Bedrock Geology of the Kassler Quadrangle Colorado

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By GLENN R. SCOTT

GEOLOGY OF THE KASSLER QUADRANGLE, JEFFERSON AND DOUGLAS COUNTIES, COLORADO

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A survey of the east flank of the Colorado Front Range with emphasis on Cretaceous rocks and on structural geology

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BEDROCK GEOLOGY OF THE KASSLER QUADRANGLE, COLORADO

By Glenn R. Scott

ABSTRACT

The Kassler quadrangle lies along the South Platte River on the east flank of the Colorado Front Range a few miles south of Denver.

Precambrian metamorphic and igneous rocks constitute the bedrock of the mountains. The oldest rocks are metasedimentary quartzite, amphibolite, lime silicate gneiss, biotite-quartz gneiss, and sillimanitic biotite-quartz gneiss. These older rocks were invaded by granitic solutions that generally produced large bodies of granite gneiss, but that locally were so intimately interbedded with the metasedimentary rocks that migmatite was formed. Gneissic granite (probably equivalent to the Boulder Creek granite) and quartz diorite and associated hornblendite also invaded the older rocks and were given a metamorphic structure by the last stage of regional metamorphism to affect the crystalline rocks of the Front Range. The biotite-muscovite granite, the Pikes Peak granite, and granite pegmatite were intruded into all earlier rocks in later Precambrian time.

In late Precambrian time a range of low mountains apparently was uplifted in the present position of the Colorado Front Range, and faults, such as the Jarre Creek fault and other northwest- and northeast-trending faults that cross the Front Range, were formed. These faults are the framework of the Front Range fault system, and major movements have taken place along them periodically since Precambrian time. After erosion in late Precambrian and Early and Middle Cambrian time, the sea encroached on the area in Late Cambrian time and started to deposit the Sawatch quartzite over the young faults. After only a few feet of sand was deposited on the sea floor, the Precambrian faults were opened, possibly by earthquakes; sand was sucked or injected into the fault system, and a widespread network of sandstone dikes was created.

About 11,500 feet of sedimentary rocks unconformably overlie the crystalline rocks. The unconformity is the result of erosion of all pre-Pennsylvanian sedimentary rocks as the Pennsylvanian Ancestral Rockies were uplifted. The Fountain arkose contains detrital material eroded from these mountains. Transgression of the Permian sea and reworking of continental fan deposits eroded from the mountains resulted in deposition of dune sand of the Lyons sandstone. The sea remained in the area only long enough to deposit maroon siltstone and limestone in the lower part of the Lykins formation. The upper part, which is of Permian(?) and Triassic(?) age, contains maroon siltstone and sandstone deposited by wind and streams. The Ralston Creek formation of Jurassic (Kimmeridgian?) age contains fresh-water limestone, siltstone, jasper, and locally gypsum. At the base of the Morrison formation is a lenticular sandstone unit. The upper part of the Morrison formation is also of continental origin and consists of fresh-water limestone, variegated siltstone, and thin sandstone beds.

Most of the Cretaceous beds in the area are of marine origin. The Lytle and South Platte formations are predominantly beach sand, but contain a thin bed of marine shale near the middle. The Graneros shale, Greenhorn limestone, and Carlile shale consist of black marine shale including (a) a thin siliceous siltstone (Mowry equivalent) in the lower part; (b) calcareous shale, brown calcarenite and gray dense limestone in the middle, and (c) chalky shale, silty and sandy shale, and calcarenite in the upper part. The Niobrara formation consists of the Fort Hays limestone member at the base and the Smoky Hill shale member. The Pierre shale is predominantly dark marine shale, but contains the friable marine Hygiene sandstone member near the middle and another soft sandstone near the top. Faunal zones were defined in the Pierre shale on the basis of a remarkable fauna of ammonites. The Fox Hills sandstone, a brackish-water marine sandstone, overlies the Pierre shale. The sea withdrew from the area for the last time after the Fox Hills sandstone was deposited. The Laramie formation, which overlies the Fox Hills, was deposited in the streams and swamps; it contains the only minable deposits of coal in the area. The Dawson arkose contains the coarse detritus that was eroded as the Front Range was uplifted during Laramide time.

Precambrian faults were reactivated during the Laramide orogeny and possibly some new faults were formed. Late Cretaceous(?) and Tertiary(?) dike rocks were intruded into the faults and later both the dike rocks and the sandstone dikes were brecciated.

INTRODUCTION

The Kassler quadrangle, an area of about 57 square miles in central Colorado, is about 18 miles south of Denver (fig. 28). The quadrangle is in Douglas County except for a small area northwest of the South Platte River that is in Jefferson County.

The quadrangle is accessible by U.S. Highway 87 from the east and by Colorado Routes 67 from the south and 75 and 221 from the north. County and U.S. Forest Service roads, logging roads, and trails traverse the western third of the area. The Atchison, Topeka and Santa Fe Railway and the Denver and Rio Grande Western Railroad cross the northeast corner of the area.

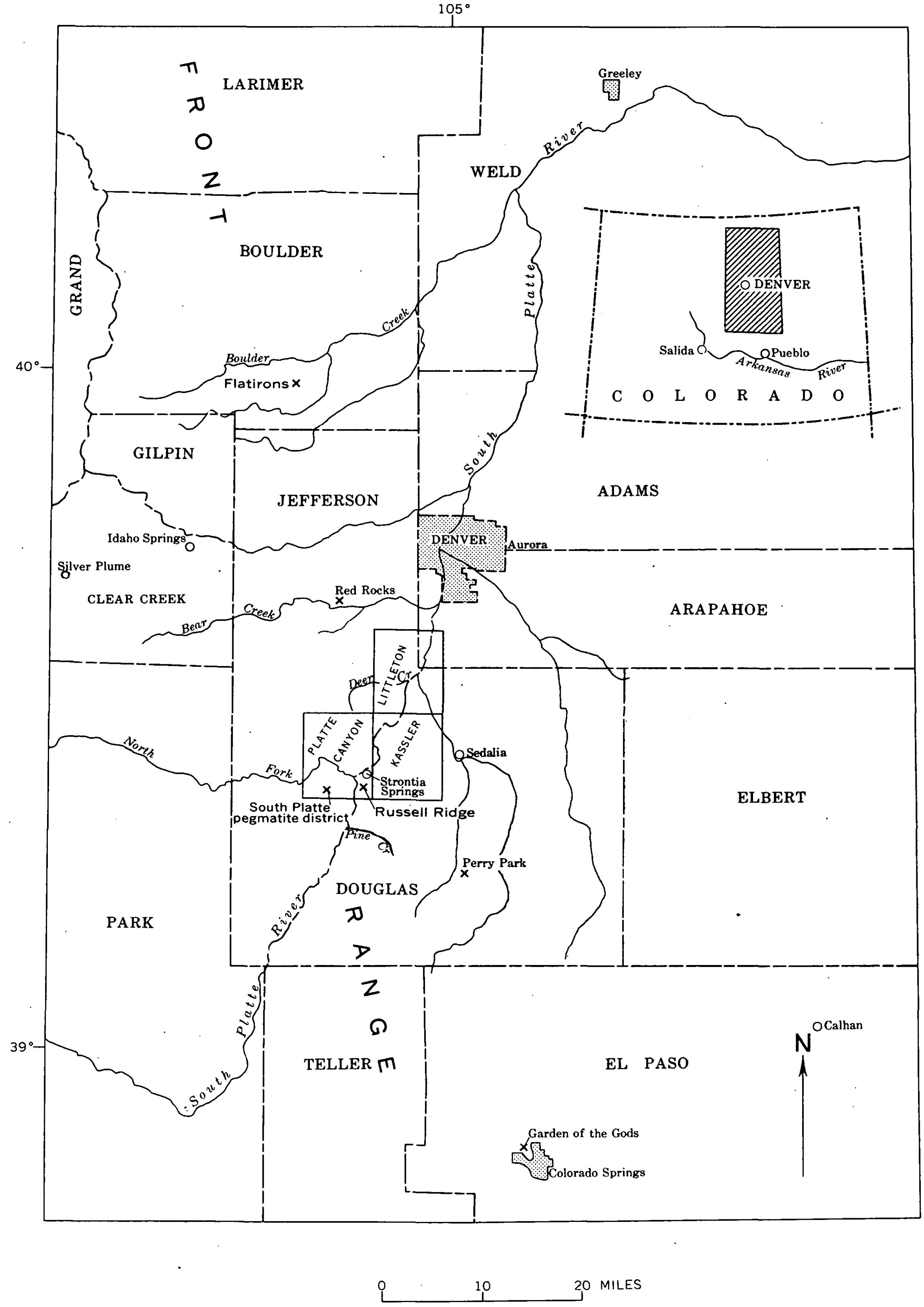

Figure 28.—Index map showing Kassler quadrangle and other places mentioned in text.

Commercial activities include farming, manufacturing, mining, and supplying of water to cities. Dry farming and beef-cattle raising are the two main agricultural activities. A large explosives manufacturing plant is at Louviers in the northeast part of the area, and a guided missile plant is north of Kassler. One of the Denver water-supply filtration plants is at Kassler, where the South Platte River emerges from the mountains, and a pumping plant to supply water for the city of Aurora lies east of Willow Creek.

The study of the Kassler quadrangle was undertaken in 1950 primarily to provide geologic information required for engineering projects planned by the Denver City Water Board and the U.S. Bureau of Reclamation along the South Platte River.

The geology was mapped in 1950, 1955, and 1956 on aerial photographs and then transferred to the topographic map of the quadrangle at the scale 1:20,000. The distribution and attitude of the rocks in the quadrangle are shown on the geologic map (pl. 2). Color names and designations in the text refer to the Rock-Color Chart of the National Research Council (Goddard and others, 1948) and to the Munsell soil-color chart (Munsell Color Co., 1954) which were used throughout the fieldwork. The fossil localities are listed on pages 118–120; the localities are also shown on plate 2.

ACKNOWLEDGMENTS

Owners of the Willow Creek, Slocum, Nelson, Penley, Lambert, Feeley, Nockols, and Helmer ranches made their lands accessible for this survey. Ray E. Johnson, forest ranger at the Indian Creek ranger station, gave helpful information on roads and trails in the Pike National Forest.

Several specialists gave advice on fossils. William A. Cobban of the U.S. Geological Survey visited the area several times and made fossil collections and identifications that are the basis for most of the stratigraphic zoning of the Cretaceous formations. R. E. Peck of the University of Missouri identified charophytes from the Jurassic formations.

GEOGRAPHIC SETTING

The quadrangle is partly in the Colorado Piedmont section of the Great Plains physiographic province and partly in the Colorado Front Range (Fenneman, 1931). The surface of the plains rises gradually toward the southwest and passes from gently rolling hills and gullies to dissected pediments at the foot of the mountains. The pediments are largely destroyed nearer the mountains, and in their place rise steep northwest-trending hogback ridges that dip sharply away from the higher mountains of the Front Range (pl. 2). The High Plains in the area range in altitude from 5,500 to 6,500 feet; the mountains, from 5,600 to 8,050 feet. The total relief is 2,550 feet.

Many of the streams in the area are consequent upon faults, upon a northwest-trending foliation of the metamorphic rocks in the mountains, and upon the hogbacks of sedimentary rocks that flank the mountains on the northeast. Most of the streams on the plains are undergoing rejuvenation; both perennial and intermittent streams have cut deep arroyos. The whole area is drained by the South Platte River and its tributaries, Plum, Indian, Willow, Jarre, and Rainbow Creeks. (pl. 2).

GENERAL GEOLOGY

Rocks ranging in age from Precambrian to Recent crop out in the Kassler quadrangle.

Rocks of Precambrian age crop out in the western part of the area and form the mountainous region of the quadrangle. Sedimentary rocks crop out east of the mountain front; the more resistant units form ridges parallel to the mountains. The formations of Paleozoic age include the Fountain formation of Pennsylvanian and Permian age; the Lyons sandstone of Permian age; and the Lykins formation, which includes the Harriman shale, Falcon limestone, Bergen shale, Glennon limestone, and Strain shale members of LeRoy (1946, p. 31), of Permian (?) and Triassic (?) age. The Mesozoic formations are the Ralston Creek formation, which includes the Entrada (?) sandstone, and the Morrison formation of Late Jurassic age; the Lytle and South Platte formations of Early Cretaceous age; the Graneros shale of Early and Late Cretaceous age; and the Greenhorn limestone, Carlile shale, and Niobrara formation, which includes the Fort Hays limestone and Smoky Hill shale members, the Pierre shale, which includes the Hygiene sandstone member, the Fox Hills sandstone, the Laramie formation, and the lower part of the Dawson arkose, all of Late Cretaceous age. Intruded into the Precambrian rocks are dikes of andesite that may be of Late Cretaceous age.

Rocks of Cenozoic age include the upper part of the Dawson arkose of Paleocene age, rhyolite of possible Paleocene age, and a series of Quaternary surficial deposits that are described in chapter A of this report (Scott, 1963). Pre-Wisconsin surficial deposits include three alluviums and an older loess that are of Nebraskan or Aftonian, Kansas or Yarmouth, and Illinoian or Sangamon age. Wisconsin surficial deposits include the Louviers alluvium, a younger loess, and the Broadway alluvium. The Recent deposits include three alluvial deposits, two eolian deposits, deposits of bog clay, and landslides.

The bedrock was tilted and faulted by uplift of the mountains. The oldest sedimentary rock, the Fountain formation, dips northeast away from the mountain front and unconformably overlies the Precambrian rocks. The sedimentary and Precambrian rocks are cut by a series of northwest-trending faults, most of which are believed to have formed during Precambrian time and which were reactivated during the formation of the ancestral Rockies in Pennsylvanian time and again during the Laramide revolution in Late Cretaceous and early Tertiary time.

PRECAMBRIAN METAMORPHIC AND IGNEOUS ROCKS

The Precambrian rocks consist of a complex series of metamorphosed sedimentary and igneous rocks. For description they are divided into three categories: (a) metasedimentary rocks, (b) granitized metasedimentary rocks, and (c) intrusive rocks. The metasedimentary rocks are the oldest of the Precambrian formations. Mappable units are quartzite, sillimanitic biotite-quartz gneiss, biotite-quartz gneiss, amphibolite, and lime silicate gneiss. Some of these rocks were changed to granite gneiss and migmatite, then were intruded by a series of igneous rocks, from oldest to youngest, gneissic granite, quartz diorite and hornblendite, biotite-muscovite granite, Pikes Peak granite, and granite pegmatite.

METASEDIMENTARY ROCKS

Metasedimentary rocks are the oldest rocks in the quadrangle and have been described previously in other areas of the Front Range. Ball (1906, p. 374; Spurr and others, 1908, p. 37) applied the name Idaho Springs formation to a similar series of metamorphic rocks, believed to be of sedimentary origin, in the vicinity of Idaho Springs, Colo. The terms used by Ball (Spurr and others, 1908, p. 37) and the terms for equivalent rocks in the Kassler quadrangle are given below:

Ball (Spurr and others, 1908, p. 37)	*This report*
Lime silicate member	Lime silicate gneiss
Hornblende-diopside gneiss unit	Amphibolite
Biotite schist	Biotite-quartz gneiss
Biotite sillimanite schist	Sillimanitic biotite-quartz gneiss
Quartz-magnetite gneiss	Quartzite

The lithologic names of the metasedimentary rock units of the Kassler quadrangle are the same as many of those used by Harrison and Wells (1956, p. 37; 1959, p. 5).

QUARTZITE

Quartzite crops out as irregularly shaped bodies east and northeast of Thomas Hill, in the south-central part of the quadrangle, and as persistent layers in an area about ½ to 1 mile north of the Indian Creek ranger station, in the southwest quarter of the quadrangle. Most of the quartzite bodies lie in conformable contact with or near lime silicate gneiss or amphibolite.

The quartzite is a medium-grained medium-gray rock that weathers olive gray. It consists mostly of quartz with some biotite, plagioclase, and magnetite and, locally, of minor amounts of hematite, apatite, epidote, diopside, and sericite. Epidote and diopside are common in the quartzite bodies near lime silicate gneiss, such as the outcrop in the NW¼NE¼ sec. 3, T. 8 S., R. 69 W. Magnetite is abundant in the quartzite in and just north of the NW¼NE¼ sec. 6, T. 8 S., R. 68 W., where two prospect pits were dug. Apatite is included in the quartz grains. The following table gives the modes (volume percent) of two samples of the quartzite:

	SC–2	SC–43
Quartz	75	93
Biotite	5	7
Plagioclase	20	----------
Muscovite	Tr.	Tr.
Sericite	Tr.	----------
Magnetite	Tr.	----------
Apatite	----------	Tr.
Hematite	----------	Tr.

SC–2: NW¼NE¼ sec. 3, T. 8 S., R. 69 W.
SC–43: NW¼NE¼ sec. 3, T. 8 S., R. 69 W.

The quartzite is even grained; most grains are 0.2 mm in diameter although a few are as much as 0.33 mm. Most grain boundaries are straight or slightly curved. The magnetite-bearing facies is slightly coarser and contains megascopic magnetite grains. Bedding resulting from the alinement of concentrations of hematite, magnetite, and biotite can be seen in the quartzite.

SILLIMANITIC BIOTITE-QUARTZ GNEISS

The sillimanitic biotite-quartz gneiss is confined to the southern part of the quadrangle and is particularly abundant where the foliation turns from N. 75° W. to N. 20° W. in secs. 34 and 35, T. 7 S., R. 69 W., and in sec. 3, T. 8 S., R. 69 W. (pl. 2). Contacts between the sillimanitic biotite-quartz gneiss and other metasedimentary rocks are conformable.

Sillimanite cannot easily be detected in the field in amounts less than 5 percent; therefore, only those rocks with more than 5 percent sillimanite and with abundant biotite and quartz but little feldspar are included in sillimanitic biotite-quartz gneiss.

The sillimanitic biotite-quartz gneiss is a yellowish-gray well-foliated rock in which plates of biotite and needles of sillimanite are set in a platy matrix of quartz and feldspar. A freshly broken fragment is dark gray and vitreous and appears quartzitic. On weathered surfaces the sillimanite gives a yellowish-gray or light-gray felted appearance like asbestos, or a silken sheen may be reflected from the needlelike crystals. The gneiss is fine grained except where it contains large masses of magnetite. Porphyroblasts of microcline and quartz as large as one-half inch in diameter are common. One-fourth-inch biotite porphyroblasts also occur in the gneiss near the Pikes Peak granite. Biotite flakes and matted layers of sillimanite generally produce the foliation and the lineation. Locally foliation is due to magnetite. In one specimen composed of magnetite and sillimanite, one-fourth mm-thick layers of magnetite are wrapped around the crests and troughs of isoclinal folds only one-half inch high. Magnetite stands out from the weathered surface of the rock and stains it light brown owing to the alteration of the magnetite to limonite.

The sillimanitic biotite-quartz gneiss is composed of quartz, biotite, feldspar, muscovite, magnetite, and sillimanite. The plagioclase content probably averages about 20 percent, but may be as high as 50 percent. As a corollary, the quartz content, which is commonly near 45 percent, may be as low as 30 percent. Microcline ranges from 2 to 12 percent. The following table gives the modes (volume percent) of three samples of sillimanitic biotite-quartz gneiss:

	SC-9	SC-12	SC-45
Microcline	12	2	----------
Quartz	45	40	50
Plagioclase	3	40	30
Biotite	8	2	15
Muscovite	2	1	Tr.
Sillimanite	25	10	5
Magnetite	5	5	Tr.

SC-9: NW¼NE¼ sec. 3, T. 8 S., R. 69 W.
SC-12: NW¼NE¼ sec. 3, T. 8 S., R. 69 W.
SC-45: SE¼NE¼ sec. 34, T. 7 S., R. 69 W.

The sillimanitic biotite-quartz gneiss in thin sections has a texture dominated by prismatic sillimanite crystals whose greatest dimensions are subparallel to the plane of schistosity. The biotite grains also have a preferred orientation and lie along grain boundaries of the feldspar and quartz. Some of the biotite grains have sutured boundaries embayed with elongate grains of feldspar and quartz. Feathery sheaves of needlelike crystals of sillimanite lie along fractured zones that contain ground-up fragments of feldspar and quartz. Most of the feldspar along the fractured zones is altered to sericite. Muscovite lies parallel and intergrown with biotite in the biotite-rich layers. The magnetite grains in the fractured zones are elongate; those in the unfractured part of the rock are rounded, oval, or irregular shaped. Hematite and limonite halos surround some of the magnetite grains.

BIOTITE-QUARTZ GNEISS

Biotite-quartz gneiss underlies a very small part of the map area (pl. 2). Most of the mappable bodies of biotite-quartz gneiss are along the west margin and in the southeast corner of the quadrangle, but thin unmappable bodies are conformably interlensed with granite gneiss throughout the quadrangle. The contacts between the biotite-quartz gneiss and other metasedimentary rock units are conformable. The contacts are marked by slight changes in the amounts of sillimanite, quartz, and microcline. Rocks that are mapped as biotite-quartz gneiss contain abundant biotite and quartz, but sparse feldspar.

The biotite-quartz gneiss is very light gray mottled with black and commonly has a salt-and-pepper appearance; it is medium grained, though some outcrops contain grains of biotite one-fourth inch in diameter. Biotite layers produce the foliation. The gneiss contains about 70 percent quartz, 20 percent biotite, and 10 percent feldspar although composition varies considerably between outcrops. Microcline and oligoclase are the most common feldspars. Muscovite, magnetite, sillimanite, apatite, hornblende, titanite, and garnet are accessory minerals. Some of the muscovite is in parallel growth with biotite. Sericite (mostly altered plagioclase) makes up as much as 10 percent of some weathered rocks. Most of the biotite lies along grain boundaries of quartz and plagioclase. Euhedral apatite is included in larger anhedral grains of quartz. Grain boundaries are straight or slightly wavy; sutured boundaries are uncommon. Most of the magnetite is between other grains; however it is also included in plagioclase and is intergrown with sillimanite.

A garnetiferous variety of the biotite-quartz gneiss crops out in the SE¼NE¼ sec. 34, in the adjacent part of sec. 35, T. 7 S., R. 69 W., and in the NE¼NW¼ sec. 28, T. 7 S., R. 69 W. The garnetiferous variety is medium gray to grayish red, depending on the amount of garnet. Many of the biotite flakes exceed 4 mm in diameter. Garnet makes up as much as 20 percent of the gneiss and is in well-formed crystals as large as 3 mm in diameter. The garnet apparently is almandine, the same variety found in the Freeland-Lamartine district by Harrison and Wells (1956, p. 40).

AMPHIBOLITE

The amphibolite, which Ball (Spurr and others, 1908, p. 37) included in the Precambrian Idaho Springs formation, crops out throughout the western part of the quadrangle. In the southwestern part of the quadrangle the amphibolite is interlayered and gradational with the granite gniess and migmatite, quartzite, and lime silicate gneiss, and may constitute as much as 10 percent of the rock. Few of the layers can be followed for more than 100 feet and their contacts are usually covered. The float indicates that most of the small ridges in the southwest corner of the area are underlain by layers of amphibolite. In the rest of the western part of the quadrangle the amphibolite occurs in pods from a few inches to tens of feet in length associated with smaller pods of lime silicate gneiss, both enclosed in the granite gneiss and migmatite. Typically, several pods of amphibolite are alined parallel to the foliation of the granite gneiss and the foliation of the pods is parallel to that of the granite gneiss. A few bodies of amphibolite crosscut the foliation of the enclosing rock, but their foliation is parallel to that of the enclosing rock.

The amphibolite is typically a dark-gray or dark greenish-gray fine- to medium-grained, even-grained gneiss consisting of hornblende, plagioclase, quartz, and locally, biotite. The common accessory minerals are apatite, magnetite, hematite, titanite, and pyrite. The following table gives the modes (volume percent) of 13 samples of the even-grained typical amphibolite:

	SC-6	SC-14	SC-15	SC-16	SC-17	SC-18	SC-21	SC-22	SC-25	SC-32	SC-33	SC-40	S-4
Hornblende	70	60	40	60	50	50	50	45	20	30	35	50	45
Plagioclase	11	40	60	30	30	40	40	50	40	35	20	30	20
Quartz	15	Tr.	------	10	20	10	10	5	8	5	20	15	35
Biotite	2	------	------	------	------	------	------	Tr.	20	30	25	40	------
Apatite	------	Tr.	------	Tr.	------	Tr.	Tr.	Tr.	1	Tr.	Tr.	5	Tr.
Magnetite	2	------	------	------	Tr.	Tr.	------	------	------	------	------	Tr.	------
Hematite	------	------	------	------	------	Tr.	------	Tr.	------	Tr.	------	Tr.	------
Titanite	------	------	------	------	------	Tr.	------	------	1	Tr.	------	Tr.	Tr.
Pyrite	------	------	------	------	------	Tr.	------	------	------	------	------	Tr.	------
Epidote	------	------	------	------	------	------	------	------	------	------	------	Tr.	------

SC-6: Along South Platte River near Strontia Springs one-half mile west of Kassler quadrangle.
SC-14: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-15: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-16: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-17: NW¼SW¼ sec. 3, T. 8 S., R. 69 W.
SC-18: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-21: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-22: SE¼ sec. 34, T. 7 S., R. 69 W.
SC-25: SW¼NW¼ sec. 5, T. 8 S., R. 68 W.
SC-32: SW¼SE¼ sec. 3, T. 7 S., R. 69 W.
SC-33: SW¼SE¼ sec. 3, T. 7 S., R. 69 W.
SC-40: Russell Ridge west of Bennett Mountain, Platte Canyon quadrangle.
S-4: NW¼SW¼ sec. 5, T. 8 S., R. 68 W.

In the amphibolite, a rock that has less than the average amount of hornblende has more than the average amount of biotite and a rock that is below average in plagioclase is rich in quartz. Alternating layers of plagioclase and hornblende, not always visible in hand specimen, give a rock its foliation, except for rocks having a high percentage of biotite; in these rocks the orientation of the biotite gives the rock its foliation. Hornblende in the amphibolite is generally in simple prisms but may have sutured borders embayed with plagioclase and quartz. Inclusions in the hornblende are quartz and opaque iron minerals. Euhedral grains of plagioclase are not common in the typical amphibolite, the form of the plagioclase being dependent upon that of the surrounding grains of hornblende and quartz. An average of 17 percent of the plagioclase has been altered to sericite. The plagioclase and quartz have been strained. Titanite was probably altered from titaniferous magnetite; two thin sections showed grains of titanite grouped around hematite and limonite. Vugs lined with crystals of hornblende, epidote, and quartz are common in the amphibolite, especially near beds of lime silicate gneiss. One vug in an amphibolite bed in sec. 16, T. 7 S., R. 69 W., along the South Platte River contains poorly formed crystals of hornblende, magnetite, titanite, scapolite, and albite.

Varieties of the amphibolite include a strongly foliated type that contains more than 70 percent hornblende in tabular crystals, a porphyroblastic type in which amphibolite porphyroblasts constitute about 15 to 20 percent of the rock, and an augen type in which segregations of hornblende crystals amount to about 50 percent of the rock.

The strongly foliated variety occurs in small outcrops throughout the area and is gradational with the typical amphibolite; it differs principally from the typical amphibolite in having, on the average, a higher percentage of hornblende, which may in part explain its being more strongly foliated. A typical sample of this variety (sample S-39 from the NE¼NW¼ sec. 4, T. 8 S., R. 69 W.) contained (volume percent) 70 percent hornblende, 11 percent plagioclase, 11 percent quartz, 3 percent magnetite, and a trace of apatite. As much as 20 percent of the plagioclase is altered to sericite. The hornblende and feldspar crystals are oriented subparallel to the plane of schistosity and give the rock a nematoblastic texture. The foliation is the result of alinement of the hornblende crystals and, in some specimens, of the biotite crystals.

The porphyroblastic variety of amphibolite crops out in sec. 3, T. 8 S., R. 69 W., and sec. 34, T. 7 S., R. 69 W.; it differs from the typical amphibolite principally in containing on the average less hornblende, 10 to 20 percent, and in having the hornblende concentrated in the porphyroblasts. This concentration gives the rock a gray color with black spots. Field data were insufficient to determine whether the porphyroblastic variety is a facies of the typical amphibolite or a distinct variety. The following table gives the modes (volume percent) of two samples of the porphyroblastic amphibolite:

	SC-4	S-26
Hornblende	15	20
Plagioclase	35	80
Quartz	20	Tr.
Biotite	30	Tr.
Apatite	Tr.	----------
Magnetite	Tr.	----------
Pyrite	----------	Tr.
Diopside or hedenbergite	----------	Tr.

SC-4: NE¼NW¼ sec. 3, T. 8 S., R. 69 W.
S-26: NE¼SW¼ sec. 3, T. 8 S., R. 69 W.

The texture is porphyroblastic; the crystals of hornblende in the porphyroblasts have a preferred orientation and the crystals of the groundmass are oriented at random. The hornblende crystals are as much as 3 mm long and have a sieve structure and inclusions of quartz. As much as 10 percent of the plagioclase is altered to sericite. A granulated zone 1 mm wide, which contained quartz and sericite as the predominant minerals, was noted in one slide.

The augen variety of amphibolite occurs where the typical amphibolite is adjacent to lime silicate gneiss, and probably represents a transitional facies between the typical amphibolite and the lime silicate gneiss. The augen variety differs from the typical amphibolite principally because the hornblende is concentrated in knots. A typical sample (sample S-35 from the NW¼ sec. 3, T. 8 S., R. 69 W.) of the augen variety had a mineral composition (volume percent) of 50 percent hornblende, 25 percent plagioclase, 25 percent quartz, and a trace of titanite. The texture is porphyroblastic; hornblende in the porphyroblasts and the groundmass shows a preferred alinement. Each porphyroblast, or augen, is about ⅜ inch long, ¼ inch wide, ⅛ to 3/16 inch thick.

LIME SILICATE GNEISS

Lime silicate gneiss in this report includes only two of the rocks that Ball (Spurr and others, 1908, p. 41) included in his lime silicate rocks. These are the quartz-epidote-garnet rock and the calcite-lime silicate rock. Lime silicate gneiss crops out mostly in the southern part of the quadrangle where beds as much as 8 feet thick and several hundred feet long were mapped. Such large beds are uncommon, but beds that cover only a few square yards are common. Most of these smaller beds are discontinuous unmappable irregular-shaped pods that are abundant in the granite gneiss and migmatite in the southwest corner of the quadrangle.

The lime silicate gneiss contains many minerals, commonly as well-formed crystals in vugs. The mineralogy varies from locality to locality. Fifteen slightly different suites of minerals were found. The more simple suites such as garnet-epidote-quartz are common, but the complex suites are generally found at only single outcrops. These suites (most of which were in beds too small to map on plate 2) and the sample locations are as follows:

1. Garnet skarn with limonite. SW¼SW¼ sec. 4, T. 8 S., R. 69 W.
2. Andradite (determined by X-ray)-epidote-quartz. Many localities along road north of Indian Creek ranger station.
3. Garnet-epidote-hornblende-biotite. SE¼NW¼ sec. 23, T. 7 S., R. 69 W.
4. Meionite (determined by X-ray)-andradite-epidote-allanite-titanite-apatite-calcite, with later azurite, malachite, chrysocolla, chalcopyrite, pyrite, limonite after pyrite. NW¼NE¼ sec. 16, T. 7 S., R. 69 W.
5. Meionite (determined by X-ray)-garnet-epidote-allanite-titanate-apatite-calcite-diopside-hornblende-gahnite. NW¼NW¼ sec. 35, T. 7 S., R. 69 W.
6. Scapolite-garnet-diopside-quartz and scapolite altered to blue talc. South Platte Canyon near Strontia Springs west of Kassler quadrangle.
7. Epidote-actinolite-hornblende-serpentine-quartz. SW¼NW¼ sec. 3, T. 8 S., R. 69 W.
8. Diopside-tremolite-quartz-limonite. NW¼SW¼ sec. 15, T. 7 S., R. 69 W.
9. Vesuvianite-hornblende-serpentine-orthoclase-quartz. In prospect pit in NW¼SW¼ sec. 3, T. 8 S., R. 69 W.
10. Epidote-scapolite-garnet-magnetite-quartz-calcite and scapolite altered to serpentine. SE¼SW¼ sec. 21, T. 7 S., R. 69 W.
11. Epidote-diopside-garnet-scapolite-quartz. South Platte Canyon near Strontia Springs west of Kassler quadrangle.
12. Tremolite-muscovite-serpentine-talc-red mineral (kaolinite?) with later malachite. NW¼NE¼ sec. 21, T. 7 S., R. 69 W.
13. Quartz-pyrite-tremolite, and limonite pseudomorphous after pyrite crystals. South Platte Canyon near Strontia Springs west of Kassler quadrangle.
14. Hornblende-orthoclase-quartz-chlorite and hornblende altered to diopside, with later chrysocolla, turquoise, smithsonite (botryoidal light green encrustation), malachite, azurite, tenorite (black pitchy), conichalcite (radiating clusters of bright green crystals), and limonite. SW¼NE¼NE¼ sec. 16, T. 7 S., R. 69 W.
15. Hornblende-scapolite-titanite-albite-magnetite-pyrite. South Platte Canyon near Strontia Springs west of Kassler quadrangle.

Some of the minerals of the lime silicate gneiss are the same as the minerals of the surrounding rocks, and the rocks that cut the gneiss commonly contain minerals derived from it. Lime silicate gneiss interbedded with amphibolite contains abundant hornblende; lime silicate gneiss cut by granite gneiss contains abundant potassium feldspar. In pegmatite dikes that cut lime silicate gneiss, hornblende commonly takes the place of biotite, and hornblende crystals locally line vugs in the pegmatites.

Most of the minerals are in well-formed crystals or in large crystalline masses. A description of them follows:

Pyrite: as well-formed crystals one-fourth inch in diameter; now partly altered to limonite.

Quartz: as small crystals in vugs and intergrown with feldspar.

Gahnite (zinc spinel): rare, as well-formed octahedrons 1 mm. in diameter; dark bluish-green, translucent: vitreous faces.

Calcite: as groundmass around crystals of garnet, diopside, scapolite and epidote. Where the calcite is dissolved, it leaves vugs lined with partly dissolved crystals of the other minerals.

Diopside: in two forms, as crystals or partly dissolved blebs one-fourth inch in length, light green to dark dusky green. Occurs as grayish-green to dusky-green crystalline masses, except in the NW¼SW¼ sec. 15, T. 7 S., R. 69 W., where diopside is intergrown with tremolite as large pale-olive cleavable masses.

Tremolite: as grayish-green bladed aggregates partly altered to red serpentine, and as granular masses of small pale-green crystals.

Actinolite: as dark greenish-gray bladed aggregates.

Hornblende: as greenish-black segregations at many localities; locally in sheaflike black crystals 2 inches in length.

Garnet: as moderate-brown to grayish-brown well-formed dodecahedral crystals of andradite intergrown with scapolite and diopside; slightly dissolved. Also as small masses of black schorlomite (determined by X-ray) with crystal faces; schorlomite shows peculiar reticulated etch figures. Probably all gradations between nontitaniferous andradite and titaniferous schorlomite are present.

Scapolite: as large columnar masses with prism faces and as well-formed prismatic crystals, white or yellowish-gray with pearly luster; intergrown with garnet and diopside crystals; scapolite commonly coated by epidote, and locally altered to serpentine and talc. Determined by X-ray diffraction to be the meionite end member. (R. S. Jones, U.S. Geological Survey, analyst.)

Vesuvianite: definitely identified only at one prospect pit in the NW¼SW¼ sec. 3, T. 8 S., R. 69 W., although not uncommon in lime silicate rocks outside the area; occurs as one-fourth inch olive-gray prismatic crystals with inner zones consisting of yellowish-gray layers alternating with olive-gray layers that parallel the crystal faces.

Epidote: as coating on scapolite and garnet, or as large crystalline masses associated with garnet and surrounded by quartz; found rarely as small perfectly formed transparent grayish olive-green to greenish-black crystals with as many as 10 forms developed on one crystal.

Allanite: as thin flat plates one-half inch long, partly altered to a dark reddish-brown metamict mineral; associated with titanite.

Titanite: as wedge-shaped dusky-brown crystals; some crystals surrounded by hornblende and epidote; some partly altered to leucoxene.

Apatite: as perfectly formed microscopic light-blue prismatic crystals surrounded by scapolite, calcite, and quartz.

Biotite: as yellowish-brown plates with hornblende.

Muscovite: as clear plates associated with tremolite.

The order of crystallization of these minerals, as determined from suite 5, on the basis that the early crystals are more nearly euhedral than later crystals, apparently was:

1. Allanite
2. Titanite
3. Diopside (as crystals)
4. Garnet (andradite-schorlomite)
5. Gahnite
6. Apatite
7. Scapolite (meionite)
8. Epidote
9. Hornblende-tremolite-actinolite
10. Diopside (massive crystalline)
11. Calcite
12. Quartz, feldspar

This sequence is almost identical with the crystalloblastic series of Becke (Turner and Verhoogen, 1951, p. 510), which in effect implies that allanite has the greatest force of crystallization of any of the above minerals and develops euhedral crystals regardless of its time of crystallization. Similarly, any other mineral in the sequence could have formed before quartz and feldspar.

GRANITIZED METASEDIMENTARY ROCKS

Granitized metasedimentary rocks include the granite gneiss and migmatite, the sillimanite granite gneiss, and the hornblende granite gneiss.

GRANITE GNEISS AND MIGMATITE

Granite gneiss and migmatite, the most common rock unit in the quadrangle, is composed of two rock types that are interlayered and gradational into each other. One type is migmatite composed of metasedimentary rocks, commonly biotite-quartz-plagioclase gneiss in layers a few inches to several feet thick with conformable ½- to 12-inch-thick layers of leucocratic granite (fig. 29). The other type is biotite granite gneiss that is strongly foliated but indistinctly layered and does not have layers of recognizable metasedimentary rocks. Biotite granite gneiss predominates in the Kassler quadrangle.

The granite gneiss and migmatite unit apparently is equivalent to the pegmatite, the granite-pegmatite and associated granites, and possibly the gneissoid granite of Ball (Spurr, and other, 1908, p. 49–51, 60–67), and to the migmatite and the granite gneiss and pegmatite of Harrison and Wells (1956, p. 49–53). In this report the term "granite gneiss" is used in a lithologic sense and is not intended to mean that the rock is of igneous origin.

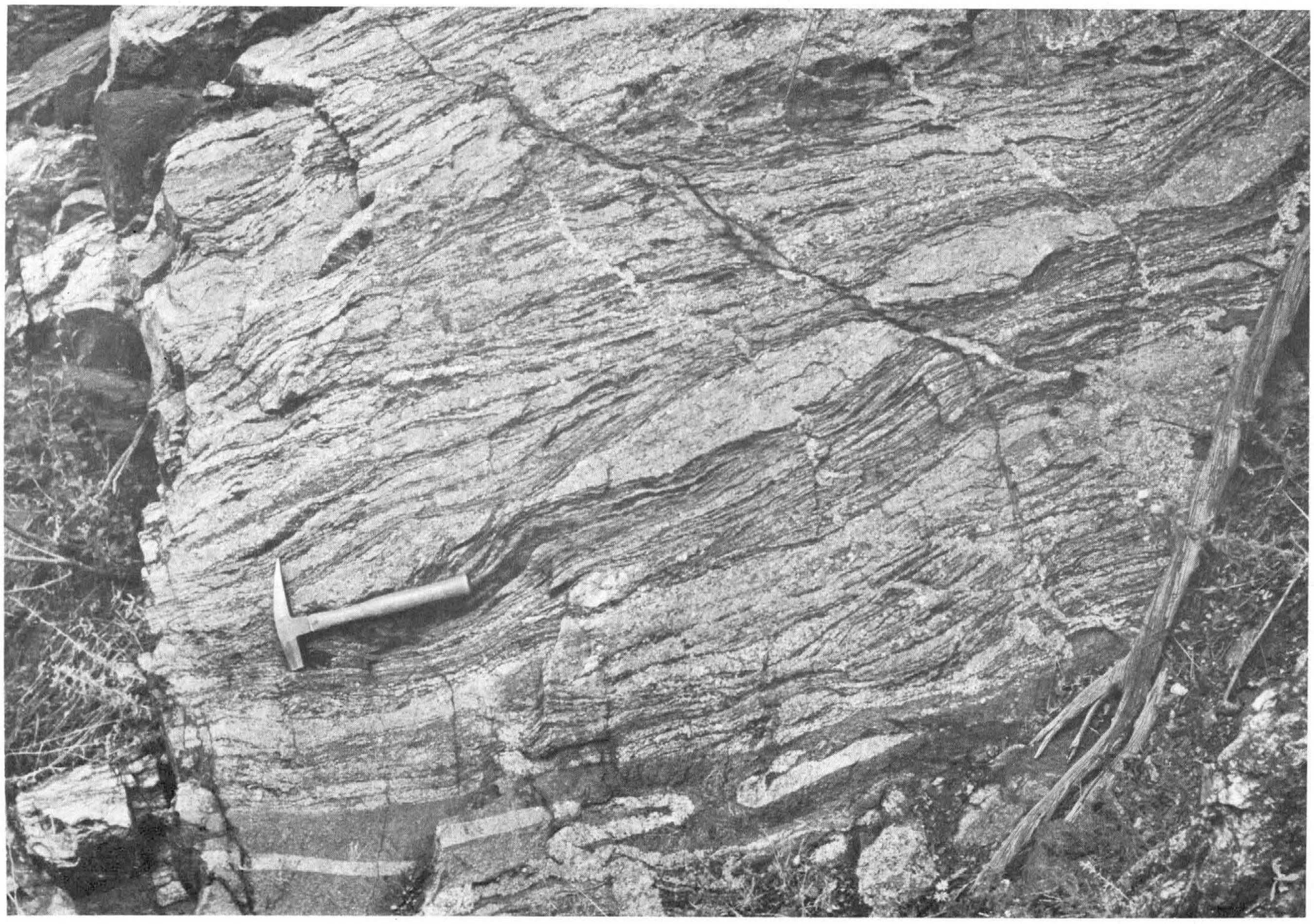

FIGURE 29.—Granite gneiss and migmatite along the South Platte River.

The granite gneiss and migmatite is the most abundant unit of the crystalline rocks; its relation to other rocks is well shown throughout the mountainous part of the quadrangle. It is well exposed in secs. 16, 21, and 28, T. 7 S., R. 69 W. The contacts of the granite gneiss and migmatite with the hornblende granite gneiss, sillimanite granite gneiss, quartz diorite and hornblendite, and the biotite-quartz gneiss are gradational. Contacts with the amphibolite, quartzite, and lime silicate gneiss, are sharp.

Composition of the granite gneiss and migmatite is variable. It contains rocks that can be classified as alaskite, granodiorite, monzonite, quartz diorite, and quartz monzonite. Most of the rock is granitic in composition.

The granite gneiss and migmatite is a pale-red, very pale orange, or grayish-orange medium-grained well-foliated rock composed of quartz, microcline, plagioclase, and biotite; part of the biotite is altered to chlorite. The accessory minerals are magnetite, titanite, apatite, limonite, muscovite, and the chlorite altered from biotite.

The following table gives the modes (volume percent) of four samples of the granite gneiss and migmatite:

	SC-8	SC-30	S-51	S-59
Quartz	55	32	41	40
Microcline	33	32	17	
Biotite	5	3	9	20
Plagioclase	7	31	31	40
Magnetite		Tr.	1	Tr.
Titanite		Tr.	1	
Apatite	Tr.	Tr.		Tr.
Chlorite	Tr.	2		
Muscovite				Tr.

SC-8: Granite gneiss from sec. 28, T. 7 S., R. 69 W.
SC-30: Thinly banded quartz monzonite facies from SE¼NW¼ sec. 5, T. 8 S., R. 68 W.
S-51: Quartz monzonite facies from SW¼SW¼ sec. 4, T. 8 S., R. 69 W.
S-59: Quartz diorite facies from SE¼SW¼ sec. 33, T. 7 S., R. 69 W.

The texture is shown by tabular crystals of quartz, feldspar, and mica oriented subparallel to the schistosity. Most grains are anhedral; feldspar crystals grew against biotite crystals; quartz and muscovite are intergrown with both feldspar and biotite; vermicular quartz is embayed in microcline. About one-third of the biotite is altered to chlorite. Most of the plagioclase is oligoclase and is twinned according to the albite law; it and part of the microcline are altered to sericite. The quartz is strained and fractured.

Structure of the gneiss is the result of (a) foliation, (b) dark beds that are folded in, or (c) intruded granite pegmatite. The foliation is the result of biotite alinement. Where stringers and pods of biotite are abundant, the foliation is conspicuous (fig. 29). The biotite layers are crenulated, and the biotite flakes are stretched along the foliation plane and perpendicular to the axes of the crenulations; they produce two lineations, one parallel to the folds and the other perpendicular to the folds. Minor folds can be seen and measured best where dark beds are folded into the gneiss. Ptygmatic folds of granite pegmatite that cross the foliation are not as common as elsewhere in the Front Range, and generally occur only in the more thickly foliated gneiss.

The granite gneiss and migmatite unit contains microfractures that have been healed with later minerals. Fractures are filled by epidote, titanite altered to leucoxene, magnetite, and clay minerals. The fractures are less than 1 mm thick and the offset is visible only in thin section. As many as five parallel fractures per inch may be observed either parallel or perpendicular to the foliation.

A more thinly banded granite gneiss crops out in the southeast corner of the quadrangle along Jarre and Indian Creeks and extends about as far west as the Pike National Forest boundary (pl. 2). The biotite in this granite gneiss is streaked out in separate layers to form the foliation. The gneiss is pale red, medium grained, and evenly banded. In a road cut in the NW¼SW¼ sec. 5, T. 8 S., R. 68 W. (pl. 2), it is isoclinally folded. A mode of this rock (sample SC–30) shows it to be quartz monzonite in composition.

SILLIMANITE GRANITE GNEISS

Sillimanite granite gneiss, a well-foliated fine-grained grayish-brown rock, crops out principally at the crests of folds in the south end of the area (pl. 2). It generally is surrounded by and gradational with sillimanitic biotite-quartz gneiss and granite gneiss and migmatite. The sillimanite granite gneiss is very resistant to weathering and forms high ridges above the surrounding rocks.

Sillimanite can be easily detected in granite gneiss if it makes up 5 percent of the total composition; therefore, those rocks that are of granitic composition and contain at least 5 percent sillimanite are mapped as sillimanite granite gneiss.

The gneiss is a dark-gray well-layered fine-grained rock composed of interlocking tabular and acicular crystals. Only the sillimanite crystals are euhedral. The following table gives the modes (volume percent) of two samples of the sillimanite granite gneiss:

	SC–11	SC–41
Quartz	10	53
Microcline	66	38
Biotite	2	2
Sillimanite	10	5
Muscovite	2	2
Magnetite	10	Tr.
Apatite	----------	Tr.

SC–11 and SC–41: NW¼NE¼ sec. 3, T. 8 S., R. 69 W.

The major minerals are microcline, quartz, sillimanite, and magnetite; the minor minerals are biotite, apatite, and muscovite. The sillimanite, magnetite, and mica are restricted to thin, less granitic layers that parallel the foliation. At axes of folds, sillimanite crystals are small and densely packed; on the limbs of folds the crystals are larger and more loosely packed. Muscovite generally is the matrix for the sillimanite crystals.

The gneiss has a simple planar structure. Sillimanite segregated into layers produces both the foliation and lineation. Locally the gneiss is intricately folded and the folds are broken by fracture cleavages.

HORNBLENDE GRANITE GNEISS

The hornblende granite gneiss crops out in the southern part of the quadrangle in a belt that parallels the border of the Pikes Peak granite (pl. 2). The contact of the hornblende granite gneiss is sharp with the sillimanite granite gneiss, but gradational with the granite gneiss and migmatite and the amphibolite. Quartzite bodies with epidote and hornblende are common along the borders of the hornblende granite gneiss and the gneiss can be traced into beds of amphibolite.

The hornblende granite gneiss is a grayish orange-pink and dark greenish-gray equigranular fine-grained well-foliated gneiss that contains quartz, microcline, biotite, and hornblende. Epidote and hornblende masses elongated parallel to the foliation are abundant. Some of the hornblende has partly replaced diopside. On weathering, the diopside dissolves readily and leaves vugs as large as 2 inches long and 1 inch wide.

In thin section the rock is xenomorphic granular in texture. The major constituents are quartz and microcline; the minor constituents are hornblende, biotite, magnetite, muscovite, apatite, epidote, and hematite. Most of the grains are rounded and anhedral; hornblende is in part lathlike and produces a lineation. The following table gives the modes (volume percent) of three samples of the hornblende granite gneiss:

	SC-1	SC-28	S-2
Quartz	50	60	50
Microcline	35	35	40
Biotite	10	Tr.	5
Hornblende	5	5	5
Magnetite	Tr.	Tr.	Tr.
Muscovite	Tr.	----------	----------
Apatite	----------	Tr.	----------
Epidote	Tr.	Tr.	----------
Hematite	----------	Tr.	----------

SC-1: SE¼NW¼ sec. 3, T. 8 S., R. 69 W.
SC-28: SE¼ sec. 34, T. 7 S., R. 69 W.
S-2: NE¼ sec. 1, T. 8 S., R. 69 W.

INTRUSIVE ROCKS

The intrusive rocks include gneissic granite, quartz diorite and hornblendite, biotite-muscovite granite, Pikes Peak granite, and granite pegmatite.

GNEISSIC GRANITE

A few tabular bodies of a rock that is predominantly gneissic granite crop out in the west-central part of the quadrangle (pl. 2). The granite is similar to the quartz monzonite of Ball (Spurr and others, 1908, p. 51), the Boulder Creek granite of Lovering and Goddard (1950, p. 25), and the granodiorite of Harrison and Wells (1956, p. 53–54).

The rock is generally a gray, pink or grayish-brown medium-grained gneiss that contains quartz, plagioclase, microcline, and biotite. The foliation is well formed except in the center of large bodies where it is indistinct. In thin section the rock is xenomorphic granular in texture. Porphyroblastic bodies near the border of the gneissic granite are cut by aplitic dikes of the biotite-muscovite granite. The porphyroblasts are microcline; many of them show carlsbad twinning. The following table gives the modes (volume percent) of two samples of gneissic granite:

	S-121	S-138
Quartz	35	31
Plagioclase	5	18
Microcline	55	45
Biotite	5	6
Titanite	----------	Tr.
Muscovite	----------	Tr.

S-121: SW¼SE¼ sec. 33, T. 6 S., R. 69 W.
S-138: Western border of the biotite-muscovite granite in the SW¼ sec. 23, T. 7 S., R. 69 W.

QUARTZ DIORITE AND HORNBLENDITE

The quartz diorite and hornblendite unit crops out in several small areas in the west-central part of the quadrangle and along the South Platte River in the northwest part of the quadrangle (pl. 2). The unit is much like the quartz-bearing diorite and associated hornblendite described by Ball (Spurr, and others, 1908, p. 54–57).

The quartz diorite is locally concordantly interlayered with the granite gneiss and migmatite and the metasedimentary rocks and is cut by hornblendite and granite pegmatite. Hornblendite dikes as much as 2 feet thick cut the quartz diorite at all angles. Ptygmatic veins of granite pegmatite cut the quartz diorite and hornblendite. The pegmatite is very coarse grained and contains 1-inch-long biotite crystals, 2-inch-long feldspar crystals, and bulbous quartz masses as large as 1½ feet in diameter.

The quartz diorite and hornblendite weathers to more rounded outcrops than the granite gneiss and migmatite, and on weathered surfaces forms pits about one-half inch in diameter.

The quartz diorite occurs in two facies, a massive facies and a well-foliated facies. The massive quartz diorite is a medium-gray fine-grained xenomorphic granular rock consisting principally of complexly twinned andesine, hornblende, orthoclase, quartz, and biotite. The accessory minerals are apatite, titanite, magnetite, and limonite.

The well-foliated quartz diorite is gneissic, owing to segregation of the minerals into mafic-rich and quartz-feldspar-rich layers. It is a black and white coarse-grained rock consisting of andesine, orthoclase, biotite, hornblende, and quartz and traces of apatite, titanite, and muscovite.

Hornblendite also has a massive and a well-foliated facies. The massive hornblendite is a greenish-black medium-grained hypidiomorphic granular rock composed of hornblende, andesine, and quartz with minor amounts of biotite, apatite, magnetite, and hematite.

The well-foliated hornblendite is gneissic, owing to discontinuous layers of plagioclase. It is a black fine-grained rock composed of hornblende and andesine with traces of biotite, quartz, magnetite, apatite, and hematite. The following table shows the modes (volume percent) of seven samples of the quartz diorite and hornblendite:

	S-60	S-71	S-40	S-122	S-7	S-52	S-32
Quartz	5	12	3	25	10	30	1
Plagioclase	50	47	11	45	25	30	22
Orthoclase	13	9	16	-----	-----	-----	-----
Biotite	7	16	40	15	Tr.	Tr.	2
Hornblende	25	11	30	15	65	40	72
Titanite	Tr.	-----	Tr.	-----	-----	-----	-----
Apatite	Tr.	-----	Tr.	Tr.	Tr.	Tr.	Tr.
Muscovite	-----	-----	-----	Tr.	-----	-----	-----
Magnetite	-----	5	-----	-----	-----	Tr.	3
Hematite	-----	-----	-----	-----	-----	Tr.	Tr.
Limonite	-----	Tr.	-----	-----	-----	-----	-----

S-60: Hornblende-quartz diorite from SE¼SE¼ sec. 33, T. 7 S., R. 69 W.
S-71: Fine-grained quartz diorite with micrographic texture from SW¼SW¼ sec. 26, T. 7 S., R. 69 W.
S-40: Well-foliated biotite-quartz monzonite from SE¼SW¼ sec. 26, T. 7 S., R. 69 W.
S-122: Well-foliated hornblende-biotite-quartz diorite from SW¼SW¼ sec. 16, T. 7 S., R. 69 W.
S-7: Hornblendite from SE¼NW¼ sec. 5, T. 8 S., R. 68 W. (not mapped).
S-52: Hornblendite(?) from NW¼SW¼SE¼ sec. 4, T. 8 S., R. 69 W.
S-32: Well-foliated hornblendite from NE¼SE¼ sec. 4, T. 8 S., R. 69 W.

BIOTITE-MUSCOVITE GRANITE

The biotite-muscovite granite occurs in a few large bodies and many small bodies throughout the quadrangle. Most of the bodies are concordant. The biotite-muscovite granite is nearly undeformed and is similar in fabric and mineralogy to the Silver Plume granite (Ball, 1906) from the type area at Silver Plume, Colo.

The granite is well exposed in large bodies on and around Carpenter Peak (pl. 2) and in small bodies scattered through the area. It crops out as rounded knobs as large as 12 feet in diameter that rise above the surrounding terrain and project from a mantle of loose weathered granite. Crystals of feldspar project from the surface of the rugged knobs.

The contacts with the country rock are generally sharp, but locally they are transitional zones several tens of feet wide. In the NE¼SW¼ sec. 23, T. 7 S., R. 69 W. (pl. 2), the biotite-muscovite granite is massive but grades outward toward the border through two gneissic zones. The inner zone contains blebs of typical granite; the outer zone is cut by pegmatites and contains randomly oriented xenoliths of granite gneiss from the walls.

The flow lines in the biotite-muscovite granite are generally concordant with the foliation of the country rock, but around the border the flow lines in small granite apophyses are locally discordant. The relation of these small discordant granite apophyses to the gneissic granite country rock is well shown in the SW¼ sec. 23, T. 7 S., R. 69 W. where the granite has a thin reaction rim of aplite and it tails out in small pegmatite dikes that cut the gneissic granite.

The granite is pale red and moderate orange pink, and weathers pale reddish brown, moderate orange pink, and pale yellowish brown. It consists principally of porphyritic fine-grained granite. The composition varies from granite to quartz monzonite to granodiorite to quartz diorite.

The granite contains alined large tabular euhedral crystals of microcline that form a flow structure. Most of the tabular crystals are one-half inch or less in length but are as much as 3 inches at an outcrop in the W½ sec. 34, T. 7 S., R. 69 W. (sample S-54).

The granite in thin section is seriate porphyritic. Needlelike crystals of rutile or some other opaque mineral penetrate the microcline, quartz, and plagioclase. Muscovite and epidote fill cataclastically fractured areas in the rock. The following table gives the modes (volume percent) of 10 samples of the biotite-muscovite granite:

	SC-27	SC-35	SC-36	SC-38	S-1	S-3	S-43	S-47	S-54	S-76
Quartz	24	18	35	22	40	45	30	28	30	40
Microcline	60	48	45	46	60	45	30	------	21	4
Orthoclase	15	------	------	------	------	------	------	6	6	9
Plagioclase	------	23	16	20	------	10	30	46	31	45
Biotite	1	6	Tr.	6	Tr.	Tr.	4	13	12	Tr.
Magnetite	------	1	Tr.	2	------	Tr.	Tr.	5	Tr.	2
Apatite	Tr.	1	Tr.	Tr.	------	------	Tr.	------	Tr.	------
Muscovite	Tr.	3	3	4	------	------	5	2	------	------
Epidote	------	------	1	------	------	------	------	------	------	------
Titanite	Tr.	------	Tr.	Tr.	------	Tr.	------	------	------	------
Chlorite	------	------	Tr.	------	------	Tr.	------	------	Tr.	------
Limonite	------	------	------	------	------	------	------	Tr.	------	------
Hornblende	------	------	------	------	------	------	1	------	------	------

SC-27: Granite from SW¼ sec. 14, T. 7 S., R. 69 W.
SC-35: Granite from NW¼NW¼ sec. 23, T. 7 S., R. 69 W.
SC-36: Cataclastically deformed granite from NW¼NW¼ sec. 23, T. 7 S., R. 69 W.
SC-38: Granite from NW¼NW¼ sec. 23, T. 7 S., R. 69 W.
S-1: Granite from SW¼NW¼ sec. 1, T. 8 S., R. 69 W.
S-3: Granite from SE¼ sec. 6, T. 8 S., R. 68 W.
S-43: Quartz monzonite from NW¼NE¼ sec. 34, T. 7 S., R. 69 W.
S-47: Quartz diorite from NE¼NE¼ sec. 34, T. 7 S., R. 69 W.
S-54: Quartz monzonite from W½ sec. 34, T. 7 S., R. 69 W.
S-76: Granodiorite from NW¼NW¼ sec. 22, T. 7 S., R. 69 W.

Some outcrops of the granite are alaskitic, as shown by the modes. Alaskitic granite is more abundant in the adjoining Platte Canyon quadrangle where it was called gneissic fine-grained granite (Peterson and Scott, 1960). The foliation in the granite is caused by the orientation of biotite plates.

Pegmatites and epidote veins are common in the alaskitic granite. Small pegmatite clots that are lacking in mica and apparently not connected with discrete pegmatite dikes are scattered through the granite.

Epidote veins and masses 6 inches across are abundant in the granite, especially in secs. 14 and 15, T. 7 S., R. 69 W. (pl. 2).

Origin.—Harrison and Wells (1956, p. 56) considered the biotite-muscovite granite to be of magmatic origin because the internal structure, which they interpreted as flow structure, is parallel to the walls of crosscutting bodies and because of the small amount of deformation. The border relation, as noted in the Kassler quadrangle, also seems characteristic of magmatic rocks. The granite may have crystallized from intrusive magma, and the transition zone around it probably formed by reactions between the magma and its walls.

The biotite-muscovite granite and the Pikes Peak granite are not in contact in the Kassler quadrangle. Hutchinson (1959, p. 1622) determined by the argon-potassium method that the ages of the Pikes Peak granite and the Doublehead pluton (a correlative of the biotite-muscovite granite) are 1,050 and 1,240 million years respectively.

PIKES PEAK GRANITE

The northeastern border of the Pikes Peak granite batholith curves across the southern part of the quadrangle. The granite, which was named by Cross (1894a, p. 1), is massive and coarse grained and consists principally of microperthite, quartz, and biotite. Figure 30 shows the typical appearance of the granite in nearly fresh outcrop. The rounded cubical shape of the outcrops is the result of weathering along joints. Segregations of biotite and hornblende weather out as knobs on the surfaces of the outcrops.

The granite, at its contact with the metamorphic rocks, may be divided into five zones. Where the foliation of the country rock is parallel to the border of the granite, the individual zones are thin, but where the foliation is normal to the border of the granite, the metamorphic layers apparently provided easier access and the zones are wide. The five zones are, from the typical granite outward, (1) a miarolitic pegmatite zone in the typical granite, (2) a metamorphic gneiss zone, (3) a porphyritic granite and xenolith zone, (4) a miarolitic pegmatite zone in the metamorphic rocks, and (5) typical metamorphic rocks.

In zone 1, small pegmatite lenses with miarolitic cavities are abundant only a few feet inside the border of the Pikes Peak granite. In zone 2 a 100-foot wide belt of foliated metamorphic rock, generally sillimanitic biotite-quartz gneiss or locally lime silicate gneiss or quartzite, concordantly follows the border of the granite. The granite between the pegmatites of zone 1 and the metamorphic rock of zone 2 is highly radioactive because of a greater concentration of allanite and cyrtolite; it also contains some xenoliths of metamorphic rocks. Zone 3 contains porphyritic Pikes Peak granite of monzonitic or dioritic composition. Xenoliths, which make up about one-third of this zone, are extremely migmatized and disoriented.

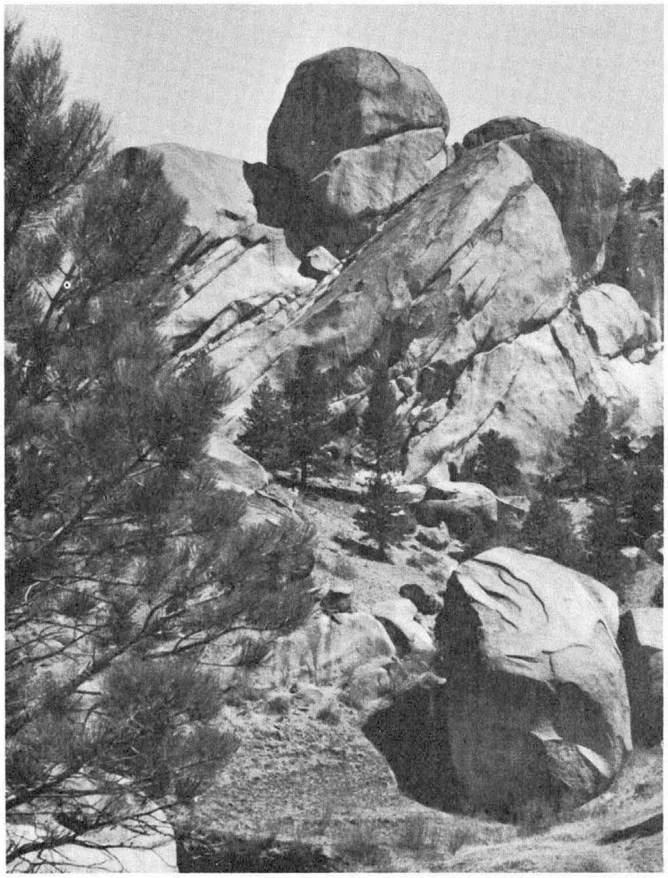

FIGURE 30.—Pikes Peak granite in nearly fresh outcrop at the Noddle Heads 3 miles southwest of the Kassler quadrangle.

Zone 4 contains pegmatites with miarolitic cavities. Pegmatites with cavities are typical of the Pikes Peak granite, but are unknown in the metamorphic rocks. The cavities contain pale-brown microcline crystals as large as 6 inches in diameter, clear quartz crystals 6 inches in length, and, locally, muscovite crystals as large as 2 inches in diameter that are perched on the microcline and quartz. Muscovite is unknown from typical pegmatites of the Pikes Peak granite; therefore I think that these pegmatites owe their composition partly to contamination from the metamorphic rocks. Xenoliths in zone 4 are less migmatized and locally are oriented parallel to the regional foliation trend rather than parallel to the border of the granite. Some layers of metamorphic rock extend into the pegmatite zone.

The granite is a homogeneous coarse-grained grayish-orange pink rock composed chiefly of microperthite, quartz, and biotite. The microperthite is in moderate reddish-orange or yellowish-gray grains as large as 1 inch in diameter, the quartz grains are as large as three eighths inch in diameter, and the biotite plates are as large as 1 inch in diameter.

The granite in thin section is hypautomorphic granular to xenomorphic granular in texture, and consists of microperthite, quartz, plagioclase, and biotite and traces of apatite, titanite, magnetite, hematite, chlorite, and zircon. Microperthite, much of which is twinned according to the carlsbad law, and plagioclase (oligoclase) are idiomorphic against quartz. Biotite and magnetite are surrounded by microperthite, and euhedral biotite lies between the microperthite and quartz. The plagioclase appears to have oscillatory zoning (alternating calcic and sodic zones); the inner parts of the plagioclase crystals are vermicular. Part of the plagioclase is altered to sericite. Red hematite is included in the plagioclase and in fractures through the granite. Opaque hairlike inclusions (rutile?) pierce the quartz and plagioclase. A sheaf of sillimanite crystals was seen in one slide. Zircon is associated with the biotite and may be the variety cyrtolite.

The following table gives the modes (volume percent) of three samples of the Pikes Peak granite:

	SC-47	SC-50	S-49
Quartz	24	37	22
Plagioclase	27	9	45
Microperthite	24	50	----------
Hornblende	10	----------	5
Biotite	12	4	24
Magnetite	1	Tr.	3
Muscovite	----------	----------	Tr.
Apatite	1	Tr.	Tr.
Titanite	11	Tr.	1
Zircon	----------	Tr.	----------
Hematite	----------	Tr.	----------
Chlorite	----------	Tr.	----------

SC-47: Biotite segregation from Pikes Peak granite along Pine Creek south of the quadrangle.
SC-50: Typical granite from NW¼NE¼ sec. 8, T. 8 S., R. 68 W.
S-49: Quartz diorite from contact zone with metamorphic rocks from the SE¼SE¼ sec. 4, T. 8 S., R. 69 W.

A deep weathered zone has formed on the Pikes Peak granite. At Pine Nook (pl. 2), where several holes were augered, the granite is weathered to a depth of more than 15 feet. Weathering has affected the biotite grains most by loosening them from the quartz and feldspar grains. Downward movement of ground water has transported the biotite from its disaggregated matrix and redeposited it at the water table in a laminated band, where it is partly altered to chlorite. Removal of the biotite leaves a friable aggregate of quartz and feldspar grains. Isolated boulders of nearly fresh granite are distributed at random and protrude from the surface of the weathered material.

Origin.—The Pikes Peak granite is of magmatic origin. Several lines of evidence (Williams and others, 1954, p. 143–144) lead to this conclusion: (a) microperthite exceeds other feldspars in quantity, (b) only a single alkali feldspar is present, (c) plagioclase is complexly twinned in combinations of albite and carlsbad twins and, (d) plagioclase shows oscillatory zoning. In addition to the above criteria, the characteristics of the border of the Pikes Peak granite are more like those of a granite of magmatic origin.

GRANITE PEGMATITE IN PIKES PEAK GRANITE

Many small pegmatites that are related to the Pikes Peak granite crop out in a narrow zone about 100 feet inside the border of the batholith. Most have lenselike miarolitic cavities that contain large well-formed crystals of microcline and smoky quartz. Other pegmatites contain no cavities but do contain subhedral crystals of quartz and feldspar that are tightly bound together.

The miarolitic pegmatites generally are thin, but long and wide, and lie flat. An average-sized pegmatite is 1 foot wide, 1 foot long, and 2 inches thick. During Laramide deformation the cavities were crushed, crystals were broken from the walls, and the cavities were filled with limonitic micaceous clay. Smoky quartz and pink microcline are the most common minerals, but topaz was found at Pine Nook associated with smoky quartz and amazonstone, the green variety of microcline. Octahedral crystals of fluorite were found in the SW¼ sec. 3, T. 8 S., R. 69 W.

The pegmatites without cavities are thin and many grade into quartz veins. Quartz in both the veinlike pegmatites and in the quartz veins is milky. These pegmatites and quartz veins were emplaced along preexisting fractures and were later fractured and recemented by iron oxide. One of the larger pegmatites, about 10 by 20 feet in cross section, in sec. 5, T. 8 S., R. 68 W., has been prospected by two opencuts. The pegmatite contains a discontinuous quartz core, exposed as three quartz pods in the opencuts; the quartz is surrounded by moderate reddish-orange potassic feldspar. The feldspar and quartz are somewhat iron stained and several quartz crystals contain inclusions of hematite crystals.

GRANITE PEGMATITE

The bodies of granite pegmatite shown on the geologic map (pl. 2) are probably not all of the same age. They are tentatively believed to be in part related to biotite-muscovite granite, in part to the granite gneiss and migmatite, and in part to an unidentified source.

Quartz-microcline-muscovite pegmatites are the most abundant; few are more than 3 feet wide or 10 feet long. They contain pink microcline crystals several inches in diameter, muscovite books locally 8 inches in diameter, quartz, and magnetite. Anthophyllite, with index of refraction of 1.66, was found in one pegmatite.

Tourmaline-bearing pegmatites are less common. They lie in the southern part of the quadrangle, generally near sillimanite-bearing rocks or biotite-muscovite granite, to which they are related. The tourmaline-bearing pegmatites are 2 to 3 feet wide; they are shown on the geologic map (pl. 2). The tourmaline crystals are black, 3 to 4 inches long, and a maximum of 1 inch in diameter. Radiating clusters of tourmaline crystals and graphic tourmaline were seen in a pegmatite in the SE¼ sec. 34, T. 7 S., R. 69 W. Grayish blue-green apatite was seen in about five of the tourmaline pegmatites. The apatite is either in crystals or in crystalline masses as large as 2 inches in diameter. Dark reddish-brown garnet, which crystallized earlier than both tourmaline and apatite, was seen in one pegmatite. In another pegmatite sillimanite surrounds and cuts across both tourmaline and apatite; hence, it was the last mineral to form.

Beryl was found in a pegmatite that intrudes a lime silicate gneiss bed in the NW¼NE¼ sec. 16, T. 7 S., R. 69 W. (shown at a prospect pit on pl. 2). Both the lime silicate gneiss and the pegmatite were later invaded by copper-bearing solutions. Microcline crystals 6 inches in diameter are common in the pegmatite. A light bluish-green beryl crystal one-fourth inch in diameter and 1 inch in length was found at the contact of microcline and quartz. This occurrence of beryl is the first known in this area south of the Bigger mine, where beryl is abundant in a pegmatite in the metamorphic rocks, or east of the South Platte pegmatite district, where beryl has been found in pegmatites in the Pikes Peak granite.

Chrysoberyl was found in the Kassler quadrangle by Maynard Bixby. The locality is listed (Schrader and others, 1917, p. 84) as "six miles west of Sedalia, at old mica prospect, with black tourmaline and muscovite, and near large garnets." The locality was not found but probably is somewhere in secs. 25, 26, 35, or 36 of T. 7 S., R. 69 W. Tourmaline-bearing pegmatite with garnet was found only in the SW¼ of sec. 25.

Where quartz-microcline-muscovite pegmatites cross beds of hornblende granite gneiss, lime silicate gneiss, or amphibolite, they pick up hornblende. Pegmatites with hornblende as the ferromagnesian mineral were seen in the SE¼SE¼ sec. 34, T. 7 S., R. 69 W., and in the NE¼SW¼NE¼ sec. 4, T. 7 S., R. 69 W. (pl. 2). Epidote and titanite are locally associated with the hornblende.

PALEOZOIC SEDIMENTARY ROCKS

Paleozoic sedimentary rocks crop out in a narrow belt along the mountain front. In ascending order they are the Fountain formation of Pennsylvanian and Permian age, the Lyons sandstone of Permian age, and the lower part of the Lykins formation of Permian(?) age. Sandstone dikes crop out along faults in the southern part of the quadrangle; they probably correlate with the Sawatch quartzite and are of Late Cambrian age.

SANDSTONE DIKES

Northwest-trending dikes of sandstone of Late Cambrian age crop out along faults in Stevens and Mill Gulches in the west-central part of the area and along the valley sides adjoining them (pl. 2, fig. 31). The

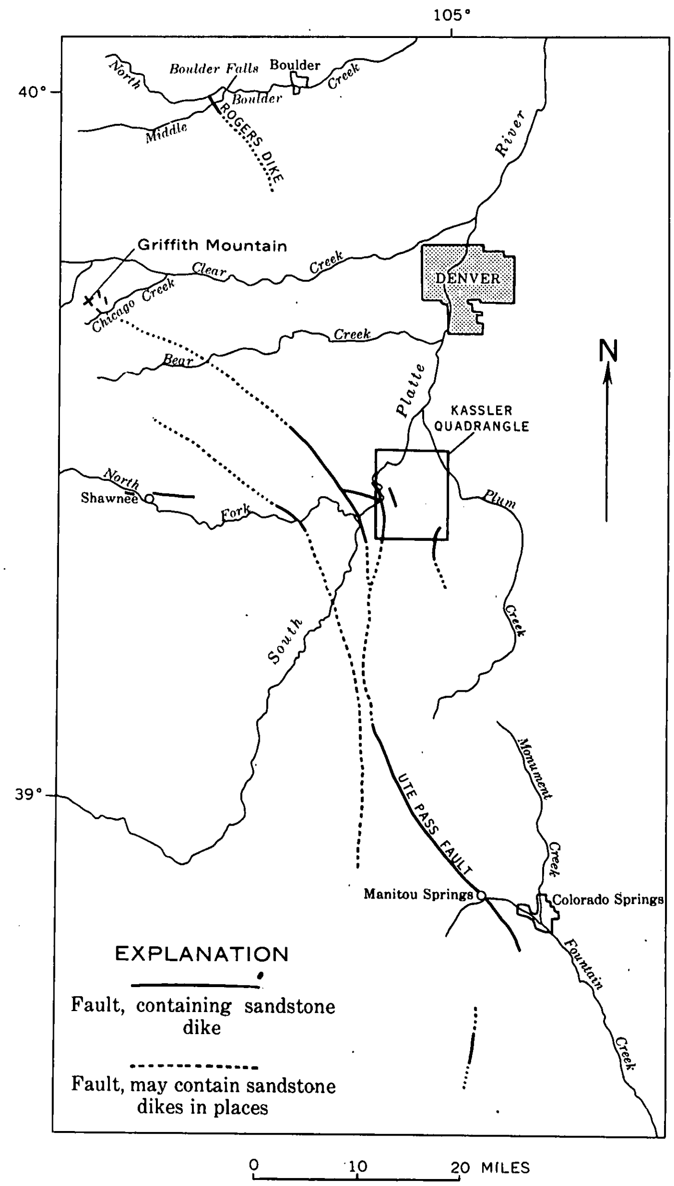

FIGURE 31.—Distribution of sandstone dikes in faults.

largest and most persistent dike trends northward along Bear Creek and Stevens Gulch, then northeastward between Stevens Gulch and Mill Gulch. The sandstone forms a small ridge where it is bordered on both sides by fault gouge. Elsewhere it forms small spurs along the sides of the valleys. The Jarre Creek fault also contains a sandstone dike in the NW¼NE¼ sec. 8 and in the SW¼SE¼ sec. 5, T. 8 S., R. 68 W.

Outside the Kassler quadrangle in the Front Range the sandstone dikes are known to occur in an area that extends from west of Colorado Springs northward to Boulder Creek and as far west as Shawnee (fig. 31). The northernmost sandstone dike in the Front Range is on the west branch of the Rogers dike in the W½SE¼ sec. 3, T. 1 S., R. 72 W., north of Colorado Highway 119 and 2.6 miles west of Boulder Falls. The westernmost sandstone dikes in the Front Range crop out as far west as the intersection of the West Chicago Creek road and the road toward Griffith Mountain in the SE¼NE¼ sec. 23, T. 4 S., R. 74 W., Georgetown quadrangle.

Sandstone dikes lie in great fault valleys, where the thickness of the shattered rock may exceed 300 feet, and along small faults where the sandstone occupies the full width of the faults. The Bear Creek fault, for instance, contains recemented fault gouge on both sides of a sandstone dike that in contrast is only slightly fractured. On the east side the fault gouge looks like vuggy granite pegmatite. Most of the quartz is milky and amorphous although occasional vugs contain small clear quartz crystals. Hematite is abundant in the vugs, and the fault gouge is slightly more radioactive than background. On the west side, the fault gouge is pulverized quartz cemented by hematite; it contains chlorite, serpentine(?), and a purple amorphous mineral (fluorite?).

The sandstone in the small faults is either extremely shattered or not shattered at all, as though some faults moved after the emplacement of the sandstone and others did not.

The sandstone dikes are composed of red or green fine-grained quartzitic sandstone. The sandstone is greenish gray to pale olive to light olive gray, yellowish brown to grayish orange or pale brown or grayish red to pale red. Many outcrops of the sandstone are mottled with several colors, such as grayish red, moderate yellowish brown, and pale red.

The sandstone is fine grained, mostly 0.2 to 0.33 mm in diameter, with some silt and a few grains larger than 5 mm. Most of the grains are rounded to subrounded, but a few are subangular. The borders of the grains are ragged, as though they were etched.

The following table gives typical modes (volume percent) of total number of grains of the sandstone dikes and Sawatch quartzite:

	S-64	S-91	S-101	S-77
Grains:				
Quartz	98	99	99	98
Microcline	2	Tr.	--	2
Muscovite	--	--	--	Tr.
Apatite	--	Tr.	--	Tr.
Rutile(?)	--	Tr.	--	Tr.
Plagioclase	--	--	Tr.	--
Magnetite	--	--	--	Tr.
Biotite	--	--	Tr.	--
Cementing material:				
Limonite	x[1]	--	x	--
Hematite	--	x	x	x
Dolomite	--	--	--	x
Pore space	15	--	--	44

[1] Mineral present.
S-64: Red sandstone from dike in SW¼NE¼ sec. 4, T. 8 S., R. 69 W.
S-91: Red sandstone from dike in NE¼NE¼ sec. 16, T. 7 S., R. 69 W.
S-101: Green sandstone from dike in NE¼NE¼ sec. 21, T. 7 S., R. 69 W.
S-77: Sawatch quartzite from Williams Canyon, Manitou Springs, Colo.

Quartz constitutes 98 to 99 percent of the sandstone; microcline, plagioclase, and other minerals constitute as much as 2 percent. Needlelike inclusions of apatite and rutile are common in the quartz grains. Biotite plates are bent between the grains.

Limonite cements the sandstone so firmly that it has the consistence of quartzite and fractures through the grains rather than around them. The limonite cement has been leached out of spherical spots in the sandstone. These spots are ⅛ to ½ inch in diameter and about 1 inch apart. Loose sand falls out of the centers of some spots when the rock is broken.

The only bedding or alinement in the dikes is parallel to the confining walls; no layering was observed that would indicate that the sand settled slowly to the bottom of a water-filled crevice. In some dikes the coarse grains are alined parallel to the walls of the fractures. Colored bands, produced by ground water, and minor fractures also are parallel to the walls of the dikes. Angular fragments of granite and other wall rocks are alined along the walls of the sandstone in almost every dike. Many of these fragments are as large as 2 to 3 inches in diameter and all are angular; the angularity indicates that the fragments did not move far.

The dikes are either tabular or lenticular and commonly are less than 1 inch thick, but are quite persistent except where faulted. Where faulted, the sandstone is brecciated, intermixed with the wallrocks, mineralized, and lenticular. Thin sections show fractures that extend through the quartz grains and leave finely ground quartz in the fractures. Both the microscopic and megascopic fractures are healed by silica and hematite.

SOURCE OF THE SAND

This discussion of the origin of the sandstone dikes deals mainly with two points: (a) the source of the sand

TABLE 1.—*Spectrographic analyses of sandstone dikes and Sawatch quartzite*

[Analysts: Paul R. Barnett and Nancy M. Conklin, U.S. Geol. Survey, Denver, Colo. In this table the following figures only were used: 1, 1.1, 1.2, 1.4, 1.6, 1.8, 2, 2.3, 2.6, 3, 3.5, 4, 4.5, 5, 6, 7, 8, and 9, with the necessary decimal point shifts; thus, the reported values should not be considered as being accurate to two significant figures but as being grouped into approximately equal geometric subdivisions. Looked for but not detected: Ag, As, Au, Be, Cd, Ge, In, Pt., Sb, Sn, Ta, Th, Tl, U, W, and Zn]

Laboratory	B	Ba	Bi	Co	Cr	Cu	Fe	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sr	Ti	V	Y	Yb	Zr
Sawatch quartzite																					
D1324	------	0.046	0.0030	0.00042	0.0019	0.0044	0.38	0.0001	0	0.28	0	0	0.00047	0.0021	0	0.0084	0.066	0.0014	0.0024	0.00017	0.018
D1331	0.0052	.062	0	.0001	.00063	.0014	.34	.00032	0	.0092	.00090	.0007	0	.0029	0	.018	.096	.0016	.0019	.0002	.046
Sandstone dikes																					
D1323	------	0.098	0	0.00061	0.0003	0.0014	0.55	0	0	0.084	0.0028	0	0.00074	0	0	0	0.042	0.0004	0	0	0.012
D1325	------	.0088	0	0	.00038	.00092	.84	.0001	0	.0093	0	0	.0002	0	0	0	.080	.0004	.0008	.00009	.012
D1326	------	.0034	0	0	.00070	.00032	.51	.0002	0	.0086	0	0	.00030	0	0	0	.11	.00064	.0008	.00005	.014
D1327	------	.016	0	.00060	.0010	.00041	1.4	.00034	0	.046	0	0	.0015	0	.00060	.0003	.11	.0022	.0008	.00006	.018
D1328	------	.07	0	.0005	.001	.0008	2	.0004	0	.09	0	.0007	.001	0	.0007	.001	.11	.0012	.0029	.00035	.022
D1332	------	.0043	0	0	.00034	.00064	.78	.0002	0	.0083	0	0	0	0	0	0	.081	.00078	.0014	.0001	.014
D1333	------	.018	0	.0002	.00057	.00058	1.7	.00063	.014	.072	0	.001	.00050	0	0	.0004	.11	.00058	.0027	.0002	.022

D1324: (S-77, p. 86 in modes). From about 2 feet above base in Williams Canyon, Manitou Springs.
D1331: From 2 in. above base in Ute Pass west of Manitou Springs.
D1323: SE¼SE¼ sec. 33, T. 7 S., R. 69 W., Kassler quadrangle.
D1325: NE¼NE¼ sec. 16, T. 7 S., R. 69 W., Kassler quadrangle.
D1326: NW¼NE¼ sec. 21, T. 7 S., R. 69 W., Kassler quadrangle.
D1327: Green sandstone from dike in NE¼NE¼ sec. 21, T. 7 S., R. 69 W., Kassler quadrangle.
D1328: Green sandstone from dike in SE¼SE¼ sec. 21, T. 7 S., R. 71 W., Pine quadrangle.
D1332: From Ute Pass fault, North Cheyenne Canyon, Colorado Springs.
D1333: Green sandstone from dike in Ute Pass fault, North Cheyenne Canyon, Colorado Springs.

and (b) the process by which the sand was emplaced. In the past, the sand generally was considered to have been derived from the Sawatch quartzite. The Sawatch quartzite was favored as the source of the sand by Crosby (1895, p. 113–147), Finlay (1916, p. 10), and Vitanage (1954, p. 500).

Specimens of sandstone from the dikes were compared with the Sawatch quartzite both petrographically and chemically. The sandstone from the dikes is texturally and lithologically indistinguishable from the Sawatch quartzite. Beds 15 feet above the base of the Sawatch most closely resemble the dikes. The cement in the sandstone dikes generally is iron oxide and in the Sawatch quartzite generally is calcite or dolomite. The difference in cement is not, however, considered to be significant because the cement is not an original constituent of the sand. The great difference in pore space between the Sawatch and the sandstone dikes may be the result of the different types of emplacement.

Quantitative spectrographic analyses of two samples of Sawatch quartzite and seven samples of sandstone dikes, as shown on table 1, show no greater variation of minor elements within each rock than between the two rocks. Although correlation between the dikes and the Sawatch quartzite cannot unequivocally be proved, the similarity of the two rocks is remarkable and suggests that further analyses or examination for microfossils may eventually confirm the Sawatch quartzite to be the source of the sandstone dikes.

PROCESS OF EMPLACEMENT

Four hypotheses have been proposed to explain the emplacement of the sandstone: (a) injection of unconsolidated sand into open fissures (Cross, 1894a, p. 3; 1894b, p. 228; Crosby, 1895, p. 113–147; Vitanage, 1954, p. 499); (b) dragging of the Sawatch sandstone into the fault zones during Laramide faulting (Finlay, 1916, p. 10); (c) injection of quicksandlike material from the sedimentary rocks of the downthrown block of the Ute Pass fault into fractures in the upthrown block during faulting (Roy, 1946, p. 1226); and (d) the possibility that the dikes represent unassimilated sandstone beds of the Precambrian Idaho Springs formation (D. B. Osterwald, *in* Vitanage, 1954, p. 493).

The first hypothesis, that is, injection of unconsolidated sand into open fissures, is the only one that fits the facts already presented. Disagreement on the origin has always centered around whether unconsolidated sand was injected into preexisting fractures or whether previously consolidated sandstone was introduced by faulting. The evidence seems conflicting because at one place the sandstone is fractured, at another it is unfractured.

If only one episode of faulting were assumed, the presence of both fractured and unfractured sandstone would be difficult to explain. However, in Laramide time alone, the faults were intruded by igneous dikes, faulted once, and mineralized. They probably were disturbed as much or more in Precambrian time and possibly again in Pennsylvanian time. The presence of unfractured or only slightly fractured sandstone between two thick layers of fault gouge in the Bear Creek fault and in the Ute Pass fault at Colorado Springs indicates that the fault gouge was formed before the sandstone was emplaced.

Northwest-trending breccia reefs are well known in the northern part of the Front Range, and northwest-trending faults containing sandstone dikes are well known in the southern part of the Front Range between the South Platte River and Colorado Springs, but their relation to each other has not been discussed. Similarities between them are apparent: The trend and the kind of movement along them is the same, they both contain much limonite and hematite, both are strongly silicified, both have chloritized shear zones, both are notably poor in ore minerals, and both cut the sedimentary rocks locally. Because of these similarities, I consider the breccia reefs of the Front Range mineral belt and the northwest-trending faults containing the sandstone dikes to be part of the same fault system.

FOUNTAIN FORMATION

The Fountain formation (Cross, 1894a) of Pennsylvanian and Permian age crops out in an eastward-dipping belt 1,500 to 3,000 feet wide that extends southeastward from near the northwest corner of the area to sec. 5, T. 8 S., R. 68 W., in the southeast quarter of the quadrangle, where it is cut off by the Jarre Creek fault (pl. 2). In general the formation is not well exposed; the sandstone of which it is composed is poorly cemented and forms a valley between the Precambrian rocks on the west, which the Fountain formation unconformably overlies, and the Lyons sandstone hogback on the east, with which it is gradational. Within the valley, however, hogbacks, ridges, and spires composed of more resistant sandstone stand conspicuously above the general rolling topography of the valley. The best examples of such features are in the area of Roxborough Park in the central part of the belt (fig. 32). Hayden (1873, p. 31) considered outcrops of the Fountain formation in this area to be the most picturesque of those along the Front Range.

The contact between the crystalline rocks and the Fountain formation is an erosional unconformity. At most exposures of the contact, the crystalline rocks show no pre-Fountain weathering; in secs. 28, 33, and 34, T. 6 S., R. 69 W., and sec. 3, T. 7 S., R. 69 W., (pl. 2) however, the granite gneiss is weathered to a depth of about 30 feet. The weathering consists of the alteration of feldspar to kaolin and biotite to chlorite. The minor folds in the weathered granite gneiss stand out in sharp relief in contrast to the unaltered adjacent granite gneiss in which the folds are not nearly so apparent. The absence of a relic soil at the base of the Fountain and the thinness or absence of a weathered layer in most of the area indicate considerable pre-Fountain erosion. The sediments that resulted from the erosion are deposited in the lower 25 feet of the Fountain formation.

The Fountain consists of moderate reddish-brown arkosic conglomeratic sandstone and minor amounts of arkosic conglomerate, siltstone, and dark reddish-brown shale. The grains range from pebbles, as much as 6 inches in diameter, to silt. Most of the sandstone is coarse grained. The gravel in the lower half of the unit is coarser than that in the upper half, and conglomerate and conglomeratic sandstone are more abundant in the lower half. Orthoclase feldspar and quartz are the predominant minerals. The feldspar grains are fresh and only slightly rounded, and the quartz grains are angular to subangular. Muscovite, in places as much as 1 inch in diameter, is common throughout the formation. Zircon is the most abundant heavy mineral; there are minor amounts of rutile, tourmaline, epidote, sphene, hornblende, garnet, staurolite, and locally apatite and clinozoisite. Pebbles in the conglomerate and conglomeratic sandstone consist of quartz, quartzite, feldspar, granite, gneiss, and schist; the pebbles of igneous and metamorphic rocks are restricted principally to the lower half of the formation.

The sediments of the formation are cemented with iron oxide, silica, and carbonate. Iron oxide is the most abundant cement; hematite films on the sand grains, pink feldspar, and red interstitial argillaceous material give the formation its red color. The occurrence of resistant beds of the Fountain in the Roxborough Park area, as well as in the Garden of the Gods in Colorado Springs, at Perry Park, in Red Rocks near Morrison, and in the Flatirons at Boulder, is probably the result of a higher content of silica cement; such occurrence apparently is also related to nearby faults or fault zones. Carbonate cement occurs only locally.

The stratification of the Fountain is typical of a formation consisting of stream-channel and minor flood-plain deposits. The sandstone beds are very thin to thick horizontal or crossbedded units. Channel cut and fill structures are common. The lithology of individual units changes vertically and horizontally, and there are abrupt changes in lithology between units. Discontinuous siltstone and shaly siltstone units, commonly green rather than red, occur locally between the sandstone or conglomerate beds or crossbeds. Locally the siltstone and shale units reach thicknesses of 50 feet.

The Fountain formation ranges in thickness from about 2,250 feet at the north edge of the quadrangle to about 1,150 feet at the south. The change in thickness is gradual throughout the entire distance and is probably the result of a strike fault which cuts out some of the beds (fig. 32), The relief of the Precambrian surface on which this formation was deposited, at least in this small area, is not the cause of the wide range in thickness. The contact of the Fountain formation with the Precambrian is not well exposed, but where ex-

FIGURE 32.—Thinning of the Fountain formation to the south by faulting. Note how individual beds approach the mountain front as they are traced to the south. Thinning is caused by strike fault.

posed, and where inferred for mapping, the contact indicates a Precambrian relief of only 1 to 2 feet. Post-Fountain erosion does not explain the range in thickness. At the top of the Fountain formation an interval of about 45 feet of interfingering beds of Fountain- and Lyons-type sandstone indicates a gradual change from conditions of sedimentation of the Fountain formation to those of the Lyons sandstone.

I found no fossils, nor have any been previously reported from the Fountain formation in the Kassler quadrangle. The Pennsylvanian and Permian age of the Fountain formation is based on Permian fossils (Maughan and Wilson, 1960) in the Ingleside formation, with which the Fountain intertongues in northern Colorado, and on the Pennsylvanian fossils in the Glen Eyrie shale member of the Fountain formation in the Colorado Springs area (pl. 3).

LYONS SANDSTONE

The Lyons sandstone (Fenneman, 1905) of Permian age overlies the Fountain formation and east of the mountains forms a continuous hogback that dips about 60° NE. The formation is well exposed throughout the quadrangle. It consists of yellowish-gray to pale-red massive fine-grained crossbedded quartzose friable sandstone about 235 feet thick that contains some lenticular layers of channel conglomerate near the base. A bed of conglomerate and coarse-grained sandstone that contains large flakes of muscovite marks the top of the formation. The sandstone is composed almost exclusively of clean well-sorted well-rounded quartz grains. Stratigraphic section 1 is typical of the formation.

The cementing material is predominantly limonite and calcium carbonate. Limonite also fills fractures and forms concretions. Some of these concretions are large and hollow, others are small accretions one-eighth inch in diameter that resemble fish eggs.

Crossbedding in the Lyons suggests an eolian origin. The Permian age is based on its correlation with the Satanka shale of Permian age in Wyoming (Maughan and Wilson, 1960) and its correlation with the Cedar Hills sandstone of Kansas (Maher, 1953).

1. *Lyons sandstone in the NE¼NW¼SE¼ sec. 27, T. 6 S., R. 69 W.*

	Feet
Lyons sandstone:	
4. Sandstone, yellowish-gray, with pink stains; thin-bedded, crossbedded, medium-grained; pebbles as much as 1 inch in diameter; some arkose beds	81.4
3. Sandstone, white, massive, friable, fine-grained	18.5
2. Sandstone, reddish-brown, pink and yellowish-gray, massive, crossbedded, fine-grained, medium hard to soft; conglomerate lenses	90.9
1. Sandstone and conglomerate, arkosic, coarse-grained. (Lower transitional part of Lyons sandstone)	44.5
Thickness of Lyons sandstone	235.3

LYKINS FORMATION

The Lykins formation (Fenneman, 1905) of Permian(?) and Triassic(?) age lies in a valley between the Lyons sandstone hogback on the west and the hogback on the east composed of the Lytle and South Platte formations (pl. 2, fig. 32). The formation conformably overlies the Lyons sandstone. It has a northeast dip of about 60° except in the southern part of the quadrangle, where it is overturned to the east by a thrust fault. It contains in ascending order the following members as described by LeRoy (1946, p. 31): the Harriman shale, the Falcon limestone, the Bergen shale, the Glennon limestone, and the Strain shale. Stratigraphic sections 2, 3, and 4 illustrate the lithology of the members.

The Harriman shale member of LeRoy is a moderate reddish-brown thin-bedded silty shale about 70 feet thick. Locally a moderate reddish-brown sandy limestone crops out a few feet above the Lyons sandstone.

The Falcon limestone member of LeRoy is a yellowish-gray massive or thinly laminated, porous limestone 2 feet thick.

The Bergen shale member of LeRoy is a moderate reddish-brown thin-bedded silty shale about 40 feet thick. The Bergen shale and the Harriman shale are mapped as Harriman and Bergen shale members.

2. *Lykins formation in NE¼NE¼ sec. 31, T. 7 S., R. 68 W.*

	Feet
Lykins formation (part):	
Strain shale member of LeRoy: Red shale, mostly covered.	
Glennon limestone member of LeRoy:	
4. Limestone, grayish orange-pink, finely laminated, fine-grained; wavy bedding, shaly to platy; upper part porous	12.0
3. Limestone, pinkish-gray, massive, laminated	2.8
Thickness of Glennon limestone member	14.8
Harriman and Bergen shale members of LeRoy (part):	
2. Shale, moderate reddish-brown, blocky, silty	33.0
1. Limestone, yellowish-gray, massive, laminated; (Falcon limestone member of LeRoy)	2.5
Measured thickness of Harriman and Bergen shale members	35.5
Covered; moderate reddish-brown shale, down to Lyons sandstone.	

3. *Lykins formation in SE¼SE¼ sec. 11, T. 7 S., R. 69 W.*

	Feet
Lykins formation (part):	
Covered, red shale.	
Glennon limestone member of LeRoy:	
4. Limestone, pale-red, thinly laminated; appears to be one-half sand, shaly, wavy bedded	12.0
3. Limestone, white, wavy-bedded; contains chert nodules as much as 1 in. in diameter	3.3
Thickness of Glennon limestone member	15.3
Harriman and Bergen shale members of LeRoy (part):	
2. Shale, red, silty, thin-bedded	40.0
1. Limestone, white; contains black manganese dendrites; friable to floury, thin-bedded; (Falcon limestone member of LeRoy)	2.0
Measured thickness of Harriman and Bergen shale members	42.0
Covered down to Lyons sandstone.	

4. *Lykins formation in the NE¼NW¼SE¼ sec. 27, T. 6 S., R. 69 W.*

	Feet
Lykins formation:	
Strain shale member of LeRoy:	
7. Covered	165.0
6. Sandstone, gray, crossbedded, limy; weathers orange gray	1.5
5. Shale, orange-red, clayey	86.0
Thickness of Strain shale member	252.5
Glennon limestone member of LeRoy:	
4. Limestone, grayish-orange to pink; wavy bedding surfaces; sandy	17.0

4. *Lykins formation in the NE¼NW¼SE¼ sec. 27, T. 6 S., R. 69 W.*—Continued

	Feet
Lykins formation—Continued	
Harriman and Bergen shale members of LeRoy:	
3. Covered; probably reddish-brown shale	43.0
2. Limestone, gray, massive, thinly stratified; (Falcon limestone member of LeRoy)	2.4
1. Covered; probably reddish-brown shale	71.8
Thickness of Harriman and Bergen shale members	117.2
Thickness of Lykins formation	386.7

The Glennon limestone member of LeRoy is an excellent marker; it is exposed in a small hogback almost continuously along the Front Range. The limestone consists of 15 to 17 feet of grayish orange-pink, moderate yellowish-brown, and yellowish-gray thin-bedded sandy layers that are finely laminated, wavy, intricately folded, and faulted or slightly brecciated. Pale-red chert nodules and granular quartzose layers with small vugs of quartz crystals were found in the middle of the limestone. Some of the quartz grains show crystal faces and indicate that part of the quartz was formed in place and was not transported from older sedimentary rocks. The chert nodules are rimmed by crystalline calcite. The lamination of some of the limestone consists of layers of calcite crystals.

The Strain shale member of LeRoy is moderate reddish-brown silty shale about 250 feet thick interbedded with some thin layers of light-green shale and some layers of grayish-orange massive, loosely cemented, crossbedded sandstone.

The age of the Lykins formation is based on its correlation with the Satanka, Forelle, and Chugwater formations of Wyoming (Maughan and Wilson, 1960) (see also pl. 3).

At the top of the Lykins there is a soft earthy sandstone about 5 feet thick. The sandstone is reddish brown and contains sand grains of two sizes; the larger grains range from 0.33 to 1.5 mm in diameter and the smaller grains average less than 0.1 mm in diameter. The grains are mostly quartz; the larger ones are frosted and well rounded and the smaller ones are angular. Silt is a minor constituent. The grains are loosely held together by calcium carbonate. The frosted grains indicate that the sandstone probably is of eolian origin. This sandstone strongly resembles and may be correlative with the Entrada sandstone of Gilluly and Reeside (1928, p. 76–78).

MESOZOIC AND CENOZOIC SEDIMENTARY ROCKS

Mesozoic rocks include, in addition to the upper Triassic(?) part of the Lykins formation, the Ralston Creek, Morrison, and Lytle and South Platte formations, the Graneros shale, Greenhorn limestone, Carlile shale, Niobrara formation, Pierre shale, Fox Hills sandstone, Laramie formation, and the lower part of the Dawson arkose. The upper part of the Dawson arkose is of Cenozoic age.

RALSTON CREEK FORMATION

The name Ralston Creek formation of Late Jurassic age was adapted from LeRoy (1946, p. 46–55) by Van Horn (1957, p. 755–756) and is used for the series of limestones and shales between the Lykins formation and the Morrison formation (see stratigraphic secs. 5, 6, and 7). Despite the probable Kimmeridgian (Morrison) age of these beds, their thinness (45 feet or less locally), and their lithologic similarity to parts of the Morrison formation, differentiation from the Morrison formation is justified because these rocks are more easily recognized and are more persistent than adjacent rocks in the Lykins or Morrison formation. A jasper horizon is a particularly persistent surface and subsurface marker bed in Colorado, New Mexico, Utah, and Arizona.

The lower boundary of the formation is at the top of the earthy light-brown Entrada(?) sandstone equivalent, or where the Entrada(?) is absent, at the top of the moderate-brown siltstone or grayish yellowish-green shale of the Lykins formation. The upper boundary is at the base of the lowest, most persistent sandstone of the Morrison formation or at the top of the uppermost algae and jasper-bearing limestone of the Ralston Creek.

The Ralston Creek formation contains either a freshwater limestone facies or a gypsum facies along the Front Range. Limestone beds crop out between Ralston and Bear Creeks (fig. 28) and between Deer Creek and Jarre Creek. Gypsum beds crop out between Bear Creek and Deer Creek and at Perry Park. Limestone beds have been seen in the gypsum facies but gypsum was not observed in the limestone facies.

5. *Ralston Creek formation in gully north of Kassler schoolhouse, SW¼SE¼ sec. 27, T. 6 S., R. 69 W.*

	Feet
Ralston Creek formation (part):	
28. Shale, olive-gray, silty; weathers to pinkish-gray flakes and pinkish-gray limy nodules	0.4
27. Shale, pale-brown, silty; weathers to pink flakes	.1
26. Shale, light olive-gray, silty, calcareous; weathers to pinkish-gray flakes	1.6
25. Limestone, yellowish-gray, nodular, silty; finely crystalline; contains charophytes	.7
24. Shale, light olive-gray, silty, calcareous; weathers to pinkish-gray flakes	4.0
23. Limestone, light olive-gray, massive, finely crystalline; contains charophytes	.4
22. Shale, light olive-gray; silty, calcareous; weathers pinkish gray	1.1?

5. *Ralston Creek formation in gully north of Kassler schoolhouse, SW¼SE¼ sec. 27, T. 6 S., R. 69 W.*—Continued

Ralston Creek formation (part)—Continued	Feet
21. Limestone, olive-gray, massive; contains lenticular nodules of grayish-brown jasper as much as 6 in. in length and 2 in. in thickness. Contains algae (*Echinochara spinosa*) and gastropods (*Gyraulus veternus* and *Lymnaea morrisonensis*). Gastropods replaced by quartz and jasper	.9
20. Shale, light olive-gray; weathers to light-gray flakes; silty, calcareous	2.0
19. Limestone, yellowish-gray; weathers nodular; contains charophytes	.2
18. Shale, yellowish-gray, chalky; weathers nodular	1.1
17. Shale, light olive-gray, silty	.5
16. Limestone, yellowish-gray, nodular, chalky; contains charophytes	.6
15. Limestone, yellowish-gray, massive, finely crystalline; weathers nodular; shows calcite cleavages; contains charophytes	1.6
14. Shale, pale-olive; silty, calcareous, weathers pale greenish yellow; partly covered; lower part has thin sandstone layers and grayish-brown shale	8.0
13. Sandstone, yellowish-gray; massive, slightly calcareous, platy; weathers pale yellowish brown	.4
12. Shale, pale-olive and grayish-brown variegated; platy to fissile, silty; has 0.5 to 1-in. layers of pale-olive sandstone	1.8
11. Limestone, very light gray, blocky, silty; weathers platy; contains charophytes	.4
10. Shale, pale-olive, silty, calcareous; thin limonite-stained beds	4.1
9. Sandstone, yellowish-gray, laminated, fine-grained; weathers platy	.4
8. Shale, pale-olive, silty, calcareous	1.4
7. Shale, grayish-brown, silty, calcareous	.8
6. Shale, pale-olive, silty, calcareous	2.0
5. Shale, grayish-brown to pale-olive mottled; sandy	1.9
4. Sandstone, pale-olive, loose, fine-grained; grades downward into silty shale	1.6
3. Shale, grayish-brown to pale-olive mottled, silty at top; pale-olive to grayish-brown mottled, sandy at bottom	6.0
2. Sandstone, grayish-orange, friable to loose, fine-grained	1.3
1. Shale, grayish orange-pink mottled with pinkish gray; silty, calcareous	2.0
Measured thickness of Ralston Creek formation	47.3

Covered. Lykins formation only a few feet below bottom of section.

6. *Ralston Creek formation in the NE¼NW¼SE¼ sec. 27, T. 6 S., R. 69 W.*

Ralston Creek formation (part):	Feet
18. Covered; probably shale	7.8
17. Limestone, gray; contains algae and some red jasper	.7
16. Covered; probably shale	3.4
15. Limestone, gray, fine-grained; contains clots of red jasper	1.7
14. Shale, gray-brown, silty	30.8
13. Shale, olive-gray, blocky, clayey	12.0
12. Limestone, gray, dense; contains jasper nodules; almost solid jasper in places	.6
Measured thickness of Ralston Creek formation	57.0

7. *Ralston Creek formation in the SW¼NW¼ sec. 30, T. 7 S., R. 68 W.*

Morrison formation: Covered.

Ralston Creek formation (part):	Feet
3. Limestone, light-gray, massive, sandy	1.0
2. Shale, light-gray, blocky, limy	12.0
1. Limestone, light-gray, dense, hard; contains algae	1.0
Measured thickness of Ralston Creek formation	14.0

Covered.

The formation is about 48 feet thick and consists of a series of yellowish-gray dense ridge-forming limestone beds separated by silty calcareous shale in the upper part, and thin, fine-grained sandstone beds separated by silty or sandy shale in the lower part. The limestone contains nodules of black to red jasper as much as 4 inches in diameter. In the northern part of the quadrangle some beds are composed almost entirely of small pellets and streaks of jasper. Sections 5–7 illustrate the typical lithology.

Limestone beds in the SW¼SE¼ sec. 27, T. 6 S., R. 69 W., contain fresh-water gastropods identified by J. B. Reeside as *Gyraulus veternus* Meek and Hayden and *Lymnaea morrisonensis* Yen, and algae identified by R. E. Peck as *Echinochara spinosa* Peck of Kimmeridgian age (plate 3). These fossils are clustered around the outside of jasper nodules in the limestone along with silicified internal fillings of ostracodes. Although calcite also has replaced the fossils, calcite casts are seldom seen and are almost impossible to extract from the matrix, whereas jasper casts can be leached out in excellent condition.

Gypsum in the formation indicates that it was deposited in a lagoon near the sea.

The Ralston Creek formation is equivalent to the Summerville formation of the San Rafael group (McKee, and others, 1956, p. 5). Its stratigraphic position is the same; it lies above the Entrada(?) sandstone and below the Morrison formation. Both the Ralston Creek and the Summerville contain gypsum and chalcedony (Gilluly and Reeside, 1928, p. 80).

MORRISON FORMATION

The Morrison formation (Emmons and others, 1896) of Late Jurassic age crops out on the west slope of the ridge formed by the Lytle and South Platte formations. The formation is about 320 to 380 feet thick and consists of a lower thin sandstone unit and an upper thick claystone and siltstone unit (see stratigraphic sections 8–10).

The lower 45-foot sandstone unit of the formation may be equivalent to the Salt Wash member of Lupton (1914, p. 127). It contains as many as four lenticular ridge-forming sandstone beds that are massive to thick bedded, crossbedded, and fine to medium grained, and are cemented by calcium carbonate. They are yellowish gray except for the basal, most persistent sandstone which is gray, medium grained, calcareous, and crossbedded, and locally contains grains of jasper from the underlying Ralston Creek formation. The sandstone beds weather light brown, orange pink, or olive gray, and are pitted; the crossbedding stands out in relief. At the base of most of the sandstone beds is a basal conglomerate made up of chips of limestone, shale, and grains of jasper from the underlying Ralston Creek formation. The sandstone beds are separated by grayish-red, reddish-brown, or greenish yellowish-gray blocky calcareous siltstone. Section 8 is typical of the sandstone unit.

The basal contact of the Morrison formation is at the base of the lowest persistent sandstone, generally 8 to 11 feet above the top limestone in the Ralston Creek formation. The upper contact of the lower sandstone unit is at the top of the uppermost yellowish-gray crossbedded calcareous sandstone that has a basal conglomerate of shale chips—generally about 45 feet above the base of the Morrison formation.

8. *Morrison formation in the NE¼NW¼SW¼ sec. 27, T. 6 S., R. 69 W.*

Morrison formation (part) : Lower sandstone unit:	*Feet*
22. Shale, olive-gray and gray-brown variegated, silty	8.0
21. Sandstone, gray, massive, fine-grained, soft, limy; weathers platy	1.0
20. Shale, gray and pink, also olive-green and gray-brown; silty, partly covered	11.3
19. Sandstone, gray, massive, medium-grained, limy; has salt-and-pepper appearance and contains grains of red jasper	1.0
Thickness of lower sandstone unit	21.3

Above the lower lenticular sandstone unit is a unit of variegated siltstone and claystone with thin limestone and sandstone beds that may be equivalent to the Brushy Basin member of Gregory (1938, p. 59). Sections 9 and 10 are typical of this upper unit. It is divided into three parts: a lower red and gray siltstone, a middle yellowish-gray claystone, and an upper red claystone. The lower part consists of gray and reddish-brown siltstone beds that locally contain thin crystalline limestone layers and yellowish-gray quartzitic lenticular sandstone beds. This lower unit of red and gray siltstone is generally about 45 feet thick.

The middle, or most characteristic, part of the Morrison is light- to yellowish-gray siltstone and claystone about 165 feet thick that contains light-gray or gray massive hard crystalline limestone and algae and fresh-water mollusks, and yellowish-gray medium-grained sandstone with limy cement. Dinosaur bone fragments were found in a dusky yellowish-green shale or claystone 125 to 150 feet below the base of the Lytle formation.

The upper part is dominantly red variegated silty claystone, but locally contains many beds of reddish-brown or yellowish-gray fine- or medium-grained sandstone. At several places a conglomerate bed containing quartzite and chert pebbles was seen at the base of this unit. The conglomerate beds grade laterally into sandstone and then into shale. The thickness of the dominantly red claystone unit is about 60 feet.

9. *Morrison formation on slope of hogback in NE¼NE¼ sec. 31, T. 7 S., R. 68 W.*

Morrison formation:	
Red claystone unit:	*Feet*
12. Covered	70.0±
Yellowish-gray claystone unit:	
11. Shale, light olive-gray, blocky, clayey, slightly leached	27.0
10. Limestone, yellowish-gray, fine-grained; no fossils	0.8
9. Shale, dusky yellowish-green; blocky, clayey, calcareous; weathers light greenish gray	27.0
8. Siltstone, dusky-yellow, sandy	.3
7. Shale, dusky yellowish-green, blocky, silty; dinosaur bone fragment in float	27.0
6. Sandstone, yellowish-gray, massive, stratified, medium-grained, friable; upper 1 ft and lower 1 ft. more resistant than middle	4.0
5. Shale, grayish yellow-green; clayey; weathers yellowish gray; breaks out in small chips	36.0
4. Shale, grayish-red; blocky, clayey; weathers pale red	42.0
Red and gray siltstone unit:	
3. Shale, grayish-red; weathers pale red; blocky, silty	51.0
2. Shale, dusky yellowish-green, blocky, silty	57.0
1. Covered down to limestone in Ralston Creek formation. Appears to be alternation of colored shale of beds 2 and 3 for remainder of covered interval	40.0
Thickness of Morrison formation (rounded)	382.0

10. *Morrison formation in quarry in NW¼SW¼ sec. 35, T. 6 S., R. 69 W.*

Lytle formation.
Morrison formation (upper part):

	Feet
Red claystone unit:	
18. Covered	40.0±
17. Shale, reddish-brown; sandy	7.0
16. Sandstone, rusty brown; medium grained; weathers brown	6.0
15. Shale, reddish-brown; sandy	2.0
14. Sandstone, reddish-brown, medium-grained	3.0
13. Shale, reddish-brown; a sandy silt	3.0
Yellowish-gray claystone unit (part):	
12. Shale, gray; stained reddish brown from overlying shale; nodular, calcareous	3.1
11. Sandstone, tan and gray; fine grained; weathers pink	2.0
10. Shale, reddish-brown, silty	6.0
9. Shale, olive-drab and green, silty	.8
8. Sandstone, tan-gray; fine grained; weathers tan gray-tan mottled	2.1
7. Shale, reddish-brown and pink, silty	1.0
6. Sandstone, light-gray; weathers maroon; medium grained	5.5
5. Shale, olive-drab, silty	.6
4. Shale, reddish-brown, silty	3.1
3. Shale, green; weathers light green	1.2
2. Sandstone, tan-gray mottled	.4
1. Shale, light-olive, blocky, limonite-stained	8.0
Covered.	
Measured thickness of Morrison formation	94.8

LYTLE AND SOUTH PLATTE FORMATIONS

The Lytle and South Platte formations form the most prominent hogback in the quadrangle (fig. 32). They are about 320 feet thick in the northern part of the quadrangle but are faulted out in the southern part (pl. 2).

Waagé (1955, p. 46) subdivided the Dakota group, in ascending order, into the Lytle formation and the South Platte formation and described (1955, p. 34–35) an excellent section of the two formations. The type locality of the South Platte formation is at the north boundary of the quadrangle.

The Lytle formation (Finlay, 1916) of Early Cretaceous age consists of about 40 feet of yellowish-gray conglomeratic sandstone that contains pebbles of quartz, chert, and quartzite and logs of agatized wood; locally it consists of medium-grained sandstone with lenses of variegated claystone. A widespread disconformity separates the Lytle formation from the South Platte formation.

The South Platte formation (Waagé, 1955) of Early Cretaceous age is subdivided into the Plainview sandstone member (56 feet), an unnamed shaly unit (64 feet), the Kassler sandstone member (72 feet), the Van Bibber shale member (20 feet), and an unnamed sandstone unit at the top (85 feet) (Waagé, 1955, p. 46). The Plainview sandstone member contains thick beds of light-gray and yellowish-gray fine-grained crossbedded sandstone with gray clayey siltstone beds and partings. The unnamed middle shaly member is primarily gray and brown siltstone and fine-grained sandstone. Near the top it contains dark-gray silty shale with some marine fossils. Waagé (1955, p. 41) identified *Inoceramus bellvuensis* Reeside, *Inoceramus comancheanus* Cragin, and *Pteria salinensis* White from this shale. In addition, a mold of an echinoid was found in float from the shale in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W. (pl. 2, loc. 2). The Kassler sandstone member, whose type locality is at the north end of the quadrangle, consists of thick beds of yellowish-gray fine- to coarse-grained cross-laminated friable sandstone that contains clay pellets and has a chert and quartzite pebble conglomerate at the base. The Van Bibber shale member contains as many as five minable refractory clay beds interspersed with thin yellowish-gray sandstone beds. The clay is finely laminated and, where fresh, is medium gray to medium dark gray; where weathered, it is white. The unnamed sandstone unit at the top of the South Platte formation contains at its base a 45-foot thick light-gray, tabular to massive, fine- to medium-grained, crossbedded sandstone that contains scattered clay pellets. This sandstone is quarried for silica sand. Crossbedded sandstone from the same horizon in the southern part of the area was used for dimension stone, a purpose for which it is especially adapted because of its hardness and well-formed system of joints. Above this unit are thin gray soft fine-grained sandstone beds interlayered with thin beds of clayey siltstone and porcellanite.

GRANEROS SHALE, GREENHORN LIMESTONE, AND CARLILE SHALE

The Graneros shale, Greenhorn limestone, and Carlile shale are about 550 feet thick and are equivalent to the Benton shale. They were not mapped separately because of poor outcrops. The best exposures in the quadrangle are in the SW¼ sec. 19, T. 7 S., R. 68 W., and in sec. 35, T. 6 S., R. 69 W. These formations are described in stratigraphic sections 11, 12, and 13.

GRANEROS SHALE

The Graneros shale (Gilbert, 1896, p. 564) lies conformably on the South Platte formation. The lower 15 feet is dark-gray fissile noncalcareous siliceous silty shale that contains light yellowish-orange bentonite layers near the top. Thin nodular sandstone beds lie in the lower part and platy sandstone beds in the upper part. This lower 15-foot-thick unit contains diagnostic fish scales that indicate that it is equivalent to the Mowry shale of Early Cretaceous (Albian) age (Dane and others, 1937, p. 210) (pl. 3).

The upper 210 feet of the Graneros shale is of Late Cretaceous (Cenomanian) age (Cobban and Reeside, 1952, chart 10b) and is composed of dark-gray soft clayey noncalcareous shale that contains several layers of black noncalcareous hard siltstone. Cone-in-cone concretions that weather dark yellowish-brown are 105 feet above the base. Thin beds of light-gray or yellowish-orange bentonite are abundant in the upper part. The formation is stained by rusty beds and veins.

GREENHORN LIMESTONE

The Greenhorn limestone (Gilbert, 1896, p. 564) contains, in ascending order, the Lincoln limestone member, the Hartland shale member, and the Bridge Creek limestone member.

The Lincoln limestone member (Logan, 1897, p. 216; Rubey and Bass, 1925, p. 47) of Cenomanian age is about 125 feet thick and contains many thin layers of pale yellowish-brown and dark-gray platy calcarenite that is composed mostly of shell fragments.

At the base of the formation is an extensive 1-foot-thick dark yellowish-orange flaky soft bentonite that is called the marker bentonite in the Denver Basin (Sternberg and Crowley, 1954, p. 38). Overlying the marker bentonite is a pale yellowish-brown oyster-shell-bearing calcarenite bed about 2 inches thick composed of broken shells of *Ostrea beloiti* Logan and local impressions of a large ammonite with large horns, *Acanthoceras*? sp. (USGS Mesozoic loc. D1). The calcarenite has a petroliferous smell when broken. Locally, thin lenses of the calcarenite bed also underlie the marker bentonite and are included in the Lincoln.

The main part of the Lincoln is made up of olive-gray platy calcareous shale that weathers yellowish orange and clayey, and thin beds of very light gray and yellowish-orange bentonite. At the top is a persistent thin platy petroliferous calcarenite bed composed of calcite prisms of *Inoceramus* shells, bones and teeth of shell-crushing sharks, and foraminifera. *Inoceramus pictus* Sowerby, a small clam with evenly spaced fine growth lines, *Ostrea elegantula* Newberry, a smooth-shelled small oyster, and *Calycoceras canitaurinum* (Haas)?, a coarsely ribbed large ammonite, were collected at USGS Mesozoic loc. D2.

The Hartland shale member (Bass, 1926, p. 33) of Cenomanian age is composed of about 60 feet of gray fissile calcareous fossiliferous shale that contains abundant paper-thin calcarenite layers, some thin yellowish-gray crystalline platy limestone beds, and some thin yellowish-orange bentonite beds. *Inoceramus pictus* was identified. Ruth Todd of the U.S. Geological Survey also identified *Thalmaninella greenhornensis* (Morrow) of Cenomanian to early Turonian age.

The Bridge Creek limestone member (Bass, 1926, p. 67) of Turonian age is about 130 feet thick and contains 7 or 8 beds of gray massive hackly or nodular, finely crystalline limestone about 6 inches to 2 feet thick, separated by bluish-gray nodular or thin-bedded calcareous shale. The upper beds in the Bridge Creek contain *Inoceramus labiatus* (Schlotheim), a slender clam, and *Ostrea* sp., an oyster (USGS Mesozoic loc. D1088); the lower beds contain *Sciponoceras gracile* Shumard at other nearby localities.

CARLILE SHALE

The Carlile shale (Gilbert, 1896, p. 565) of Turonian age contains, in ascending order, the Fairport chalky shale member, the Blue Hill shale member, and the Codell sandstone member.

The Fairport chalky shale member (Rubey and Bass, 1925, p. 16, 40) contains about 45 feet of grayish-yellow thick-bedded nodular chalky marl that weathers pale yellowish orange and clayey; *Inoceramus labiatus*, *Ostrea* sp., and *Collignoniceras*? sp. were found near the base of this member at USGS Mesozoic loc. D1089.

The Blue Hill (?) shale member (Logan, 1897, p. 218) includes about 8 feet of dark-gray blocky noncalcareous silty shale with a thin olive-gray fine-grained sandstone at the base. The shale contains rusty brown iron-stained beds and streaks.

The Codell sandstone member (Bass, 1926, p. 28, 64; Dane and Pierce, 1933) is a gray, finely crystalline, irregularly bedded to massive hard calcarenite that is only 2 feet thick in this area. It weathers pale yellowish brown and is very resistant to erosion. Sand grains and small quartz and phosphatic pebbles were observed in it. Shark teeth, fish scales, and shell fragments are abundant; the rock generally breaks around the shell fragments. *Prionocyclus wyomingensis* Meek, *Ostrea* (*Alectryonia*) *lugubris* Conrad, and *Scaphites whitfieldi* Cobban were collected at USGS Mesozoic locs. D1086 and D1087.

According to Johnson (1930), the Carlile shale is overlain disconformably by the Fort Hays limestone member of the Niobrara formation. Apparently two scaphite zones, *Scaphites nigricollensis* Cobban and *Scaphites corvensis* Cobban, are missing from the Front Range section as a result of this disconformity (pl. 3; Cobban and Reeside, 1952, chart 10b).

11. *Graneros shale, Greenhorn limestone, and Carlile shale in the SW¼SW¼ sec. 19, T. 7 S., R. 68 W.*

Carlile shale:

	Feet
Codell sandstone member:	
11. Calcarenite, gray; weathers brown; massive; contains worm tubes, pieces of mollusks; made up primarily of calcite prisms from *Inoceramus* shells	1.0

11. *Graneros shale, Greenhorn limestone, and Calile shale in the SW¼SW¼ sec. 19, T, 7 S., R 68 W.*—Continued

	Feet
Carlile shale—Continued	
Blue Hill(?) shale and Fairport chalky shale members of the Carlile shale, and the Bridge Creek limestone member of the Greenhorn limestone:	
10. Shale, gray, most covered. This interval is slightly thicker than normal because of duplication by faulting	194.0
9. Limestone, light-gray, hard, finely crystalline; breaks into angular pieces; base of Bridge Creek limestone member	2.0
Thickness of Blue Hill(?) shale and Fairport chalky shale members of the Carlile shale and the Bridge Creek limestone member of the Greenhorn limestone	196.0
Hartland shale member:	
8. Shale; weathers yellowish gray; calcareous, poorly exposed	37.0
7. Limestone, gray, thin-bedded; weathers yellowish gray	.2
6. Shale; weathers yellowish gray; calcareous; mostly covered	24.6
Thickness of Hartland shale member	61.8
Lincoln limestone member:	
5. Limestone, gray, platy, finely crystalline; weathers grayish orange; contains ammonites, *Inoceramus pictus* (USGS Mesozoic loc. D2)	.4
4. Shale; weathers yellowish gray; calcareous; mostly covered	125.0
3. Limestone, gray, medium-crystalline; weathers dark yellowish orange; composed almost entirely of oyster shells, *Ostrea beloiti, Acanthoceras* sp (USGS Mesozoic loc. D1)	.1
Thickness of Lincoln limestone member	125.5
Graneros shale:	
2. Shale; weathers yellowish gray; calcareous	17.0
1. Shale, black, fissile, clayey; weathers olive gray; lower part is equivalent to the Mowry shale; mostly covered	211.0
Thickness of Graneros shale	228.0

12. *Graneros shale at Helmer Bros. clay mine, NE¼SW¼ sec. 13, T. 7 S., R. 69 W.*

	Feet
Graneros shale (Mowry shale equivalent) (part):	
5. Shale, medium-gray, silty; limonitic streaks; weathers to small chips	10.0
4. Sandstone, grayish-yellow, blocky, laminated, fine-grained	1.4
3. Shale, medium-gray, blocky; weathers to chips	2.9
2. Sandstone, yellowish-gray, laminated, fine-grained, hard	1.1
1. Sandstone, moderate reddish-brown, ocherous	1.3
Measured thickness of Graneros shale	16.7

13. *Graneros shale, Greenhorn limestone, and Carlile shale, in limestone quarry in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W.*

	Feet
Carlile shale:	
Codell sandstone member:	
38. Limestone, yellowish-gray, nodular; worm tubes, limonite nodules, oyster shells, and shark teeth	1.00
37. Shale, yellowish-gray, fissile	.10
36. Limestone, yellowish-gray, sandy, nodular; worm tubes, oyster shells, and shark teeth fragments	.75
35. Calcarenite, yellowish-brown, sandy, lumpy, nodular, hard; limonite balls; moderate yellowish brown, crystalline in lower part; fossiliferous; contains *Ostrea lugubris, Prionocyclus wyomingenis* (USGS Mesozoic loc. D1098)	1.7
Thickness of Codell sandstone member	3.55
Blue Hill(?) shale member:	
34. Shale, dark-gray, blocky, silty, noncalcareous; rusty brown streaks; weathers gray and muddy	8.00
33. Sandstone, olive-gray, fine-grained; weathers gray	.10
Thickness of Blue Hill(?) shale member	8.10
Fairport chalky shale member:	
32. Shale, olive, blocky, thin-bedded, chalky, clayey; weathers tan gray; contains 0.1 ft calcarenite near base. *Collignoniceras*? sp. 8.0 feet above base; *Inoceramus* sp. (USGS Mesozoic loc. D1089)	47.00
Thickness of Carlile shale	58.65
Greenhorn limestone (part):	
Bridge Creek limestone member: (part)	
31. Shale, gray; blocky, calcareous; weathers light gray; contains *Inoceramus labiatus* (USGS Mesozoic loc. D1088)	10.0
Rest of Greenhorn limestone and upper part of Graneros shale covered.	
Graneros shale (part):	
Covered.	
30. Shale, gray and yellowish-orange, clayey, blocky; weathers fissile	27.0
29. Ironstone concretions, dark yellowish-orange, clayey, pisolitic; cone-in-cone around outside; these concretions probably are the same as similar concretions at Pueblo and other places in southern Colorado that contain *Calycoceras*	1.2
28. Shale, gray, clayey, blocky; weathers to thin chips; contains many 2- to 4-in. thick soft bentonite beds that weather fissile	36.0
27. Bentonite, dark yellowish-orange	.9
26. Shale, gray, clayey, blocky; weathers fissile	15.0
25. Ironstone nodules, 0.4-ft-thick, clayey, in dark-gray shale	1.8
24. Shale, dark-gray, clayey, soft; yellowish-orange streaks	5.0
23. Ironstone concretions, dark-gray to yellowish-orange, silty; weather blocky	.7

13. *Graneros shale, Greenhorn limestone, and Carlile shale in limestone quarry in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W.*—Continued

	Feet
Graneros shale (part)—Continued	
22. Shale, dark-gray, clayey, soft	2.0
21. Ironstone nodules, moderate yellowish-brown, clayey, soft centers	1.2
20. Shale, dark-gray, clayey, soft; weathers fissile	11.0
19. Sandstone, grayish-orange, nodular	.1
18. Shale, dark-gray, clayey, platy, soft	1.0
17. Sandstone, grayish-orange, platy, fine-grained	.1
16. Shale, dark-gray, bentonitic	12.5
15. Shale, pale yellowish-brown, nodular, and gray siltstone mottled with brown	1.5
14. Siltstone, very dusky red, platy	.1
13. Shale, pale yellowish-brown, platy	2.0?
(Mowry shale equivalent:)	
12. Bentonite, yellowish-orange	.2
11. Sandstone, yellowish-orange; weathers olive gray, nodular	1.0
10. Shale, black, platy, hard; weathers fissile, medium gray; noncalcareous; contains fish scales	4.0
9. Shale, light olive-gray, fissile, soft	.7
8. Siltstone, yellowish-gray, platy; dark yellowish-orange streaks	2.25
7. Sandstone, yellowish-gray and dark yellowish-orange, platy, unevenly bedded; top surface uneven; contains clay balls	.8
6. Shale, medium light-gray, fissile, and thin sandstone layers	.9
5. Sandstone, nodular, fine-grained, and interlayered medium light-gray to dark yellowish-orange and white shale	1.0
4. Sandstone, dark yellowish-orange to white, massive, fine-grained	.7
3. Shale, light olive-gray and yellowish-brown; sandy near top; carbonaceous	.5
2. Sandstone, light olive-gray, nodular, fine-grained, carbonaceous	.3
1. Siltstone, brownish-gray, carbonaceous	1.6
Measured thickness of Graneros shale	133.05

NIOBRARA FORMATION

The Niobrara formation (Meek and Hayden, 1862, p. 419, 422) of Late Cretaceous age is predominantly marine limestone, chalk, and chalky shale. The lower part is well exposed at many places, but the upper part is poorly exposed. Hard beds at the base, in the middle, and at the top form small hogbacks. The Fort Hays limestone member (Williston 1893, p. 108–109) at the base and the Smoky Hill shale member (Cragin, 1896, p. 51) make up the formation.

FORT HAYS LIMESTONE MEMBER

The Fort Hays limestone member of Coniacian age averages 35 feet in thickness and contains yellowish-gray, dense hard thick massive limestone beds at the base and softer, thin tabular limestone beds at the top. Thin calcareous silty shale beds and bentonite beds separate the limestone beds. The lowest bentonite lies 11 feet above the base. Sandy limestone beds at the base contain clusters of altered pyrite crystals. The lithology of the member is shown in stratigraphic section 14.

Two zones of fossils were found in the member. The lower 15 feet (USGS Mesozoic loc. D1090) contains *Inoceramus* sp. (not *deformis*) and *Ostrea congesta;* the upper 20 feet (USGS Mesozoic locs. D4 and D1091) contains *Inoceramus deformis* Meek and *Ostrea congesta.* Mrs. Cecelia Head, who formerly owned the quarry in the NE¼NW¼SE¼ sec. 2, T. 7 S., R. 69 W. (USGS Mesozoic loc. D1085), loaned to the author an impression of an ammonite said to be found in the middle of the member. W. A. Cobban identified it as *Peroniceras* sp., which is most common in rocks of Coniacian age but is rare in the western interior of the United States.

14. *Niobrara formation in limestone quarry in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W.*

	Feet
Niobrara formation (part):	
Smoky Hill shale member (part):	
38. Shale, yellowish-gray; clayey, calcareous, blocky; weathers to small light-gray chips	8.00
Fort Hays limestone member:	
37. Limestone, yellowish-gray, massive; upper part weathers shaly. *Inoceramus deformis* (USGS Mesozoic loc. D1091)	1.40
36. Shale, yellowish-gray, calcareous	1.25
35. Limestone, yellowish-gray, nodular; weathers shaly; *Inoceramus deformis*	.60
34. Shale, yellowish-gray; weathers to irregular flakes	1.25
33. Limestone, yellowish-gray, massive; *Inoceramus deformis*	1.80
32. Shale, yellowish-gray, platy, hard, calcareous	.40
31. Limestone, yellowish-gray, massive; 1-in. thick shaly parting 5 in. from top; lower 3 in. platy limestone; weathers shaly	1.90
30. Shale, yellowish-gray, hard, calcareous	.20
29. Limestone, yellowish-gray, massive, *Inoceramus deformis*	2.10
28. Shale, yellowish-gray, calcareous; bentonite in lower 2 in	.60
27. Limestone, yellowish-gray, massive, nodular; *Inoceramus deformis*	.80
26. Shale, yellowish-gray, platy; bentonite at base; *Inoceramus deformis*	.90
25. Limestone, yellowish-gray, massive	2.70
24. Shale, yellowish-gray; bentonite in lower 1 in	.25
23. Limestone, yellowish-gray, massive	2.10
22. Shale, yellowish-gray; bentonitic in middle	.20
21. Limestone, yellowish-gray, massive; *Inoceramus deformis, Ostrea congesta*	.60
20. Shale, yellowish-gray, platy; bentonite at base	.50

14. *Niobrara formation in limestone quarry in the SW¼NW¼ sec. 35, T. 6 S., R. 69 W.*—Continued

Niobrara formation (part)—Continued

Fort Hays limestone member—Continued	Feet
19. Limestone, yellowish-gray, massive; weathers hackly; *Inoceramus deformis, Ostrea congesta*	2.00
18. Shale, yellowish-gray, granular, bentonitic	.20
17. Limestone, yellowish-gray, massive; weathers hackly; *Inoceramus* sp. (not *deformis*) (USGS Mesozoic loc. D1090)	1.10
16. Bentonite, grayish yellowish-green, blocky	.75
15. Limestone, yellowish-gray, massive	.40
14. Shale, yellowish-gray, fissile	.20
13. Limestone, yellowish-gray, massive	.30
12. Shale, dusky yellow; bentonite at base	.50
11. Limestone, yellowish-gray, massive; weathers blocky	.75
10. Shale, dusky yellow	.10
9. Limestone, yellowish-gray, massive; platy at base; *Inoceramus* sp. (not *deformis*)	1.50
8. Shale, dusky-yellow, platy to blocky	1.60
7. Limestone, yellowish-gray, massive	5.20
6. Shale, yellowish-gray, fissile	.20
5. Limestone, yellowish-gray, massive	.70
4. Limestone, yellowish-gray, nodular; worm tubes	.50
3. Shale, yellowish-gray, silty, fissile, calcareous	.20
2. Limestone, yellowish-gray, nodular; worm tubes	.40
1. Shale, yellowish-gray, fissile	.20
Thickness of Fort Hays limestone member	34.35

The Fort Hays limestone generally dips 60° NE.; in the southern part of the area, however, it is overturned to the east and cut out by a thrust fault. In a quarry in the NE¼NE¼ sec. 24, T. 7 S., R. 69 W., the limestone is folded strongly by a bedding-plane fault. In the SE¼ sec 30, T. 7 S., R. 68 W., the limestone is brecciated by the Jarre Creek fault and recemented with calcite.

SMOKY HILL SHALE MEMBER

The Smoky Hill shale of Coniacian and Santonian age conformably overlies the Fort Hays limestone and is 535 feet thick in this area (pl. 2). The member is best exposed in the NE¼ sec. 27, T. 6 S., R. 69 W., and in the SW¼ sec. 19, T. 7 S., R. 68 W., along a branch of the Jarre Creek fault. The lithology of the member is shown in stratigraphic section 14.

The member consists of chalky shale with several thick beds of chalky limestone. A yellowish-gray soft calcareous shale in the lower 22 feet contains thin beds of limestone similar to those of the Fort Hays that weather hackly and contain *Inoceramus deformis* and *Ostrea congesta*. Next is yellowish-gray chalky fissile shale that contains thin bentonite beds and a yellowish-gray chalky platy speckled limestone about 70 feet above the base. About 135 feet above the base is a very pale orange thin-bedded speckled chalky ridge-forming limestone 17 feet thick that weathers to a sticky calcareous clay. The limestone contains *Clioscaphites choteauensis* Cobban and large shells of *Inoceramus platinus* Logan that are covered with shells of *Ostrea congesta*.

Clioscaphites choteauensis is shown by Cobban and Reeside (1952, chart 10b) as being expected near the top of the Smoky Hill. Inasmuch as it was found in the middle instead of near the top, in the Kassler quadrangle the characteristic faunas of the Telegraph Creek formation and Eagle sandstone (pl. 3) may lie in the upper part of the Smoky Hill rather than in the lower part of the Pierre shale. The upper half of the Smoky Hill member contains grayish-orange fissile to thick-bedded chalky shale. At the top is yellowish-orange thick-bedded speckled chalky ridge-forming limestone that weathers to large irregular flakes and slabs and then to calcareous clay. Unweathered limestone is dark gray. The upper limestone contains smooth baculites, *Ostrea congesta*, *Inoceramus* sp., and fish scales and bones.

Chalk beds in the Smoky Hill are contorted and fractured. In the SW¼SW¼ sec. 19, T. 7 S., R. 68 W., the dip varies 36° in 12 feet of section—from a normal dip of 60° NE., to an overturn of 84° SW. In the SW¼ sec. 30, T. 7 S., R. 68 W., the member is drastically brecciated by the Jarre Creek fault and the fragments are recemented by calcite. Small fractures in the chalk at other places are also recemented by calcite.

Analyses of the chalk that were considered typical by Elias (1931, p. 38–39) show an average of 85 percent calcium carbonate, most of the other 15 percent being insoluble in acids. No quarries were opened in this clayey chalk in the Kassler quadrangle.

The names Fort Hays limestone and Timpas limestone have been considered to be synonymous and are used interchangeably by many geologists, but the upper boundary of the type Timpas limestone is not coincident with the upper boundary of the type Fort Hays limestone. Gilbert (1896, p. 566–567) defined the Timpas limestone as the lower 175 feet of the Niobrara group. He recognized 50 feet of limestone beds at the base that are now called Fort Hays, but he also included in his Timpas a hogback-forming white limestone and underlying shale of the Smoky Hill; he stated that the upper limit of the Timpas was indefinite even at the type locality. Away from the type locality I found that the white limestone in the Smoky Hill becomes softer and even more indefinite. Along the mountain front near Kassler, it forms only a local low ridge between the Fort Hays and the middle chalky limestone rather than the prominent bench that is common south of the

Arkansas River. Over the years this erroneous interpretation of Gilbert's nomenclature has been used in many articles on Front Range geology. The proper relationship of these beds is shown in Cobban and Reeside (1952, chart 10b).

The conformable contact of the Smoky Hill shale and the Pierre shale is marked by a change from yellowish orange to olive gray and from chalk to calcareous shale. The change can be seen in a cut at the north edge of the quadrangle.

PIERRE SHALE

The Pierre shale (Meek and Hayden, 1862, p. 419, 424), of Late Cretaceous Campanian to Maestrichtian age, is predominantly olive-gray clayey shale and sandstone of marine origin. Limestone and ironstone concretions are abundant and characteristic of the Pierre. Fossils are abundant and were collected intensively.

Faunal zonation of the Pierre for this quadrangle was based partly on earlier work by Cobban in other areas and partly on the local fossils. Most of the faunal zones are based on *Baculites*, but some are based on other ammonites (table 2) that have equal value as zone fossils. Thirteen zone lines, including one of phosphatic nodules, are shown on the geologic map (pl. 2). One extra fossil zone, *Baculites obtusus*, is shown on plate 3 but not on the geologic map. The character of the structural disturbance in the Pierre shale caused by the Jarre Creek fault (pl. 2) became known only after the faunal zones were traced in the field. Until that time a questionable single fault had been drawn through the Pierre.

The Pierre shale is well exposed only in the southern part of the quadrangle where, unfortunately, the rocks are faulted and a complete stratigraphic section cannot be measured. No beds are resistant enough to form ridges, but the formation is well exposed on the flanks of eroded pediments and in the banks of streams. The best outcrops are in sec. 19, T. 7 S., R. 68 W., and serve as the basis for the description below.

The Pierre shale consists of about 5,200 feet of marine sediments which contain five major groups of strata. Table 3 shows the main subdivisions of these five units.

The basal part of the Pierre shale consists of 1,200 feet of olive-gray clayey fissile, chiefly noncalcareous shale (table 3). The lower 80 feet is calcareous clayey shale and thin bentonite interbeds; from 80 to 500 feet above the base the shale is iron-stained, noncalcareous, and silty and has beds of bentonite that contain selenite crystals. Peculiar crystals from the SE¼SW¼ sec. 19, T. 7 S., R. 68 W., are flattened so that the c axis is shortened and the forms (110) and (010) nearly eliminated. The resultant crystals are dominantly a combination of the forms (111) and (103). The lower 500 feet of shale is generally unfossiliferous. A horizon between 500 and 600 feet is distinguished by *Baculites asperiformis* Meek, and is characterized lithologically by large brown septarian limestone concretions, small gray limestone concretions, and hard fissile lenticular siltstone beds. At 600 feet above the base large rough hard gray petroliferous crystalline masses of limestone were found. The term "tepee butte limestone" is used for this type of limestone because near Pueblo the large masses weather to cone-shaped hills that were called tepee buttes by Gilbert (1896, p. 569). These tepee butte limestones weather to dark yellowish-orange cavernous fragments from which project casts of gastropods, pelecypods, and cephalopods, including *Baculites asperiformis* Meek.

Between 600 and 1,200 feet above the base is slightly calcareous, blocky shale that contains abundant clayey ironstone concretions. The smooth ovate *Baculites* n. sp. lies between 800 and 1,100 feet above the base within this horizon.

The medium-grained olive-brown Hygiene sandstone member (Fenneman, 1905, p. 31–33) is exposed from 1,200 to 1,775 feet above the base. Its outcrop belt is covered by a profuse growth of yuccas. It consists of thin-bedded friable micaceous shaly sandstone with a few thick-bedded hard limonite- or calcite-cemented sandstone beds. Small crystals of marcasite are abundant in the unweathered greenish-gray sandstone. Where weathered, the sandstone is dusky yellow and limonitic. Fossils apparently were the centers for calcite concentration in the sandstone, for nearly all fossils are found in the centers of dark greenish-gray hard sandy limestone concretions. Weathered concretions are light greenish gray and split around the fossils. Interconnected crevices in the concretions contain marcasite crystals and encrustations of clear barite.

From 1,200 to 1,400 feet the Hygiene is a sparsely fossiliferous, friable olive-brown shaly sandstone that has some platy calcareous hard sandstone beds in its lower part, but in the upper part small limestone concretions and thinly laminated beds are abundant. They commonly contain well-preserved *Inoceramus sublaevis* Hall and Meek. The thin limestone beds locally thicken abruptly to form large masses of rough gray crystalline tepee butte limestone. *Baculites gregoryensis* Cobban is found in beds from 1,200 to 1,400 feet in the Hygiene sandstone member. At 1,400 feet *Baculites scotti* Cobban is first found in limestone beds at the base of a thick section that is characterized by hard thin sandy ironstone beds and ironstone concretions. This ironstone unit lies from 1,400 to 1,775 feet above the base of the Pierre and also contains *B. scotti*. The ammonites

TABLE 2.—*Stratigraphic distribution by ammonite zones of fossils of the Pierre shale*

[Numbers refer to fossil localities shown on pl. 2; see also p. 118–120. aff., most closely resembles the species listed; cf., not certainly identified but resembles the species listed; ?, may be the species listed]

Species	*Baculites obtusus* Meek	*Baculites asperiformis* Meek					*Baculites* n. sp.	*Baculites gregoryensis* Cobban									*Baculites scotti* Cobban																		
	17	15	16	18	19	20	21	22	22a	23	24	25	26	27	30	32	28	29	31	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Coelenterata:																																			
Corals																													X						
Molluscoidea:																																			
Bryozoa:																																			
Membranipora sp																																			
Brachiopoda:																																			
Lingula nitida Meek and Hayden																																			
Terebratula helena Whitfield																																			
Mollusca:																																			
Pelecypoda:																																			
Nucula planimarginata Meek and Hayden																																			
sp																												X							
Nuculana evansi (Meek and Hayden)																													cf						
n. sp																																			
Nemodon sulcatinus (Evans and Shumard)																																			
Inoceramus sublaevis Meek and Hayden										X											X							cf				X			
tenuilineatus Hall and Meek								X	X	X			X		X		X	X											X						
aff. *convexus* Hall and Meek								X		X		X	X	X	X			X																	
cf. *cycloides* Wegner								X								X																			
typicus (Whitfield)																																			
saskatchewanensis Warren																	X				X			X			X				X	X			
sagensis Owen																																			
? *fibrosus* (Meek and Hayden)																																			
pertenuis Meek and Hayden																																			
barabini Morton																					X														
balchii Boehm																																			
sp		X																	X	X		X													X
Pteria linguaeformis (Evans and Shumard)																			X		X				X										
sp													X		X														X						
Ostrea inornata Meek and Hayden																																			
sp																																			
Pecten nebrascensis Meek and Hayden																																			
(*Syncyclonema*) *hallii* Gabb																																			
Modiolus meeki (Evans and Shumard)																																			
Crenella elegantula Meek and Hayden																																			
Astarte gregaria (Meek and Hayden)																																			
Lucina occidentalis Morton															X						X			X				X		X					X
subundata Hall and Meek																					X		X					X		X					
sp																													X						
Tellina scitula Meek and Hayden																																			
Geltena gracilis (Meek and Hayden)																	X				X	X		X	X			X							
sp										X		X	X										X							X					
Pelecypod, genus undetermined					X																X							X		X					
Scaphopoda:																																			
Dentalium gracile Hall and Meek																															X				
Scaphopod, undetermined																																			
Gastropoda:																																			
Margaritella n. sp																																			
Polinices? sp																								X							X				
Amauropsis paludinaeformis (Hall and Meek)																																			
Anchura? sp																													X						
Drepanochilus nebrascensis (Evans and Shumard)																					X			X						X					
sp																																			
Aporrhais meeki Whitfield					X																X														
Piestochilus sp																															X				
Gastropod, undetermined																																			
Cephalopoda:																																			
Baculites obtusus Meek	?																																		
asperiformis Meek					X	X																													
n. sp. (weakly ribbed venter)							cf																												
gregoryensis Cobban								X			X		X		X																				
scotti Cobban																	X				X	X	X	X			X	X		X	X	X	X	X	X
crickmayi Williams																																			
rugosus Cobban																																			
eliasi Cobban																																			
grandis Hall and Meek																																			
clinolobatus Elias																																			
sp		X	X	X						X				X				X											X						
Exiteloceras jenneyi (Whitfield)																																			
Solenoceras mortoni (Meek and Hayden)																																			
sp																																			
Oxybeloceras crassum (Whitfield)																												X		X	X				
sp																											X								
Didymoceras nebrascense (Meek and Hayden)																																			
n. sp. (tightly coiled)																												X		X	X				
n. sp. (loosely coiled)																												X		X					
sp													X																X						

TABLE 2.—*Stratigraphic distribution by ammonite zones of fossils of the Pierre shale*—Continued

Species—Continued	*Baculites obtusus* Meek	*Baculites asperiformis* Meek					*Baculites* n. sp.	*Baculites gregoryensis* Cobban									*Baculites scotti* Cobban																		
	17	15	16	18	19	20	21	22	22a	23	24	25	26	27	30	32	28	29	31	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Mollusca—Continued																																			
Cephalopoda—Continued																																			
Hoploscaphites n. sp.				X	X																											X	X		
Discoscaphites n. sp.																																			
sp.																																			
Anapachydiscus? complexus (Hall and Meek)																					X			X											
Menuites? n. sp.																					X			X											
Pachydiscid ammonite																						X	X		X	X			X						
Placenticeras meeki Boehm																																			
intercalare (Meek and Hayden)																																			
sp.										X																									
Sphenodiscus sp.																																			
Crustacea:																																			
Arthropoda:																																			
Dakoticancer sp.																																			
Fish:																																			
Ichthyodectes sp. (scales)			X																																
Bones																																			
Vertebra																														X					
Teeth																																			
Petrified wood																																			

Species	*Baculites scotti* Cobban—Continued					*Didymoceras nebrascense* (Meek and Hayden)		*Didymoceras stevensoni* (Whitfield)	*Exiteloceras jenneyi* (Whitfield)						*Baculites compressus* Say s.l.	*Baculites eliasi* Cobban		*Baculites baculus* Meek and Hayden	*Baculites grandis* Hall and Meek							*Baculites clinolobatus* Elias										
	49	50	51	52	53	54	56	55	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Coelenterata:																																				
Corals												X																								
Molluscoidea:																																				
Bryozoa:																																				
Membranipora sp.																										X										
Brachiopoda:																																				
Lingula nitida Meek and Hayden																																				X
Terebratula helena Whitfield																																	X	X		
Mollusca:																																				
Pelecypoda:																																				
Nucula planimarginata Meek and Hayden																																	X			
sp.																															X					
Nuculana evansi (Meek and Hayden)																																				
n. sp.											X	X																								
Nemodon sulcatinus (Evans and Shumard)												X																								
Inoceramus sublaevis Meek and Hayden																																				
tenuilineatus Hall and Meek																																				
aff. *convexus* Hall and Meek																																				
cf. *cycloides* Wegner																																				
typicus (Whitfield)																		X																		
saskatchewanensis Warren	X	X			X																															
sagensis Owen															X																					
? *fibrosus* (Meek and Hayden)																										X		X	X		X			X	X	
pertenuis Meek and Hayden								X																												
barabini Morton																																				
balchii Boehm										X																										
sp.							X		X		X	X		X			X																	X		
Pteria linguaeformis (Evans and Shumard)																																				
sp.																																				
Ostrea inornata Meek and Hayden							X																													
sp.								X			X	X		X																X						
Pecten nebrascensis Meek and Hayden																																	X			
(*Syncyclonema*) *hallii* Gabb												X																								
Modiolus meeki (Evans and Shumard)																																	X			
Crenella elegantula Meek and Hayden																																	X			

TABLE 2.—*Stratigraphic distribution by ammonite zones of fossils of the Pierre shale*—Continued

Species—Continued	*Baculites scotti* Cobban—Continued					*Didymoceras nebrascense* (Meek and Hayden)		*Didymoceras stevensoni* (Whitfield)	*Exiteloceras jenneyi* (Whitfield)						*Baculites compressus* Say s.l.	*Baculites eliasi* Cobban		*Baculites baculus* Meek and Hayden	*Baculites grandis* Hall and Meek							*Baculites clinolobatus* Elias										
	49	50	51	52	53	54	56	55	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Mollusca—Continued																																				
Pelecypoda—Continued																																				
Astarte gregaria (Meek and Hayden)																																	X			
Lucina occidentalis Morton		X																																		
subundata Hall and Meek						X																														
sp.											X	X	X																				X			
Tellina scitula Meek and Hayden																																	cf			
Geltena gracilis (Meek and Hayden)		X																X	X	X	X			X			X	X	cf	X	X					
sp.										X							X								?									X		?
Pelecypod, genus undetermined																																				
Scaphopoda:																																				
Dentalium gracile Hall and Meek												X																								
Scaphopod, undertermined												X																								
Gastropoda:																																				
Margaritella n. sp.											X																									
Polinices? sp.																																	X			
Amauropsis paludinaeformis (Hall and Meek)											X	X																								
Anchura? sp.																																				
Drepanochilus nebrascensis (Evans and Shumard)																																				
sp.																																	?			
Aporrhais meeki Whitfield																																				
Piestochilus sp.																																				
Gastropod, undetermined												X																						X		
Cephalopoda:																																				
Baculites obtusus Meek																																				
asperiformis Meek																																				
n. sp. (weakly ribbed venter)																																				
gregoryensis Cobban																																				
scotti Cobban	X	X	X		X																															
crickmayi Williams						X																														
rugosus Cobban													X	X																						
eliasi Cobban																cf	cf																			
grandis Hall and Meek																			X		X	X	?	X	X											
clinolobatus Elias																											X	X			X	X	X	X		
sp.							X	X	X		X	X						X								X										X
Exiteloceras jenneyi (Whitfield)											X	X	X																							
Solenoceras mortoni (Meek and Hayden)							X				X	X																								
sp.						X				X																										
Oxybeloceras crassum (Whitfield)																																				
sp.								X	X					X																						
Didymoceras nebrascense (Meek and Hayden)						X	X																													
n. sp. (tightly coiled)																																				
n. sp. (loosely coiled)																																				
sp.								X						X																						
Hoploscaphites n. sp.		X		X	X			X				X	X					X																X		
Discoscaphites n. sp.																																	X			
sp.																								X		X				X						
Anapachydiscus? *complexus* (Hall and Meek)																																				
Menuites? n. sp.																																				
Pachydiscid ammonite																																				
Placenticeras meeki Boehm														X																						
intercalare (Meek and Hayden)												cf																								
sp.													X																							
Sphenodiscus sp.																																		X		
Crustacea:																																				
Arthropoda:																																				
Dakoticancer sp.																																	X			
Fish:																																				
Ichthyodectes sp. (scales)											X																									
Bones																						X														X
Vertebra																																				
Teeth																																				X
Petrified wood																																				X

TABLE 3.—*Lithology and faunal zones of the Pierre shale*

Unit	Height of top of unit above base of section (feet)	Lithology	Fossils
Shale, gray, clayey and silty	5,200	Contains phosphatic nodules and ironstone beds.	
Sandstone, shaly, olive-brown	4,700	Contains large calcareous sandstone concretions.	*Baculites clinolobatus*, *Inoceramus? fibrosus*.
Shale, olive-gray, clayey	4,050	Contains layers of cone-in-cone and aragonite, and ironstone concretions.	*Baculites grandis* from 4,050 to 3,900 ft.
	3,740	Contains brown limestone concretions.	*Inoceramus typicus* at 3,740 ft.
	3,450	Blocky.	*Baculites eliasi* at 3,450 ft.
	3,115	Silty.	
	2,800	Chalky; contains limestone concretions.	
	2,700	Contains gray limestone concretions.	*Placenticeras meeki* at 2,530 ft. *Exiteloceras jenneyi* at 2,430 ft.
	2,200	Contains ironstone concretions.	*Didymoceras nebrascense*
	2,150	Contains ironstone concretions and has sandy shale at top.	
	1,825	Contains tepee buttes	*Baculites scotti*.
Hygiene sandstone member, olive-brown	1,775	Shaly; contains thin, hard ironstone layers and concretions.	*Anapachydiscus? complexus*, *Menuites?* n. sp. from 1,775 to 1,575 ft.; *Baculites scotti* 1,575 to 1,400 ft.
	1,400	Shaly, platy, calcareous; contains tepee buttes and limestone beds in upper part.	*Baculites gregoryensis*, *Inoceramus sublaevis*.
Shale, olive-gray, clayey	1,200	Calcareous, blocky; contains clayey ironstone concretions.	*Baculites* n. sp. from 1,100 to 800 ft.
	600	Septarian limestone concretions and siltstone beds.	*Baculites asperiformis*.
	500	Silty, noncalcareous.	
	80	Calcareous, bentonitic.	

Anapachydiscus? complexus (Hall and Meek) and *Menuites?* n. sp. are 100 to 200 feet below the top of the sandstone.

About 700 feet of olive-gray clayey shale overlies the Hygiene sandstone member. From 1,775 to 1,825 feet the shale contains tepee butte limestone masses more than 15 feet in diameter, and small oval gray dense limestone concretions. *Baculites scotti* Cobban occurs abundantly in the small concretions and in the tepee butte limestone. The clayey shale above the tepee buttes from about 1,825 to 2,150 feet includes a thin belt of sandy shale covered by yuccas. From 2,150 to 2,200 feet, *Didymoceras nebrascense* (Meek and Hayden) is common in yellowish-orange ironstone concretions in the lower part and in gray limestone concretions in the upper part. From 2,200 to 2,700 feet above the base, gray limestone concretions are abundant in olive-gray clayey shale. Moderate yellowish-brown clayey ironstone nodules and thin layers of brown fibrous aragonite and cone-in-cone are scattered on the slopes overlying this part of the section. Large gray tepee butte limestone masses are found in this part of the section in the southern part of the area. Phosphatic nodules shaped like tear drops and dumbbells were noted about 2,700 feet above the base. *Exiteloceras jenneyi* (Whitfield) and *Baculites* n. sp. were found in limestone concretions at 2,430 feet above the base; at 2,530 feet the large ammonite *Placenticeras meeki* Boehm is abundant.

Clayey shale constitutes the next 415 feet of strata from 2,700 to 3,115 feet above the base. From 2,700 feet to 2,800 feet, gray hard dense limestone concretions occur in three or four layers in light olive-gray sandy chalky shale. They contain *Baculites corrugatus* Elias in the Littleton quadrangle but are too poorly exposed to yield fossils in the Kassler quadrangle.

The overlying 315 feet of Pierre shale is poorly exposed in the northern part of the area and probably faulted out in the southern part of the area. An outcrop in the SW¼NW¼ sec. 36, T. 6 S., R. 69 W., shows light olive-gray silty shale that contains moderate yellowish-brown concretionary ironstone layers and layers of pale yellowish-brown aragonite and yellowish-gray cone-in-cone.

Above 3,115 feet, the strata again become olive-gray clayey shale, and this lithology extends to 4,200 feet above the base. Ironstone concretions and small gray limestone concretions lie in a gray blocky clayey shale from 3,115 to 3,450 feet; at about 3,450 feet they contain *Baculites eliasi* Cobban. Yellowish-brown limestone concretions in olive-gray clayey shale lie between 3,450 and 3,740 feet. At about 3,740 feet in the zone of *Baculites baculus* Meek and Hayden (tables 2 and 3), the concretions contain many small, sharply ribbed *Inoceramus typicus* (Whitfield). The shale is olive gray and clayey, and contains cone-in-cone layers, aragonite layers, and reddish-brown and black ironstone concretions from 3,740 to 4,050 feet. At 3,900 to 4,050 feet the ironstone concretions contain *Baculites grandis* Hall and Meek.

The upper part of the formation is dusky yellow or olive-brown shaly sandstone from 4,050 to 4,700 feet, and olive-gray clayey or silty shale from 4,700 to 5,200 feet—the contact of the Fox Hills sandstone. *Baculites clinolobatus* Elias, the highest baculite, and *Inoceramus? fibrosus* (Meek and Hayden), which are characteristic of the Mobridge member of the Pierre shale in South Dakota, lie in large gray calcareous sandstone concretions between 4,050 and 4,700 feet. Above the sandy beds, about 500 feet of blocky light olive-gray clayey shale contains ironstone nodules and layers (see stratigraphic sections 15 and 18). One of these layers, which crops out in the NE¼SE¼ sec. 19, T. 7 S., R. 68 W., and in the NE¼SW¼ sec. 29, T. 7 S., R. 68 W., is 27 feet thick and is composed of innumerable moderate yellowish-brown pea-sized limonite nodules and phosphatic pebbles. This layer lies about 290 feet below the top of the Pierre shale and is an excellent marker bed. Above the limonite layer is light olive-gray silty shale and thin limestone interbeds, one of which contained *Yoldia evansi* (Meek and Hayden) and comminuted plant fragments.

15. *Pierre shale on slope of pediment in the NE¼SW¼ sec. 29, T. 7 S., R. 68 W.*

	Feet
Fox Hills sandstone.	
Pierre shale (part):	
4. Covered; partly sandstone and shale	61.0
3. Limestone, yellowish-gray, blocky, dense, hard; contains plant fragments, *Yoldia evansi*	.5
2. Covered; presumed to be olive-drab limonitic sandy shale	157.0
1. Shale, moderate yellowish-brown, limonitic; limonite layers; made of one-fourth in. limonite nodules and phosphatic pebbles as much as 2 in. in maximum dimension, some of which are casts of mollusks, *Baculites clinolobatus*, *Geltena* sp	27.0
Measured thickness of Pierre shale	245.5

The contact of the Pierre shale with the Fox Hills sandstone is so poorly exposed that its position could only be inferred from the texture of the overlying soil. The lithology in the contact zone is gradational; therefore, the Pierre contact was placed at the top of the highest marine clay shale and the base of the lowest massive sandstone that contains large hard brown sandstone concretions.

Phosphatic nodules are particularly abundant in the upper part of the Pierre. Beds of nodules lie in both of the upper two faunal zones. Good outcrops of the phosphatic nodule beds are in the NE¼SW¼ sec. 18, T. 7 S., R. 68 W., in the SE¼SE¼ sec. 19, T. 7 S., R. 68 W., and along the Jarre Creek fault in a slice of Pierre that is only 30 feet thick in the SW¼SE¼ sec. 32, T. 7 S., R. 68 W. The pebbles are rounded and abraded and include phosphatic casts of *Geltena* sp. and *Baculites clinolobatus* and teeth and bones of fish. Some pebbles have holes that were bored by worms on the floor of the ocean.

The pebbles were analyzed chemically and by X-ray diffraction. J. P. Schuch of the U.S. Geological Survey found that the dull granular pebbles contain 12.4 percent P_2O_5 and the vitreous pebbles as much as 25 percent P_2O_5. A. J. Gude 3d of the U.S. Geological Survey found by X-ray that the pebbles contain very abundant apatite and minor amounts of calcite and quartz.

FOX HILLS SANDSTONE

The Fox Hills sandstone (Meek and Hayden, 1862, p. 419, 427) of Late Cretaceous age is predominantly brackish-water marine sandstone. It is best exposed in the NE¼SW¼ and the SE¼NW¼ sec. 29, T. 7 S., R. 68 W., and in a gully in the SE¼SW¼ sec. 7, T. 7 S., R. 68 W. (pl. 1). The exposed thickness of the formation is only 30 feet, but 155 feet of covered beds were included, and make a possible thickness of 185 feet. Neither the lower nor the upper contacts were exposed. Stratigraphic sections 16 and 18 illustrate the lithology of the formation.

The formation is divided into a lower sandy shale, a middle ridge-forming sandstone, and an upper soft sandstone. The lower part is mostly soft, olive-brown sandy shale that contains thin limy sandstone layers and carbonaceous plant fragments. The middle part is 29 feet of olive-gray to yellowish-gray fine-grained massive to slabby sandstone. It is friable to hard and is thin bedded; in some places it is crossbedded in thin laminae. The sandstone is composed of subrounded quartz grains that are firmly cemented with calcium carbonate. Cone-in-cone layers lie between some of the sandstone layers. This middle part also contains dark-brown hard calcareous sandstone concretions as large as 4 feet in diameter. The upper part is almost completely covered, but probably is olive-brown or olive-gray soft sandstone. A few poorly preserved brackish-water pelecypods were found in the middle sandstone.

The Fox Hills sandstone is a transitional deposit between the marine Pierre shale and the continental Laramie formation. The upper contact lies under a covered interval, below which is marine sandstone and above which is nonmarine sandstone and coal.

16. *Fox Hills sandstone on slope of pediment in the NE¼SW¼ sec. 29, T. 7 S., R. 68 W.*

	Feet
Fox Hills sandstone (part):	
5. Sandstone, olive-gray, nodular, limonitic; contains laminated clay balls; fine-grained; 1 ft. slabby sandstone at top	8.0
4. Covered; probably shale with cone-in-cone layers	5.0
3. Sandstone, yellowish-gray, massive, fine-grained	1.0
2. Covered; may be soft sandstone	12.0
1. Sandstone, yellowish-gray, slightly crossbedded, friable, fine-grained	3.0
Measured thickness of Fox Hills sandstone	29.0

LARAMIE FORMATION

The Laramie formation (King, 1876) of Late Cretaceous age is predominantly fresh-water siltstone, claystone, sandstone, and coal. The best outcrops are in the center of sec. 29, T. 7 S., R. 68 W., and at the Lehigh Mine along the west border of sec. 20, T. 7 S., R. 68 W., and in sec. 7, T. 7 S., R. 68 W., but the formation is generally covered. The basal contact is not exposed; the upper contact is well exposed at the localities listed above.

The formation is about 660 feet thick and consists of light olive-gray and pale yellowish-brown clayey shale, yellowish-gray friable well-graded sandstone, moderate-brown hard limonitic sandstone, moderate-brown hard limonitic conglomerate, white clean friable conglomerate; and brownish-black lignitic coal beds ranging in thickness from 0 to 6 feet (see stratigraphic sections 17 and 18). The sandstone and fine-grained conglomerate beds consist of medium-grained clean angular to subrounded quartz sand that is loosely compacted and cemented by calcium carbonate or silica. The many concretions and concretionary layers are concentrically banded and range from ¼ inch to 4 feet across.

17. *Laramie formation on slope of pediment in the NE¼SW¼ sec. 29, T. 7 S., R. 68 W.*

	Feet
Laramie formation (part):	
Upper part covered.	
10. Sandstone, moderate-brown, shaly, hard, limonitic; leaf impressions	1.5
9. Covered; limonitic friable sandstone; concretions on surface	75.0
8. Sandstone, yellowish-gray, massive, soft, friable; contains nodules and layers of dark yellowish-orange sandstone	1.7
7. Coal, grayish-black, soft, lignitic	.2
6. Sandstone, pinkish-gray, soft, friable, fine-grained	2.8
5. Coal, brownish-black, soft	.6
4. Shale, pale yellowish-brown, silty	7.6
3. Coal, brownish-black, peaty, soft, impure	1.6
2. Sandstone, yellowish-gray, soft, friable, medium-grained	25.0
1. Covered; may be shale; may be partly Fox Hills sandstone	155.0
Measured thickness of Laramie formation	271.0

18. *Dawson arkose, Laramie formation, Fox Hills sandstone, and Pierre shale in arroyo in the NW¼ SW¼ sec. 20, T. 7 S., R. 68 W.*

[Measured by G. R. Scott and Richard Van Horn. Clay mineral identification by A. J. Gude 3d, USGS laboratory serial number listed after clay mineral. Samples collected by Richard Van Horn]

	Feet
Dawson arkose (part):	
33. Conglomerate, arkosic; has dark yellowish-orange and black clay at base; base covered; montmorillonite (204714)	100.0
32. Covered	28.0
Measured thickness of the Dawson arkose	128.0

18. *Dawson arkose, Laramie formation, Fox Hills sandstone, and Pierre shale in arroyo in the NW¼SW¼ sec. 20, T. 7 S., R. 68 W.*—Continued

	Feet
Laramie formation:	
31. Conglomerate; very light-gray; predominantly dark-gray and red chert	1.0
30. Clay, medium-gray; montmorillonite (204715)	.2
29. Conglomerate; predominantly dark-gray and red chert; upper half very light gray, lower half yellowish brown; montmorillonite (204716)	.9
28. Shale, medium-gray; becomes very sandy and light gray in upper 4 ft.; montmorillonite (204717)	18.0
27. Conglomerate, yellowish-brown; predominantly dark-gray chert; some red chert	3.0
26. Shale, medium-gray; montmorillonite (204718)	7.3
25. Sandstone, light-gray, friable, medium-grained; some iron stains; kaolinite (204719)	3.0
24. Shale, medium-gray; base covered	2.0
23. Sandstone and shale, gray to buff	273.0
22. Sandstone, light-gray, medium-grained, iron-stained; few pea-sized iron concretions; few leaf prints; kaolinite (204720)	6.0
21. Sandstone and shale, gray and buff	32.2
20. Shale, medium- to dark-gray, kaolinite (204721)	4.0
19. Sandstone, light-gray, iron-stained, crossbedded, medium-grained	1.0
18. Shale, medium-gray; upper part dark-brown and carbonaceous; montmorillonite (204722)	10.5
17. Sandstone, light-gray, fine-grained	1.6
16. Shale, dark-gray, carbonaceous	1.0
15. Sandstone, light-gray, iron-stained, medium-grained; kaolinite (204723)	3.3
14. Sandstone and shale, gray and buff	52.0
13. Sandstone, light-gray, medium-grained; kaolinite (204724)	2.0
12. Coal	6.0
11. Covered	42.0
10. Sandstone, light-gray, medium-grained; kaolinite (204725)	4.0
10a. Covered	64.0
Thickness of Laramie formation	538.0
Fox Hills sandstone:	
9. Covered	80.0
8. Shale, medium-gray, clayey, montmorillonite (204726)	6.0
7. Covered	98.0
Thickness of Fox Hills sandstone	184.0
Pierre shale (part):	
6. Shale, light olive-gray, very silty; contains *Discoscaphites* sp. Contains sandstone layers, fine-grained, loose, as much as 1.5 ft. thick, montmorillonite (204727–8)	163.0
5. Limestone, brown; plant-fossil layer	.1
4. Covered	72.0
3. Shale, light olive-gray silty; thin limestone layers, limonite nodules, and limestone nodules; montmorillonite (204729)	54.0
2. Limonite nodules, phosphatic nodules, and shale; brown; montmorillonite (204730)	27.0
1. Shale, light olive-gray, silty, partly covered; montmorillonite (204731)	100.0
Measured thickness of Pierre shale	416.1

The thin sandstone and conglomerate beds are lenticular; the thick shale beds are persistent and regular in thickness. Bedding planes are fairly even in the thick sandstone beds, which commonly part along layers of heavy minerals. Bedding planes are undulatory in the shale, and occur along layers of carbonaceous material.

Abundant leaf prints lie along the bedding planes of sandstone and ironstone beds near the top of the formation. R. W. Brown identified several Upper Cretaceous leaves from an ironstone bed at loc. 85 about 125 feet below the top of the Laramie formation, in the SE¼NW¼ sec. 29, T. 7 S., R. 68 W. They are: *Ficus arenacea* Lesquereux, *F. planicostata* Lesquereux, *F. trinervis* Knowlton, *Anona robusta* Lesquereux, and *Dombeyopsis sinuata* Knowlton.

DAWSON ARKOSE

The Dawson arkose (Richardson, 1912, p. 267–276) of Late Cretaceous and Paleocene age, which consists of conglomerate, sandstone, siltstone, and claystone, underlies almost 18 square miles of the east part of the quadrangle (pl. 2). The conglomeratic lower part of the Dawson forms local ridges (fig. 32); the upper part forms brush-covered badlands. The thickness of the Dawson is about 1,450 feet; of this, approximately the lower 500 feet has been assigned on the basis of fossils to the Cretaceous by Brown (1943). The Cretaceous part of the formation dips northeast at 50° or more. The dip decreases upward in the section, but 400 feet above the base of the Tertiary or 900 feet above the base of the Dawson it is still at least 12°.

Eldridge (1888, p. 97) proposed the name Willow Creek beds and, later, Arapahoe formation for the 600 to 1,200 feet of beds cropping out "from 1 to 3 miles southeast of the mouth of Platte Canon, where it has its greatest and most typical development." This includes almost the entire section between the Laramie formation and the Castle Rock conglomerate, but these beds are here called Dawson arkose because by previous usage the name Arapahoe has been restricted to beds that underlie the Denver formation in the Denver area.

The Dawson arkose in the Kassler quadrangle consists of light-gray, yellowish-gray, moderate-brown, or pale reddish-brown conglomerate (see section 18), sandstone, and clayey shale; the clayey shale contains some green beds and lenses of brownish-black lignitic coal. The lower part of the Dawson is characterized by conglomerate, the upper part by shale. Bedding is irregular, most beds being curved and lenticular. Individual beds range in thickness from 0 to 200 feet; conglomerate beds are the thickest. Shale beds have been thinned and highly contorted by compression during lithification. Channel-and-fill crossbedding is pronounced.

Granitic fragments are abundant in the conglomerate, quartz is common, and chert, rhyolite, quartzite, sandstone, petrified wood, chalcedony, and scoria occur in minor amounts. The greater part of the material consists of pebbles ¼ to 1 inch in diameter. Lesser amounts of sand and cobbles, as much as 6 inches in maximum dimension are present. Biotitic olive-gray clayey shale is common. Because of the fluvial origin of the formation, vertical variations in grain size are extreme. Most of the grains are subrounded, unpolished, and are loosely compacted with much pore space. The grains are cemented with calcium carbonate, silica, opal, or iron oxide. Local increases in silica cement result in quartzite beds, as at Wildcat Mountain, the highest point east of the mountains in this quadrangle. Alteration of feldspar to kaolinite has caused the basal conglomerate to become nearly white.

Leaf prints are the only fossils found in the Dawson arkose of this area. Platy sandstone beds that are cemented by iron oxide are the best source of fossil-leaf prints in the Dawson arkose. The iron oxide may have been altered from iron sulfide that was deposited under swampy conditions. R. W. Brown (written communication, 1950) identified two species of Upper Cretaceous leaves, *Ficus planicostata* Lesquereux and *F. trinervis* Knowlton, from the lower part of the Dawson arkose at loc. 86 in the NW¼SE¼ sec. 29, T. 7 S., R. 68 W. Paleocene leaves were collected by Arthur Lakes of the Colorado School of Mines and later by Brown (1943, p. 73) from a gully in the SE¼NW¼ sec. 20, T. 7 S., R. 68 W. The Paleocene leaf *Rhamnus goldianus* Lesquereux was found in ironstone in the SE¼SW¼SE¼ sec. 30, T. 6 S., R. 68 W.

INTRUSIVE DIKE ROCKS

Two intrusive dike rocks were mapped. One is andesite, which crops out in small bodies throughout the mountains. The other is rhyolite, which crops out at only one place west of Roxborough Park.

ANDESITE

Andesite of Late Cretaceous (?) age crops out as dikes in the western one-fourth of the quadrangle (pl. 2). The dikes are poorly exposed because of a cover of surficial material and vegetation and most of them were mapped on the basis of float. They are discontinuous lens- to tabular-shaped bodies that range in length from 25 feet to 1 mile and in width from 1 to 10 feet. They range in thickness from 1 inch to 10 feet. The wallrocks are metasedimentary and granitic rocks. The dikes that intrude northwest-trending faults are nearly vertical; the dikes that intrude northeast-trending faults are nearly horizontal.

The andesite is pale brown, olive gray, or black. It weathers to dark gray or brownish gray. The texture is generally microporphyritic, but a few megaporphyritic dikes were seen. Most of the feldspar phenocrysts are smaller than 2 mm in length and are alined in a flow structure that is parallel to the walls of the dike. Average composition of the andesite is 50 percent pyroxene, 40 percent andesine, and 10 percent magnetite. The magnetite alters to limonite.

In thin section the andesite is composed of a groundmass of andesine crystals set in a cryptocrystalline mass that appears to be altered basaltic glass (petrography based mostly on an examination of thin sections by R. E. Wilcox, of the U.S. Geological Survey). The groundmass texture is felted. The felted andesine crystals have a composition of An_{33-36} in the centers and An_{27-30} in the rims. Andesine phenocrysts as large as 2 mm in length are set in the groundmass and have a composition of An_{45-48}. The phenocrysts are twinned according to both the albite and the carlsbad laws and some of them are curved. The rock is crowded with opaque skeletal growths of magnetite. Knots of cordierite were seen scattered through the andesite. The cordierite has inclusions of magnetite; and it may have formed from clayey inclusions of fault gouge picked up by the andesite during intrusion. Most of the andesite is lacking in ferromagnesian minerals, but one specimen contained 50 percent pyroxene as groundmass and another about 10 percent hornblende as phenocrysts. Pyrite was seen in one dike that cuts amphibolite.

The andesite in the northwest-trending faults was intruded into fault gouge and was brecciated by later faulting. The dikes are lenticular and continuous. The andesite in the northeast-trending faults was intruded into almost horizontal fractures that contain little if any fault gouge. They are tabular and discontinuous, are jointed perpendicular to the walls, and occur in very small lenses.

The andesite probably correlates with group 1 of the intrusive rocks of the Front Range mineral belt described by Lovering (1935, p. 30). Lovering stated that group 1 is later in age than the Late Cretaceous Laramie formation and older than the Laramide revolution. These dikes may be part of the body of andesite that was eroded and deposited in the Denver formation and in the Dawson arkose; therefore the dikes could be as old as Late Cretaceous.

RHYOLITE

A small weathered body of rhyolite of Paleocene(?) age crops out in the NE¼SE¼ sec. 15, T. 7 S., R. 69 W. (pl. 2). The rock probably was intruded into the granite gneiss along a fault or fracture, which now is covered by the deeply weathered rock in the area of its outcrop. The rock is microporphyritic; the groundmass, which constitutes 91 percent of the rock, is a crystalline aggregate of potassic feldspar and quartz; the phenocrysts which constitute 7 percent of the rock are anorthoclase. Traces of plagioclase, biotite, magnetite, and microcline are present. Flowlines of feldspar crystals are weakly formed in the rock.

STRUCTURE

The rocks of the Kassler quadrangle have been affected by diastrophism at least six times. The earliest and most severe was the Precambrian metamorphism of a series of limestone, shale, and sandstone deposits that now constitute the metasedimentary rocks. The second was later in Precambrian time when the biotite-muscovite granite and all earlier rocks were subjected to cataclastic deformation. The third was in latest Precambrian time when mountains were slightly raised and a system of northwest and northeast-trending faults was formed. The fourth time was in the Early Pennsylvanian when the ancestral Rockies were uplifted and the Precambrian faults were locally reactivated. The fifth time was in the Laramide Revolution when the Rocky Mountains were formed; the Precambrian faults were again reactivated and some new faults were formed in both the crystalline rocks and in the sedimentary rocks. The sixth and last time was in late Pliocene time when the Rocky Mountains were uplifted slightly.

PRECAMBRIAN STRUCTURE

Precambrian diastrophism can be divided into seven episodes that eventually resulted in the formation of a thick mass of banded metasedimentary rocks and three intrusive bodies. Recrystallization and deformation was the first episode of a long cycle of metamorphism that formed rocks of varying composition. A second episode of metamorphism was the metasomatism of the recrystallized sedimentary rocks to produce the granite gneiss and migmatite; the third episode was further metasomatism and plastic flow of the foliated rocks caused by intrusion of the gneissic granite. The fourth episode was intrusion of the biotite-muscovite granite which may be a late phase of intrusion of the gneissic granite. The fifth episode was the cataclastic deformation of all rocks of the age of the biotite-muscovite granite and earlier. The sixth episode was the intrusion of the Pikes Peak granite, which, although it is the largest batholith in the Front Range, has produced only slight metamorphic effects in the foliated rocks. The seventh episode was slight uplift and faulting of the Precambrian rocks.

FAULTS

Faults that are inferred, from the presence of dikes of sandstone, to be of Precambrian age, lie along major fault zones in the southwest part of the quadrangle. These faults trend north or northwest and contain cemented breccia. Most of them were truncated or abut against later sedimentary rocks. The attitude of the faults is nearly vertical and some cross each other or branch. Thick layers of gouge can be seen along the larger faults, but the smaller ones contain only sandstone dikes. The larger faults also have been intruded by andesite dikes and, as indicated by brecciation of the dikes and sandstone, have been active several times since Precambrian time.

FOLDS

Most of the Precambrian folds in the area are either tight and asymmetrical or isoclinal and overturned. In an area about a mile southwest of Kassler a group of smaller folds can be studied in excellent outcrops. The folds are tight and the distance between the crest of an anticline and the trough of a syncline does not exceed 75 feet. Drag folds of many sizes can be measured on the flanks of the larger folds and all the drag folds are similar to the large folds in bearing and plunge. Broad arcuate patterns of some of the rock units in the southern part of the area outline some larger open folds.

The lineations that were measured on folds and minerals in the area were plotted on the lower hemisphere of a Schmidt equal-area net. Concentrations of poles on the net were then contoured to show the average bearings and plunges of the folds. The resulting diagram (fig. 33) shows concentrations of poles at 38° N. 80° W., 65° N. 20° E., 35° N. 25° W., and 45° N. 85° E. The 38° N. 80° W. fold is considered to be the major fold axis b_1 and the 65° N. 20° E. fold is considered to represent the crinkles, a_1, on the flanks of the major fold. The major fold is an isoclinal fold overturned toward the southwest. As shown on figure 33, no lineations have a southwest bearing, but many have a northeast bearing which indicates that the fold limbs generally dip to the northeast.

Minor folds were observed in the NW¼ sec. 3, T. 7 S., R. 69 W., that are imposed on the flanks of the major folds. The bearing of these minor folds is about 30° to 40° more northerly than the major folds. One of the concentrations of poles on figure 33 is at 35° N. 25° W. and may indicate a minor fold system.

The bends in the ridges that trend northwest in the center of sec. 33, N½ sec. 34, and NW cor. sec. 35, T. 7 S., R. 69 W. (pl. 2), probably resulted from broad

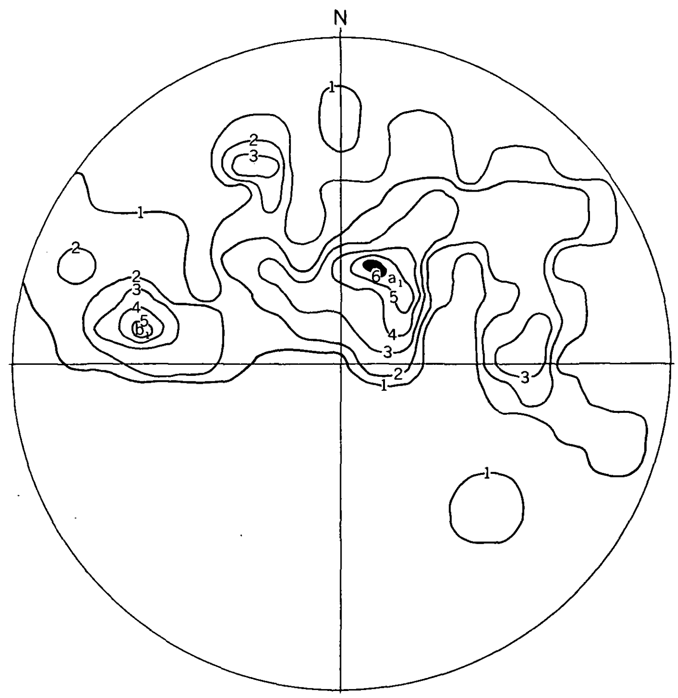

FIGURE 33.—Contour diagram of lineations, lower hemisphere plot of 52 poles. b_1, major fold axis; a_1, axis of crinkles on major fold. Contoured on number of poles.

northeast-plunging folds of the rocks formed before the intrusion of the biotite-muscovite granite, inasmuch as some small bodies of the granite are intruded along the fold axes.

PENNSYLVANIAN STRUCTURE

Mountains of Pennsylvanian age rose in about the same position as the north end of the modern Front Range. Along the east margin of the Front Range north of Perry Park, which lies 4 miles south of the quadrangle, pre-Pennsylvanian sedimentary rocks are absent and Pennsylvanian arkose rests on Precambrian rocks that locally are deeply weathered. Pebbles of cherty Mississippian rocks in the basal layers of the arkose indicate that a once continuous layer of Mississippian limestone was stripped off in Pennsylvanian or pre-Pennsylvanian time. The lack of pre-Pennsylvanian rocks in the quadrangle indicates that the front of the ancestral Rockies was slightly east of the present east edge of the Front Range.

The history of Pennsylvanian diastrophism in the Kassler quadrangle, which began with uplift, is as follows. The pre-Pennsylvanian rocks were stripped from the Precambrian rocks as the ancestral Rockies rose, and the mountains were reduced to a gently sloping surface. A minimum of 140 feet of uplift (the thickness of marine pre-Pennsylvanian rocks at Perry Park) was required to expose the Precambrian rocks at sea level in Pennsylvanian time. The Precambrian rocks were weathered and eroded, and the Fountain formation then was deposited on the gently sloping Precambrian rocks in the Pennsylvanian period. The ancestral Rockies must have been lowered, not simply eroded off, to explain the encroachment of the Permian sea, for the Fountain arkose has not been eroded, though it was originally deposited above sea level.

LARAMIDE STRUCTURE

The Rocky Mountains are the result of the Laramide period of mountain building in Late Cretaceous and early Tertiary time. The magnitude of the Laramide force is shown by the present height of the mountains—more than 25,000 feet of arching at the center of the Front Range and about 17,000 feet on the flanks at the contact of the sedimentary rocks and the crystalline rocks.

FAULTS

Faults of four types are recognized that are related to faulting, intrusion, or mineralization during the Laramide Revolution:

1. Reactivated northwest-trending Precambrian faults that contain cemented breccia, sandstone dikes, and andesite dikes. A thrust fault along the mountain front is included in this type.
2. Northwest-trending Laramide faults with uncemented iron-stained fault breccia.
3. Almost flat, west-trending north-dipping Precambrian faults with thin layers of fault gouge, mineralized probably in Laramide time.
4. Almost flat, west-trending north-dipping faults with andesite dikes.

Laramide movement along the Precambrian faults is indicated by the brecciation of both the sandstone and the andesite. The amount of movement and brecciation was slight compared to the brecciation along the faults prior to the injection of the sandstone and andesite.

The Jarre Creek fault is a high-angle branching reverse fault that cuts the sedimentary rocks in the south end of the quadrangle (pl. 2). It dips steeply to the west and throws flat-lying Dawson arkose against the crystalline rocks near the mouth of Jarre Creek (fig. 34). Just south of Jarre Creek, the fault twisted a large mass of Dawson arkose upward in a hingelike movement. The arkose crops out with vertical dips as a high ridge called Bee Rock. Outcrops of Dawson north and south of Bee Rock are nearly horizontal, as though they are separated by tear faults from the high ridge. Just northwest of Bee Rock, the rocks apparently were intensely brecciated, for no rocks crop out and that area is now occupied by landslides. Toward the north, the fault cuts across the older sedimentary rocks and branches into several faults (pl. 2), one in the Fountain formation and the others in the Pierre shale, which is thinned and its bedding twisted by the fault. Slices of more resistant beds lie along the eastern branches of the fault. Farther north, the fault gradually cuts across younger rocks and cannot be recognized beyond sec. 18, T. 7 S., R. 68 W., where it apparently cuts the Fox Hills and Laramie formations. The fault trends south to Perry Park where it is dissipated in bedding faults. Farther south the trend is taken up by another reverse fault that continues south to Colorado Springs. The Jarre Creek fault probably formed during Precambrian time, inasmuch as between Bee Rock and Perry Park sandstone dikes can be seen at many places in the Jarre Creek fault and in smaller, probably related fractures in the Pikes Peak granite.

A branch of the Jarre Creek fault follows the Fountain formation north from Jarre Creek. The thinness of the formation between Jarre Creek and Roxborough Park is due to deletion of beds along the Jarre Creek fault. The eastward bulging of Precambrian rocks at Jarre Creek was the result of great compressive stress and apparently localized the fault. Beds in the Fountain formation slid along each other in bedding faults, and a 3-mile-long outcrop was faulted to about two-thirds its original thickness. Apparently the lower part of the Fountain formation was removed by the bedding faults. As beds in the upper middle part of the Fountain are traced south from Kassler to the south end of Roxborough Park (fig. 32) they gradually swing west toward the Precambrian rocks and then disappear in a belt that apparently contains the crushed fragments of the lower part of the Fountain formation. Several small areas of the Fountain formation one-half mile north of Jarre Creek have been stripped bare of the overlying pediment gravel in a search for minable deposits of uranium. The Fountain formation there is not only severely crushed but contains many faults with reddish-gray slickensided clayey fault gouge. The fault continues north through Roxborough Park where it gradually slices higher into the middle part of the Fountain formation and leaves the lower part unfaulted 1 mile south of the South Platte River. It crosses the river west of Kassler and apparently joins a northwest-trending fault in the Precambrian rocks that offsets the mountain front one-half mile north of the quadrangle boundary.

A few northwest-trending near-vertical faults were seen that contain shattered rock, stained deep maroon by hematite. The shattered rock is not recemented and does not contain milky quartz like the Precambrian faults. These iron-stained faults are interpreted as Laramide in age. A good example is the fault in the center of sec. 5, T. 8 S., R. 68 W.

FIGURE 34.—Jarre Creek fault. Dawson arkose is faulted against crystalline rocks. The low tree-covered mountains on left are composed of Pikes Peak granite; the higher, almost bare mountains on right are composed of foliated crystalline rocks.

Mineralized west-trending Precambrian faults that dip 27° N.W. were seen along the South Platte River (pl. 2) and in a few other places where the rocks are well exposed. The fault gouge in them is generally less than 3 feet thick, is lenticular, and is locally mineralized. Another flat-lying set, into which andesite of Cretaceous(?) age was intruded, apparently was formed in early Laramide time, for the andesite in these faults is not brecciated.

A few north-trending near-vertical faults with displacements of less than 1 foot were seen in the Lytle, South Platte, and Lyons formations. One of these in the Lyons sandstone is in the NW¼SW¼ sec. 30, T. 7 S., R. 68 W.

FOLDS

The Front Range anticline is the largest and most spectacular fold in the area. The truncated hogbacks are remnants of a blanket of sedimentary rocks that originally lay over all the crystalline rocks in the quadrangle. The sedimentary rocks now dip northeast in a monocline off the Front Range. In general, the steepest dips are related to the Jarre Creek fault in the southern part of the area. One mile northeast of Jarre Creek at Wildcat Mountain the Dawson arkose is almost vertical. South of Wildcat Mountain the upper part of the Dawson arkose gradually flattens to 6°. Most of the older strata along the fault zone also dip very steeply northeast or are overturned to the southwest. In the northern part of the area the rocks dip 60°–70° NE. Dips in the Pierre shale are variable, partly because of the influence of the Jarre Creek fault and partly because of slippage over each other of the soft shale layers at the time of uplift.

Uplift of mountains in Pennsylvanian and Laramide time tilted the overlying blanket of sedimentary rocks twice. The amount of tilting in Pennsylvanian time can only be guessed, but tilting in Laramide time is known to be more than 50° (fig. 35). The tilting certainly was not confined to the sedimentary rocks but involved also the uppermost of the underlying Precambrian rocks. All planar and linear elements that were part of the internal structure of the Precambrian

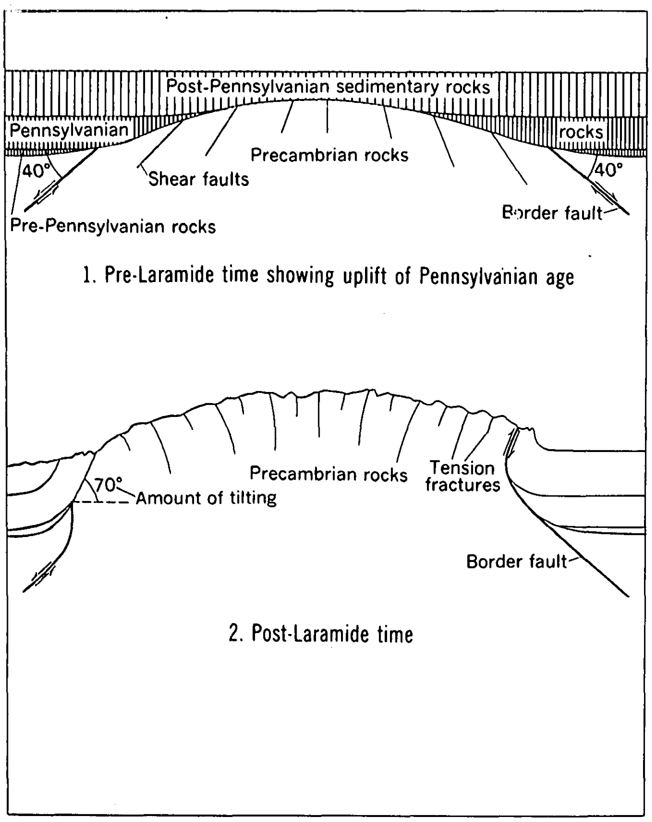

FIGURE 35.—Simplified hypothetical cross section of Front Range showing tilting of pre-Laramide structural features and formation of border faults.

rocks were reoriented. How far this reorientation extends into the center of the mountains was not determined, but rocks throughout the Front Range may be affected to some extent. Interpretation of the original attitudes and significance of Precambrian internal structures is made complicated, if not impossible, by the tilting.

In order to determine the effect of tilting, the attitudes of pre-Laramide rocks were reconstructed by rotating out the 60° to 70° of dip now shown by the sedimentary rocks. Sedimentary structures indicate that the Fountain formation was originally deposited on a surface that sloped about the same as the Pleistocene pediments (about 2° E.) and that this surface was tilted to about 60° or 70° during the Laramide uplift. The internal structures of pre-Laramide rocks near the mountain front also were rotated 60° to 70°. Structures in the crystalline rocks that were parallel to the mountain front had a change of dip only; structures that were not parallel had a change of both trend and dip. The amount of tilting was determined on several Precambrian structures where both trend and dip were changed. A Precambrian fault that now is a reverse fault was originally formed as a normal fault. A Precambrian fold that now has a gentle plunge to the west originally plunged nearly vertically.

Presumably the amount of rotation would be greatest at the east and west fronts of the range, and, unless the whole range was tilted as a block, would decrease to zero somewhere near the center. The outcropping pre-Laramide rocks on the west flank of the Front Range dip about the same as the rocks on the east flank; therefore I infer that the range rose nearly vertically and that the tilting on the two sides is nearly symmetrical. The rotation may have been evenly spread between the center and the front of the range, but it seems more likely that the rotation was concentrated in a narrow strip near the front. Small faults and shear zones may have absorbed most of the tilting within only a few miles of the mountain front.

Figure 35 shows my theory of the effect of tilting on the faults along the east and west flanks of the Front Range. Most of the fracturing and reorientation caused by uplift of preexisting structures I believe was concentrated along the edges of the crystalline mass. Tension fractures probably opened between the large shear faults in the center of the range.

HISTORY OF LARAMIDE STRUCTURE

The uplift of the Rocky Mountains started far to the west near the end of Pierre shale (early Maestrichtian) time, but the sea covered the Kassler quadrangle until the end of Fox Hills (late Maestrichtian) time, when it withdrew from the area. The uplift of the mountains apparently progressed slowly eastward. Active uplift of the present Front Range began in early Dawson (Danian?) time. The Precambrian rocks were arched as they were pushed up, and the sedimentary rocks on the flanks slid over the Precambrian rocks or over each other along preexisting faults. The eastern flank of the Front Range probably remained stationary because of deeply buried northwest-trending faults of Precambrian age that were reactivated in Laramide time. Steeply dipping Precambrian faults that now lie along the eastern flank of the Front Range apparently were gently dipping normal faults (fig. 35) prior to the Laramide uplift.

The complex history of faults in the quadrangle is well exemplified by that of the northwest-trending faults, whose history started in Precambrian time. Their history is believed to be:

1. The northwest-trending faults were formed and mountains uplifted in late Precambrian time after the intrusion of the Pikes Peak granite.
2. The land that rose in the late Precambrian diastrophism was eroded during Early and Middle Cambrian.
3. The sea encroached in Late Cambrian time and deposited part of the sand of the Sawatch quartzite.
4. Fractures were reopened along the northwest-trending faults during a minor Late Cambrian diastrophism or earthquake, and the unconsolidated sand about 15 feet above the bottom of the sediments on the floor of the Sawatch sea was injected into the fractures or was sucked in by vacuum, and apparently filled even the smallest of voids.
5. The sand was indurated.
6. The faults may have been reactivated in the Pennsylvanian orogeny.
7. Andesite was intruded into the faults in Late Cretaceous(?) time.
8. The mountains were uplifted, the sedimentary rocks were tilted, and the faults were reactivated in the major movement of the Laramide orogeny in Paleocene time. The Front Range high-angle reverse faults cut the sedimentary rocks at this time as a result of the reactivation of preexisting faults that were buried under the sedimentary rocks. The sandstone and andesite in the northwest-trending faults were brecciated and locally intermixed with the brecciated wallrocks.
9. The wallrocks and fault gouge along the faults were weakly mineralized with pyritic ore in a calcite or quartz gangue.

POST-LARAMIDE STRUCTURE

Disastrophism in the central Rocky Mountains during the late Tertiary and Quaternary periods is postulated by many authors. Lovering and Goddard (1950, p. 63) described Miocene deposits cut by faults. Lovering and Tweto (1953, p. 33) describe small postmineral (post-Miocene?) faults. Stark and others (1949, p. 147–148) described tilted Pliocene beds in the Arkansas Valley near Salida.

The last sentence on structural geology in reports on the geology of the Front Range repeatedly states that the mountains were raised intermittently by epeirogenic uplift to produce the late Tertiary and Quaternary pediments and stream terraces. To resort to uplift to explain Quaternary erosion and alluviation seems quite unnecessary. Quaternary geomorphic processes were not primarily the result of uplift but of climatic change. Mountain glaciation also must be considered the result of climatic change, and the cycles of mountain glaciation probably correspond exactly with the cycles of continental glaciation; furthermore the cycles of erosion and alluviation on the unglaciated plains around the mountains also correspond with these glacial stages and are the result of cyclical fluctuations in climate.

Evidence of Quaternary faulting in the Front Range is meager, and the Front Range is not now an active earthquake area. The lack of evidence for post-Pliocene faulting or uplift lends support to the belief that the Front Range has been stable for a long time, possibly since the end of Pliocene time. The gentle slope of the sediments in the Ogallala formation in eastern Colorado (about 35 feet per mile near Calhan to 20 feet per mile near Kansas) indicates that the mountains could have been at almost their present altitude since Pliocene time.

Quaternary fresh-water mollusks in the Kassler quadrangle (Scott, 1960) give another line of evidence in opposition to great uplift in the Pleistocene. If uplift had been progressive, then the environment would have become progressively colder, but the mollusk assemblage from a middle Pleistocene alluvium is like that found today in the arid to semiarid foothills and lower mountains of New Mexico and Arizona; the mollusks from a late Pleistocene alluvium now live near timberline in the modern Rocky Mountains, but the mollusks in an early Recent alluvium were again warmth-loving and apparently needed a climate almost as warm as was required by the middle Pleistocene mollusks. The climates, therefore, were not progressively warmer or colder but fluctuated because of climatic changes that were not related to progressive uplift.

GEOLOGIC HISTORY

The geologic history of the Kassler quadrangle, as interpreted not only from the geology of the quadrangle but also from that of surrounding areas, is complex. The major events were: the emplacement and metamorphism of the Precambrian rocks, the formation of late Precambrian faults which set the framework that controlled the later structural history of the Front Range, the uplift of the ancestral Rockies, the deposition of the Pennsylvanian to Cretaceous rocks in the Denver basin, the uplift of the Rocky Mountains, the deposition of the Tertiary rocks, and the deposition of the Quaternary deposits and formation of the modern topography. Most of these events have long been known, but to them can be added some details that have become known as a result of this investigation.

The oldest rocks in the area were derived from sediments deposited in a basin in Precambrian time and were lithified by their own weight to shale, sandstone, and limestone. The sediments were uplifted and crumpled; heat and pressure in the zone of flowage changed the sedimentary rocks to more compact crystalline metamorphic rocks. These metamorphic rocks were then invaded by granitic fluids that converted some of the rocks to granite gneiss and migmatized others. Granite pegmatites invaded most of the metamorphic rocks in the last stage of this episode of granitization. The gneissic granite was intruded into the foliated rocks at the same time as the quartz monzonite (Boulder Creek granite) of the Georgetown area. The quartz diorite and hornblendite was intruded later. Later the biotite-muscovite granite was intruded into the metasedimentary rocks as widespread small bodies of granite with many associated pegmatites.

The granite of the Pikes Peak batholith was intruded into the older metamorphic and igneous rocks. Around the border of the batholith the country rock was slightly granitized. Pegmatitic fluids were intruded into fractures which opened in the granite and in the metamorphic rocks as the granite cooled. The pegmatites cooled slowly enough to form large crystals of quartz, feldspar, and other minerals.

During the long period of erosion that separated the Precambrian from the Paleozoic, a great thickness of rocks was removed and the land reduced nearly to a plain.

In this area, erosion apparently continued for some time from the Precambrian into the Paleozoic era. In Late Cambrian time the sea spread into the area and the Sawatch quartzite was deposited. The area apparently was structurally unstable, and earthquakes may have reopened large tension cracks along the Precambrian faults on the sea floor. Into these cracks the sand of the Sawatch quartzite may have poured and formed thick clastic dikes.

The sea was spread over the area throughout most of Ordovician time, but apparently withdrew in Silurian, Devonian, and Early Mississippian time.[1] In middle Mississippian time the sea again encroached on the area and deposited limestone. Uplift of the ancestral Rockies in Early Pennsylvanian time and subsequent erosion stripped off most of the earlier Paleozoic rocks. Coarse detritus that constitutes the Fountain formation was stripped from the mountains by streams and deposited on a slightly uneven but gently sloping floor as broad coalescing fans. After the land was lowered sufficiently, the sea again spread over the area, and the Permian Lyons sandstone was deposited as nearshore dunes, and the lower part of the Lykins formation was deposited as marine shale and limestone. The sea again withdrew, and in later Permian and Triassic(?) time the area apparently was a dry land on which silt and sand were deposited by wind and intermittent streams.

The Early Jurassic sea may have covered the area, but no deposits are preserved. Upper Jurassic limestone, sandstone, and siltstone of the Ralston Creek formation and the Morrison formation were deposited in fresh-water lakes and swamps or by streams that cut channels across marshy lagoonal flats and deposited sand in the channels. In Early Cretaceous time the sediments of the Lytle formation were deposited on a flood plain; then the sea spread over the area and deposited the sediments of the South Platte formation along a beach and in the shallow water offshore. The Graneros, Greenhorn, and Carlile formations were deposited in a deeper sea except for the Codell sandstone member which is calcarenite and may have been deposited on a beach. The sea deepened slightly, the water became warmer, and the Fort Hays limestone and the Smoky Hill shale members of the Niobrara formation were deposited. The sea in which the lower part of the Pierre shale was deposited was a cooler sea and bituminous black shale was deposited. The sea then warmed and circulation improved, but, because the sea was withdrawing, only a little shale was deposited before the start of deposition of the Hygiene sandstone member. The sea again deepened and shale was deposited. Toward the end of the Cretaceous period, the sea began to withdraw for the last time as the Rocky Mountains started to rise, and sandy shale was deposited in the upper part of the Pierre. Sandstone with broken plant fragments and a predominance of brackish-water fossils was deposited in the Fox Hills

[1] Marine rocks of Silurian age were found in Albany County, Wyo., in 1960 and described by Chronic and Ferris (1961) in a symposium on lower and middle Paleozoic rocks of Colorado.

sandstone. The sea then withdrew completely from this area and the continued rise of the Rocky Mountains, slow at first and probably far to the west, caused the deposition of the fresh-water sandstone, coal, and claystone of the Laramie formation; the mountain rise then became more rapid along the axis of the Front Range and caused the deposition of the coarse conglomerate in the lower or Cretaceous part of the Dawson arkose; then the rise slowed again, and the siltstone of the Paleocene part of the Dawson arkose was deposited. The conformity of deposition of beds in the lower two-thirds of the Dawson arkose indicates that uplift and tilting of the east flank of the Front Range did not happen until late Dawson time.

In Cenozoic time, at the climax of the Laramide structural disturbance, the Precambrian faults were reactivated, the Cambrian sandstone dikes were faulted, and andesite dikes were intruded into the Precambrian northwest- and northeast-trending faults, and possibly into newly created, flat-lying Laramide faults. In the latter part of the structural disturbance, faults were again reactivated, the andesite dikes were faulted and brecciated, rhyolite was intruded into the Precambrian rocks, and welded tuff was interlayered with the upper part of the Dawson arkose. Probably the last event was the hydrothermal alteration of the faults and the postbrecciation emplacement of copper and uranium minerals along the northeast-trending flat-lying faults and fractures.

ECONOMIC GEOLOGY

Rocks in the quadrangle contain both nonmetallic and metallic deposits. The nonmetallic deposits include mica, feldspar, clay, coal, limestone, road metal, structural stone, and sand. Metallic deposits include iron, copper, and uranium.

NONMETALLIC DEPOSITS

Clay, limestone, road metal, and sand are now being mined; coal and structural stone were formerly mined; mica and feldspar were never mined in the quadrangle.

MICA

Muscovite was seen in sufficient quantity to warrant prospecting at five places in the quadrangle (pl. 2).

1. Pegmatite on the ridge top in the SW¼NE¼SW¼ sec. 28, T. 7 S., R. 69 W., exposed in a 3-by-3-foot pegmatite. Mica in 4-inch books, warped, fractured, and stained by iron.
2. Pegmatite on north side of road in pit dug for quartz crystals in pegmatitic border zone of Pikes Peak granite in the NW¼SE¼ sec. 3, T. 8 S., R. 69 W. Mica in 4-inch weathered books lying on dump.
3. Pegmatite 30 feet S. 40° W. from General Land Office marker (half section corner?) on section line between sec. 33, T. 7 S., R. 69 W., and sec. 4, T. 8 S., R. 69 W. Mica in 6-inch books, hard, flat and free-splitting, but slightly ruled, warped, and stained by iron.
4. Pegmatite on logging road in SE¼SW¼ sec. 22, T. 7 S., R. 69 W. Mica in 4-inch books warped and slightly stained by iron.
5. Pegmatite east of prospect pits in the SW¼NE¼ sec. 25, T. 7 S., R. 69 W. Mica in 3-inch books.

The mica described above may be suitable for scrap mica if the deposits are large enough to be mined.

FELDSPAR

Feldspar crystals of large size and possibly in minable quantity were found at three places in the quadrangle:

1. Pegmatite in NW¼SW¼ sec. 3, T. 8 S., R. 69 W., opened by prospect pit. Twelve-inch pieces of microcline feldspar.
2. Pegmatite in SW¼SE¼ sec. 10, T. 7 S., R. 69 W. Large pieces of potash feldspar, but deposits in this area probably are too small to mine.
3. Pegmatite east of prospect pits in the SW¼NE¼ sec. 25, T. 7 S., R. 69 W. Although the rock in this area seems to be about one-half pegmatite, the feldspar pods may be too small to mine.

CLAY

Brick clay and refractory clay are available in the Kassler quadrangle. Four mines were being worked in 1958 in the South Platte formation for refractory clay and at least five other mines or prospects were formerly worked. The clay beds in the South Platte are lenticular and rarely exceed 9 feet in thickness.

The four working mines are the Hogback, Hillside, Helmer Bros. underground, and Helmer Bros. open-pit. All four mines and other prospects in the South Platte formation were described by Van Sant (1959, p. 53–61).

Thin clay beds lie under and over the coal in the Laramie formation but they are said, by the former coal miners, to be too thin to be mined. Brick clay is available in the Graneros and the Pierre shales, the Fox Hills sandstone, and the lower part of the Laramie formation, but has not been used.

COAL

Several lenticular subbituminous coal beds lie near the base of the Laramie formation. Five mines were operated in this area. G. C. Martin (1908) described two of these mines as follows: "Platte Canyon Fuel and Power Co. [probably mine No. 1], sec. 36, T. 6 S., R. 69 W. Shaft 210 feet deep—then 20 feet horizontal west to coal, 6-foot bed, dips 20° * * * Old Lehigh mine (NW¼SW¼ sec. 20, T. 7 S., R. 68 W.) south of Platte Canyon mine, 8- to 12-foot bed [upper easternmost coal bed]; 12-foot bed (sandstone); 4-foot bed [lower coal bed]." Platte Canyon Fuel and Power Co. mine No. 2 lies one-fourth mile south of mine No. 1. The shafts of both of the Platte Canyon mines are closed. Fragments of weathered coal and carbonized tree stumps lie on the dumps. A railroad was built to these two mines about 1900, but the mines and the railroad were abandoned before any coal was hauled. The entrance to the Lehigh mine is also caved and the access road is washed out.

The inclined shaft of the Willow Creek mine in the NW¼NW¼ sec. 7, T. 7 S., R. 68 W., is still open; however, the mine was shut down after a cave-in farther down in the mine. Two beds were worked in the Willow Creek mine, a 6-foot upper bed and a 4-foot lower bed.

The shaft of Morgan's mine in the SW¼SW¼ sec. 6, T. 7 S., R. 68 W., is also open and some coal is still mined for local consumption. Mr. Morgan did most of the exploration for coal in the quadrangle; three of his prospect pits lie along the strike of the bed on the Willow Creek Ranch in sec. 7, T. 7 S., R. 68 W.

Other outcrops of the coal were observed, but none was as thick as the beds that were mined. The beds appear to be too thin and the coal of too low grade to permit mining under present economic conditions.

LIMESTONE

The Glennon limestone member of LeRoy of the Lykins formation and the Fort Hays limestone member of the Niobrara formation are the only limestones thick enough to be quarried. The Glennon limestone member was probably quarried for agricultural lime, for several kilns were observed along the outcrop. This limestone is not only thinner but less pure than the Fort Hays limestone. The thickness of the bed usually quarried ranges from 14 to 17 feet. No quarries were operating in 1960 in the Glennon member.

The Fort Hays limestone is quite pure and is used for foundry limestone. The thickness ranges between 30 and 40 feet; however, the quarried thickness averages less than 30 feet in most places. The Helmer Bros. quarry in the SE¼ sec. 2, T. 7 S., R. 69 W., is operating part time. At least five abandoned quarries are located along the outcrop of the Fort Hays member.

Other limestone beds lie below the Glennon limestone member of the Lykins formation, in the Ralston Creek formation, and near the middle and at the top of the Smoky Hill shale member of Niobrara formation. They have not been used because of their thinness or impurity.

STRUCTURAL STONE

One quarry in the NW¼ sec. 30, T. 7 S., R. 68 W., was observed in the upper part of the South Platte formation where the degree of jointing made the rock favorable for dimension stone. About 1,000 cubic yards of sandstone have been removed for use as structural stone in the abandoned coal-mining town of Lehigh.

The Pikes Peak granite has been quarried along the North Fork of the South Platte River west of the quadrangle and probably would be suitable elsewhere at one of the rare unweathered exposures.

SAND

Sand is quarried from the South Platte formation and Lyons sandstone for three purposes: as silica sand, molding sand, and core sand. The sandstone is suitable for silica sand and has been used for glass-bottle manufacture, but the quantity available is too small to support a large glass factory (Vanderwilt, 1947, p. 262–264). Six quarries (pl. 2) are operated in the South Platte formation; all the product is used for molding and core sand. The sand bed that is quarried from the South Platte lies near the top of the formation in the unnamed sandstone unit (Waagé, 1955, p. 46). The mined bed is a 28-foot-thick massive soft friable white sandstone; thin iron-stained interlayers are removed before crushing.

The bed in the Lyons sandstone which has been quarried at the localities shown on plate 2, is an 18.5-foot-thick massive fine-grained soft friable white sandstone that lies about 80 feet below the top of the formation. Three small quarries were opened, but no sandstone was being taken from the Lyons sandstone in 1950.

ROAD METAL

Road metal is defined as material that may be applied to a road to improve the performance characteristics of that road.

Weathered Pikes Peak granite is used extensively for road metal on the mountainous part of State Route 67. No crushing or other treatment is necessary to prepare it for this use. A 15-foot blanket of suitable weathered granite overlies the unweathered granite in most of its outcrop area. A quarry is operated in the NE¼SW¼ sec. 6, T. 8 S., R. 68 W.

The Dawson arkose is used for road metal on several small county roads. No quarries are open for this purpose, but where the road traverses the arkose, graders have spread it for road metal.

METALLIC DEPOSITS

Metallic ore minerals have not as yet been found in minable quantities in the quadrangle, but deposits of iron, copper, and uranium may well be present there in minable quantities—awaiting discovery.

IRON

Hematite occurs in small pods along the west side of the Bear Creek fault in sec. 33, T. 7 S., R. 69 W., and in sec. 4, T. 8 S., R. 69 W. (pl. 2). The pods are northwest-trending bodies interlayered with the foliated rocks and apparently are related to mineralization along the Bear Creek fault. Lovering and Tweto (1953, p. 31) described a similar small body of high-grade hematite mined from the Hurricane Hill reef in the Clark tunnel in the Boulder tungsten district. Other small deposits of hematite were observed in the quartzite in the southeast corner of the area, for instance, in the NE¼ sec. 6, T. 8 S., R. 68 W. Pyrite is a common mineral in lime silicate gneiss, amphibolite, and in veins, but is too disseminated to be of economic interest. Magnetite is abundant in the granite gneiss and migmatite and in the granite pegmatite. It has been concentrated in sluices as a byproduct of gravel pits along the South Platte River.

COPPER

Copper minerals were seen in many prospects in the quadrangle, both in veins and disseminated near faults in the lime silicate gneiss and amphibolite. The most common minerals in these deposits are malachite and azurite. Other copper minerals seen at a few prospects are chalcopyrite, tenorite, chrysocolla, turquoise, and conichalcite. Smithsonite, a zinc mineral, was seen at one copper prospect. Three samples (see table below) from a copper prospect opened by a 10-foot shaft along a northwest-trending fault in the SW¼SW¼ sec. 22, T. 7 S., R. 69 W. (pl. 2), were tested for uranium, nickel, cobalt, and copper by the U.S. Geological Survey.

[Values for eU are for radioactivity, expressed in terms of equivalent uranium; analyst S. P. Furman. Values for Ni and Co were obtained by rapid methods used for geochemical prospecting, analyst H. E. Crowe. Values for Cu were obtained by the more precise electrolytic method, analyst D. L. Skinner]

Laboratory analysis	Rock	eU	Ni	Co	Cu
D81776	Limonite gossan	0. 001	0. 002	0. 017	2. 36
D81777	Biotite-quartz gneiss	. 002	. 01	. 09	5. 03
D81778	Lime silicate gneiss	. 001	. 004	. 03	2. 54

Although uranium, nickel, and cobalt are present only in traces, the copper content approaches that necessary for an ore deposit. In a copper mine in the NE¼ sec. 16, T. 7 S., R. 69 W., copper is slightly more abundant, and may constitute a minable deposit under more favorable economic conditions than at present.

URANIUM

The Kassler quadrangle had been prospected for uranium and more than 100 claims had been located. Three claims had been explored by power equipment but uranium minerals were discovered in only one. On the Bonzo No. 1, in the South Platte canyon in the SE¼SW¼SW¼ sec. 33, T. 6 S., R. 69 W. (pl. 2), a pod of uraninite with secondary minerals gummite and autunite and with other unidentified minerals was exposed in the early exploration. Further exploration in an incline and raise yielded more pocketlike deposits of uranium minerals.

A fractured zone in the NW¼NE¼ sec. 21, T. 7 S., R. 69 W. (pl. 2) has been explored by a bulldozer open-cut. Mr. Vance Haynes, a geologist and prospector, reported uraninite on this dump; oxidized uranium minerals were found later, but the radiation count in the pit was only slightly above background.

Test trenches and shafts have been dug in the Fountain formation north of Jarre Creek in search of uranium deposits. The pits were said to contain oxidized uranium minerals and to be quite radioactive, but they have been abandoned.

Radioactivity above background was measured along the Bear Creek fault in sec. 33, T. 7 S., R. 69 W., and in the saddle on the section line between secs. 26 and 35, T. 7 S., R. 69 W. (pl. 2).

Springs flow from one of the radioactive faults that contains a sandstone dike in Stevens Gulch in the middle of the N½ sec. 21, T. 7 S., R. 69 W. The water from two of these springs was analyzed by chemists of the U.S. Geological Survey. Sample 245703 is from a spring that flows directly from fractures in the sandstone dike. Sample 245704 is from a larger spring that flows up through valley alluvium after flowing from the fault.

Analysis, in parts per million, of water from springs in Stevens Gulch, N½ sec. 21, T. 7 S., R. 69 W.

[Total solids analyzed by gravimetric method. Specific conductance and pH analyzed electrically. Ca and Mg analyzed by versenate volumetric method. Li, Sr, Na, and K analyzed by flame photometer. U analyzed by fluorimetric method. Analyses by Wayne Mountjoy, except analyses of pH and uranium by H. H. Lipp.]

	245703	245704
Uranium	0. 001	0. 001
Lithium	3	4
Strontium	17	12
Calcium	724	708
Sodium	488	500
Potassium	9	9
Magnesium	2	2
Total solids	3, 980	4, 130
Specific conductance micromhos	5, 370	5, 500
pH	7. 0	7. 4

The residues of the two samples were analyzed spectrographically for 64 elements. The results of this semiquantitative analysis are shown below:

Spectrographic analysis of residues from spring water in Stevens Gulch, N½ sec. 21, T. 7 S., R. 69 W.

[Figures are percent of residue; M, major constituent (>10 percent). Si, Al, Cs, F, and Rb, were not looked for. Usual sensitivities do not apply owing to use of dilution technique. Analyst, J. C. Hamilton, U.S. Geol. Survey]

	245703	245704
Magnesium	0.07	0.07
Calcium	M	M
Sodium	M	M
Titanium	Tr.	0
Boron	Tr.	Tr.
Barium	.0007	.0007
Copper	.0007	.0007
Strontium	.7	.7
Vanadium	.0015	.0015

R. D. George (George and others, 1920, p. 394) gave an analysis of water from Strontia Springs, which flows from a fault about 1 mile southwest of and parallel with the fault along Stevens Gulch. Although the total solids make up a greater proportion of that water, the chemical composition of the spring water from the two localities is similar.

Water and gas from the springs in Stevens Gulch were analyzed for radium and radon. The results are shown below:

Radium and radon in spring water from Stevens Gulch, N½ sec. 21, T. 7 S., R. 69 W.

[Analyst, A. B. Tanner, U.S. Geol. Survey]

	Spring in sandstone dike		Spring in valley alluvium	
	Water phase	Gas phase	Water phase	Gas phase
Ra^{226} (micromicrocuries per liter ± 20 percent)	40		40	
Rn^{222} (micromicrocuries per liter ± 10 percent)	7,500	29,000	3,600	17,000
Partition ratio: Rn in water ÷ Rn in gas	0.26		0.21	
Equilibrium partition ratio	.32		.29	

In explanation of these results Tanner stated (written communication, 1956):

The concentration of radium in the water samples was anomalous by about an order of magnitude and that of radon by about half an order of magnitude. Natural waters containing more than 3 micromicrocuries per liter of radium or more than 2,000 micromicrocuries per liter of radon are unusual. The anomalies in radium and radon concentration suggest the presence of slight anomalies (0.005 to 0.010 percent eU) in uranium concentration in the vicinity of the sampling points.

Along faults, the lime silicate gneiss and the amphibolite were the rocks most receptive to mineralizing solutions, probably because they contain vugs and because many of their constituents are easily dissolved by acid-charged water. The amount of acid that acted on these rocks is demonstrated by etched figures on schorlomite and by crystals of diopside, apatite, garnet, scapolite, epidote, and quartz that have been pitted and rounded and given a waxy appearance by solution.

Uranium and other ore minerals in the amphibolite and lime silicate gneiss apparently were not entirely dependent on fractures for their localization. The minerals are disseminated through the rock as though some were original constituents. Some of the rocks are fractured, others are not. Many of the fractures are healed by hornblende.

ENGINEERING PROBLEMS

The engineering problems in the Kassler quadrangle are varied because there are so many geologic units. The problems involving the crystalline rocks are caused principally by fractures and faults and the freedom of water circulation in them. These fractures must be grouted beneath large concrete dams, both to provide a solid foundation and to prevent seepage. In building highways, drains should be installed to carry away the water seeping from the fractures and to prevent frost heaving and pumping under the pavement. The weathered mantle is sufficiently deep over most of the crystalline rocks that small one-way logging roads can be built without blasting, but larger roads would require considerable blasting, except in the Pikes Peak granite where the weathered rock is thicker.

Clay is the principal cause of trouble in road construction in the Graneros shale, Greenhorn limestone, Carlile shale, Niobrara formation, Pierre shale, Fox Hills sandstone, Laramie formation, and the Dawson arkose. Some of the clay expands when wet, and should either be removed and backfilled with permeable material or should be kept dry. Cuts in these shales should not exceed a slope of 45°, and in the Pierre shale cuts should be less than 20°. On the flanks of the pediments, landslides can be observed on 25° slopes several places in the Pierre shale.

Most of the alluvium in the area is well drained, but the soils in the older alluvium and the Piney Creek and post-Piney Creek alluvium are clayey, waterlogged, full of organic matter, and not suitable for fill; they should be stripped and backfilled with free-draining granular material. Both the clayey and organic-rich materials expand when wet and shrink when dry and thus make unstable foundations. The loess also may cause similar problems because it contains much clay from the Pierre shale and the Dawson arkose. The bog clay, which is crossed by a north-trending road south of Roxborough Park school, sags and allows the road to become rutted and difficult to traverse after rains. The subbase of the road was built of bog clay, whereas the bog clay should have been stripped and backfilled with permeable material. Because water is the primary cause of trouble in the clayey sediments, drains should be established wherever water can stand or where it seeps out at the contact of a permeable bed overlying the clayey shales—such as where alluvium overlies the Pierre shale.

The geologic materials are listed below by excavation characteristics:

Rock excavation (requires blasting):
- All crystalline rocks.
- Sandstone dikes.
- Fountain formation.
- Lyons sandstone.
- Lykins formation; the limestone layers and possibly all shale below a depth of 25 feet.
- Morrison formation; the thick limestone and sandstone layers and possibly all shale below a depth of 25 feet.
- Lytle and South Platte formations.
- Graneros shale, Greenhorn limestone, and Carlile shale; possibly all beds below a depth of 15 to 25 feet.
- Codell sandstone member of the Carlile shale and Fort Hays limestone member of Niobrara formation.
- Smoky Hill shale member of the Niobrara formation below a depth of 10 to 25 feet.
- Pierre shale; possibly all shale below a depth of 50 to 100 feet.
- Fox Hills sandstone; the massive sandstone and possibly all shale below a depth of 50 feet.
- Laramie formation; the massive sandstone and possibly all shale below a depth of 25 feet.
- Dawson arkose; the conglomerate and sandstone and possibly all siltstone and claystone below a depth of 10 to 25 feet.

Common excavation (requires power equipment such as bulldozer with hooks, earth mover, and power shovel):
- All surficial deposits.
- Parts of the bedrock units above the depths mentioned under "Rock excavation" above.

FOSSIL LOCALITIES

Localities of fossils in the bedrock formations in the Kassler quadrangle are listed below in stratigraphic order. Fossils were collected by the field workers in the years indicated.

Locality (pl. 2)	USGS Mesozoic locality	
		RALSTON CREEK FORMATION
1	------	SE¼SW¼SE¼ sec. 27, T. 6 S., R. 69 W. Scott, 1954.
		SOUTH PLATTE FORMATION
2	------	SW¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W. E. B. Eckel, 1954.
		GREENHORN LIMESTONE
		Lincoln limestone member
3	D1	SW¼SW¼ sec. 19, T. 7 S., R. 68 W., from oyster limestone at base. Scott, W. A. Cobban, and Richard Van Horn, 1954.
4	D2	SW¼SW¼ sec. 19, T. 7 S., R. 68 W., from brown platy calcarenite at top. Scott, Cobban, and Van Horn, 1954.
		GREENHORN LIMESTONE—Continued
		Bridge Creek limestone member
5	D3	SE¼NW¼ sec. 30, T. 7 S., R. 68 W., from thin light-gray limestone bed. Scott, 1953.
6	D1088	SE¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W., light-gray limestone at top. Scott, 1956.
		CARLILE SHALE
		Fairport chalky shale member
7	D1089	SE¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W., from tan chalky platy shale at base. Scott, 1956.
		Codell sandstone member
8	D1086	NE¼NW¼SE¼ sec. 2, T. 7 S., R. 69 W., from brown calcarenite. Scott, 1956.
9	D1087	SW¼SW¼ sec. 12, T. 7 S., R. 69 W., from brown calcarenite. Scott, 1956.
10	D1097	SE¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W., from brown calcarenite. Cobban, 1956.
		NIOBRARA FORMATION
		Fort Hays limestone member
11	D1090	SE¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W., from lower 15 ft. Scott, 1956.
12	D1091	SE¼SW¼NW¼ sec. 35, T. 6 S., R. 69 W., from upper 15 ft. Scott, 1956.
13	D1085	NE¼NW¼SE¼ sec. 2, T. 7 S., R. 69 W., from middle of limestone. Loaned to Scott by Mrs. Cecelia Head, 1956.
14	D4	NE¼NW¼ sec. 30, T. 7 S., R. 68 W., from near top of limestone. Scott, 1954.
		PIERRE SHALE
15	D260	SW¼NW¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., about 600 ft above base. Scott, 1954.
16	D261	SW¼NW¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., about 630 ft above base. Scott, 1954.
17	D802	NE¼SW¼SE¼NE¼ sec. 30, T. 7 S., R. 68 W., from limestone concretions. Scott, 1956.
18	D262	SW¼NW¼SW¼SE¼ sec. 19, T. 7 S., R. 68, W., from light-brown limonitic limestone layer about 640 ft above base. Scott, 1954.
19	D5	SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from tepee limestone. Scott, Cobban, and Van Horn, 1954.
20	D264	NW¼NE¼ sec. 30, T. 7 S., R. 68 W., about 600 ft above base. Cobban and Scott, 1954.
21	D394	NW¼NW¼ sec. 12, T. 7 S., R. 69 W., from ironstone concretions in gray clayey shale. Scott and R. D. Miller, 1955.
22	D798	SE¼SE¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from shale just below Hygiene sandstone member. J. H. Smith, 1956.
22a	D1105	SE¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from tan-gray limestone concretion in tan sandy shale, 26 feet above D798. Scott, 1956.
		Hygiene sandstone member
23	D791	NW¼NW¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from small gray calcareous concretions. Scott, Cobban, and Van Horn, 1956.
24	D1099	SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from tan-gray sandy shale 15.5 feet above D791. Scott, 1956.

Locality (pl. 2)	USGS Mesozoic locality	
		PIERRE SHALE—Continued
		Hygiene sandstone member—Continued
25	D1100	SW¼SE¼ sec. 19, T. 7 S., R. 68W., from sandy limestone concretions 18 feet above D1099. Scott, 1956.
26	D9	SE¼SE¼ sec. 19, T. 7 S., R. 68 W., from shaly sandstone. Scott, Cobban, M. E. Cooley, and Van Horn, 1954.
27	D790	NW¼SE¼NW¼NW¼NW¼ sec. 19, T. 7 S., R. 68 W., from phosphatic nodule zone. Scott, Van Horn, and Cobban, 1956.
28	D809	NW¼NE¼NW¼NW¼ sec. 32, T. 7 S., R. 68 W., from sandy calcareous concretions. Scott and Cobban, 1956.
29	D828	NW¼SW¼ sec. 1, T. 7 S., R. 69 W., from gray limestone nodules. Same level as D391 and D6. Scott, 1956.
30	D391	SE¼NW¼NW¼NW¼ sec. 19, T. 7 S., R. 68 W., from gray limestone concretions in sandy shale. Scott, Van Horn, Miller, and Cobban, 1955.
31	D1101	SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from gray earthy limestone concretions 28.5 feet above D1100. Scott, 1956.
32	D779	Near center N½N½ sec. 35, T. 6 S., R. 69 W., from iron-stained limestone bed in Highline canal 190 ft below D6. Scott and W. L. Peterson, 1956.
33	D1102	SW¼SE¼ sec. 19, T. 7 S., R. 68 W., 21 ft above D1101. Scott, 1956.
34	22840	NE¼NW¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from limy nodules 86 ft above loc. 33 Scott, Cobban, Cooley, and Van Horn, 1950.
35	D799	NE¼SE¼SW¼SE¼ sec. 19, T. 7 S., R. 68 W., from sandstone ledge near middle of Hygiene sandstone member. Scott and Cobban, 1956.
36	D810	NW¼NE¼NW¼NW¼ sec. 32, T. 7 S., R. 68 W., from sandy calcareous concretions. Scott and Cobban, 1956.
37	D392	SW¼NE¼NW¼NW¼ sec. 19, T. 7 S., R. 68 W., from small gray and brown limestone concretions. Scott, Miller, Cobban, and Van Horn, 1955.
38	D826	NE¼SW¼SW¼ sec. 1, T. 7 S., R. 69 W., from gray sandy calcareous nodules. Scott, 1956.
39	?	SW¼NE¼SE¼ sec. 35, T. 6 S., R. 69 W., from gray sandy calcareous nodules 25 ft. below D1012. Scott, 1956.
40	D393	SE¼NE¼NW¼NW¼ sec. 19, T. 7 S., R. 68 W., from sandy limestone concretions. Scott and Miller, 1955.
41	22838	NW¼NW¼ sec. 32, T. 7 S., R. 68 W., from limy sandy nodules in sandy shale. Scott and Cobban, 1950.
42	D6	SW¼NE¼ sec. 35, T. 6 S., R. 69 W., from gray limy concretions. Scott, 1954.
43	D1012	SW¼NE¼SE¼ sec. 35, T. 6 S., R. 69 W., from gray sandy tepee limestone and limy nodules. Scott, 1956.
44	D792	SE¼SW¼NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from hard sandy bed 44 ft. above 22840 and 25. ft below top of Hygiene sandstone member. Scott, Cobban, and Van Horn, 1956.
45	D1103	NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from ironstone concretions in gray sandy shale 47 ft. above D792. Scott, 1956.
46	D800	SW¼NW¼SE¼SE¼ sec. 19, T. 7 S., R. 68 W., from brown ironstone concretions. Scott, 1956.
47	D793	SW¼SW¼SE¼NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from top of Hygiene sandstone member a little higher than D792. Scott and Van Horn, 1956.
		Shale above Hygiene sandstone member
48	D824	SW¼NE¼SW¼ sec. 1, T. 7 S., R. 69 W., from tepee butte limestone in sandy shale. Scott, 1956.
49	D827	NE¼NE¼ sec. 2, T. 7 S., R. 69 W., from brown silty calcareous nodules in sandy shale. Scott, 1956.
50	D285	SW¼NW¼NW¼ sec. 1, T. 7 S., R. 69 W., from gray tepee limestone and brown limestone concretions. Scott, 1955.
51	D1104	NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from tan-gray chalky shale 31 ft above D1103 and about 10 ft. above D793. Scott, 1956.
52	D263	NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from concretion 33 ft above D1104. Scott, 1954.
53	D794	NW¼SE¼NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from sandy shale above D263. Cobban and Scott, 1956.
54	D795	NE¼SE¼NW¼SE¼ sec. 19, T. 7 S., R. 68 W., from gray tepee limestone and rusty ironstone concretions. Scott and Cobban, 1956.
55	D8	NE¼NW¼ sec. 19, T. 7 S., R. 68 W., from olive-gray limestone concretion in clayey shale. Scott and Miller, 1954.
56	D7	NE¼SW¼NW¼ sec. 1, T. 7 S., R. 69 W., from olive-gray limestone concretions in clayey shale. Scott, 1954.
57	D808	SW¼SW¼SE¼SW¼ sec. 29, T. 7 S., R. 68 W., from iron-stained concretions. Scott and Cobban, 1956.
58	D811	NE¼SE¼SW¼SW¼ sec. 29, T. 7 S., R. 68 W., from brown-weathering dark-gray limestone concretions in gray clayey shale. Scott, 1956.
59	D807	NW¼NW¼NE¼NW¼ sec. 32, T. 7 S., R. 68 W., from brownish-gray tepee butte limestone. Cobban and Scott, 1956.
60	D803	SW¼NE¼SE¼NE¼ sec. 30, T. 7 S., R. 68 W., from brownish-gray tepee butte limestone. Scott, Cobban, and Smith, 1956.
61	D825	Center NW¼ sec. 1, T. 7 S., R. 69 W., from gray limestone concretions in clayey shale. Scott, 1956.

PIERRE SHALE—Continued

Shale above Hygiene sandstone member—Continued

Locality (pl. 2)	USGS Mesozoic locality	
62	D804	SW¼NE¼SE¼NE¼ sec. 30, T. 7 S., R. 68 W., from brown and gray limestone nodules 15 to 30 ft above D803. Scott, Cobban, and Smith, 1956.
63	D801	SE¼NW¼SE¼SE¼ sec. 19, T. 7 S., R. 68 W., from iron-stained limestone concretions in clayey shale. Cobban, 1956.
64	D796	SW¼NW¼NE¼SE¼ sec. 19, T. 7 S., R. 68 W., from gray calcareous concretions above D795. Cobban, 1956.
65	D789	NE¼SW¼SW¼ sec. 18, T. 7 S., R. 68 W., from gray calcareous concretions and ironstones. Scott, 1956.
66	D788	NW¼SE¼SW¼ sec. 18, T. 7 S., R. 68 W., from brown- and gray-weathering limestone concretions. Scott, Cobban, and Van Horn, 1956.
67	D806	SW¼NE¼NE¼NW¼ sec. 32, T. 7 S., R. 68 W., from brown- and gray-weathering limestone concretions. Scott and Cobban, 1956.
68	D805	NW¼SW¼SW¼NE¼ sec. 32, T. 7 S., R. 68 W., from sandy concretions in sandy shale. Scott and Cobban, 1956.
69	D812	SE¼NW¼SE¼SW¼ sec. 29, T. 7 S., R. 68 W., from brown ironstone concretions in clayey shale. Cobban, 1956.
70	D813	NE¼NW¼SE¼SW¼ sec. 29, T. 7 S., R. 68 W., from ironstone concretions in clayey shale. Scott, 1956.
71	D834	NE¼NE¼ sec. 30, T. 7 S., R. 68 W., from gray clayey shale. Scott, 1956 (collection missing).
72	D786	NW¼SE¼NW¼ sec. 18, T. 7 S., R. 68 W., from ironstone concretions and cone-in-cone layers in dark clayey shale. Scott, Van Horn, and Cobban, 1956.
73	D787	SW¼NE¼NW¼ sec. 18, T. S., R. 68 W., from dark clayey shale a little above D786, Van Horn, 1956.
74	22837	SE¼SE¼ sec. 19, T. 7 S., R. 68 W. from sandy shale. Scott, 1950.
75	D585	NW¼SW¼NW¼ sec. 7, T. 7 S., R. 68 W., from gray limestone concretions in gray sandy shale. Scott, 1955.
76	D10	NE¼SW¼ sec. 18, T. 7 S., R. 68 W., from hard 8-inch sandstone layer in sandy shale. Scott, Cobban, Cooley, Van Horn, 1954.
77	22839	SE¼NE¼SE¼ sec. 19, T. 7 S., R. 68 W., from sandy shale. Scott, 1950.
78	D11	NE¼SW¼ sec. 18, T. 7 S., R. 68 W., from hard calcareous concretion about 50 ft above D10. Scott, Cobban, Cooley, and Van Horn, 1954.
79	D12	NE¼SW¼ sec. 18, T. 7 S., R. 68 W., from hard sandstone layer about 55 ft above D11. Scott, Cobban, Cooley, and Van Horn, 1954.
80	22836	SE¼NE¼SE¼ sec. 19, T. 7 S., R. 68 W., from sandy shale. Scott, 1950.

PIERRE SHALE—Continued

Shale above Hygiene sandstone member—Continued

Locality (pl. 2)	USGS Mesozoic locality	
81	22841	NW¼SE¼ sec. 32, T. 7 S., R. 68 W., from friable sandstone in cut. Scott, Cobban, and Van Horn, 1950.
82	D814	SE¼SW¼NE¼SW¼ sec. 29, T. 7 S., R. 68 W., from sandy limestone concretions in shaly sandstone. Cobban and Scott, 1956.
83	D13	NE¼SW¼ sec. 18, T. 7 S., R. 68 W., from top of exposures of upper sandy shale about 100 ft above D12. Scott, Cobban, Cooley, and Van Horn, 1954.
84	D815	NW¼SE¼NE¼SW¼ sec. 29, T. 7 S., R. 68 W.; fossils replaced by olive-green sandy phosphatic nodules. Cobban and Scott, 1956.

LARAMIE FORMATION

85	------	SE¼NW¼ sec. 29, T. 7 S., R. 68 W., from sandy ironstone bed about 125 ft below top of Laramie formation. Scott, 1950.

DAWSON ARKOSE

86	------	NW¼SE¼ sec. 29, T. 7 S., R. 68 W., from sandy ironstone bed in lower part of Dawson arkose. Scott, 1950.
87	------	SW¼NE¼ SW¼ sec. 8, T. 7 S., R. 68 W.; fossil leaves from clayey ironstone beds in upper part of Dawson arkose. Scott, 1950. *Ficus* sp.; age not determinable.

REFERENCES CITED

Ball, S. H., 1906, Precambrian rocks of the Georgetown quadrangle, Colorado: Am. Jour. Sci., 4th ser., v. 21, p. 371–389.

Bass, N. W., 1926, Geology of Hamilton County, pt. 2 of Geologic investigations in western Kansas: Kansas State Geol. Survey Bull. 11, 95 p.

Brown, R. W., 1943, Cretaceous-Tertiary boundary in the Denver Basin, Colorado: Geol. Soc. America Bull., v. 54, no. 1, p. 65–86.

Chronic, John, and Ferris, C. S., Jr., 1961, Early Paleozoic outlier in southeastern Wyoming, *in* Lower and middle Paleozoic rocks of Colorado: Rocky Mtn. Assoc. Geologists 12th Field Conf., South central Colorado, 1960, p. 143–146.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the western interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1043.

Cragin, F. W., 1896, On the stratigraphy of the Platte series, or Upper Cretaceous of the Plains: Colorado Coll. Studies, v. 6, p. 49–52.

Crosby, W. O., 1895, Sandstone dikes accompanying the great fault of Ute Pass, Colorado: Essex Inst. Bull., v. 27, p. 113–147.

Cross, C. W., 1894a, Description of the Pikes Peak sheet [Colorado]: U.S. Geol. Survey Atlas, Folio 7, 5 p.

——— 1894b, Intrusive sandstone dikes in granite: Geol. Soc. America Bull., v. 5, p. 225–230.

Dane, C. H., and Pierce, W. G., 1933, Geology and oil and gas prospects in part of eastern Colorado: U.S. Dept. Interior Memo. 72215, June 8, 1933, 8 p.

Dane, C. H., Pierce, W. G., and Reeside, J. B., Jr., 1937, The stratigraphy of the Upper Cretaceous rocks north of the Arkansas River in eastern Colorado: U.S. Geol. Survey Prof. Paper 186–K, p. 207–232.

Eldridge, G. H., 1889, On some stratigraphical and structural features of the country about Denver, Colorado: Colorado Sci. Soc. Proc., v. 3, pt. 1, p. 86–118.

Elias, M. K., 1931, The geology of Wallace County, Kansas: Kansas State Geol. Survey Bull, 18, 254 p.

Emmons, S. F., Cross, C. W., and Eldridge, G. H., 1896, Geology of the Denver Basin in Colorado: U.S. Geol. Survey Mon. 27, 556 p.

Fenneman, N. M., 1905, Geology of the Boulder district, Colorado: U.S. Geol. Survey Bull. 265, 101 p.

——— 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Finlay, G. I., 1916, Description of the Colorado Springs quadrangle [Colorado]: U.S. Geol. Survey Atlas, Folio 203, 15 p.

George, R. D., Curtis, H. A., Lester, O. C., Crook, J. K., Yeo, J. B., and others, 1920, Mineral waters of Colorado: Colorado Geol. Survey Bull. 11, 474 p.

Gilbert, G. K., 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geol. Survey Ann. Rept. 17, pt. 2, p. 551–601.

Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U.S. Geol. Survey Prof. Paper 150, p. 61–110.

Goddard, E. N., and others, 1948, Rock-color chart: Natl. Research Council, 6 p.

Gregory, H. E., 1938, The San Juan Country: U.S. Geol. Survey Prof. Paper 188, 123 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.

Hayden, F. V., 1873, The geological features of the east slope of the Colorado Range of the Rocky Mountains from Cache la Poudre River southward to Pikes Peak: U.S. Geol. and Geog. Survey Terr., embracing Colorado, 7th Ann. Rept., chap. 1, p. 31 [1874].

Hutchinson, R. M., 1959, A^{40}/K^{40} age determinations of rocks associated with north end of Pikes Peak batholith, Jefferson, Douglas, and Park Counties, Colorado [abs.]: Geol. Soc. America Bull., v. 70, no. 12, pt. 2, p. 1622.

Johnson, J. H., 1930, Unconformity in the Colorado group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 789–794.

King, Clarence, 1876, Annual report upon the geological exploration of the fortieth parallel from the Sierra Nevada to the eastern slope of the Rocky Mountains: U.S. Geol. Explor. 40th Parallel Atlas, maps 1 and 2.

LeRoy, L. W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colorado: Colorado School Mines Quart., v. 41, no. 2, 115 p.

Logan, W. N., 1897, The upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, v. 2, p. 195–234.

Lovering, T. S., 1935, Geology and ore deposits of the Montezuma quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 178, 119 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, O. L., 1953, Geology and ore deposits of the Boulder County tungsten district, Colorado: U.S. Geol. Survey Prof. Paper 245, 199 p.

Lupton, C. T., 1914, Oil and gas near Green River, Grand County, Utah: U.S. Geol. Survey Bull. 541, p. 115–133.

McKee, E. D., Oriel, S. S., Swanson, V. E., MacLachlan, M. E., MacLachlan, J. C., Ketner, K. B., Goldsmith, J. W., Bell, R. Y., and Jameson, D. J., 1956, Paleotectonic maps of the Jurassic system: U.S. Geol. Survey Misc. Geol. Inv. Map I–175, 6 p.

Maher, J. C., 1953, Permian and Pennsylvanian rocks of southeastern Colorado: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 913–939.

Martin, G. C., 1908, U.S. Geol. Survey Mine Notes 9–911, notebook 1: U.S. Geol. Survey Archives No. 2541.

Maughan, E. K., and Wilson, R. F., 1960, Pennsylvanian and Permian strata in southern Wyoming and northern Colorado, *in* Guide to the geology of Colorado: Geol. Soc. America, p. 34–42.

Meek, F. B., and Hayden, F. V., 1862, Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska Territory, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc., v. 13, p. 415–447 [1861].

Munsell Color Co., Inc., 1954, Soil color charts.

Peterson, W. L., and Scott, G. R., 1960, Precambrian rocks and structure of the Platte Canyon and Kassler quadrangles, Colorado, *in* Guide to the geology of Colorado: Geol. Soc. America, p. 181–183.

Richardson, G. B., 1912, The Monument Creek group: Geol. Soc. America Bull., v. 23, p. 267–276.

Roy, C. J., 1946, Clastic dikes of the Pikes Peak region [Colorado] [abs.]: Geol. Soc. America Bull., v. 57, no. 12, p. 1226.

Rubey, W. W., and Bass, N. W., 1925, The geology of Russell County, Kansas, with special reference to oil and gas resources: Kansas State Geol. Survey Bull. 10, p. 1–86.

Schrader, F. C., Stone, R. W., and Sanford, Samuel, 1917, Useful minerals of the United States: U.S. Geol. Survey Bull. 624, 412 p.

Scott, G. R., 1960, Quaternary sequence east of the Front Range near Denver, Colorado, *in* Guide to the geology of Colorado: Geol. Soc. America, p. 206–211.

——— 1963, Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 421–A, 70 p.

Spurr, J. E., Garrey, G. H., and Ball, S. H., 1908, Economic geology of the Georgetown quadrangle, Colorado: U.S. Geol. Survey Prof. Paper 63, 422 p.

Stark, J. T., and others, 1949, Geology and origin of South Park, Colorado: Geol. Soc. America Mem. 33, 188 p.

Sternberg, C. W., and Crowley, A. J., 1954, Cretaceous sands of the Denver basin, *in* Jensen, F. S., Sharkey, H. H. R., and Turner, D. S., eds, The oil and gas fields of Colorado—a symposium: Rocky Mountain Assoc. Geologists, 302 p.

Turner, F. J., and Verhoogen, Jean, 1951, Igneous and metamorphic petrology: New York, McGraw-Hill Book Co., 602 p.

Vanderwilt, J. W., 1947, Mineral resources of Colorado: Colorado Mineral Resources Board, 547 p.

Van Horn, Richard, 1957, Ralston Creek formation, a new name for the Ralston formation of LeRoy (1946) [Colorado]: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 755–756.

Van Sant, J. N., 1959, Refractory-clay deposits of Colorado: U.S. Bur. Mines Inv. Rept. 5553, 156 p.

Vitanage, P. W., 1954, Sandstone dikes in the South Platte area, Colorado: Jour. Geology, v. 62, no. 5, p. 493–500.

Waagé, K. M., 1955, Dakota group in northern Front Range foothills, Colorado: U.S. Geol. Survey Prof. Paper 274–B, 51 p.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman & Co., 406 p.

Williston, S. W., 1893, The Niobrara Cretaceous of western Kansas: Kansas Acad. Sci. Trans., v. 13, p. 107–111.

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