. 2 S., R. 71 W.
4. Same body as specimen for mode 3, but in SW¼NW¼ sec. 24, T. 2 S., R. 71 W.

Hornblende grains range in length from 0.1 to 20 mm. Most of the grains are subhedral to euhedral and only moderately poikilitic. The hornblende is partly altered locally to chlorite.

Biotite, the most abundant of the minor minerals in the hornblende diorite, occurs as aggregates seemingly contemporaneous with hornblende, but some grains along cleavages in the hornblende may represent an alteration of hornblende. Magnetite-ilmenite, in grains ranging in size from 0.04 to 0.14 mm, occurs largely in or associated with hornblende. Other accessory minerals are apatite in grains as much as 0.25 mm long, sphene, partly coated with leucoxene, and rutile.

Hornblendite, associated with some of the smaller bodies of hornblende diorite, is black to greenish black, medium to coarse grained, and poorly to moderately foliated. It consists predominantly of hornblende (table 19), grains of which range in length from 0.1 to 6 mm. Accessory minerals are plagioclase, biotite, apatite, magnetite-ilmenite, hematite, and leucoxene.

HORNBLENDE-BIOTITE LAMPROPHYRE

Hornblende-biotite lamprophyre occurs as sparse widely scattered small dikes and sills. The two longest dikes trend east (pl. 1) in the W½ sec. 29, T. 3 S., R. 70 W., and are continuous with dikes mapped as biotite syenite in the Golden quadrangle (Van Horn, 1957). The total length of the northernmost of these dikes in the two quadrangles is 5,300 feet, and of the southernmost, 4,500 feet. The dikes terminate at the unconformity at the base of the Fountain Formation, of Pennsylvanian and Permian age, in the Golden quadrangle (Van Horn, 1957). A hook-shaped dike about 800 feet long is present in the NW¼ sec. 21, T. 3 S., R. 71 W., and other smaller bodies are scattered through the same township. Although the exposed thickness of some of these intrusive bodies is as much as 25 feet, most are less than 15 feet thick and can be traced for only short distances along strike.

Some of these intrusive bodies are concordant with the enclosing schists and gneisses, but others are discordant. In several of the outcrops there are rounded inclusions, as much as 3 inches in diameter, of a fine- to medium-grained quartz-feldspar rock.

In most exposures the lamprophyre is rather mafic and inequigranular and contains subhedral grains of hornblende and biotite 1–5 mm long in a gray finer grained matrix. Thin sections of specimens from several of the bodies contain 40–60 percent microcline, 20–35 percent hornblende, and 11–25 percent biotite. Plagioclase (albite) forms 5 percent or less of these sections. Quartz is absent in most of the sections but forms 15 percent of a thin section from the exposure in sec. 11, T. 3 S., R. 71 W., which also contains untwinned alkali feldspar. In several thin sections small irregular relicts of an unidentified pyroxene were noted within hornblende grains. The accessory minerals epidote, sphene, apatite, allanite, and zircon are rather abundant and together constitute 3–10 percent of the rock. Hornblende and biotite, which are commonly altered slightly to oxyhornblende and oxybiotite, form irregular aggregates of ragged grains in a granular matrix composed predominantly of microcline. Some of the rocks have a fair preferred orientation of the hornblende and biotite. The textures are not typically igneous but suggest instead partial metamorphism of porphyritic lamprophyre. One dike in the SE¼ sec. 16, T. 3 S., R. 71 W., too small to be shown on the map, consists of foliated aggregates of hornblende and biotite in a matrix of fine muscovite and quartz; this rock may have originally contained microcline, which was later altered to muscovite and quartz.

The petrography of the long dikes in sec. 29, T. 3 S., R. 70 W., was not studied for this report. The dikes were correlated with the other exposures of hornblende-biotite lamprophyre on the basis of megascopically similar appearance and texture. They may represent a phase poor in potassic feldspar because as reported by Van Horn (1957), their eastward extensions in the Golden quadrangle are composed principally of biotite and plagioclase and contain very small amounts of quartz.

The radioactivity of some of the lamprophyre dikes and sills is two to three times that of the enclosing gneisses and schists. This abnormally high radioactivity is probably caused by zircon and allanite present in concentrations totaling several percent in parts of the rock. Although the abnormal radioactivity suggests a relation to the radioactive dikes of Tertiary age in the central Front Range (Phair, 1952, p. 4; Sims and others, 1955, p. 8; Wells, 1960), the lamprophyre dikes and sills are of pre-Pennsylvanian age and very likely Precambrian, as suggested by structural, lithologic, and textural features.

GRANITIC PEGMATITE AND APLITE

Pegmatite of granitic composition occurs in numerous dikelike, lenticular, and irregularly shaped bodies in the Precambrian rocks of the Ralston Buttes district. Only the larger ones are shown on plate 1. Although pegmatites were observed in nearly all the major Precambrian rock units, they are particularly abundant in the mica schist unit. Dikes and sills of aplitic material, not shown on the map, are generally small and much less abundant. Other pegmatitic and aplitic material of granitic composition occurs locally as thin concordant seams along the foliation of the schists and gneisses.

Many of the pegmatites occur as rather regular tabular bodies that cut across the layering and foliation of the folded metamorphic rocks; these pegmatites are clearly later than the folding and are probably later than the peak of regional metamorphism. Some of the more irregular pegmatites are clearly concordant, and their age relationship to the folding and metamorphism is not as clear. On the other hand, the very thin concordant seams of pegmatite may be much older than most of the large pegmatites because such seams are commonly contorted and folded as complexly as the rocks with which they are finely interlaminated.

The pegmatites range in size from small lenses, dikes, and sills less than a foot thick to large irregular bodies 500 feet thick. Several dikes are 3,000–4,000 feet long (pl. 1). Some of the pegmatites have a reticulate pattern that suggests emplacement along intersecting fractures or joints; others are branching to sinuous in pattern. Some of the bodies are completely discordant with the host gneisses and schists; others appear to be concordant or sill-like in gross outline but, in detail, have discordant apophyses along the contacts. Large irregular masses of pegmatite are particularly abundant north of Golden Gate Canyon and south of Centralia Mountain. The pegmatite masses shown in these areas contain septa and inclusions of gneiss or schist which are too small to be delineated at the scale of the map.

The pegmatites are composed principally of quartz and microcline, commonly perthitic, and contain lesser amounts of plagioclase, biotite, muscovite, and tourmaline. Locally the pegmatites contain beryl, crysoberyl, apatite, magnetite-ilmenite, garnet, allanite, monazite, triplite, sillimanite, and an unidentified violet-blue mineral containing iron and phosphate. A pegmatite prospect in the SE¼ sec. 30, T. 2 S., R. 71 W., contains material of abnormal radioactivity which may be associated with rare-earth-bearing minerals. A prospect pit in the NW¼ sec. 28, T. 3 S., R. 71 W., contains rare-earth-bearing garnet and xenotime in an inclusion of amphibolitic rock in pegmatite (J. W. Adams, oral commun., 1961).

A sample of brown garnet from a pegmatite in mica schist from the S½ sec. 15, T. 3 S., R. 71 W., examined by E. J. Young of the U.S. Geological Survey, is probably mainly spessartite-almandite on the basis of the following properties: Refractive index, 1.795 ± 0.005; average specific gravity, 4.12; unit cell dimension (a_0), 11.592 ± 0.002; and, as determined with the visual arc spectroscope, dominant manganese and iron and a small amount of calcium and magnesium. A dark-brown mineral from pegmatite float in the SW¼ sec. 3, T. 3 S., R. 71 W., was identified as triplite by Young, using the X-ray diffractometer. The properties of the triplite include: Specific gravity, 3.80 ± 0.05; refractive indices, $n_x = 1.668 \pm 0.005$, $n_y = 1.676 \pm 0.005$, and $n_z = 1.688 \pm 0.005$. Prisms of pale-green apatite from a muscovite-bearing pegmatite in the center of sec. 10, T. 3 S., R. 71 W., were identified by Young as fluorapatite, on the basis of refractive indices ($n_e = 1.633 \pm 0.002$; $n_o = 1.637 \pm 0.002$).

Most of the pegmatites in the Ralston Buttes district show only a crude zoning. Podlike aggregates of relatively coarse quartz and microcline or of quartz, muscovite, and accessory minerals such as beryl are irregularly distributed in a matrix of finer grained feldspar-quartz pegmatite. Some of the larger pegmatites which have been prospected or mined show two or three lithologic and structural zones.

Scrap mica, feldspar, and beryl have been produced sporadically from some of the larger pegmatites in the Ralston Buttes district, but large-scale mining of pegmatites was not in progress during the time of this investigation. The locations of many of the pegmatite mines and prospects are shown on plate 1. Detailed investigation of individual pegmatites was beyond the scope of the present investigation, but descriptions of some of the pegmatites in this district are included in reports by Hanley, Heinrich, and Page (1950, p. 85–87), Waldschmidt and Gaines (1939), and Waldschmidt and Adams (1942).

Ball (in Spurr and Garrey, 1908, p. 86) and Lovering and Goddard (1950, p. 29) noted that the mineral composition of many of the pegmatites in the Front Range is closely related to that of the Precambrian host rock. Similar relations were noted in the Ralston Buttes district, where pegmatites in mica schist commonly contain muscovite and, rarely, sillimanite, whereas pegmatites in amphibolite, hornblende gneiss, or biotite gneiss commonly have biotite but little or no muscovite. Exceptions to this generalization are found, however, and the other constituent minerals of the pegmatites show no consistent relations to the host rock.

The discordant contacts of many of the larger pegmatites and the altered rock, containing abundant tourmaline and muscovite adjacent to some of the pegmatites, suggest an intrusive origin rather than processes of metamorphic differentiation. The apparent mineralogic relations between certain pegmatites and their host rock might then be simply the effect of contamination of the original pegmatite fluid by constituents of the host rock. The pegmatites in the Ralston Buttes district resemble those of other parts of the Front Range both in their widespread distribution and in mineralogy and structure. The larger pegmatites are believed to be genetically related to Precambrian granitic rocks of the Front Range. The fact that many of the larger pegmatites appear to postdate the major folding suggests that they may be related to the Silver Plume Granite (Lovering and Goddard, 1950, p. 28) or biotite-muscovite granite (Harrison and Wells, 1956, p. 54–56; 1959, p. 17–20). Many of the larger pegmatites shown in the Idaho Springs–Ralston shear zone (pl. 1) do not appear to be sheared, although some of the small pegmatite lenses are. The larger bodies may thus be younger than the cataclastic deformation that characterizes the shear zone, but because they were not studied petrographically, we cannot be certain that they are entirely devoid of cataclastic features.

In addition to its occurrence in pegmatites and small aplites, quartzo-feldspathic material also occurs intimately interlayered with the Precambrian schists and gneisses. Such material, which ranges in texture from aplitic to pegmatitic, occurs as conformable lenses or seams along the foliation of the schist or gneiss. Individual seams or lenses are commonly less than 1 inch thick, although a few reach several inches. Such mixed rocks, composed of schist or gneiss and varying amounts of quartzo-feldspathic material, are similar to the injection gneiss of Bastin (Bastin and Hill, 1917, p. 29) and Lovering and Goddard (1950, p. 20), and to the migmatite of Harrison and Wells (1956, p. 49–50).

In the Ralston Buttes district there are no persistent belts or large bodies of migmatite as described by Harrison and Wells elsewhere in the Front Range. Instead, the proportion of finely interlayered quartzo-feldspathic material to schist or gneiss varies greatly from one outcrop to another. For this reason, and partly because the mapping scale is much smaller than that used by Harrison and Wells, it was impracticable to delineate the local small areas of migmatite as a separate map unit. Mineralogically, the quartzo-feldspathic material in the mixed rocks is dominantly quartz, plagioclase, and microcline. The fact that the seams of this material are commonly folded as complexly as their host rocks indicates that they probably were formed prior to or contemporaneously with major folding. Data on the origin of the thin conformable seams is not conclusive. The seams may have formed by magmatic processes involving injection of the host rock, or they may have been formed by metamorphic or metasomatic processes.

METAMORPHISM OF PRECAMBRIAN ROCKS

The metamorphism of the Precambrian rocks of the Ralston Buttes district is closely related to the complex structural and intrusive history of the Precambrian Era. The sequence of Precambrian structural events (discussed in more detail in the section "Structural Geology") is as follows: (1) An early period of plastic folding accompanied by regional metamorphism; (2) a second period of plastic folding and regional metamorphism accompanied by intrusion and partial metamorphism of the principal Precambrian igneous rocks; and (3) a third period of deformation, largely cataclastic and localized along the Idaho Springs-Ralston shear zone. For purposes of discussion we have divided the metamorphic rocks produced by this sequence of events into the following three categories:

1. Rocks containing mineral assemblages indicative of high-grade regional metamorphism. They represent the cumulative effects of the first two periods of deformation.
2. Rocks which are less widely distributed than rocks of category 1 and which contain somewhat different mineral assemblages in part superimposed on earlier metamorphic features. The charaterizing minerals of rocks in this category apparently formed in response to variations in pressure, temperature, or other metamorphic factors at some time during the second period of deformation.
3. Polymetamorphic rocks in which the mineral assemblages of earlier high-grade regional metamorphism have been texturally and structurally modified by cataclasis, accompanied by some recrystallization, during the third period of deformation. Rocks in this category occur in the Idaho Springs–Ralston shear zone.

The metamorphic classification of the rocks of the first category may be made in general terms, characterizing most of the succession of metamorphosed sedimentary and volcanic(?) rocks in the Ralston Buttes district. The presence of sillimanite in the pelitic rocks permits a general correlation with the sillimanite zone of progressive regional metamorphism (Harker, 1939, p. 209, 227–229). In terms of the facies concept, the rocks belong to the amphibolite facies of Eskola (1939, p. 351–355) or the almandine-amphibolite facies as defined by Turner (in Fyfe and others, 1958, p. 228–232) and Turner and Verhoogen (1960, p. 544–545).

Although the rocks of the first category acquired their characterizing features during the first two periods of deformation, evidence that would enable distinction of mineral assemblages produced by the first period of folding from those produced by the second is lacking. The wide distribution of sillimanite in the pelitic rocks suggests that metamorphic conditions characteristic of the sillimanite zone prevailed over much of the district during the pervasive deformation that characterized the second period. Structural features suggest that the first period of deformation was equally pervasive, but evidence is less clear for determining the highest grade reached during this period. Wells, Sheridan, and Albee (1964) have correlated relict staurolite with the first period of deformation in the Coal Creek area, the southern part of which corresponds to the northernmost part of the Ralston Buttes district. The relict staurolite was found as inclusions in andalusite in samples of schist obtained from the part of the quartzite unit lying north of the Ralston Buttes district. Similar relict staurolite was not found in the Ralston Buttes district. In fact, except for a local occurrence of a micaceous aggregate possibly pseudomorphous after staurolite, there is nothing in the pelitic rocks south of the Coal Creek area to indicate that an early staurolite zone extended much beyond that area. Conditions approximating the sillimanite zone very likely existed in much of the Ralston Buttes district south of the Coal Creek area during the first period, because some of the lineations which we have correlated with the first period are defined by the longest dimension of aggregates of sillimanite. Such evidence is fragmentary, however, and, for this reason, in the following discussion we consider the metamorphic rocks of the first category as the cumulative effects of the first two periods of deformation. Both periods very likely were characterized by deep-seated regional metamorphic conditions involving high temperature and pressure.

The high-grade rocks of the first category contain the following assemblages of minerals, some of which may not represent equilibrium assemblages:

Pelitic rocks:
- Biotite-muscovite-quartz-sillimanite
- Biotite-muscovite-plagioclase-quartz-sillimanite
- Biotite-garnet-muscovite-quartz-sillimanite
- Biotite-muscovite-quartz-plagioclase

Quartzo-feldspathic rocks:
- Biotite-microcline-plagioclase-quartz
- Biotite-hornblende-microcline-plagioclase-quartz
- Biotite-microcline-muscovite-plagioclase-quartz

Calc-silicate rocks and impure marble:
- Clinopyroxene-epidote[3]-hornblende-plagioclase-sphene
- Calcite-clinopyroxene-epidote-hornblende-plagioclase
- Calcite-clinopyroxene-epidote-hornblende-plagioclase-scapolite
- Calcite-clinopyroxene-hornblende-microcline-plagioclase
- Clinopyroxene-epidote-hornblende-microcline-plagioclase-quartz
- Epidote-garnet-magnetite-quartz
- Epidote-garnet-hornblende-plagioclase-quartz
- Clinopyroxene-epidote-garnet-plagioclase-quartz
- Biotite-calcite-clinopyroxene-hornblende
- Calcite-tremolite

Mafic rocks:
- Hornblende-plagioclase
- Hornblende-plagioclase-quartz
- Biotite-hornblende-plagioclase-quartz
- Biotite-plagioclase-quartz
- Biotite-garnet-quartz
- Biotite-garnet-grunerite-quartz

The plagioclase in all these assemblages is oligoclase-andesine. The most sodic oligoclase occurs in the assemblage biotite-microcline-plagioclase-quartz, whereas calcic andesine occurs in calc-silicate gneiss and some of the amphibolite and hornblende gneiss.

The rocks most characteristic of the first category are the high-grade pelitic assemblages, biotite-muscovite-quartz-sillimanite and biotite-muscovite-plagioclase-quartz-sillimanite, which occur in the mica schist unit, as well as in other rock units. Petrographic studies of textural relations in the pelitic rocks revealed that muscovite and sillimanite commonly form an apparently stable pair and formed at about the same time as quartz and biotite. These minerals are associated in some of the rocks with plagioclase or garnet.

[3] The term epidote as used here and in other assemblages includes both epidote and clinozoisite.

We observed no textural or mineralogic evidence that microcline had ever been present in abundance in the pelitic rocks, although the minor occurrences will be discussed later in this section. From these relations we infer that the most pervasive effect in these pelitic rocks was progressive regional metamorphism to a grade generally equivalent to the sillimanite-almandine-muscovite subfacies of the almandine-amphibiolite facies (Turner and Verhoogen, 1960, p. 549). This grade of metamorphism is analogous to the lower sillimanite zone, a term used informally by various New England geologists for the lower of two grades of rocks in a twofold subdivision of the sillimanite zone. Strictly speaking, the pelitic rocks of our first category in the Ralston Buttes district are not directly comparable to those that J. B. Thompson, Jr. (1957, fig. 5) reported in the lower sillimanite zone of New Hampshire, because the New Hampshire rocks also contain staurolite as a stable mineral. However, we use the term "lower sillimanite zone" in a more general sense to indicate that the pelitic rocks of the Ralston Buttes district are characterized predominantly by the pair sillimanite-muscovite, in contrast with the pair sillimanite-potassic feldspar, which characterizes rocks of somewhat higher grade in the upper (or second) sillimanite zone of New England. The common pelitic assemblages of our first category are similar to those reported by Guidotti (1963) for his "sillimanite grade" of metamorphism in the Bryant Pond quadrangle, Maine (probably analogous to the lower sillimanite zone), in contrast with rocks of somewhat higher grade which he mapped as "sillimanite-potash feldspar grade" (probably analogous to the upper sillimanite zone).

Locally, however, sparse grains of microcline in the pelitic rocks of the Ralston Buttes district contain needles of sillimanite having no intervening sheath of muscovite. Examples of this were noted in the descriptions of the mica schist unit and the unit of interlayered biotite gneiss and mica schist. Even in these specimens, however, the pair silimanite-microcline is by no means characteristic of the whole rock, for elsewhere in each thin section are more abundant examples of the pair sillimanite-muscovite having the textural relations typical of most of the pelitic rocks that contain sillimanite. The uncommon presence of sillimanite-microcline as a stable pair in grains in the pelitic rocks suggests that only locally the grade of metamorphism reached that of the upper sillimanite zone or the sillimanite-alamandine-orthoclase subfacies of Turner and Verhoogen (1960, p. 549–550). The fact that this higher grade assemblage is uncommon in the Ralston Buttes district indicates that there is no well-defined zoning analogous to the type which Guidotti (1963, fig. 2) marked by a "sillimanite-potash feldspar isograd" in Maine. In fact, microcline is not associated with sillimanite in the Ralston Buttes district except in a few specimens of pelitic rocks. In the quartzo-feldspathic rocks microcline is associated with quartz, plagioclase, biotite, and, locally, muscovite. These relations, together with the dominance of the pair sillimanite-muscovite in the pelitic rocks, suggest that for some reason, perhaps the effect of water pressure, the regional metamorphism progressed beyond the grade of the lower sillimanite zone only very locally.

We conclude that the pelitic rocks of the first category in the Ralston Buttes district belong almost exclusively to the lower sillimanite zone. This situation differs from that in some of the classic areas of the Scottish Highlands (Barrow, 1912) and New England (Billings, 1937), where metamorphic rocks are divisible into several zones, including zones of a lower grade. In some areas farther west in the Front Range, however, sillimanite-microcline is a more common stable pair (R. B. Taylor, oral commun., 1962). This suggests that muscovite may have become unstable west of the Ralston Buttes district, and that zoning between sillimanite-muscovite and sillimanite-microcline may be present on a broader regional scale. Evaluation of these possibilities, however, must await completion of detailed studies elsewhere in the central Front Range.

Metamorphic rocks of the second category are mainly pelitic types similar in structural features and general mineralogy to the pelitic rocks of the first category, but those of the second category also contain andalusite and cordierite, and some have late crystals of biotite that transect the foliation. Cordierite and the late biotite occur in parts of the schist layers in the quartzite unit. Andalusite occurs as fine-grained layers in the quartzite of the quartzite unit and as porphyroblasts in parts of the schist layers of the quartzite unit. The cordierite and andalusite in schist layers of the quartzite unit appear to have been superimposed upon earlier formed metamorphic features. Evidence for this has been presented by Wells, Sheridan, and Albee (1964), who noted that relict microfolds are present in undeformed andalusite and cordierite and that irregular rounded grains of relict staurolite occur as inclusions in andalusite in specimens from adjacent parts of the Coal Creek area. Andalusite is also found as porphyroblasts in the mica schist unit of the Ralston Buttes district; it is fairly abundant in the northeastern part of that unit, particularly in secs. 34–36, but is uncommon in the western part. One of the thin sections from this northeastern area contains an unaltered poikiloblastic grain of andalusite (fig. 5), a glomeroporphyroblast of sillimanite (fig. 6), and andalusite transected by sillimanite (fig. 7).

The occurrence together and the apparent spatial distribution of the polymorphs andalusite and sillimanite seem particularly significant. Miyashiro (1953, p. 207, fig. 11) constructed a stability diagram showing a triple point for the three polymorphs andalusite, sillimanite, and kyanite. J. B. Thompson, Jr. (1955, p. 97) derived a similar diagram from thermochemical data, and Bell (1963, p. 1055) reported a revised experimental determination of the triple point. Under conditions of pressure and temperature near the triple point, rather small variations in pressure and temperature may result in the change from one polymorph to another. Hietanen (1956) has given a similar interpretation to occurrences of the three polymorphs together in cordierite-bearing mica schist in Idaho.

Structural features discussed elsewhere in this report suggest that the second period of deformation produced the synclinal fold in the quartzite unit and was accompanied by intrusion of the principal Precambrian igneous rocks. Metamorphic conditions were apparently maintained long enough after the solidification of the igneous rocks to metamorphose them partially. It is tempting to relate the andalusite, cordierite, and late transecting biotite of the quartzite unit to this part of metamorphic history during which the igneous rocks were intruded, because these minerals definitely seem to be superimposed upon a preexisting structural and metamorphic fabric. The position of andalusite on the stability diagram (Thompson, J. B., Jr., 1955, fig. 3; Bell, 1963, fig. 1) suggests that it formed under conditions of relatively lower pressure and (or) relatively lower temperature than the regional metamorphism characterized by sillimanitic schist. However the only observed paragenetic relations between andalusite and sillimanite suggest that sillimanite formed at the expense of andalusite in the mica schist unit, although the data available are not sufficient to establish how many generations of each of these minerals were formed. In view of the somewhat conflicting data, it seems unwarranted to ascribe the metamorphic rocks of the second category to a rigidly defined scheme involving classical concepts of thermal metamorphism. Although the specific conditions under which the andalusite and cordierite formed are unknown, the two minerals are probably related to the long and complex second period of deformation. Variations in temperature, pressure, and other metamorphic factors during this period may have caused the observed mineralogic differences between the rocks of the second category and those of the first category.

In addition to features related to progressive regional metamorphism, the high-grade rocks of the first and second categories show minor evidence of retrogressive metamorphism. Thus, examples of sillimanite and andalusite that are partially or completely altered to fine-grained mica and quartz are fairly common in the pelitic rocks, but are not as common as examples of unaltered sillimanite and andalusite. Likewise, some grains of microcline in the quartzo-feldspathic rocks are altered around their borders to fine-grained sericitic mica. Fine-grained minerals of the epidote group are probably also retrograde products formed by the alteration of plagioclase and hornblende, but larger grains of epidote in some layers of calc-silicate gneiss are not necessarily retrograde because they seem to have formed contemporaneously with the other minerals.

The third general category of metamorphic rocks includes the rocks of the Idaho Springs–Ralston shear zone, in which the effects of the third period of Precambrian deformation were superimposed on the various igneous and metamorphic rocks. Rocks in this category include cataclastically deformed parts of the quartz monzonite, the Boulder Creek Granodiorite, the unit of interlayered gneiss and schist, and the quartzite unit, as well as the two units of cataclastic rocks.

The characterizing features of the rocks in this third category are the cataclastic effects, although there is also evidence of mineral growth. Where intense, the cataclasis produced augen, flaser, and finely porphyroclastic gneisses characterized by mortar structure and thin closely spaced granulated zones. The older foliation is commonly greatly modified or completely obscured by the cataclastic effects, which produced a new foliation. Old minerals apparently recrystallized, and new ones crystallized in varying amounts during the cataclastic granulation of the rocks. Evidence of mineral growth is of various kinds. Some unbroken grains of micas occur in granulated zones and show preferred orientation and relatively large grain size in contrast with the very fine grains of feldspar and quartz. Intense suturing of quartz grains as well as overgrowths of quartz enclosing smaller grains are also features suggesting mineral growth. Reconstitution or recrystallization of some of the feldspars is suggested by the apparent decrease of polysynthetic twinning in plagioclase and potassic feldspar, with increasing cataclasis, and also by the fact that potassic feldspar appears to be more perthitic in the more intensely cataclasized rocks. Suggestive also of new crystallization are fine interstitial irregular grains of potassic feldspar in granulated zones. Grains of antiperthite may also be related to reconstitution because such grains were not observed in the relatively uncataclasized rocks.

The rocks of the Idaho Springs–Ralston shear zone appear to have been granulated under pressure-temperature conditions that were sufficiently intense that the rocks remained cohesive and some recrystallization occurred. Although chlorite and epidote are present locally, and although muscovite may be somewhat more abundant in some of the cataclasized igneous rocks than in the relatively unaffected counterparts, such mineralogic features are not conspicuous and do not indicate a major pervasive change to mineral assemblages of a much lower grade. Instead, the main changes in the rocks have been structural, and retrogressive mineralogic changes have only been minor.

The features of the cataclastic rocks noted above suggest that during the third period of deformation the pressure-temperature conditions were less intense than during the preceding periods of more plastic deformation but that they were more intense than would be expected in a near-surface fault zone. Moench, Harrison, and Sims (1958, p. 1737; 1962, p. 54) and Harrison and Wells (1959, p. 32), in discussing the features of late folds and associated cataclastic rocks in the Idaho Springs–Central City area, inferred that these structures are the expression at depth of faulting nearer the surface. Because the features of the shear zone in the Ralston Buttes district also suggest deep-seated effects and are not characterized by simple gouge or breccia, we have also concluded that these rocks represent the deeper part of a fault zone, the upper or near-surface parts of which have since been removed by erosion.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

By Richard Van Horn

Rocks of Paleozoic and Mesozoic age form a narrow southeast-trending belt of hogbacks and valleys in the northeastern part of the Ralston Buttes district. They include the Fountain Formation, Lyons Sandstone, Lykins Formation, Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, and lower part of the Pierre Shale. About 6,000 feet of these rocks is exposed in the district.

The measured sections of the rocks of Paleozoic and Mesozoic age included in this report are part of the almost continuous exposure along Ralston Reservoir and Ralston Creek. The sections were measured when the water in the reservoir was at a low stage. Control stations were located by a planetable survey. Sections between the control stations were measured by tape-and-compass surveys. All measurements were corrected for dip and strike.

PALEOZOIC ROCKS

Rocks of Paleozoic age in the Ralston Buttes district include the Fountain Formation, the Lyons Sandstone, and a part of the Lykins Formation. For convenience, the entire Lykins Formation is discussed in this section, although its upper part is Triassic(?) in age. The rocks of these three formations are generally unfossiliferous, and their age assignment is based mostly on lithologic similarities with rocks in nearby areas.

PENNSYLVANIAN AND PERMIAN: FOUNTAIN FORMATION

The Middle and Upper Pennsylvanian and Lower Permian Fountain Formation, about 800 feet thick, is predominantly conglomerate and mudstone. It lies on a smooth but slightly undulating surface cut over Precambrian rocks of many kinds, and hence its base marks a pronounced unconformity. The basal beds of the Fountain generally form steep slopes on the lower flank of the Front Range, but in many places most of the formation underlies a strike valley between the mountain slope and the hogback formed by the Lyons Sandstone. The wide range in width of outcrop (pl. 1) is due to topographic position, to dip of the beds, and to faulting. North of Ralston Buttes, the lower part of the formation is cut out by a fault.

The Fountain is composed of pink to reddish-orange coarse-grained, conglomeratic crossbedded arkosic sandstone and conglomerate interbedded with lenticular dark-reddish-brown micacous indurated silty mudstones. Light-gray bleached streaks and zones are common. A few lenticular beds of pinkish-gray fine-grained crossbedded quartzose sandstone similar to that in the overlying Lyons Sandstone occur in the upper 30 feet. The coarse fraction, which includes cobbles as much as 7 inches in diameter, is composed of quartz and pink feldspar and minor amounts of schist, gneiss, quartzite, granite, and limestone. The conspicuous pink color is due in part to pink feldspar and in part to a coating of iron oxide on the clastic grains. The mudstones are generally similar to the coarse rocks but are finer grained. Mudcracks were observed in one bed of mudstone north of Ralston Buttes.

The lenticularity, crossbedding, and coarse poorly sorted quality of the deposits indicate the terrestrial origin of this formation.

Section of the Fountain Formation measured in NE¼SW¼ sec. 31, T. 2 S., R. 70. W., Ralston Buttes district

	Thickness (feet)
Lyons Sandstone, unit 3.	
Fountain Formation:	
2. Conglomerate, moderate-orange-pink; many light-gray and moderate-reddish-orange zones; pebbles and cobbles are predominantly quartz and feldspar but include some schist, gneiss, quartzite, and limestone; to 7 in. in diameter. Contains many beds 6 in.–5 ft thick of dark-reddish-brown mudstone, many of which appear to be very lenticular and pinch out within a short distance. The upper 30 ft has a few lenticular beds of pinkish-gray to moderate-reddish-brown sandstone very similar to the overlying Lyons Sandstone	651
1. Mudstone, dark-reddish-brown, micaceous. About 60 percent of unit is mudstone; the remainder is conglomerate similar to overlying conglomerate beds	157
Total Fountain Formation	808
Precambrian rocks.	

PERMIAN: LYONS SANDSTONE

The Lyons Sandstone, about 150 feet thick, lies conformably on the Fountain Formation. It forms a low hogback at its southernmost exposures in the district and gradually rises to the north where it forms the high ridge in the N½ sec. 31, T. 2 S., R. 70 W. Farther north, in the vicinity of Ralston Buttes, the Fountain Formation forms the crest of the hogback, and the Lyons is on the east side of the ridge, but north of the buttes the Lyons again forms the crest of the hogback. Like the Fountain Formation, the Lyons has an irrregular belt of outcrop owing to the effects of topography, folding, and faulting.

The Lyons is composed principally of light-gray to grayish-orange and pinkish-gray fine- to medium-grained quartzose sandstone which is crossbedded. Some beds of siltstone, mudstone, and conglomerate occupy the upper 50 feet. A bed of light-gray conglomerate marks the top of the formation south of Ralston Buttes but is absent north of the buttes. Pebbles and cobbles in the conglomerate are predominantly quartz and chert but include some sandstone. The pinkish color appears only in the lower 10 feet of the formation at Ralston Creek but marks a thickening wedge northward until, several miles north of the Ralston Buttes district, the entire formation is pinkish gray.

Many features indicating that the Lyons was deposited at and near a seashore have been described by W. O. Thompson (1949). These features include dune-sand deposits, barrier-bar deposits, fluvial-channel deposits, rhomboid ripple marks, swash marks, bubble impressions, kelp marks, and animal tracks. Only a few of these features were recognized in the Ralston Buttes district; the crossbedding at several places is similar to that of sand dunes and barrier bars.

The Lyons was assigned a Permian age by Gilmore (in Lee, 1927, p. 12) on the basis of fossil reptile tracks. The contact with the overlying Lykins Formation is lithologically abrupt and may represent an unconformity.

Section of the Lyons Sandstone measured on the north side of Ralston Reservoir, Ralston Buttes district

	Thickness (feet)
Lykins Formation, unit 13.	
Lyons Sandstone:	
12. Conglomerate, light-gray; pebbles predominantly quartz and chert to 1 in. in diameter, noncalcareous	3. 2
11. Sandstone, very pale orange, fine-grained; predominantly quartz with tiny limonite specks, noncalcareous	2. 2
10. Conglomerate, light-gray; pebbles of quartz, chert, and sandstone to 4 in. in diameter, noncalcareous	8. 8
9. Sandstone, very light gray, irregularly mottled moderate-yellowish-brown, fine-grained, noncalcareous	5. 2
8. Siltstone, grayish-orange and light-greenish-gray, irregularly bedded, clayey, slightly calcareous. Channels into underlying unit	0. 9–2. 7
7. Sandstone, very light gray and grayish-orange, fine-grained, noncalcareous	0. 1–1. 9
6. Sandstone, light-gray, fine- to medium-grained noncalcareous, very hard; predominantly quartz. Shows low-angle festooned crossbedding in lower part	18. 0
5. Siltstone, light-gray, medium-gray, and grayish-orange, shaly, calcareous	1. 8
4. Mudstone, moderate to dark-reddish-brown, very hard, noncalcareous. Attitude: N. 9° W.; 43° E	2. 2
3. Sandstone, light-gray to grayish-orange, steeply and greatly crossbedded and festoon-bedded, fine- to medium-grained; predominantly quartz. Minor thin siltstone or very fine grained sandstone in the festooned beds. Lower 10 ft is pinkish gray. Attitude of contact with underlying Fountain Formation: N. 7° W.; 43° E	105. 8
Total Lyons Sandstone	148. 2–151. 8
Fountain Formation, unit 2.	

PERMIAN(?) AND TRIASSIC(?): LYKINS FORMATION

The Lykins Formation consists of about 450 feet of soft, red beds. It is generally poorly exposed and characteristically underlies the western part of a valley bordered by hogbacks of Lyons Sandstone on the west and the Dakota Group on the east. North of Fireclay, where the Dakota does not form a hogback, the Lykins occurs high on the east side of the hogback formed by the Lyons Sandstone. A limestone bed 14 feet thick and about 90 feet above the base of the formation—the Glennon Limestone Member of LeRoy (1946, p. 36)—is well exposed in several abandoned quarries south of Ralston Buttes, but the Lykins is not exposed north of the buttes.

The Lykins is mostly grayish-red mudstone but includes some limestone and a few thin beds of very fine grained sandstone. LeRoy (1946, p. 30–47) named and described five members of this formation, which are indicated on the accompanying measured section but not shown on the geologic map. From oldest to youngest these members are: The Harriman Shale, 55 feet thick; the Falcon Limestone, 3 feet thick; the Bergen Shale, 30 feet thick; the Glennon Limestone, 14 feet thick; and the Strain Shale, 350 feet thick. The Harriman Shale Member at most places contains a 1-foot limestone bed near its base. The Falcon and Glennon Limestone Members are very light gray hard finely crystalline to dense dolomitic wavy-bedded (crinkled) limestone. At a few places both limestones have markings that may represent poorly formed ripple marks. The upper 10 feet of the Glennon Limestone Member is reddish-brown tough wavy-bedded (crinkled) silty limestone.

Several dissociated segments of the dayscladacean alga *Mizzia minuta* Johnson and Dorr (USGS fossil loc. 55–RR–5, table 20) were found and identified by Richard Rezak (written commun., 1956) near the top of the Glennon Limestone Member at Ralston Reservoir. According to Rezak the genus *Mizzia* has been found only in Middle and Late Permian rocks of the world, and in North America it has been recognized only in rocks of Guadalupe age. Rezak also stated that many concentric domelike features in the Glennon Limestone Member appear to be due to blue-green algae. Mudge (in McKee and others, 1959) indicated that the contact between rocks of Permian and Triassic age is about 90 feet above the Glennon.

The mudstone of LeRoy's Harriman, Bergen, and Strain Members is grayish red, tough, thin bedded, slightly calcareous, and contains some thin beds of light-gray very fine grained sandstone. At a few places the mudstone is mottled light bluish gray. Locally, normal bedding gives way to nested lenticles about 1 inch long and a quarter of an inch thick (fig. 12). These lenticular structures are similar to the structures described by Moore and Scruton (1957, p. 2726–2727, 2735) from layers at water depths of 6–360 feet near the Mississippi Delta.

A castlike structure almost identical with the lobate plunge structure described by Hessland (1955, p. 45,

TABLE 20.—*Cretaceous and Permian fossils of the Ralston Buttes district*

USGS fossil locality No.	Location					Fossils (Cretaceous fossils identified by W. A. Cobban and Permian fossils by Richard Rezak, both of the U.S. Geological Survey)	System	Formation	Standard classification		Collector and year
	¼ sec.	¼ sec.	Sec.	Township South	Range West						
D 41 and D 295						*Baculites scotti* Cobban *Inoceramus* sp. *Lucina* sp.	Cretaceous	Pierre Shale	European stages		G. R. Scott, 1955. W. A. Cobban, G. R. Scott, and Richard Van Horn, 1954.
D 44	NE	SW	20	2	70	*Baculites* aff. *B. gregoryensis* Cobban *Inoceramus* sp. *Cymbophora*, n. sp.					W. A. Cobban, G. R. Scott, and Richard Van Horn, 1954.
D 42						*Baculites* n. sp. aff. *B. gregoryensis* Cobban					
D 467	SE	SW	20	2	70					Upper Campanian	Richard Van Horn, 1954.
D 43	NW	SW	20	2	70	*Baculites gregoryensis* Cobban *Inoceramus* sp.					W. A. Cobban, G. R. Scott, and Richard Van Horn, 1954.
D 466	SW	NW	20	2	70	*Baculites mclearni* Landes *Inoceramus azerbaidjanensis* Aliev					Richard Van Horn, 1955.
D 16	SE	NW	5	3	70	*Inoceramus labiatus* (Schlotheim) *Kanabiceras* sp.		Benton Shale		Lower Turonian	W. A. Cobban, G. R. Scott, and Richard Van Horn, 1954.
D 15											
D 77	SE	NW	5	3	70	*Inoceramus* cf *I. fragilis* Hall and Meek				Upper Cenomanian	W. A. Cobban, Richard Rezak and Richard Van Horn, 1954.
D 14						*Inoceramus pictus* Sowerby (=*I. prefragilis* Stephenson) *Ostrea* sp.					W. A. Cobban, G. R. Scott, and Richard Van Horn, 1954.
55-RR-5	SW	NW	6	3	70	*Mizzia minuta* Johnson and Dorr Stromatolitic sediments	Permian	Lykins	Texas and New Mexico Provincial Series	Guadalupe	Richard Rezak and Richard Van Horn, 1955.

pl. 1, figs. 1a, b) was found about 30 feet below the top of the Strain Shale Member on the south side of Ralston Reservoir. It is 1.4 inches long and 0.5 inch across at the wide end. The other end tapers to a rounded blunt point, 0.1 inch wide and slightly curved to one side. The wide end merges into the enclosing rock so it is difficult to tell where the structure ends. Hessland stated that this type of structure is formed by water movements, and although it is not indicative of any particular depth of water, he believed that the structure shown on his plate 1 formed in sediments deposited on tidal flats during Cambrian time. If this interpretation is correct, such structures can form in shallow water. On the other hand, similar features described as flute-casts in papers summarized by Hsu (1959) have generally been attributed to turbidity currents or to deep waters on the continental slope. Moreover, there is a possibility that the structure is a poorly preserved reptilean footprint. A faint resemblance to some of the trackways found in the Moenkopi Formation (Peabody, 1948) was pointed out by E. D. McKee of the U.S. Geological Survey (oral commun., 1959). An indentation about 3 cm to the right of the structure could be construed to be the remains of a cast of a second toe. If it is a footprint, the structure connotes a land—or at most, very shallow water—environment.

The limestone and its problematic ripple marks indicate a shallow water origin. According to Rezak (written commun., 1956), "the association of fragments of *Mizzia* with stromatolitic sediments indicates a shallow water, near shore, marine environment, possibly intertidal. The crinkly limestone of the Lykins (Glennon Limestone Member), especially the upper 8 inches of the topmost unit at Ralston Reservoir, very closely resembles the intertidal algal deposits of South Florida and the Bahamas." T. R. Walker (1957) noted the occurrence of stromatolite heads in the "crinkled" member of the Lykins Formation near Colorado Springs, and he also indicated the possibility that the limestone formed in a shallow marine or intertidal flat environment.

Unfortunately the origin of the mudstone is not as clear. The association with the limestone indicates a shallow marine environment, but the lenticular and lobate plunge structures described above may indicate deposition in water of moderate depth.

The contact of the Lykins with the overlying Ralston Creek Formation is generally not well exposed. The relationships seem to indicate that, at least locally, the Ralston Creek unconformably overlies the Lykins.

FIGURE 12.—Lenticular sandstone structures in the upper part of the Lykins Formation. Hammer points to a well-formed lenticle of sandstone. Note the thin bed of fine-grained silty sandstone below the hammerhead. Picture taken in small gulch south of Ralston Reservoir.

Section of the Lykins Formation measured on both sides of Ralston Reservoir, Ralston Buttes district

	Thickness (feet)
Ralston Creek Formation, unit 21.	
Lykins Formation:	
Strain Shale Member of LeRoy (1946):	
20. Mudstone, grayish-red; uneven lenticular structures (irregular layers). ⅛–1 in. beds of light-gray very fine grained sandstone occur at a few places. Lobate plunge structure occurs 30 ft below top. The mudstone is generally calcareous and looks like fine-textured alluvium. Poorly exposed	344
Glennon Limestone Member of LeRoy (1946):	
19. Limestone, pale-reddish-brown and very light gray, thin, wavy-bedded (crinkled), silty. Attitude: N. 7° W.; 43° E. *Mizzia minuta* Johnson and Dorr. USGS fossil loc. 55–RR–5. Los Angeles abrasion test: 44.0 percent loss	10. 0
18. Limestone, very light gray to white, finely crystalline, dolomitic, very hard; some chert. Has been quarried. Los Angeles abrasion test: 44.7 percent loss	3. 5
Lykins Formation—Continued	
Bergen Shale Member of LeRoy (1946):	
17. Mudstone, grayish-red, calcareous, poorly exposed	29. 9
Falcon Limestone Member of LeRoy (1946):	
16. Limestone, very light gray to white, finely to medium crystalline; appears dolomitic at places. Thin pale reddish brown laminae occur throughout but are particularly numerous at the base	2. 2
Harriman Shale Member of LeRoy (1946):	
15. Mudstone, grayish-red; lenticular structures (irregular layers); hard, slightly calcareous	40. 9
14. Limestone, very light to medium gray, finely to medium crystalline; vuggy or sugary texture	1. 4
13. Mudstone, grayish-red; lenticular structures (irregular layers); hard, slightly calcareous. Basal 2 ft very sandy and calcareous. Attitude of contact with underlying Lyons sandstone: N. 5° W.; 48° E	12. 8
Total Lykins Formation	444. 7
Lyons Formation, unit 12.	

MESOZOIC ROCKS

Rocks of Mesozoic age include the Ralston Creek Formation, Morrison Formation, Dakota Group, Benton Shale, Niobrara Formation, and the lower part of the Pierre Shale, in addition to part of the Lykins Formation.

JURASSIC

RALSTON CREEK FORMATION

The name Ralston Creek Formation (Van Horn, 1957) is used in place of the name Ralston Formation (LeRoy, 1946, p. 47) because the name "Ralston" was preempted at the time LeRoy applied it. The type section, as described by LeRoy, is on the south side of Ralston Creek at the upstream end of Ralston Reservoir in the NE cor. SW¼NW¼ sec. 5, T. 3 S., R. 70 W., Ralston Buttes quadrangle, Colorado. The formation is poorly resistant to erosion and in most places occupies the floor of a valley west of the Dakota hogback. The best exposure is at the type section, which can be examined only when Ralston Reservoir is about 30 feet below its high stage.

The Ralston Creek Formation, about 110 feet thick, is more closely allied paleontologically and lithologically with the overlying Morrison Formation than with the underlying Lykins Formation. In the Ralston Buttes district it is composed of varicolored claystone, limestone, and some calcareous siltstone. Thin layers and small disseminated nodules of moderate-red, white, light- and dark-gray chalcedony occur in the middle part of the formation. The claystone is grayish red, grayish orange, dusky red, pale green, or light gray

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and is tough, silty, and generally calcareous. The limestone is commonly light gray, but at places it is grayish red or grayish orange and contains disseminated nodules of chalcedony. When weathered it has the rough, grainy appearance of siltstone. Thick beds of light-gray to grayish-red calcareous siltstone occur at a few places in the lower part of the formation.

At the base of the formation as exposed below the high-water mark of Ralston Reservoir (unit 21 of the measured section) is a bed of grayish-red to light-gray fine- to medium-grained calcareous sandstone 5 feet thick. This bed was not indicated in the sections measured by LeRoy (1946, p. 41, 51) along Ralston Creek but is here tentatively assigned to the Ralston Creek Formation. It was not seen in the Long Lake Ditch to the south of the reservoir nor at a good exposure of the Lykins-Ralston Creek contact 2½ miles north of Ralston Creek and is apparently not a continuous body. It is similar to the Entrada Sandstone in some respects and may be an erosional remnant of that formation.

LeRoy (1946, p. 55) reported finding the fossil plant *Aclistochara* in this formation, and T. C. Yen (in Imlay, 1952, p. 961) reported the presence of *Unio*-like pelecypods that may compare with *Vetulonaia faberi* Holt, a species from the Morrison Formation of western and northwestern Colorado. The environment of the *Unio*-like pelecypod is unknown, but *Aclistochara* indicates a fresh- or brackish-water environment. The Ralston Creek Formation was probably deposited in swamps and lakes similar to those of the Morrison deposits. At Ralston Creek the basal sandstone of the overlying Morrison Formation was deposited in a channel cut into the upper part of the Ralston Creek Formation.

Section of the Ralston Creek Formation measured on the south side of Ralston Reservoir, Ralston Buttes district

	Thickness (feet)
Morrison Formation, unit 47.	
Ralston Creek Formation:	
46. Claystone, dusky-red and pale-green, silty	8. 8
45. Siltstone, very light gray	. 8
44. Claystone, dusky-red and pale-green, silty	4. 6
43. Limestone, light-gray, very hard. Attitude: N. 4° W.; 54° E	1. 0
42. Claystone, dusky-red and pale-green, silty	8. 6
41. Chert, moderate-red, white, light- to dark-gray; sparse vugs 0.1 in. in diameter contain tiny quartz crystals	. 4
40. Claystone, light-gray mottled grayish-red, calcareous	3. 0
39. Claystone, grayish-red mottled light-gray, calcareous	8. 8
38. Limestone, light-gray	1. 1
37. Claystone, light-gray and grayish-red; contains lenticular bed of limestone as much as 1 ft thick, 2.9 ft above base	14. 5
Ralston Creek Formation—Continued	
36. Limestone, light-gray; contains fragments of *Unio*-like pelecypod. Attitude: N. 7° W.; 50° E	1. 9
35. Claystone, grayish-red and grayish-orange, silty; contains some soft calcareous siltstone	7. 5
34. Siltsone, grayish-orange streaked grayish-red, soft, calcareous	4. 0
33. Claystone, grayish-red, silty, calcareous	1. 0
32. Siltstone, light-gray and grayish-red, calcareous; contains some silty claystone	3. 1
31. Siltstone, light-gray, calcareous, clayey; contains many ⅛-in. disseminated nodules and zones of of moderate-red chert. A thin hard dense limestone or marlstone is present at the top	2. 5
30. Siltstone, light-gray, clayey; contains a few thin layers of calcite	1. 5
29. Siltstone, grayish-orange, soft, calcareous	1. 1
28. Siltstone, grayish-orange, hard, siliceous	1. 2
27. Chert; moderate-red to light-gray, and grayish-orange siltstone	. 4
26. Siltstone, light-gray and grayish-orange, calcareous; contains many disseminated ⅛-in. chert nodules	4. 8
25. Siltstone, grayish-orange, calcareous	15. 5
24. Siltstone, light-brown, calcareous	5. 9
23. Claystone, medium-gray; 0.1-in.-thick grayish-red band at top	1. 2
22. Siltstone, grayish-red, calcareous	3. 0
21. Sandstone, grayish-red to light-gray, fine- to medium-grained, moderately hard, calcareous. Attitude: N. 4° W.; 42° E	5. 4
Total Ralston Creek Formation	111. 6
Lykins Formation, unit 20.	

MORRISON FORMATION

The Morrison Formation, about 250 feet thick, consists of varicolored mudstone, limestone, siltstone, and sandstone. It crops out on the west slope of the hogback formed by the sandstones of the Dakota Group.

The Morrison is principally greenish-gray, dusky-red, and dark-gray claystone and mudstone. Thin beds of light- to dark-gray siltstone are interbedded with thick beds of claystone and mudstone. The upper part contains several thin beds of fine-grained sandstone. Mudstone and thin limestone beds occur in the lower part, and the base is marked by a light-gray cross-bedded fine- to medium-grained sandstone 10–40 feet thick.

At a few places a lenticular sandstone as much as 15 feet thick crops out about 20 feet above the basal sandstone of the Morrison. One such place is in the trough of the plunging syncline north of Ralston Reservoir. Here it at first appeared as though the basal sandstone had been faulted. Closer examination, however, showed that the supposed offset of the basal sandstone is an illusion caused by a good exposure of the basal sandstone on one side of the supposed fault and another good exposure of the stratigraphically higher sandstone on the other side.

The contact with the overlying Dakota Group is not clearly exposed in the section measured at Ralston Reservoir. In the sandstone beds below unit 61 of the measured section, white specks of claylike material fill spaces between sand grains and are clearly visible under a magnifying glass. The sandstone beds above unit 62 (see measured section of the Dakota Group) lack this filling. Waagé (1955, p. 23) pointed out that interstitial clay occurs in conglomerates of the upper part of the Morrison but not in the Dakota. If this criteria can be extended to the sandstone beds, then the contact as shown is a logical choice. Comparison of the accompanying measured sections and the section measured by Waagé (1959, section 8) at the same general locality shows that Waagé placed the boundary at the base of the sandstone unit probably equivalent to unit 64. Waagé (written commun., 1954) measured this part of his section in a series of small gullies north of the trail along the north side of Ralston Reservoir, whereas the section in this report was measured along the trail. Probably the thin sandstone beds 62 and 60 were not exposed where Waagé measured his section. In 1957 Van Horn indicated the Morrison Formation to be 310 feet thick, but that figure included some strata now assigned to the Dakota Group. As currently recognized, the Morrison is about 250 feet thick in the Ralston Buttes area.

The Morrison Formation was deposited in freshwater lakes and swamps. LeRoy (1946, p. 60) discovered *Aclistochara* in the lower part, and Yen (1952, p. 28) described several species of fresh-water gastropods found south of Golden. Dinosaur remains have also been found south of Golden (Emmons and others, 1896, p. 486–506). The Morrison is unconformably overlain by the Dakota Group.

Section of the Morrison Formation measured on both sides of Ralston Reservoir, Ralston Buttes district

Dakota Group, unit 62.

Morrison Formation:	Thickness (feet)
61. Claystone, greenish-gray to dark-gray, noncalcareous; contains some sandy siltstone	5.0
60. Sandstone, light-gray, very fine grained, hard, noncalcareous; contains white specks of interstitial clay	2.0
59. Claystone, greenish-gray to dark-gray, noncalcareous	10.3
58. Sandstone, light-gray, very fine grained, hard, slightly calcareous; contains white specks of interstitial clay	2.5
57. Claystone, greenish-gray to dark-gray, noncalcareous	1.9
Morrison Formation—Continued	
56. Sandstone, light-gray, fine- to medium-grained; some limonite stain in upper 1.5 ft; noncalcareous; contains some medium-gray very thin beds which may be crossbedding, and white specks of interstitial clay	7.1
55. Covered; a few outcrops show greenish-gray and dusky-red claystone and some dense limestone	78.7
54. Sandstone, light-gray, calcareous; some slickensides	3.0
53. Claystone, pale-green	12.0
52. Mudstone, dusky-red; 1-ft-thick siltstone in middle	15.3
51. Sandstone, very light gray, fine-grained, calcareous	3.3
50. Mudstone, dusky-red	39.5
49. Sandstone, very light gray, fine-grained, calcareous	.6
48. Mudstone, dusky-red	23.3
47. Sandstone, very light gray, medium- to fine-grained, massive, crossbedded; some thin bedded; predominantly quartz; contains very small light-colored limonite dots and concretions to ½ in. in diameter. Occupies a channel cut into top of Ralston Creek Formation	42.0
Total Morrison Formation	246.5

Ralston Creek Formation, unit 46.

CRETACEOUS

DAKOTA GROUP

The Dakota Group (Waagé, 1955) is predominantly sandstone, siltstone, and claystone, but it includes some conglomerate and conglomeratic sandstone near the base. In the section measured at Ralston Reservoir it is 300 feet thick. The Dakota forms the easternmost hogback in the Ralston Buttes district. North of Ralston Buttes the Dakota does not form a hogback but merges into the eastern slope of the hogback of Lyons Sandstone. Excavations made for the Denver and Salt Lake Railway have cut into the upper part of the Dakota at several places in the northern part of the area.

As redefined by Waagé (1955), the Dakota Group includes the Lytle and South Platte Formations, which are separated by a disconformity. The two formations and several members are recognizable at Ralston Reservoir and shown on the measured section but are not differentiated on the geologic map. The Dakota Group of this report is essentially the same as that of Waagé. The several members defined by Waagé are rather easily identified in the measured section, except in the lower part. The disconformity at the base of the South Platte Formation is not readily apparent. It was placed at the base of the only conglomeratic sandstone bed in the measured section, unit 68. This bed overlies varicolored claystone beds of the Lytle Formation and is presumably the bed that LeRoy (1946, p. 73) regarded as the base of the Dakota.

The Dakota is composed of light-gray fine- to medium-grained sandstone, commonly crossbedded and ripple marked; light- to dark-gray siltstone, crossbedded and ripple marked at places; and dark-gray claystone. The base of the Dakota is marked by a sandstone that is locally conglomeratic; the top is composed of a thick light-gray fine-grained quartzose sandstone. Rocks of the Dakota Group are usually noncalcareous, are generally hard and resistant to erosion, and at many places contain fragments of fossil plants.

Johnson (1931, p. 358) stated that, "land plants represent the fossils commonly found in the Dakota in this [the Denver] region." The bulk of these apparently come from two horizons, one near the base of the Dakota and one near the middle. He also noted the presence of dinosaur tracks, fish scales, and some poorly preserved casts of bivalves which came from the uppermost sandstone. Although Waagé (1961, p. 78) reported that a marine pelecypod was found near the middle of the Dakota, most of the fossil evidence indicates a predominantly terrestrial origin. The ripple marks in the upper part, which are so well exposed for many miles along the hogback, are similar to those found on the tidal flats of Cholla Bay, Sonora, Mexico, which have been described by McKee (1957). The contact of the Dakota Group with the overlying Benton Shale is transitional.

Section of the Dakota Group measured on the north side of Ralston Reservoir, Ralston Buttes district

	Thickness (feet)
Benton Shale, unit 108.	
Dakota Group:	
South Platte Formation:	
First sandstone of Waagé (1955):	
107. Sandstone, light-gray, fine-grained, silty; predominantly quartz	6.0
106. Sandstone, very light gray, yellowish-gray and orange-stained, fine- to medium-grained, hard; interference ripple marks, predominantly quartz	11.0
105. Claystone; very light gray at top and dark gray at base	2.9
104. Siltstone, medium-gray to light-gray, sandy; contains plant fragments	1.8
103. Claystone, dark-gray	.5
102. Sandstone, very light gray, fine-grained; predominantly quartz	.4
101. Claystone, dark-gray	.4
100. Siltstone, very light gray	.7
99. Claystone, dark-gray	.4
98. Sandstone, very light gray, fine-grained; predominantly quartz	2.9
97. Siltstone, very light gray	1.4
Dakota Group—Continued	
South Platte Formation—Continued	
First sandstone of Waagé (1955)—Continued	
96. Sandstone and siltstone, very light gray, fine-grained; predominantly quartz	4.5
Van Bibber Shale Member—First shale of Waagé (1955):	
95. Claystone, dark-gray, slightly carbonaceous	1.5
94. Sandstone, very light gray, fine-grained, hard	6.6
93. Claystone, dark-gray; contains 0.2 ft bed of very light gray claystone 0.9 ft above base	4.0
92. Sandstone, very light gray, very fine grained; predominantly quartz	.7
91. Claystone, dark-gray	.5
90. Sandstone, very light gray, thin- to thick-bedded, very fine grained	3.3
89. Claystone, dark-gray; contains lenses of light-gray siltstone	5.7
88. Sandstone, very light gray, fine-grained, silty; contains some thin beds of claystone	5.4
87. Claystone, dark-gray, limonite-stained; weathers hackly. Very light gray and with greasy luster 0.2 ft above base; claystone marker bed of Waagé (1952, p. 381). This bed has been mined (beds 12 and 13 of LeRoy (1946, p. 73) and beds 39–45 of Waagé (1961, p. 118))	17.9
86. Siltstone, medium-gray, hard; prominent ripple marks on upper surface well exposed in excavation for the clay mine. Attitude: N. 10° W.; 48° E	3.2
85. Claystone, dark-gray	.2
84. Siltstone, medium-gray, hard	.6
83. Claystone, dark-gray	.1
82. Siltstone, medium-gray, hard	.9
81. Claystone, dark-gray; basal 0.1 ft very light gray claystone	2.6
80. Siltstone, medium-gray	.8
79. Claystone, dark-gray	4.0
Kassler Sandstone Member—(Second sandstone of Waagé (1955):	
78. Siltstone, medium-gray; contains carbonaceous fragments. Lower 6 ft grades downward to medium-grained sandstone. Crops out where large (6×10 ft) boulder blocks the trail	25.4
Second shale, third sandstone, and third shale of Waagé (1955):	
77. Claystone, dark-gray. Very light gray and with greasy luster 0.3 ft from top; 0.3-ft-thick claystone second key marker bed of Waagé (1955)	8.5
76. Siltstone, medium-gray; wavy bedded with some light-gray fine-grained sandstone and thin partings of dark-gray claystone. Channels cut 0.4 ft into underlying bed	2.5

	Thickness (feet)
Dakota Group—Continued	
South Platte Formation—Continued	
Second shale, third sandstone, and third shale of Waagé (1955)—Continued	
75. Sandstone, light- to medium-gray, medium- to fine-grained; limonite stains and spots. Lower 18 ft has platy appearance caused by numerous thin claystone and siltstone partings	41. 5
74. Claystone, dark-gray; some gray chert nodules in upper 3 ft	9. 4
Plainview Sandstone Member:	
Fourth sandstone of Waagé (1955):	
73. Siltstone, medium- to light-gray, thin-bedded; has platy appearance caused by thin dark-gray claystone partings; contains some very fine grained sandstone. Weathers nodular and platy	22. 8
72. Sandstone, medium- to very light gray, massive, fine-grained. Lower 3 ft platy and very fine grained	11. 3
Fourth shale of Waagé (1955):	
71. Claystone, dark-gray, silty, partly covered	4. 8
Basal conglomeratic sandstone of Waagé (1955):	
70. Sandstone, very light gray, limonite-stained, medium-grained. Has many 1-in.-diameter cavities	3. 6
69. Claystone, dark-gray, slightly fissile	. 5
68. Sandstone, very light gray, limonite-stained, medium-grained, slightly conglomeratic. Pebbles are light- to very light gray chert	6. 8
Total South Platte Formation	228. 0
Lytle Formation:	
67. Claystone, varicolored, predominantly greenish-gray; thin bands are moderate red to dusky red; noncalcareous	5. 1
66. Poorly exposed, principally fine-grained sandstone and siltstone. Greenish-gray, 0.2-ft-thick, claystone bed 11 ft below top. Slightly calcareous sandstone 36 ft below top	38. 2
65. Claystone, greenish-gray to dark-gray, noncalcareous	14. 8
64. Sandstone, medium-gray, very fine grained, noncalacareous	1. 4
63. Claystone, greenish-gray to dark-gray, noncalcareous	7. 0
62. Sandstone, light-gray, very fine grained, hard, noncalcareous	2. 5
Total Lytle Formation	69. 0
Total Dakota Group	297. 0
Morrison Formation, unit 61.	

BENTON SHALE

The Benton Shale, about 500 feet thick, is principally shale interbedded with bentonite, siltstone, and limestone. It is exposed in a few places east of the hogback formed by the Dakota Group; the best exposure is on the north bank of Ralston Reservoir. In this excellent exposure it was possible to recognize paleontologic and lithologic equivalents of the Graneros Shale, Greenhorn Limestone, and Carlile Shale. Within the limits of the Greenhorn Limestone it was also possible to recognize equivalents of the Lincoln Limestone, Hartland Shale, and Bridge Creek Limestone Members. This division of the Benton into Graneros, Greenhorn, and Carlile equivalents at Ralston Reservoir is most readily apparent when the section is viewed from a distance or seen on aerial photographs. The outcrops of the noncalcareous Graneros and Carlile Shale equivalents are medium gray, whereas the intervening calcareous Greenhorn equivalent is light gray. W. A. Cobban recognized these equivalents in the area during the course of this study. He also identified the fossils which are shown in table 20 and on the accompanying measured section. These formations, which are more typically exposed in southeastern Colorado and Kansas, were not mapped in the Ralston Buttes district.

Graneros Shale equivalent.—The Graneros Shale equivalent is composed of 180 feet of dark-gray noncalcareous shale interbedded with many thin beds of dark-gray siltstone. The base is marked by a 12-foot bed of platy, minutely crossbedded light- to dark-gray siltstone which is transitional between the Dakota Group and the Benton Shale and was placed by Waagé (1955) in the Benton. The transitional siltstone at Ralston Creek is sandy and weathers into thin slabs, but as it passes southeastward into the Golden quadrangle it becomes interbedded with shale typical of the Benton. The only fossil found in the Graneros equivalent resembled a fish scale.

Greenhorn Limestone equivalent.—Conformably overlying the equivalent of the Graneros Shale is 256 feet of the Greenhorn Limestone equivalent, and, in this, equivalents of the Lincoln Limestone, Hartland Shale, and Bridge Creek Limestone Members can be recognized. The lower 73 feet of the Greenhorn equivalent, the equivalent of the Lincoln Limestone Member, is composed of light-gray to black calcareous fissile shale, and some thin beds of medium- to yellowish-gray fossiliferous limestone and very light gray to yellowish-orange bentonite. The limestone beds contain the excellent guide fossil to the upper Cenomanian, *Inoceramus pictus* Sowerby (= *Inoceramus prefragilis* Stephenson).

Overlying the Lincoln Limestone Member equivalent is 60 feet of light-gray to black calcareous fissile shale and some thin beds of very light gray to yellowish-orange bentonite, probably the equivalent of the Hartland Shale Member. A thin limestone bed near the middle of this unit contains *Inoceramus* cf. *I. fragilis* Hall and Meek.

The overlying Bridge Creek Limestone Member equivalent, which is about 123 feet thick, is composed principally of light-gray to black calcareous fissile shale. Two thin medium- to yellowish-gray dense limestone beds in the lower 3 feet contain *Inoceramus* cf. *I. fragilis* Hall and Meek. The upper part of this upper unit contains a sparse scattering of thin irregular limestone chips, some of which contain *Inoceramus labiatus* (Schlotheim) and *Kanabiceras* sp., an ammonite. *Inoceramus labiatus* occurs near the base of the Turonian and is common in the uppermost part of the Greenhorn Limestone.

Carlile Shale equivalent.—Conformably overlying equivalents of the Greenhorn Limestone is 70 feet of medium-dark-gray noncalcareous siltstone and some light-gray thin-bedded silty sandstone, equivalent to the Carlile Shale. Sandstone and siltstone at the top of the Carlile (units 177–179 of the measured section) are probably equivalent to the Codell Sandstone Member of the Carlile Shale. Contact of these strata with the overlying Niobrara Formation seems to be conformable, although Johnson (1930b) noted a probable unconformity between the Benton and Niobrara in eastern Colorado.

Section of the Benton Shale measured on both sides of Ralston Reservoir, Ralston Buttes district

	Thickness (feet)
Niobrara Formation, unit 180.	
Benton Shale:	1
Carlile Shale equivalent:	
179. Siltstone, yellowish-gray; calcareous in upper half and slightly calcareous in lower half, weathers nodular	5.0
178. Siltstone, medium-dark-gray, noncalcareous, wavy-bedded; contains many thin well-cemented layers, much ferruginous staining in 3- to 6-in. layers. A lenticular silty sandstone occurs 3 ft from top, and thin plates of selenite occur near the base	10.0
177. Sandstone, light-gray, thin-bedded, fine-grained, silty, noncalcareous	2.3
176. Siltstone, medium-dark-gray, wavy-bedded, noncalcareous	7.0
175. Sandstone, light-gray, thin-bedded, fine-grained, silty, noncalcareous	1.0
174. Siltstone, medium-dark-gray, wavy-bedded, noncalcareous	46.0
Total Carlile Shale equivalent	71.3
Benton Shale—Continued	
Greenhorn Limestone equivalent:	
Bridge Creek Limestone Member equivalent:	
173. Shale, black to light-gray; many bluish-gray chips, silty, calcareous, fissile. The outcrop has a sparse scattering of thin irregularly shaped limestone chips. Contains *Inoceramus labiatus* (Schlotheim) and *Kanabiceras* sp. USGS fossil loc. D 16	120.0
172. Limestone, medium- to yellowish-gray, dense	.6
171. Shale, black to light-gray, silty, calcareous, fissile	1.3
170. Limestone, medium- to yellowish-gray, dense. Contains *Inoceramus* cf. *I. fragilis* Hall and Meek. USGS fossil loc. D 15. Attitude: N. 19° W.; 63° E	.8
Total Bridge Creek Limestone Member equivalent	122.7
Hartland Shale Member equivalent:	
169. Shale, black to light-gray, calcareous, fissile	22.3
168. Bentonite, very light gray; pale-yellowish-orange stain	.9
167. Shale, black to light-gray, calcareous, fissile	.8
166. Bentonite, very light gray; pale-yellowish-orange stain	.3
165. Shale, black to light-grey, calcareous, fiissile	3.7
164. Bentonite, very light gray; pale-yellowish-orange stain	1.0
163. Shale, black to light-gray, calcareous, fissile	1.2
162. Bentonite, very light gray; pale-yellowish-orange stain	.5
161. Shale, black to light-gray, calcareous, fissile	2.5
160. Limestone, medium- to yellowish-gray, dense *Inoceramus* cf. *I. fragilis* Hall and Meek. USGS fossil loc. D 77	.3
159. Shale, black to light-gray, calcareous, fissile	3.7
158. Bentonite, very light gray; pale-yellowish-orange stain	.1
157. Shale, black to light-gray, calcareous, fissile	17.5
156. Bentonite, very light gray; pale-yellowish-orange stain	.2
155. Shale, black to light-gray, calcareous, fissile	2.9
154. Bentonite, very light gray; pale-yellowish-orange stain	.2
153. Shale, black to light-gray, calcareous, fissile	2.0

Benton Shale—Continued	Thickness (feet)
Greenhorn Limestone equivalent—Continued	
Hartland Shale Member equivalent—Continued	
152. Bentonite, very light gray; pale-yellowish-orange stain	.3
Total Hartland Shale Member equivalent	60.4
Lincoln Limestone Member equivalent:	
151. Limestone, medium- to yellowish-gray, dense; contains many oyster shells	0.3
150. Shale, black to light-gray, calcareous, fissile	1.0
149. Sandstone, light-gray, thin-bedded, fine-grained, silty, calcareous, fossiliferous	.7
148. Bentonite, very light gray; pale-yellowish-orange stain	.1
147. Shale, black to light-gray, calcareous, fissile	4.6
146. Bentonite, very light gray; pale-yellowish-orange stain	.3
145. Shale, black to light-gray, calcareous, fissile; contains thin beds of silty sandstone	.6
144. Bentonite, very light gray; pale-yellowish-orange stain	.2
143. Shale, black to light-gray, calcareous, fissile	2.8
142. Bentonite, very light gray; pale-yellowish-orange stain	.7
141. Shale, black to light-gray, calcareous, fissile	1.8
140. Limestone, medium- to yellowish-gray, dense; contains *Inoceramus pictus* Sowerby. USGS fossil loc. D 14	.1
139. Shale, black to light-gray, calcareous, fissile; contains many thin irregularly shaped limestone lenses with *Ostrea* and *Inoceramus pictus* Sowerby. USGS fossil loc. D 14	24.5
138. Bentonite, very light gray; pale-yellowish-orange stain	1.5
137. Limestone, medium- to yellowish-gray, dense; contains *Inoceramus pictus* Sowerby. USGS fossil loc. D 14	.2
136. Shale, black to light-gray, calcareous, fissile; contains some thin beds of bentonite	16.2
135. Shale, yellowish-gray, silty, calcareous	3.0
134. Bentonite, very light gray; pale-yellowish-orange stain	.9
133. Shale, yellowish-gray, silty, calcareous	13.0
132. Bentonite, very light gray, pale-yellowish-orange stain	.9
Total Lincoln Limestone Member equivalent	73.4
Total Greenhorn Limestone equivalent	256.5

Benton Shale—Continued	Thickness (feet)
Graneros Shale equivalent:	
131. Shale, pale-yellowish-brown; dark-yellowish-orange stain; silty, slightly calcareous, fissile	2.0
130. Siltstone, dark-yellowish-orange, calcareous	.8
129. Shale, dark-gray, clayey, noncalcareous, fissile	3.5
128. Siltstone, dark-yellowish-orange, slightly calcareous	.7
127. Shale, dark-gray, clayey, noncalcareous, fissile; thin bed of bentonite at top	2.6
126. Siltstone, dark-yellowish-orange, slightly calcareous	.7
125. Shale, dark-gray, clayey, noncalcareous, fissile	13.9
124. Bentonite, very light gray; pale-yellowish-orange stain	.9
123. Shale, dark-gray, clayey, noncalcareous, fissile	3.2
122. Siltstone, dark-gray, clayey, slightly calcareous, blocky-weathering	1.0
121. Shale, dark-gray, clayey, noncalcareous, fissile. Middle covered	25.9
120. Siltstone, dark-gray, clayey, slightly calcareous, blocky-weathering	.2
119. Shale, dark-gray, clayey, noncalcareous, fissile	13.0
118. Siltstone, dark-gray, clayey, slightly calcareous, blocky-weathering	.1
117. Shale, dark-gray, clayey, noncalcareous, fissile	37.0
116. Covered; probably shale with some bentonite near base	54.0
115. Shale, dark-gray, clayey, noncalcareous, fissile	10.0
114. Siltstone, medium-gray, very hard	.3
113. Shale, dark-gray, clayey, noncalcareous, fissile	.2
112. Siltstone, medium-gray, very hard	.2
111. Shale, dark-gray, clayey, noncalcareous, fissile	3.9
110. Siltstone, medium-gray, sandy	1.1
109. Shale, dark-gray, clayey, noncalcareous, fissile	6.0
108. Siltstone, light- and medium-gray, thin-bedded; some minute crossbedding; sandy, hard. Attitude: N. 5° W.; 52° E	12.5
Total Graneros Shale equivalent	193.7
Total Benton Shale	521.5

Dakota Group, unit 107.

NIOBRARA FORMATION

The Niobrara Formation is composed of the Fort Hays Limestone Member and the overlying Smoky Hill Shale Member. Both members contain many foraminifers and are marine. The Niobrara is about 350 feet thick.

Fort Hays Limestone Member.—The Fort Hays Limestone Member, about 28 feet thick, is 78 percent limestone and 22 percent shale. It occurs east of the hogback of the Dakota Group and generally forms a small bench between the Benton Shale and the Smoky Hill Shale Member.

The Fort Hays is composed of medium- to yellowish-gray hard dense limestone, and medium-dark-gray calcareous shale. As exposed at Ralston Reservoir, just east of the Ralston Buttes district, the member is composed of 26 limestone beds, which range from 0.1 to 2.2 feet in thickness and are separated by thin shale beds. The fossil *Inoceramus deformis* Meek occurs in the limestone. Along the east side of the district several small monzonite sills intrude the Fort Hays.

Smoky Hill Shale Member.—The Smoky Hill Shale Member conformably overlies the Fort Hays Limestone Member and is about 320 feet thick. It is principally calcareous shale but contains two beds of shaly chalk. The Smoky Hill is poorly exposed in this area; the most complete section crops out along the west side of Ralston Reservoir in the Golden quadrangle.

The Smoky Hill is predominantly light-gray to dusky-yellow calcareous shale but includes a few thin beds of bentonite and gypsum. A 25-foot-thick bed of light-gray shaly chalk occurs 150 feet above the base, and a grayish-yellow shaly chalk occurs 260 feet above the base.

The contact with the overlying Pierre Shale is conformable but generally covered. Where the contact is exposed it is readily apparent because of the difference in the weathered color of the grayish-yellow Smoky Hill Shale Member and the overlying grayish-brown Pierre Shale.

PIERRE SHALE

Only the lower 3,000 feet of the Pierre Shale is preserved in the Ralston Buttes district, although the total thickness is about 7,000 feet. The few exposures, in the northeast corner of the district, are predominantly grayish-brown to olive-gray clayey shale but include some hard calcareous sandy siltstone.

A hard calcareous, sandy siltstone crops out in the railroad cut at Arena Siding. This siltstone, about 60 feet thick, is the Hygiene Sandstone Member of the Pierre Shale. It contains the fossil *Baculites* aff. *B. gregoryensis* Cobban (table 20, D 44).

LARAMIDE INTRUSIVE ROCKS

Compared with their widespread occurrence in the Front Range mineral belt, Laramide intrusive rocks are uncommon in the Ralston Buttes district. A long dike of leucosyenite intrudes Precambrian rocks in the western part of the district, and several monzonite sills intrude the younger sedimentary rocks in the northeastern part.

LEUCOSYENITE

A long northwest-trending dike of leucosyenite is exposed north of Guy Gulch in the western part of the Ralston Buttes district (pl. 1). It has been traced for about 3 miles, but in several places it seems to be discontinuous at the surface. The thickness ranges from 25 to 75 feet. Parts of the dike appear to be nearly vertical, whereas other parts dip at moderate angles to the northeast. The dike has sharp chilled contacts.

The leucosyenite is fine grained and orange pink to reddish brown and is composed almost entirely of interlocking euhedral laths of alkali feldspar. Interstitial to the feldspar laths are hematite (about 5 percent of the rock) and small amounts of quartz, chlorite, and zircon. The feldspar is intensely altered to aggregates of extremely fine grained material of low birefringence. Unaltered remnants of the feldspar are commonly perthitic, but some appear to have lamellar twinning.

At the contacts of the dike are thin chilled zones, ranging from 3 to 6 inches in thickness, that consist of euhedral laths of alkali feldspar, less than 0.1 mm in length, and fine layers containing ovaloid aggregates of yellow-green chlorite. The feldspar is intensely altered like that in the central part of the dike. The chlorite is moderately birefringent.

The dike of leucosyenite has been classified as Laramide in age because it is not metamorphosed and has chilled contacts. The trend of the dike is subparallel to the Junction Ranch fault system, one of the many northwest-trending fault systems in this part of the Front Range. The faults in these systems probably originated in Precambrian time; however, many of them are known to have been active during the Laramide orogeny. Although the leucosyenite differs in some details from most Laramide intrusive rocks in the Front Range (Lovering and Goddard, 1950, p. 46; Sims and others, 1955, p. 8–10; Harrison and Wells, 1956, p. 57–61; Wells, 1960), texturally and compositionally it resembles the Laramide rocks more than the hornblende-biotite lamprophyre of presumed Precambrian age.

The radioactivity of the leucosyenite is 1½–2½ times that of the Precambrian rocks it intrudes. In this respect it resembles certain other Tertiary dike rocks in the Front Range (Phair, 1952, p. 4–5; Sims and others, 1955, p. 8–9; Wells, 1960, p. 257–260).

MONZONITE

By Richard Van Horn

Mafic monzonite sills intrude the Fort Hays Limestone Member of the Niobrara Formation at several places east of Ralston Buttes. These sills are similar in composition and appearance to the mafic monzonite of Ralston dike, half a mile east of the Ralston Buttes district (Van Horn, 1957).

The sill exposed in the NE¼NW¼ sec. 32, T. 2 S., R. 70 W., is porphyritic monzonite and has an aphanitic groundmass. It consists mainly of plagioclase, potassic feldspar, augite, and minor amounts of apatite, magnetite and olivine. A greatly altered brown mineral, which occurs in accessory amounts, may have originally been biotite. The phenocrysts are principally feldspar and augite; the augite forms small dark-green crystals that are obvious in hand specimens. A chemical analysis of this rock (table 21) is markedly similar to analyses of samples from the lava flows east of Golden (Emmons and others, 1896, p. 306, 308).

TABLE 21.—*Chemical analysis of monzonite sill, Ralston Buttes district* [1]

[Analyses by P. L. D. Elmore, K. E. White, and S. D. Botts using methods similar to those described by Shapiro and Brannock (1956)]

	Percent		Percent
SiO_2	51.4	TiO_2	.90
Al_2O_3	16.2	P_2O_5	.58
Fe_2O_3	6.2	MnO	.18
FeO	2.9	H_2O	3.6
MgO	3.6	CO_2	.36
CaO	6.4		
Na_2O	3.3	Summary	100.12
K_2O	4.5		

[1] Sample from NE¼NW¼ sec. 32, T. 2 S., R. 70 W. Lab. No. 149011.

Waldschmidt (1939, p. 30) examined a thin section from a sill about a mile to the south. Except for potassic feldspar, the mineral assemblage that he described is similar to that of the sill discussed in this report. Most of the phenocrysts in the thin section that he examined were altered to calcite.

CENOZOIC SURFICIAL DEPOSITS

By RICHARD VAN HORN

The Cenozoic deposits in the Ralston Buttes district are principally Pleistocene in age; no deposits of undoubted Tertiary age were found within the district. Many different types of Cenozoic deposits are present in the area, but only alluvium of several different ages is shown on the geologic map (pl. 1). Although Tertiary erosion surfaces are not depicted on the map, they are discussed in the next section as preparation for discussion of Quaternary deposits.

TERTIARY EROSION SURFACES

When viewed from the east, at a distance of several miles, the eastern flank of the Front Range has the appearance of a high-level plain with many peaks rising above it. Various geologists have described from one to five erosional surfaces in the Southern Rocky Mountains (Howard, 1956). In the Ralston Buttes district, however, only two seem to be meaningful, although several roughly accordant levels can be visualized. The highest is marked only by a series of roughly accordant peaks that rise like monadnocks above the lower and better preserved surface. This lower surface was called the Rocky Mountain peneplain by Lee (1917), the Bergen Park peneplain by Van Tuyl and Lovering (1935), and the subsummit surface by Howard (1956).

In the Ralston Buttes district, Mount Tom and Blue, Centralia, and Douglas Mountains all rise above the subsummit surface to form a series of peaks roughly accordant with each other and with the ridges on the east side of James Peak on the Continental Divide, 25 miles to the west. These roughly accordant peaks are probably the equivalent of the summit surface of Howard (1956), the Flattop surface of Lee (1917), and the higher surfaces of Van Tuyl and Lovering (1935).

In this district the subsummit surface appears to be the western part of an old southeast-trending valley nearly coincidental with the southeast-trending parts of Deer Creek, upper Van Bibber Creek, and Crawford Gulch; the old valley also closely follows the Hurricane fault system. This apparent old valley is bounded on the west by Centralia Mountain and Mount Tom. To the north it narrows and passes west of Blue Mountain and east of Mount Thorodin, which is 3 miles northwest of the district. Southwest of the Ralston Buttes district a low divide separates this valleylike feature from a similar feature that extends southeastward from the headwaters of North Fork Clear Creek past Bergen Park. Howard (1956) pointed out that the subsummit surface is probably the result of pedimentation rather than peneplanation and that most geologists now believe the surface is late Tertiary in age. It is probably equivalent to the surface on which the Ogallala Formation was deposited in eastern Colorado and western Kansas and Nebraska.

No mappable surficial deposits were found on the Tertiary erosion surfaces, although several boulders of the distinctive quartzite of Coal Creek (quartzite unit of pl. 1) were found on a long spur between secs. 27 and 28, T. 2 S., R. 71 W., on the south side of Ralston Creek. These boulders could only have come from the north side of Ralston Creek and probably are a remnant of an alluvial deposit formed at a level about 500 feet higher (7,850 ft) than the present course of Ralston Creek (7,350 ft). Similar boulders were found also on a spur in the NW¼SW¼ sec. 28, T. 2 S., R. 71 W., at an altitude of 8,050 feet. The material on the spur consists of 1 foot of silty, cobbly, humic gravel overlying a saprolitic medium-grained pegmatite. No soil was recognized although the material is finer grained and darker at the top than it is at the base. About 40 percent of the pebbles are similar to the underlying pegmatite, and 30 percent are quartzite from the Coal Creek area. Although most of the pebbles are subangular, a few are well rounded owing to stream action. The relation of these deposits to the outcrops of quartzite of Coal Creek is such that the boulders could have been deposited by an east-flowing post-Tertiary Ralston Creek or by an even older southeast-flowing late Tertiary stream. The latter possibility, however, seems more likely.

Just south of the district, in the N½ sec. 34, T. 3 S., R. 71 W., a small gravel deposit forms a small knob on a long spur north of Clear Creek at an altitude of 7,400 feet (1,000 ft above Clear Creek) (Erskine and others, 1950). One of the cobbles in this deposit is bostonite, which must have come from several miles west of the district, probably from the vicinity of Idaho Springs or Central City. The spur, which is below the subsummit surface, may be part of the Flagstaff Hill berm of Van Tuyl and Lovering (1935). This deposit must have been formed by an east-flowing ancestral Clear Creek, after the apparent southeast-trending late Tertiary valleys had been abandoned.

QUATERNARY DEPOSITS

Alluvial deposits of Pleistocene age occur only in the northeastern part of the Ralston Buttes district, but deposits of Recent age are present at many places throughout the district. The geologic names that have been assigned to the surficial deposits are those used by Hunt (1954, p. 114), Malde (1955, p. 244), and Scott (1960).

The age assigned to the various deposits is based on four general kinds of evidence: topographic position, volcanic-ash content, relict soils, and fossil vertebrates. The topographic position of the various terrace or pediment deposits was the principal means of assigning relative ages to the deposits, because, in any particular valley, the higher deposits are the older.

One outcrop of volcanic ash, found in the Verdos Alluvium, is similar to the Pearlette Ash Member of the Sappa Formation and is assumed to be of Kansan age (Frye and Leonard, 1952, p. 70). The volcanic ash was found in a gravel pit in the NW¼NE¼ sec. 32, T. 2 S., R. 70 W., Golden quadrangle (about 1,300 ft east of the Ralston Buttes district). The ash shards are clear, colorless, quite broken, and flat. They constitute about 10 percent of the light-gray silt bed in which they occur. No bubble junctures were seen. This ash is similar to one near Denver described by Hunt (1954, p. 96) and classed by John C. Frye as very similar to the Pearlette. On the basis of physiographic evidence, Hunt thought the ash might be older than Yarmouth.

Relict soils also were used as an aid in making age assignments, but generally the older ones are partly eroded and are of little value except for indicating a pre-Wisconsin age. The oxidized horizon generally has been removed by erosion from these soils, although at places the pre-Rocky Flats alluvium and the Rocky Flats Alluvium have moderate-reddish-brown zones that may be oxidized horizons. The Rocky Flats Alluvium and the Verdos Alluvium have strong accumulations of calcium carbonate that may be the Cca horizons of strongly developed soils. The accumulation of calcium carbonate is moderately strong in the Louviers Alluvium and moderate in the Broadway Alluvium. No appreciable accumulation of calcium carbonate was seen in the pre-Piney Creek alluvium, the Piney Creek Alluvium, and the post-Piney Creek alluvium.

Fossil vertebrates, indicative of a post-Mankato age, were found only in the pre-Piney Creek alluvium and Piney Creek Alluvium. These two deposits are separable by differences in color, grain size, and degree of cohesion. The Piney Creek Alluvium is darker (generally dark grayish brown) and finer grained, and it has much less coherence than the pre-Piney Creek alluvium.

PLEISTOCENE(?): PRE-ROCKY FLATS ALLUVIUM

One small remnant of pre-Rocky Flats alluvium, probably correlative with the old gravel of Malde (1955, p. 223), occurs in the N½ sec. 29, T. 2 S., R. 70 W. It slopes east-northeast about 250 feet per mile and is 200 feet above Leyden Creek. The upper surface of the deposit is littered with cobbles and small boulders. The deposit is a moderate-reddish-brown coarse bouldery gravel in a clayey sand matrix. The boulders are commonly about 3 feet in diameter but are as large as 6 feet in diameter. The coarse material is predominantly sandstone and quartzite but includes small amounts of conglomerate and partly decomposed granitic rocks. The thickness of the deposit probably ranges from 6 to 15 feet and exhibits considerable local variation. A thin veneer of quartzite cobbles on a small remnant of an erosion surface, just north of the SW cor. sec. 29, T. 2 S., R. 70 W., may correlate with the pre-Rocky Flats alluvium. It is not shown on the geologic map.

The age of the pre-Rocky Flats alluvium is not determinable from the available evidence. The higher topographic position indicates it is older than the Rocky

Flats Alluvium, but, because it is only 50 feet higher, it seems to be closely associated with the Rocky Flats Alluvium of Nebraskan or Aftonian age. This topographic relation suggests that the pre-Rocky Flats alluvium is probably of early Nebraskan age.

PLEISTOCENE

NEBRASKAN OR AFTONIAN

Rocky Flats Alluvium.—In the Ralston Buttes district, Rocky Flats Alluvium (Scott, 1960, p. 1541) occurs only in the northeast corner, on Rocky Flats. Its upper surface there slopes east and east-southeast about 150 feet per mile and is about 150 feet above Leyden Creek. Farther east, in the Golden quadrangle, the upper surface is more than 300 feet above Leyden Creek. The surface is relatively smooth and is broken only by a few shallow east-flowing drains which carry water during the infrequent heavy rains. At places quartzite cobbles litter the surface. The deposit is probably 20–30 feet thick, but local channel fills may exceed 50 feet.

The deposit is a coarse, bouldery, cobble gravel containing very little silt or fine sand. The coarse fraction is composed predominantly of quartzite from Coal Creek but includes some other metamorphic rocks and sandstone. Boulders as much as 2 feet in diameter are common, and at a few places the boulders are as much as 20 feet in diameter. A strongly developed soil exposed in the South Boulder Diversion Canal, a mile east of the district, is composed of 3 feet of reddish-brown clayey sand overlying 6 feet of calcium carbonate impregnated cobbly gravel. The reddish-brown oxidized horizon and the thick zone of calcium carbonate accumulation are typical of pre-Wisconsin soils.

The age of the Rocky Flats Alluvium is designated as Nebraskan or Aftonian because the next lower and younger deposit, the Verdos Alluvium, contains volcanic ash correlated with the Pearlette Ash Member of the Sappa Formation of Kansan age.

KANSAN OR YARMOUTH

Verdos Alluvium.—Verdos Alluvium (Scott, 1960, p. 1541) occurs in the Ralston Buttes district only on the divide between Ralston and Van Bibber Creeks, where it slopes about 250 feet per mile north toward Ralston Creek. The northern end of the deposit is about 200 feet above the level of Ralston Creek. The upper surface is littered with cobbles and with boulders that range in diameter from 18 inches to as much as 3 feet. The deposit probably does not exceed 20 feet in thickness.

The deposit varies in composition but consists dominantly of a micaceous, silty, and cobbly gravel, as shown in an exposure in a roadcut in the N½ sec. 8, T. 3 S., R. 70 W. The coarse material is principally schist and micaceous quartzite probably derived from the Van Bibber Creek drainage. A section measured from a hole dug just east of the district in the NW¼ SE¼ sec. 5, T. 3 S., R. 70 W., is as follows:

	Thickness (feet)
1. Sand, dark-brown, firm, slightly calcareous, clayey, silty, fine to medium; some pebbles	0.5
2. Sand, reddish-brown, firm, moderately calcareous, clayey, silty, fine to medium; some pebbles	1.0
3. Sand, very light gray, firm, strongly calcareous, silty, fine to medium; some pebbles. Strongly impregnated with calcium carbonate	.9
4. Sand, very pale brown, loose, strongly calcareous, silty, fine to medium	1.0

Unit 2 is probably the oxidized zone of a pre-Wisconsin soil, and unit 3 is the calcium carbonate enriched zone. The calcareous nature of all the units probably results from calcium carbonate derived from the nearby Niobrara Formation.

Although volcanic ash was not found in the Verdos Alluvium of the Ralston Buttes district, it is present in equivalent deposits in the Golden quadrangle in the NW¼NE¼ sec. 32, T. 2 S., R. 70 W. Here the volcanic ash is disseminated in a light-gray silt bed about 30 feet long and 18 inches thick that is overlain by about 10 feet of gravel. The bed is exposed near the north end of the west side of a gravel pit just above the debris slope, at the bottom of the working face. The ash may be the equivalent of the Pearlette Ash Member of the Sappa Formation of Kansan age.

ILLINOIAN OR SANGAMON

Slocum Alluvium.—A small thin remnant of a terrace deposit that is probably Slocum Alluvium of Illinoian or Sangamon age (Scott, 1960, p. 1542) occurs in the NW¼SW¼ sec. 8, T. 3 S., R. 70 W., in the Van Bibber Creek drainage. The deposit slopes northeast toward Ralston Creek but remains below the present divide that separates the two streams. This relationship indicates that Van Bibber Creek no longer joined Ralston Creek within the confines of the district when the Slocum was deposited. The ancestral Van Bibber Creek had apparently been captured from the Ralston Creek drainage prior to the deposition of the Slocum. The surface of the deposit is littered with cobbles and boulders as much as 5 feet in diameter, but the composition of the deposit itself, or the soil formed on it, is not known. Projection of the terrace at its present slope brings it midway between the closest Verdos Alluvium and Louviers Alluvium, which are about 1,000 feet northeast of the deposit of Slocum Alluvium.

WISCONSIN

Louviers Alluvium.—The Louviers Alluvium (Scott, 1960, p. 1542) is present in Ralston Creek, in a valley tributary to Ralston Creek, and in a valley tributary to Van Bibber Creek. The Louviers in Ralston Creek is on the northwest side of Ralston Reservoir and is a remnant of a once larger body of alluvium. Other remnants are present in the Golden quadrangle. Several northeast-sloping isolated patches of Louviers are present in a small tributary to Ralston Creek from the south in secs. 6 and 7, T. 3 S., R. 70 W. This alluvium was probably deposited by the several small unnamed streams that head in the Precambrian rocks immediately to the west. Another small deposit of Louviers slopes southeastward in the small valley tributary to Van Bibber Creek in sec. 8, T. 3 S., R. 70 W. The average thickness of these deposits probably does not exceed 10 feet.

Little is known about the composition of the Louviers Alluvium. It appears to be finer grained than the older deposits. The few pebbles and cobbles that are present are principally quartz, micaceous quartzite, and dark metamorphic rocks. The following section was measured in a shallow pit in the NE¼NE¼ sec. 7, T. 3 S., R. 70 W.:

	Thickness (feet)
1. Sand, dark-grayish-brown, loose, noncalcareous, silty, fine	0.3
2. Sand, dark-brown, firm, noncalcareous, blocky, clayey, silty, fine	1.4
3. Sand, dark-brown (top) to yellowish-brown (bottom), loose, noncalcareous, silty, fine	2.4

The section is interpreted to be an ancient soil of middle Wisconsin age. Unit 2 is probably the oxidized or clay-enriched zone. No zone of calcium carbonate accumulation was found in the pit; in the Golden quadrangle, the middle Wisconsin soil generally has a rather strong zone of calcium carbonate accumulation.

Broadway Alluvium.—The Broadway Alluvium (Scott, 1960, p. 1543) mantles a terrace cut into the Louviers Alluvium in secs. 6 and 7, T. 3 S., R. 70 W., south of Ralston Creek, and was probably derived from the short stream valleys that head in the mountains immediately to the west. The surface of the deposits slopes 300–400 feet per mile north toward Ralston Creek; the slope lessens as Ralston Creek is approached. In the SE¼SE¼ sec. 6, T. 3 S., R. 70 W., the deposits consist of about 2 feet of silty cobbly gravel alluvium overlain by 3 feet of brown colluvium. The coarse fraction of the alluvium is composed principally of pegmatite, micaceous quartzite, and schist. The nearby deposit to the southeast is about 20 feet thick. Its upper part is light brown silty coarse sand; its lower part, which is coarser, contains many pebbles and cobbles.

RECENT

Two deposits of early Recent age occur in the Ralston Buttes district. The older deposit is not shown separately on the geologic map because it covers only a

TABLE 22.—*Recent fossils of the Ralston Buttes district*

[D 194 and D 199 are Recent, all others are probably Recent. Identifications by C. B. Schultz, L. G. Tanner, and G. E. Lewis (written commun., 1957)]

USGS fossil loc. No.	*Bison bison* (Linnaeus)	*Bison* cf. *B. bison* (Linnaeus)	*Odocoileus* sp.	*Cervus canadensis* (Erxleben)	Remarks
D 186			×		From 0.6 ft below crest of narrow ridge at base of Recent soil.
D 181	×				Float on steep face of Piney Creek Alluvium.
D 187	×				From 4.0 ft below top of bank in reddish-brown crudely bedded fine to coarse alluvium containing some charcoal layers (pre-Piney Creek (?) alluvium).
D 188			×		From 2.5 ft below top of bank in material like D 187.
D 182	×				From 0.8 ft below top of bank in material like D 187.
D 179		×			From 1.5 and 3.6 ft below top of bank in reddish-brown crudely bedded coarse alluvium containing many angular pebbles and cobbles (pre-Piney Creek (?) alluvium).
D 190	×				From 1.6 ft below top of bank in dark-brown silty sand (Piney Creek Alluvium). Overlies 10 ft of reddish-brown coarse alluvium (pre-Piney Creek (?) alluvium).
D 184	×				From 1.4 ft below top of bank in very dark brown micaceous sandy to cobbly silt (Piney Creek (?) Alluvium).
D 185	×				From 1 ft below top of bank in black loose micaceous sandy silt with some charcoal (Piney Creek Alluvium). Overlies weak- to dark-red hard dense crudely bedded sand as much as 20 ft thick (pre-Piney Creek (?) alluvium).
D 189			×		From 1.6 ft below top of bank in very dark gray brown slightly firm silty sand containing some pebbles and charcoal (Piney Creek Alluvium).
D 180	×				From 3.2 ft below top of bank in brownish-gray sandy silt (Piney Creek Alluvium). Overlies 4 ft of reddish-brown firm silty sand containing some pebbles and cobbles (pre-Piney Creek alluvium).
D 183	×				From 1.2 ft below top of bank in black silty sand (Piney Creek Alluvium). Overlain by 0.9 ft of reddish-brown Recent slope wash.
D 197			×		See measured section under Piney Creek Alluvium.
D 194	×				From 0.5 ft below top of bank in very dark gray massive very fine silty sand containing many pebbles, few cobbles and scattered boulders (Piney Creek Alluvium). Overlies 4 ft of brown massive firm fine to coarse sand containing pebbles, cobbles, and boulders (pre-Piney Creek (?) alluvium).
D 199	×				From 1.5 ft below top of bank in yellowish-brown loose coarse sand containing many pebbles and cobbles. Recent alluvial fan.
D 195				×	From 2.9 ft below top of bank in very dark gray massive very fine silty sand containing many pebbles and few cobbles (Piney Creek Alluvium). Overlies 3 ft of brown massive firm fine to coarse sand containing pebbles, cobbles, and boulders (pre-Piney Creek(?) alluvium).

small area. It is mapped with the Piney Creek Alluvium, although it is discussed separately in the text. At most places where both deposits are present, the younger deposit (Piney Creek Alluvium) overlies the older (pre-Piney Creek alluvium), rather than occupying a lower terrace. Both deposits are present in the mountainous as well as the foothill parts of the district.

Vertebrate fossils found in these deposits are listed in table 22 and the localities are shown in figure 13.

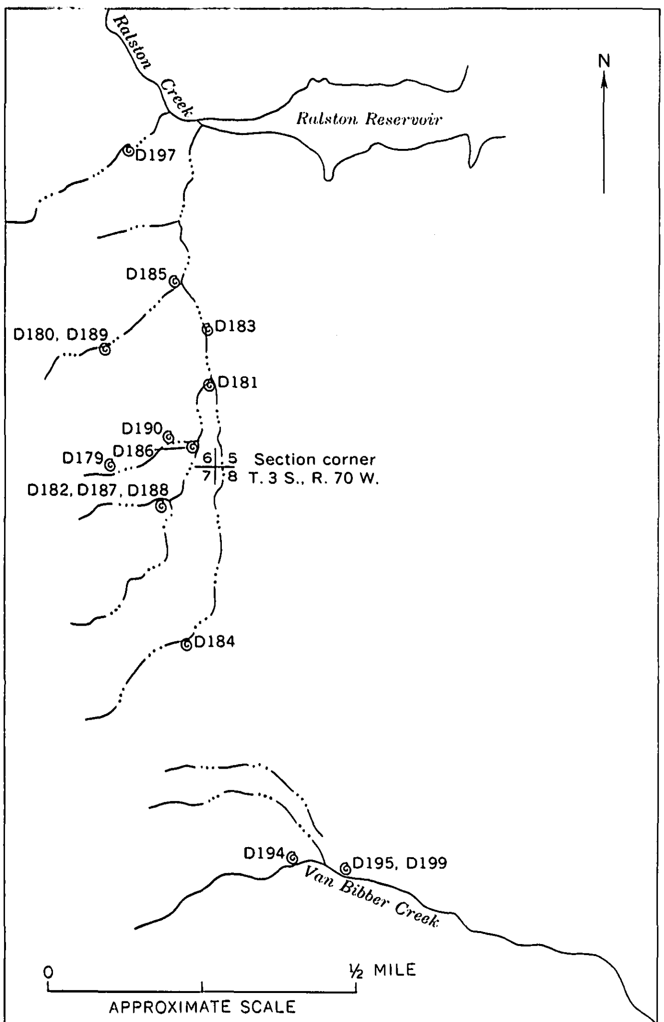

FIGURE 13.—Recent fossil localities and USGS fossil locality numbers.

Pre-Piney Creek alluvium.—Although deposits of pre-Piney Creek alluvium (Scott, 1960, p. 1543) are not shown on the geologic map, they are present in the area. The deposits are 5–10 feet thick and are composed of brown to reddish-brown, commonly iron-stained, firm silty to cobbly gravel containing some boulders. There is an unusually coarse bouldery deposit of this material adjacent to Van Bibber Creek east of the mountain slope. At places the material looks like colluvium and contains lentils of stream-rounded cobbly gravel; elsewhere it is predominantly silty sand and some pebbles. Locally, channels filled with Piney Creek Alluvium extend downward into the pre-Piney Creek alluvium.

The following section was measured at a small terrace remnant in the lower part of Elk Creek in the NW¼ NW¼ sec. 34, T. 3 S., R. 71 W. (not shown on the geologic map):

	Thickness (feet)
Piney Creek Alluvium:	
1. Sand, grayish-brown, loose, silty; some subangular to angular pebbles and cobbles	4.0
Pre-Piney Creek alluvium:	
2. Gravel, moderate-yellowish-brown; subangular to angular cobbles and boulders	5.0
3. Sand, grayish-brown; some subangular to angular pebbles and cobbles	0–2.0
4. Gravel, moderate-yellowish-brown; subangular to angular cobbles and boulders	2.0

Fossil vertebrates (table 22) found in deposits of pre-Piney Creek alluvium are probably of Recent age. These deposits are unconformably overlain by Piney Creek Alluvium.

Piney Creek Alluvium.—The Piney Creek Alluvium (Hunt, 1954, p. 114) is dark-gray to dark-brown micaceous loose sandy silt or silty sand in which angular pebbles and cobbles are irregularly distributed. In the foothills the deposit contains small discontinuous layers and isolated lumps of charcoal. The thickness of the deposit is generally 3–10 feet but locally is as much as 20 feet.

The soil formed on the Piney Creek Alluvium is very weakly developed and consists of a slight darkening of the upper 6 inches. Both soil and parent material commonly lack discernible calcium carbonate. Fossil vertebrate remains of probable Recent age (table 22) were found at a few places.

The following partial section of Piney Creek Alluvium and pre-Piney Creek alluvium was measured in the NE¼ SE¼ sec. 6, T. 3 S., R. 70 W.

	Thickness (feet)
Recent slope wash:	
1. Sand, weak-red, loose, silty, medium	0.5
Piney Creek Alluvium:	
2. Silt, dark-brown, loose, micaceous	.4
3. Sand, dark-gray-brown to dark-gray, loose, micaceous fine to medium	2.1
4. Silt, very dark gray, slightly firm, micaceous, charcoaly	.3
5. Sand, dark-gray-brown, loose, micaceous, fine; charcoaly layer 0.1 ft below the top	.6

Piney Creek Alluvium—Continued	Thickness (feet)
6. Silt, very dark gray, slightly firm, micaceous, charcoaly, interbedded, in 0.2- to 0.4-ft-thick beds, with dark-gray-brown loose micaceous charcoaly fine sand	1.2
Pre-Piney Creek alluvium:	
7. Sand, dark-reddish-brown (stained and mottled weak red), firm, silty, medium to coarse; some pebbles and cobbles. Teeth of *Odocoileus* sp. (deer) (USGS fossil vertebrate loc. D 197) are associated with charcoal in the upper 0.1 ft	1.6

Post-Piney Creek alluvium.—Post-Piney Creek alluvium (Malde, 1955, p. 244) underlies the flood plains of the major streams in the area except where the streams flow on bedrock. The thickness is not known because there are no cuts below stream level. At one place in Golden Gate Canyon, 5 feet of this material is exposed above stream level.

The deposits consist of coarse cobbly gravel containing boulders and, characteristically, a small amount of silt- and clay-size material. The coarseness varies with the size of the stream. At most places the alluvium lies directly on bedrock, but at some places it probably lies on older surficial deposits.

The alluvium in the valley of Ralston Creek presents a special problem, in that it resembles both Piney Creek and post-Piney Creek deposits. At many places along Ralston Creek, low terraces marked by meander scars and built of what resembles Piney Creek Alluvium, merge with the flood plain both upstream and downstream. The alluvial deposits in these terraces consist of silty to cobbly gravel and are believed to be post-Piney Creek alluvium, although they may be remnants of older deposits being reworked by Ralston Creek.

OTHER SURFICIAL DEPOSITS

Other surficial deposits, including a landslide, talus, alluvial fans, and colluvium, are not shown on the geologic map. A landslide at the center of the NW¼ NW¼ sec. 24, T. 3 S., R. 71 W., seems to be confined to a highly fractured pegmatite dike. The head is at the north contact of the pegmatite, and the toe is in Tucker Creek. The highly fractured rock, the steepness of the slope, and the continued erosion of the toe by Tucker Creek are all contributary causes of the landsliding. A 350 × 100-foot block at the toe has moved a few feet downhill since 1953. An excavation for road fill at the toe may have helped trigger this movement.

Talus covers steep slopes at several places in the district. The talus consists of a thick pile of loose angular rock at or near the angle of repose. On some slopes the talus is stabilized by trees and low bushes, but on others it is very loose and slides readily.

Fan-shaped deposits of heterogeneous silt- to boulder-size material are common along small valley bottoms where the small streams enter large ones. These alluvial fans are locally as much as 20 feet thick.

Colluvium mantles much of the Ralston Buttes district. It is as much as 15 feet thick but is generally much less. It is principally massive sandy silt, but it contains a great many cobbles and some boulders.

At two places in the foothills area a sloping very dark gray soillike horizon of clayey silt was found. The age of the deposit or soil(?) is not known, but it seems to be older than the Piney Creek Alluvium and younger than the Louviers Alluvium.

The following section showing the relation of the Pleistocene or Recent soillike horizon to adjacent deposits was measured in the SE¼SW¼ sec. 8, T. 3 S., R. 70 W. (fig. 14):

FIGURE 14.—Pleistocene or Recent soil(?). The pick blade is at the top of the layer of clayey silt, which is described as unit 3 in the measured section.

	Thickness (feet)
1. Sand, very dark gray brown, loose, massive, noncalcareous silty; contains many roots	0.2
2. Silt, dark-brown to dark-gray-brown, moderately firm, massive, noncalcareous, sandy, coarse; some pebbles and a few cobbles. At places it contains some charcoal. Thin layers similar to the underlying material occur near the base	5.9
3. Silt, very dark gray, soillike, firm, vertically jointed, noncalcareous, slightly clayey, sandy, coarse; some charcoal. Slopes steeply eastward, at angle greater than slope of top and bottom of gulch	.7
4. Silt, light-brownish-gray, firm, massive, noncalcareous, sandy, coarse	3.0

Unit 2 has the appearance of colluvium; downstream from the measured section it is overlain by what appears to be Piney Creek Alluvium. Unit 3 is the soillike horizon. The vertical jointing observed in it is similar to the prismatic structure found in some old soils (Malde, 1955). At the other locality where this soillike horizon was found (SW¼NW¼ sec. 8, T. 3 S., R. 70 W.), the material is almost identical in thickness, appearance, and slope. There the soillike horizon overlies a reddish-brown silt that grades downward into a reddish-brown clean coarse sand; the the soillike horizon is overlain by Piney Creek Alluvium.

PLEISTOCENE AND RECENT CAPTURES OF VAN BIBBER CREEK

The physiographic and lithologic relations of the different terrace deposits suggest that Van Bibber Creek captured part of the Ralston Creek drainage prior to Illinoian time, and that it captured part of the Crawford Gulch drainage in late Wisconsin or early Recent time. The earlier capture is shown by the physiographic relations between the Verdos Alluvium and the younger, Slocum Alluvium in sec. 8, T. 3 S., R. 70 W. The Verdos Alluvium caps the divide between Van Bibber and Ralston Creeks and slopes downward toward Ralston Creek; this indicates that the alluvium was derived from the Van Bibber Creek drainage by a stream which probably joined Ralston Creek near the present position of Ralston Reservoir. The Slocum Alluvium and all younger deposits of Van Bibber Creek, however, are topographically lower than the divide between the two streams. This shows rather conclusively that Van Bibber Creek captured part of the Ralston Creek drainage and took its present course between Kansan and Illinoian time.

The lithology of the Pleistocene and Recent deposits suggests that Van Bibber Creek captured part of the Crawford Gulch drainage in late Wisconsin or early Recent time. Pebbles of Boulder Creek Granodiorite are present in the Recent deposits of Van Bibber Creek. These pebbles could only have come from outcrops on Mount Tom. On the other hand, pebbles of Boulder Creek Granodiorite were not found in any of the Pleistocene deposits of Van Bibber Creek, which suggests that Mount Tom was not included in the Van Bibber Creek drainage during Pleistocene time.

In addition the district map (pl. 1) shows the similarity in shape and the straight-line relationship of the valleys of Crawford Gulch and the upper part of Van Bibber Creek. Both have gently sloping west sides and steeply sloping east sides. Remnants of a valley older and higher than the present valley are easily discernible on aerial photographs of the area. These valleys undoubtedly were once parts of the same valley. The lower part of Van Bibber Creek has incised a narrow, steep-walled valley into the bedrock. There is no evidence for an older, higher valley in this area. These observations seem to indicate that Van Bibber Creek captured Crawford Gulch above sec. 11, T. 3 S., R. 71 W., in late Wisconsin or early Recent time.

STRUCTURAL GEOLOGY

The Precambrian rocks were deformed during three major periods of Precambrian deformation and, in addition, were faulted during late Precambrian time. During the Laramide orogeny in Late Cretaceous and early Tertiary time, they were faulted further, and the Paleozoic and younger sedimentary rocks were sharply upturned and faulted.

Major folds in the Precambrian rocks trend east to northeast (pl. 1). The Precambrian Idaho Springs–Ralston shear zone trends northeast across the northern part of the Ralston Buttes district. Sedimentary formations of Paleozoic and Mesozoic age trend north-northwest. Major systems of fault and fracture zones trend northwest, and some cut both the Precambrian rocks and the younger sedimentary formations.

Geologic data on the Ralston Buttes district were insufficient for detailed analysis, dating, and correlation of events in the structural history; information from adjoining areas also had to be used. However, some problems remain unsolved. Many of these stem from imperfect knowledge of regional structural and stratigraphic relations. Their solution must await the completion of studies in other parts of the east-central Front Range.

STRUCTURE OF PRECAMBRIAN ROCKS

The structural history of the Precambrian rocks of the Ralston Buttes district comprises the following events, all but the last of which took place during the Precambrian:

1. An early period of plastic folding of Precambrian sedimentary and volcanic(?) rocks, probably accompanied by regional metamorphism.
2. A second period of plastic folding and regional metamorphism, accompanied by intrusion and partial metamorphism of the principal Precambrian igneous rocks.
3. A third period of Precambrian deformation during which igneous rocks and metasedimentary and metavolcanic(?) rocks were cataclastically deformed in the Idaho Springs–Ralston shear zone.
4. Probable movements of late Precambrian age forming ancestral equivalents of some or all of the presently recognized northwest-trending systems of faults and fracture zones.
5. Complex movements along the northwest-trending fault systems during the Laramide orogeny, in late Cretaceous and early Tertiary time, accompanied locally by deposition of hydrothermal veins and intrusion of dikes.

TERMINOLOGY

PLANAR STRUCTURAL FEATURES

Four main classes of planar structural features have been mapped in the Precambrian rocks of the Ralston Buttes district: (1) foliation due to mineral parallelism, generally but not always parallel to compositional layering, (2) foliation produced by intense granulation and shearing in the Idaho Spring–Ralston shear zone, (3) slip cleavage, and (4) axial planes of minor folds. In addition, there are faults and fracture zones which are considered separately.

In the broad connotation, foliation is a general term that includes planar structural features of several kinds —relict bedding, compositional layering, gneissic structure and schistosity in metamorphic rocks, primary flow structure in igneous rocks, and cleavage of various kinds. In the Ralston Buttes district we have mapped several types of foliation and have used separate qualifying descriptive phrases for the different symbols (see explanation of pl. 1) in order to designate the character of the features observed in the outcrops. In addition we show slip cleavage as a separate symbol.

The most common type of foliation is due to mineral parallelism—a preferred planar orientation of tabular or micaceous minerals or elongate and acicular minerals, with or without preferred linear orientation. In the older igneous rocks this foliation is probably related mainly to folding that occurred in the metamorphic rocks at the time the igneous rocks were intruded; in places it has been modified by cataclasis. In the metasedimentary and metavolcanic(?) rocks, the foliation due to mineral parallelism is generally parallel to the compositional layering. In many small folds the compositional layering and the foliation formed by planar arrangement of minerals are parallel with one another around the noses of the folds. In some outcrops compositional layering is not evident, but the areal relations indicate general parallelism of the foliation with layering of a larger order of magnitude.

Less commonly, foliation due to mineral parallelism transects the compositional layering. Unlike slip cleavage, the transecting foliation is not associated with crinkles.

Compositional layering, expressed by differences in mineralogy or by the relative proportions of minerals and hence by differences in color or texture, is a conspicuous feature of many but not all of the metasedimentary and metavolcanic(?) rocks. The layers range in thickness from about 1 inch to several feet, but some are as much as several hundred feet thick. Small-scale compositional layering is particularly well shown by calc-silicate gneiss. Large-scale layering is shown by the alternation of quartzose, mica-rich, conglomeratic and porphyroblastic rocks in the mica schist unit. The layering in some units, such as the interlayered hornblende gneiss, amphibolite, and biotite gneiss, is not as well defined because individual layers are commonly 10 feet or more thick and color and textural differences are not great. The compositional layering in most of the metasedimentary rocks probably reflects original bedding, although it has been modified by metamorphic differentiation and possibly by the local introduction of quartzo-feldspathic material.

In rocks of the Idaho Springs–Ralston shear zone a megascopic foliation characterized by closely spaced curved and anastamosing planes resulted from the shearing and attendant granulation. This type of foliation is shown on plate 1 by a separate symbol. In some of the rocks in the zone, these planes are accentuated by a dark coloration caused by concentrations of very fine epidote, biotite, and chlorite. Micaceous minerals occur as oriented flakes along these foliation planes but are very fine and, in some rocks, difficult to distinguish. Thin sections show that the cataclastic foliation is caused by a series of thin subparallel granulated zones, commonly anastamosing and wrapping around porphyroclasts (fig. 15), augen, and flaser. The granulated zones are separated by layers and lenses of less deformed rock and, in some rocks, by elongate lenses of intensely sutured quartz. Grains of muscovite, biotite, and chlorite in the granulated zones are oriented parallel to the zones. Some grains of these micas appear to be broken and smeared, but

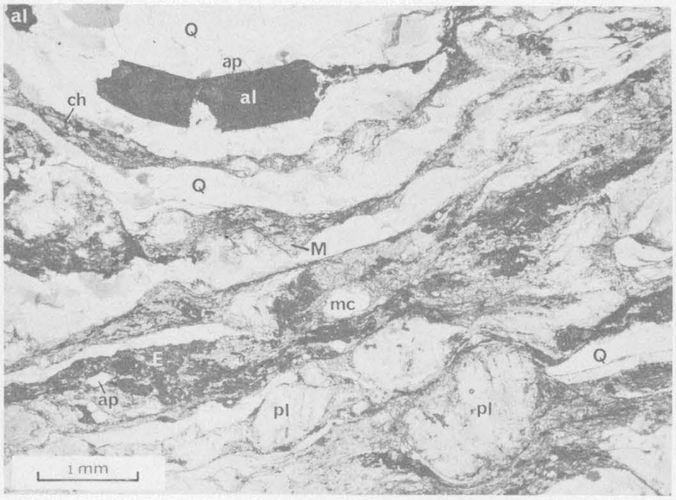

FIGURE 15.—Cataclastically deformed Boulder Creek Granodiorite from the Idaho Springs–Ralston shear zone, showing porphyroclasts of plagioclase (pl) and microcline (mc) and elongate lenses of sutured quartz (Q). The darker areas that anastamose around porphyroclasts and separate the quartz lenses are zones of finely granulated quartz and feldspars that contain chlorite (ch), muscovite (M), and clinozoisite-epidote (E). A large grain of allanite (al) has been broken and smeared out parallel to the granulated zones. Also shown are small grains of apatite (ap). Nicols partly crossed.

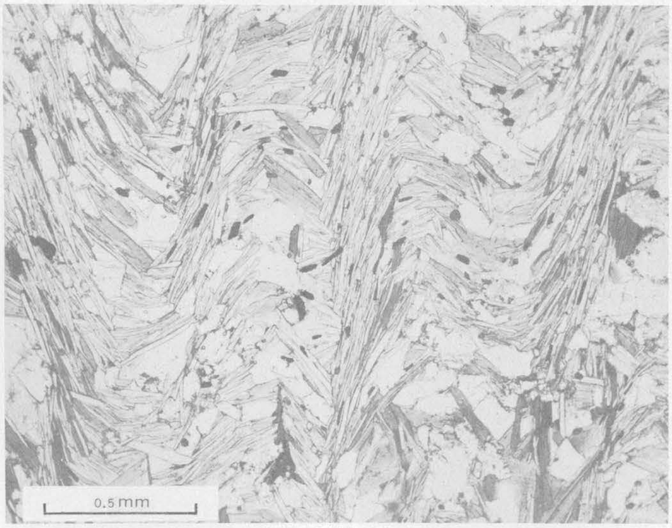

FIGURE 16.—Mica schist showing slip cleavage. Crinkled micaceous foliation in the schist extends from left to right. Slip cleavage, defined by concentrations of oriented mica flakes in the limbs of crinkles, extends from top to bottom and is parallel or subparallel to the axial planes of the crinkles. As shown typically here, the slip cleavage of the Ralston Buttes district most commonly consists of planes of incipient parting along the cleavages of the oriented micas. Plane-polarized light.

many others are unbroken crystals that evidently grew in place.

A planar feature commonly observable in parts of the mica schist unit and less commonly in the schist layers of the quartzite unit is called slip cleavage, following the usage of White (1949). The slip cleavage is associated with minute crinkles, but unlike that described by White in Vermont, it shows little visible microfaulting. The slip cleavage is shown by a separate symbol on plate 1 in order to distinguish it from the other types of foliation. It is commonly oriented at large angles to the compositional layering and the crinkled micaceous foliation.

In the Ralston Buttes district, slip cleavage consists of planes of incipient parting formed on the limbs of minute crinkles (fig. 16). The slip cleavage is parallel or subparallel to the axial planes of the crinkles. Amplitudes and wavelengths of the crinkles range from a fraction of a millimeter to about 5 mm. Where the crinkles and the slip cleavage are most pronounced, particularly in mica-rich schist, the ratio between amplitude and wavelength of the crinkles is 1:1 or larger, and the preferred orientation of the mica flakes forming the slip-cleavage planes causes the rock to split easily along these planes. Where crinkles are broad and open and wavelengths exceed amplitudes, slip cleavage is correspondingly less pronounced.

Some thin sections show that planes of slip cleavage are discontinuous. The most conspicuous parts of such planes occur where the crinkles are tight and the mica flakes defining the planes are perfectly alined. The less distinct parts occur where the crinkles are broad and open, and the micas flakes defining the planes are arranged en echelon. Actual breaks or microfaults along the slip cleavage are not common in the Ralston Buttes district.

The attitude of slip cleavage is shown on plate 1 only where this feature is conspicuous. Where exposures are too poor to allow determination of the attitude of the slip cleavage, we have plotted the lineation formed by the axes of the crinkles, a feature equivalent to the intersection of the slip cleavage and the crinkled micaceous foliation.

The attitudes of the axial planes of minor folds, as much as 50 feet in wavelength, are also shown on plate 1. A separate symbol is used for these to distinguish features of this size from the tiny crinkles associated with the slip cleavage.

LINEATION

The term "lineation" is used in a descriptive and nongenetic sense for any kind of linear structure within or on a rock (Cloos, 1946, p. 1). Lineation is common in all Precambrian rocks of the Ralston Buttes

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district except pegmatite, aplite, and hornblende-biotite lamprophyre. The types of lineation include alinement of elongate minerals or mineral aggregates, streaking, rodding, elongate pebbles, boundinage, and the axes of crinkles, crenulations, and minor folds. The bearing and plunge of linear features are indicated on the map (pl. 1).

Mineral alinement is commonly expressed by elongate minerals such as hornblende and by elongate glomeroporphyroblasts of sillimanite or mica pseudomorphous after sillimanite. Although biotite and muscovite tend to be less elongate in habit, close observation commonly reveals a slight elongation and alinement of individual flakes. More evident, however, is a mica lineation caused by alinement of elongate aggregates of flakes along the foliation planes. A similar linear feature in some rocks consists of elongate concentrations of quartz and feldspar which contrast with darker minerals. Elongate trains of garnet along the foliation planes are also present but are less common. In some of the complexly folded rocks, certain minerals, commonly quartz, are concentrated along small crenulations. The pencillike lineation thus formed is termed "rodding."

A lineation formed by intense cataclastic granulation and shearing is marked by a very fine micaceous streaking that resembles slickenside striae. Studies of thin sections suggest that this lineation was produced partly by smearing of mica flakes during the shearing, and partly by growth of new mica flakes parallel to the movement plane.

The small folds whose axes are measured as lineation are described separately in a succeeding section. Boudinage is recognizable in a few exposures, but accurate measurement of this type of lineation was seldom possible.

Some outcrops of mica schist contain as many as five different lineations, but only two or three of them can be shown at the map scale (pl. 1). These outcrops may show an alinement of elongate streaks of biotite or of sillimanite glomeroporphyroblasts; they may also show axes of tiny crinkles, larger minor folds, and gentle warps of one or two directions. For such outcrops, two of the more conspicuous and persistent lineations are shown together with the foliation symbol, and a symbol for a minor fold is plotted nearby.

SMALL FOLDS

Small folds whose axes are measured as lineation include small crinkles, somewhat larger crenulations, and still larger minor folds. The crinkles associated with slip cleavage generally have wavelengths and amplitudes of only a few millimeters, and the ratio of amplitude to wavelength ranges from about 1:5 to 2:1. The wavelengths of crenulations or warps range from half an inch to several inches, and the ratio of amplitude to wavelength is generally about 1:2 or smaller; locally some of these crenulations are almost chevron shaped. Wavelengths of the minor folds range from about 6 inches to 50 feet. Such folds range from broad and open to closed or nearly isoclinal, and some of the tight ones are overturned.

METAMORPHOSED SEDIMENTARY AND VOLCANIC(?) ROCKS

Folds in the metamorphosed sedimentary and volcanic(?) rocks range in size from fractions of an inch to over a mile wide. In this report, major folds are those large enough that the traces of their axial surfaces could be plotted on plate 1. In contrast with these, the minor folds, crenulations, and crinkles described in the preceding section are generally confined to single outcrops and are denoted by symbols on plate 1.

We use the terms "anticline" and "syncline" in a structural sense, mainly on the basis of the attitude of foliation and layering. Because "tops" are not actually known, however, the Precambrian folds may not all be stratigraphic anticlines and synclines; thus, the terms "antiform" and "synform" might be more appropriate. However, in the discussions that follow, the cores of anticlines are generally assumed to be occupied by relatively old rocks. In one exceptional example, younger rocks (by our stratigraphic interpretation) occur in the core of a structural anticline; as explained on p. 62, this anticline is interpreted as a crossfold on the overturned limb of an older anticline.

The major folds indicated on plate 1 represent our interpretation of the major structure in the Precambrian metasedimentary and metavolcanic(?) rocks. Criteria used for delineating the traces of axial surfaces of these folds include (1) attitudes of foliation and compositional layering, and orientation of linear features; (2) distribution of rock units; and (3) our interpretation of rock distribution in terms of possible stratigraphy. Classification of some of the major folds as anticlines or synclines is largely interpretive and tentative, because the dips of the foliation and layering are generally steep and the stratigraphic relations of the units are uncertain. Such folds are designated as inferred folds.

The major folds range from broad and open to closed or nearly isoclinal. Individual folds change from open and upright in one place to tight and overturned in another.

MAJOR FOLDS

The structural pattern formed by the major folds and the many related minor structural features is considered to be the combined result of two periods of Precambrian plastic deformation. The reality of these two periods is strongly supported by geologic evidence, as we will show; however, our data are not sufficient to establish definitely the extent to which the first deformation contributed to the present structural pattern. Tentatively, we have concluded that, of the major Precambrian folds shown on plate 1, one large anticline and the predecessor of an adjacent syncline are related to the first period of deformation. Although most of the folds are assigned to the second period, it is possible that some of these originated during the first period and then were intensified or modified during the second period. The Idaho Springs–Ralston shear zone, formed during a third period of deformation, obscures the effects of the earlier deformations in much of the northern part of the district and seriously hampers the correlation of earlier structural features across the zone.

FIRST PERIOD OF DEFORMATION

The major folds attributed to the first deformation include an anticline, whose axial surface trends northeast in the mica schist unit in the southwestern part of the district, and the probable predecessor of an adjoining syncline, whose axial surface trends east-northeast through Mount Tom (pl. 1). Although no major fold of the first period can be recognized north of the Idaho Springs–Ralston shear zone, certain linear features present in the rocks of the quartzite unit belong to the first period and suggest that an early fold, now completely obscured, predated the syncline shown in that area.

The anticline is a large structural feature defined by the symmetrical repetition of lithologic units on each side of the central unit of mica schist. The fold is broad, open, and upright near the center of the district, but toward the southwest it becomes tight and overturned. As shown in the vicinity of section *A–A′*, the axial surface dips 70° NW. and the northwestern limb dips more gently to the northwest than the overturned limb. The limbs of the fold, outlined effectively by the subdivisions of the hornblende gneiss unit, converge southwestward toward the fault in Guy Gulch. For about a mile west of the fault the character of this early fold is complicated by the effects of later crossfolding. Near the western boundary of the district the fold is nearly isoclinal, and the axial plane dips about 75° NW. The axis of the anticline is believed to plunge gently to the west-southwest. The tight segment of the fold near the western boundary may be a structural saddle reflecting local sinuosity of the gently plunging axis.

The major anticline occupies the largest part of section *A–A′* (pl. 1), but we do not consider the other anticline, shown near the south end of the section, to be related to it as a subsidiary fold. We believe that this southern anticline was formed as a crossfold during the second period of deformation.

Most of the minor folds indicated by form lines in section *A–A′* show apparent relative movements that are the reverse of those one would expect for normal drag folds on the major large anticline; exceptions are those in mica schist on the southeastern limb. Many of these minor folds probably formed during the second period of deformation, but some may have formed during the first period by one or more of the methods described for reversed drag folds by Harrison and Wells (1959, p. 29, fig. 10) and by Moench, Harrison, and Sims (1962, p. 42).

Although the syncline shown near the northwestern end of section *A–A′* is correlated with the second period of deformation, a simpler version of the present fold probably formed during the first period contemporaneously with the formation of the large anticline to the south. The arcuate distribution of the rock units east of the large body of Boulder Creek Granodiorite suggests that a broad open syncline plunging gently west-southwest was formed during the first period. The major part of the fold, however, was modified considerably by the folding and the syntectonic intrusion of the Boulder Creek Granodiorite during the second period.

In the quartzite unit, in the northern part of the district, a lineation formed by mineral alinement commonly plunges south-southwest. In many exposures, however, this lineation is folded by northeast-plunging minor folds belonging to the major syncline into which the quartzite is folded. Because the mineral alinements are deflected in plunge and bearing by the folding, they must have formed prior to the northeast-plunging folds. The formation of this lineation is correlated with the deformation of the rocks during the first period, and the major syncline and associated minor folds are correlated with the second period. Although an early major fold may have formed at the same time as the mineral alinements, the plan of such a fold could not be determined from the available data.

SECOND PERIOD OF DEFORMATION

The largest folds belonging to the second period of deformation are the syncline in the northwestern part of the district, the syncline traced through Mount Tom, and the anticline near the southern boundary of the district (pl. 1). Several smaller folds also attributed to this period occur in the southwestern and northeastern parts of the district.

The large syncline north of Ralston Creek is defined by the distribution and attitudes of the subdivisions of the quartzite unit and by most of the minor structural features present in that area (pl. 1). The axis of this asymmetric fold plunges about 20° N. 60° E., and the axial surface dips about 80° SE. The complexly and tightly folded southeastern limb dips steeply northwest along part of its extent, but locally is slightly overturned. The northwestern limb is relatively simple and dips 50°–75° SE. The trough of the syncline is fairly simple for a distance of 1,000 feet northeast from the western boundary of the district. Between this area and the phacolithic body of Boulder Creek Granodiorite, however, the trough is crumpled into subordinate folds, including an anticline flanked by synclines. The anticline appears to be a local doubly plunging fold in this disharmonically folded and much thickened part of the schist layer. Many of the small minor folds, here and elsewhere in the schist layers of the quartzite unit, are thickened in the crests and more intensely folded than the quartzite layers. Farther northeast the major syncline is simpler in form, and a second schist layer defines the position of the trace of the axial surface. The absence of a much-thickened section of this schist layer in the trough suggests that the major folding here was more harmonic than farther southwest. Most of the asymmetric minor folds in the quartzite unit (pl. 1) indicate apparent relative movements that correspond to the expected pattern of normal drag folds associated with the major syncline. In the northeastern exposures of the unit, however, the asymmetry of some of the minor folds suggests that these may be reversed drag folds related to tight folding of layers of contrasting competency. It is also possible that some of these apparently reversed minor folds are actually related to movements during the third period of Precambrian deformation.

The syncline whose axial surface is traced through Mount Tom is broad and open in the central part of the district but becomes tight and overturned farther west. In the eastern part of the fold the axial surface is vertical, and the axis appears to plunge west-southwest at a moderately steep angle. In the western part, the axial surface dips north and is distorted in plan, and the axis plunges about 50° N. 65° W. The overturning of this syncline along its trend probably reflects the effects of folding during the second period of deformation combined with syntectonic intrusion of Boulder Creek Granodiorite in the northern limb. A simpler version of this syncline probably formed during the first period of deformation, as noted on p. 61.

The anticline close to the southern boundary of the district is upright and moderately tight. The trace of the axial surface trends nearly due west over most of its extent but trends N. 75° W. in the western part. The axial surface dips vertically to 85° N., and the axis plunges at a low to moderate angle west-northwest. As shown in the section, the asymmetry of the minor folds on the limbs of the anticline indicates movements consistent with normal drag folds on a major anticline. The unit of interlayered gneisses forms the core of this anticline (section *A–A′*, pl. 1), whereas this same unit comprises the apparently youngest unit of metasedimentary and metavolcanic(?) rocks on the limbs of the larger anticline whose axial surface is traced in the mica schist to the north. The presence of younger rocks in the core of this southernmost structural anticline is explained by our interpretation that the rock units affected by this fold are in the overturned limb of the large older anticline. This relationship and the absence of a pattern of rock distribution indicating a syncline between the two anticlines, together with the differences in the trend of the axial surfaces of the two anticlines and the bearing of their axes, support our conclusion that the southernmost anticline was formed during the second period of deformation as a crossfold on the southern limb of the larger and older anticline.

Several folds of smaller size elsewhere in the district are tentatively correlated with the second period of deformation. South of Ralston Creek in the northeastern part of the district, three folds are defined by the distribution and attitudes of the rocks in the undivided hornblende gneiss unit and the mica schist unit. The northwesternmost of these folds is a syncline whose axis plunges about 65° S. 55° W. To the southeast is an anticline whose axis plunges about 70° S. 75° W. Farther east is a small southwest-plunging syncline, the features of which are noted in the description of the Schwartzwalder mine. In the west-central part of the district, in the unit of interlayered gneisses between Mount Tom and Guy Gulch, there is a small fold inferred to be a syncline. As shown on plate 1, the attitudes of foliation and layering in this area form a complex pattern. The fold could be interpreted as an open fold containing many tight minor folds, as we have indicated on plate 1, or as a complex overturned fold. Southwest of Guy Gulch in the vicinity of Douglas Mountain an overturned anticline and a syncline, both plunging west-southwest, have been inferred on the basis of the rock distribution.

Reconnaissance work west of the district has provided supporting evidence of these folds. The asymmetry shown by the combination of these two folds suggests a relative movement of units that could represent a normal drag fold on the northern limb of the large anticline of the first period. However, because this asymmetry is the same as that shown by the small anticline along Elk Creek and by the anticline near the southern boundary, we have concluded that all these folds are later structural features superimposed on the large older anticline. Minor folds in the vicinity of Elk Creek (pl. 1) plunge 68° N. 70° W. and may represent the approximate plunge of the small anticline inferred from the rock distribution in this area.

RELATION OF LINEATIONS TO MAJOR FOLDS

In many metamorphic terranes, lineations genetically related to large folds are either parallel to or at a large angle to the major fold axes. Such relations, for example, have been described for two major fold systems recognized in the Chicago Creek area of the Front Range near Idaho Springs (Harrison and Wells, 1959, p. 27–33). In a coordinate system used recently in a geometric sense by Moench, Harrison, and Sims (1962, p. 40), "*B* refers to major fold axes and to linear elements essentially parallel to them, *A* refers to linear elements that are nearly at right angles to axes of major folds."

The geometric relations of lineations to some of the major folds in the Ralston Buttes district can be demonstrated, but the relations of lineations to other folds are only partly known and are largely interpretive. *B* lineations, or those subparallel to major fold axes, are the principal types recognized in the district. In the quartzite unit these lineations plunge northeast, following the orientation of the axis of the major syncline outlined by this unit. Elsewhere in the district, lineations commonly plunge west-southwest or west and west-northwest. Those plunging west and west-northwest are subparallel to the axes of major folds of the second period of deformation. The lineations plunging west-southwest appear to reflect the orientation of the axes of the earliest folds in some parts of the area, and the axes of some folds of the second period in other parts of the area. Orientation of lineation, therefore, does not serve to identify the generation of folding except locally.

A lineations have been recognized only where some of the axes of crinkles and crenulations and other minor lineations are oriented at a large angle to the axes of major and minor folds. With the exception of the early mineral alinements noted in the quartzite unit and described previously, definitive age relations among different types of lineation are rarely discernible in the district.

As an aid to structural interpretation, we made statistical studies of the lineations. Orientation diagrams were prepared for the lineations in three geographic subdivisions of the district: (1) the area encompassing the major syncline in the quartzite unit (fig. 17); (2) the northern part of the district (fig. 19), excluding the area occupied by quartzite unit; and (3) the southern part of the district (fig. 20). The boundary between the areas represented by figures 19 and 20 was arbitrarily chosen as the southern boundary of T. 2 S. All lineations measured in the outcrops were plotted on the lower hemisphere of Schmidt equal-area nets for contouring. Because the diagram for the quartzite unit (fig. 17) was contoured on an unequal distribution of the various types of lineation, we have included a scatter diagram (fig. 18) showing this distribution. The orientation diagrams for the other two areas, however, represent an approximately even distribution of the various types of lineation with only one exception, which is noted in the discussion of figure 19. Some inaccuracies are unavoidable in this method of contouring, because structural elements of two periods of folding vary in bearing and plunge, and they overlap in orientation, thereby complicating

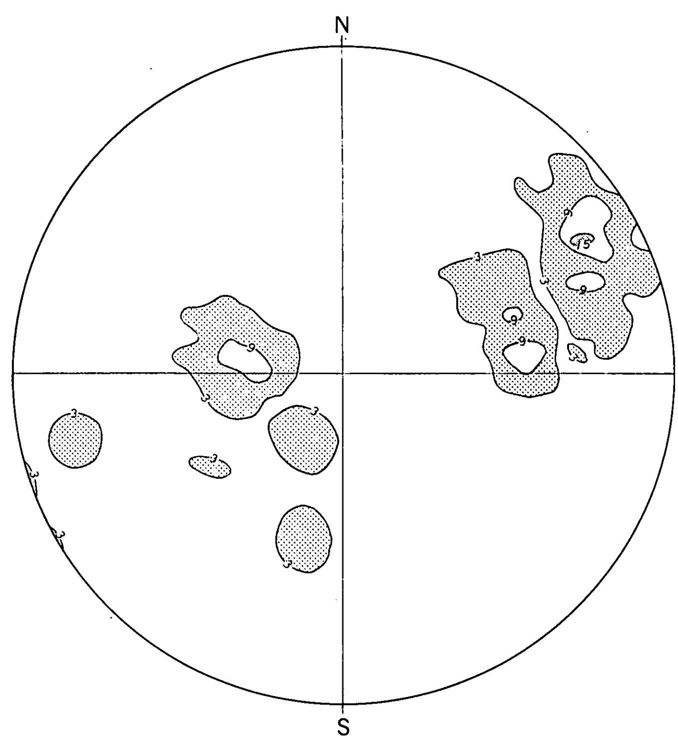


FIGURE 17.—Orientation diagram of lineations in the quartzite unit of Precambrian age. Lower-hemisphere projection of 57 poles on equal-area net. Contoured in percent of poles per percent area.

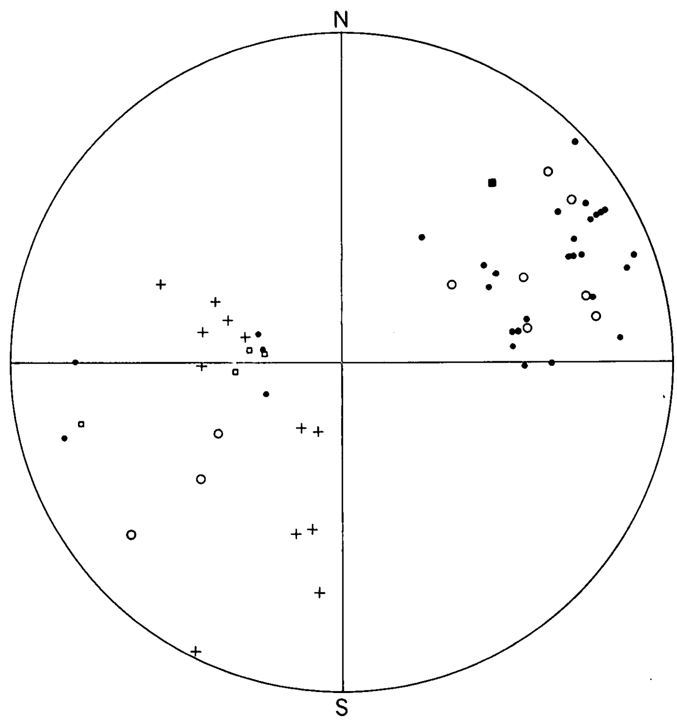


FIGURE 18.—Scatter diagram of lineations in the quartzite unit of Precambrian age. Lower hemisphere projection of 57 poles on equal-area net. +, mineral alinement; ●, axis of minor fold; ○, axis of crinkle or crenulation; □, streaking; ■, longest dimension of elongate pebble.

the interpretation of the contours. Nevertheless these diagrams illustrate major facets of our knowledge of the Precambrian folding.

The greatest statistical concentration of lineations in the quartzite unit (fig. 17) is the 15-percent contour representing a plunge and bearing of 18° N. 60° E. This statistical concentration is consistent with the form of the syncline and the attitudes of the limbs, which indicate that the major axis plunges about 20° N. 60° E. The lineations forming this maximum concentration are, therefore, *B* lineations. As shown in the northeast quadrant of figure 18, these lineations include axes of minor folds, axes of crinkles and crenulations, and a single reading on an elongate pebble in conglomeratic quartzite. Subordinate concentrations indicated by the 9-percent contours in the northeast quadrant of figure 17 range in plunge and bearing from 23° N. 70° E. to 44° N. 85° E. The genetic explanation for these subordinate concentrations is not apparent in the field, because where crenulations or crinkles of two slightly diverging northeast trends exist in the same outcrop, neither set noticeably warps the other. Therefore these deviations from the maximum concentration may reflect either a normal variation in bearing and plunge to be expected in small folds associated with the major syncline, or an unrecognized minor stage of the folding.

The contours in the western quadrants of figure 17 represent a variety of lineations, as indicated in figure 18. Because field evidence indicates differences in the ages of some of these lineations, the contours in these quadrants represent an overlap of structural data and, in view of the limited number of readings, are not statistically meaningful. Therefore, the various lineations must be considered individually.

In many outcrops of the quartzite unit, mineral alinement is warped or folded by northeast-plunging minor folds. Without this significant field evidence, one might erroneously conclude from figure 18 that all the mineral alinements are *A* lineations oriented at large angles to the major axis of folding. Such *A* lineations, although showing differences in plunge and bearing on opposite limbs of an open fold, should maintain a symmetrical relation to the fold. However, many of the mineral alinements in the quartzite unit do not show this symmetry as they are traced from limb to limb of minor folds. Instead, the deflections in plunge and bearing across the axes of the folds indicate that the mineral alinements existed prior to the formation of the northeast-plunging folds. We have interpreted this as evidence that much of the mineral alinement in the quartzite unit is relict from the first period of deformation.

Field observations also indicate that some of the minor folds and crinkles plotted in the southwest quadrant (fig. 18) are local reversals in the direction of plunge of these features, and suggest correspondingly that the major axis of the syncline is somewhat sinuous in longitudinal section. However, the asymmetry of two steeply plunging minor folds plotted in the northwest quadrant of figure 18 indicates that unless these are reversed drag folds, they are not genetically associated with the syncline. These folds and some of the streaking may be related to movements in the Idaho Springs–Ralston shear zone during the third period of deformation.

The greatest statistical concentration of lineations in the northern part of the district (fig. 19), excluding the area occupied by the quartzite unit, is the 16-percent contour indicating a plunge and bearing of 52° S. 72° W. Although the types of lineation contoured in this diagram are mostly evenly distributed, a major exception is a concentration in the southwest quadrant of nearly all the lineations formed by a streaking which is related to cataclastic deformation of the third period. The statistical "high" in this quadrant, therefore, is made up of the overlap of struc-

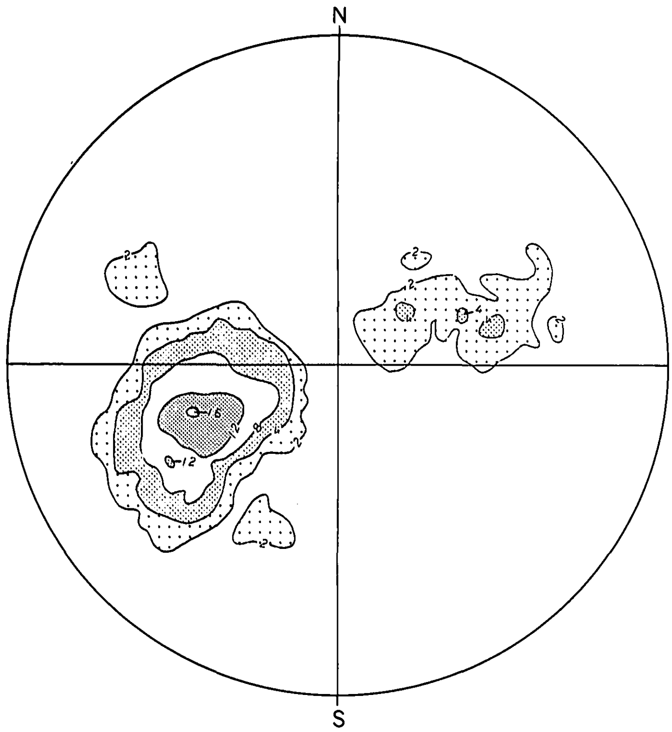


FIGURE 19.—Orientation diagram of lineations in metamorphosed sedimentary and volcanic(?) rocks of Precambrian age, T. 2 S., northern part of Ralston Buttes district. Lineations in the quartzite unit are excluded. Lower hemisphere projection of 136 poles on equal-area net. Contoured in percent of poles per percent area.

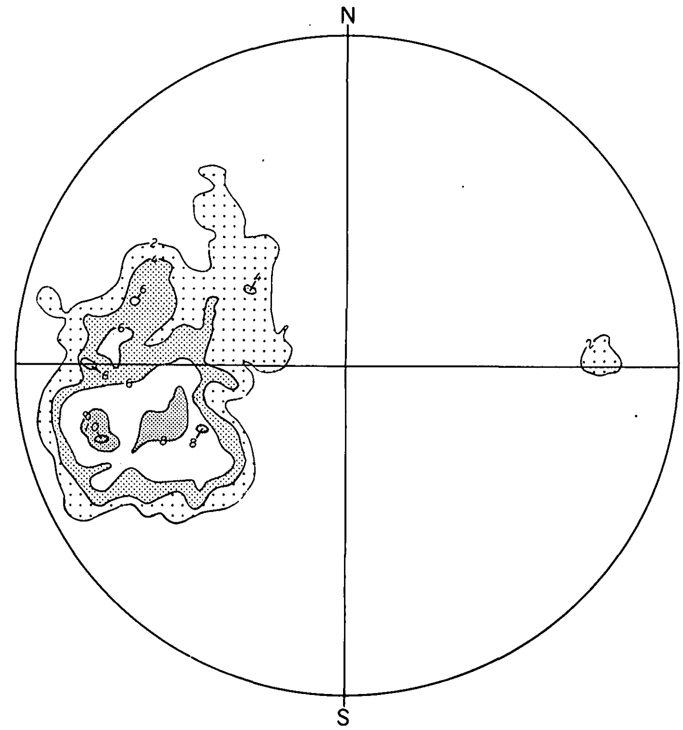


FIGURE 20.—Orientation diagram of lineations in metamorphosed sedimentary and volcanic(?) rocks of Precambrian age, T. 3 S., southern part of Ralston Buttes district. Lower hemisphere projection of 167 poles on equal-area net. Contoured in percent of poles per percent area.

tural elements belonging to three periods of deformation. More useful to our description of lineations related to major folds are the 12-percent contours which represent lineations ranging from 40° to 63° in plunge and from S. 55° W. to S. 80° W. in bearing. Some of the lineations in this range are the *B* type; they reflect the moderately steep southwest plunges of the axes of major folds of the second period along the contact between the undivided hornblende gneiss unit and the mica schist unit (pl. 1). Some of the lineations may be related to modified unrecognized folds of the first period of deformation in this area. The smaller concentrations of lineations in the northeast quadrant range in plunge and bearing from 48° N. 76° E. to 68° N. 52° E. This range is similar to that of some of the concentrations shown for the quartzite unit (fig. 17). These smaller concentrations may indicate minor fold elements that are common to all the metasedimentary rocks of the northern part of the district. With the exception of the syncline in the quartzite unit, however, no other major northeast-plunging fold is known in the district.

The greatest statistical concentration of lineations in the southern part of the district (fig. 20) is the 10-percent contour indicating plunge and bearing of 23° S. 73° W., but other lesser concentrations are indicated by 8-percent contours centered at 42° S. 72° W. and 50° S. 67° W. In the northwest quadrant the 6-percent contours indicate lineations ranging in plunge from 23° to 33° and in bearing from N. 73° W. to N. 90° W.

The maximum concentration at 23° S. 73° W. (fig. 20) probably represents *B* lineations of the first period of deformation because it is consistent with the probable bearing and plunge of the large anticline of this age. The concentrations having steeper plunges in the southwest quadrant are similar to concentrations in figure 19 and are probably *B* lineations related to the second period of folding. Major folds related to this steeper southwest plunge are the two shown near Douglas Mountain and possibly the small syncline southwest of Mount Tom. The statistical concentrations indicating a west-northwest plunge are *B* lineations reflecting the axes of major crossfolds belonging to the second period of deformation, such as the anticline in the southernmost part of the district and the anticline along Elk Creek. These orientations deviate only slightly from that of the western part of the syncline traced through Mount Tom.

DISCUSSION OF THE TWO EARLY PERIODS OF DEFORMATION

Mineralogical, textural, and structural features of the Precambrian metasedimentary and metavolcanic(?) rocks indicate that during the first two periods, deformation was chiefly plastic and that folding took place at great depth and at high pressure and temperature. The evidence includes: (1) Suites of metamorphic minerals which indicate high-grade metamorphism; (2) distinct foliation and lineation due to mineral alinement in many of the rocks, indicating extensive crystallization or recrystallization of minerals in a stress environment; (3) common occurrence of porphyroblasts, some showing linear arrangement; (4) absence, except in the Idaho Springs–Ralston shear zone, of widespread cataclastic textures and structures which would indicate deformation by granulation and rupture; and (5) the character of major and minor folds, including common disharmonic folds and rounded crests and troughs. Lacking any evidence of earlier events, we assume that in the early stages of the first period of folding, the original sedimentary and volcanic(?) rocks recrystallized, and that the rocks were already foliated and high in metamorphic grade by the time of the second period of folding. The general parallelism between compositional layering and the foliation formed by planar arrangement of minerals, the persistence of this parallelism around the noses of many minor folds, and the apparent absence of widespread axial-plane foliation suggest that during both periods folds formed by flexure.

Our division of the early deformational history into two separate periods is based on facts and interpretations that have been discussed in preceding pages and can be summarized briefly as follows:

1. The presence in the quartzite unit of deformed mineral alinements indicates that this lineation must have been formed prior to the recognized folds in that unit.
2. The symmetrical repetition of units adjacent to the mica schist unit in the southern half of the district probably indicates a large fold of the first period of deformation; the available structural data suggest that this fold is a west-southwest-plunging anticline.
3. The west-northwest plunge of the axes of the major anticline near the southern boundary of the district and of the anticline along Elk Creek, together with the manner in which these folds distort the rock patterns, suggests strongly that these folds are crossfolds superimposed on the large west-southwest-plunging anticline.
4. The asymmetry shown by these crossfolds, by the two folds near Douglas Mountain, and by many of the minor folds in the southern part of the district is the same; hence pervasive movement in a consistent pattern apparently occurred after the large west-southwest-plunging anticline had formed.
5. The orientations of major folds, lineations, and other minor structural features are all consistent with the interpretation that younger folds cross older folds at small angles.
6. The overturned part of the syncline traced westward through Mount Tom and the accompanying change in bearing of the axis suggest modification of an early simple syncline by later folding.

The validity of our interpretation of two early periods of plastic folding depends a great deal on whether the symmetrical repetition of units in the southern half of the Ralston Buttes district truly represents a large fold. It might be argued alternatively, for example, that what seems to be repetition by folding is in reality a depositional feature and that the entire succession of units from the southern boundary of the district to the western boundary near Mount Tom represents a continuous stratigraphic sequence in which lithologies are cyclically repeated, as in certain transgressive-regressive deposits. If this were true, the entire structural pattern south of the Idaho Springs–Ralston shear zone could be the result of a single period of folding. Then, the early mineral alinement in the quartzite unit would have to be interpreted either as a product of a localized early deformation (rather than as an element of a pervasive districtwide deformation) or as an old but foreign alinement brought to this area by a very large horizontal displacement on the Idaho Springs–Ralston shear zone. Although the stratigraphic hypothesis is plausible, we favor the structural hypothesis because the symmetry of the lithologic units in the southern half of the district is nearly perfect and because most of the available structural data support it.

In a similar manner, our classification of this large fold as an anticline depends on the validity of our interpretations of the structural data, because we have no independent evidence of the age relations of the rock units to prove that this fold is both stratigraphically and structurally an anticline. Thus, for example, if the smaller anticline near the southern margin of the district were actually related to the larger fold rather than being a younger crossfold, then the absence of a reversal of the succession of units between these two folds would require that the larger fold be a syncline. We believe, however, that a large syncline is less likely because the anticline near the southern boundary, the folds at Elk Creek and Douglas Mountain, and many of the minor folds in the area all have patterns of asymmetry that suggest that they were superimposed as younger crossfolds on the larger fold. By our interpretation, therefore, these crossfolds cannot be regarded as drag folds that would indicate the nature of the larger fold.

Although we believe that our interpretation of two early periods of plastic deformation is consistent with most of the geologic data in the Ralston Buttes district, this interpretation and the classification of the large early fold as an anticline must be considered tentative until the geology of this district can be related more definitely to regional patterns of Precambrian structure and stratigraphy, which are as yet incompletely known. Major problems remaining within the district as well as some regional problems are discussed next.

One of the major unsolved problems of the Ralston Buttes district is the relation of structural patterns on the two sides of the Idaho Springs–Ralston shear zone. Certain facts are troublesome and are thus far unexplained: (1) no early fold of the first period of deformation can be recognized in the quartzite unit; (2) the large syncline in the quartzite unit has no complimentary anticline in the metasedimentary and metavolcanic(?) rocks to the southeast; and (3) the large syncline in the quartzite unit plunges northeast, whereas all folds of the second period south of the Idaho Springs–Ralston shear zone plunge southwest and west-northwest. Perhaps, as suggested by Tweto and Sims (1963, p. 998–1000), the Idaho Springs–Ralston shear zone is a profound and very ancient zone of discontinuity, and the cataclasis is only a relatively young event in its history. Another possibility is that the cataclasis itself reflects movements of large magnitude in which unrelated structural units were brought into juxtaposition. Still another possibility is that the differences on the two sides of the shear zone merely reflect the effects of superimposed foldings and the chance destruction of some of the evidence by igneous intrusion and cataclasis. The answer to this problem may well lie outside the Ralston Buttes district.

The geology in the area between Ralston Creek and the large body of Boulder Creek Granodiorite to the south is also problematic. In this area the mica schist unit and the bordering belts of hornblende gneiss on each side all thin westward. Although this pattern could have been formed by folding during the first period, evidence of such folding has not been found. Therefore, we have tentatively concluded that the westward thinning of these units represents stratigraphic pinching.

The relation of slip cleavage to the deformation history of the Precambrian rocks is not definitely known. The close association of slip cleavage and crinkles in the micaceous foliation in schist suggests that both features formed after the micaceous foliation had formed. Unlike the late foliation in the Idaho Springs–Ralston shear zone, the slip cleavage has a wide variation in strike. This variation and the occurrence of the slip cleavage in rocks principally outside the shear zone suggest that most of the slip cleavage is not related to the third period of deformation; possible exceptions are a few occurrences of slip cleavage in schist of the quartzite unit. Most of the slip cleavage may have formed during the second period of deformation as a subsidiary effect of folding in incompetent rocks. However, no evidence of a consistent geometric relation between the cleavage and minor folds has been found.

Local occurrences of micaceous foliation transecting the compositional layering are in marked contrast with the more general parallelism of foliation and layering and cannot be explained by the available data. Although the transecting foliation could be a locally formed axial-plane foliation, none of the occurrences are traceable to a fold nose defined by layering or even to the overturned limb of a tight fold. The transecting foliation may be only an exceptional feature of minor significance, but it is also possible that it could be a relict of a once-pervasive axial-plane foliation—now largely obscured by the effects of the second period of deformation.

A major problem of regional scope is the correlation of Precambrian structural events recognized in the Ralston Buttes district with those recognized farther west in the Front Range. Although they are in general agreement regarding the relatively late period of deformation characterized by cataclasis, geologists who studied the Idaho Springs–Central City area in great detail reported only one early period of plastic folding (Moench and others, 1954, 1958; Harrison and Wells, 1959, p. 27–33). However, Moench, Harrison, and Sims (1962, p. 45) also recognized that a convergence of lithologic units in part of the Idaho Springs–Central City area suggests the possibility of a fold system older than their single early period of plastic folding. Because linear elements of such an older fold system apparently are not present in that area, Moench, Harrison, and Sims (1962, p. 45) concluded that the convergence of lithologic units represents stratigraphic pinchouts rather than structurally controlled features. Recent detailed studies in the Blackhawk quadrangle west of the Ralston Buttes district by R. B. Taylor (oral commun., 1964) indicate that the Precambrian rocks were deformed during three major Precambrian periods of deformation, but his conclusions concerning the structural features differ in some respects from ours. Taylor characterized the results of three major periods as follows, beginning with the oldest: (1) Plastic folds whose axes trend N. 45°–60° W.; (2) plastic folds whose axes trend north-northwest to north-northeast, and syntectonic intrusion of the Boulder Creek Granodiorite; (3) plastic folds whose axes trend east-northeast, followed by cataclastic deformation in the Idaho Springs–Ralston shear zone. Taylor did not confirm our conclusions regarding an anticline plunging gently west-southwest in the southern part of the Ralston Buttes district, but he noted that, if present, the fold must predate his earliest folds. Taylor also noted that if his structural interpretations are correct, the syncline outlined by the quartzite unit may be mostly the result of early plastic folding during the third period, rather than a product of deformation during the second period.

Finally, another regional problem concerns the detailed history of the Idaho Springs–Ralston shear zone. Although we have classified this structural zone as the effect of the third period of deformation, our observations have been limited to the relatively short segment of the zone within and adjacent to the Ralston Buttes district. By interpreting the available geologic data on the regional relations of the shear zone throughout its length, Tweto and Sims (1963, p. 998–1000, 1008) concluded that the cataclasis is a relatively young Precambrian feature of the zone. They believe that movements occured in the shear zone as early as the stage of regional metamorphism and primary folding, and that movements probably recurred at many times during a long, complex history.

IGNEOUS ROCKS

The principal Precambrian igneous rocks, including Boulder Creek Granodiorite, quartz monzonite, and hornblende diorite and associated hornblendite, form intrusive bodies of various sizes and shapes. The Boulder Creek Granodiorite and the quartz monzonite occur principally in elongate large bodies, which commonly trend parallel or subparallel to the major folds (pl. 1). A moderately large body of Boulder Creek Granodiorite in the trough of the syncline in the quartzite unit has the structural position and shape of a phacolith. Hornblende diorite forms a small pluton in the northeastern part of the district and, together with associated hornblendite, forms small irregular dikelike bodies in the same area.

All the principal igneous rocks contain a weak to moderately well developed foliation caused by the planar parallelism of micaceous or elongate minerals. In the parts of the igneous bodies that lie within the Idaho Springs–Ralston shear zone, this foliation is largely obscured by the younger foliation resulting from granulation and shearing.

Although the field relations and textural features indicate that the older of the two foliations formed prior to cataclasis in the shear zone, the available structural data do not conclusively show whether some of this early foliation represents an igneous flow structure or whether it is all a metamorphic foliation formed after consolidation of these rocks. At least some of this foliation is of metamorphic rather than igneous origin because: (1) the foliation and lineations in the igneous rocks are in many places parallel to those in adjacent wallrock; (2) the moderately well foliated parts of the hornblende diorite have typical metamorphic textures as observed in thin sections; (3) in the bodies of Boulder Creek Granodiorite in the west-central and southwestern parts of the district there are a small number of minor folds which are similar in bearing and plunge to minor folds in wallrock; and (4) foliation in the southeastern end of the large body of Boulder Creek Granodiorite in the west-central part of the district is discordant with the contact, which suggests that at least part of the foliation in this body formed after the rock consolidated.

From areal and structural relations we conclude that the principal igneous rocks were emplaced during the second of the three periods of Precambrian deformation. In the Idaho Springs–Ralston shear zone the cataclasis of the third period of deformation is superimposed upon textural and structural features that characterize uncataclasized Boulder Creek Granodiorite and quartz monzonite everywhere in the district. These geologic relations indicate that these igneous rocks must have been emplaced prior to the third period. Although the hornblende diorite and associated hornblendite do not occur in the shear zone, foliation in the hornblende diorite is the same type as the metamorphic foliation of the wallrocks and is therefore probably older than the cataclasis of the third period of deformation. The principal reason for believing that the major igneous rocks were emplaced during the second period of deformation rather than the first is the phacolithic nature of the Boulder Creek Granodiorite in the trough of the syncline in the quartzite unit, which suggests that it was emplaced during the major folding which produced the syncline. For reasons presented in the description of major folds, we believe that the syncline was formed during the second period of deformation. Similarly, the elongate body of Boulder Creek Granodiorite north of Mount Tom generally parallels an adjacent large syncline. Although this particular syncline probably appeared during the first period of deformation, it was considerably modified during the second period.

In summary, the principal Precambrian igneous rocks all appear to have been emplaced during the second period of deformation and should therefore be classified as syntectonic. After they consolidated but before the close of the second period, these rocks were deformed; locally, minor folds formed. Finally, during the third period of deformation, later in the Precambrian, some of these rocks were deformed cataclastically.

IDAHO SPRINGS–RALSTON SHEAR ZONE

The Idaho Springs–Ralston shear zone, which trends northeast across the northern part of the Ralston Buttes district (pl. 1), is a major structural feature assigned by us to the third period of Precambrian deformation. The shear zone was named by Tweto and Sims (1960; 1963, p. 998–1000), who indicated that it extends from the Idaho Springs area northeast to the mountain front. As interpreted by Tweto and Sims (1963, p. 999), the structural history of the zone is long and complex, dating back to the time of primary Precambrian folding and regional metamorphism. The rocks of the segment of the shear zone in the Ralston Buttes district have been described in preceding parts of this report. The following discussion summarizes the structural features and regional relations.

STRUCTURAL FEATURES

The Idaho Springs–Ralston shear zone, shown by the shaded area on plate 1, trends about N. 65° E. across the northern part of the Ralston Buttes district and ranges in width from about 4,700 feet near the western edge of the district to 8,200 feet southeast of Blue Mountain. The southeastern boundary of the zone corresponds to the southeastern contact of the quartz-feldspar cataclastic gneiss. Southeast of this boundary, zones of cataclasis are scattered, narrow, and faint. The northwestern boundary is less definite but generally corresponds to the trough of the syncline outlined by the quartzite unit.

Within the shear zone, intensely cataclasized rocks form lenses and layers that alternate with rocks that are only slightly to moderately cataclasized. The alternation of intensely cataclasized rocks with relatively coarse rocks is illustrated in the northeastern part of the map (pl. 1) by the interfingering of quartz-feldspar cataclastic gneiss with less deformed associated rocks. This pattern of alternation is repeated throughout the shear zone but could not be shown on the map because of scale. It even appears at the scale of hand specimens and thin sections.

Where cataclasis was intense, foliation and lineation related to it are distinct. Although the attitude of the foliation varies somewhat, the strike is generally N. 50°–60° E., and the dip, 70°–85° SE. (pl. 1). Lineation formed by fine micaceous streaking of the slickenside type occurs on these foliation planes and, although difficult to recognize in many places, generally plunges southwest at moderate angles.

In most of the shear zone, the late or cataclastic foliation is subparallel to the earlier formed foliation. Locally, however, the late foliation cuts the early foliation, a relationship which is common in the Boulder Creek Granodiorite from the boundary of the Ralston Buttes district westward for about 2 miles.

Although small folds persistent along strike for long distances characterize the Idaho Springs–Ralston shear zone in the Idaho Springs area (Harrison and Wells, 1959, p. 30–32; Moench and others, 1962, p. 45–48; Tweto and Sims, 1963, p. 999), such folds have not been recognized in the shear zone within the Ralston Buttes district. Undulations along the southeastern boundary of the shear zone (pl. 1) might represent discontinuous and minor warping, but they could reflect equally well only the anastamosing pattern of the shearing. Some of the crinkling in the schist layers on the southeast limb of the syncline in the quartzite unit could have resulted from the third deformation, but the crinkling is discontinuous and is in no way comparable with the folds farther southwest in the shear zone.

REGIONAL RELATIONS

Recognized as a shear zone as early as 1930 by Adler, the Idaho Springs–Ralston shear zone was described by Lovering and Goddard (1950, p. 54) as a "mylonitized zone" and as "one of the most conspicuous pre-Cambrian faults in the Front Range." As shown by

Lovering and Goddard (1950, pl. 2) and Tweto and Sims (1963, pl. 1), the Precambrian shear zone extends about 23 miles northeast from the vicinity of Chicago Creek between Idaho Springs and Georgetown to the Coal Creek area north of the Ralston Buttes district. Tweto and Sims (1963) showed that the shear zone is an element of a master shear zone extending diagonally across much of Colorado. The northeastern part of the shear zone was called the "Ralston shear zone" by C. M. and M. F. Boos (1957, figs. 7, 13, p. 2650), and more recently, Tweto and Sims (1960, 1963) applied the name Idaho Springs–Ralston shear zone to the entire zone.

Distinctive features of the Idaho Springs–Ralston shear zone in the Idaho Springs–Central City area, recently summarized by Tweto and Sims (1963, p. 998–999), include granulation (most intense in igneous rocks and the more massive metasedimentary rocks) and folds of a young generation that trend parallel to the shear zone and are superimposed on older folds. Moench, Harrison, and Sims (1954; 1962, p. 45–55) and Harrison and Wells (1959, p. 27, 30–33) ascribed these features to the second of two Precambrian deformations recognized in that area and inferred that this deformation was a deep-seated reflection of faulting nearer the surface. Tweto and Sims (1963) concluded that the linear zones of granulated and folded rocks represent an ancient Precambrian structural trend that was a fundamental control of the entire Colorado mineral belt.

As noted in the discussion of metamorphism, the features of the Idaho Springs–Ralston shear zone in the Ralston Buttes district also support the idea that the deformation occurred along the deeper part of a fault zone, the upper part of which has since been removed by erosion. The absence in the Ralston Buttes district of folds comparable to the young folds in the shear zone in the Idaho Springs–Central City area may be due primarily to differences in the rocks. The shear zone in the Ralston Buttes district is largely in competent rocks—quartz monzonite, Boulder Creek Granodiorite, quartzite, and, as inferred from the composition of quartzo-feldspathic cataclastic gneisses, microcline gneiss. In the Idaho Springs–Central City area, competent rocks similar to these are cataclasized but not folded, and only the intervening incompetent rocks contain young folds. On the other hand, the shear zone in the Ralston Buttes district is about parallel to the east-northeast-trending syncline in the quartzite unit, a fold which we have assigned to the second period of deformation. The syncline may actually be equivalent to the young folds within the shear zone farther southwest. This view is held by R. B. Taylor (oral commun., 1964), who was mapping the shear zone in the Blackhawk quadrangle west of the Ralston Buttes district in 1964.

Evidence from the Ralston Buttes district does not conclusively indicate the direction of fault movement on the shear zone. In the Idaho Springs area, Moench, Harrison, and Sims (1962, p. 54) and Tweto and Sims (1963, p. 999) envisaged upward movement on the northwest side during the stage of younger folding and cataclasis, although Tweto and Sims concluded that movements had occurred in many different directions through the history of the shear zone. In and near the Ralston Buttes district, however, a few features suggest downward movement on the northwest side. Small warps, gentle folds, and deflections of older foliation by late crosscutting foliation just west of the boundary of the Ralston Buttes district, and also a few minor folds in sec. 14, T. 2 S., R. 71 W., suggest downward movement on the northwest side. Relations along the shear zone in the area between the Ralston Buttes district and Idaho Springs led R. B. Taylor (oral commun., 1964) to conclude that the zone is structurally similar to the steep limb of a monocline, stepping down to the northwest. Lovering and Goddard (1950, p. 23, 54) noted that the structure of the southeast side of the syncline in the quartzite unit suggests drag along an early fault, and hence a downward movement on the northwest; but we think that the syncline is older than the shear zone.

BRECCIA-REEF FAULTS AND FRACTURE ZONES IN PRECAMBRIAN ROCKS

Many faults and fracture zones that cut the Precambrian rocks of the Ralston Buttes district (pl. 1) are similar to, indeed extensions of, faults elsewhere in the Front Range that have been termed "breccia dikes," "breccia reefs," or "breccia-reef faults" (Lovering and Goddard, 1950, p. 79; Lovering and Tweto, 1953, p. 30). These faults and fracture zones trend predominantly northwest, although a few trend nearly north or north-northeast and others nearly east. Some of the faults in and near the Ralston Buttes district extend from the Precambrian into the sedimentary terrane, where they cut rocks ranging in age from Pennsylvanian to Cretaceous.

We use the term "breccia-reef fault" because nearly all the faults contain breccia over at least part of their extent, and because many can be traced northwest into what had previously been mapped as breccia reefs. Because displacement of geologic contacts is not evident along some breccia zones and zones of iron-stained fractured rock, these zones are referred to as fracture zones rather than faults. The breccia-reef faults and fracture zones are denoted by the same symbols on plate 1.

Four northwest-trending fault systems, each containing two or more breccia-reef faults or fracture zones, are shown on the index map of plate 1; from west to east: the Junction Ranch, Hurricane Hill, Rogers, and Livingston fault systems. These can be traced northwest into the Front Range mineral belt, and the names are those that Lovering and Goddard (1950, pl. 2) applied to the breccia reefs there.

The Junction Ranch fault system includes the long fault extending along Guy Gulch, which branches southeastward, and a shorter fracture zone to the west (pl. 1). The Hurricane Hill fault system is more complex and has more branches. It includes the many faults and fracture zones of the Golden Gate Canyon area; the long branching fault and fracture zone extending from Blue Mountain southeast to Crawford Gulch and thence to the southeastern part of the district; the west-trending fault near the Ralston Creek Ranch and shorter faults and fracture zones in that area; the faults and fracture zones in sec. 21, T. 2 S., R. 71 W., and extending southeast from there; the branch faults and fracture zones crossing Belcher Hill and the area northwest from there; and the branch fault or fracture zone northwest of the Aubrey Ladwig mine. The Rogers fault system includes all the faults and fracture zones extending southeast from the SE¼ sec. 16, SE¼ sec. 15, sec. 14, and SW¼ sec. 13, T. 2 S., R. 71 W., and branches from them. The Livingston fault system includes the southeast-branching fault separating the Fountain Formation from Precambrian rocks at the northern boundary of the district and a fault farther east near Rocky Flats.

The faults and fracture zones show a wide variation in character: some are simple and discrete and contain little or no gouge or breccia; others are wide zones composed of breccia or strongly shattered rock. Some breccia zones grade along the strike into complexly fractured or gougy zones. Individual fault breccias generally range in width from a fraction of an inch to a few tens of feet, but locally some of the breccia zones are much wider. The north-northeast-trending breccia zone between Van Bibber Creek and the Aubrey Ladwig mine is as much as 1,000 feet wide (pl. 1). The maximum width of breccia zones along the Junction Ranch fault system is 200 feet. Along the Hurricane Hill fault system, breccia zones are as much as 450 feet wide near Ralston Creek, 400 feet wide southeast of the Ascension mine, and 200 feet wide at Golden Gate Canyon near the eastern boundary of the district. North of Ralston Creek the breccia zone along part of the Rogers fault system widens to as much as 500 feet. Most commonly, however, the individual fault breccias observed in many surface exposures, prospects, and mine workings range in width from 1 to 10 feet.

A generalized mineralogic zoning has been recognized in the Ralston Buttes district in the material cementing the fragments of altered wallrock in the fault breccias. In the northwestern part of the district the fault breccias are commonly cemented by quartz, fluorite, and hematite. In the remainder of the district they are commonly cemented by ankerite and potassic feldspar, as well as by varying amounts of quartz. The parts of fault systems that are not heavily mineralized either by quartz or ankerite are simply iron-stained fracture zones.

Some of the fault breccias contain few if any openings, but others, particularly in the southern part of the district, are locally more vuggy. The absence or sparsity of vugs in some of the fault breccias may reflect repeated episodes of movement and mineralization, evidence for which was observed in detailed studies of some of the uranium deposits. During the course of such episodes, many of the vugs would have been destroyed or filled. Correspondingly, where vuggy openings are still locally abundant in some of the breccias, the history of movement and (or) mineralization may not have been so complex.

Many of the breccias weather reddish brown or yellowish brown, although those containing abundant quartz tend to be brownish white. Outcrops of breccia containing ankerite and potassic feldspar as the principal cementing materials commonly weather to a knotty surface, on which wallrock fragments and grains of potassic feldspar stand out in relief. Wall-like outcrops of resistant fault breccia occur locally but are less common than in the Front Range mineral belt. More commonly in the Ralston Buttes district, the faults and fracture zones are marked by low rounded outcrops of breccia, by topographic depressions on ridges, or by scattered float of either breccia or iron-stained fractured rocks.

The general trend of the fault systems in the Ralston Buttes district is about N. 30°–50° W., although individual faults split, branch, and change trend. Most of the faults and fracture zones that make up these fault systems dip steeply northeast, although locally, in complexly fractured rocks, some dip southwest. Actual measurement of the dip cannot be made except where faults are well exposed in mine workings or where resistant breccia forms wall-like outcrops. The general steepness of dip, however, can be inferred because topography has very little effect on the traces of many of the faults. Low-angle faults and fractures occur in some of the complexly broken parts of fault systems but are subsidiary to the more conspicuous, high-angle faults.

The Junction Ranch fault system has an apparent left-lateral horizontal displacement of as much as 4,000 feet (pl. 1)—the largest observed in the district. Displacements along the Hurricane Hill fault system are small but complex; apparent left-lateral movement occurred near Ralston Creek, whereas apparent right-lateral movement occurred in the Ascension mine area. Parts of the Hurricane Hill fault system show virtually no displacement at the scale of mapping. A major fault of the Rogers system, north of Ralston Creek opposite the Schwartzwalder mine (pl. 1), dips steeply northeast and has an apparent horizontal displacement of about 2,200 feet as the result of several movements that displaced the northeast block upward and to the southeast. Apparent right-lateral movement of this kind characterizes most faults of the Rogers system, but locally the apparent movement was left-lateral.

Studies of the relations of ore deposits to structural features in the Colorado mineral belt convinced Tweto and Sims (1960, p. B8; 1963, p. 1001) that the breccia-reef faults of the Front Range are of Precambrian origin, although younger than northeast-trending shear zones such as the Idaho Springs–Ralston shear zone, and that many of these faults underwent recurrent movement during the Laramide orogeny. Lovering and Goddard (1950, p. 79) had recognized earlier that some of the northwest-trending faults in the Front Range may follow zones of weakness much older than the recorded Laramide movements. C. M. and M. F. Boos (1957, p. 2638) also noted northwest- to north-northwest-trending faults of Precambrian origin in the Front Range.

Although we have no conclusive evidence from the Ralston Buttes district to prove the Precambrian ancestry of the breccia-reef faults, we infer from the regional studies made by Tweto and Sims (1963, p. 1001) that at least some and perhaps all of these faults in the district originated in Precambrian time. However, nearly all recognizable features, including the characterizing breccia or shattering, the alteration and mineralization, and at least some of the displacement, are products of the Laramide orogeny.

The district's breccia-reef faults and fracture zones are economically important because most of the uranium deposits occur along them. Aside from these deposits, however, the fault breccias are virtually barren, consisting principally of wallrock fragments and gangue minerals and local small concentrations of fluorite, hematite, and sulfide minerals.

FOLDS AND FAULTS IN PALEOZOIC AND MESOZOIC ROCKS

By Richard Van Horn

Faults and associated folds in the Paleozoic and Mesozoic rocks are related to the Livingston and Rogers fault systems (pl. 1). The faults and folds are relatively minor features of the great monoclinal upturn along the lower flank of the Front Range. The evidence for faulting is generally indirect and consists of repetition of beds, overturning, and apparent offset of beds across covered areas.

Livingston fault system.—The two faults in the northeastern corner of the Ralston Buttes district (pl. 1) are part of the Livingston fault system. The eastern fault is probably the main fault, and the western is a major branch fault. The main Livingston fault trends southeast and overlaps the Golden fault in an echelon relationship in the Golden quadrangle. The branch fault splits just north of Ralston Buttes. The major branch turns east and rejoins the main Livingston fault in the Golden quadrangle; the other continues south between the two Ralston Buttes and then dies out in a southeast-plunging syncline in the southeast-sloping valley between the two buttes. A zone of brecciated Lyons Sandstone occurs along the east side of this valley.

An anticline northeast of Ralston Buttes probably was formed before faulting occurred. Northeast of the major branch of the Livingston fault the anticline is overturned, probably as a result of the faulting. Geologic section *B–B′* (pl. 1) shows the anticline near its southern end, where it has been tilted but not overturned. North of the line of the geologic section, westward dips near the crest of the ridge help delineate the anticline. As the anticline is followed northeast of the major branch of the Livingston fault it becomes more overturned, and the crest and west limb have been removed by erosion. The strongly overturned east limb is preserved on the long ridge north of Ralston Buttes between the Livingston fault and its major branch.

The overturned beds on the east side of the hogback between the major branch and the main Livingston faults have been ascribed by Hampton (1958) to creep of nearly vertical beds. Although the slope of the hill is such that nearly vertical beds might be subject to overturning due to creep, there are some serious objections to this hypothesis. West of the crest of the hogback, the Fountain Formation is overturned and dips as much as 56° W.; at the north end of the hogback it dips 64° W. Obviously creep could not have caused these beds to overturn because, in this topographic setting, it would have imparted an eastward rather than a westward dip to the beds. In addition, in the small valley in the SE¼ sec. 19, T. 2 S., R. 70 W., the first clay unit of the Dakota Group forms a west-pointing V that extends above 200 feet up the valley. If this clay unit were nearly vertical instead of west dipping, its outcrop would cross the valley, forming a straight line instead of a west-pointing V.

A small area on the east side of Ralston Buttes and west of Fireclay does, however, appear to have been affected by creep. This area contains the east half of the Fountain and most of the Lyons. Dips in this area are about 50° W., although just uphill they are about 50° E. The topographic setting and the outcrop width of the Lyons show that the Lyons either dips east or abruptly expands to a thickness of 500 feet. The eastward dip seems more logical; hence, the anomalous dips must be caused by creep.

Rogers fault system.—A steeply dipping reverse fault, a part of the Rogers fault system, cuts the Fountain and Lyons Formations east of Ralston Creek but dies out to the southeast in a syncline in the Lykins Formation. This syncline and an adjoining anticline to the northeast both plunge southeast and die out in the lower part of the Benton Shale. The syncline is clearly exposed along the crest of the hogback formed by sandstone of the Dakota Group. A wide zone in the trough is highly shattered and fractured, but no evidence of offset of beds was found.

Other faults.—In the mile north of Van Bibber Creek, the contact between Precambrian rocks and the Fountain is offset by four faults, but only two of them can be traced for more than a short distance. The northern two, which are related to the Rogers fault system, show displacement to the east on the north side, and the southern two show displacement to the west on the north side. The fault at Van Bibber Creek continues east into the Golden quadrangle, where it apparently offsets the Dakota Group and then either dies out or becomes a strike fault in the Benton Shale.

The curved fault in the Dakota Group and Benton Shale in sec. 32, T. 2 S., R. 70 W., is probably due to slippage around the crest of an anticline. West-dipping (overturned) beds lie on the east side of the fault and east-dipping beds on the west side.

GEOLOGIC HISTORY

The geologic history of the Ralston Buttes district includes events ranging in age from early Precambrian to the present. Many of the events, particularly those of the Precambrian Era, cannot be dated accurately from available information, but their relative positions in a sequence of events are known.

The earliest geologic event recorded in the district was the accumulation of a thick succession of sedimentary strata early in Precambrian time. Although metamorphism has greatly modified these rocks and obscured their original character, the thick succession of strata evidently consisted principally of shale, sandstone, and rocks gradational from calcareous or dolomitic shale to argillaceous limestone, and lesser amounts of conglomerate, pebbly sandstone, and impure limestone. In addition, the succession may have contained volcanic flows, sills, or tuffaceous rocks of intermediate to mafic composition. The metamorphosed products of these various rocks appear to be conformable, but the depositional sequence is not known with certainty.

Somewhat later in the Precambrian these rocks were folded during two separate periods of deformation. The rocks were metamorphosed to assemblages characteristic of high-grade metamorphic facies and were deformed into folds trending east to northeast. The rocks that are now exposed probably represent the older part of the original succession, because the deformations apparently occurred at great depth.

The available data suggest that the principal Precambrian igneous rocks—Boulder Greek Granodiorite, quartz monzonite, and hornblende diorite—were intruded syntectonically during the second period of deformation. Locally dikes and sills of hornblende-biotite lamprophyre intruded the Precambrian rocks at some time well after the peak of deformation had been reached during the second period of folding but before the deformation ceased. Some irregular bodies of pegmatite probably were intruded about this time, or even earlier, but most pegmatites were emplaced later in the Precambrian, probably after the third period of deformation.

A third period of deformation occurred later in the Precambrian, probably after the erosion of a considerable thickness of rocks. This deformation was predominantly cataclastic and was localized along the northeast-trending Idaho Springs–Ralston shear zone.

Still later in the Precambrian, northwest-trending faults were formed. These were accentuated and modified by later movements.

From later Precambrian to Pennsylvanian time, erosion was dominant in the area and created a major unconformity that is marked by the contact between the Precambrian rocks and the terrestrial Fountain Formation. Little is known of the time interval represented by this unconformity. The presence of limestone pebbles in the Fountain Formation suggests that sedimentary rocks may have been deposited in nearby areas; if so, they were eroded completely before the Fountain Formation was deposited. Streams, flowing over the eroded surface of the folded and faulted Precambrian rocks, deposited the sediments of the Fountain Formation on lowlands that bordered a sea to the east. After deposition of the Fountain, the sea encroached on this land area and the Lyons Sandstone was deposited on or near its beach. Later, as the Permian sea covered more land, the red mudstone and algal limestone of the Lykins Formation were deposited in shallow water; the limestone may have formed in intertidal zones. Marine conditions probably persisted into Early Triassic time, and then the sea withdrew. Some erosion probably ensued during later Triassic and (or) Early Jurassic time.

The earliest Jurassic sediments known in the area are represented by a 5-foot bed of sandstone (possibly equivalent to the Entrada Sandstone) at the base of the Ralston Creek Formation. This formation and the succeeding Morrison Formation consist of sediments deposited by sluggish rivers on a low flat plain and in lakes and swamps in Late Jurassic time.

Terrestrial conditions persisted into the Early Cretaceous, when the seas began to readvance on the land. The rocks of the Dakota Group were deposited at the margin of this sea, and as the sea continued to advance, the succeeding Benton, Niobrara, and Pierre Formations were deposited in deeper waters. According to Lovering and Goddard (1950, p. 58), the uplift of the present Front Range probably began about middle Pierre time, although the Denver basin had been subsiding and filling for some time prior to the uplift. The uplift of the Front Range marked the beginning of the Laramide orogeny, which reached its culmination early in Tertiary time; the Paleozoic and Mesozoic formations were bent upward along the mountain front, and movements along faults occurred in several stages. At the same time igneous dikes and sills were intruded locally. Later, veins containing pitchblende and base-metal sulfide minerals were deposited along faults and fractures in the Precambrian terrane.

All traces of early Tertiary sedimentary rocks have been eroded from the Ralston Buttes district, but erosion surfaces cut during the latter part of the Tertiary are still partly preserved. The Pleistocene history—probably similar, though on a smaller scale, to the later Tertiary history—is marked by recurrent periods of erosion, alluviation, and soil formation. The major streams, except for Van Bibber Creek, remained in about their present positions during these periods.

During early Recent time the valley bottoms received large quantities of coarse material (pre-Piney Creek alluvium), which was partially eroded and covered by deposits of the younger Piney Creek Alluvium. In relatively modern time (possibly in the 19th century), erosion of the Piney Creek Alluvium started in the lower reaches of the main valleys. It has progressed headward, and at present only the upper 2–3 miles of most tributary streams remains ungullied. In the steeply sloping parts of the major streams near the mountain front, almost all the pre-Piney Creek alluvium and the Piney Creek Alluvium has been removed by erosion.

ECONOMIC GEOLOGY

Uranium has been the principal mineral commodity sought in the Ralston Buttes district since 1953. Other materials produced in the district from time to time include feldspar, scrap mica, and beryl from Precambrian pegmatites, and limestone, dimension stone, and clay from younger sedimentary rocks.

The Ralston Buttes district ranks first in uranium production among the mining districts of the Front Range, having supplied about 80 percent of the total output of U_3O_8 through 1960 (Sims and Sheridan, 1964). In contrast with nearby mining districts in the Front Range mineral belt, which have been worked for many years for precious and base metals and some uranium, the Ralston Buttes district was not worked for metal until the 1950's except for very minor early attempts to mine copper ore. By 1960 the annual production from the district had reached 298,000 pounds of U_3O_8. Although the ores of the district contain small amounts of precious and base metals, these have not been recovered.

URANIUM DEPOSITS

The uranium deposits in the Ralston Buttes district are in hydrothermal veins occupying openings in fault breccias and fractures that cut Precambrian rocks. Pitchblende, minor amounts of secondary uranium minerals, and, in one mine, coffinite are associated with generally sparse base-metal sulfides in a gangue of carbonate minerals, potassic feldspar, and, in some veins, quartz. The known uranium deposits are concentrated in two main areas—the Ralston Creek area and the Golden Gate Canyon area. The geologic age of the deposits, as determined by geologic and lead-uranium dating, is Late Cretaceous or early Tertiary.

HISTORY AND PRODUCTION

Pitchblende may have been discovered in the Ralston Buttes district in 1884 or earlier, because a note in Mining and Science Press (1884) described thin seams of pitchblende but gave no specific location other than Jefferson County. Active search for uranium in the Ralston Buttes district began in 1949 when Fred Schwartzwalder brought uranium-bearing samples to the U.S. Atomic Energy Commission from deposits he had discovered near Ralston Creek. These deposits became the sites of the Schwartzwalder and Mena mines. In 1951–52 additional discoveries were made in the district by geologists of the U.S. Geological Survey (Adams and others, 1953, p. 2), and later G. B. Friden discovered uranium deposits on the properties now known as the Aubrey Ladwig mine and the Ascension mine. An exploratory drilling and trenching program was conducted in 1954–55 by the Atomic Energy Commission in the Ralston Creek area, and exploration was done also under several contracts with the Defense Minerals Exploration Administration.

The first shipment of uranium ore from the Ralston Buttes district was made from the Schwartzwalder mine in November 1953. Since then uranium ore has been shipped from five mines—the Mena, Schwartzwalder, Aubrey Ladwig, Ohman, and Ascension (pl. 1).

The production of uranium ore from the Ralston Buttes district for 1953–60 is shown for individual mines and years in table 23. The total production from the district during this period was about 82,200 tons of crude ore that contained about 1,211,000 pounds of U_3O_8. Although the value of this yield is not known accurately, it is at least $5½ million. The largest producer was the Schwartzwalder mine, whose shipments totaled about 77,660 tons of crude ore containing an average of 0.76 percent U_3O_8.[3]

The fieldwork related to economic geology for this report was concluded in 1956. Consequently, the descriptions presented here do not include detailed geologic data from the more recently developed lower levels of some of the mines. Also, we have no geologic data on the Ohman mine because it was developed after our field studies.

[3] After this report was prepared for publication, Downs and Bird (1965) published a report containing more recent data from the Schwartzwalder mine. They summarized production for the period 1953–64 (p. 183); also, their cross section (fig. 3, p. 188) shows lower mine levels that were developed after our studies were completed.

TABLE 23.—*Uranium production from the Ralston Buttes district, 1953–60*

[Production data are published with the permission of mineowners. Except as noted, all data were compiled from records of U.S. Bur. of Mines, Denver, Colo.]

Mine	Year	Crude ore shipped (short tons)	Grade (percent U_3O_8)	U_3O_8 (pound)
Ascension	1956	439.51	0.23	2,063.44
	1957–1959			
	1960	1,010	.27	5,385
Total		1,449.51		7,448.44
Average			0.26	
Aubrey Ladwig	1955	386.72	0.31	2,419.80
	1956	1,554.96	.23	7,107.35
	1957–60			
Total		1,941.68		9,527.15
Average			0.25	
Mena	1956	247.70	0.32	1,603.10
	1957	242.31	.16	781.99
	1958	271	.32	1,739
	1959	129	.31	795
	1960	109	.23	511
Total		999.01		5,430.09
Average			0.27	
Ohman (Nare lease)	1959	5	1.18	118
	1960	192	.23	870
Total		197		988
Average			0.25	
Schwartzwalder	1953 [1]	51.29	1.32	1,354.06
	1954 [1]	660.86	.70	9,265.26
	1955 [1]	848.77	.66	11,237.71
	1956	11,151.61	.54	119,857.09
	1957	14,982.75	.71	211,524.05
	1958	14,631	.78	228,168
	1959	17,146	.92	315,510
	1960	18,188	.80	291,162
Total		77,660.28		1,188,078.17
Average			0.76	
Total for district	1953–60	82,247.48		1,211,471.85
Average for district	1953–60		0.74	

[1] Production data for Schwartzwalder mine, 1953–55, were complied from records of Division of Raw Materials, U.S. Atomic Energy Comm., Denver, Colo.

LOCATION AND DISTRIBUTION

The known uranium deposits are grouped in two main areas: the Golden Gate Canyon area in the southeastern part of the district and the Ralston Creek area in the northeastern part. The locations of four mines that have produced uranium ore and of seven other uranium deposits or groups of deposits that have been explored are shown on plate 1. (A fifth producing mine, the Ohman, was developed after our field studies of uranium deposits. This mine, not shown on pl. 1, is near the Buckman adit.) The uranium deposits near Golden Gate Canyon are associated with the complexly branching Hurricane Hill system of faults and fracture zones. The deposits near Ralston Creek are associated with similarly complex faults and fracture zones of the Rogers system.

In addition to the deposits shown on the map (pl. 1), numerous radioactive anomalies and occurrences of uranium minerals are known elsewhere along the Rogers and Hurricane Hill breccia-reef systems. Anomalies exist also along the Junction Ranch system, but thus far no potentially significant uranium deposits have been found along it in the Ralston Buttes district. The Livingston fault system lies principally within sedimentary rocks in the Ralston Buttes district; no uranium deposits are known along the fault system in the mapped area.

GENERAL FEATURES

The uranium deposits in the Ralston Buttes district are principally in hydrothermal veins that occupy openings in the breccias and related fractures along the breccia-reef fault and fracture systems. One deposit, however, is in a fractured zone along and near a pegmatite contact, and another is in fractures that cut a sulfide-bearing quartz vein. All the deposits in the district are in Precambrian terrane. Pitchblende, the main uranium mineral, and minor amounts of secondary uranium minerals are associated with base-metal sulfides; coffinite is known to occur in one of the deposits. The gangue in many of the veins is typically ankerite with associated potassic feldspar, but in some veins, quartz is abundant.

Many of the uranium-bearing veins are actually mineralized fault breccias in which the ore minerals and gangue fill spaces between breccia fragments and occupy openings in complex networks of fractures in cemented breccia. They thus differ from classical fissure veins in having poorly defined walls and a very large proportion of rock fragments mixed with the filling of ore and gangue.

Deposits in the Golden Gate Canyon area show typical epithermal characteristics (Lindgren, 1933, p. 444–447), such as voids, crustification, and simple mineralogy. Deposits in the Ralston Creek area, in contrast, appear to be transitional between epithermal and mesothermal (Lindgren, 1933, p. 529–532), because their mineralogy is a little more complex; they contain moderate amounts of base-metal sulfides and sulfosalts, but they lack the intensely altered walls characteristic of the typically mesothermal uranium-bearing veins in the Front Range mineral belt (Sims and Sheridan, 1964).

The uranium deposits range in size from veinlets or mineralized fault breccias less than an inch thick to large shoots composed of complexly branching or coalescing major veins that have mining widths of as much as 35 feet. Material of minable grade occurs across the entire thickness of the breccia in some of the mineralized faults, but in general, the richest concentrations of pitchblende are confined to breccia along either the hanging wall or the footwall of the faults. Typically, the uraniferous material forms lenses or shoots that are discontinuous along strike and commonly have their longest dimension in the downdip direction. Individual ore bodies range in size from small pods or lenses containing 50 tons or less to large shoots containing several thousand tons of ore.

Zoned wallrock alteration, conspicuous along some of the veins in the Front Range mineral belt (Lovering and Tweto, 1953, p. 58–63; Tooker, 1956, 1963), was not observed along the veins of the Ralston Buttes district. Alteration—generally a bleaching—is limited to rock fragments in the mineralized breccias, to irregular areas less than 3 feet thick adjacent to parts of some veins, and to zones up to several inches wide along some fractures. Altered wallrocks were not studied during this investigation. Adams and Stugard (1956, p. 200–202) indicated that propylitization occurred early in the process of formation of the ore at the Union Pacific deposit and was accompanied or followed by potassic alteration which raised the potash content of the wallrock from less than 1 percent to more than 3 percent. The presence of potassic feldspar in many of the veins of the district suggests that the introduction of potassium was widespread in the early stages of vein formation. In addition to these processes, silicification occurred during one or more stages at the Schwartzwalder mine.

MINERALOGY AND PARAGENETIC RELATIONS

Pitchblende is the main uranium mineral of the uranium deposits in the Ralston Buttes district, although the ore from at least one mine also contains coffinite in undetermined amounts. In this report, the term "pitchblende" refers to a variety of the mineral species uraninite, following the usage of Palache, Berman, and Frondel (1944, p. 614) and Frondel (1958, p. 12, 15). In most of the ore, the pitchblende is black, hard and colloform or massive, and is not visibly idiomorphic. Near the surface in some of the mines and prospects, however, it is partly a sooty form evidently derived by supergene alteration of primary hard pitchblende. A uraninite X-ray pattern was obtained from colloform pitchblende from the Mena mine by E. J. Young (oral commun., 1957) and from several other ore samples from the district during earlier investigations by the U.S. Geological Survey (J. W. Adams, oral commun., 1960). More recently, however, coffinite, the hydrous uranium silicate, was identified in ore from new deeper workings at the Schwartzwalder mine (J. D. Schlottmann, oral commun., 1960). Because coffinite and the pitchblende variety of uraninite are not readily distinguished other than by X-ray methods, some of the black material at various mines and prospects may contain coffinite in addition to pitchblende.

Secondary uranium minerals identified in specimens from some of the deposits during our investigation and the earlier studies by the U.S. Geological Survey (Adams and others, 1953; Adams and Stugard, 1956) include the sooty form of pitchblende, and torbernite, metatorbernite, uranophane, autunite, meta-autunite, uranopilite, johannite, betazippeite, and phosphuranylite. Metazeunerite and fourmarierite were reported (Todd New, oral commun., 1956) in samples from the Aubrey Ladwig mine. The secondary minerals are commonly found along the fault breccias and in fractures in the wallrock in the near-surface, oxidized parts of the deposits. The oxidized zone containing these secondary minerals has a vertical thickness of less than 50 feet in most of the deposits.

Copper and other base-metal sulfide and sulfosalt minerals are commonly associated with the pitchblende in the uranium deposits. Silver is found in some of the deposits, but gold is generally absent or very scarce. The suite of metallic minerals other than uranium minerals in the deposits of the Ralston Buttes district includes pyrite, chalcopyrite, bornite, chalcocite, sphalerite, galena, tetrahedrite-tennantite, native bismuth, native silver, native copper, niccolite, pararammelsbergite(?), maucherite(?), marcasite, covellite, malachite, azurite, chalcanthite, hematite, and emplectite(?). In addition, at least two unidentified metallic minerals were found in ore from the Mena mine. (See mine description.) Native bismuth, native silver, and native copper were identified only at the Mena mine, but anomalous amounts of bismuth were also found in ore from the Schwartzwalder mine. Niccolite and associated pararammelsbergite(?) and maucherite(?) were found in ore from the Mena mine. A nickel mineral, probably niccolite, was found in ore from new lower workings of the Schwartzwalder mine (J. D. Schlottmann, oral commun., 1961). Molybdenite and pyrrhotite were found in the wallrocks of veins at the Schwartzwalder mine but were not identified in polished sections of the uranium-bearing ore. The high molybdenum content of several samples of ore from the Schwartzwalder mine suggests that molybdenite or some other molybdenum mineral may form part of the suite of vein minerals, but some of the molybdenite and probably all the pyrrhotite disseminated as irregular grains in the wallrocks may represent Precambrian mineralization. Anomalous amounts of vanadium were found in some of the ore from the Schwartzwalder and Mena mines, but the mineralogic nature of the vanadium is not known.

Uraniferous asphaltite is associated with base-metal sulfides and pitchblende in a carbonate-bearing fault breccia at the Fork prospect in Halfmile Gulch (pl. 1). The asphaltite is probably related to oil seepage in this vicinity. The oil presumably seeps upward through fractures in the Precambrian rocks and comes from younger sedimentary rocks that underlie the west-dipping Golden reverse fault. The trace of the Golden fault is east of the Ralston Buttes district.

In a detailed study of the paragenetic relations of the minerals in the Union Pacific prospect in Golden Gate Canyon, Adams and Stugard (1956) found that pitchblende was deposited before the sulfide minerals. According to their findings, pitchblende, hematite, some ankerite, and possibly minor pyrite were deposited first; then base-metal sulfides and most of the ankerite; and lastly, fine-grained pyrite and coarse-grained calcite.

We found the same general sequence in ores of the Schwartzwalder and Mena mines. Pitchblende at both mines is found as thin stringers and irregular blebs, and as colloform crusts rimming rock fragments of the breccia (figs. 21, 22) and coating earlier formed potassic feldspar and ankerite (figs. 22, 23). Galena, sphalerite, copper minerals, and other metallic minerals occur with gangue as a cementing matrix of the pitchblende-coated breccia fragments (figs. 21–23) and as a network of veinlets that, in places, cut across stringers of pitchblende. The ore minerals are gen-

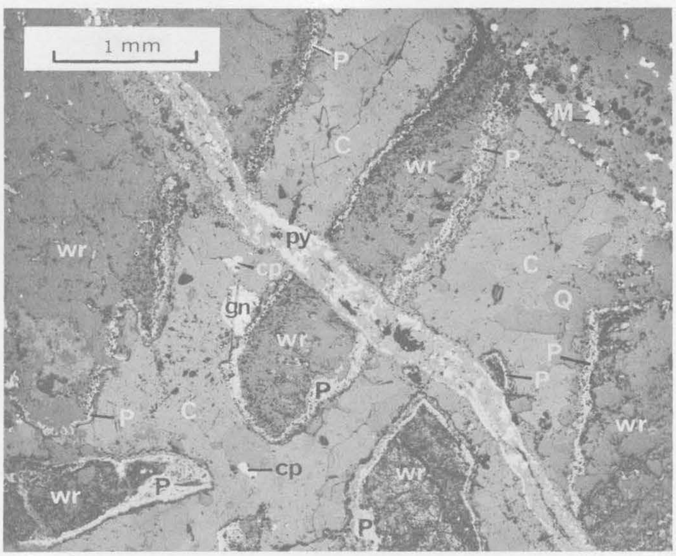


FIGURE 21.—Polished section of uranium ore, Schwartzwalder mine. Pitchblende (P) coats breccia fragments of altered Precambrian wallrock (wr). The pitchblende-coated breccia fragments are cemented by gangue consisting principally of a carbonate mineral (C) and quartz (Q). The gangue contains small grains of chalcopyrite (cp) and galena (gn). The pitchblende-coated breccia fragments and the gangue are transected by a late veinlet of pyrite (py) and calcite (center) and by a veinlet of marcasite (M) and calcite (upper right).

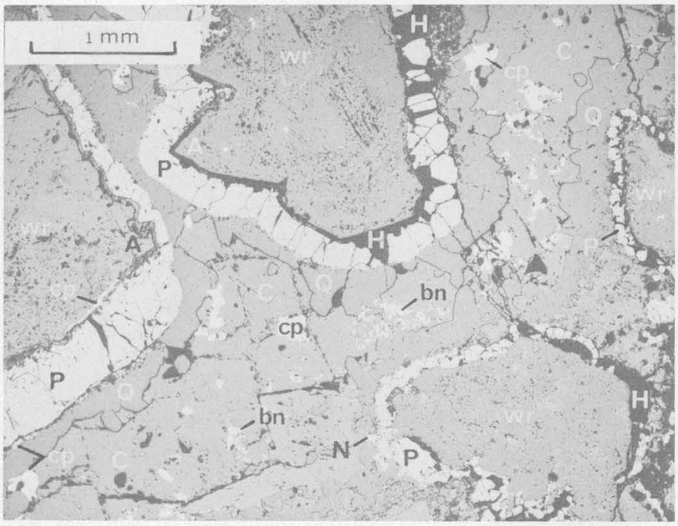


FIGURE 22.—Polished section of uranium ore, Mena mine. Pitchblende (P) occurs as colloform coatings on breccia fragments of altered Precambrian wallrock (wr); ankerite (A) occurs as a discontinuous coating between the pitchblende and the breccia fragments. Discontinuous layers of quartz (Q) coat outer surfaces of pitchblende. The remaining open space is filled by a carbonate mineral (C) containing chalcopyrite (cp) and bornite (bn). Locally, as at lower left, chalcopyrite rims the outer surface of pitchblende and replaces ankerite along the inner surface of pitchblende; chalcopyrite also occurs as a very thin filling (not discernible at this scale) along some shrinkage cracks in pitchblende. A small grain of niccolite (N) occurs at the rotund outer surface of pitchblende; at much higher magnification, a very thin rim of pararammelsbergite(?) which is overlain by a rim of maucherite(?) is apparent on the niccolite. H, holes in section.

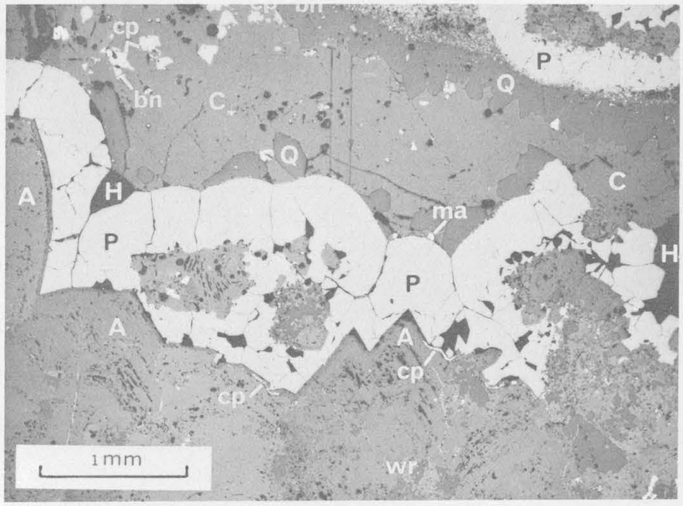


FIGURE 23.—Polished section of uranium ore, Mena mine. Crystals of ankerite (A) coat breccia fragments of altered Precambrian wallrock (wr). Pitchblende (P) occurs as colloform coatings on the ankerite. Along the rotund outer surfaces of the pitchblende are discontinuous layers of quartz (Q) and minute grains of maucherite(?) (ma) which have cores of pararammelsbergite(?). The remaining open space is filled by a carbonate mineral (C) containing chalcopyrite (cp) and bornite (bn), and intergrowths of the two (cp–bn). Locally, chalcopyrite has replaced ankerite along the contact between ankerite and pitchblende. H, holes in section.

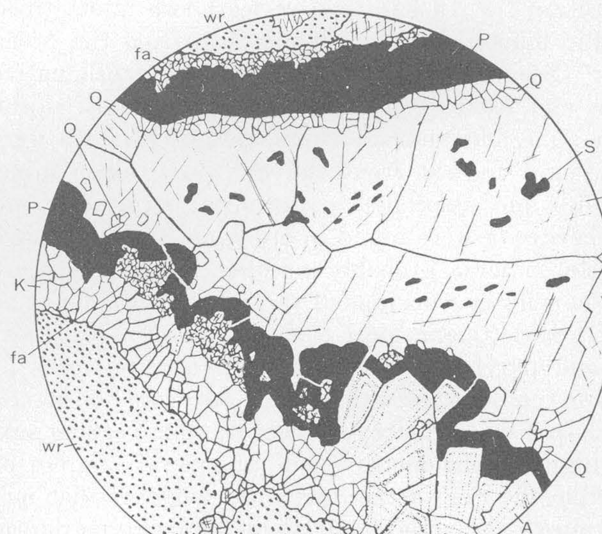


FIGURE 24.—Camera-lucida drawing of thin section of pitchblende-bearing ore from the North adit of the Mena mine. S, base-metal sulfide and sulfosalt minerals; C, carbonate mineral (ankerite or calcite); Q, quartz; P, pitchblende; A, ankerite showing growth zoning; fa, fine-grained ankerite; K, potassic feldspar; wr, breccia fragments of altered Precambrian wallrock.

erally very fine grained. Individual stringers or colloform coatings of pitchblende are very thin, generally ranging in thickness from 0.1 to 1 mm. In parts of the ore, late veinlets of pyrite, marcasite, and calcite cut the pitchblende-coated breccia fragments and the gangue (fig. 21).

Samples from the Mena mine proved especially valuable for petrographic study because the ore minerals are relatively free of the intense fracturing and rebrecciation which have affected some of the other deposits. The sequence of deposition of minerals is illustrated by a camera-lucida drawing (fig. 24) of a thin section of ore from the North adit of the mine. Crystals of potassic feldspar occur as coatings on breccia fragments of altered Precambrian wallrock. As determined from other parts of the same thin section, the coatings of feldspar crystals are discontinuous and are overlapped by coatings of ankerite, some of which is relatively coarse and shows growth zoning. The ankerite is in turn coated by colloform pitchblende. Next in the sequence are tiny crystals of quartz forming a discontinuous coating on the pitchblende. Quartz is sparse along the lower layer of pitchblende in the drawing but is continuous within the field of view along the upper layer. Last in the sequence, and filling the central part of the space, is an assemblage consisting principally of unzoned carbonate crystals and subordinate amounts of base-metal sulfide and sulfosalt minerals. These general paragenetic relations are also illustrated in figures 22 and 23. In parts of the ore, colloform pitchblende is broken by small fractures (fig. 25), which are filled by chalcopyrite and gangue. Thin fillings of chalcopyrite and gangue also occur along shrinkage cracks in pitchblende, as observed in many of the specimens under high magnification. The channelways provided by fractures and shrinkage cracks enabled copper-bearing solutions to migrate outward from the center of veinlets, causing local replacement of ankerite along the inner surface of pitchblende, as in figures 22 and 23. In some of the polished and thin sections of the Mena ore, veinlets of carbonate and the sulfide and other metallic minerals transect pitchblende stringers. The distribution of the various metallic minerals other than pitchblende is spotty and irregular, and detailed studies of the paragenetic relations among them were not made. Adams, Gude, and Beroni (1953, p. 16) reported that ankerite apparently formed both before and after the pitchblende, and that calcite is the youngest of the gangue minerals.

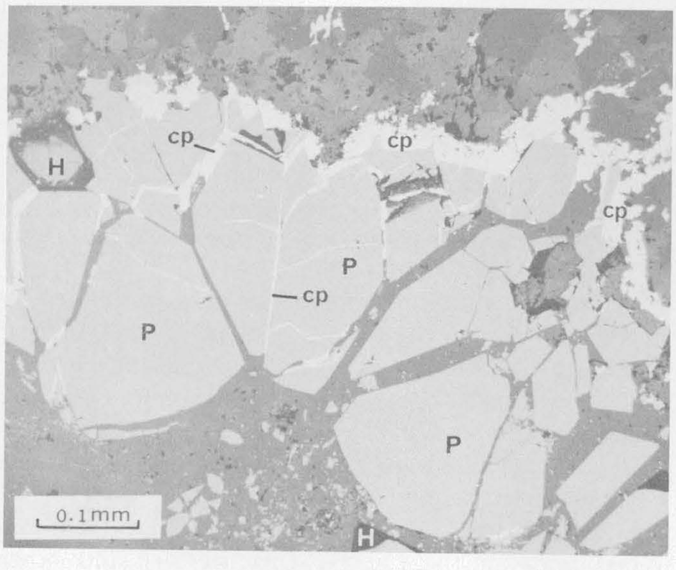


FIGURE 25.—Polished section of uranium ore, Mena mine. Chalcopyrite (cp) rims fractured colloform pitchblende (P) and fills many fractures in the pitchblende. Some of the fractures in pitchblende are cemented by a carbonate gangue (dark gray). H, holes in section.

The paragenetic history of the Mena vein may be summarized as follows: (1) Faulting, brecciation, and alteration of wallrock fragments; (2) deposition of crystals of potassic feldspar on breccia fragments and along walls of small fissures; (3) deposition of both coarse- and fine-grained ankerite; (4) deposition of pitchblende, then minor quartz; (5) minor fracturing; and (6) deposition of late ankerite, calcite, and base-metal sulfides and associated metallic minerals.

Unlike the ores from the Union Pacific prospect and the Mena mine, much of the ore from the Schwartzwalder mine, particularly in the main veins and ore shoots, is complexly fractured and brecciated. Fault movements must have occurred in at least three stages—one or more preceding the pitchblende, one or more preceding the sulfide and other metallic minerals, and at least one following the sulfide minerals. The late fracturing was less intense along some of the thin veinlets and subsidiary branches from the main veins; a specimen from such a veinlet is shown in figure 21. Several small faults cut the ore-bearing fault breccias of the Schwartzwalder mine but generally have displacements of 5 feet or less.

Some of the ore from the Ascension mine also shows the effects of complex fracturing and brecciation. The textural features of one specimen (fig. 26) suggest that the pitchblende deposition may have been interrupted

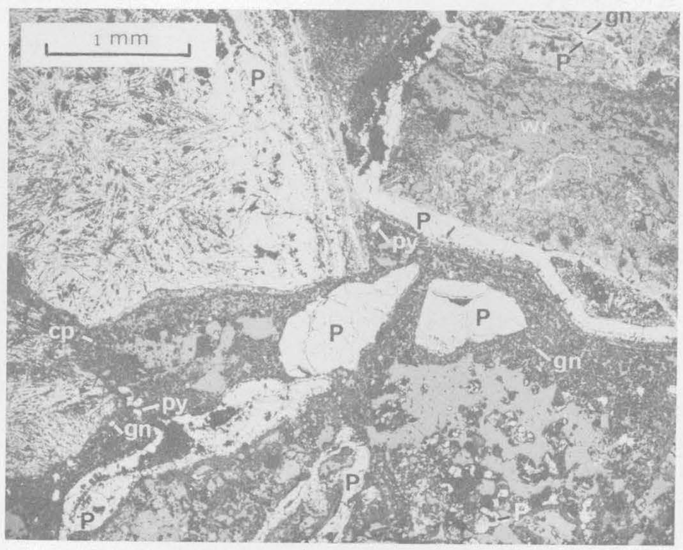


FIGURE 26.—Polished section of brecciated uranium ore, Ascension mine. Pitchblende (P) occurs in brecciated colloform fragments (center), in a breccia fragment of banded ore (upper left), and as a coating on a breccia fragment of altered Precambrian wallrock (wr) (upper right). The gangue, principally quartz in this specimen, contains fine grains of pyrite (py), chalcopyrite (cp), and galena (gn). Galena also occupies the center of a very thin veinlet bordered by pitchblende at the extreme upper right.

by fracturing. Early pitchblende is represented in figure 26 by the brecciated colloform fragments and the breccia fragment of banded ore. The fact that pitchblende rimming the large breccia fragment of wallrock (upper right of photomicrograph) seems to be undisturbed suggests that it is somewhat younger. Except for this possible division of the pitchblende stage, however, the general paragenetic relations appear to be the same as in the other deposits, because the galena and chalcopyrite are younger than the pitchblende.

The principal gangue mineral in the Ralston Buttes district is ankerite, but potassic feldspar is a common minor constituent, and some veins also contain appreciable amounts of quartz and late calcite. Potassic feldspar and ankerite were deposited before pitchblende, and some ankerite was deposited after. Quartz is more abundant in the Schwartzwalder mine than in most of the other deposits and was apparently deposited during both the pitchblende stage and the later sulfide stage.

Potassic feldspar from the Mena vein and from the Fork prospect was examined by E. J. Young, of the U.S. Geological Survey, who reported as follows (written commun., 1959):

The feldspar was studied by means of ($\bar{2}01$) X-ray method of Bowen and Tuttle (1950) and was found to be pure $KAlSi_3O_8$. Comparison of the X-ray diffractogram with those of MacKenzie (1954) shows that the feldspar is monoclinic (triclinicity was not detected) and, consequently, orthoclase.

The feldspar has the following refractive indices (± 0.002):

$$\alpha = 1.519$$
$$\beta = 1.523$$
$$\gamma = 1.524$$

The size of the optic angle was determined with the universal stage from thin section and from mounted grains. Optic angles varied from 23° to 65°, averaging 43° for nine determinations. The optic sign is negative, and if identification of the prominent cleavage as (001) is correct, then the optic plane is $\perp$ (010).

From the size of the optic angle and the orientation of the optic plane, the feldspar fits the low temperature "true orthoclase" illustrated by Chaisson (1950) or the orthoclase cryptoperthite type of alkali feldspar described by Tuttle (1952).

AGE OF THE DEPOSITS

A sample of pitchblende (lab. No. GS/585) from the Mena mine was submitted to L. R. Stieff and T. W. Stern of the U.S. Geological Survey for age determination. It was selected from ore that came from the main ore shoot at a point 60 feet from the portal of the North adit, and it consisted of numerous botryoidal crusts and thin veinlets of the pitchblende variety of uraninite; only small amounts of other vein material were present. Correction for nonradiogenic lead was made from calculations based on the isotopic composition of galena (lab. No. GS/631) from the same vein. The galena sample was from the Black Judge shaft, about 75 feet above the place from which the pitchblende sample was taken. T. W. Stern (written commun., 1960) reported as follows:

The sample was crushed, and the thin veinlets of uraninite were picked out by hand. These veinlets were ground to pass through 200 mesh screen.

Semiquantitative spectrographic analysis of GS/585

[Analyst: K. V. Hazel]

Percent	*Elements*	*Percent*	*Elements*
>10	U	0.05 -0.1	Ti, Mn, Mg
5 -10	----------	.01 -.05	Zr, B
1 -5	Si, Ca	.005 -.01	Cu, Y
0.5-1	Fe, Pb	.001 -.005	Sr, Ba, Be
.1- .5	Al, As	.0005 -.001	Yb
		.0001 -.0005	------------
		.00005-.0001	Ag

Quantitative analysis of the pitchblende (GS/585) by Frank Cuttita and J. J. Warr revealed the following (in percent): Lead, 0.865; uranium, 66.2; thorium, 0.09.

Pitchblende (GS/585) and galena (GS/631) from the Mena mine were isotopically analyzed by M. H. Delevaux with the following results, in atom percent:

Lab. No.	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
GS/585	0.271	80.94	7.84	10.95
GS/631	1.236	29.98	19.76	49.02

Age determinations, in millions of years, are as follows:

Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}
73 ± 0.2	73 ± 1.7	66 ± 57

The foregoing errors are due only to uncertainties in the physical constants used to calculate the ages given here. (See Stieff and others (1959) for constants and method of age calculation used.)

The agreement between these lead-uranium ages is evidence of their validity even though examples of fortuitous agreement have been reported. Stieff and I conclude that an age of 73 ± 5 million years is indicated for this sample. Thorium and radiogenic Pb^{208} contents were too low to permit calculation of a meaningful lead-thorium age.

Comparison of the figure of 73 ± 5 million years quoted above with the revised geological time scale of Holmes (1959, p. 183) indicates that the sample from the Mena mine is Late Cretaceous or early Tertiary (Laramide) in age. This is presumably the age of all the pitchblende-bearing vein deposits of the Ralston Buttes district.

Determinations on samples of uraninite from the Wood mine in the Central City district and other mines in the Front Range gave ages ranging from 55 $\pm$ 6 to 70 $\pm$ 7 million years (Faul and others, 1954, table 9, p. 263); about 60 million years was the commonest reported age. Although the age determination of the sample from the Mena mine suggests that this deposit may be slightly older than some of the others in the Front Range, all the deposits are probably related to hydrothermal activity during the complex sequence of events that made up the Laramide orogeny, which in Colorado extended from Late Cretaceous into the Eocene.

GRADE AND CHEMICAL COMPOSITION

The grade of uranium ore shipped from the district during 1953–60, from annual averages for each mine, ranged from 0.16 to 1.32 percent U_3O_8. The average grade of all ore shipped from the district through 1960 was 0.74 percent U_3O_8 (table 23).

The grade of individual samples from the various mines is listed in separate tables. A grab sample of ore from the site of an outcrop now occupied by the portal of the North adit of the Mena mine contained 0.24 percent uranium, 10.82 percent copper, and 5.8 percent bismuth, and it assayed 43.6 ounces of silver per ton; the chemical and spectrographic analyses of this sample are shown in tables 24 and 25. A grab sample from the Ascension mine contained 6.48 percent uranium, and a channel sample from the 74-foot level at the Aubrey Ladwig mine contained 1.92 percent uranium.

TABLE 24.—*Partial analysis of pitchblende ore sample (field No. N-1; lab. No. 242065)*[1] *from the Mena mine, Ralston Buttes district*

[Results in percent except as indicated. U.S. Geol. Survey analysts: C. G. Angelo (eU), J. S. Wahlberg (U), D. L. Skinner (Au, Ag), W. D. Goss (Mo, Zn, Cu, Pb, Bi), Claude Huffman, Jr., and R. F. Dufour (Ni, Co)]

eU	0.28	Cu	10.82
U	.24	Pb	.12
Au..ounces per ton..	None	Bi	5.8
Ag..........do..	43.60	Ni	.008
Mo	.10	Co	.004
Zn	.17		

[1] From an outcrop of the Mena vein in a bulldozer cut near Ralston Creek. The site is now occupied by the portal of the North adit.

NOTE.—U, Zn, and Pb were analyzed by volumetric method. Mo, Ni, and Co were analyzed by colorimetric method. Au, and Ag were analyzed by fire-assay method. Cu was analyzed by electrolytic method. Bi was analyzed by gravmetric method.

Radiometric, chemical, and spectrographic analyses of 30 channel samples from the Schwartzwalder mine are listed in table 26 (in pocket). The grade of these samples, some of which are from wallrock adjacent to the veins ranges from 0.009 to 6.36 percent uranium. The average grade of all samples taken from the main

TABLE 25.—*Analyses, in percent, of pitchblende-bearing ore from three mines, Ralston Buttes district*

[Symbols: ..., not looked for; 0, looked for but not detected; M, major constituent (>10 percent); <, less than percentage shown (here, standard sensitivities do not apply). U.S. Geol. Survey analysts: C. G. Angelo (eU, Mena mine), J. S. Wahlberg (U, Mena mine), D. L. Schafer (eU, Aubrey Ladwig and Ascension mines), H. H. Lipp (eU, Aubrey Ladwig and Ascension mines), and R. G. Havens (spectrographic analyses)]

Lab. No.	Field No.	Location	Type of sample	Chemical analyses	Radiometric analyses	Semiquantitative spectrographic analyses										
				U	eU	Si	Al	Fe	Ti	Mn	Ca	Mg	Na	K	Ag	As
242065	N-1	Mena mine; sample from former outcrop, now the site of portal of North adit.	Grab sample from vein (mineralized fault breccia), 18 in. thick.	0.24	0.28	M	7	7	0.7	0.07	0.7	0.15	1.5	M	0.3	1.5
253101	S-L-1	Aubrey Ladwig mine; sample taken near wall of crosscut at foot of stope in the 74-ft level (fig. 33).	Channel sample, 0.7 ft long, from mineralized fault breccia.	1.92	1.6	M	7	M	.3	1.5	.7	1.5	.3	M	0	0
253103	S-A-2	Ascension mine; sample taken from stope in northwestern part of drift along the Ascension fault (pl. 7).	Grab sample from mineralized fault breccia.	6.48	4.8	......	7	7	.7	.07	3	1.5	......	3	0	0

Lab. No.	Semiquantitative spectrographic analyses																			
	Ba	Be	Bi	Co	Cr	Cu	Ga	La	Mo	Nb	Ni	Pb	Sb	Sc	Sr	U	V	Y	Yb	Zn	Zr
242065	0.7	0.0007	7	0.007	0.015	M	0.0007	0	0.15	0.007	0.007	0.7	0.3	0.003	0.03	0.3	0.07	0.003	0.001	0.3	0.015
253101	.07	.0015	0	<.007	.003	0.015	.0007	.007	.07	.015	.007	.15	0	.0015	.03	1.5	.03	.007	< .003	.07	.07
253103	.07	.003	0	0	.007	.015	.0003	0	0	.015	.007	.07	0	.003	.007	7	.03	.03	0	0	.15

NOTE.—The concentrations in the spectrographic analyses are reported as elements, not as oxides or compounds.

The following classification is used for the spectrographic data: Figures are reported to the nearest number in the series, 7, 3, 1.5, 0.7, 0.3, 0.15, etc. 60 percent of the reported results may be expected to agree with the results of quantitative methods. Because sample S-A-2 contains a high percentage of U, it was diluted with quartz (plus Na) in order to avoid the matrix effect; consequently the usual sensitivities do not apply. Elements looked for but not detected: P, Au, B, Cd, Ce, Dy, Er, Gd, Ge, Hf, Hg, In, Ir, Li, Nd, Os, Pd, Pt, Re, Rh, Ru, Sn, Sm, Ta, Th, Tl, Te, and W. In sample S-L-1 and S-A-2, the following elements were also looked for but not detected: Eu, Ho, Lu, Pr, Tb, Tm.

ore shoots is 1.89 percent uranium; the average grade of all other samples of coarse breccia adjacent to the ore shoots and of material between branches of veins is 0.26 percent uranium. The chemical analyses show that some samples contain as much as 1.16 percent copper, 4.77 percent MnO, 0.077 percent V_2O_5, 0.053 percent nickel, 0.050 percent cobalt, 0.95 percent molybdenum, 0.19 percent zinc, 1.63 percent lead, and assay as much as 7.1 ounces of silver per ton. Cobalt, vanadium, and molybdenum minerals have not been identified as yet in the ore. Some of the manganese reported in the analyses may be from garnet in rock fragments in the breccias, because a spectrographic analysis of one garnet fraction recovered from garnetiferous wallrock in the mine indicated 7 percent manganese (table 31, sample 3). The spectrographic analyses (table 26) show that some channel samples contain as much as 0.7 percent titanium, 0.7 percent arsenic, 0.15 percent bismuth, 0.015 percent yttrium, and 0.15 percent zirconium.

The spectrographic analyses suggest that zirconium content is related to uranium content, at least in ores from the Ascension and Schwartzwalder mines (tables 25, 26). To check the possibility that the zirconium may be present in the pitchblende itself, samples of pitchblende were carefully picked from ore samples from five different deposits in the Ralston Buttes district. Samples consisting of extremely fine grained material were purified of sulfides and gangue minerals by gravity and flotation methods. Results of spectrographic analyses of the purified samples are listed in table 27, which shows that zirconium forms 0.7 to 1.5 percent of each sample. Although some samples were not completely free of sulfides, the results indicate that zirconium and uranium are closely related. A similar relation was observed in ores of the Central City district (Drake, 1957, p. 160–161; Sims and others, 1963, p. 37–38); thus, mineralization in the two areas may have been related.

Yttrium also shows a fairly consistent association with uranium. Bismuth, titanium, and columbium are apparently associated with uranium in some samples, and ytterbium and vanadium may be associated with uranium in the vein near the Buckman adit. Chemical features of uranium deposits in the Front Range are discussed in greater detail in a report by Sims and Sheridan (1964).

LOCALIZATION OF THE DEPOSITS

Mining, exploration, and mapping in the Ralston Buttes district have demonstrated that the uranium deposits were controlled primarily by structural environment and the character of the host rocks. Because the deposits are principally fillings of open spaces in breccias and along subsidiary faults and fractures, their deposition was governed mainly by structural and physical factors that provided adequate open spaces. Chemical features of certain wallrocks also seem to have influenced precipitation of pitchblende.

In each of the two main areas—Golden Gate Canyon and Ralston Creek—the uranium deposits occur where a major northwest-trending fault system splits into a complex branching network of faults and fractures, many of which curve or bend repeatedly. These structural conditions provided abundant open spaces for deposition of vein matter.

As was first recognized by Adams and Stugard (1956), faults in the Golden Gate Canyon area contain pitchblende deposits where they cut "beds" of hornblende gneiss but are almost barren where they cut rocks of other kinds. The favorable hornblende gneiss beds mentioned by Adams and Stugard are part of the hornblende gneiss unit of the present report and lie near the contact with the microcline gneiss unit (pl. 1). Elsewhere in the Golden Gate Canyon area, we observed that uranium deposits at the Ascension mine occur where breccia-reef faults of the Hurricane Hill fault system cut layered calc-silicate gneiss and associated rocks of the hornblende gneiss unit. At the Aubrey Ladwig mine, uranium deposits occur in brecciated zones in garnetiferous biotite-quartz gneiss and in and near the fractured contacts between pegmatite and the garnetiferous gneiss; the garnetiferous gneiss is in the transition zone between the mica schist unit and layered calc-silicate gneiss of the hornblende gneiss unit.

At the Schwartzwalder mine in the Ralston Creek area, subsidiary faults of the Rogers fault system cut a transition zone of garnetiferous biotite-quartz gneiss and associated rocks along the contact between the mica schist unit and the undivided hornblende gneiss unit. The Mena mine is on a fault that cuts hornblende gneiss, amphibolite, and biotite gneiss of the undivided hornblende gneiss unit, and the North Star mine and uranium prospects to the southeast are on faults cutting similar rocks complexly interlayered with microcline gneiss.

Although chemical composition was probably a contributing factor in the localization of the uranium deposits in hornblende gneiss, garnetiferous biotite-quartz gneiss, and related rocks, we believe that the physical characteristics of these rocks exerted a greater influence. These rocks are generally competent and brittle, and therefore abundant open spaces tended to form when the rocks were fractured and brecciated.

TABLE 27.—*Analyses, in percent, of selected samples of pitchblende, Ralston Buttes district*

[Symbols: ------, not looked for; 0, looked for but not detected; M, major constituent (>10 percent); <, less than percentage shown (here, standard sensitivities do not apply). U.S. Geol. Survey analysts: C. G. Angelo and E. J. Young (eU), H. H. Lipp (U), and N. M. Conklin (spectrographic analyses)]

Lab. No.	Sample No.	Location	Radiometric analyses	Chemical analyses	Semiquantitative spectrographic analyses																			
			eU	U	Al	Fe	Mg	Ca	Ti	Mn	Ag	Ba	Be	Bi	Cr	Cu	Mo	Nb	Pb	U	V	Y	Yb	Zr
253105	S-P-1	Mena mine, North adit	75	78	<0.1	0.7	<0.05	0.7	0.7	0.15	0	<0.03	0.007	0.15	0.015	0.015	0	0.07	0.7	M	0	0.3	------	0.7
253106	S-P-2	Thin vein in roadcut near Buckman adit	31	------	<.1	.7	<.05	.7	.7	.15	0	<.03	0	0	<.01	.015	0	.07	.7	M	.07	.7	0.15	.7
253107	S-P-3	Schwartzwalder mine, Minnesota level	53	------	.3	.7	.07	.3	.7	.07	.007	<.03	0	1.5	<.01	.7	.3	0	1.5	M	0	.15	------	.7
253108	S-P-4	Aubrey Ladwig mine, open-cut	51	------	.15	.3	<.05	.3	1.5	.07	0	.03	0	.15	.015	.3	.03	.7	3	M	0	.03	------	1.5
253109	S-P-5	Ascension mine	29	------	.7	1.5	<.05	.3	1.5	.07	0	<.03	.007	0	<.01	.07	0	.07	1.5	M	0	.15	------	1.5

NOTE.—The concentrations in the spectrographic analyses are reported as elements, not as oxides or compounds. The following classification is used for the spectrographic data: Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc. 60 percent of the reported results may be expected to agree with the results of quantitative methods. Because the samples contain a high percentage of U, they were diluted with quartz (plus Na) in order to avoid the matrix effect; consequently, the usual sensitivities do not apply, and only the more abundant constituents could be detected. Elements not looked for: Si, Na, Cd, Cs, F, Rb. Elements looked for but not found: K, P, As, Au, B, Ce, Co, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Nd, Ni, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sr, Sm, Ta, Tb, Te, Th, Tl, Tm, W, Zn.

In contrast, in less competent rocks, such as schist, tight or gouge-filled fractures tended to form. Furthermore, in rocks of contrasting competencies, as at the Schwartzwalder mine, faults and fractures were commonly deflected from one rock type into another, forming cymoid curves and branching structures favorable to ore deposition.

Adams and Stugard (1956), however, postulated that the control was primarily chemical, at least in the Golden Gate Canyon area. They suggested that ferrous iron released during the alteration of hornblende by mineralizing solutions was partly oxidized to hematite, and, at the same time, uranium was reduced and deposited as pitchblende. They concluded (1956, p. 208) that wallrocks rich in ferrous iron were the most favorable host for deposition of "pitchblende-bearing veins of the carbonate type" and emphasized that rocks rich in biotite, magnetite, tourmaline, or iron sulfides could have been as effective as the hornblendic rocks in inducing precipitation of pitchblende. Bird (1957a, p. 92; 1957b, p. 44) visualized a generally similar process for deposits at the Schwartzwalder mine and suggested that ferrous iron from the garnetiferous biotite gneiss may have acted as a reducing agent in precipitating the pitchblende, and that relatively impervious schist overlying the garnetiferous biotite gneiss acted as a structural trap that impeded the uranium-bearing solutions.

Although we believe that structural environment and the physical nature of certain rocks were the principal controls, it seems especially significant that economically important uranium deposits are absent in various parts of the Ralston Buttes district where faults cut competent but iron-poor rocks such as quartzite, quartz monzonite, and microcline gneiss. Therefore, the distribution of the uranium deposits suggests that some sort of chemical control probably contributed to their localization, although we cannot conclusively demonstrate from available data that the oxidation-reduction mechanism postulated by Adams and Stugard and by Bird was the actual process involved.

SUMMARY OF RECONNAISSANCE FOR RADIOACTIVITY

During the study of the Ralston Buttes district, traverses were made with a scintillation detector throughout the area of Precambrian rocks as follows: 622 readings were taken along breccia-reef faults and fracture zones, and 425 readings on outcrops of the various rocks. A statistical summary of these readings is shown in table 28.

TABLE 28.—*Summary of readings of radioactivity, in milliroentgens per hour, taken during reconnaissance traverses of the Ralston Buttes district*

	Along breccia-reef faults and fracture zones							
	<0.01	0.01–0.02	0.02–0.03	0.03–0.04	0.04–0.05	0.05–0.1	0.1–1.0	>1.0
Number of readings	2	228	282	79	11	6	9	5
Percent of total readings taken along breccia-reef faults and fracture zones	.3	36.7	45.3	12.7	1.8	.9	1.5	.8
Percent of total readings taken along faults and fracture zones and at outcrops of country rocks	.2	21.8	27.0	7.5	1.0	.6	.9	.5

	At outcrops of country rock (Precambrian rocks and leucosyenite of Laramide age)							
	<0.01	0.01–0.02	0.02–0.03	0.03–0.04	0.04–0.05	0.05–0.1	0.1–1.0	>1.0
Number of readings	10	238	118	47	10	2	0	0
Percent of total readings taken at outcrops of country rock	2.4	56.0	27.7	11.1	2.4	.5	0	0
Percent of total readings taken along faults and fracture zones and at outcrops of country rock	1.0	22.7	11.3	4.5	1.0	.2	0	0

Statistically, the radioactivity of the country rocks is surprisingly similar to that of the faults and fracture zones. In the lower range of radioactivity, the percentage of readings, or frequency, is about the same in the two environments. In the higher range (0.05–1 milliroentgen per hour), however, outcrop readings on country rocks are only 0.2 percent of the overall total of readings, whereas readings along faults and fracture zones are 2 percent of the overall total of readings. Many of the high readings at outcrops of country rock are caused by monazite or other radioactive minerals in pegmatites and dike rocks. Most of the high readings along faults and fracture zones are probably related to uranium. Some faults were only slightly to moderately radioactive at the surface but when explored at depth proved to be pitchblende bearing; this probably reflects both the leaching of uranium from surface exposures and the small size of some of the deposits.

The reconnaissance showed that if the trace of a breccia-reef fault or fracture zone shows any abnormal radioactivity, it is generally on the order of 1½–2 times the radioactivity of the country rock. Where radioactive faults pass beneath surficial material a foot or more in thickness, the readings normally fall to background levels, and only in a few places could covered faults be traced by radioactivity.

Along faults and fracture zones, the intensity of radioactivity is commonly inversely proportional to the length of the most radioactive part. For example, readings of 1½–2 times the radioactivity of the country rock are commonly obtained over distances of several hundred yards along a fault or fracture zone, whereas readings of 3 or more times background levels are limited mostly to a few feet.

The meaning of seemingly abnormal readings in the lower range of radioactivity may be ambiguous because of differences in the radioactivity of the various Precambrian rocks. Mica schist, for example, seems to have a generally higher level of radioactivity than amphibolite and hornblende gneiss. Similarly, areas which contain abundant pegmatites or are near dikes generally show higher radioactivity than the ordinary gneisses.

During the reconnaissance study, 12 samples of fault breccia were taken in order to check actual uranium content against radioactivity. The results, shown in table 29, indicate that the radioactivity, expressed in terms of equivalent uranium percentage, is generally two or more times greater than the uranium percentage. This suggests that leaching has removed part of the uranium from the surface exposures. Local prospectors report that the leached zone over high-grade deposits is commonly only 2–10 feet thick but in some places is over 50 feet thick. Most of the samples in table 29 probably do not indicate underlying ore. The data from this study suggest that abnormal radioactivity related to uranium is not confined wholly to individual ore bodies but is disseminated in varying but generally small amounts along the fault breccias. In some areas such minor surface signs of radioactivity combined with other geologic and mineralogic evidence have led to the discovery of ore below the leached surface outcrops.

SUGGESTIONS FOR URANIUM PROSPECTING

Geologic features useful as guides in the search for uranium deposits in the Ralston Buttes district include (1) the association of the deposits with breccia-reef fault systems, (2) the apparent favorability of certain Precambrian rocks for localization of deposits along the faults and fracture zones, (3) the common association of pitchblende with copper minerals and other base-metal sulfides, and (4) abnormal radioactivity and the presence of secondary uranium minerals.

Most of the uranium deposits in the district are along or near northwest-trending breccia-reef fault and fracture systems. Furthermore, the main groups of deposits occur where such fault and fracture systems consist of complex zones of faults and fractures or where the fault systems show changes in trend.

The relatively dark metamorphic rocks rich in hornblende, biotite, or garnet in company with biotite, appear to have been the most favorable wallrocks for the deposition of uranium deposits in the Ralston Buttes district. The general favorability of these rocks was probably due chiefly to their physical behavior when faulted or fractured but may also have been related partly to their chemical nature. Rocks of this type are characteristic of the hornblende gneiss unit and its subdivisions, and include hornblende gneiss, amphibolite, biotite-quartz-plagioclase gneiss, layered calc-silicate gneiss, and rocks of the transition zone at the contact with the mica schist unit, particularly garnetiferous biotite-quartz gneiss. Rocks of this general type also occur in the unit of interlayered gneisses and

TABLE 29.—*Analyses, in percent, of samples of fault breccia, Ralston Buttes district*

[U.S. Geol. Survey analysts. C. G. Angelo (eU), and R. P. Cox and H. H. Lipp (U)]

Lab. No.	Field No.	Location	Radiometric analyses eU	Chemical analyses U	Type of sample
242052	DS-55-69	SE¼ sec. 34, T. 2 S., R. 71 W	0.006	0.003	Chip, 3.5 ft long.
242053	70	SW¼ sec. 34, T. 2 S., R. 71 W	.006	.002	Grab.
242054	RA 623 A	NW¼ sec. 35, T. 3 S., R. 71 W	.011	.005	Chip, 1.5 ft long.
242055	B	do	.012	.008	Chip, 1.25 ft long.
242056	C	do	.006	.003	Chip, 1.5 ft long.
242057	RA 624 A	NE¼ sec. 17, T. 3 S., R. 71 W	.005	.002	Grab, east wall of pit.
242058	B	do	.006	.001	Grab, west wall of pit.
242059	C	do	.004	.001	Grab, outcrop at road.
242060	RA 625	SE¼ sec. 7, T. 3 S., R. 71 W	.006	.001	Grab.
242061	626	NW¼ sec. 24, T. 3 S., R. 71 W	.004	.001	Do.
242063	628	NW¼ sec. 28, T. 2 S., R. 71 W	<.001	----------	Do.
242064	629	NE¼ sec. 30, T. 2 S., R. 71 W	.006	.001	Do.

are complexly interlayered with microcline gneiss in some areas.

Since copper minerals and other base-metal sulfides are commonly associated with the pitchblende of the Ralston Buttes district, they may serve as a guide to prospecting, particularly in conjunction with the other geologic features.

Abnormal radioactivity and traces of secondary uranium minerals are other evidence useful to the prospector. Caution is necessary, however, in the interpretation of radioactivity data, because high radioactivity alone does not establish the presence of a minable deposit of uranium. Monazite and certain other minerals in pegmatites and dikes cause some radioactivity; daughter products remaining after uranium has been leached are another cause. On the other hand, radioactivity at surface exposures of some of the uranium deposits is not always strikingly high. Leaching has removed a large part of the uranium from some of the surface exposures.

OTHER ECONOMIC DEPOSITS

In addition to uranium, the Ralston Buttes district contains deposits of pegmatite minerals, clay, limestone, dimension stone, and sand and gravel. Production of these materials has been small.

Minerals produced from pegmatites in the district include scrap mica, feldspar, and beryl. No production records are available, but the size of the pits and quarries indicates that the total production has been small. Pegmatite mines and prospects are shown on plate 1. Pegmatites in the SE¼ sec. 30, T. 2 S., R. 71 W., and the NW¼ sec. 28, T. 3 S., R. 71 W., have been explored for minerals containing rare earths, but no production has been reported.

Scheelite, molybdenite, and pyrrhotite occur in small quantities along vague, irregular fractures and as disseminated grains in several places in the Precambrian terrane of the Ralston Buttes district. None of these deposits appear to be minable. A prospect containing molybdenum (SE¼ sec. 21, T. 3 S., R. 71 W.) and one containing tungsten (NW¼ sec. 24, T. 3 S., R. 71 W.) are shown on the geologic map (pl. 1). Although both are on or near fault systems that presumably underwent Laramide movement, evidence that the ore minerals are related to Late Cretaceous or early Tertiary mineralization is not conclusive. Both occurrences are at the contact (pl. 1) of the layered calc-silicate gneiss with the interlayered hornblende gneiss, amphibolite, and biotite gneiss, and both resemble tungsten-molybdenum deposits described by Tweto (1960). It is entirely possible that the minerals represent mineralization that occurred during Precambrian time.

Molybdenite and pyrrhotite have also been found in small quanitites in the host rocks at the Schwartzwalder mine but have not been recognized in polished sections of the pitchblende ore. Although abnormal amounts of molybdenum occur in the ore from this mine and may be related to unrecognized molybdenum minerals in the ore, part of the molybdenite and probably all the pyrrhotite in the wallrock may be unrelated in origin to the uranium.

Clay has been mined from the Fountain, Dakota, and Benton Formations in the district. Refractory grade clay occurs only in the upper part of the Dakota (Waagé, 1952, 1961), and much of the readily accessible clay has been mined. The reserves of refractory clay from the north boundary of the district to Fireclay are not known. The clay lies in beds that are overturned and probably greatly fractured. It has been mined to an unknown extent. Most of the clay above an altitude of 6,400 feet has been removed from the area between Fireclay and the plunging anticline in sec. 32, T. 2 S., R. 70 W. Two mines were worked on a part-time basis in this area in 1955 and 1956. The area from the plunging anticline to the eastern boundary contains most of the refractory clay deposits in the district. Except for a few prospect pits and tunnels, the clay is relatively untouched; it is of good quality, according to Waagé (1961, p. 88, 89).

Small amounts of common clay have been mined from mudstone beds in the Fountain Formation and from the lower part of the Benton Shale. Clay from the Benton Shale has a tendency to bloat and is generally blended with other clays. Waagé (1952, p. 388) stated that the Benton might be a source of bloating clay suitable for manufacturing lightweight concrete blocks, but no tests have been made to verify this. In 1956 common clay was mined from a small pit in mudstone of the Lykins Formation about 2 miles north of the Ralston Buttes district.

Limestone beds in the Lykins Formation and Fort Hays Limestone Member of the Niobrara Formation were extensively quarried for mortar many years ago. Only one small quarry in the Lykins Formation just east of the Ralston Buttes district was active in the area in 1955. This rock, in demand for its red color, was crushed and used to surface private driveways.

Lyons Sandstone was quarried in the Ralston Buttes district for use as dimension stone, but none of the quarries have been operated for many years.

Just east of the Ralston Buttes district, in Clear Creek Canyon, several quarries in Precambrian gneiss have been operated for concrete aggregate, riprap, and ballast. Similar rock is abundant in the Ralston Buttes district.

Sand and gravel have been extracted from the Quaternary pediments east of the Ralston Buttes district. The material covering the pediments in the district is silty and contains many cobbles and boulders that would require crushing. It is generally inferior to material that can be obtained from the terraces and flood plain of Clear Creek east of the Ralston Buttes district.

URANIUM MINES AND PROSPECTS

During the present investigation, the underground workings and surface areas of three mines — the Schwartzwalder, Ascension, and Aubrey Ladwig—were studied and mapped in detail. A fourth, the Mena, was mapped in less detail, and various prospects were examined but not mapped. Some of the mines and prospects described by Adams and others (1953) and by Adams and Stugard (1956) were not reexamined except to fit the earlier descriptions into the areal geology. The Ohman mine was developed subsequent to our field studies in the district, so we have no detailed geologic data on it. However, it is near the Buckman adit, which has been described by Adams and Stugard (1956, p. 205–206).

RALSTON CREEK AREA

The Schwartzwalder, Mena, and North Star mines and several uranium prospects lie in an area of about 4 square miles along Ralston Creek in the northeastern and north-central parts of the district (pl. 1). The mines and prospects are in rocks of the hornblende gneiss unit and the unit of microcline gneiss complexly interlayered with other rocks (pl. 1), and most of them are on faults and fractures of the Rogers fault system. One prospect near the western part of the area is on a fault of the Hurricane Hill fault system.

MENA MINE

The Mena mine, formerly known as the Hoffmeister prospect and the Nigger shaft, is on Ralston Creek near the boundary between secs. 23 and 26, T. 2 S., R. 71 W., as these sections are plotted on the 1948 edition of the Ralston Buttes topographic map (pl. 1). However, because the original section corners between 23 and 26 were missing, a resurvey of the area was made by a registered land surveyor in June 1954, and this showed that the mine workings actually lie in the north-central part of sec. 26, several hundred feet from the section line. Although the workings of the Mena mine are shown correctly on plate 1 with regard to topography and drainage, the position of the section line has not been corrected.

At the time of our fieldwork, mineral rights to the property were owned by L. W. Bolis, Golden, Colo., and were leased to J. W. Walsh, Denver, Colo. Mineral rights to the adjacent property in sec. 23 were owned by the Union Pacific Railroad Co.

The mine may be reached by either of two access roads. Parts of these were built after the base map was prepared and are not shown on plate 1. A steep dirt road about 2 miles long passes northwest through A. G. Brumm's ranch and connects with State Highway 72 in Coal Creek Canyon. Another dirt road follows Ralston Creek southeastward past the Schwartzwalder mine and connects about 9 miles to the southeast with the junction of State Highways 58 and 93 northwest of Golden, near the mouth of Golden Gate Canyon.

The geology of the mine, then known as the Nigger shaft, was mapped in 1952 by Adams, Gude, and Beroni (1953, fig. 9). During the present investigation, it was visited intermittently by Sheridan, Maxwell, and R. U. King, and additional mapping was done (figs. 27, 28). The following description is based partly on the data obtained by Adams, Gude, and Beroni (1953) and partly on field and laboratory work made during the present investigation.

HISTORY AND PRODUCTION

The first discovery of pitchblende in the Ralston Buttes district was made by Fred Schwartzwalder in 1949 at the property now known as the Mena mine. At the time of this discovery, the property contained a small shaft and a short adit that had been prospected for copper in 1912–14 by a man named Hoffmeister (Adams and others, 1953, p. 13).

In 1954–55 two core holes were drilled and a small amount of trenching by bulldozer was done by the U.S. Atomic Energy Commission during an exploration program in the Ralston Creek area. More recently, J. W. Walsh drove two more adits and a new shaft with drifts and raises. Walsh has conducted exploration on the property intermittently since 1955, partly under an exploration contract with the Defense Minerals Exploration Administration.

The total production from the mine through 1960 was 999.01 tons (table 23). The average grade of shipments was 0.27 percent U_3O_8.

MINE WORKINGS

Workings at the Mena mine include an old shaft and adit, two new adits, and a new shaft with drifts and raises. The old shaft, now called the Black Judge shaft (formerly the Nigger shaft and Hoffmeister prospect), was shown in plan and in section by Adams, Gude, and Beroni (1953, fig. 9). The shaft is inclined steeply to the northeast to a depth of about 22 feet and connects to a drift and stope which extend 13 feet north from the bottom of the shaft. A short abandoned adit (the Hoffmeister adit) extends northwest from a point 130 feet southeast of the Black Judge shaft (fig. 27). The two newer adits (fig. 28), totaling 344 feet of workings, are on the north and south sides of Ralston Creek (fig. 27). Since the termination of field investigations in 1956, a new vertical shaft has been excavated to a depth of at least 90 feet from a collar 70 feet east of the portal of the North adit, and drifts were driven from it. In addition to these new workings, a winze has been excavated to a depth of about 20 feet near the portal of the South adit, and the vein has been partly stoped in the North adit.

WALLROCKS

The Mena mine (pl. 1) is near the northern margin of the undivided hornblende gneiss unit, which forms an east-trending belt. Rocks in the vicinity of the mine are interlayered hornblende gneiss, amphibolite, and biotite gneiss with lesser amounts of calc-silicate gneiss. Locally some of the hornblendic rocks are garnetiferous. Thin bodies of pegmatite and aplite cut the gneisses. Foliation strikes N. 60°–90° W. and dips southwest at moderate angles.

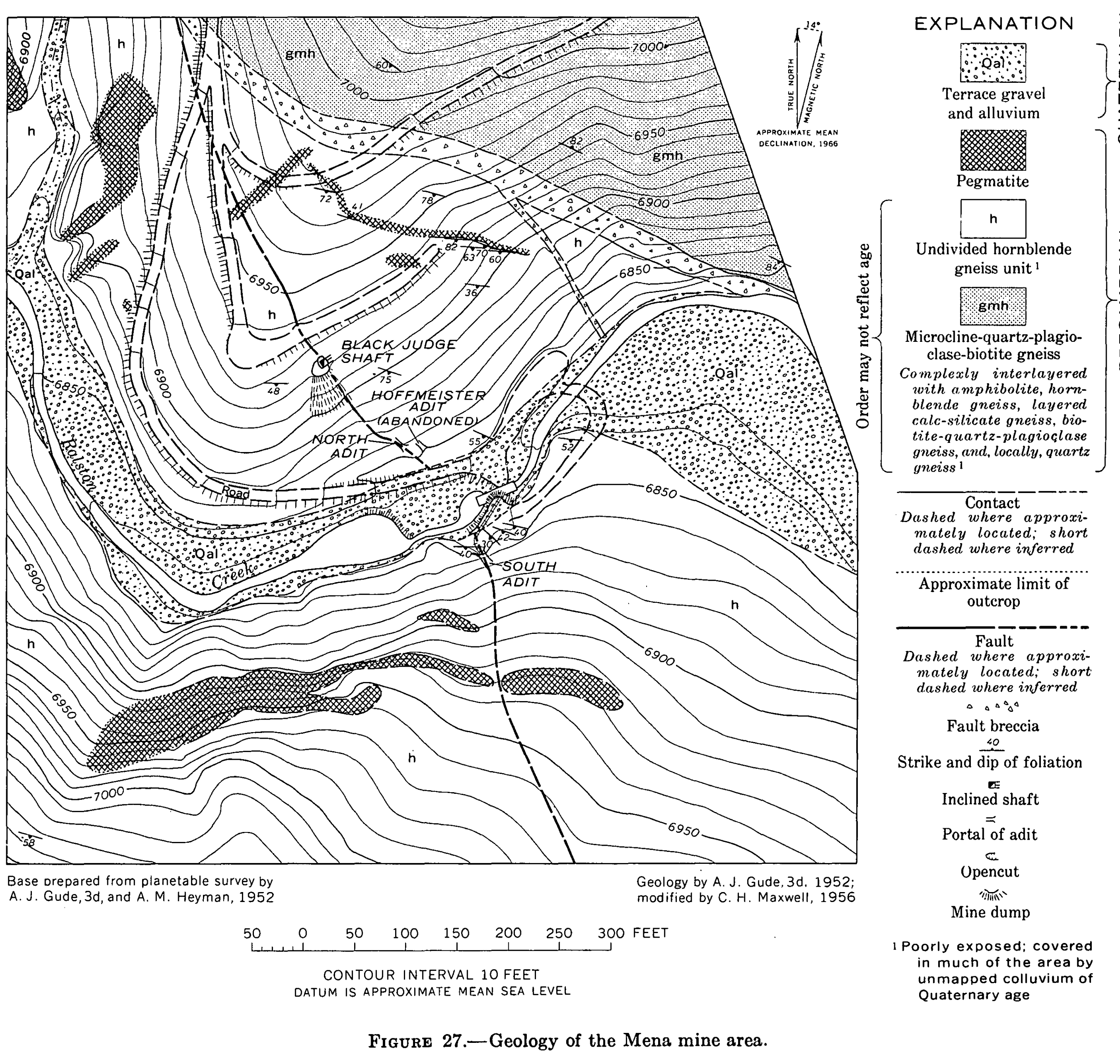
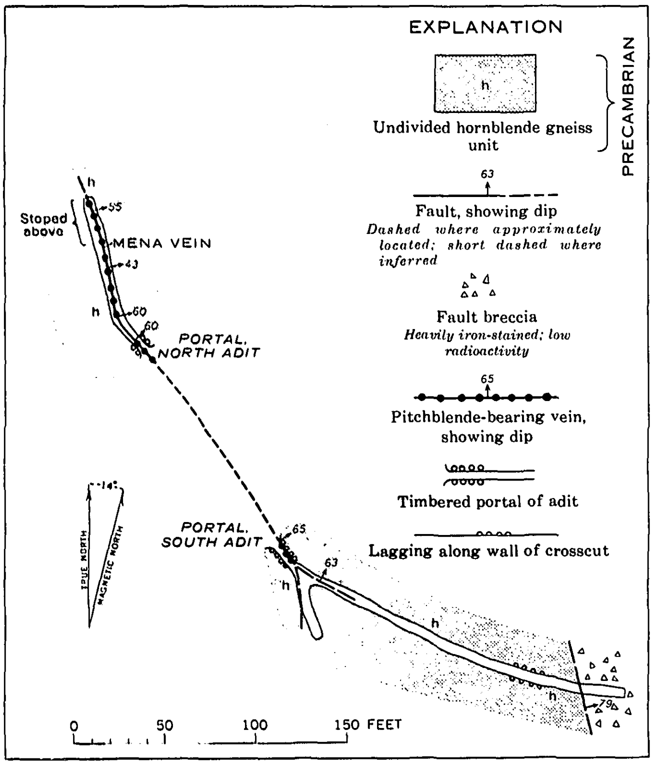


FIGURE 27.—Geology of the Mena mine area.



Base surveyed by compass and tape

Geology and base by D. M. Sheridan and R. U. King, August 1956

FIGURE 28.—North and South adits, Mena mine.

BRECCIA-REEF FAULTS

The Precambrian rocks in the vicinity of the Mena mine are cut by a group of northwest-trending breccia-reef faults of the Rogers fault system (pl. 1). The Mena vein is a mineralized breccia in a fault of this system. The fault containing the Mena vein has been traced by outcrops and breccia float for a distance of 2,000 feet (pl. 1). At its northwestern and southeastern extremities it merges with other breccia-reef faults. In the vicinity of the mine (figs. 27, 28), the fault strikes N. 10°–35° W. and dips 43°–70° NE. The thickness of the breccia ranges from ½ to 3½ feet. Despite the presence of breccia along this fault, the displacemen must have been small because no noticeable offset was observed in pegmatites cut by the fault. In this report the shear zone described by Adams, Gude, and Beroni (1953, p. 16) in the Nigger shaft (now called the Black Judge shaft) is considered to be a part of the fault containing the Mena vein. Adams and colleagues noted that the shear zone is as much as 8 feet thick in the workings at the shaft, but that the carbonate-rich part containing the ore averages 2 feet in thickness.

In the northwestern part of the mapped area (fig. 27), the fault containing the Mena vein merges with a zone of fault breccia that trends N. 60° W. This zone of breccia is as much as 35 feet in outcrop width and is well exposed at Ralston Creek at the eastern margin of the area (fig. 27). About 250 feet northeast of the Black Judge shaft, a branch fault containing about 5 feet of breccia extends S. 30° E. away from the wide zone of breccia. The breccia in the heading of the South adit (fig. 28) probably represents the same branch fault, but surface exposures were too poor to locate it south of Ralston Creek (fig. 27).

A major breccia-reef fault forming the southwestern margin of the Rogers fault system crosses Ralston Creek about 800 feet west of the mine (pl. 1). It trends N. 45° W. and is apparently almost vertical over most of its extent in secs. 23 and 26.

URANIUM DEPOSITS

The known uranium deposits on the Mena property are along the Mena vein and are largely north of Ralston Creek. The main ore shoot in the North adit strikes N. 10° W. and dips 43°–60° NE. (fig. 28). The thickness of the pitchblende-bearing breccia in the adit ranged from 1 to 3½ feet, and the horizontal length of the shoot exposed in August 1956 was about 65 feet. The shoot appears to rake steeply. Production data and presence of pitchblende in the Black Judge shaft suggest that the length of the ore shoot along the rake is at least 65 feet.

Uraniferous breccia was also cut in the first 6 feet from the portal of the North adit and in the first 12 feet from the portal of the South adit. These deposits are also on the Mena vein and may represent parts of two other ore shoots, parts of which may be concealed by the alluvium along Ralston Creek. Data available during fieldwork were insufficient to allow determination of the size or extent of the deposits.

The mineralized breccia comprising the Mena vein is a dense tan material that weathers reddish at the surface. It consists mostly of brecciated and highly altered fragments of Precambrian wallrock cemented largely by ankerite. The breccia contains a network of thin dark stringers and veinlets of pitchblende, sulfide and other metallic minerals, and gangue, including potassic feldspar, ankerite, quartz, and calcite. Although individual veinlets commonly range from 12 to 25 mm in thickness, petrographic studies of thin and polished sections indicate that the colloform coatings of pitchblende in these veinlets are rarely over 1.0 mm thick and are generally less than 0.5 mm. thick. However, such coatings are so abundant in much of the breccia as to constitute very rich ore. The colloform coatings of pitchblende occur on breccia fragments (fig. 22, 24) and along the walls of thin veinlets and on irregular fracture surfaces. Where the pitchblende occurs with other metallic minerals and gangue in the thicker veinlets, the textural relations indicate that it was deposited relatively early along the margins of veinlets and on breccia fragments, and that other minerals filled the remaining open spaces (figs. 22–24). The rounded botryoidal appearance of colloform pitchblende coating a fracture surface has been illustrated by Walker and Adams (1963, fig. 27).

Metallic minerals identified in samples of ore from the Mena mine include pitchblende, chalcopyrite, pyrite, galena, tetrahedrite- tennantite, chalcocite, bornite, native bismuth, native copper, niccolite, pararammelsbergite(?), maucherite(?), covellite, and secondary copper minerals. In addition, native silver was found by J. W. Walsh (oral commun., 1957) in underground workings connected to his new shaft. Sphalerite was not identified in the various ore samples, but one ore sample contained 0.17 percent zinc (table 24), which suggests that sphalerite probably occurs in small amounts in the ore. The analyzed sample also contained 0.1 percent molybdenum, but no molybdenite was recognized.

The textural relations of pitchblende, other metallic minerals, and gangue minerals are illustrated in figures 22–25. The general paragenetic relations of minerals in the ore are described on pages 78–79.

Native bismuth is abundant in parts of the Mena vein. It occurs with other metallic minerals in gangue that cements open spaces in the ore and is therefore apparently younger than the colloform coatings of pitchblende. As shown in figure 29, the native bismuth is veined and embayed by chalcopyrite. Thin vermiform veinlets composed of a very fine grained intergrowth of two or more unidentified metallic minerals occur along the contacts between chalcopyrite and native bismuth, and cut native bismuth, chalcopyrite, and gangue (fig. 29). These same unidentified minerals form a thin rim on native bismuth (upper right fig. 30), and locally on native bismuth (lower left fig. 30), in niccolite-bearing ore.

Niccolite was observed in some Mena ore; in one specimen as a minute grain along the rotund outer surface of pitchblende (fig. 22), and in another specimen as subhedral to rounded grains associated with native bismuth in gangue cementing brecciated fragments of colloform pitchblende (fig. 30). As observed under high magnification, the niccolite in these specimens has a thin continuous double rim of other nickel minerals. The optical characteristics of these nickel minerals, including a comparison of the reflectivity of each of these minerals and of niccolite and native bismuth in red, green, and orange light, suggest that the very thin

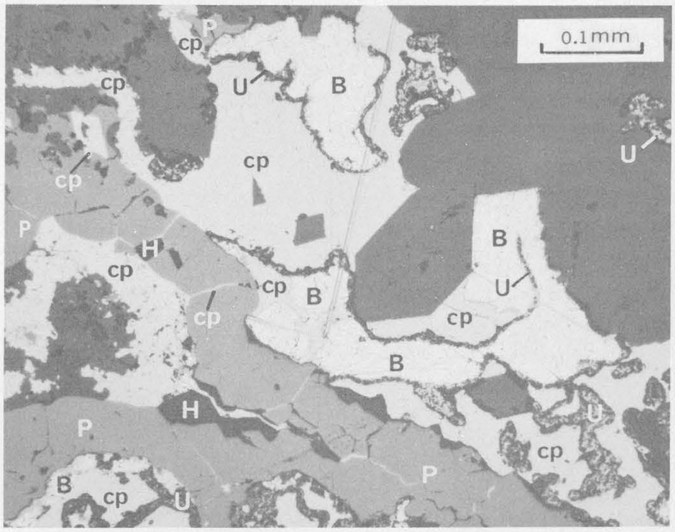


FIGURE 29.—Polished section of uranium ore, Mena mine. Native bismuth (B) and chalcopyrite (cp) occur in gangue (dark gray), consisting principally of a carbonate mineral which cemented open spaces in ore containing colloform pitchblende (P). Chalcopyrite veins and embays native bismuth (center), and fills shrinkage cracks in pitchblende. Late vermiform veinlets consisting of a very fine grained intergrowth of two or more unidentified metallic minerals (U) occur along the contacts of native bismuth and chalcopyrite, and cut native bismuth, chalcopyrite, and gangue. H, holes in section.

white innermost rim on the niccolite is pararammelsbergite and that the relatively grayish outer rim is maucherite. The same thin double rim of pararammelsbergite(?) and maucherite(?) occurs discontinuously on native bismuth (fig. 30), and minute grains of maucherite(?) with cores of pararammelsbergite(?) occur locally along the rotund outer surfaces of colloform pitchblende (fig. 23).

J. W. Adams observed bands of orange-brown material 0.02 mm thick in ankerite adjacent to pitchblende (Adams and others, 1953, p. 16; Walker and Adams, 1963, p. 63, fig. 9). He believed that the bands were caused by radiation damage of ankerite, whereby iron was oxidized from the ferrous to the ferric state. Adams also tentatively identified a light- to dark-brown mineral, which occurs sparsely in oxidized breccia, as a hydrated uranium oxide (Adams and others, 1953, p. 16), similar to that found at the North Star mine; Walker and Adams (1963, p. 58) noted that this brown mineral is a slightly translucent form of pitchblende presumably comparable with an "ill-defined material called hydropitchblende."

Compared with some of the ore from the Schwartzwalder mine, most samples of Mena ore show relatively little evidence of postmineral fracturing and breccia-

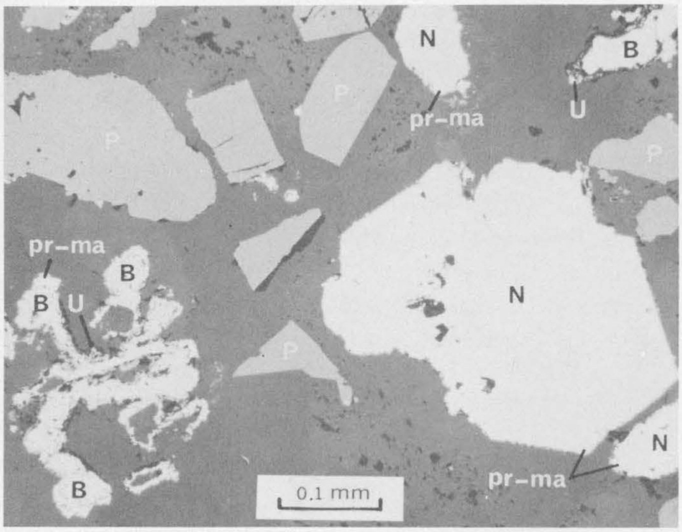


FIGURE 30.—Polished section of uranium ore, Mena mine. Breccia fragments of colloform pitchblende (P) are cemented by a carbonate gangue (dark gray) that contains subhedral to rounded grains of niccolite (N) and irregular grains of native bismuth (B). Although not discernible in the photomicrograph, a thin double rim (pr–ma) surrounds each of the niccolite grains and consists of a very thin layer of pararammelsbergite(?) overlain by a layer of maucherite(?). The same sequence of pararammelsbergite(?) and maucherite(?) occurs as a discontinuous double rim on native bismuth (left center). A very fine grained intergrowth of two or more unidentified metallic minerals (U) occurs as a rim on native bismuth (upper right, and locally at lower left).

tion. The late movements may have been taken up largely by other faults of the Rogers fault system in the vicinity of the Mena mine.

A grab sample of ore from the Mena vein at about the site of the present portal of the North adit was analyzed by chemical methods, fire assays, and semiquantitative spectrographic methods (tables 24, 25). The sample came from a part of the vein in which native bismuth is visible, and its bismuth content, 5.8 percent, is unusually high for ores of the district.

Adams, Gude, and Beroni (1953, table 1) reported analyses for three samples from the Black Judge (Nigger) shaft. These ranged in uranium content from 0.004 to 0.310 percent; two of the samples contained over 20 percent $CaCO_3$.

NORTH STAR MINE

The North Star mine is in the SE¼ sec. 23, T. 2 S., R. 71 W., about half a mile north of Ralston Creek (pl. 1). The mine, now inactive, is on property belonging to A. G. Brumm. At the time fieldwork was done in this area, the mineral rights were held by the Union Pacific Railroad Co. Adams, Gude, and Beroni (1953, p. 11) stated that according to Brumm, 4 tons of copper ore was shipped in 1894, and 12 tons in 1916.

Pitchblende was discovered at the mine in April 1952 by J. W. Adams and his associates in the U.S. Geological Survey, who mapped and described the mine (Adams and others, 1953, p. 11–13, fig. 7). Geologic studies were not made at this mine during the present investigation; the following description is summarized from the report of Adams and his associates and is supplemented with data on areal geology from the present investigation.

The mine workings, now only partly accessible, consist of a short upper level and a lower adit connecting with a stope that formerly opened to the surface (Adams and others, 1953, fig. 7). The portal of the lower adit is partly caved, and part of the stope is backfilled.

The North Star mine is in the unit of microcline gneiss complexly interlayered with other rocks (pl. 1). Rocks in the immediate vicinity of the mine are predominantly amphibolite, hornblende gneiss, biotite gneiss, and pegmatite; but microcline gneiss, calc-silicate gneiss, and quartz gneiss were also found in the general area. Layering and foliation near the mine strike northeast and dip 75°–85° SE.

The mine is located on a northwest-trending breccia-reef fault that forms part of the Rogers fault system (pl. 1). This fault, together with three other discontinuous faults, lies a short distance northeast of the main group of faults of the Rogers system. At the mine, the mineralized breccia forms a vein dipping 25°–45° NE.

The ore in the North Star mine is composed principally of altered rock fragments cemented by copper and uranium minerals. The breccia was not uniformly filled by vein matter; the best ore was in a zone 6 inches to 1 foot thick near the face of the lower adit. The ore consists of bornite, chalcocite, covellite, malachite, azurite, pitchblende, uranophane, and several unidentified uranium minerals. A brown mineral locally abundant in the ore is thought to be a hydrated uranium oxide (Adams and others, 1953, p. 12). Walker and Adams (1963, p. 58, figs. 3, 4) described this mineral as "an olive-green or light-brown slightly translucent colloform pitchblende," and noted that it is presumably comparable with an "ill-defined material called hydropitchblende."

A grab sample of pitchblende-bearing breccia from the dump contained 0.85 percent uranium; the uranium content of eight channel samples from the underground workings ranged from 0.002 to 0.510 percent (Adams and others, 1953, table 1). The grab sample

239-740-O—67——7

assayed 20.3 ounces of silver per ton, but no silver minerals were recognized in the ore.

SCHWARTZWALDER MINE

The Schwartzwalder mine, formerly the Ralston Creek mine, is on the southwest side of Ralston Creek in the SE¼ sec. 25, T. 2 S., R. 71 W. (pl. 1). Mine workings are on a steep slope at altitudes ranging from 6,540 to 6,895 feet. A dirt road about 8 miles long connects the mine with the junction of State Highways 58 and 93 northwest of Golden near the mouth of Golden Gate Canyon. The road did not extend to the mine area when the base map was being prepared; thus, only the part near Ralston Reservoir and along Ralston Creek is shown on plate 1.

Since 1949, when the discovery was made by Fred Schwartzwalder, the mine has become the largest producer of uranium ore in the Ralston Buttes district, and one of the largest sources of uranium from vein deposits in the United States.

Many geologic investigations of the property have been made since the uranium discovery. J. P. Anderson (written commun., 1950) and K. E. Baker (written commun., 1953) made preliminary investigations for the U.S. Atomic Energy Commission. Preliminary studies by the U.S. Geological Survey were described by Adams, Gude, and Beroni (1953, p. 13–14), and the preliminary results of the present investigation were briefly described by Sheridan (1956). The results of other geologic studies have been published by Bird and Stafford (1955), by Bird (1956, 1957a, b), and by Wright and Everhart (1960, p. 349–352). While the present investigation was in progress, geologic investigations of the property were also made by the U.S. Atomic Energy Commission (R. C. Derzay and A. G. Bird, written commun., 1957; J. D. Schlottman and A. V. Green, written commun., 1957) and by Newmont Exploration Ltd. (G. W. H. Norman, oral commun., 1956).

During the present investigation, Sheridan and Maxwell made preliminary geologic studies intermittently in 1953 and 1954 to assist geologists and engineers of the Defense Minerals Exploration Administration and the U.S. Atomic Energy Commission in the exploration of the property. Detailed mapping of the surface and the underground workings started in October 1955 and continued intermittently through November 1956, at which time the Survey's field studies at the mine terminated. During this period the geology and topography of the mine area were mapped by planetable methods (pl. 2), and the geology of three levels and part of one raise was mapped on bases surveyed by transit-and-tape methods (pls. 3–5, fig. 31).

HISTORY AND PRODUCTION

Secondary uranium minerals were discovered at the site of the Schwartzwalder mine early in 1949 by Fred Schwartzwalder. This was the second discovery of uranium in the Ralston Buttes district, the first having been made somewhat earlier by Mr. Schwartzwalder on the property now called the Mena mine. At the time of the discovery, old workings at the site consisted of a caved adit and three shallow pits excavated by the Golden Mining Co. in 1897 and earlier in attempts to mine copper (Adams and others, 1953, p. 13).

Mr. Schwartzwalder's early work on the property consisted of excavating an opencut at the site of the old caved adit where the discovery had been made, and driving a new adit southwest from the opencut into rocks that contained secondary uranium minerals in fractures. At a point about 40 feet from the portal of his new adit, Schwartzwalder found pitchblende in a northwest-trending fault breccia that dips southwest (pl. 3). He began mining along the dip of this discovery, now known as the Ralston Creek vein, and made his first shipment in November 1953—51.29 tons containing 1.32 percent U_3O_8 (table 23).

With exploration assistance from the Defense Minerals Exploration Administration from September 1953 through December 1954, Mr. Schwartzwalder continued his search for additional deposits of uranium on the property and built an access road 1.7 miles long. Exploratory work during this phase of the operation consisted of 300 feet of trenching by bulldozer, 149 feet of drifting and crosscutting on the upper level, and 250 feet of crosscutting on the Minnesota level (pl. 4). Mining activities were carried on concurrently with this exploration, partly along the original Ralston Creek vein and partly along other ore shoots discovered by the exploration. Shipments in 1954 totaled 660.86 tons of ore containing 0.70 percent U_3O_8, and in 1955 they totaled 848.77 tons containing 0.66 percent U_3O_8 (table 23).

From April 1954 to March 1955, the U.S. Atomic Energy Commission also conducted an exploration program on the property. They excavated numerous bulldozer trenches and cuts and bored 11 diamond-drill holes totaling 3,528 feet. This exploration proved the existence of additional deposits of uranium ore. In 1955 and in January 1956 the property was explored under options by several companies; the work included long-hole drilling, core drilling, and sampling.

In February 1956, the Denver-Golden Oil and Uranium Co. of Denver, Colo., purchased the lease rights from Mr. Schwartzwalder and the mineral rights, except for oil and gas, from Paul R. and Anna L. White. Shipments of crude ore from 1956 through 1960 exceeded 11,150 tons per year (table 23).

The total production from the Schwartzwalder mine through 1960 (table 23) was 77,660.28 tons that contained 1,188,078.17 pounds of U_3O_8. Although we do not have detailed records of production since 1960, the mine has continued to be one of the major producers of uranium ore from vein deposits in the United States.

MINE WORKINGS

Underground workings at the Schwartzwalder mine in November 1956 consisted of about 1,900 feet of adits, crosscuts, and drifts on the Upper, Minnesota, and Charlie levels, and two raises and numerous stopes (fig. 31; pls. 3–5). The relative positions of the workings are shown on a composite plan of the mine. (See index map on pl. 2.) The workings are projected to the plane of geologic section *A–A′* (pl. 2). The Minnesota level is separated from the Upper level and the Charlie level by vertical distances, respectively, of 123.5 and 108 feet. A fourth level, the Steve level, was driven subsequent to the fieldwork at the mine. According to information received from A. G. Bird (oral commun., 1957), the portal of the Steve adit (not shown) is about 300 feet N. 20° E. from the portal of the Charlie adit (pl. 2) and about 116 feet below the Charlie level. An underground shaft was sunk to a depth of 390 feet from the Steve level and has levels turned from it at depths of 125, 250, and 358 feet (A. G. Bird, oral commun., 1961).

Subsequent to the mapping of the Upper level and connecting workings (pl. 3), the inclined workings along the Ralston Creek vein were extended so that they opened to the winze at the end of the crosscut and to the raise along the Nebraska vein from the Minnesota level. By November 1956, the Nebraska vein had been stoped from the Minnesota level (pl. 4) nearly to the Upper level; the Colorado vein had been stoped 80 feet upward from the Minnesota level; stoping of the Nebraska vein on the Charlie level (pl. 5) was begun; and a raise was driven on the Illinois vein from the Charlie level.

GEOLOGIC SETTING

The Schwartzwalder mine is in the transition zone along the contact between the mica schist unit and the undivided hornblende gneiss unit (pl. 1). Northwest-trending faults of the Rogers breccia-reef fault system cut the rocks of the mine area. A major branch of this system has right-lateral displacement where it cuts the Fountain Formation east of the mine.

Much of the area in the vicinity of the Schwartzwalder mine is covered by Quaternary deposits of colluvium, commonly 10–20 feet thick, and of alluvium along Ralston Creek. Consequently, many of the contacts between bedrock units shown on the map of the mine area (pl. 2) are inferred from the distribution of float and scattered outcrops.

WALLROCKS

The Precambrian rocks in the Schwartzwalder mine area (pls. 2–5, fig. 31) have been subdivided into several map units:

1. Microcline-quartz-plagioclase-biotite gneiss complexly interlayered with hornblende gneiss and amphibolite.
2. Undivided hornblende gneiss unit, consisting here predominantly of layered calc-silicate gneiss, amphibolite, and hornblende gneiss, but containing minor thin layers and lenses of quartz gneiss, impure marble, and garnetiferous biotite-quartz gneiss.
3. Rocks in the transition zone along the contact between the mica schist unit and the undivided hornblende gneiss unit, including:
   a. Quartz gneiss.
   b. Fine-grained mica schist.
   c. Biotitic hornblende gneiss.
   d. Garnetiferous biotite-quartz gneiss which is locally interlayered with garnetiferous mica schist and garnetiferous amphibole-quartz gneiss.
   e. Finely interlayered mica schist and micaceous quartzite (gradational unit shown on pls. 3, 4, only).
   f. Finely interlayered mica schist, garnetiferous schist, and micaceous quartzite (gradational unit shown on pl. 3 only).
4. Mica schist unit.
5. Aplitic rock.
6. Pegmatite.

The rocks of the mine area were described earlier in this report. The following discussion summarizes their distribution in the mine area.

Microcline gneiss occurs in the northern and east-central parts of the mine area (pl. 2) and contains minor unmapped layers of hornblende gneiss and amphibolite. The hornblende gneiss unit, which occupies the entire central part of the mine area, is predominantly amphibolite and hornblende gneiss near the contact with the microcline gneiss, but it is predominantly layered calc-silicate gneiss elsewhere, except the part designated as the transition zone. This zone consists principally of garnetiferous biotite-quartz gneiss but also contains biotitic hornblende gneiss, fine-grained mica schist, and quartz gneiss. It thins from about 300 feet in the southeastern part of the area to 45 feet in the western part. The mica schist unit occupies the southern part of the mine area (pl. 2). Schist of this unit is coarser grained than the schist of the transition zone.

The mine workings (section *A–A′*, pl. 2; fig. 31, pls. 3–5) are mostly in rocks of the transition zone. On the Upper level (pl. 3) garnetiferous biotite-quartz gneiss is the principal wallrock of the Ralston Creek and Colorado veins. The hanging wall of the Ralston Creek vein (section *A–A′* pl. 3), however, is composed of fine-grained mica schist, quartz gneiss, and finely interlayered mica schist, garnetiferous schist, and micaceous quartzite. A unit of finely interlayered mica schist and micaceous quartzite forms the west wall near the portal. On the Minnesota level (pl. 4), garnetiferous biotite–quartz gneiss is the wallrock of the Kansas vein, most of the Nebraska vein, and parts of the Colorado and Walder veins. Fine-grained mica schist occurs at the portal and along the southeast wall of the adit. In the vicinity of the Colorado and Walder veins, it is bordered by lenses of quartz gneiss and finely interlayered mica schist and micaceous quartzite. Quartz gneiss also occurs at the heading of the northwest drift on the Nebraska vein. Most of the wallrock on the Charlie level (pl. 5) is fine-grained mica schist, but garnetiferous biotite-quartz gneiss occurs near the portal and in most of the exposed footwall of the Nebraska vein. A thin layer of quartz gneiss occurs between garnetiferous biotite-quartz gneiss and fine-grained mica schist in the west wall of the northwest drift on the Nebraska vein.

Dikes and irregular masses of pegmatite are fairly abundant at the surface in the Schwartzwalder mine area (pl. 2), but only thin stringers are exposed by the underground workings. The pegmatite bodies range in trend from due west in the northern part of the area to northwest and west-northwest in the western and southern parts. The largest body of pegmatite exposed lies north of Ralston Creek and is 370 feet long and 45 feet in maximum width.

Two tabular bodies of aplitic rock, each about 2 feet thick, are exposed in roadcuts about 300 feet northeast of the portal of the Charlie adit (pl. 2), and float of the same rock occurs northwest of the Charlie portal.

FOLDS

Two folds can be recognized from the distribution of lithologic units and the attitudes of compositional layering and foliation in the Schwartzwalder mine area (pl. 2). The largest and most conspicuous fold is a syncline, the axial region of which is outlined by the long nose of garnetiferous biotite-quartz gneiss in the central part of the area. The nose of a small anticline is defined by garnetiferous biotite-quartz gneiss south of the portal of the Upper adit. The axes of both folds apparently plunge steeply southwest. Traces of the axial surfaces of these folds are not shown on the map (pl. 2) because the detailed structural relations are incompletely known in parts of the mine area.

East of the Illinois vein (pl. 2) the large syncline appears to be tight, nearly isoclinal, and overturned, so that the axial surface dips steeply northwest. North of Ralston Creek the syncline aparently bends sharply toward the northeast and in general is defined by the broad lobe of the undivided hornblende gneiss unit that extends northeastward. Southwest of the Illinois vein the syncline is more open. The small anticline south of the portal of the Upper adit (pl. 2) appears to be open and upright near the nose, but where intersected by workings of the upper level, it appears to be tight and overturned.

The predominant plunge and bearing of lineation in the mine area is about 68° S. 68° W., which probably corresponds to the axis of folding. Lineation is well shown in some of the rocks north of Ralston Creek by the alinement of hornblende crystals and by the axes of small minor folds; elsewhere in the area lineation is not as conspicuous.

FAULTS AND FRACTURES

The Schwartzwalder mine area is cut by many faults and fractures of the Rogers breccia-reef fault system (pls. 1, 2). A major fault in this system lies opposite the mine on the north side of Ralston Creek and another lies about half a mile southwest of the mine (pl. 1). These faults bound a major zone of faulting that trends about N. 50° W. and is about 3,500 feet wide in the vicinity of the mine. The northern fault dips steeply northeast, has right-lateral horizontal displacement of about 2,200 feet, and, as indicated by topographic positions of the displaced segments of the Fountain Formation, probably has a reverse-fault component. The net effect of several probable movements on this fault, therefore, was movement of the northeast block upward and to the southeast. The southern bounding fault, as indicated by topographic expression, also dips steeply northeast, but the net movement is not known. About half a mile southwest of the mine area (pl. 1), an apparent left-lateral horizontal movement of about 250 feet is shown by the displacement of the contact between the hornblende gneiss and mica schist units, but elsewhere along this fault and its branches, similarly small apparent horizontal displacements are right lateral.

The traces of breccia-reef faults and fractures are shown on the map of the mine area (pl. 2). Faults that contain pitchblende-bearing veins as known from underground workings and drill core, are indicated on the map as named vein-fissures, and in the following discussion of structural data such faults are referred to as vein-fissures. Because material of ore grade is generally of very limited extent or poorly exposed at the surface, the vein-fissures are shown by fault symbols on the map of the mine area (pl. 2). In the geologic section showing underground workings (section *A–A′*, pl. 2), however, such faults are indicated by vein symbols where they are known to contain ore.

South of Ralston Creek the principal vein-fissures are the Illinois, Colorado, and Nebraska. The Illinois trends N. 10° W. (pl. 2) and dips steeply west (section *A–A′*, pl. 2) in its northern part, but it bends southeast near the Minnesota adit and splits into two less well defined faults in the southeastern part of the area. The character of the movement is not known. In the vicinity of section *A–A′* (pl. 2) the lithologic distribution suggests that the block west of the vein-fissure was downthrown, but farther southeast a reverse movement seems more probable. A subparallel fracture zone northeast of the Illinois vein-fissure contains the Washington vein, which also dips west.

The Colorado vein-fissure trends N. 12° W. and dips steeply northeast over much of its extent (pl. 2). The Walder vein-fissure, nearly vertical, lies east of the Colorado and is near the portal of the Upper adit. The Colorado has several known branch faults and probably has many others, as suggested by the complex network of faults present where the bedrock is well exposed—notably in roadcuts north-northwest of the portal of the Charlie adit.

A fault that lies in the southwestern part of the area is inferred to be the Nebraska vein-fissure exposed at the surface (pl. 2). It dips only 27° NE., as exposed in a small exploratory trench, but must become much steeper with depth if it is in fact the Nebraska vein-fissure. In its southeastern part, the fault curves toward the east and may join the Colorado vein-fissure, but the relations are obscured by surficial deposits. Reverse movements along both the Nebraska and Colorado vein-fissures are suggested by the pattern of lithologic units shown in geologic section *A–A′* (pl. 2).

The Montana vein-fissure, the only one mapped north of Ralston Creek (pl. 2), trends N. 45° W. and dips 30°–47° NE.

In the Upper level of the Schwartzwalder mine (pl. 3), the principal vein-fissures are the Colorado and Ralston Creek, which intersect at this level (section *A–A′*, pl. 3). The relatively steep Colorado vein-fissure dips 65°–76° NE., and the Ralston Creek dips gently southwest. In the lower part of the inclined workings below the Upper level, the hanging-wall fault of the Ralston Creek vein splits into three branches; farther southwest, the upper two branches dip northeast (section *A–A′*, pl. 3). The complexity of the fault pattern is shown by the inset maps of levels in the inclined workings (pl. 3), especially by the map of the 6,871.4-foot level. As shown in sections *A–A′* and *B–B′*, the Kansas fault displaced the hanging-wall and footwall faults of the Ralston Creek vein about 2.5–4 feet. Minor faults and fractures in the lower part of the inclined workings trend northwest and dip steeply northeast and southwest. In the heading of the southeast drift on the Colorado and Ralston Creek vein-fissures (pl. 3), a set of steeply dipping faults trends nearly due north. It is not known whether these faults actually displace the Colorado and Ralston Creek vein-fissures or whether they represent part of a bend in these vein-fissures.

In the workings on the Minnesota level the principal vein-fissures are the Walder, Colorado, Kansas, and Nebraska, which all trend N. 25°–40° W. and dip northeast (pl. 4, fig. 31). A minor fault zone that trends northeast along the adit displaces the Colorado vein-fissure and subsidiary fractures related to the Walder vein-fissure as much as 2 feet (left-lateral displacement). The contact between fine-grained mica schist and garnetiferous biotite-quartz gneiss is displaced right laterally 5 feet by the Walder vein-fissure and left laterally only about 1 foot by the Colorado vein-fissure. Displacement on the Kansas vein was not identified on this level. The Nebraska vein-fissure displays left-lateral displacement of wallrock units in the northwest drift and right-lateral displacement in the southeast drift. The dips of these rocks suggest that the northeast side was displaced upward—a reverse-fault movement. At the southeast and northwest ends of the workings on the Nebraska vein-fissure, the strike of the vein-fissure changes from about N.

40° W. to nearly north. It thus has the form of the cymoid curves described by McKinstry (1948, p. 314). After studying extensions of the workings on the Minnesota and Charlie levels, J. D. Schlottmann and A. V. Green (written commun., 1957) suggested that the Nebraska and Kansas veins represent a cymoid loop.

Faults and fractures on the Charlie level are shown on plate 5. The principal vein-fissures are the Illinois, Colorado, Kansas, and Nebraska. The Illinois strikes N. 17° W. over most of its exposure on this level, but at the two ends it strikes more nearly north. It dips steeply west. A sinuous branch of the Illinois extends N. 45° W. The Colorado vein-fissure strikes N. 40° W. and dips moderately to steeply northeast. At the southeast, this vein-fissure is cut by a northeast-trending fault. Development work has shown that displacement on this fault is right lateral (J. D. Schlottmann and A. V. Green, written commun., 1957). Many faults cross the adit near the Illinois vein-fissure and between the Colorado and Kansas, and are subparallel to the main vein-fissures. The Nebraska vein-fissure strikes N. 10°–30° W. and dips 50°–68° NE. The fault zone considered to be the downward projection of the Kansas vein-fissure curves northwest from the adit and joins the Nebraska vein-fissure at the heading in the northwest drift, forming a pattern suggestive of one end of a cymoid loop.

In summary, the pattern of faults and fractures in the Schwartzwalder mine area is complex: between the major breccia-reef faults of the Rogers system that trend N. 50° W. is a series of north-northwest-trending subsidiary faults, many of which are mineralized over parts of their extent. Some of the faults in the mine workings have the pattern of cymoid curves and loops. Changes in strike that define these curves and loops may be explained in part by refraction of faults with changes in competency from layer to layer of the rocks, but there are probably other, unknown reasons. J. D. Schlottman and A. V. Green (written commun., 1957) have suggested that the cymoid loops observed underground are parts of a large multicymoid loop, the sides of which trend northeast along the ends of the individual ore-bearing cymoid loops in the mine area. However, we did not recognize major northeast-trending faults of such a system at the surface (pl. 2).

Evidence from mapping and from study of polished sections of vein material indicates that movement on the faults was complex. The available evidence suggests that there were at least three and perhaps four or more periods of movement during the Laramide orogeny. One or two periods of faulting and brecciation preceded the introduction of pitchblende. Following the deposition of pitchblende but prior to the introduction of the main sequence of base-metal sulfides, fracturing and brecciation recurred. Still later, all vein materials were faulted, as exemplified by the displacement of vein material by northeast-trending faults on the Minnesota and Charlie levels.

VEINS AND ORE SHOOTS

The uranium-bearing veins of the Schwartzwalder mine are mostly mineralized fault breccias. The ore minerals and gangue occur as coatings on rock fragments, as cement in breccia, and as veinlets both in breccia and along faults and fractures.

In such mineralized fault breccia, the boundaries between ore and waste or between vein and complexly fractured wallrock are not sharp; this is especially true where the vein matter has been ground fine by repeated fracturing and brecciation. Consequently, detailed mapping requires nearly constant use of a Geiger-Mueller counter.

At the time of mapping, the principal productive veins were the Ralston Creek, Nebraska, Colorado, Walder, Kansas, and Illinois. In addition, a small amount of ore was mined from the Washington vein when the Charlie adit was driven, and the Montana vein north of Ralston Creek had been prospected. The existence of other ore-bearing veins on the property was known from exploratory drilling. Subsequently, mining on the Charlie level, on the new Steve level, and in workings opening from the underground shaft extending below the Steve level, opened additional ore-bearing veins (A. G. Bird, oral commun., 1961).

On the maps of the mine levels (pls. 3–5), vein material has been subdivided according to the character of brecciation and amount of radioactivity. The distinction between fault breccia and coarsely brecciated or shattered wallrock was based on the degree of fracturing and alteration. The fault breccia consists of highly altered discrete fragments of wallrock cemented in varying degree by carbonate minerals, quartz, and ore minerals, whereas the coarsely brecciated wallrock is less broken and altered. In general, vein matter whose radioactivity ranges from 5 to over 20 milliroentgens per hour is high-grade uranium ore. It occurs most commonly in the fault breccias and along individual faults and fractures. Locally some of the coarsely brecciated material is also high grade, but generally this material is of lower grade. Base-metal sulfides occur in both the fault breccias and the coarsely brecciated wallrock, but they are most abundant in the breccias. Mineralized fault breccia containing visible sulfide minerals is generally not as uraniferous as highly fractured dark breccia lacking visible sulfides.

The Ralston Creek vein (section A–A', pl. 2) is uraniferous over a strike length of 45 feet along the drift in the Upper level (pl. 3). The ore shoot extends along the dip of the vein for at least 90 feet (section A–A', pl. 3) and probably extends an additional 25 feet or more to the southwest along the reversal of dip of the upper two branches of the hanging-wall fault of the vein-fissure. The shoot ranges in thickness from 6 inches to 8 feet. The vein consists partly of fault breccia and partly of coarsely brecciated wallrock, both of which are uraniferous in the workings below the level. The richest parts of the vein are 1 inch to 3 feet thick and consist of breccia adjacent to the hanging-wall and footwall faults. Similar high-grade material occurred along branches of the hanging-wall fault in the lower part of the inclined workings and in the vertical winze. Mining was extended along the ore shoot in the lower part of the workings at the time our fieldwork terminated, but the maximum strike length of the shoot in this part of the workings is not known.

The Colorado vein is ore bearing on both the Minnesota and Charlie levels (pls. 4, 5) but is virtually devoid of uranium in the Upper level (pl. 3). The ore shoot is elongate downdip and, judging from underground exposures and drill-hole data, has a height of at least 300 feet. The strike length of the ore shoot is about 75 feet at the foot of the stopes driven upward from the Minnesota level but, according to Clyde True (oral commun., 1956), is 90 feet in the upper part of the stope, 60–75 feet above the Minnesota level. The vein is 1–4 feet thick at and near the Minnesota level, but according to True the mining thicknesses in the stopes ranged from 4 to 15 feet. Toward the southeast (pl. 4) the Colorado vein is intersected and slightly displaced by faults of the Walder vein system. Development work on the Colorado vein on the Charlie level (J. D. Schlottmann and A. V. Green, written commun., 1957) indicates that the uraniferous material extends at least 60 feet along the vein northwest from the adit.

The Kansas vein contains ore on the Minnesota and Charlie levels (pls. 4, 5) but is virtually devoid of uranium in the workings of the Upper level (section A–A', pl. 2; pl. 3). The ore shoot probably extends 150–220 feet down the dip of the vein. On the Minnesota level, medium- to high-grade ore averages 1½ feet in thickness in the exposed part of the vein for a horizontal distance of 17 feet, but the grade is lower in the northwest drift. Workings were extended to the southeast on the Kansas vein on the Minnesota level in 1956. On the Charlie level the Kansas vein merges to the northwest with the Nebraska vein.

The Nebraska vein is exposed on the Minnesota and Charlie levels (pls. 4, 5) and in the raise from the Minnesota level (fig. 31). The longest dimension of the shoot on the vein plunges steeply downdip a distance of at least 400 feet (section A–A', pl. 2). The strike length of the shoot is about 95 feet in the drift on the Minnesota level, but according to A. G. Bird (oral commun., 1956) it decreases to 60 feet at a height of 75 feet above the level. The main ore shoot is restricted to the part of the vein, or cymoid, that strikes N. 40° W. (pl. 4). High-grade parts of the vein on the Minnesota level range from 3 inches to 2½ feet in thickness, but the presence of accompanying low- to medium-grade ore provides a mining thickness of as much as 8 feet. On the Charlie level (pl. 5) the exposed strike length of the Nebraska vein was 65 feet at the time of mapping, but ore was showing in the breast at each end of the drift. High-grade ore occurs over a length of 25 feet and a maximum thickness of 9 feet near the intersection of the Nebraska and Kansas veins in the northwestern part of the drift (pl. 5). Southeastward along the Nebraska vein, high-grade ore occurs in a zone 10–18 inches thick between two controlling faults. Near the adit an additional thickness of as much as 18 feet of uraniferous coarsely brecciated rock lies between the Nebraska and Kansas veins. Thin seams of high-grade uraniferous breccia occur along faults or fractures that cross the adit in the hanging wall of the Kansas vein.

The Walder vein, discovered near the surface east of the dump of the Upper adit (pl. 2), was worked for a short period by opencut mining. The pit was largely caved at the time of our mapping, and most of the vein was covered. As shown in geologic section A–A' (pl. 2), the Walder vein extends down nearly vertically to the Minnesota level (pl. 4). The vein is inferred to split a short distance below the surface because the part exposed in the caved pit appears to dip steeply northeast. On the Minnesota level the ore shoot on the Walder vein is as much as 7 feet thick, including both highly radioactive breccia along several branching vein-fissures and intervening less radioactive coarsely brecciated rock. In the adit and in the short southeast drift, the vein of highly radioactive breccia, 6 inches to nearly 2 feet thick, forms the western side of the ore shoot. To the east of this vein, stringers of high-grade material 1–2 inches thick follow fractures in and near coarsely brecciated wallrock. North-

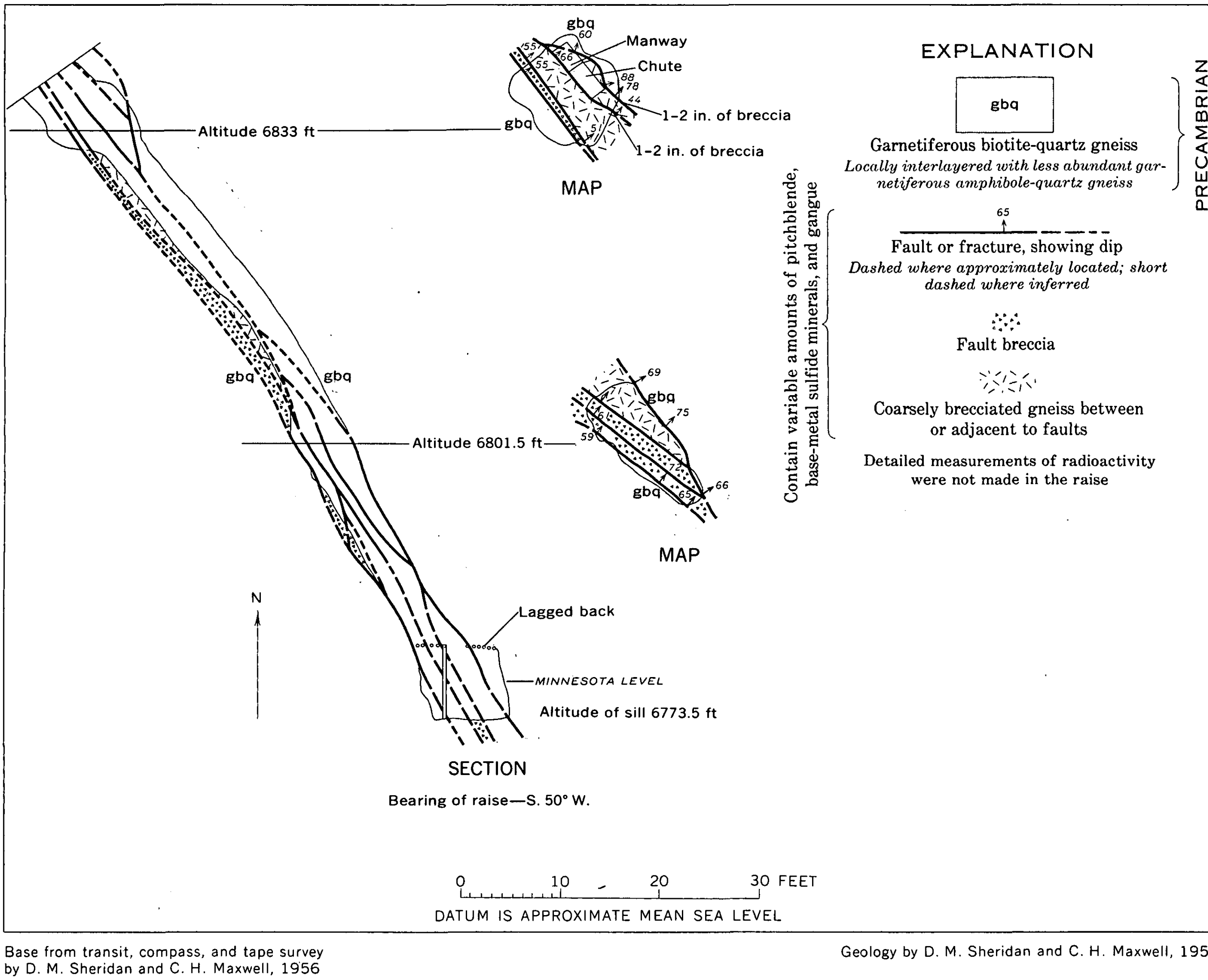


FIGURE 31.—Maps and section showing geology in lower part of raise on the Nebraska vein from the Minnesota level, Schwartzwalder mine.

westward along the strike, the Walder vein and adjacent fractures to the east form a complex fracture zone; although this zone is uraniferous near the adit in the first northwest drift, the radioactivity drops markedly 20 feet to the northwest.

Except for a few scattered outcrops of breccia at the surface of the mine area along the Illinois vein-fissure (pl. 2), the Illinois vein was best exposed at the time of mapping in drifts on the Charlie level (pl. 5). Near the raise in the drift to the southeast, the Illinois vein contains a rich ore shoot 35 feet long, but northwest of this the vein is highly oxidized over most of its exposure and is less radioactive. Southeast of the rich shoot, material along some of the faults and fractures is slightly to moderately radioactive, but the main fault breccia is almost devoid of uranium at the breast. In the first northwest drift of the Charlie level, a sinuous branch of the Illinois vein is vertical to steeply dipping and contains high-grade uranium ore ranging from 1 to 6 inches in thickness.

The Washington vein was examined only in cuts that were later destroyed by opening of the Charlie level. It contained abundant secondary uranium minerals in 1½–2 feet of sheared and coarsely brecciated garnetiferous biotite-quartz gneiss.

The Montana vein crops out north of Ralston Creek and dips at a low angle northeast. Radioactivity of as much as 5 milliroentgens per hour was noted in the partially leached exposures of the vein. In detail, the vein is composed of two or three subparallel and branching mineralized faults, containing 6 inches to 2 feet of breccia. At the time of mapping the vein had been prospected but not developed.

A. G. Bird (oral commun., 1961) has kindly provided us with information on findings since 1956. One of the uraniferous faults shown on the map of the Charlie level (pl. 5) in the hanging wall of the Kansas vein has been mined as the "Unknown vein." The Washington vein joins the Illinois vein at depth along the strike. Workings below the new Steve level have shown that the dip of the Nebraska vein reverses direction and that the vein coalesces with the Illinois vein. According to Bird the junction of the veins rakes steeply down the plane of the Illinois vein. Bird also noted that in one stope on the Nebraska vein the mining width was as much as 35 feet and that the average width of this vein on the Steve level and below was perhaps 10–12 feet. The greater mining widths along this and other veins in the new workings apparently result from complex branching and splitting of the controlling vein-fissures.

WALLROCK ALTERATION

Alteration appears to be confined mainly to the fault breccias and to the shattered or coarsely brecciated wallrocks that contain ore. Breccia fragments are intensely altered to a very fine grained aggregate of quartz, ankerite, clay minerals, and, locally, chlorite. In addition, some fragments are veined and rimmed by potassic feldspar. No regular zones of alteration were recognized, although the predominant process of alteration in some parts of the breccias appears to have been silicification. Irregular bleached areas, generally less than 3 feet thick, border some of the complexly faulted and fractured areas; and bleached zones 1 inch to 1½ feet thick were observed locally along thin fault breccias and veinlets.

MINERALOGY AND PARAGENETIC RELATIONS

URANIUM-BEARING VEINS

Metallic minerals observed in hand specimens and polished sections of vein material from the Schwartzwalder mine are pitchblende, pyrite, chalcopyrite, tetrahedrite-tennantite, bornite, chalcocite, galena, sphalerite, marcasite, malachite, azurite, chalcanthite, secondary uranium minerals, and manganese and iron oxides. Coffinite and a nickel mineral, probably niccolite, were reported by J. D. Schlottmann (oral communs., 1960, 1961) as constituents of ore from the new lower workings. According to A. G. Bird (oral commun., 1961), the distribution of the nickel-bearing mineral is spotty, but locally the mineral is abundant enough to give high-nickel assays. Emplectite(?) was tentatively identified in the ore by F. W. Kuehnel (written commun., 1956). Molybdenum is commonly present in the ore (table 26), but no molybdenum mineral has been recognized in any of the ore samples studied. However, disseminated grains of a mineral identified megascopically as molybdenite have been observed in wallrocks. Abnormal amounts of vanadium in the ore (table 26) suggest that a vanadium mineral may be present in small amounts, but none was recognized in the available specimens.

The gangue minerals are ankerite, quartz, potassic feldspar, and calcite. The feldspar has very low birefringence and is similar to that in the Mena vein and other deposits in the district. Barite was reported by Adams, Gude, and Beroni (1953, p. 13).

In most of the ore, the metallic and gangue minerals occur as grains less than 1 mm in size. Locally, however, pyrite, chalcopyrite, galena, sphalerite, and carbonate minerals occur as grains as much as 12 mm in diameter.

The principal economic constituent of the ore is black primary pitchblende, which occurs as thin colloform films, commonly less than 0.1 mm thick, coating breccia fragments (fig. 21), crystals of ankerite, and the walls of thin veinlets in the breccia. The amount of coffinite, reported from the newer workings, is unknown. We did not recognize coffinite in our studies of ore from three levels.

Secondary uranium minerals occur in the near-surface oxidized parts of the veins, in fractures in the adjacent wallrock, and locally as thin coatings on mine walls. At the Upper adit, partial oxidation of primary uranium minerals extends as much as 100 feet down from the surface, but complete alteration of pitchblende to secondary uranium minerals extends down only 10–20 feet. Thus secondary uranium minerals have constituted a very small part of the total uranium output. Torbernite, autunite, and metatorbernite were identified in the fractured wallrock of the Upper adit by Adams, Gude, and Beroni (1953, p. 13). Torbernite contributed appreciably to the value of ore mined in an opencut on the Walder vein east of the portal of the Upper adit (pl. 2), and meta-autunite was found in a sample from the Washington vein near the portal of the Charlie adit. Johannite and betazippeite occur as a thin coating on the mine wall near the hanging wall of the Ralston Creek vein in the inclined workings of the Upper level (pl. 3). (Identifications of meta-autunite, johannite, and betazippeite were by X-ray, optical, and chemical methods by E. J. Young, U.S. Geological Survey (written commun., 1956).) Part of the pitchblende in ore mined from the upper workings was sooty, probably as the result of alteration of primary hard pitchblende.

Although paragenetic relations in much of the ore are obscured by the effects of repeated brecciation and postmineralization fracturing, the main features determined from megascopic and petrographic studies are similar to those recognized in ore from the Mena mine. These features, indicating deposition of pitchblende prior to most of the other metallic minerals, are generally similar to those recognized by Adams and Stugard (1956, p. 200–203) at the Union Pacific prospect, and by F. W. Kuehnel (written commun., 1957), who also studied the Schwartzwalder ore.

The first stage was brecciation of Precambrian rocks along fault planes, probably early in the Laramide orogeny, possibly in part along ancient Precambrian faults. Next, hydrothermal solutions introduced along these open zones altered the breccia fragments and deposited quartz, ankerite, pyrite, potassic feldspar, and, possibly, small amounts of fluorite.

After introduction of gangue minerals, movement recurred along many of the faults, and new openings formed in the early breccias. In some places, as exemplified by the sinuous northwest-trending branch of the Illinois vein on the Charlie level (pl. 5), this renewed movement was not restricted to the main fault breccias but also opened new subsidiary faults and fractures in the wallrocks. A second wave of hydrothermal fluids then deposited ankerite, pitchblende, and possibly quartz in these openings. The coffinite reported from the newer workings in the lower part of the mine may have been deposited at this stage but somewhat later than the pitchblende, as this is the general relationship observed elsewhere in the Front Range (Sims and Sheridan, 1964).

After pitchblende deposition, fracturing and brecciation recurred and were followed by the main stage of base-metal sulfide and sulfosalt deposition, which was accompanied by deposition of ankerite and quartz. The paragenetic relations among the sulfide and sulfosalt minerals were not studied.

Finally, the ores were refractured, and veinlets of late calcite containing pyrite and marcasite were introduced (fig. 21).

IRON SULFIDE MINERALS IN WALLROCKS

The wallrocks of the Schwartzwalder mine area contain pyrite and pyrrhotite as disseminated irregular grains that range in size from microscopic particles to as much as an inch across. These minerals are particularly common in rocks of the transition zone along the contact between the hornblende gneiss and mica schist units. Because they are so widely distributed, occurring even at considerable distances from veins, we believe that much of the pyrite and probably all the pyrrhotite are unrelated to the uranium mineralization. They may be products of a Precambrian mineralization, or possibly of the Precambrian regional metamorphism. However, some of the pyrite that occurs in coarsely brecciated wallrocks adjacent to veins is probably related to the uranium mineralization.

Studies of polished sections show that the grains of pyrrhotite and pyrite are composed of interlocking aggregates of smaller grains. In one specimen pyrrhotite appears to vein and embay pyrite. Some of the pyrrhotite is rimmed by marcasite and contains minute laths of marcasite. A sample of pyrrhotite picked from garnetiferous biotite-quartz gneiss contained 0.007 percent cobalt and 0.03 percent nickel. (Partial semiquantitative spectrographic analysis by N. M. Conklin, U.S. Geol. Survey.)

CHEMICAL AND SPECTROGRAPHIC DATA

Chemical and spectrographic analyses of 30 channel samples from the workings on the Upper and the Minnesota levels are listed in table 26. Most of the samples represent material from the main veins and ore shoots, but some represent coarsely brecciated rock adjacent to ore-bearing veins or between branches of veins. The uranium content of the entire group of samples ranges from 0.009 to 6.36 percent. The average uranium content of all samples from main veins and ore shoots is 1.89 percent, and the average uranium content of all samples from outside of the main veins and ore shoots is 0.26 percent.

Although individual samples contain appreciable amounts of base-metal sulfides and silver, uranium is the only consistent and characteristic economic constituent of the ore. The ratio of uranium to total copper, lead, and zinc is 1.62:1 in the weighted average of 18 analyzed channel samples from 5 major ore shoots. The ratio of uranium to total gold and silver is 403:1.

Chemical analyses (table 26) of 30 samples show that subsidiary metals vary in abundance as follows:

	Percent
MnO	0.02 –4.77
Pb	0.07 –1.63
Cu	0.0095–1.16
Mo	0.006 –0.95
Zn	0.012 –0.19
V_2O_5	0.013 –0.077
Ni	0.002 –0.053
Co	<0.005 –0.050

The samples assay 0–7.10 ounces of silver per ton. Traces of gold were noted in three samples.

The uranium, lead, zinc, and copper in the ores occur, respectively, as pitchblende and coffinite, galena, sphalerite, and the suite of copper minerals. The nickel may be present as niccolite, which has been tentatively identified in ore from new lower workings (J. D. Schlottmann, oral commun., 1961). The silver may occur in tetrahedrite-tennantite and in galena. The habitat of the molybdenum has not been established. Molybdenite was observed as isolated grains in wallrock near the Illinois vein on the Charlie level, but no molybdenite was identified in specimens of vein material. The high molybdenum content of sample SW–G–30 (table 26), however, suggests that a molybdenum mineral is locally present in the veins. Cobalt or vanadium minerals have not been identified in the ore. The moderately high concentrations of manganese oxide in some samples are attributed, at least in part, to garnet in some of the altered rocks in breccias and vein walls; a garnet concentrate obtained from one sample of garnetiferous wallrock contained 7 percent manganese (sample 3, table 31). No rhodochrosite or rhodonite was observed in the ore.

Among the minor elements shown by the spectrographic analyses (table 26), most of the arsenic and antimony is probably in tetrahedrite-tennantite. The bismuth may be in emplectite, which was tentatively identified in the ore by F. W. Kuehnel (written commun., 1956). The barium may be in barite, which was observed by Adams, Gude, and Beroni (1953, p. 13). Zirconium, yttrium, and possibly some of the bismuth are probably associated with the uranium in pitchblende.

OTHER PROSPECTS

Uranium minerals or abnormal radioactivity have been noted at several other prospects in the Ralston Creek area. Material on the dump of a small shaft on a fault in the SW¼ sec. 22, T. 2 S., R. 71 W., was slightly radioactive, but no uranium minerals were found. Exploratory trenching in the SE¼ sec. 23, T. 2 S., R. 71 W., southeast of the North Star mine, exposed small shoots of pitchblende and copper minerals along northwest-trending faults, but no production has been reported. Secondary uranium minerals were also found in material from several small shafts in the SW¼ sec. 24, T. 2 S., R. 71 W., but no shipments have been reported.

GOLDEN GATE CANYON AREA

Several mines and prospects lie in an area of about 3 square miles in the vicinity of Golden Gate Canyon, in the southeastern part of the Ralston Buttes district (pl. 1). These include three major mines—the Ascension, Aubrey Ladwig, and Ohman—and several prospects, including the Union Pacific, Buckman, and Fork. All the deposits are in rocks of the hornblende gneiss unit (pl. 1) and on faults and fracture zones of the Hurricane Hill fault system.

ASCENSION MINE

The Ascension mine is on the west side of Tucker Gulch in the NW¼ sec. 24, T. 3 S., R. 71 W. (pl. 1). The portal of the main adit is 130 feet west of the gulch at an altitude of 6,955 feet and is about a fifth of a mile northwest from the point where Tucker and Crawford Gulches merge to form Golden Gate Canyon. The geology and topography of the mine area (pl. 6) and the geology of the underground workings (pl. 7) were mapped in November and December 1956.

HISTORY AND PRODUCTION

Radioactivity was discovered on the property in 1955 or early 1956 by G. B. Friden, Lakewood, Colo., who obtained leases to the mineral rights from Mrs. Bessie B. Nare, owner of the property. Mr. Friden assigned the leases to the Yellow Queen Uranium Co. in October 1956.

All work on the property has been done since January 1956. Exploration by bulldozing and core drilling disclosed the presence of uranium-bearing material along several faults and fractures. Subsequently, the main adit level and a smaller upper adit were driven for development work and mining.

Shipments of ore from the Ascension mine in 1956 amounted to 439.5 tons containing 0.23 percent U_3O_8 (table 23). Mining and development work ceased temporarily in 1957, but exploration by core drilling and trenching was resumed late in 1957 under a contract with the Defense Minerals Exploration Administration. In 1960, the mine shipped 1,010 tons of ore containing 0.27 percent U_3O_8 (table 23).

MINE WORKINGS

In 1956 the underground workings consisted of the main adit and a small adit 70 feet above the main level (pl. 6). The main level contained 425 feet of workings (pl. 7). A small, irregular stope, about 12 feet long and 25–35 feet high, was driven near the point where the adit opens into the northwest-trending drift. Another stope, about 16 feet long and 36 feet high, was driven in the northwestern part of the drift, near the small crosscut. The small upper adit, which was not mapped in detail, was driven 6 feet N. 85° W. and then 10 feet N. 45° W. In addition to the underground workings there are several exploratory bulldozer cuts on the property (pl. 6).

WALLROCKS

The Ascension mine is in an east-northeast-trending belt of layered calc-silicate gneiss which contains some amphibolite, hornblende gneiss, and biotite gneiss. Adjacent to the layered calc-silicate gneiss on the north side is mica schist, and on the south, interlayered hornblende gneiss, amphibolite, and biotite gneiss. All these rocks are elements of the hornblende gneiss unit (pl. 1).

On the map of the mine area (pl. 6), layers or lenses of feldspar-quartz gneiss, garnetiferous biotite-quartz gneiss, and sillimanitic mica schist have been distinguished within the belt of layered calc-silicate gneiss. The sillimanitic mica schist, which has an average thickness of 20 feet, is particularly useful as a marker layer because it can be traced through the mine area and gives a measure of fault displacements. A large subcircular body of pegmatite crops out in the west-central part of the area, and another large body trends east-northeast across the portal of the main adit.

Compositional layering in the metamorphic rocks trends N. 70°–90° E. and dips steeply north and south. Lineations plunge 12°–40° S. 65° W.–N. 80° W.

FAULTS AND FRACTURES

Breccia-reef faults and associated fractures in the Ascension mine area are a part of the northwest-trending Hurricane Hill fault system (pl. 1). Southeast of the mine area, in the west-central part of sec. 24, fault breccia is present in a zone half a mile long and as much as 400 feet wide, but just north of the mine area the faults are inconspicuous. Indeed, the main fault could not be traced for a distance of 1,200 feet in mica schist. Displacements are very small all along the Hurricane Hill fault system (pl. 1).

The faults in the vicinity of the Ascension mine are shown in detail on plate 6. The fault along which the drift in the main underground workings was driven, here called the Ascension fault, trends N. 62° W. and dips 66°–85° NE. over most of its extent in the mapped area, but near the western margin of the area it trends N. 32° W. and is vertical. As shown on the map and in the sections (pl. 6), part of this fault actually consists of subparallel anastamosing fault surfaces. In the southeastern corner of the area the Ascension fault merges with the western branch of another major fault. The two branches of this fault trend N. 15° W. along Tucker Gulch and then coalesce north of the main portal to form a well-defined fault trending N. 48° W. and dipping 64°–75° NE. Farther northwest at an altitude of 7,050 feet this fault steepens to 82° and trends N. 74° W.

In the V-shaped block between the major northwest-trending faults discussed above are several minor faults which, in general, trend nearly west and dip at low angles to the north. A fault dipping 37° N. at the small upper adit presumably connects to the east with a zone of intense brecciation dipping 34° NE. at radioactive locality R11 (pl. 6). Other minor faults and fractures in the mapped area range in dip from 13° to 90°.

Both of the major faults have caused right-lateral displacement of the lithologic units (pl. 6). Horizontal displacement along the Ascension fault is about 210 feet, and along the fault in Tucker Gulch, about 175 feet. Calculations made from projections of the fault planes and the faulted segments of the marker layer of sillimanitic mica schist suggest that the dip-slip component of movement along each of these faults is on the order of 750 feet but that the stratigraphic separation is only about 140 feet. As shown in section *A–A′* (pl. 6), the apparent relative movement on both major faults is normal in character, but on two intervening faults it is reverse.

URANIUM DEPOSITS

Pitchblende-bearing vein material occurs in and along fault breccias and in thin stringers along subsidiary faults and fractures. The known deposits occur near the central part of the mapped area (pl. 6). Information from core-drill holes and from the surface and underground mapping indicates that the uranium mineralization extends over a vertical distance of at least 200 feet, but the persistence of individual ore shoots within this range cannot be determined from the available data.

Abnormal radioactivity was noted at several localities over a horizontal distance of 175 feet along the Ascension fault, in a zone that corresponds geologically and structurally to the mineralized zone in the underground workings (pls. 6, 7). Radioactive localities R1 and R6 on plate 6 are, respectively, 135 and 105 feet above the sill of the drift. Radioactive localities R5 and R7–9 are along branching faults and subsidiary fractures in the hanging wall of the Ascension fault. Radioactive localities R10, at the upper adit, and R11, 115 feet north of the main portal, are on a low-angle fault in the footwall of the fault in Tucker Gulch. Radioactivity at these various localities ranged from 0.08 to 0.8 mrph (milliroentgens per hour), or 4–40 times the background. Although uranium has been partly leached from the exposed parts of the mineralized faults and fractures, a grab sample of breccia from a few feet beneath the surface at the upper adit (loc. R10) contained 0.39 percent equivalent uranium and 0.37 percent uranium. (Analyses by D. L. Schafer and H. H. Lipp, U.S. Geological Survey.)

Bulldozing subsequent to our mapping has disclosed another uranium occurrence less than a quarter of a mile southeast of the mapped area along the same fault system.

In the underground workings (pl. 7) pitchblende occurs in breccia along the Ascension fault and in subsidiary faults and branching fractures in the hanging wall. The radioactivity of accessible mineralized material ranged from 0.2 to over 20 mrph, but much of the mineralized area was inaccessible because of timbering and stoping.

In the vicinity of the small stope near the southeast end of the drift, the uranium-bearing segment of the breccia along the Ascension fault dips 74° NE. and is at least 20 feet in strike length and 12 inches thick. In the same area, three subsidiary branch faults and fractures in the hanging wall are uraniferous over a total exposed length of 55 feet; mineralized breccia along these northeast-dipping faults and fractures ranges from 1 to 3 inches in thickness.

Another uraniferous segment of the breccia along the Ascension fault occurs in the northwestern part of the drift (pl. 7) at the main stope and is at least 25 feet long. The breccia is 18–30 inches thick and dips 80° NE. On a curved fault at the breast of the small crosscut in the vicinity is rich pitchblende-bearing material 1–4 inches thick. On the north wall of this crosscut, thin seams of uraniferous material extend 12 feet along a branch fracture dipping 70° N.

The main fault breccia as well as the subsidiary faults are largely devoid of uranium northwest of the stoped area in the northwestern part of the drift and in the southwest-trending crosscut southeast of the drift. In the southwest-trending crosscut the radioactivity along the Ascension fault is 0.1 mrph; along other fractures in this crosscut and in the adit toward the portal, the radioactivity is 0.05 mrph.

At the time the mapping was done, long-hole drilling to depths of 25 feet or less indicated that the ore continued below the drift level. In 1958, uraniferous material was found in a core hole about 95 feet below the drift. Data are not available to indicate whether individual ore bodies are continuous to that depth.

The distribution of uraniferous localities at the surface and underground suggests that the ore deposits plunge steeply down the dip of the Ascension fault. The vertical dimension of individual ore shoots may be 2½ or more times the horizontal dimension.

Production data show that the average grade of ore shipped through 1960 was 0.26 percent U_3O_8, but this figure reflects the effects of unavoidable dilution of ore of much higher grade with waste. A sample of some of the most radioactive material mined from the main stope (sample S–A–2, pl. 7) contained 4.8 percent equivalent uranium and 6.48 percent uranium, and a sample of 4-inch-thick black ore from the subsidiary fault at the breast of the small crosscut (sample S–A–3, pl. 7) contained 23.8 percent equivalent uranium and 40.18 percent uranium. (Analyses by D. L. Schafer and H. H. Lipp, U.S. Geol. Survey.) In this mine, ore characteristically occurs as thin pitchblende-rich stringers in otherwise barren material along many of the faults.

At the Ascension mine, ore consists principally of colloform coatings of pitchblende on altered breccia fragments cemented by quartz and carbonate minerals. Brecciated fragments of colloform pitchblende in some of the ore (fig. 26) are the result of repeated fracturing and brecciation along some of the faults and fractures. Base-metal sulfides and sulfosalts seem to be very sparse. Grains of chalcopyrite, galena, and pyrite were observed in polished sections of the ore (fig. 26), but only traces of copper stain were found in the mine area. Southeast of the mine area, however, copper minerals have been found along the southeast continuation of the fault system. Traces of fluorite were found in fault breccia near the mine area, but none was observed in the ore. The results of a semiquantitative spectrographic analysis of a sample of ore from the Ascension mine are given in table 25.

AUBREY LADWIG MINE

The Aubrey Ladwig mine, commonly referred to as the Aubrey Ladwig lease but also known as the Gary mine, is near the head of the western fork of Halfmile Gulch in the west-central part of the SW¼ sec. 18, T. 3 S., R. 70 W. (pl. 1). An access road follows Cressmans Gulch westward from roads connecting with State Highways 58 and 93 northwest of Golden. The geology and topography of the mine area, including a detailed map of the open pit with sketch sections of the walls, are shown on plate 8. A plan and sections of diamond-drill holes in the vicinity of the open pit are shown in figure 32. The geology of underground workings opening from a vertical shaft is shown in figure 33.

HISTORY AND PRODUCTION

Uranium was discovered on the Aubrey Ladwig property in the fall of 1954 by G. B. Friden of Lakewood, Colo. In June 1955, the Denver-Golden Oil and Uranium Co., Denver, Colo., obtained the lease to the property. After preliminary exploration by trenching and drilling during the summer, production began in the fall of 1955. At first, production was largely from an open pit. Later, ore was mined from a shaft and underground workings.

Through 1956 the total production from the Aubrey Ladwig mine was 1,941.68 tons of ore containing 9,527.15 pounds of U_3O_8 (table 23). No production was reported from 1957 through 1960.

MINE WORKINGS

Workings consist of an open pit, a vertical shaft opening to a crosscut and a stope, and many exploratory pits and trenches (pl. 8, fig. 33). The open pit is about 60 by 30 feet in plan and 35–50 feet deep (pl. 8). A timbered two-compartment vertical shaft is collared at an altitude of 7,318 feet in the southeastern end of the open pit. The 74-foot level (fig. 33) opens from the bottom of the shaft and comprises a curved crosscut 137 feet long, several short drifts totaling 55 feet in length, and an inclined stope about 40 feet long and 12 feet wide. The stope rises to the southwest at an angle of 23° near the level but steepens to 45° higher up. Several exploratory trenches are west and southeast of the mapped area.

WALLROCKS

The Aubrey Ladwig mine is near the contact between the mica schist unit and layered calc-silicate gneiss of the hornblende gneiss unit (pl. 1). Most of the workings are in the transition zone along the contact between these major map units, and in pegmatite (pl. 8). Rocks of the transition zone here are predominantly garnetiferous biotite-quartz gneiss but include some mica schist and biotite schist. Layered hornblende-epidote-garnet gneiss (pl. 8) and quartz gneiss are part of the main sequence of layered calc-silicate gneiss south of the mine. The metamorphic rocks are cut by many irregular discordant bodies of pegmatite which together cover half of the mapped area. The pegmatite is composed principally of quartz, feldspar, and muscovite. Foliation in the metamorphic rocks of the area strikes northeast and dips vertically or steeply to the southeast (pl. 8); in the underground workings the foliation locally dips steeply northwest.

The main pit and the shaft are on a sharp bend in the contact between pegmatite and garnetiferous biotite-quartz gneiss. The gneiss has been folded into tight upright folds that are nearly isoclinal; one fold axis plunges 15° SW. (See detailed map of pit and sketch section *D–E*, pl. 8.) The pegmatite contact is sharply discordant, cutting the gneiss at nearly right angles to the folds. In the underground workings, sharp discordance of the pegmatite contact is shown near the shaft (fig. 33) and locally in the north wall of the crosscut extending west from the shaft. Other pegmatites in the underground workings are subparallel to the foliation, and some contain septa of schist or gneiss.

The pegmatites in the vicinity of the mine are largely unweathered except for limonitic material along fractures and joints. In contrast, the other Precambrian rocks, especially the garnetiferous biotite-quartz gneiss, are deeply weathered. Core holes indicate that these rocks are weathered to depths of 40–50 feet, except where the rocks are protected by a cap of pegmatite.

FAULTS AND FRACTURES

The Aubrey Ladwig mine is not on a recognizable breccia-reef fault and thus differs in this respect from most other uranium mines in the Ralston Buttes district. The nearest breccia-reef faults that might possibly be projected into the mine area are exposed half a mile southeast and northwest of the mine (pl. 1) and are part of the Hurricane Hill fault system. One small outcrop of weathered breccia was found about 700 feet south-southeast of the shaft outside the geologic map of the mine area.

The mine workings are on a complex network of short fractures and faults of small displacement; the most prominent strike northeast and northwest. These fractures are probably part of a zone of shattering that takes the place of well-defined breccia-reef faults in this segment of the Hurricane Hill fault system.

The detailed distribution of faults and fractures in the open pit and in the underground workings is shown on plate 8 and in figure 33. Discontinuous irregular fractures cut some of the pegmatite into small blocks, and, locally, small faults displace the contact between pegmatite and gneiss (sketch section *D–E*, pl. 8). Data from diamond-drill holes indicate that the contacts between pegmatite and gneiss or schist are commonly fractured. Pitchblende-bearing breccia on the 74-foot level is as much as 18 inches thick and strikes northwest. Northeast-striking fractures appear to be somewhat younger, as they cut and displace the mineralized breccia. They commonly contain narrow seams of gouge and small amounts of breccia.

URANIUM DEPOSITS

Most of the ore at the Aubrey Ladwig mine occurs along and near fractured or coarsely brecciated contacts between pegmatite and garnetiferous biotite-quartz gneiss, but some ore is in mineralized breccia in the gneiss. In addition, highly radioactive material was found in garnetiferous biotite-quartz gneiss in drill holes (fig. 32).

In the vicinity of the main pit, pitchblende and secondary uranium minerals apparently occurred as fillings and coatings along fractures in pegmatite and the adjacent garnetiferous gneiss. Lenses and pods of pitchblende weighing as much as 60 pounds and rimmed by secondary uranium minerals were mined in the lower part of the open pit and in the upper part of the shaft. According to G. H. Brodie (oral commun., 1956) these pods were elongate parallel to gently dipping fractures and were most abundant in pegmatite, rarely extending far into the gneiss. W. N. Monson (oral commun., 1956) reported that all the rock removed northwest of the bend in the pit was ore. This ore zone, which was elongate parallel to the contact over a length of 60 feet, extended farther into pegmatite than into gneiss. Presumably the ore consisted partly of high-grade lenses or pods and partly of lower grade material.

Of the various faults and fractures shown on the detailed map of the main pit and in the sketch sections of the walls (pl. 8), the most radioactive are the northwest set of fractures dipping at low angles northeast along the northeast wall of the main pit and at the northeast end of the northwest wall.

The pitchblende-bearing fault breccia in the northeastern part of the underground workings (fig. 33) is similar in attitude to the most radioactive set of fractures in the open pit. It strikes N. 60° W. and dips 30° NE. at drift level but steepens upward to 43°. At drift level the breccia forms an ore shoot 17 feet long and 1 foot thick. This breccia was stoped updip for 40 feet. Drill hole 12 (fig. 32) intersected ore 20–30 feet below the level of the workings at a point 27 feet northeast of the ore shoot cut by the workings. This suggests that the ore shoot extends at least an additional 30 feet downdip and that the dip steepens below the level as well as above. The radiometric data from holes 12 and 13 suggest that the mineralization may occur in several subparallel fracture zones in addition to the breccia intersected by the workings.

Several other uraniferous localities in the mapped area (pl. 8) are indicated by the radiometric data from jackhammer holes. Most of these are in garnetiferous biotite-quartz gneiss near contacts with pegmatite.

The major ore minerals at the Aubrey Ladwig lease are pitchblende and meta-autunite. Lenses and pods of pitchblende in the open pit and the shaft commonly had a rim of secondary uranium minerals. Meta-autunite occurs as square plates as much as 5 mm across along fracture surfaces in pegmatite. Apparently it was abundant in the ore mined from the open pit, but it is sparse on the walls of the pit. Metatorbernite, metazeunerite, and fourmarierite have also been reported in samples from the mine (Todd New, oral commun., 1956). Phosphuranylite has been identified by X-ray methods by E. J. Young, U.S. Geological Survey (written commun., 1956). Although pyrite is fairly common in the ore, no base-metal sulfides were recognized in any of the material available for study at the time of mapping. Small amounts of fluorite were tentatively identified in a specimen from the dump. Copper sulfides were reportedly present in some of the ore (R. C. Derzay and A. G. Bird, written commun., 1957). The results of semiquantitative spectographic analysis of a channel sample of ore from the underground workings are given in table 25 (sample S–L–1).

Production records (table 23) indicate that ore shipped from the Aubrey Ladwig mine in 1955 averaged 0.31 percent U_3O_8, and in 1956, 0.23 percent U_3O_8. The property was not sampled in detail for grade by the U.S. Geological Survey, but a few samples were obtained from various localities. A channel sample 0.7 foot long taken across the mineralized breccia in the underground workings (fig. 33) contained 1.6 percent equivalent uranium and 1.92 percent uranium. (Analyses by D. L. Schafer and H. H. Lipp, U.S. Geol. Survey.) Radioactivity measurements along the breccia near the sill of the drift ranged from 1 to 13 mrph (milliroentgens per hour). In the face of the stope the fracture zones representing the upward projection of the breccia gave readings of 1.5–2 mrph. Other faults and fractures near the heading of the crosscut (fig. 33) gave readings of 0.5–1 mrph. The northwest fracture zone in the first short drifts northeast of the bend in the crosscut gave readings of 0.2–0.5 mrph. In general, the northeast-trending fractures are radioactive only where they cut and displace northwest-trending fractures.

Analyses of five samples taken in pits and trenches on fracture zones and contacts away from the shaft and the main pit are given in table 30.

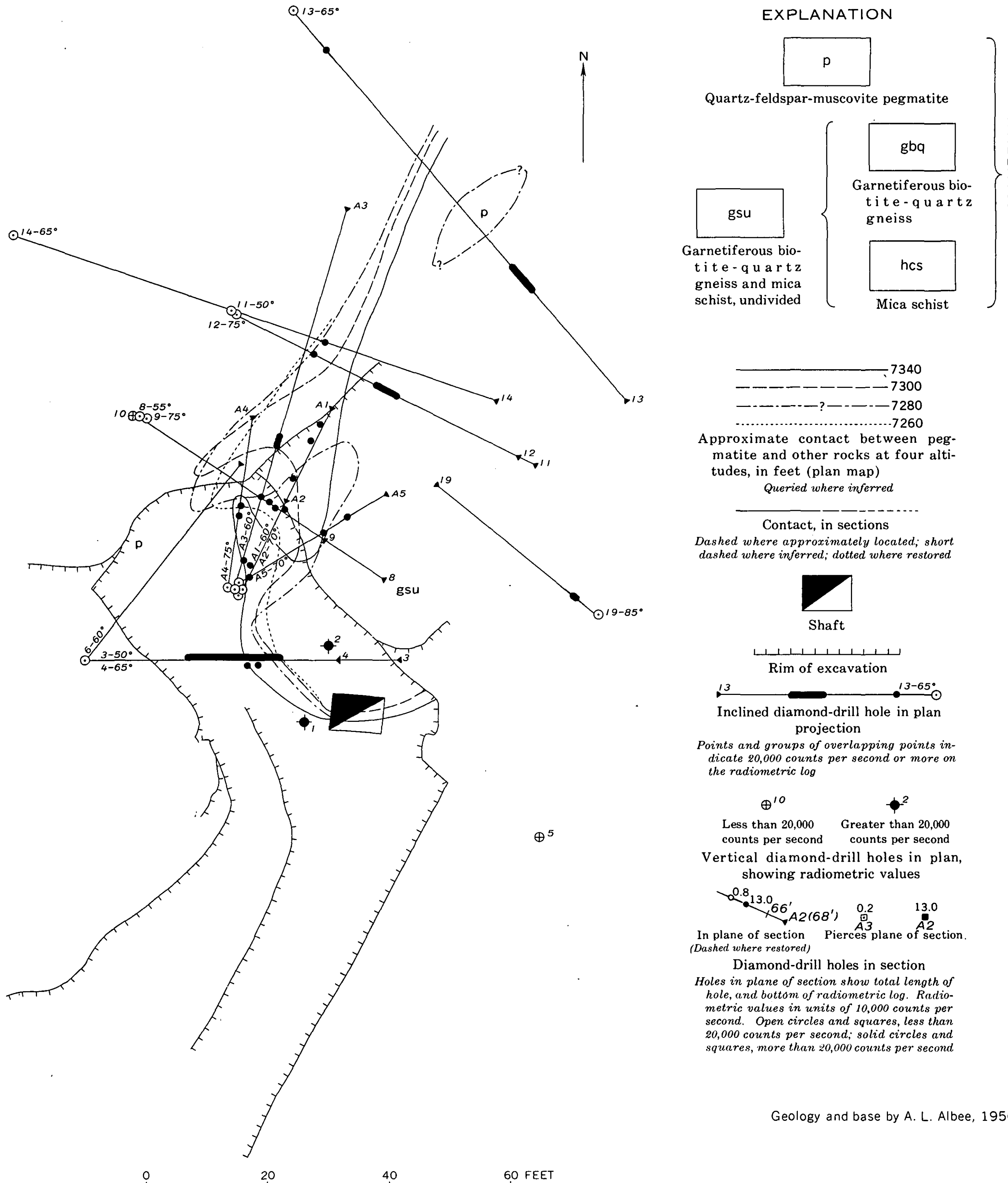
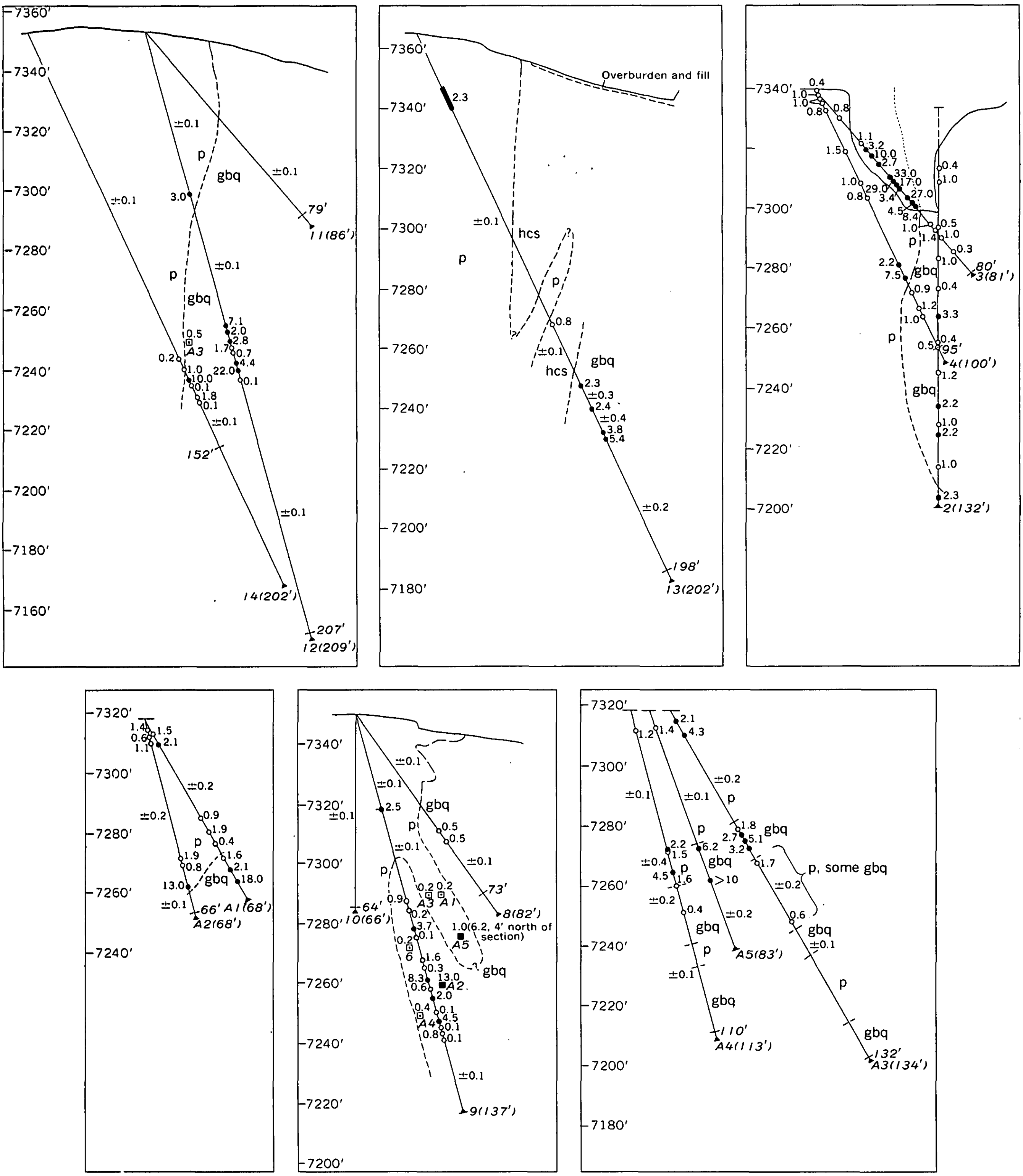
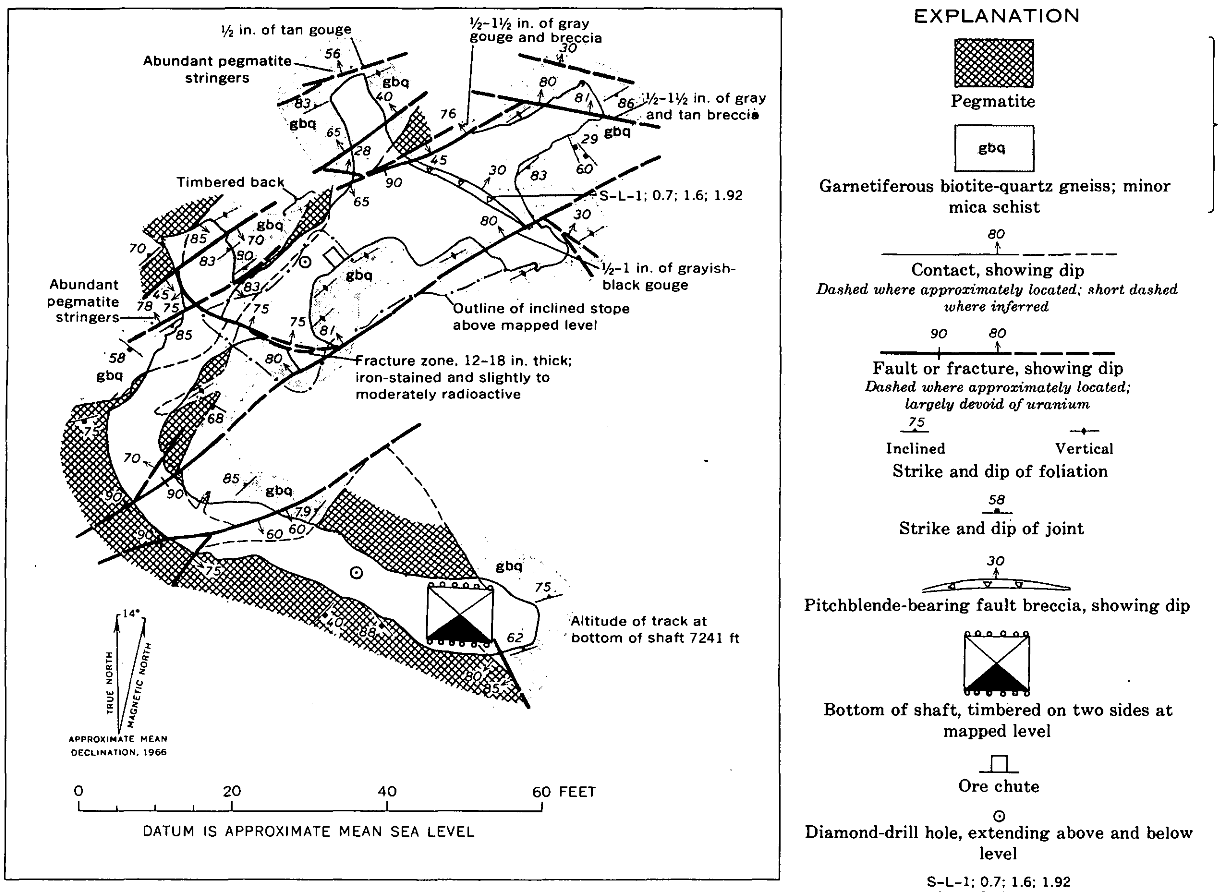


FIGURE 32.—Plan and sections of diamond-drill



holes near the open pit, Aubrey Ladwig mine.



Base from compass and tape survey by D. M. Sheridan, November 1956

Geology by D. M. Sheridan, November 1956

FIGURE 33.—Geology of the 74-foot level, Aubrey Ladwig mine.

TABLE 30.—*Analyses, in percent, of five near-surface samples*[1] *from the Aubrey Ladwig mine, Ralston Buttes district*

[U.S. Geol. Survey analysts: C. G. Angelo (eU) and R. P. Cox (U)]

Serial No.	Sample No.	Total length of channel sample (ft)	Radiometric analyses	Chemical analyses
			eU	U
243202	G-1	5.0	0.072	0.089
243203	G-2	5.2	.016	.024
243204	G-3	(2)	.051	.055
243205	G-4	2.5	.013	.016
243206	G-5	14.0	.006	.005

[1] The location of the samples is shown on pl. 8. All were taken from pits and trenches away from the main pit and shaft. Sample G-1 is a composite of two channel samples, each 2.5 ft long, taken 1 ft apart. Sample G-5 is a composite of 3 channel samples, 4, 4, and 6 ft long.

[2] Sampled circular area, 1.5 ft in diameter.

Radioactivity data for 15 drill holes in the vicinity of the main pit are shown in figure 32. The radiometric values are reported in units of 10,000 counts per second. The mine operators used a factor of 1,000 counts per second = 0.1 percent U_3O_8 to evaluate their radiometric logs. They based this factor on standard test holes and a comparison with assay values of diamond-drill core from the Schwartzwalder mine. Two of the holes are in the area later occupied by the open pit. The drill-hole sections (fig. 32) were prepared prior to the underground mining, and they do not show the mine workings.

FORK PROSPECT

The Fork prospect is in the NE¼NW¼ sec. 19, T. 3 S., R. 70 W., in Halfmile Gulch about 0.9 mile north of Golden Gate Canyon (pl. 1). A pit about 6 feet deep, excavated in 1955 by the Union Pacific Railroad Co., exposed uraniferous material along a northwest-trending breccia-reef fault and fracture zone. The pit was sampled in September 1955 by Maxwell and J. W. Adams. No production has been recorded.

The Fork prospect is in layered calc-silicate gneiss which forms an east-trending lens, as much as 100 feet in outcrop width, within a thick enclosing layer of mica schist (pl. 1); these rocks are subdivisions of the hornblende gneiss unit. The breccia-reef fault or fracture zone on which the pit is located has been traced over a distance of about half a mile in sec. 19 and is considered to be part of the Hurricane Hill fault system (pl. 1).

The Fork prospect is of interest chiefly because the vein material contains uraniferous asphaltite in addition to pitchblende and base-metal sulfides. J. W. Adams (written commun., 1956) identified pyrite, chalcopyrite, marcasite, galena, sphalerite, ankerite, potassic feldspar, molybdenite(?), pitchblende, and asphaltic material in samples from this deposit. Although a detailed paragenetic study was not made, Adams noted that pyrite is probably the oldest of the sulfide minerals, and marcasite the youngest. The asphaltic material occurs as fillings in vein cavities and fractures. In a later examination of other samples, G. W. Walker and J. W. Adams (1963, p. 64 and fig. 19) observed pitchblende as spheroids and as thin films between pyrite and the hydrocarbon.

Uraniferous asphaltite was separated from the vein material by heavy-liquid separation. A semiquantitative spectrographic analysis (by R. G. Havens, U.S. Geol. Survey) of the asphaltite (serial No. 235785) showed the following constituents: Si (.x+), Al (.x−), Fe (x.), Ti (.0x+), Mn (.0x+), Ca (.x+), Mg (.0x+), Na (<.1), Ag (.000x), As (.x−), Ba (.00x+), Be (.000x+), Co (<.01), Cr (.000x), Cu (.0x+), Mo (.00x+), Nb (.0x), Ni (.0x−), Pb (.0x+), U (x.+), V (.00x+), Y (.00x+), Yb (<.002), Zr (.0x+).[4]

The uraniferous asphaltite is probably related to oil seepage along the uranium-bearing faults. Oil seeps have been noted in Percambrian rocks about 1 mile southeast of the Fork prospect. Presumably the oil comes from sedimentary rocks that underlie the west-dipping Golden reverse fault and seeps upward through faults and fractures in the overlying Precambrian rocks. The trace of the Golden fault lies in the Golden quadrangle (Van Horn, 1957) east of the Ralston Buttes district.

OHMAN MINE

The Ohman mine, also known as the Nare lease, is near the Buckman adit (pl. 1) in the Golden Gate Canyon area. In 1959 the mine produced 5 tons of ore that contained 1.18 percent U_3O_8, and in 1960, 192 tons of ore that contained 0.23 percent U_3O_8.

Because the mine was developed after our field studies were completed, we have no detailed geologic information about the mine workings. However, the general geology of the area is shown on plate 1 of this report and on a map by Adams and Stugard (1956, fig. 46).

[4] The following classification is used for the spectrographic data, in percent: x.+= 4.64−10; x.=2.15−4.64; x.−=1.0−2.15; 0.x+=0.46−1.0; 0.x=0.215−.464; 0.x−= 0.10−.215; etc.

UNION PACIFIC PROSPECT

The Union Pacific prospect is in the SW¼SE¼ sec. 19, T. 3 S., R. 70 W., about 550 feet north of the road in Golden Gate Canyon (pl. 1). At the time fieldwork was done in this area the Union Pacific Railroad Co. held the mineral rights to the property. Uranium was discovered at this prospect in 1951 by J. W. Adams and M. H. Staatz of the U.S. Geological Survey. The geology of the prospect has been described by Adams, Gude and Beroni (1953, p. 4–9) and by Adams and Stugard (1956). No additional studies were made during the present investigation. The following summary is largely from the published reports.

Mine workings on the property consist of an inclined shaft 57 feet deep and a drift that extends about 6 feet into the southeast wall of the shaft at the 30-foot level. The shaft was probably originally a copper prospect.

Adams and Stugard (1956, pl. 11) showed that the Union Pacific prospect is in an east-northeast-trending layer of hornblende gneiss which is about 100 feet thick, dips steeply north, and is bordered north and south by quartz-biotite gneiss. In the terminology of the present report, the hornblende gneiss of Adams and Stugard is amphibolite and hornblende gneiss, and the quartz-biotite gneiss of Adams and Stugard is biotite-quartz-plagioclase gneiss. These rocks are layers in a subdivision of the hornblende gneiss unit shown on plate 1 of this report as interlayered hornblende gneiss, amphibolite, and biotite gneiss. The hornblende gneiss layer in the vicinity of the shaft is about 250 feet north of the gradational contact with the microcline gneiss unit.

The Union Pacific prospect is on a fault zone 10–15 feet wide that strikes N. 15°–20° W. and dips 35° NE. Right-lateral displacement of about 20 feet along this fault zone is shown on the map by Adams, Gude, and Beroni (1953, fig. 3). We consider the fault zone to be part of the Hurricane Hill breccia-reef fault system (pl. 1). The central part of the fault zone at the shaft consists of brecciated fragments of gneiss in a groundmass of ankerite and potassic felspar. Zones of bleached and sheared gneiss 3–5 feet thick are present along the hanging wall and footwall. Chemical and spectrographic analyses of fault breccia and ore were reported by Adams and Stugard (1956, tables 1, 2).

Pitchblende associated with base-metal sulfides and gangue minerals occurs in a zone less than half a foot thick along the hanging wall of the central breccia of the fault zone. Adams and Stugard (1956, p. 195–200) identified pitchblende, hematite, tennantite, chalcopyrite, bornite, chalcocite, covellite, sphalerite, galena, emplectite(?), pyrite, ankerite, potassic feldspar, and chlorite in the ore. A sample from the dump contained 0.11 percent uranium, and channel samples from the workings contained 0.003–5.84 percent uranium (Adams and others, 1953, table 1, fig. 4). Most of the pitchblende was found in the walls of the short drift.

OTHER PROSPECTS

Other prospects containing pitchblende in the Golden Gate Canyon area include the Buckman property and the Ladwig Nos. 1, 2, and 3. Uranium was discovered at these prospects by J. W. Adams and associates in 1951–52. All the prospects have been described by Adams, Gude, and Beroni (1953, p. 8–11), and the Buckman adit has been described by Adams and Stugard (1956, p. 205–206). No additional work was done at these properties during the present investigation, but the breccia-reef faults on which the deposits occur have been traced in greater detail to the northwest and southeast (pl. 1). We consider these faults to be part of the Hurricane Hill fault system (pl. 1).

Adams and Stugard (1956, fig. 46) showed that the pitchblende deposits at the Union Pacific and the three Ladwig prospects occur where faults cut a layer of hornblende gneiss that trends east-northeast and is 100–150 feet thick. These prospects are shown on our geologic map (pl. 1). The Buckman adit lies in biotite gneiss south of the hornblende gneiss layer. The biotite gneiss and the hornblende gneiss layer are in the interlayered hornblende gneiss, amphibolite, and biotite gneiss, a subunit of the hornblende gneiss unit. The following summaries are largely from the reports by Adams and his associates (1953, 1956).

BUCKMAN PROPERTY

The Buckman adit, on land owned by Nora R. Buckman, Golden, Colo., is about 15 feet east of the road along Golden Gate Canyon in the NE¼ sec. 25, T. 3 S., R. 71 W. Mine workings, which were excavated in 1916, consist of an adit driven 86 feet about N. 70° E., and a winze 25 feet deep at the heading. The adit is in biotite gneiss which is cut by a discontinuous sulfide-bearing quartz vein and pegmatites. Two segments of the quartz vein, each about 20 feet long, lie subparallel to the foliation of the biotite gneiss, which strikes N. 70° E. and dips steeply northwest. Pyrite, chalcopyrite, and molybdenite in the quartz vein probably represent a period of mineralization unrelated to the uranium deposition and may be Precambrian in age. Pitchblende occurs in two northeast-trending shears that cut the quartz vein and wallrocks and dip moderately to steeply southeast. The pitchblende is most abundant where the shears cross the quartz vein; there it rims brecciated fragments of quartz. Hematite is the only other abundant metallic mineral in the pitchblende-bearing material. Small amounts of chalcopyrite, pyrite, and covellite in the hematite may be relicts of the sulfides in the original quartz vein. Small amounts of uranophane and uranopilite also occur at the deposit. The uranium content of samples of pitchblende-bearing material from the adit ranged from 0.062 to 0.86 percent (Adams and others, 1953, table 1).

About 300 feet northwest of the adit, at the east side of the road, a vertical north-trending vein 1–3 inches wide contains a pod of pitchblende-bearing material less than 2 feet long. The vein cuts a layer of hornblende gneiss which is probably the westward extension of the layer that contains the other prospects to the east. A grab sample of the vein material contained 1.23 percent uranium (Adams and others, 1953, table 1). Associated with the pitchblende in the vein are a carbonate mineral and small amounts of chalcopyrite.

Although the pitchblende deposits of the Buckman property are not directly on a breccia-reef fault, the shears and the small vein-fissure containing these deposits are probably related to a major northwest-trending breccia-reef fault of the Hurricane Hill fault system that lies 300 feet west of the adit (pl. 1).

LADWIG NO. 1

The Ladwig No. 1 property is in the SE¼SW¼ sec. 19, T. 3 S., R. 70 W., about 900 feet west-southwest from the Union Pacific prospect. Mineral rights to this property as well as Ladwig Nos. 2 and 3 are owned by L. C. Ladwig, Golden, Colo.

Uranium minerals at this property are associated with a northwest-trending breccia-reef fault. Apparent left-lateral movement along the fault may have displaced the favorable bed of hornblende gneiss as much as 100 feet (Adams and Stugard, 1956, fig. 46). The radioactive locality is about 500 square feet in area and is largely covered by thin soil. Pitchblende and secondary copper minerals were found in fragments of fault breccia, and torbernite was noted in fragments of altered wallrock. A grab sample from 1 foot below the soil cover contained 1.36 percent uranium (Adams and others, 1953, table 1).

LADWIG NO. 2

The Ladwig No. 2 property is in the SE¼SE¼ sec. 19, T. 3 S., R. 70 W., about 1,800 feet east-northeast from the Union Pacific prospect. Workings on the property consist of a shaft 12 feet deep, several shallow trenches, and an adit, the portal of which is caved. A fault marked by a breccia zone 1–6 feet thick trends north-northwest across the favorable layer of hornblende gneiss in this area; the shaft and adit are on this fault. Pitchblende, torbernite, and copper minerals were found in samples of breccia on the dump of the shaft. A grab sample of this material contained 0.30 percent uranium (Adams and others, 1953, table 1). Other radioactive breccia was found in debris from a shallow trench east of the shaft in the vicinity of a subparallel fault. No uranium minerals were found at the dump of the adit.

LADWIG NO. 3

The Ladwig No. 3 property is in the SE¼ sec 19, T. 3 S., R. 70 W., about 1,300 feet east-northeast from the Union Pacific prospect. Two small prospect pits are in a north-trending zone of fault breccia. Pitchblende and copper minerals were noted in one specimen on the dump of the lower of the two pits.

GARNET FROM PRECAMBRIAN METAMORPHIC ROCKS

No attempt has been made to carry out a systematic study of the garnet types present in the Precambrian metamorphic rocks of the Ralston Buttes district. Semiquantitative spectrographic analyses (table 31) of three garnet concentrates indicate that one sample is almandite-spessartite (sample 3) and two are predominantly almandite with smaller amounts of pyrope (samples 7, 8). Index of refraction and unit cell size were measured for each of 13 garnet concentrates (table 32). These results, though inconclusive, may be useful in planning a more comprehensive study in the future, for in a general way they indicate an appreciable range of composition for the garnet types present in metamorphic rocks of this district.

IDENTIFICATION OF MICA FROM PRECAMBRIAN ROCKS

During the field and petrographic studies of the Precambrian rocks of the Ralston Buttes district we decided that the mineralogy of the white mica that occurs in several types of rock should be investigated. Although such mica having high birefringence is or-

TABLE 31.—*Semiquantitative spectrographic analyses, in percent, of three garnet concentrates*

[0, looked for but not detected; M, major constituent (>10 percent). Analyst: R. G. Havens]

Sample No.	Lab. No.	Field No.	Al	Fe	Mg	Ca	Ti	Mn	Ba	Co	Cr	Cu	Ge	Ni	Sc	Sr	Y	Yb	Zr
3	244853	SW-110	M	M	0.7	0.7	0.015	7	0.0007	0.007	0.0015	0.007	0.007	0.003	0.003	0.003	0	0	0.015
7	244857	DS-53-45	M	M	3	.7	.07	.7	.0007	0	0	.0007	0	0	.007	0	.07	.007	.015
8	244858	DS-53-47	M	M	3	.3	.07	.3	.0015	0	0	.0015	0	.0015	.003	0	.03	.003	.07

NOTE.—The concentrations in the spectrographic analyses are reported as elements, not as oxides or compounds.

The following classification is used for the spectrographic data: Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc., in percent. 60 percent of the reported results may be expected to agree with the results of quantitative methods. Elements not looked for: Si, Na, Cs, F, Rb. Elements looked for but not found: K, P, Ag, As, Au, B, Be, Bi, Cd, Ce, Dy, Er, Eu, Ga, Gd, Hf, Hg, Ho, In, Ir, La, Li, Lu, Mo, Nb, Nd, Os, Pb, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, V, W, Zn.

TABLE 32.—*Refractive index and unit cell size of garnet concentrates*

[Measurements by E. J. Young]

Sample No.	Lab. No.	Field No.	Rock type	Location	Refractive index (*n*) ±0.005	Unit cell size (a_0, in angstrom units)
1	244851	SW-80	Garnetiferous biotite-quartz gneiss	Schwartzwalder mine, Minnesota level (pl. 4), footwall side of Colorado vein, south side of adit.	1.795	11.620±0.003
2	244852	SW-84	do	Schwartzwalder mine, Minnesota level (pl. 4), southeast drift on Nebraska vein, footwall side.	1.800	11.562± .004
3	244853	SW-110	do	Schwartzwalder mine, Upper level (pl. 3), floor of upper part of inclined workings.	1.815	
4	244854	SW-125	do	Schwartzwalder mine, Upper level (pl. 3), breast south of vertical winze.	1.805	11.530± .003
5	244855	SW-132A	do	Schwartzwalder mine, surface outcrop near western edge of mapped area (pl. 2).	1.815	11.531± .002
6	244856	RC-11(115)	do	Schwartzwalder mine, diamond-drill hole	1.805	11.630± .003
7	244857	DS-53-45	Garnetiferous quartz-biotite schist	At western contact of microcline gneiss unit (pl. 1), SW¼ sec. 8, T. 3 S., R. 71 W.	1.805	
8	244858	DS-53-47	do	At southern contact of microcline gneiss unit (pl. 1), SE¼ sec. 28, T. 3 S., R. 71 W.	1.813	
9	244859	RA-163	Garnetiferous biotite-quartz-plagioclase gneiss.	Layer in northernmost part of microcline gneiss unit (pl. 1), southwest of Union Pacific prospect, SW¼ sec. 19, T. 3 S., R. 70 W.	1.803	11.540± .001
10	244860	RA-209b	Garnetiferous quartz-biotite schist	At northern contact of microcline gneiss unit (pl. 1), NE¼ sec. 18, T. 3 S., R. 71 W.	1.810	11.539± .002
11	244861	DS-53-38b	Outer part of lens of calc-silicate rock	Lens in mica schist unit, E½ sec. 36, T. 2 S., R. 71 W. (pl. 1)	1.785	11.696± .004
12	244862	DS-53-40	Garnetiferous mica schist	Layer near northern contact of mica schist unit (pl. 1), SW¼ sec. 25, T. 2 S., R. 71 W.	1.815	11.545± .002
13	244863	DS-55-28	Garnetiferous feldspathic quartz-biotite schist.	Layer in mica schist unit (pl. 1), SW¼ sec. 2, T. 3 S., R. 71 W.	1.805	11.547± .002
14	244864	DS-M-7	Garnetiferous biotite-quartz gneiss	In lens of layered calc-silicate gneiss, Fork prospect (pl. 1), NW¼ sec. 19, T. 3 S., R. 70 W.	1.800	11.596± .004
15	244865	GD-12-67	do	At contact between layered calc-silicate gneiss and mica schist unit (pl. 1), Aubrey Ladwig mine, SW¼ sec. 18, T. 3 S., R. 70 W.	1.795	11.601± .005
16	279601	DS-58-R3	Fine-grained garnetiferous schist	Layer in quartzite unit (pl. 1), south slope of Blue Mountain, SW¼ sec. 16, T. 2 S., R. 71 W.	1.805	11.574± .005

dinarily assumed to be muscovite in routine petrographic examinations, muscovite actually cannot be readily distinguished from other white micas, such as paragonite, by ordinary optical methods. Further study was undertaken, therefore, in order to determine the nomenclature used in this report.

A group of seven samples from the district was selected from typical outcrops of various Precambrian rocks that contain appreciable amounts of white mica. R. L. Yoder of the U.S. Geological Survey carefully separated the mica from the samples. Laboratory studies of the mica were then made by E. J. Young, also of the U.S. Geological Survey, using both optical methods and the X-ray diffractometer.

In the seven samples only muscovite was found. The optical and X-ray data from this study are listed in table 33. The distinction between muscovite and paragonite can be readily made with the X-ray diffractometer because the basal *d*-spacing for muscovite is approximately 9.98 A and that for paragonite ranges from 9.58 to 9.66 A. Determinations of 2V using Mallard's constant (Winchell, 1946, fig. 1) are probably correct to ± 5°, but considerable variation was noted in each sample.

On the basis of these data we concluded that muscovite is probably the most abundant type of white mica in the principal Precambrian rocks of the Ralston Buttes district. Consequently, the name muscovite is used throughout the report except for very fine grained alteration products of other minerals, for which the term sericite is used to emphasize the grain size.

TABLE 33.—*Optical and X-ray data for seven samples of white mica*

Lab. No.	Field No.	Rock type	Map unit and location (pl. 1)	Basal *d*-spacing (argstrom units)	Refractive index (+0.003)		2V (degrees)			Mineralogic determination
					n_y	n_z	Smallest	Largest	Average	
253089	DS-53-21	Mica schist	Mica schist unit, N½ sec. 15, T. 3 S., R. 71 W.	9.96	1.599	1.605	30	52	44	Muscovite
253090	DS-53-39	Porphyroblastic mica schist.	Mica schist unit, E½ sec. 36, T. 2 S., R. 71 W.	10.02	1.594	1.599	24	42	36	Do.
253091	DS-55-25	Crenulated mica schist	Mica schist unit, W½ sec. 2, T. 3 S., R. 71 W.	9.99	1.600	1.603	30	42	40	Do.
253092	RA-19	Mica schist	Mica schist unit, S½ sec. 14, T. 3 S., R. 71 W.	9.97	1.595	1.601	39	45	42	Do.
253093	RA-175	Sillimanitic mica schist.	Mica schist unit, NW¼ sec. 18, T. 3 S., R. 70 W.	9.96	1.594	1.601	----	----	42	Do.
253094	RA-385b	Andalusite-bearing mica schist.	Schist layer in quartzite unit, NE¼ sec. 19, T. 2 S., R. 71 W.	9.98	1.600	1.604	25	45	39	Do.
253095	RA-559	Cordierite-bearing mica schist.	Schist layer in quartzite unit, SW¼ sec. 16, T. 2 S., R. 71 W.	10.00	1.598	1.603	36	51	42	Do.

REFERENCES CITED

Adams, J. W., Gude, A. J., 3d, and Beroni, E. P., 1953, Uranium occurrences in the Golden Gate Canyon and Ralston Creek areas, Jefferson County, Colorado: U.S. Geol. Survey Circ. 320, 16 p.

Adams, J. W., and Stugard, Frederick, Jr., 1956, Wall-rock control of certain pitchblende deposits in Golden Gate Canyon, Jefferson County, Colorado: U.S. Geol. Survey Bull. 1030–G, p. 187–209.

Adler, J. L., 1930, Geologic and petrographic relations of the Coal Creek quartzite and contiguous crystalline formations in Jefferson, Boulder, and Gilpin Counties, Colorado: Chicago Univ., Ph. D. thesis.

Barrow, George, 1912, On the geology of lower Dee-side and the Southern Highland border, pt. 1 *of* Excursion to the east of Scotland: Geologists' Assoc. (London) Proc., v. 23, p. 274–290.

Bastin, E. S., and Hill, J. M., 1917, Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colorado: U.S. Geol. Survey Prof. Paper 94, 379 p.

Bell, P. M., 1963, Aluminum silicate system—experimental determination of the triple point: Science, v. 139, no. 3559, p. 1055–1056.

Billings, M. P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, no. 4, p. 463–566.

Billings, M. P., 1950, Stratigraphy and the study of metamorphic rocks: Geol. Soc. America Bull., v. 61, no. 5, p. 435–448.

Bird, A. G., 1956, Primary pitchblende deposits at the Ralston Creek mine [Colorado]: Uranium and Modern Mining [formerly, Uranium], v. 3, no. 8, p. 8, 44.

———1957a, Uranium deposits in Golden Gate Canyon and Ralston Creek area of Jefferson County, Colorado: Mines Mag., v. 47, no. 3, p. 91–93.

———1957b, Pitchblende occurrences in the Golden Gate Canyon-Ralston Creek areas of Jefferson County, Colorado [abs.]: Geol. Soc. America Bull., v. 68, no. 12, pt. 2, p. 1858–1859.

Bird, A. G., and Stafford, H. S., 1955, Uranium deposits of the Colorado Front Range foothills region: Mines Mag., v. 45, no. 3, p. 81–82.

Boos, C. M., and Boos, M. F., 1957 Tectonics of eastern flank and foothills of Front Range, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 12, p. 2603–2676.

Bowen, N. L., and Tuttle, O. F., 1950, The System $NaAlSi_3O_8$–$KalSi_3O_8$–H_2O: Jour. Geology, v. 58, no. 5, p. 489–511.

Bozbag, H. A., 1943, Precambrian geology of an area near the mouth of Golden Gate Canyon: Colorado School Mines, Golden, M.S. thesis.

Chaisson, Ursula, 1950, The optics of triclinic adularia: Jour. Geology, v. 58, no. 5, p. 537–547.

Cloos, Ernst, 1946, Lineation, a critical review and annotated bibliography: Geol. Soc. America Mem. 18, 122 p.

Downs, G. R., and Bird, A. G., 1965, The Schwartzwalder uranium mine, Jefferson County, Colorado: The Mountain Geologist, v. 2, no. 4, p. 183–191.

Drake, A. A., Jr., 1957, Geology of the Wood and East Calhoun mines, Central City district, Gilpin County, Colorado: U.S. Geol. Survey Bull. 1032–C, p. 129–170.

Emmons, S. F., Cross, Whitman, and Eldridge, G. H., 1896, Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, 556 p.

Emmons, W. H., and Laney, F. B., 1926, Geology and ore deposits of the Ducktown mining district, Tennessee: U.S. Geol. Survey Prof. Paper 139, 114 p.

Erskine, C. F., Morgan, G. B., and Robertson, L. B., 1950, High-level gravels west of Golden, Colorado, and their physiographic significance [abs.]: Geol. Soc. America Bull., v. 61, no. 12, pt. 2, p. 1552.

Eskola, Pentti, 1939, Die metamorphen Gesteine, *in* Barth, T. F. W., Correns, C. W., and Eskola, Pentti, Die Enstehung der Gesteine: Berlin, Springer-Verlag, p. 263–407.

Faul, Henry, ed., and others, 1954, Nuclear geology—a symposium on nuclear phenomena in the earth sciences: New York, John Wiley & Sons, 414 p.

Fraser, G. D., 1949, Coal Creek quartzite, Jefferson and Boulder Counties, Colorado [abs.]: Geol. Soc. America Bull., v. 60, no. 12, pt. 2, p. 1960.

Frondel, Clifford, 1958, Systematic mineralogy of uranium and Thorium: U.S. Geol. Survey Bull. 1064, 400 p.

Frye, J. C., and Leonard, A. B., 1952, Pleistocene geology of Kansas: Kansas Geol. Survey Bull. 99, 230 p.

Fyfe, W. S., Turner, F. J., and Verhoogen, Jean. 1958, Metamorphic reactions and metamorphic facies: Geol. Soc. America Mem. 73, 259 p.

Gabelman, J. W., 1948, The Geology of the Golden Gate-Van Bibbler Creek area, Jefferson County, Colorado: Colorado School Mines, Golden, M.S. thesis.

Grout, F. F., 1932, Petrography and petrology: New York, McGraw-Hill Book Co., 522 p.

Guidotti, C. V., 1963, Metamorphism of the pelitic schists in the Bryant Pond quadrangle, Maine: Am. Mineralogist, v. 48, nos. 7, 8, p. 772–791.

Hampton, O. W., 1958, Bedrock creep north of Golden, Colorado [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1727.

Hanley, J. B., Heinrich, E. W, and Page, L. R., 1950, Pegmatite investigations in Colorado, Wyoming, and Utah, 1942–1944: U.S. Geol. Survey Prof. Paper 227, 125 p.

Harker, Alfred, 1939, Metamorphism—a study of the transformations of rock-masses: 2d ed, New York, E. P. Dutton & Co., 362 p.

Harrison, J. E., and Wells, J. D., 1956, Geology and ore deposits of the Freeland-Lamartine district, Clear Creek County, Colorado: U.S. Geol. Survey Bull. 1032–B, p. 33–127.

———1959, Geology and ore deposits of the Chicago Creek area, Clear Creek County, Colorado: U.S. Geol. Survey Prof. Paper 319, 92 p.

Hessland, Ivar, 1955, Studies in the lithogenesis of the Cambrian and basal Ordovician of the Böda Hamn sequence of strata: Upsala Univ., Geol. Inst., Bull., v. 35, p. 35–110.

Hietanen, Anna, 1956, Kyanite, andalusite, and sillimanite in the schist in Boehls Butte quadrangle, Idaho: Am. Mineralogist, v. 41, nos. 1, 2, p. 1–27.

Holmes, Arthur, 1959, A revised geological time-scale: Edinburgh Geol. Soc. Trans., v. 17, pt. 3, p. 183–216.

Howard, A. D., 1956, Upland surfaces of the Rocky Mountains, *in* pt. 4 *of* Internat. Geog. Union, Comm. for the Study and Correlation of Erosion Surfaces Around the Atlantic, 8th, [1st] Report: Internat. Geog. Cong., 18th and 19th Gen. Assembly, Rio de Janeiro 1956, p. 28–40.

Hsu, K. J., 1959, Flute- and groove-casts in the Prealpine Flysch, Switzerland: Am. Jour. Sci., v. 257, no. 7, p. 529–536.

Hunt, C. B., 1954, Pleistocene and Recent deposits in the Denver area, Colorado: U.S. Geol. Survey Bull. 996–C, p. 91–140.

Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, no. 9, p. 953–992.

Johnson, J. H., 1925, The geology of the Golden area, Colorado: Colorado School Mines Quart., v. 20, no. 3, 25 p.

———1930a, The geology of the Golden area, Colorado: 2d ed., revised, Colorado School Mines Quart., v. 25, no. 3, 33 p.

———1930b, Unconformity in Colorado group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 6, p. 789–794.

———1931, The paleontology of the Denver quadrangle, Colorado: Colorado Sci. Soc. Proc., v. 12, no. 11, p. 355–378.

———1934, Introduction to the geology of the Golden area, Colorado: Colorado School Mines Quart., v. 29, no. 4, 36 p.

Lee, W. T., 1917, The geologic story of the Rocky Mountain National Park, Colorado: U.S. Natl. Park Service, 89 p.

———1927, Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U.S. Geol. Survey Prof. Paper 149, 80 p.

LeRoy, L. W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colorado: Colorado School Mines Quart., v. 41, no. 2, 115 p.

Lindgren, Waldemar, 1933 Mineral deposits: 4th ed., New York, McGraw-Hill Book Co., 930 p.

Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U.S. Geol. Survey Prof. Paper 223, 319 p.

Lovering, T. S., and Tweto, Ogden, 1953, Geology and ore deposits of the Boulder County tungsten district, Colorado: U.S. Geol. Survey Prof. Paper 245, 199 p.

McKee, E. D., 1957, Primary structures in some Recent sediments [U.S. and Mexico]: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1704–1747.

McKee, E. D., and others, 1959, Paleotectonic maps of the Triassic system: U.S. Geol. Survey Misc. Geol. Inv. Map I–300, 33 p.

MacKenzie, W. S., 1954, The orthoclase-microcline inversion: Mineralog. Mag., v. 30, no. 225, p. 354–366.

McKinstry, H. E., 1948, Mining geology: New York, Prentice-Hall, 680 p.

Malde, H. E., 1955, Surficial geology of the Louisville quadrangle, Colorado: U.S. Geol. Survey Bull. 996–E, p. 217–259.

Marvine, A. R., 1874, Report [on the geology of the region traversed by the Northern or Middle Park division during the working season of 1873]: U.S. Geol. and Geog. Survey Terr., 7th Ann. Rept. (Hayden), p. 83–192.

Mining and Science Press, 1884 [note, pitchblende]: Mining and Sci. Press, v. 48, no. 11, p. 195.

Miyashiro, A., 1953, Calcium-poor garnet in relation to metamorphism: Geochim. et Cosmochim. Acta, v. 4, p. 179-208.

Moench, R. H., Harrison, J. E., and Sims, P. K., 1954, Precambrian structures in the vicinity of Idaho Springs, Front Range, Colorado [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1383–1384.

Moench, R. H., Harrison, J. E., and Sims, P. K., 1958, Precambrian folding in the central part of the Front Range mineral belt, Colorado [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1737.

———1962, Precambrian folding in the Idaho Springs-Central City area, Front Range, Colorado: Geol. Soc. America Bull., v. 73, no. 1, p. 35–58.

Moore, D. G., and Scruton, P. C., 1957, Minor internal structures of some recent unconsolidated sediments [Gulf of Mexico]: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 12, p. 2723–2751.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1944, Elements, sulfides, sulfosalts, oxides, v. 1 *of* The system of mineralogy of James Dwight Dana and Edward Salisbury Dana: 7th ed, New York, John Wiley & Sons, 834 p.

Peabody, F. E., 1948, Reptile and amphibian trackways from the lower Triassic Moenkopi formation of Arizona and Utah: California Univ. Dept. Geol. Sci. Bull., v. 27, no. 8, p. 295–468.

Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U.S. Geol. Survey TEI–247, 53 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Services Ext., Oak Ridge, Tenn.

Rogers, A. F., and Kerr, P. F., 1942, Optical mineralogy: 2d ed., New York, McGraw-Hill Book Co., 390 p.

Runner, J. J., and Hamilton, R. G., 1934, Metamorphosed calcareous concretions and their genetic and structural significance: Am. Jour. Sci., 5th ser., v. 28, no. 163, p. 51–64.

Scott, G. R., 1960, Subdivision of the Quaternary alluvium east of the Front Range near Denver, Colorado: Geol. Soc. America Bull., v. 71, no. 10, p. 1541–1543.

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036–C, p. 19–56.

Sheridan, D. M., 1955, Geology of the High Climb pegmatite, Custer County, South Dakota: U.S. Geol. Survey Bull. 1015–C, p. 59–98.

———1956, Ralston Buttes, Colorado, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1956: U.S. Geol. Survey TEI–640, p. 125–137, issued by U.S. Atomic Energy Comm., Tech. Inf. Service Ext., Oak Ridge, Tenn.

Sheridan, D. M., Maxwell, C. H., Albee, A. L., and Van Horn, Richard, 1958, Preliminary map of bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–179.

Sims, P. K., 1956, Uranium deposits in the Front Range, Colorado: Mines Mag., v. 46, no. 3, p. 77–79.

Sims, P. K., Drake, A. A., Jr., and Tooker, E. W., 1963, Economic geology of the Central City district, Gilpin County, Colorado: U.S. Geol. Survey Prof. Paper 359, 231 p.

Sims, P. K., Osterwald, F. W., and Tooker, E. W., 1955, Uranium deposits in the Eureka Gulch area, Central City district, Gilpin County, Colorado: U.S. Geol. Survey Bull. 1032–A, p. 1–31.

Sims, P. K., and others, 1963, Geology of uranium and associated ore deposits, central part of the Front Range mineral belt, Colorado: U.S. Geol. Survey Prof. Paper 371, 119 p.

Sims, P. K., and Sheridan, D. M., 1964, Geology of uranium deposits in the Front Range, Colorado: U.S. Geol. Survey Bull. 1159, 116 p.

Spurr, J. E., and Garrey, G. H., 1908, Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado: U.S. Geol. Survey Prof. Paper 63, 422 p.

Stieff, L. R., Stern, T. W., Oshiro, Seiki, and Senftle, F. E., 1959, Tables for the calculation of lead isotope ages: U.S. Geol. Survey Prof. Paper 334–A, p. 1–40.

Thompson, J. B., Jr., 1955, The thermodynamic basis for the mineral facies concept: Am. Jour. Sci., v. 253, no. 2, p. 65–103.

———1957, The graphical analysis of mineral assemblages in pelitic schists: Am. Mineralogist, v. 42, p. 842–858.

Thompson, W. O., 1949, Lyons sandstone of Colorado Front Range: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 1, p. 52–72.

Tooker, E. W., 1956, Altered wall rocks along vein deposits in the Central City-Idaho Springs region, Colorado, *in* Swineford, Ada, ed., Clays and clay minerals: Natl. Research Council Pub. 456, p. 348–361.

———1963, Altered wallrocks in the central part of the Front Range mineral belt, Gilpin and Clear Creek Counties, Colorado: U.S. Geol. Survey Prof. Paper 439, 102 p. [1964].

Tröger, W. E., 1952, Tabellen zur optischen Bestimmung der gesteinsbildenden Minerale: Stuttgart, E. Schweizerbart, Verlagsbuchhandlung, 147 p.

Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. America Mem. 30, 342 p.

———1951, Observations on twinning of plagioclase in metamorphic rocks: Am. Mineralogist, v. 36, nos. 7, 8, p. 581–589.

Turner, F. J., and Verhoogen, Jean, 1960, Igneous and metamorphic petrology: 2d ed, New York, McGraw-Hill Book Co., 694 p.

Tuttle, O. F., 1952, Optical studies on alkali feldspars (Bowen volume): Am. Jour. Sci., pt. 2, p. 553–567.

Tweto, Ogden, 1960, Scheelite in the Precambrian gneisses of Colorado: Econ. Geology, v. 55, no. 7, p. 1406–1428.

Tweto, Ogden, and Sims, P. K., 1960, Relation of the Colorado mineral belt to Precambrian structure, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B8–B10.

———1963, Precambrian ancestry of the Colorado mineral belt: Geol. Soc. America Bull., v. 74, no. 8, p. 991–1014.

Underhill, James, 1906, Areal geology of the lower Clear Creek [Colorado]: Colorado Sci. Soc. Proc., v. 8, p. 103–122.

Van Hise, C. R., and Leith, C. K., 1909, Pre-Cambrian geology of North America: U.S. Geol. Survey Bull. 360, 939 p.

Van Horn, Richard, 1957, Bedrock geology of the Golden quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ–103.

Van Tuyl, F. M., Johnson, J. H., Waldschmidt, W. A., Boyd, James, and Parker, B. H., 1938, Guide to the geology of the Golden area [Colorado]: Colorado School Mines Quart., v. 33, no. 3, 32 p.

Van Tuyl, F. M., and Lovering, T. S., 1935, Physiographic development of the Front Range [Colorado]: Geol. Soc. America Bull., v. 46, no. 9, p. 1291–1350.

Waagé, K. M., 1952, Clay deposits of the Denver-Golden area, Colorado: Colorado Sci. Soc. Proc., v. 15, no. 9, p. 373–390.

———1955, Dakota group in northern Front Range foothills, Colorado: U.S. Geol. Survey Prof. Paper 274–B, p. 15–51.

———1959, Stratigraphy of the Dakota group along the northern Front Range foothills, Colorado: U.S. Geol. Survey Oil and Gas Inv. Chart OC–60.

———1961, Stratigraphy and refractory clayrocks of the Dakota group along the northern Front Range, Colorado: U.S. Geol. Survey Bull. 1102, 154 p.

Waldschmidt, W. A., 1939, The Table Mountain lavas and associated igneous rocks near Golden, Colorado: Colorado School Mines Quart., v. 34, no. 3, 62 p.

Waldschmidt, W. A., and Adams, J. W., 1942, The beryl-monazite pegmatite dike of Centennial Cone, Colorado: Colorado School Mines Quart., v. 37, no. 3, p. 29–38.

Waldschmidt, W. A., and Gaines, R. V., 1939, Occurrence of chrysoberyl near Golden, Colorado: Am. Mineralogist, v. 24, no. 4, p. 267–271.

Walker, G. W., and Adams, J. W., 1963, Mineralogy, internal structural and textural characteristics, and paragenesis of uranium-bearing veins in the conterminous United States: U.S. Geol. Survey Prof. Paper 455–D, p. 55–90.

Walker, T. R., 1957, Origin of the "Crinkled" Member of the Lykins Formation in central Colorado [abs.]: Geol. Soc. America Bull., v. 68, no. 12, pt. 2, p. 1875.

Waters, A. C., and Campbell, C. D., 1935, Mylonites from the San Andreas fault zone: Am. Jour. Sci., 5th ser., v. 29, no. 174, p. 473–503.

Wells, J. D., 1960, Petrography of radioactive Tertiary igneous rocks, Front Range mineral belt, Colorado: U.S. Geol. Survey Bull. 1032–E, p. 223–272.

———1963, Preliminary geologic map of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I–383.

———1967, Geology of the Eldorado Springs quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey Bull. 1221–D, 85 p.

Wells, J. D., Sheridan, D. M., and Albee, A. L., 1961, Metamorphism and structural history of the Coal Creek area, Front Range, Colorado, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C127–C131.

———1964, Relationship of Precambrian quartzite-schist sequence along Coal Creek to Idaho Springs Formation, Front Range, Colorado: U.S. Geol. Survey Prof. Paper 454–O, p. O1–O25.

White, W. S., 1949, Cleavage in east-central Vermont: Am. Geophys. Union Trans., v. 30, no. 4, p. 587–594.

Winchell, Horace, 1946, A chart for measurement of interference figures: Am. Mineralogist, v. 31, nos. 1, 2, p. 43–50.

Wright, R. J., and Everhart, D. L., 1960, Uranium, chap. 5 *of* Del Rio, S. M., Mineral resources of Colorado, first sequel: Denver, Colo., Publishers Press, p. 329–365.

Yen, Teng-Chien, 1952, Molluscan fauna of the Morrison Formation: U.S. Geol. Survey Prof. Paper 233–B, p. 21–51.

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