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GEOLOGIC MAP OF THE FRONT RANGE MINERAL BELT, COLORADO[1] [EXPLANATORY TEXT]

by

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ILLUSTRATIONS

[1]Published by permission of the Director, Geological Survey, United States Department of the Interior, of the Colorado State Geological Survey Board, and of the Colorado Metal Mining Fund.

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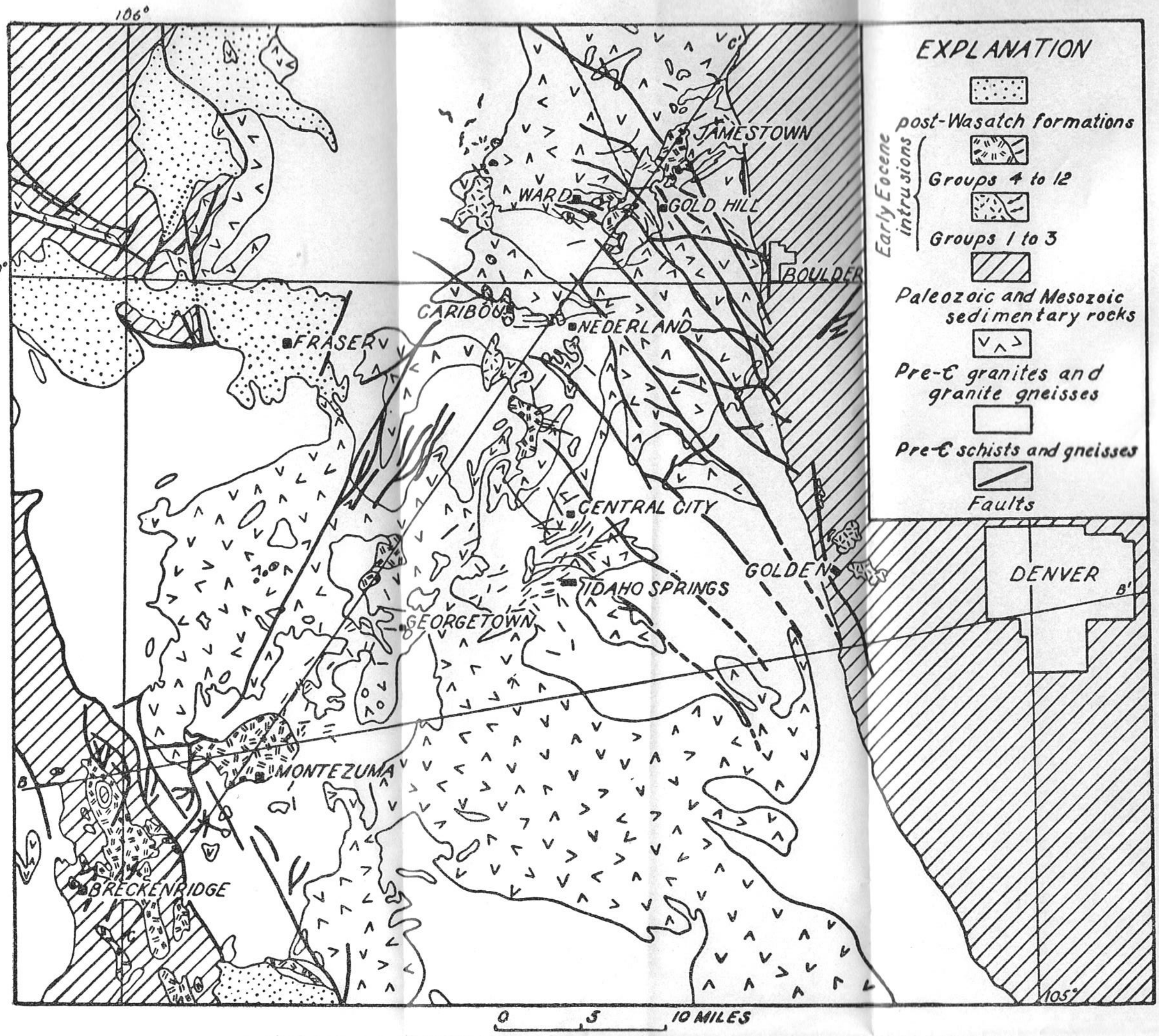
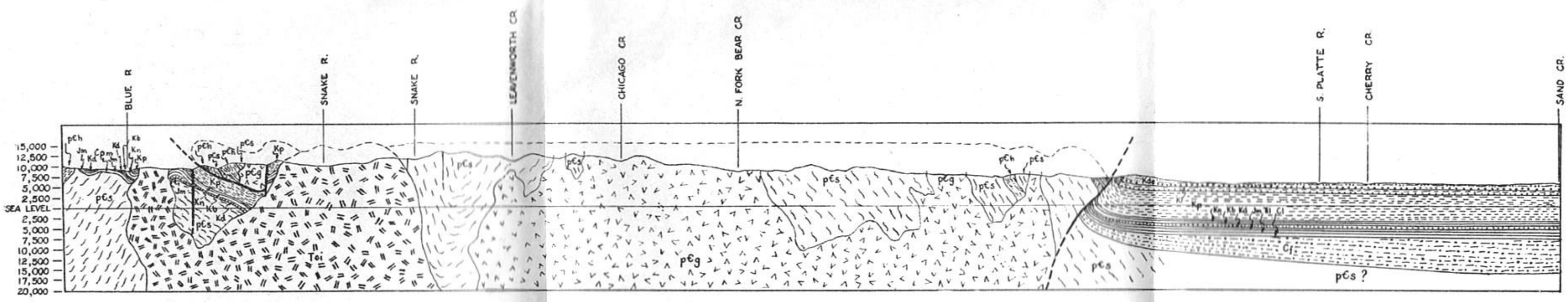
Introduction

The Front Range of the Rocky Mountains in Colorado lies mainly between the 106th and 105th meridian from the Wyoming boundary southward to Canon City (Colo.), but nearly all its more productive mining districts, with the notable exception of Cripple Creek, lie in a narrow belt that extends southwest from Jamestown to Breckenridge (pl. 1). Most of the mining districts have been mapped by State or Federal geologists, but the maps have appeared in separate district reports. Many of the less productive areas within the mineral belt and the region bordering the belt heretofore have received little attention. In many of the earlier reports the rock units were not correlated, and the need has been felt increasingly for a geologic map of the whole mineral belt that shows its major structural features and the inter-relation of the different mining districts. The writers have bridged the gaps between the geologic maps already available and have added structural details in some of the areas previously mapped. Most of the new mapping was done by the writers, assisted by Henry F. Donner, Robert M. Rigg, and Stanley Jerome during the summer of 1936, but parts of the region were mapped by the writers at other times during the past 10 years. The sources of all information utilized in preparing this new geologic map of the Front Range mineral belt are given on the index map (see large scale geologic map issued by the U. S. Geol. Survey).

This work is part of a cooperative geological survey of the State of Colorado made by the Geological Survey of the United States Department of the Interior working with the Colorado State Geological Survey Board and the Colorado Metal Mining Fund. The writers wish to express their appreciation of the universal consideration and courtesy accorded to them by mining men throughout the Front Range and especially acknowledge their indebtedness to Mr. Chas. W. Henderson of the Federal Bureau of Mines, Denver, Colo., for much helpful information.

Plate 1.





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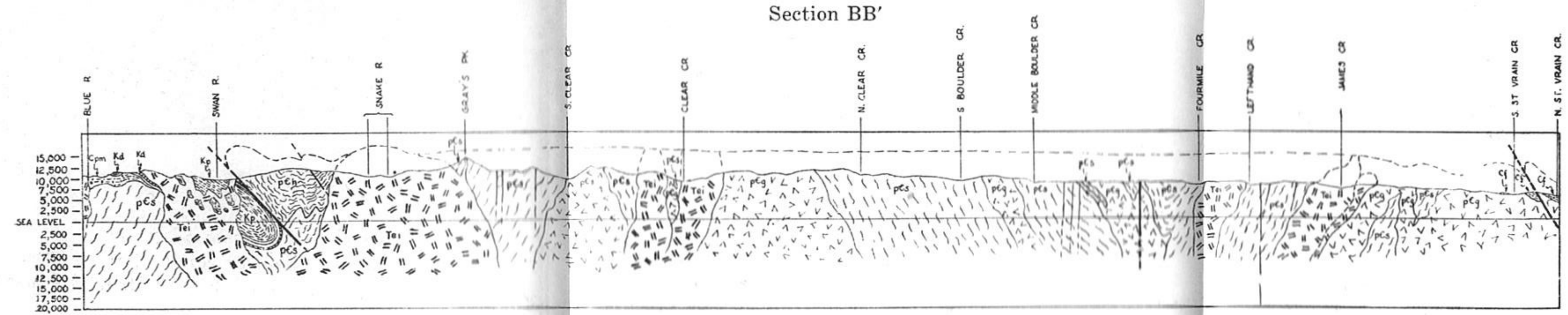

Section CC′

(p€s) pre-Cambrian schist, (p€h) pre-Cambrian hornblende gneiss, (p€g) pre-Cambrian granites, (Cf) Fountain sandstone, (Cl) Lyons sandstone, Cpm) Maroon formation, (Trl) Lykins formation, (Jm) Morrison formation, (Kd) Dakota sandstone, (Kb) Benton shale, (Kn) Niobrara formation, (Kp) Pierre shale, (Kl) Laramie formation, (Kde) Denver formation, (Tei) Eocene (?) intrusive rocks.

Plate 1. Sketch map and cross sections of the Front Range mineral belt.

Topography

The plains that adjoin the Front Range at the northeastern limit of the mineral belt attain an altitude of 5,300 to 5,500 feet. From Boulder southwest to Silver Plume, the mineral belt is chiefly in the deeply trenched remnants of the late Tertiary erosion surfaces that rise toward the west from an altitude of about 7,500 feet at the Range front to 9,000 feet a few miles east of its crest. From Silver Plume southwest to the Montezuma district, the Continental Divide winds back and forth across the mineral belt in some of the highest country of the Rocky Mountains. Since the Continental Divide is close to the west edge of the Front Range, there are no broad benchlike remnants of the late Tertiary erosion surfaces between the divide and the west edge of the pre-Cambrian terranes, but some striking examples of early Tertiary surfaces are preserved on flat-topped summits of the high mountains along the divide. The average altitude of the valleys in the Breckenridge district just west of the main ridge of the Front Range is about 9,000 feet. A few miles to the east, on the Continental Divide between the Argentine and Silver Plume districts, Grays Peak and Torreys Peak, the two highest peaks in the Front Range, rise to altitudes of 14,274 and 14,264 feet, respectively.

On the east slope of the Front Range the major streams take a course almost due east from the Continental Divide to the plains, and their larger tributaries flow southeast or northeast to join them. In the section of the mineral belt that lies on the west slope the master stream is the northward flowing Blue River. Its chief tributaries in the mineral belt are the Snake River and the Swan River, which flow westward but have large tributaries that flow south or southwest and north or northwest.

Geology

General Features

The rocks exposed in the Front Range are mostly pre-Cambrian granite, gneiss, and schist, but at many places within the mineral belt these early rocks are cut by intrusive "porphyries" of late Cretaceous or early Eocene age. The crystalline core of the range is nearly everywhere bordered by steeply tilted Paleozoic sedimentary rocks, but in the west-central part steeply dipping Mesozoic formations rest directly on the pre-Cambrian. In the northern part of the Front Range gently dipping Tertiary beds overlap the truncated edges of the Mesozoic and Paleozoic formations and rest on pre-Cambrian rocks; in the southern part an extensive series of interbedded Tertiary tuff and lava rests upon pre-Cambrian, Paleozoic, and Mesozoic rocks. Mid-Tertiary intrusive rocks are common in the southern and west-central parts of the range, but within the mineral belt the known intrusives are not later than Eocene.

Mesozoic and Paleozoic sediments are present in the southwestern part of the mineral belt near Breckenridge, where it leaves the Front Range, crosses an intermontane trough, and enters the Mosquito Range. At the northeastern border of the belt, near Boulder, a few porphyries have been found in the Paleozoic and Mesozoic rocks, but, so far as known in this area, the porphyritic intrusives outside the pre-Cambrian terrane are not accompanied by mineral deposits. Within the mineral belt the principal rocks, in the order of their abundance, are pre-Cambrian metamorphics, pre-Cambrian intrusives (chiefly granite), Laramide[4] intrusives (chiefly diorite and quartz monzonite porphyries), and Paleozoic and Mesozoic sediments. The marked northeasterly trend of the porphyry belt and the associated ore deposits reflects both the direction of the early Eocene orogenic forces and the regional and local distribution of the earlier rocks. The northeasterly course of the mineral belt corresponds rather closely with the irregular areas of relatively weak schists and gneisses that lie between the granite batholiths. Within the granite masses fracturing is conspicuous, but apparently stresses were relieved only along a few persistent major zones of northwest trend, whereas within

[4]The term "Laramide" as used by the writers refers to the interval during which the Laramide or Rocky Mountain revolution was taking place—the transition from late Cretaceous to early Eocene marking the end of one great era and the beginning of another. In no place does Laramide refer to the time when the Laramie formation was being deposited.

the schist and gneiss the greater deformation resulted in the formation of less persistent but more closely spaced shear zones of northeast trend. The mineralization of this relatively open ground, however, seems closely linked with the more widely spaced fracture system of northwest trend.

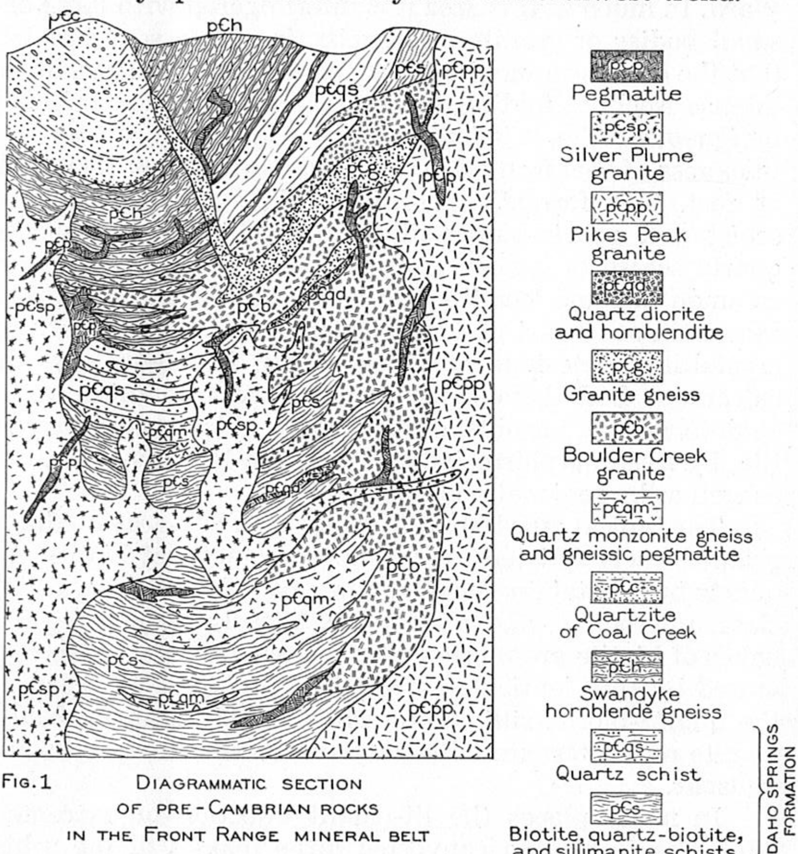

Figure 1. Diagrammatic section of pre-Cambrian rocks in the Front Range mineral belt, showing general age and structural relations.

PRE-CAMBRIAN ROCKS

The general age and structural relations of the pre-Cambrian rocks are shown in figure 1.

Idaho Springs formation.—The oldest rocks in the mineral belt are the metamorphosed sediments of the Idaho Springs formation, the type locality of which is at Idaho

Springs,[5] about 30 miles west of Denver. The formation is widely distributed throughout the mineral belt and is predominant in a broad zone that extends from Webster Pass, south of Montezuma, northward through Idaho Springs to Ward. In much of this area it is interfingered with large and small bodies of granite and gneiss, in places so intimately that the details cannot be shown on the map. Because of the intense isoclinal folding, crumpling, and complex injection by igneous rocks, it is impossible to estimate accurately the thickness of this formation, which must be many thousands of feet. The formation consists chiefly of quartz-biotite schist and quartz-biotite-sillimanite schist, but quartzite, quartz schist, or quartz gneiss and hornblende gneiss are common in some localities. In a few places, as on Warrior Mountain southeast of Idaho Springs, beds of coarsely recrystallized limestone are present, but in most places the calcareous beds have been transformed into mixtures of epidote, garnet, hornblende, other lime silicates and magnetite, by metamorphism induced through igneous emanation as well as by regional metamorphism.

The typical quartz-biotite schist is a dark-gray medium-grained finely foliated rock composed chiefly of biotite and quartz but containing varying amounts of muscovite, orthoclase, microcline, and plagioclase. Closely packed parallel flakes of biotite are more or less segregated into bands separated by thin lenticular layers of quartz and feldspar. In the quartz-biotite-sillimanite schist felted laminae of sillimanite rods alternate with the bands of biotite, quartz, and feldspar.

In many places the lit-par-lit injection of extremely fluid granite magma converted large masses of the schist into injection gneiss, and some areas of the Idaho Springs formation are so thoroughly injected with layers of granite, aplite, and pegmatite that the rock now resembles primary granite gneiss. This granitic addition so greatly increased the rigidity and brittleness of the schists that fractures in the injection gneiss and veins that fill such fractures are commonly more persistent and continuous than in the more flexible, uninjected parts of the formation.

[5]Spurr, J. E., Garrey, G. H., and Ball, Sidney, Economic geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

The Idaho Springs formation is the metamorphic equivalent of a shaly formation with thin intercalated layers of limestone and sandstone, which graded upward through sandy shale to sandstone. Although the Idaho Springs formation has been very closely folded, and granulation of the feldspar and quartz grains is common, the original bedding is nearly everywhere parallel to the planes of schistosity.

Swandyke hornblende gneiss.—The volcanic and clastic Swandyke hornblende gneiss lies with apparent conformity on the Idaho Springs formation, and at many places its characteristic hornblendic facies is intercalated with quartz schist of the Idaho Springs formation in a thick transition zone. In such localities, equivalent facies rather than time-equivalents have been mapped, and the quartz schists are shown as members of the Idaho Springs formation even where they overlie the Swandyke gneiss. The hornblende gneisses and interbedded quartz schists and quartz gneisses that occur near the base of the Swandyke formation occupy an extensive area of more than 50 square miles in the southwestern part of the mineral belt in the Jefferson Lake, Hall Valley, Swandyke, and Montezuma districts. Elsewhere in the mineral belt the Swandyke hornblende gneiss is much less abundant. Irregular areas are scattered along the eastern edge of the belt from a locality east of Idaho Springs northeastward to Coal Creek, and small areas are found in the northern part of the Jamestown district. Hornblende gneiss is also sparingly scattered through the Central City quadrangle but has been included by Bastin[6] in the Idaho Springs formation.

The metamorphic features of the Swandyke hornblende gneiss are quite as fully developed as those that characterize the Idaho Springs formation. The feldspars and quartz grains are generally strained or crushed, and large volumes of the Swandyke gneiss have undergone lit-par-lit injection with aplite and pegmatite. Much of this injection gneiss is indistinguishable from that of the Idaho Springs formation.

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[6]Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, 1917.

In most places the Swandyke gneiss consists of alternate light and dark layers; the color indicates the varying amount of hornblende contained. The hornblende commonly constitutes from 40 percent to 80 percent of the gneiss, and plagioclase, chiefly andesine, is the most abundant of the other constituents. Quartz is common in some places and almost absent in others. In some facies biotite is almost as abundant as hornblende, and these facies grade commonly into biotite schist and quartz-biotite gneiss. In many localities, especially in the region southeast of Swandyke and in the area east of Corona Pass, the Swandyke hornblende gneiss is interlaced with strongly metamorphosed banded biotite-quartz monzonite gneiss and gneissic pegmatite. The intimate association of these three kinds of rock in many places suggests a genetic relation. The writers have nowhere found the Swandyke gneiss definitely intrusive into the Idaho Springs formation, though locally dikes of hornblende-quartz diorite have been metamorphosed to a hornblende gneiss, similar in appearance.

The lithology and structural relations suggest that the Swandyke hornblende gneiss represents dioritic intrusive rocks and related extrusive rocks that were in part contemporaneous with but mostly younger than the upper part of the Idaho Springs formation. The much metamorphosed biotite-quartz monzonite gneiss and gneissic pegmatite associated with the hornblende gneiss may belong to the same period of igneous activity, but they were probably intruded at a late stage into the mass of interbedded volcanic and clastic rocks that make up the bulk of the Swandyke gneiss.

Quartzite and schist at Coal Creek.—Near Coal Creek, in the northeastern part of the mineral belt, there is a series of quartzite, conglomerate, and schist at least 2,000 feet thick that is unlike any member of the Idaho Springs or Swandyke hornblende gneiss formations. Structurally the series forms a syncline that trends east-northeast. It is intruded by granite gneiss on the north and is separated from the extensive area of Idaho Springs and Swandyke gneiss formations to the south by a narrow zone of strongly sheared Boulder Creek granite and granite gneiss. The quartzite is metamorphosed so strongly as to be almost massive, but the bedding is still recognizable by the somewhat diffused bands of grayish quartzite which alternate with white. In the conglomerate layers, which are relatively scarce, the pebbles have been crushed into thin ellipsoids. A few narrow layers of quartz-biotite-muscovite schist occur in the quartzite and have been distinguished on the map in order to bring out the structure more clearly. In most places the schists are phyllitic and therefore show a lower grade of metamorphism than do those of the Idaho Springs formation to the south. The structure on the southeastern side of the syncline strongly suggests drag along a pre-Cambrian fault that warped the quartzite area down far below its normal level. The successive intrusions of the Boulder Creek granite and the granite gneiss along the fault zone and the deformation that followed these intrusions have further obscured the relations of the formations to one another. It is believed, however, that the quartzite is a remnant of a younger sequence that corresponds broadly in age to the Needle Mountains group of the San Juan Mountains. The age and structure of the quartzite has long been a subject of controversy, and some geologists believe it to be older than most of the Idaho Springs formation;[7] the present writers consider the quartzite younger than the Idaho Springs and Swandyke formations.

Quartz monzonite gneiss.—Aside from the very early pegmatites and aplites common in the Idaho Springs formation and in the Swandyke hornblende gneiss, the oldest igneous rock intrusive into these two formations is the quartz monzonite gneiss. This gneiss commonly occurs in irregular sheet-like masses. Its boundaries as well as its gneissic structure are essentially parallel to the schistosity of the inclosing rocks. Sheets too small to be shown on the map are abundant in the large area of hornblende gneiss west and south of Montezuma. Large masses, each several square miles in area, are present south of Silver Plume, northeast and southeast of Idaho Springs, in central Gilpin County, and along the crest of the range in the vicinity of the Moffat

[7]Adler, J. L., Geology of the Coal Creek quartzite: Unpublished thesis, University of Chicago, Chicago, Ill., 1932.

tunnel. Very small bodies are found as far north as Jamestown.

Nearly everywhere the metamorphic structure is highly developed, owing to the parallel elongation of biotite and the mashed aggregates of feldspar and quartz. Hornblende is not uncommon, and locally, in the more massive varieties of the gneiss, augite is also present. In most places the abundance of dark minerals and pronounced gneissic structure distinguish the quartz monzonite gneiss from the granite gneiss, but where the dark minerals are not abundant it becomes difficult to tell them apart. In general, this quartz monzonite gneiss is gray and medium-grained and ranges in composition from quartz diorite to quartz monzonite. Banding of dark and light gray is common, and in places the bands are much contorted. The country rock that forms the walls of the quartz monzonite gneiss shows lit-par-lit injection, and the incompletely assimilated inclusions of schist and hornblende gneiss, which are abundant in the quartz monzonite gneiss, also give evidence of the fluidity and activity of the invading magma. Associated with the quartz monzonite gneiss are many bodies of gneissic pegmatite in which the granulation of feldspar and quartz is very striking.

The quartz monzonite gneiss and associated gneissic pegmatite are definitely younger than the Swandyke hornblende gneiss and older than the Boulder Creek granite, but their relationship to the quartzite on Coal Creek is uncertain. The quartz monzonite gneiss has heretofore been interpreted as the earliest intrusion in the batholithic cycle during which all the pre-Cambrian igneous rocks of the Front Range were intruded. Although the writers believe this to be most probable, they note the possibility that the quartz monzonite gneiss may have been intruded before the deposition of the beds forming the quartzite and may be genetically related to the more highly metamorphosed Idaho Springs and Swandyke formations.

Boulder Creek granite.—The Boulder Creek granite forms stocks and small batholiths whose regional distribution indicates that they are satellitic to the large batholiths of Pikes Peak granite in the southern part of the Front Range and to the batholiths of the similar Sherman granite in the northern part of the range. As the name is used here the Boulder Creek granite includes the quartz monzonite of Ball[8] in the Georgetown quadrangle and several masses in the Central City quadrangle mapped by Bastin[9] as Silver Plume granite. A small batholith occupies more than 100 square miles in the northern part of Jefferson County and southern part of Boulder County, and a smaller one lies in Clear Creek County southeast of Georgetown. Stock-like masses are scattered on the west side of the batholiths, chiefly in the central and southwestern parts of Boulder County and the northwestern part of Clear Creek County.

Typical Boulder Creek granite is a moderately dark-gray coarse-grained biotite quartz monzonite or biotite granite that shows a marked primary gneissic structure. The chief constituents are microcline and orthoclase, quartz, oligoclase or andesine, biotite, and muscovite. In small isolated lenses close to the larger bodies of Boulder Creek granite and along the edges of the larger masses themselves foliation is very pronounced, and locally the rock grades into a quartz monzonite gneiss. In such localities the foliation has evidently been induced in large part by compression during the implacement of the nearby stock or batholith. In most places, however, the Boulder Creek granite is little crushed or granulated and exhibits fewer metamorphic effects than the granite gneiss bodies with which it is nearly contemporaneous. In general the gneissic structure is primary and parallel to the walls of the magmatic chamber.

Excellent exposures of the Boulder Creek granite may be seen in the canyon of Boulder Creek between Nederland and Boulder.

Granite gneiss.—The granite gneiss occurs as irregular bodies and dikes in the Boulder Creek granite, of which it appears to be an aplitic facies. It is also abundant as sheets, dikes, and small irregular masses that cut the earlier metamorphic rocks. It is most abundant in the southern

[8]Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., plate 2.
[9]Bastin, E. S., and Hill, J. M., op. cit., plate 1.

part of the Boulder Creek granite batholith in Jefferson and Gilpin Counties, where irregular masses finger out into the granite, but it is common throughout Clear Creek, Gilpin, and Boulder Counties. Few large bodies of granite gneiss are found. Lenticular masses from half a mile to a mile wide and 1 to 3 miles long are common, but many of the dikes are too small to be shown on the map.

The granite gneiss is a rather light gray, fine-grained, even-textured rock composed of quartz, orthoclase and microcline, and sodic plagioclase, with minor amounts of biotite. It shows a marked primary gneissic structure, which is expressed chiefly by the parallelism of the small grains of biotite and to a less extent by the orientation of the sodic plagioclase. Small bodies, especially those in the schist terrane near the edge of a batholith, commonly show strained quartz, incipient mortar structure, and other evidence of mild dynamic metamorphism. In most places where the granite gneiss is found in the metamorphic formations its foliation is essentially parallel to the structure of the enclosing rocks. Locally it grades into coarse-textured pegmatite that shows little or no gneissic structure.

Quartz diorite and associated hornblendite.—Quartz diorite of pre-Cambrian age is found chiefly in the Georgetown and Central City quadrangles, where it occurs as small stocks and enlarged dike-like masses. It is a medium coarse-grained, unevenly granular rock containing prominent hornblende crystals set in a medium-grained matrix of gray feldspar. Locally some quartz is visible, and biotite is not uncommon. Near the edge of the intrusive masses the rock commonly grades into a gneissic hornblende diorite or even into hornblende schist and hornblendite. It is approximately contemporaneous with the granite gneiss and the two may be complementary dike rocks related to the Boulder Creek granite. It is probable that many of the pre-Cambrian copper deposits in Jefferson County are related to the hornblende diorites and gabbros of this group.

Pikes Peak granite.—The Pikes Peak granite, whose type locality includes the east and south shoulders of Pikes

Peak, forms a large batholith to the south of the mineral belt, but within the area shown on the map it is represented only by the edges of a few stocks in the southern part of Clear Creek County. The typical Pikes Peak granite is a pink coarse-grained, porphyritic rock consisting largely of microcline, orthoclase, and quartz, with some biotite and the common accessory minerals. In some of the small stocks present in the southern part of the mineral belt, a primary gneissic structure parallel to the edges of the enclosing rock is evident and faintly suggests the characteristic texture of the Silver Plume granite, from which it is easily distinguished by the much coarser grain. Biotite is much less prominent than in the Boulder Creek granite, and the gnessic texture is confined to the borders of the small masses. Pegmatites are uncommon within the larger bodies of Pikes Peak granite but are moderately abundant near the edge of the batholiths and in the bordering schists. Beryl, topaz, zircon, fluorite, and other minerals of economic importance have been found in pegmatite genetically related to the main batholith south of the mineral belt. Samarskite in the Pikes Peak granite at Devil's Head, far to the south of the mineral belt, has been analyzed for its lead, uranium, and thorium content, and the ratio of lead to uranium and thorium indicated its age to be approximately one billion years.[10]

Silver Plume granite.—The Silver Plume granite includes a number of slightly different varieties—in batholiths, stocks, and dike-like masses, all of which are later than the pre-Cambrian rocks already described. In the northern part of the mineral belt a large compound batholith[11] extends as far south as the Jamestown and Ward districts and can be traced northward far beyond the limits of the area shown on the map. Another large body is found in the northern part of the Montezuma quadrangle, and irregular tongues of it extend into the Silver Plume district. Similar granites are found in both the northern and southern parts of the Front Range. These late granites are com-

[10]Physics of the Earth, vol. 4, Age of the Earth: National Research Council Bulletin 90, p. 338, 1931.

[11]Boos, M. F., and Boos, C. M., Granites of the Front Range, the Longs Peak-St. Vrain batholith: Geol. Soc. America Bull., vol. 45, no. 2, pp. 303-322, 1934.

monly characterized by the presence of medium-grained biotite and by a marked parallelism of the tabular potash feldspars and a lack of orientation of the biotite. They have a marked tendency to cut across the foliation of the schist and gneiss, in contrast to the concordant habit of the older intrusives. It is worthy of note that most of the granite batholiths of this group were intruded into synclines in the schists, but they themselves do not follow schistosity except locally.

In general, the Silver Plume granite is light gray, medium-grained, slightly porphyritic and granular, and is composed chiefly of pink and gray feldspars, smoky quartz, and biotite. Muscovite is present in some varieties, and the amount of biotite differs from place to place. Small masses of slightly more calcic granite occur in or close to the larger batholiths. This facies is finer-grained than the typical Silver Plume and may lack the well-oriented feldspar, but it locally contains small parallel flakes of biotite.

Analysis of cerite from pegmatite in the Silver Plume granite near Jamestown shows that the ratio of lead to uranium and thorium corresponds to an age of approximately 940,000,000 years.[12] Dikes of Silver Plume granite cut the Pikes Peak granite at several places and give definite field evidence of the relative ages of the two granites.

Pegmatites.—Granite pegmatites and associated bodies of aplite and fine-grained porphyritic granite occur in small bodies throughout the mineral belt. The largest bodies of pegmatite are found close to the edges of the batholiths of the different intrusives already described. Because of their strong lithologic similarity, the pegmatites related to the Boulder Creek granite, the Pikes Peak granite, and the Silver Plume granite have all been grouped as one unit. These later pegmatites, in contrast to the earlier ones that were responsible for much of the lit-par-lit injection of the metamorphic rocks, cut across the schistosity as commonly as they follow it.

[12]Goddard, E. N., and Glass, Jewell, J., Deposits of radioactive cerite near Jamestown, Colo. (abstract): Am. Mineralogist, vol. 21, no. 3, p. 199, March 1936.

The most abundant variety is a quartz-orthoclase-biotite pegmatite, but some varieties contain much muscovite, and a few distinctly different facies have also been noted. Near the edges of the bodies of Boulder Creek granite, magnetite-tourmaline pegmatites are common, and in some of them beryl is a moderately abundant constituent. Most of the pegmatites within areas of granite have sharp contacts with the enclosing rocks, but gradational contacts are not rare. Some individual masses of pegmatite cut cleanly across the granite in some places and merge gradually with it in others. The structural relations of the pegmatites to one another and to other rocks indicate that their intrusion took place over a long period of time.

Although the mineralogy of pegmatites of different ages is not distinctive enough to class them separately, certain differences are worthy of note. The early aplite and pegmatite seams injected into the metamorphic rocks consist chiefly of quartz and oligoclase or quartz and microcline. The pegmatites associated with the Boulder Creek granite contain a greater variety of minerals, among which oligoclase, orthoclase, microcline, quartz, biotite, muscovite, and magnetite are abundant, and tourmaline, garnet, allanite, epidote, corundum, sillimanite, apatite, and hornblende are present locally. Oligoclase is more common than orthoclase in the pegmatites related to the Boulder Creek granite, but the reverse is true of the later pegmatites, which are approximately contemporaneous with the Pikes Peak granite itself. The pegmatites associated with the Silver Plume granite are generally simpler in mineralogy than those associated with the Pikes Peak granite or the Boulder Creek granite. Orthoclase and microcline are more abundant than quartz in the Silver Plume pegmatites, and biotite, muscovite, and magnetite are common. In the Jamestown district some late pegmatites contain unusual rare-earth minerals, such as cerite, yttrocerite, tornebohmite, allanite, monazite, and pitchblende.[13]

[13]Goddard, E. N., and Glass, Jewell, J., op. cit.

Sedimentary Rocks

General Features

Although the region occupied by the Front Range has been covered completely by the ocean at least once since pre-Cambrian time, it was a strong positive element throughout the Paleozoic era and much of the Mesozoic. The presence of a pre-Tertiary highland in the Front Range region is shown by the conspicuous overlap that occurs at its border and by the distinct unconformities between formations whose unconformable relations are not evident away from the border of the range. Thus we find the Front Range surrounded by belts of outward dipping Paleozoic and Mesozoic sedimentary rocks whose thicknesses change greatly, and are commonly thinnest close to the mountains. In some localities the thickness of a formation ranges from that of a mere film at the edge of the crystalline rocks to more than 10,000 feet a few miles away. The changes in thickness are most conspicuous in the Permian and Pennsylvanian formations but may be found in nearly all the other systems to a less degree. The minor unconformities that exist between members of the various lower Paleozoic formations and the marked unconformity at the base of the Pennsylvanian grits account for the local disappearance of some or all of the lower Paleozoic formations in the southern half of the Front Range, though these formations, if viewed regionally, would be regarded as moderately persistent. The lower Paleozoic formations do not appear north of the south end of Perry Park, near Castle Rock, where they are overlapped by the arkosic grit of the Pennsylvanian Fountain formation, which rests on the pre-Cambrian rocks from this locality northward almost to the Wyoming line.

The general character of the Paleozoic sedimentary rocks exposed in the mineral belt is shown in the columnar sections of figure 2.

Along the west edge of the Front Range between North Park and South Park, strata of Permian and Pennsylvanian age or of the Jurassic Morrison formation lie directly upon

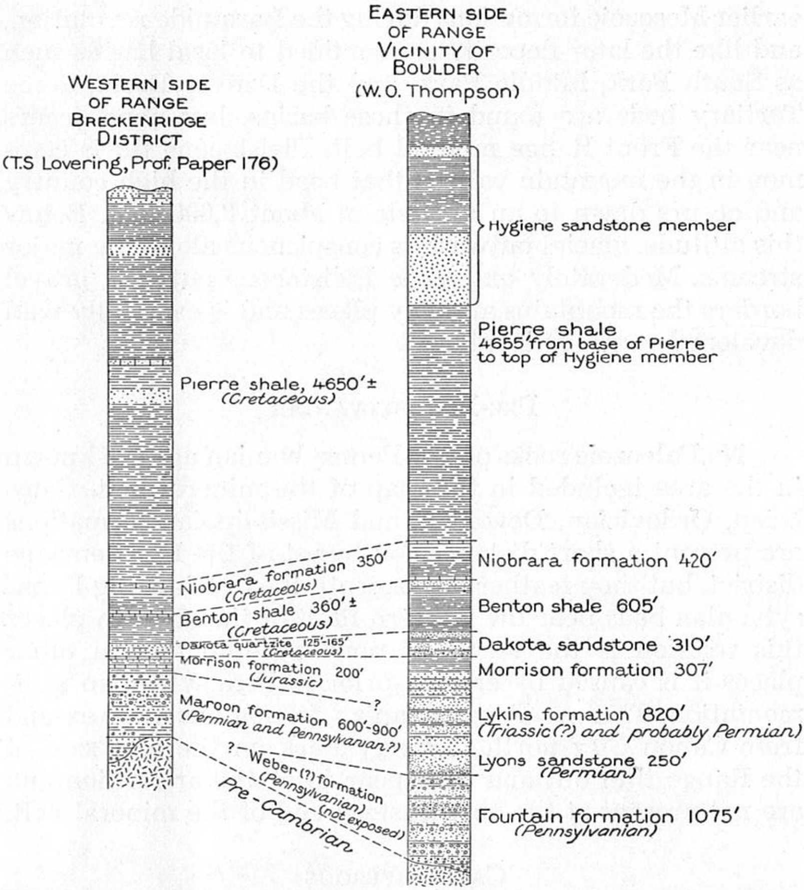

Figure 2. Correlation of sedimentary formations at the northeastern and southwestern edges of the mineral belt.

the crystalline rocks; in a few localities between the Fraser River and the Williams River, however, both are absent. Along the northern and eastern edges of South Park crystalline rocks are overlain by Upper Cretaceous formations, although a few miles to the west the section also includes rocks of Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, and Jurassic age. To the north, however, only post-Mississippian rocks occur near the Front Range. The continental deposits of late Cretaceous and possibly of early Eocene age were folded with the underlying earlier Mesozoic formations during the Laramide revolution, and like the later deposits are confined to local basins such as South Park, Middle Park, and the Denver Basin. Some Tertiary beds are found in these basins, but none occurs near the Front Range mineral belt. Pleistocene till is common in the mountain valleys that head in the high country and occurs down to an altitude of about 8,000 feet. Below this altitude, glacial outwash is conspicuous along the major streams. Moderately extensive Pleistocene outwash gravel borders the mountains at many places and is especially well developed south of Boulder.

Pre-Pennsylvanian

No Paleozoic rocks of pre-Pennsylvanian age are known in the area included in the map of the mineral belt. Cambrian, Ordovician, Devonian, and Mississippian formations are present a short distance southwest of the Breckenridge district, but they feather out beneath the overlapping Pennsylvanian beds near the western limit of the area. In places this relation is the result of nondeposition and in other places it is caused by erosion prior to Pennsylvanian sedimentation. The pre-Pennsylvanian formations that extend from Canon City north to Perry Park on the east side of the Range thin out and disappear in a similar fashion and are not present at the northeastern end of the mineral belt.

Carboniferous

Permian, Pennsylvanian and Triassic (?) of the east side of the Front Range

Fountain Formation.—The lower Pennsylvanian is represented by the Fountain formation on the east slope of the range and crops out almost continuously from the Wyoming line south to Canon City. Where exposed in the foothills belt near Boulder, it ranges from 500 to 1,500 feet in thickness. It is moderately coarse arkose containing abundant mica, quartz, red feldspar, and rock fragments derived from pre-Cambrian formations to the west. Fragments of the crystalline rocks are found chiefly in the conglomerates at the base of the formation. The conglomerate layers higher in the Fountain are composed chiefly of white quartz pebbles.[14] Thin lenticular layers of red, red-brown, and light-green micaceous shale and strongly cross-bedded sand and grit are common throughout the formation, but show little persistence along either the strike or the dip. Many of the individual members are thick, and all show a noteworthy lack of jointing.

Lyons sandstone.—The light orange-red arkosic Lyons sandstone lies directly on the Fountain formation in the vicinity of Boulder, but as followed north past Loveland it rests on progressively younger beds. It is approximately 200 feet thick and consists of medium-grained grit that shows evidence of a much greater degree of weathering and decomposition prior to deposition than does the material in the Fountain formation. In some places south of Boulder, as at Morrison, the Lyons sandstone is decolorized so completely that it is easily mistaken for the white grit of the upper part of the Fountain formation. In most localities it is much more massive than the underlying Fountain and forms cliffs that show conspicuous joints, in marked contrast to the relatively unjointed Fountain formation. Cross-bedding is even more conspicuous in the Lyons than in the Fountain. At Lyons, the type locality 10 miles north of Boulder, it is dominantly a cross-bedded fine-grained quartzose sandstone and is much less arkosic than farther south. No determinative fossils have been found, although some fossil footprints of amphibians occur at the type locality and it is regarded as Permian.

Lykins formation.—The red, shaly Lykins formation conformably overlies the Lyons sandstone everywhere along the east border of the Front Range. Near Boulder its thickness ranges from 600 to 800 feet. The formation is usually marked by a longitudinal foothill valley whose reddish soil indicates the character of the soft underlying red beds. The lower 230 feet of the Lykins formation is mostly a brick-red sandstone. Lying on this is a thin, resistant member

[14]Fenneman, N. M., Geology of the Boulder district, Colo.: U. S. Geol. Survey Bull. 265, pp. 22-23, 1905.

about 35 feet thick known as the "crinkled sandstone", or the "crinkled limestone". This is a fine-grained calcareous sandstone that grades locally into a dense limestone at its base and at places is overlain by other beds of limestone. It is a light-purplish pink closely laminated rock, which everywhere shows crumpling and intense small-scale deformation, although the overlying and underlying rocks are apparently massive and undeformed. Above this member the formation consists of interbedded argillaceous sandstone and sandy micaceous shales of brick-red color.

Fossils tentatively referred to the Permian by Girty have been found in the lower part of the Lykins in Perry Park, 30 miles south of Golden, and others of Pennsylvanian aspect have been found several hundred feet above the base.[15] Because of the apparent lateral gradation into the Permian and Triassic Chugwater formation of Wyoming the Lykins is regarded as of probable Permian and Triassic age,[16] but it is only the unfossiliferous upper beds that are doubtfully referred to the Triassic..

Permian and Pennsylvanian of the West Slope of the Front Range

On the west slope of the Front Range the Permian and Pennsylvanian rocks appear only in scattered areas in the southwestern part, where they have been much cut by faults and igneous intrusives. Along the south border of Middle Park and within the valley of the Blue River north of Dillon, the red Pennsylvanian grits are present in only a few localities. Between Dillon and South Park, the Pennsylvanian rocks, very thick to the west of the longitude of Hoosier Pass, feather out in a short distance to the east—and, like the older Paleozoic systems, are lacking along the northern and eastern sides of South Park. Ransome[17] estimated the thickness of the Permian and Pennsylvanian beds

[15] Johnson, J. H., The geology of the Golden area, Colo.: Colo. School of Mines Quart., vol. 25, p. 10, 1930.

[16] Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, p. 12, 1927.

[17] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: U. S. Geol. Survey Prof. Paper 75, p. 30, 1911.

near Hoosier Pass, 8 miles south of Breckenridge, to be at least 10,000 feet, and in South Park, a few miles farther south, Gould [18] measured a thickness of about 10,000 feet. In the Breckenridge area, however, these beds are only 600 to 1,000 feet thick,[19] and at Georgia Pass, a few miles to the east, they are entirely absent and Cretaceous quartzite rests directly upon the pre-Cambrian Swandyke hornblende gneiss.

Maroon and Weber (?) formations.—The lower part of the Pennsylvanian series on the west slope of the range is the so-called "Weber grits" and where well developed it consists predominantly of gray grit and dark-colored shales and limestones, many of which contain marine fossils. The purplish-red beds overlying the so-called Weber grits have been called the Maroon formation, and the two formations have been separated chiefly by color distinction. In some localities, however, dark-red beds of Maroon appearance are present near the base of the Weber (?) formation. Limestones are much more common in the lower part of the Weber (?) than in the upper part, and throughout the formation the grit and sandstone are strongly cross-bedded. Gradations from grit and sandstone into either shale or conglomerate occur within short distances along either the strike or dip. The lower part of the Maroon is generally of dark red color, which in the upper beds gives place to a brilliant brick-red.

Fossils have not been found in the few localities where the beds occur along the valley of the Blue River north of Dillon or near the southern edge of Middle Park. The characteristic lithology and the position of the beds beneath the Jurassic Morrison formation suggest Permian or Pennsylvanian age. So far as known, these reddish and purplish brown micaceous grits of doubtful age that occur north of Dillon are everywhere less than 500 feet thick, whereas the Permian and Pennsylvanian a few miles farther west attain a thickness of several thousand feet. South of Dillon fossils

[18] Gould, D. B., Stratigraphy and structure of Pennsylvanian and Permian rocks in the Salt Creek area, Mosquito Range, Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 971-1009, 1935.

[19] Ransome, F. L., op. cit., p. 31.

that are definitely of Pennsylvanian age have been found in the Weber (?) at many localities.

The Maroon formation was ascribed to the Permian by David White,[20] chiefly on the basis of *Walchia* and related fossil plants found in the formation in South Park and in the valley of the Eagle River. White regarded these plants as diagnostic of the Permian, but the recent work of Elias[21] on a flora which is of unquestioned Permian aspect but which contains undoubted Pennsylvanian plants and lies between formations of known Pennsylvanian age, throws doubt on the diagnostic value of the plants used by White in assigning a Permian age to the Maroon formation.

Triassic

Rocks of Triassic age do not occur on the west slope of the Front Range and, with the possible exception of the upper beds of the Lykins formation, are not recognized on the east slope.

Jurassic

Sundance formation.—According to Lee[22] a light-colored cross-bedded sandstone of the Jurassic Sundance formation is present north of Boulder and thin remnants of it are found south of Boulder, but in the area adjacent to the mineral belt it is lacking.

Morrison formation.—The persistent Upper Jurassic Morrison formation lies directly upon the Lykins formation near Boulder with a small unconformity. The base of the Morrison is a slightly conglomeratic sandstone containing chert grains of many different colors and small chert pebbles. This light colored sandstone ranges in thickness from 10 to 20 feet and is one of the most persistent members of the formation. Above the base the formation is dominantly shale but contains several interbedded limestones and sandstones. The pink, green, purple, gray, and black variegated

[20]Oral communication.

[21]Elias, M. K., A Permian flora from the Pennsylvanian of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 1475, 1936.

[22]Lee, W. T., op. cit., p. 16.