Geology and Ore Deposits of the Garfield Quadrangle, Colorado

GEOLOGICAL SURVEY PROFESSIONAL PAPER 289

Prepared in cooperation with the Colorado State Geological Survey Board and the Colorado Metal Mining Fund

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By McCLELLAND G. DINGS *and* CHARLES S. ROBINSON

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Prepared in cooperation with the Colorado State Geological Survey Board and the Colorado Metal Mining Fund. A comprehensive study of the geology, ore deposits, and mines in an area of the Sawatch Range

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By McClelland G. Dings and Charles S. Robinson

ABSTRACT

The Garfield quadrangle, the area of this report, is a rugged and mountainous region in the Sawatch Range of Chaffee and Gunnison Counties, Colo. Erosional and depositional features of alpine glaciers, such as U-shaped valleys, cirques, serrated ridges, moraines, and lake basins, are the conspicuous elements of the topography. Altitudes range from 9,000 to 14,100 feet.

The units mapped in the quadrangle may be grouped according to age and type into pre-Cambrian metamorphic and intrusive rocks, sedimentary rocks of Paleozoic and Mesozoic age, intrusive and extrusive rocks of Tertiary age, and Quaternary surficial deposits.

The rocks of pre-Cambrian age are exposed in the southern, central-western, and northwestern parts of the quadrangle and include quartz-mica schist, quartz-hornblende schist, quartz-hornblende gneiss, granite gneiss, and, intrusive into these, gneissic granite, hornblende diorite, Pikes Peak granite, and a granite tentatively correlated with the Silver Plume granite. The older schists and gneisses are in large part metamorphosed sedimentary rocks, and the granite gneiss is principally an injection gneiss and migmatite formed by granitic intrusion and replacement of the older schists and gneisses.

Sedimentary rocks of Paleozoic age occur in several areas in the southern and western parts of the quadrangle. Most areas are remnants of eroded synclines or down-faulted blocks and some are masses partly or completely surrounded by younger intrusive bodies. The Paleozoic formations comprise the Sawatch quartzite (Upper Cambrian), Manitou dolomite (Lower Ordovician), Harding quartzite (Middle Ordovician), Fremont dolomite (Middle and Upper Ordovician), Chaffee formation (Upper Devonian), Leadville limestone (Mississippian), Belden shale (Pennsylvanian), and the Minturn formation (Pennsylvanian and probably Permian). The Pennsylvanian and Permian(?) rocks account for about 5,100 feet of the maximum thickness of about 6,300 feet of Paleozoic rocks. Sedimentary rocks of Mesozoic age are restricted to a few square miles in the extreme southwest corner of the quadrangle where they form the northeast limb of a syncline. The Morrison formation (Upper Jurassic) rests on rocks of pre-Cambrian age and is overlain successively by the Dakota sandstone (Lower and Upper Cretaceous), and the lower part of the Mancos shale (Upper Cretaceous). Total thickness of the Mesozoic rocks is about 700 to 800 feet.

A great succession of intrusive rocks, probably of early Tertiary age, occupies a large part of the quadrangle. These rocks form chonoliths, stocks, sills, dikes, and one small batholith: the Mount Princeton batholith. The relative ages of most of these intruded bodies are clearly shown by crosscutting relations, by inclusions of one rock in another, or by relations to periods of faulting. Fourteen major varieties of intrusive rocks are recognized. Chronologically, these are: (1) quartz diorite porphyry, (2) Tincup quartz monzonite porphyry (new name), (3) rhyolite, (4) quartz diorite, (5) gneissic quartz monzonite, (6) Mount Pomeroy quartz monzonite, (7) andesite, (8) Mount Princeton quartz monzonite, (9) monzonitic and latitic dikes, (10) rhyolitic dikes, (11) kersantite dikes, (12) Mount Antero granite (new name), (13) quartz latite porphyry, and (14) Mount Aetna quartz monzonite porphyry. The rocks of most of the intrusive bodies show marked differences in physical appearance, which generally are much greater than their differences in composition. Excluding the dike rocks, the nine oldest intrusive rocks fall into three series, when considered in order of age, and each series shows a progressive change in rock composition from early basic or intermediate to later more acidic. The main period of intrusive activity probably extended from the Paleocene into the Oligocene epochs.

Volcanism, later than the intrusive activity, produced breccias, flows, and tuffs. Rhyolitic breccias and flows locally rest on eroded surfaces of the Mount Aetna porphyry. They were probably formed during the Miocene epoch, which was characterized in southwestern Colorado by the extrusion of breccias and flows. The northern edge of a large area of fossiliferous water-laid tuff of probable Pliocene age is preserved at the southern border of the quadrangle.

The Quaternary deposits consist of glacial moraine, glaciofluvial deposits, landslides, talus, and alluvium. Glacial moraine is widespread, and the floors and lower slopes of almost every major valley are at least partly covered by it, although the deposits rarely exceed 20 feet in thickness. Most are ground moraine; the large glaciers terminated beyond the borders of the quadrangle. Glaciofluvial deposits are also widespread, but the only two large areas of this material border West Willow Creek and South Arkansas River. Three fairly large areas of landslide, with typical hummocky surfaces, are in the mapped area; the largest of these is in Tomichi Creek valley. Talus is present on many of the steep slopes. Alluvial deposits are limited to small strips along a few of the larger streams.

The dominant structure of the rocks of the quadrangle is moderately complex with folds, faults, and fractures of diverse trends. The dominant structure is a reverse fault (Tincup-Morning Glim fault) of large displacement that trends northwest diagonally across the quadrangle for a distance of about 17 miles. Deformation occurred during pre-Cambrian, late Cretaceous or early Paleocene (Laramide orogeny), and early(?) Tertiary time. Structures formed in the ancient schists and gneisses during the pre-Cambrian consist chiefly of northwest-trending open folds, except in the southeastern part of the quadrangle near the main mass of Tertiary intrusive rocks where the foliation of the metamorphic rocks has a dominant north to northeast trend. The major structures in the sedimentary rocks are chiefly northwest-trending folds and faults that formed during the Laramide orogeny. These structures are evident even though the sedimentary rocks were invaded by large intrusive bodies and have been eroded to a series of discontinuous patches, preserved chiefly in synclines and down-faulted blocks. The folds are mainly broad and gently north-plunging

structures. The two major faulted structures are an east-trending graben (Quartz Creek graben) in the western part of the quadrangle, and a northwest-trending thrust fault (Tincup-Morning Glim fault) that extends diagonally across the quadrangle and has a probable maximum dip slip displacement of several miles. Faults of this Laramide orogeny locally influenced the intrusion of the Tertiary bodies and, above all, locally formed channels into which economically important ores were deposited, such as the Madonna ore body along the Madonna fault and the Akron ore body along the Star fault. The early(?) Tertiary deformation produced a series of dominantly north to northeast-trending fractures. Many of the fractures were later filled by vein material and dikes, especially those in the eastern part of the Mount Princeton batholith.

Contact metamorphism of the Paleozoic sedimentary rocks occurred around the borders of the Mount Princeton batholith. The most pronounced effect of this metamorphism is a recrystallization to marble of limestone and dolomite beds that lie within half a mile of the batholith. In the Taylor Gulch area, however, the recrystallization extends as far as 1½ miles from the outcrop of the batholith. Near the batholith all sandstone beds have been changed to quartzite, and the impure limy and dolomitic beds typically contain epidote, garnet, and diopside, and locally pass into hornfels. The limy beds of the Belden and Minturn formations are, on the whole, less metamorphosed than the older limy beds.

Included within the Garfield quadrangle are part or all of the Tincup, Tomichi, Monarch, Chalk Creek, and Quartz Creek mining districts. Mining operations began about 1860 when a few small placer deposits yielded gold, but the greatest period of activity occurred between 1880 and 1893 when oxidized ore bodies, some rich in silver and lead, were mined. A second period of activity occurred from 1905 to 1920 when the Mary Murphy group of mines yielded much gold. The production from 1860 to 1950 has an estimated value of $30,000,000. The principal metals produced are gold, silver, lead, zinc, and copper, probably in this order of relative values, although copper is far below any of the others in total value. Very minor amounts of tungsten and molybdenum ore have been produced. The three most productive mines are the Mary Murphy in the Chalk Creek district, the Madonna in the Monarch district, and the Gold Cup in the Tincup district.

Some nonmetallic products have been mined in the quadrangle. The most economically important of these is a pure limestone (Leadville limestone) that is obtained chiefly from a quarry at Monarch. A small quantity of marble has been produced from a quarry in Taylor Gulch in the Monarch district, and a small tonnage of amorphous graphite was shipped from two mines in Graphite Basin during the First World War.

The ore deposits in the Garfield quadrangle, comprising replacement bodies in sedimentary rocks and fissure veins, are believed to have been deposited during three separate periods of ore deposition. The first period of ore deposition was related to the Mount Princeton batholith and deposited the replacement bodies, hubnerite-molybdenite veins, and most of the pyritic quartz veins found in the quadrangle. The second period of ore deposition, represented by quartz-beryl-pyrite veins, was related to the Mount Antero stock. The third period was related to volcanism associated with the volcanic breccias, and the principal deposits formed at this time were quartz-fluorite veins and a few pyritic quartz veins.

The replacement deposits are chiefly in the limestone and dolomite beds of Paleozoic age, whose structure and stratigraphy have been important in localizing ore bodies. The Manitou dolomite and beds in the upper part of the Leadville limestone were especially favorable host rocks. The largest and richest replacement deposits are in these favorable stratigraphic zones along premineral faults. Small faults, particularly bedding slips along favorable zones, localized many of the smaller ore bodies. Minor concentrations of ore occur along the axes of small folds.

The veins are separated on the basis of the most characteristic minerals into the following groups: pyritic quartz, hubnerite-molybdenite, quartz-fluorite, and quartz-beryl-pyrite. Of the various types of veins, the pyritic quartz veins are the most abundant and widely distributed, as well as the most economically important. These veins are chiefly in fissures in the Mount Princeton quartz monzonite in a conspicuous zone that extends from upper Tomichi Creek valley northeast almost to the corner of the quadrangle. Most of the pyritic quartz veins strike N. to N. 35° E., and the majority dip west or northwest at 50° to 90°. They range from stringers a few feet long and a fraction of an inch thick to strong veins a mile long and 10 feet thick, although the largest number on which substantial prospecting has been done are 500 to 1,000 feet long and 1 to 3 feet thick. The hubnerite-molybdenite veins are relatively short and narrow and are restricted to a few square miles in the northwestern part of the quadrangle. The quartz-fluorite veins are chiefly concentrated in the Brittle Silver Basin area in the northern part of the Tomichi district. The quartz-beryl-pyrite veins are the least numerous of all the veins and are localized near the Mount Antero stock at the east-central border of the quadrangle.

The mineralogy of the pyritic quartz veins is quite similar to that of the replacement deposits, with the exception that quartz is the principal gangue mineral of the pyritic quartz veins and limestone and dolomite of the replacement deposits. Oxidized and primary sulfide ore occurs in both the replacement and pyritic quartz veins. The chief primary sulfide ore minerals are silver-bearing galena, gold-bearing pyrite, sphalerite, and chalcopyrite. Cerussite, smithsonite, gold, silver, cerargyrite, calamine, anglesite, and secondary copper minerals are the chief ore minerals of the oxidized zone.

The estimated $30,000,000 production from the quadrangle is believed to have been about equally divided between the replacement deposits and the pyritic quartz veins. Nearly all of the output from the pyritic quartz veins is from a few veins on the Mary Murphy group of claims in the Chalk Creek district.

INTRODUCTION

Location and accessibility.—The Garfield quadrangle, covering about 233 square miles, is in the Sawatch Range, in Chaffee and Gunnison Counties, west-central Colorado, about 20 miles west of Salida and 25 miles east of Gunnison (fig. 1). The quadrangle lies between longitude 106° 15′ and 106° 30′ W., and latitude 38° 30′ and 38° 45′ N., and includes parts of the Gunnison and San Isabel National Forests.

The nearest railroad station on a standard gauge railroad is at Salida on the Royal Gorge route of the Denver and Rio Grande Western Railroad. A narrow gauge branch line of the same railroad extends from Salida to the limestone quarry of the Colorado Fuel and Iron Corporation at Monarch, in the southeastern

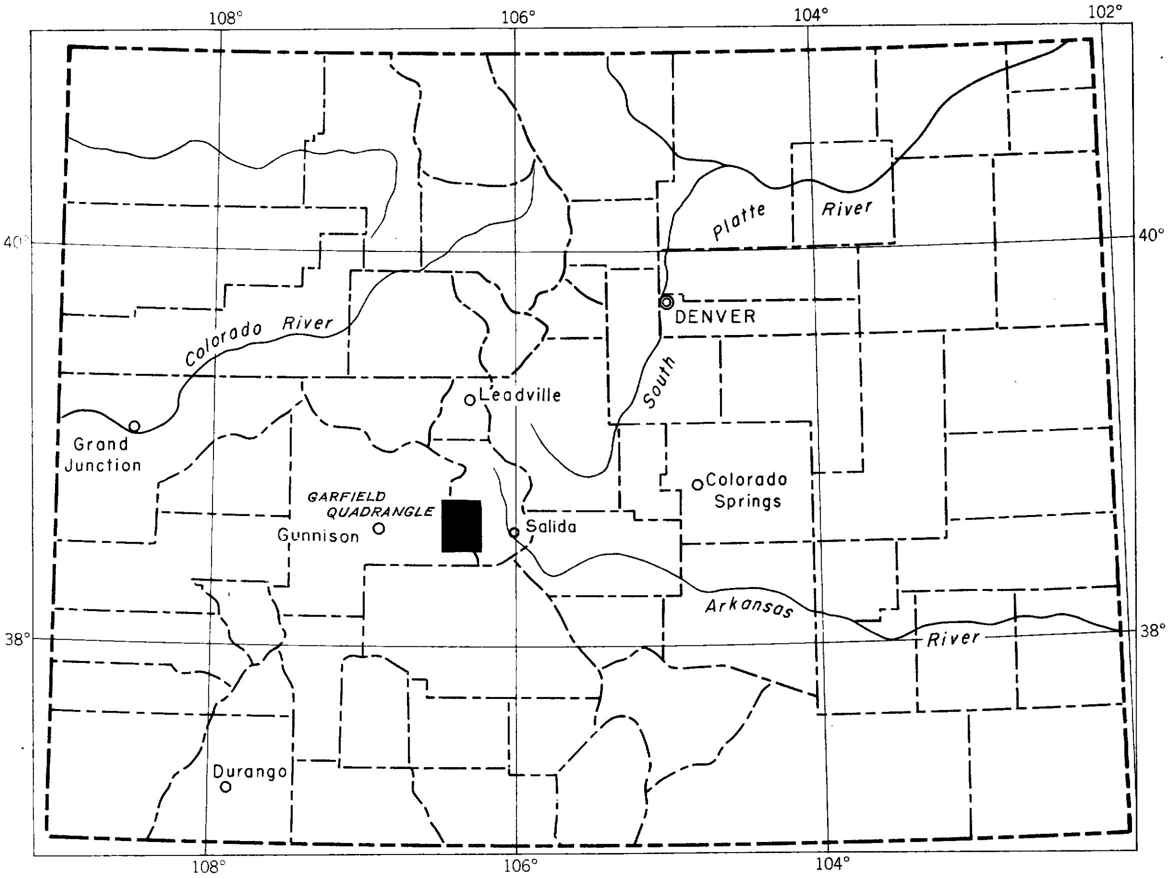


FIGURE 1.—Index map of Colorado showing location of the Garfield quadrangle.

part of the quadrangle. The only paved road is U. S. Highway 50 which traverses the southeastern corner of the quadrangle for a distance of about 8 miles. Agate Pass in the Continental Divide is crossed by this highway a few thousand feet south of the quadrangle boundary. This pass is popularly known as Monarch Pass, but Monarch Pass lies several thousand feet west of Agate Pass on Colorado State Highway 328 which traverses or closely parallels the southwestern border of the quadrangle. A road from Sargents, 6 miles south of the quadrangle, to Whitepine crosses Highway 328 in Tomichi Creek valley about half a mile south of the quadrangle. In the west, State Highway 162 enters the quadrangle about 1 mile northeast of Pitkin and leads up North Quartz Creek, over Cumberland Pass (altitude 12,015 feet), and down West Willow Creek valley to Tincup, which lies 0.2 mile north of the Garfield quadrangle. In the northeast, an improved road from Nathrop, on U. S. Highway 285 in the Arkansas River valley, enters the quadrangle in Chalk Creek valley and leads west to St. Elmo and thence south nearly to Hancock Lake. Old mine roads, many now no more than trails, follow many of the larger stream valleys. Trails lead from many of the roads, but several large areas are without roads or trails.

The only towns with permanent residents are Garfield, Monarch, St. Elmo, and Whitepine. In 1951 the permanent population of the first three averaged less than 20 for each town and the population of Whitepine has varied from about 25 to 150 within the past 4 years depending upon the fluctuating activity in the Akron and Erie mines nearby. The only other towns of appreciable size near the quadrangle are Pitkin, about 1 mile west of the west-central border of the area, and Tincup, about a quarter of a mile north of the northwest corner of the quadrangle. Tincup, as well as most of the other towns in and near the quadrangle, has a small summer tourist population. Pitkin has a permanent population of about 100.

Five mining districts lie entirely or in part within the limits of the quadrangle. The Tincup district lies west of the Continental Divide and north of Cumberland Pass in the northwest corner of the area. South of Cumberland Pass and west of the Continental Divide, along North Quartz Creek, is the Quartz Creek district. The Tomichi district centers around the old towns of Tomichi and Whitepine on Tomichi Creek, west of the Continental Divide in the south-central part of the area. The Monarch district lies east of the Continental Divide around the town of Garfield. The Chalk Creek district adjoins the Monarch district on the north and includes the area drained by Chalk Creek and its tributaries.

Topography and drainage.—The topography of most of the quadrangle is typical of glaciated mountainous regions. The altitudes range from 9,000 feet in the northeast and southwest corners to 14,100 feet at the eastern border, northeast of the old town of Shavano. Plate 2 shows the topography that is typical of most of the Garfield quadrangle. The crest of the Sawatch Range, which marks the Continental Divide in this region, bears north-northwest through the central part of the quadrangle, and consists of peaks and connecting ridges at altitudes of 11,500 feet to 13,500 feet. With the exception of a few square miles in the extreme southwest part of the quadrangle, the chief topographic features are the cirques, U-shaped valleys, serrated ridges, moraines, and lake basins typical of glaciated mountainous regions. Unglaciated stream divides are broad and rolling, but glaciated divides are narrow, knife-edge ridges.

Drainage east of the Continental Divide is by tributaries of the Arkansas River, principally Chalk Creek, in the northeast part of the quadrangle, and the South Arkansas River in the southeast. The area west of the divide is drained, in the north, by Willow and Quartz Creeks, and in the south by Tomichi and Hot Springs Creeks, all of which flow into the Gunnison River, a tributary of the Colorado River.

Climate and vegetation.—The climate of the area is typical of high mountainous districts at this latitude. During the summer, thundershowers occur almost daily and are often accompanied by hail. Snow starts falling in September and continues at frequent intervals until May. Clear but cold weather usually prevails during September and October. The snow begins to melt in May and is nearly all gone by July except on the higher north slopes and in some cirques. In general, the days during the summer are temperate, but frost may occur any night. Temperatures fall as low as 40 degrees below zero during the winter.

Most of the mountain slopes are covered to timberline by evergreens, chiefly lodgepole pine and Engelmann spruce, with the heaviest stands of timber on the north slopes. The principal deciduous trees are aspen, willow, and alder; the last two are common in stream valleys. Large areas above timberline, which averages 11,800 feet in altitude, are covered by smooth grassy slopes.

Fieldwork and acknowledgments.—The fieldwork upon which this report is based was done during the summers of 1947 through 1951. The average field season was from the middle of June to the end of September. The senior author was assisted by J. E. Watson for 6 weeks during 1947, and by Charles S. Robinson for 3 months during the summer of 1948. Robinson was reassigned to the project in June 1949 and has helped in every phase of the work since then. The authors were assisted during the summer of 1949 by D. H. Whitebread and in 1950 by M. R. Brock. In the summer of 1951 the senior author was assigned to other work and was able to spend only a small part of his time in the quadrangle, but Robinson completed the field mapping with the assistance of Brock and R. M. Honea.

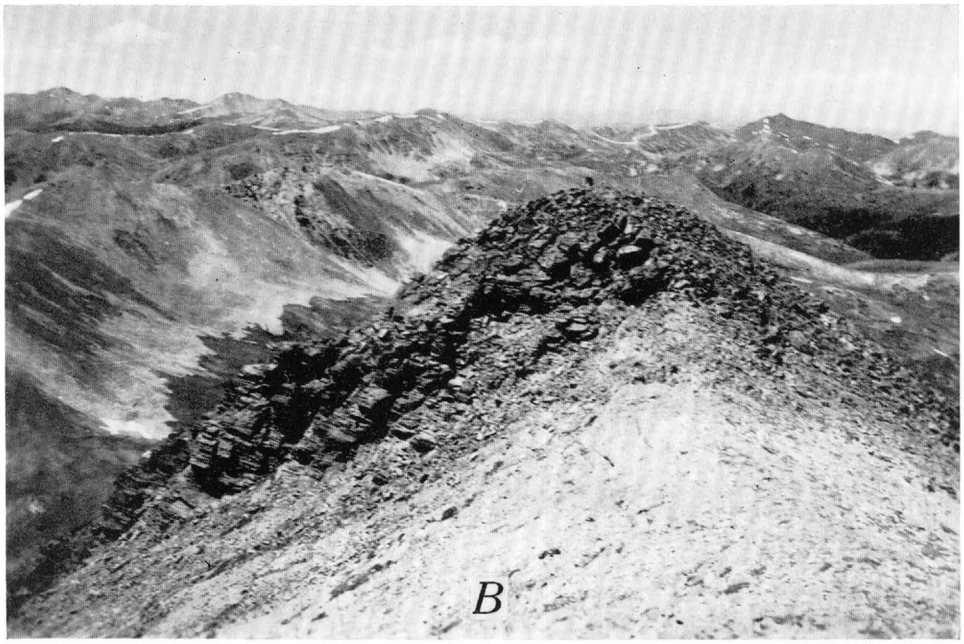
The regional geologic mapping was done on the Geological Survey topographic map of the Garfield quadrangle (scale 1: 62,500), which was enlarged to a scale of 1:31,680. The Tincup mining district and the southern, or Whitepine, area of the Tomichi mining district were mapped by planetable method at a scale of 1:6,000, and a small area near the head of Cree Creek at a scale of 1:2,400. Detailed examinations were made of nearly all mines and prospects that were accessible during the course of this investigation.

It is a pleasure to acknowledge the generous cooperation of the people of the region, and special thanks are due all members of the staff of the Callahan Zinc-Lead Co. at Whitepine, Harold R. Koster and W. E. Burleson of Salida, and Lowry Englebright of Tincup, for their aid in furnishing information and maps of individual mines.

Previous work.—The selected bibliography at the end of this report includes all the principal publications that relate directly to the Garfield quadrangle and some that deal with the main geologic features of the surrounding region. By far the most extensive and useful reference is Crawford's (1913) excellent report on the Monarch and Tomichi districts published by the Colorado Geological Survey. Although Goddard's (1936) publication on the Tincup district was intended as a reconnaissance report, it nevertheless presents much valuable mine data and was the first published description of many of the mines in this old district. Tweto's (1943) [1] report on the geology and ore deposits in the tungsten-molybdenum area near Cumberland Pass is of much value for its surface and underground geology, as well as furnishing information concerning individual mines. This area of about 1 square mile lying chiefly west of Cumberland Pass has been incorporated, with minor additions and modifications, on the geologic map (pl. 1).

[1] Tweto, Ogden, 1943, Molybdenum-tungsten deposits of Gold Hill, Quartz Creek, and Tincup mining districts, Gunnison County, Colo.: U. S. Geol. Survey Strategic Min. Inv., open-file report.

A. Tincup thrust fault near Napoleon Pass brings schist of pre-Cambrian age on right against sedimentary rocks of late Paleozoic age on left. The mountain to the left of Napoleon Pass is the type locality of the Tincup quartz monzonite porphyry (Tt) which here irregularly cuts sedimentary rocks of late Paleozoic age. Rocks of early Paleozoic age (EP) compose the cliff and ridge bordering the east side of North Quartz Creek valley. Road in valley is built in glacial deposits which form a thin veneer over gneissic granite (pre-Cambrian).



B. Outcrop of quartz latite porphyry, east rim of Brittle Silver Basin, showing platy structure that erroneously resembles bedding planes of sedimentary rocks Mountains in the background are largely composed of the Mount Princeton quartz monzonite which extends beneath the ridge of quartz latite porphyry shown in foreground. Glaciated valley on the left is typical of many other valleys of similar origin in the Garfield quadrangle.

GENERAL GEOLOGY

The rocks of the Garfield quadrangle range in age from pre-Cambrian to Tertiary, and Quaternary deposits of surficial material locally mask the older rocks. The pre-Cambrian rocks are metamorphosed sedimentary rocks and intrusive bodies; the rocks of Paleozoic and Mesozoic age are of sedimentary origin; and the rocks of Tertiary age are intrusive and extrusive igneous rocks and one small patch of fossiliferous water-laid tuff. The Quaternary deposits include glacial moraine, glaciofluvial deposits, landslides, talus, and alluvium.

The geologic structure is moderately complex and has resulted from deformation during pre-Cambrian, Late Cretaceous or early Paleocene, and early (?) Tertiary time. Structures include folds, faults, and fracture zones of diverse trends, but the outstanding structures trend northwest, especially an overthrust fault (pl. 2A) of large displacement that extends along strike at least 17 miles. Metamorphic effects of the Mount Princeton batholith are pronounced in a zone about half a mile wide in the sedimentary rocks bordering the batholith.

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks include a group of schists and gneisses, believed to be of sedimentary origin, and a group of intrusive rocks. The main types of schist and gneiss are quartz-mica schist, quartz-hornblende schist, quartz-hornblende gneiss, and granite gneiss. Into these were intruded a gneissic granite, the Pikes Peak granite, a hornblende diorite, and a granite tentatively correlated with the Silver Plume granite.

SCHISTS AND GNEISSES

Schists and gneisses of pre-Cambrian age are exposed in the southeastern, central-western, and northwestern parts of the quadrangle (pl. 1). Those of the southeastern area represent the irregular western border of a much larger area of foliated rocks that extends eastward for several miles but is largely covered by glaciofluvial deposits. Although the various types of schists and gneisses shown on the geologic map and described below are fairly distinct mappable units, there are much local variation and intergrading of all types, and hundreds of small blocks and fragments are contained in the younger rocks, especially in the pre-Cambrian granites. Individual bands or lenses may have a thickness of a fraction of an inch or many feet; some can be traced for long distances, but most are short.

The four major metamorphic rock units shown on the geologic map are quartz-mica schist, quartz-hornblende schist, quartz-hornblende gneiss, and granite gneiss. The first three are probably about the same relative age. The granite gneiss is essentially an injection gneiss and migmatite formed by granitic replacement of the older schists and gneisses, and part of the rock is therefore younger than the other foliates.

The schists and gneisses, other than the injected granitic parts, are essentially metamorphosed sedimentary rocks as indicated chiefly by their compositions and the local presence of quartzite beds that parallel the foliation of the schists and gneisses. Insofar as could be observed the foliation of the schists and gneisses conforms to the bedding of the former sedimentary rocks. The degree of metamorphism was probably of medium grade and occurred in the pre-Cambrian before the intrusion of the Pikes Peak granite.

QUARTZ-MICA SCHIST

Quartz-mica schist is exposed at many places in the area surrounding the junction of North and Middle Quartz Creeks, near the west-central margin of the quadrangle. The several patches of schist shown in this vicinity probably connect beneath the broad belt of glacial deposits and form one large mass. Although there are many local variations, the foliation dominantly strikes east or northeast and dips steeply in the eastern part and moderately either to the north or south in the western part.

Most of the rock is gray or brownish-gray fine-grained schist in which quartz, biotite, and muscovite can be recognized megascopically. Within short distances, however, the rock grades into or contains lenses of dark quartz-biotite schist, light quartz-muscovite schist, or beds or lenses of pink to gray quartzite. Some parts of the fine-grained quartz-mica schist contain numerous aggregates of quartz and some pink feldspar in oval forms ranging from 1 to 5 mm long. Foliation is moderately to well developed, and in a few places the schist grades into gneiss. Under the microscope the schist typically shows a crystalloblastic texture and the occurrence of biotite, muscovite, and some quartz aggregates in elongated forms parallel or subparallel to the foliation. Most of the schist is composed essentially of 50 to 70 percent quartz, 20 to 30 percent biotite, and 5 to 15 percent muscovite. Accessory minerals are albite, oligoclase, orthoclase, myrmekite, chlorite, magnetite, and garnet.

The bulk of the quartz-mica schist has probably been derived from a somewhat clayey and feldspathic sandstone.

QUARTZ-HORNBLENDE SCHIST

Quartz-hornblende schist underlies a greater area than any of the other schists and gneisses. It is exposed over an extensive area along East Willow Creek and forms a small area in the extreme southeast corner of the quadrangle. The larger mass is about 3 miles wide near the north border of the quadrangle; it wedges out 5½ miles south, between the Mount Princeton batholith and the Tincup fault. Several of the high peaks in the northern part of the quadrangle, such as Fitzpatrick Peak and Emma Burr Mountain, are composed of this dark schist. In the Willow Creek region the foliation dominantly strikes northwest and dips northeast. In the southeast part of the quadrangle the trend of the foliation is much more erratic, although a general northwest strike and moderate dip to the southwest predominates.

The bulk of the schist is fine grained, strongly foliated, and dark grayish-green to greenish black. The composition of the schist varies locally, but the microscope shows that most of the rock is composed largely of anhedral grains of quartz and hornblende. These minerals, and in some specimens white feldspar, biotite, and muscovite, can be recognized with the aid of a hand lens. Biotite is present locally in large amounts, and in places exceeds hornblende. Plagioclase, commonly andesine, is present in a few places in amount nearly equal to quartz.

A small part of the area mapped as schist includes beds and lenses of gray or pinkish, fine-grained, banded or streaky quartzite. Many quartzite beds contain biotite-rich laminae or bands as much as 1 inch thick.

Most of the schist was probably originally dolomitic sandstone and somewhat calcareous beds of clayey sandstone and sandy shale with minor relatively pure sandstone beds.

QUARTZ-HORNBLENDE GNEISS

Dark-green to almost black quartz-hornblende geniss is well exposed in cliffs on the north side of the mountain between South and Middle Quartz Creeks, in the west-central part of the quadrangle, where it forms a body 1½ miles long. Bodies as long as a few hundred feet occur locally within the granitic gneiss and the quartz-hornblende schists west of the Continental Divide, and also in the granite gneiss east of Garfield. The mass on Middle Quartz Creek is cut off on the east by the Mount Princeton batholith, on the south by the Silver Plume(?) granite, and on the west it passes under glacial debris along the valley of South Quartz Creek. The foliation strikes northeast, with vertical or steep dips.

The gneiss is typically composed of fine-grained minerals arranged in distinct bands a fraction of an inch to several inches wide. Individual bands vary in color from light greenish-gray to black, depending upon the relative amounts of light and dark minerals. Hornblende, quartz, and epidote can be seen megascopically in most specimens. Locally, parts of the rock are composed mainly of epidote or of epidote and quartz. Some of the gneiss grades into quartz-hornblende schist that is similar to the schist in the northwestern part of the quadrangle. Microscopic examination shows a crystalloblastic texture, with grains 0.05 to 1.5 mm long. Quartz and green hornblende constitute about 90 percent of the rock; each is found in varying amounts in both the light and dark bands of the gneiss. Epidote is common. Very minor constituents are chlorite, andesine, orthoclase, biotite, sphene, and magnetite.

The composition and occurrence of the quartz-hornblende gneiss indicate that it was originally part of the same series of sedimentary rocks that formed the quartz-hornblende and quartz-mica schists. The reason for showing the gneiss as a separate unit on the geologic map (pl. 1) is that in the field the pronounced banding of the gneiss sets it apart in appearance from the platy schists.

GRANITE GNEISS

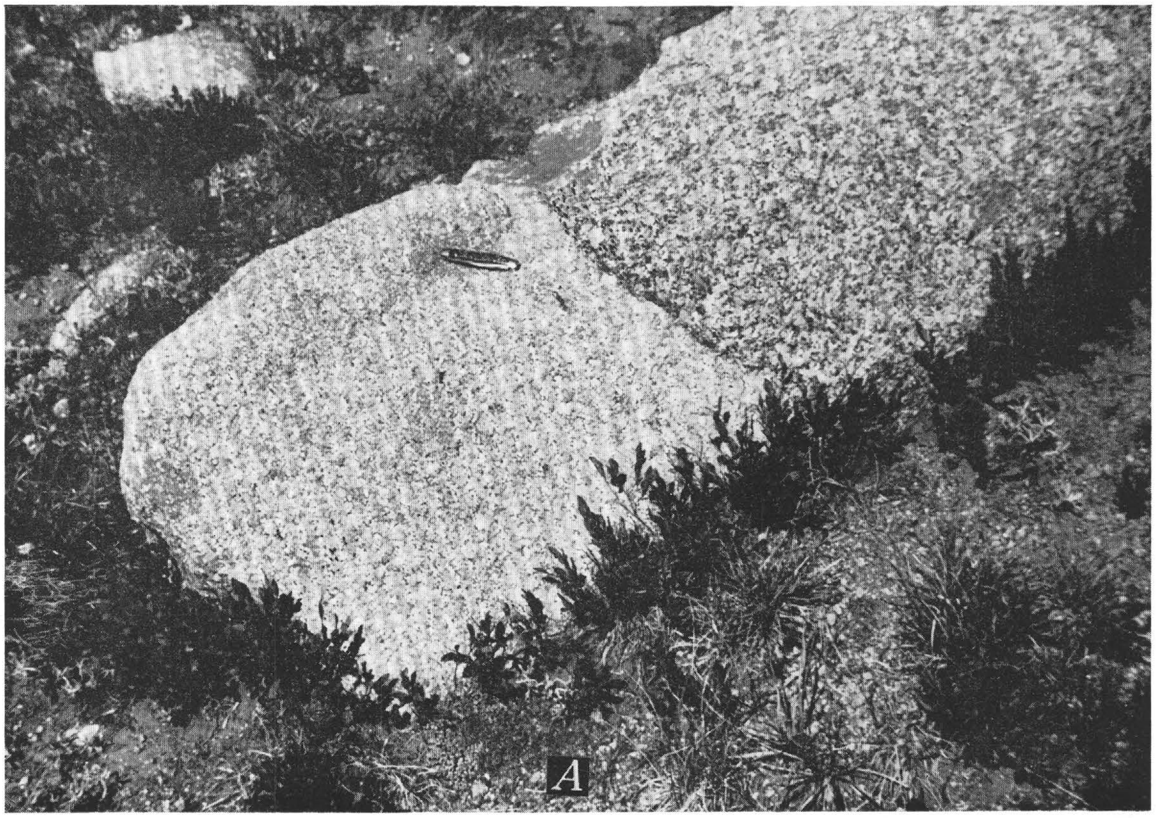
Granite gneiss crops out in a small area at the eastern border of the quadrangle between the South Arkansas River and its North Fork. The granite gneiss is intimately associated with the younger pre-Cambrian and Tertiary granites and occurs as inclusions from a few inches long to masses nearly a mile in length. In many places it grades into the bordering rock and its delineation on the geologic map is therefore somewhat arbitrary. The rock unit mapped as granite gneiss consists chiefly of typical injection gneiss and migmatite, although small bodies of schist, pegmatite, and granite are embraced in this unit.

The typical rock is medium grained, gray to pinkish gray, and is a definite gneiss consisting of light and dark bands. The bands are composed mostly of quartz and white or pink feldspar, with variable amounts of biotite or hornblende; porphyroblasts of feldspar and pegmatite stringers are common. The dark bands vary in width from a few feet to thin faint lines. The dark schist grades into gray or pinkish granitic rock, locally containing relicts of the schist.

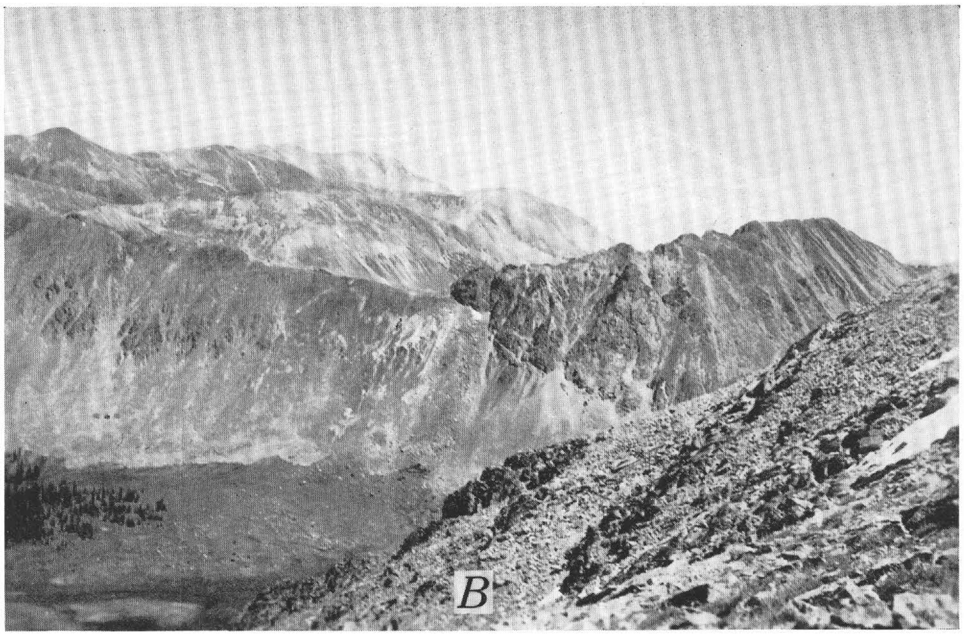
The attitude of the gneissic structure is erratic although an average northeast strike and steep dip prevails. Locally the gneiss is complexly folded.

GNEISSIC GRANITE

A foliated granite of pre-Cambrian age, here called gneissic granite, is exposed in several large areas in the western part of the quadrangle. The granite belt extends from the northern boundary of the map southward for 15 miles to Stridiron Creek, and attains a maximum width of about 3 miles at a point about mid-



A. Sharp contact of Silver Plume(?) granite (left) and Pikes Peak granite. Continental Divide about half a mile north of old Monarch Pass.



B. Gently dipping contact of quartz latite porphyry (dark ridge across valley at right) and Mount Pomeroy quartz monzonite. View east from ridge of Van Wirt Peak.

way between Halls Gulch and Middle Quartz Creek. The regional extent of this granite is not known, as very little detailed geologic work has been done in the areas bordering the Garfield quadrangle. Although gneissic structure is absent or very faintly developed in fairly large areas, especially in the southern half of the belt, most of the granite shows a medium to strong foliation which ranges in strike from N. 10° W. to N. 60° W. and generally dips northeast.

The gneissic granite is typically a gray to brownish-gray, fine-grained rock having faint but generally distinct foliation. The foliation is defined by narrow (0.5 to 2 mm) bands, lenses, or streaks of biotite and less conspicuous lenses of slightly smoky quartz in a light-gray granular aggregate of quartz, white and light-gray feldspar, and a few small flakes of biotite. Weathered surfaces are gray, greenish gray, or reddish brown. The normally fine-grained granite is locally medium to coarse grained; at places the rock contains irregular biotitic aggregates as much as three quarters of an inch wide and a few large irregular grains of quartz and white feldspar in a fine-grained matrix.

Under the microscope the gneissic granite shows a pronounced cataclastic texture; almost all grains are crushed, broken, or frayed. Quartz occurs as granular lenses, streaks, small irregular grains, or as larger crushed and somewhat rounded aggregates. Quartz constitutes 30 to 40 percent of the rock. Potash feldspar, chiefly microcline and orthoclase, in irregular large and small broken grains constitutes about 40 to 60 percent of the rock. Plagioclase, generally strongly kaolinized, occurs sparingly, and uncertain determinations indicate that it is oligoclase. Biotite, in part altered to chlorite, epidote, and magnetite, is everywhere present in shreds, frayed grains, or streaky clusters. Accessory minerals include sphene, zircon, and apatite.

Aplitic and especially pegmatitic bodies are rare. Most of the aplites are west of North Quartz Creek about a mile north of its junction with Middle Quartz Creek. Here a few narrow dikes cut the gneissic granite. All of these show a faint to distinct gneissic structure parallel to the foliation of the enclosing gneissic granite, even though some of the dikes cut obliquely across the foliation of the granite.

The foliation in the gneissic granite is chiefly the result of metamorphic differentiation caused by stress, as indicated by the bands and shreds of quartz and biotite, the cataclastic texture of the granite, and the concordant foliation of the aplites. The time of metamorphism was during the pre-Cambrian and probably before the intrusion of the Pikes Peak batholith, because the Pikes Peak granite, although far removed in space, shows far less intense effects of dynamic metamorphism than does the gneissic granite.

PIKES PEAK GRANITE

Granite similar to the well-known Pikes Peak granite (Cross, 1894) forms disconnected masses in the southeastern part of the Garfield quadrangle. The two largest areas center around Missouri Hill and along the South Arkansas River east of Garfield. Road cuts along the main highway from Monarch to Agate Pass are chiefly in Pikes Peak granite. This granite is cut at many places by bodies of the younger Silver Plume(?) granite, especially within a radius of half a mile from Agate Pass (pl. 3*A*). Many relatively small isolated inclusions of Pikes Peak granite, not shown on the geologic map, occur in the Silver Plume(?) granite for a mile or two west of the Continental Divide along the southern margin of the quadrangle. The contact between these two granites is therefore shown almost everywhere on plate 1 as gradational.

The Pikes Peak granite is typically a pink, coarse- to medium-grained rock, having many pink feldspar phenocrysts ½ to 1 inch long, and conspicuous small grains of fresh black biotite. Locally the freshly broken rock is gray, but in most places weathered surfaces are pinkish, and in some large areas, light red. The reddish color is due to the pink feldspars and iron stain derived from the weathering of biotite. Quartz, feldspar, and biotite can be recognized in all hand specimens, and in a few specimens small grains of magnetite can be seen. Many feldspar phenocrysts enclose small grains of biotite. Although a parallel or subparallel orientation of the feldspar phenocrysts occurs locally, most outcrops show a random arrangement. Microscopic examination shows that feldspars, including orthoclase, microcline, microperthite, and plagioclase, constitute about 60 percent of the rock, and quartz and biotite about 40 percent. The ratio of potash to plagioclase feldspar varies but is generally about 2 to 1. The dominant potash feldspar is generally orthoclase, although locally it is microcline. The plagioclase is mostly medium oligoclase. It is largely restricted to the groundmass and only rarely forms phenocrysts. Quartz is abundant in irregular grains and as an intergrowth with the potash feldspars. Biotite is in part altered to chlorite, or less commonly, to epidote. The accessory minerals are zircon, apatite, sphene, and black iron oxide.

The Pikes Peak granite penetrates, and encloses many fragments of, the older schists and gneisses, and is cut at many places by the Silver Plume(?) granite. It is therefore younger than the schists and gneisses and older than the Silver Plume(?) granite. However, its relation to the distant exposures of pre-Cambrian gneissic granite and hornblende diorite could not be determined, although by inference the Pikes Peak granite is assumed to be younger than the gneissic granite, as previously stated in the discussion of the relative degree of metamorphism of the two masses.

HORNBLENDE DIORITE

In the southwestern part of the quadrangle, four small irregular intruded dark hornblende-rich diorite bodies occur in the pre-Cambrian gneissic granite. They are restricted to an area about 5 miles long and 1½ miles wide extending northward from Stridiron Creek to a point a short distance north of the junction of North and Middle Quartz Creeks. The hornblende diorite forms most of the western and southern slopes of Bald Mountain and occupies irregular areas high on both slopes above Stridiron Creek. The outline of the bodies was determined chiefly from the distribution of float, as outcrops are uncommon in this heavily wooded area. In the one place where the contact of the diorite and the gneissic granite was seen, in a small and poor exposure near Coyote Park trail, a small stringer of the diorite penetrates the granite. On Bald Mountain the diorite is overlain by the Sawatch quartzite of Late Cambrian age. The age of the hornblende diorite is probably pre-Cambrian; it is certainly older than Late Cambrian and younger than the gneissic granite. The diorite is also probably older than the Silver Plume(?) granite, because this granite seems to cut into the diorite on the eastern side of the small stock located southeast of the end of the road up Stridiron Creek, although the age relation is not clear, and no contact was seen. Although the hornblende diorite is restricted to a relatively small area in the Garfield quadrangle, it is evidently abundant a few miles to the west, in the Gold Brick district, where Crawford and Worcester (1916, p. 43–45) mapped many large areas of hornblende-rich diorite and related rocks which undoubtedly correlate in part, at least, with the hornblende diorite of the Garfield quadrangle. Crawford and Worcester considered the hornblende-rich diorite to be the youngest of the pre-Cambrian crystalline series, but the Silver Plume(?) granite is absent there.

Several textural and compositional varieties of the hornblende diorite have been found, but most of the rock is fairly uniform. It is characteristically massive, greenish black, and medium grained, although grain size may range from fine to moderately coarse. Weathered surfaces are commonly greenish gray, greenish black, or reddish brown. Hornblende and feldspar are the only minerals that can ordinarily be identified megascopically. Feldspar is generally uniformly distributed, but in one facies of the rock, it forms conspicuous patches 0.1 to 0.2 inch long, composed of aggregates of small grains. In another facies, the feldspar forms chainlike aggregates of small grains, which are particularly conspicuous on weathered surfaces. Some of the rare basic facies consisting almost entirely of hornblende would more properly be termed hornblendite.

Thin sections show that the rock contains 45 to 65 percent hornblende and 35 to 50 percent plagioclase. Quartz, orthoclase, and biotite are present in minor amount. Some of the rock is composed of large anhedral grains of hornblende and plagioclase in a matrix of small crushed grains of feldspar, quartz, and hornblende. Other thin sections show no such pronounced distinction in grain size, although anhedral grains predominated in all sections examined. The hornblende is the common green variety; it has ragged borders, and ranges from small specks to grains as much as 6 mm long. Many of the grains are partly or completely altered to chlorite. Biotite is present locally, in frayed flakes, but is uncommon. The plagioclase is chiefly an intermediate to calcic andesine, and much of it is partly altered to sericite. Orthoclase and quartz are present in all rocks examined but are minor constituents; they form anhedral grains less than 0.15 mm long. The chief accessory minerals are magnetite and epidote; apatite and zircon are rare.

SILVER PLUME(?) GRANITE

The Silver Plume(?) granite is widespread in the southern third of the Garfield quadrangle and is exceeded in total areal extent only by the Mount Princeton quartz monzonite. Outcrops are few, however, especially in the Canyon Creek region, for the granite disintegrates easily and is covered by a heavy growth of timber.

The granite is tentatively correlated with the Silver Plume granite (Ball, 1906, p. 371–389), which is widely recognized in other parts of Colorado, and is generally distinguished by its age relations, composition, and the physical appearance of part of the rock. However, the authors hestitate to correlate it definitely with the Silver Plume because a large part of the granite lacks the characteristic feldspar phenocrysts of the Silver Plume, and it is separated from the nearest known exposures of Silver Plume granite near Twin Lakes (Stark and Barnes, 1935, pl. 1) by about 30 miles. Furthermore, Stark and Barnes show a large area of Pikes Peak granite in the Monarch area of the Garfield quadrangle, whereas in the present report this is shown as largely the questionable Silver Plume granite with only small areas of Pikes Peak granite. In this area there are, however, many examples of the questionable

Silver Plume granite clearly cutting typical Pikes Peak granite. In his description of the granites of the Monarch and Tomichi districts, Crawford (1913, p. 49) referred to this granite as porphyritic granite but made no attempt to map it separately from the older coarse biotite granite, the Pikes Peak granite of this report.

The Silver Plume(?) granite is typically a pink to light-gray, medium-grained rock, commonly containing variable amounts of tabular feldspar phenocrysts a fraction of an inch to 1 inch long. Weathered surfaces are gray or pinkish gray to reddish brown, with reddish shades the more common. There are two main textural varieties. The more abundant variety contains numerous tabular feldspar phenocrysts in parallel or subparallel orientation in a medium-grained groundmass and occurs mostly west of Waterdog Lakes. East of these lakes the rock grades into a dominantly phenocryst-free facies. In addition to these two main types there are several other facies, and textural variations are more common than compositional differences. Coarse-grained rock is rare, but fine-grained rock either with or without feldspar and quartz phenocrysts underlies fairly large areas east of the Continental Divide. In addition to quartz and feldspar, biotite can be recognized in all hand specimens of the various types. A few facies, generally the fine-grained ones, are dark gray owing to a much higher content of biotite than usual.

Microscopic examination of thin sections shows that the chief constituents are quartz, potash feldspar (orthoclase, microperthite, and microcline), and plagioclase feldspar (oligoclase). The ratio between potash and plagioclase feldspar varies, but generally potash feldspar is dominant, although the difference between the two is not great. Orthoclase and microcline likewise vary locally in relative amounts although microcline is more common in the nonporphyritic granite east of Waterdog Lakes. Most of the plagioclase is strongly altered to sericite and kaolin. Biotite is everywhere present. Among the phenocrysts orthoclase and microcline greatly exceed oligoclase. Accessory and secondary minerals are sphene, zircon, apatite, iron oxides, chlorite, sericite, and kaolin. Much, if not all, of the "granite" is quartz monzonite, but the term "granite" is so firmly associated with the term "Silver Plume" that it would be inadvisable here to change the name.

A few narrow aplite dikes and many pegmatite bodies are genetically related to the Silver Plume(?) granite. The pegmatites range from very narrow dikelets to large irregular bodies as much as 500 feet long, although the vast majority are dikes or lenses only a few feet thick and less than 50 feet long. They are composed largely of quartz and microcline-perthite. A few contain one or more of the following minerals: biotite, muscovite, hornblende, and magnetite, but no rare or unusual minerals were observed in them.

The Silver Plume(?) granite is probably the youngest of the pre-Cambrian rocks in the mapped area. The granite clearly intrudes Pikes Peak granite (pl. 3*A*), as is well shown at many places along the Continental Divide north of Monarch Pass. As previously stated, the granite apparently cuts the hornblende diorite.

PALEOZOIC SEDIMENTARY ROCKS

The succession of stratified rocks of Paleozoic age in the mapped area ranges from Cambrian to Permian(?) in age and attains a thickness of about 6,300 feet. The Paleozoic rocks have been strongly folded, faulted, and eroded. The chief period of folding and faulting occurred during the Laramide orogeny. Faults of several thousand feet displacement occur at several places. Unconformities are present between all the Paleozoic formations and between the Paleozoic and Mesozoic rocks. Some of these periods of erosion were of long extent, especially the period near the close of the Paleozoic and before the deposition of the Morrison formation (Upper Jurassic) as shown in the southwest corner of the quadrangle where Morrison rocks rest on granite of pre-Cambrian age. Also it is very probable that several thousand feet of sedimentary rocks of Cretaceous age have been removed from the region by erosion. A moderately long period of erosion occurred between Late Ordovician and Late Devonian time. Sufficient time elapsed between deposition of the Leadville limestone (Mississippian) and the overlying Belden shale for erosion to produce a karst topography on the surface of the limestone. Following all these periods of erosion some of the rocks still remaining were probably engulfed in the extensive intrusions of Tertiary age. Consequently the sedimentary rocks that once covered the entire region to a great thickness are now preserved only in fault blocks, synclines, or less commonly, as xenoliths. Plate 1 shows the occurrence of these rocks and their spotty preservation in a belt about 19 miles long, extending northwest from the Monarch district to and beyond the Tincup district.

The lower 800 to 1,200 feet of the Paleozoic section, comprising formations ranging from Cambrian to Mississippian in age, is chiefly dolomite and limestone, although the relatively thin Harding and Sawatch formations are mostly quartzite. Overlying this section is a series of predominantly clastic rocks of Pennsylvanian and Permian(?) age consisting chiefly of quartzite and black shale with subordinate limestone. Fossils are sparse and generally poorly preserved. At many places the sedimentary rocks have been metamorphosed to quartzite, marble, hornfels, or argillite.

The geologic map of Colorado (Burbank, Lovering, Goddard, and Eckel, 1935) shows that the Paleozoic strata of the Garfield quadrangle lie at the southeast end of a fairly continuous but strongly faulted belt of sedimentary rocks extending northwest about 50 miles to Aspen. Southeast of the quadrangle, the same rocks are exposed only in discontinuous small patches for about 30 miles and then disappear beneath younger deposits in the northern part of the San Luis Valley. This belt of exposures of Paleozoic rocks, from Aspen to the San Luis Valley, lies 10 to 30 miles southwest of, and generally parallel to, another and more prominent belt of the same rocks extending from Minturn southeast through Leadville into the Sangre de Cristo Range.

The following formations of Paleozoic age were recognized in the quadrangle: Sawatch quartzite, Manitou dolomite, Harding quartzite, Fremont dolomite, Chaffee formation, Leadville limestone, Belden shale, and Minturn formation. Previous geologic work either in the quadrangle or in adjoining localities, chiefly by Johnson (1944, p. 303–378) and Goddard (1936, p. 560), established the correlation and age of the Sawatch (Cambrian); Manitou, Harding, Fremont (all Ordovician); Chaffee (Devonian); and Leadville (Mississippian) formations. The Belden shale (Pennsylvanian) and Minturn formation (Pennsylvanian and Permian?) are correlated by the authors of this report with these formations as recognized by Tweto (1949, p. 192–228) in the Pando area, on the northeast flank of the Sawatch Range. Correlations of the various formations in the mapped area are based on lithology and paleontological evidence.

SAWATCH QUARTZITE

The Sawatch quartzite, of Late Cambrian age, rests unconformably on a fairly even surface of crystalline rocks of pre-Cambrian age in most areas west of the Continental Divide where the Paleozoic sedimentary rocks are exposed. East of the Continental Divide, only a few thin erosional remnants of the quartzite are preserved, and the lowermost Paleozoic rock is generally the Manitou dolomite. The contact of the Sawatch quartzite and the Manitou dolomite is fairly even but is rarely exposed except in mine workings.

On the west side of the divide the quartzite extends in a broken belt for about 18 miles from the southern part of the Tomichi mining district northwestward to, and beyond, the border of the quadrangle. Outcrops are sparse and generally expose only a few feet of section. The rock has "floated" long distances on the slopes, and the lower part of the formation is generally covered by loose rock from the upper part.

The quartzite attains a maximum thickness of 125 feet in the Tincup mining district and decreases in thickness fairly uniformly to the southeast. One mile southeast of the mouth of Halls Gulch, the quartzite is absent beneath the Manitou dolomite for a distance of about 1,500 feet (see pl. 1). This gap probably represents erosion along a pre-Ordovician river channel. In the area east of Whitepine, the Akron tunnel exposed only 14 feet of Sawatch quartzite, and about a mile farther southeast the quartzite is absent and the Manitou dolomite rests on granite of pre-Cambrian age. East of the Continental Divide no Sawatch quartzite is exposed at the surface, but small erosional remnants only a few feet thick were cut in the Madonna, Lilly, Clinton, and Evening Star mines in the Monarch district. On the crest of the Continental Divide due east of Lake Hill, loose fragments of Sawatch quartzite and Manitou dolomite cover a small area, thus showing that the quartzite was once continuous over the divide.

The Sawatch formation in the Garfield quadrangle consists of three rather distinct lithologic units which correspond to the lower quartzite, glauconitic sandstone, and upper quartzite members as recognized by Johnson (1944, p. 310) in the Sawatch Range.

The lower quartzite member is chiefly white, vitreous, medium-grained quartzite consisting of fairly well rounded sand grains bonded by quartz. At most places the basal 2 feet consists of either conglomerate, conglomeratic quartzite, arkosic sandstone, or lenses of conglomeratic quartzite in quartzite. The lower member contains variable amounts of feldspar and white mica. The color is chiefly white although pinkish shades are common, and some of the rock is locally light green or light gray. The lower quartzite member is well exposed for several hundred feet horizontally on the west slope of Duncan Hill in the Tincup district, about 1,500 feet south of West Gold Hill mine. Here it averages about 22 feet in thickness and rests on an even erosional surface of weathered gneissic granite. The rock is pink, gray, or white, medium-grained quartzite in beds 2 to 20 inches thick. Lenses of conglomerate 2 to 12 inches thick occur locally at the base. The lenses consist mostly of well-rounded white quartz pebbles rarely exceeding three-quarters of an inch in diameter, and a few small pebbles of granite, in a sandy or quartzitic matrix.

The glauconitic sandstone member, which has a maximum thickness of about 45 feet, consists chiefly of glauconitic sandstone, glauconitic quartzite, and limy sandstone. Locally it contains beds of white quartzite similar to the quartzite in the lower and upper members, and beds of sandstone and sandy limestone. The glauconitic beds weather brown, reddish brown, or purplish brown colors which contrast strongly with the white of most of the formation. Crossbedding is characteristic of this member.

The upper quartzite member has a maximum thickness of about 50 feet and is similar to the lower member in color and composition, except that it does not contain mica, feldspar, or the conglomeratic beds and lenses.

The best exposure of the Sawatch formation in the quadrangle is on the small hill immediately north of Quartz Creek, at the extreme western boundary of the quadrangle, where the following section was measured:

Section of Sawatch quartzite on hill north of Quartz Creek in secs. 10 and 11, T. 50 N., R. 4 E.

Manitou dolomite.	
Unconformity.	
Sawatch quartzite:	*Feet*
Upper quartzite member: Quartzite, white with some pinkish shades, vitreous, medium-grained; beds 4 to 12 inches thick. Top 2 feet leached and weathered	40
Glauconitic sandstone member:	
Limy sandstone, white with some tan and pink shades, crossbedded, porous, sparse but widely distributed glauconite in lower part	22
Quartzite, white with some pinkish shades, vitreous, medium-grained; beds 10 to 18 inches thick	8
Quartzite, purplish red with some limonite blotches, medium-grained, crossbedded, glauconitic; beds 1 to 4 feet thick	15
Lower quartzite member:	
Quartzite, white and pink with limonite blotches, medium-grained, slightly micaceous; beds 6 to 18 inches thick	15
Quartzite, white and pink, medium-grained, micaceous, sparse feldspar, conglomeratic quartzite lenses half an inch thick or less; beds 4 to 20 inches thick	10
	110
Unconformity.	
Pre-Cambrian gneiss.	

The Peerless formation, which overlies the quartzite beds at many places in central Colorado, is not present in the mapped area.

No fossils were found, but the quartzite beds undoubtedly belong to the Sawatch formation because they can be shown to be closely correlative with that formation in adjoining areas. The Sawatch is generally recognized as of Late Cambrian age.

MANITOU DOLOMITE

At most places the Manitou dolomite, of Early Ordovician age, rests unconformably on a slightly irregular surface of the Sawatch quartzite, but in the southern part of the Tomichi district, and in the Monarch district, it rests on pre-Cambrian granite except for a few local remnants of Sawatch quartzite. The Manitou dolomite is equivalent to the limestone below the quartzite in the Tomichi limestone of Crawford's nomenclature (1913, p. 56–61).

The Manitou dolomite is 175 to 250 feet thick at most places. It shows a general thinning to the northwest, averaging about 240 feet thick in the Monarch district and 185 feet in the Tincup district. In Halls Gulch 4 miles south of the Tincup district, a thickness of 175 feet was measured in a prospect adit located 2,500 feet west of the mouth of the gulch. According to Crawford (1913, p. 57), the thickness has a wide range in the Monarch district; he reported 290 feet in the Garfield mine, 260 feet east of Garfield in beds exposed along the South Arkansas River, 80 to 90 feet in the Madonna No. 6 tunnel, and about 75 feet in the Monarch Contact tunnel. He states,

> The reduced thickness south and southwest of Monarch points to one of two possibilities: (1) that the deposition of the limestone in this vicinity was less than elsewhere, or (2) that more of the originally deposited limestone had been removed by erosion prior to the deposition of the "parting quartzite" [Harding quartzite of this report]. Because of the nearly uniform character of the limestone and the lack of paleontological evidence it is impossible to say which of these is the true explanation. In view of the abrupt change from limestone of varying thickness to a coarse siliceous quartzite it would seem probable that the quartzite lies unconformably on the limestone.

The authors of this report believe that the great range in thickness can be better accounted for by assuming that known faults, possibly accompanied by a squeezing of the beds, have cut out a large part of the Manitou in both the Madonna No. 6 and Monarch Contact sections. Furthermore, the 290-foot section in the Garfield mine is almost certainly the result of repetition of beds caused by the fault in the tunnel 220 feet west of the granite. This is also indicated by the fact that about 1,500 feet north of the old Garfield tunnel a fairly recent adit, the upper Garfield (pl. 1), cuts only 235 feet of Manitou in what appears to be a normal thickness.

The Manitou is characteristically a bluish-gray, crystalline, well-bedded dolomite locally containing sparse to abundant black (less commonly gray or white) chert nodules and lenses at some horizons. Locally the color is light gray to white; the textures range from very fine to coarse. Individual beds range in thickness from a few inches to several feet, and bedding is usually pronounced. Some isolated outcrops are difficult to distinguish from the Fremont dolomite. Metamorphic processes, particularly those related to the intrusion of the Mount Princeton quartz monzonite, have locally changed the dolomite to marble, with a resultant increase in grain size and general color change to white or light gray. Although the great bulk of the formation is dolomite, some beds are limestone, dolomitic limestone, or limy dolomite. The few observed variations from the usual carbonate beds are thin seams or partings of reddish clay, and locally in the Monarch district a sandy limestone bed about 15 feet thick occurs near the top of the formation. The rocks in the Monarch area contain less magnesium than those in other areas to the west and northwest and are chiefly dolomitic limestones.

The Manitou formation is well exposed in the Monarch district along the South Arkansas River, 3,000 feet east of Garfield, where the beds are vertical. At this locality the Manitou beds are chiefly dolomitic limestone rather than dolomite. Some beds contain chert. A thickness of 240 feet measured here agrees closely with the 245-foot thickness of carbonate beds beneath Crawford's (1913, p. 57) unit 8, which is undoubtedly the basal bed of the Harding quartzite.

In the Tincup district, the upper part of the Manitou dolomite is exposed almost continuously for about 1½ miles in road cuts along State Highway 162 from the Deacon mine north to the sharp switchback west of the Indiana mine (see pl. 1). The middle and lower parts of the formation are well exposed in a few places southwest of the Deacon mine on the steep slope west of the road. The total thickness in this area is about 185 feet. The formation consists of medium-gray dolomite in beds 2 to 10 inches thick. Gray to black chert is widely distributed in nodules and lenses. Some beds are separated by pink shaly lenses or partings.

Paleontological evidence indicates that the age of the Manitou dolomite is Early Ordovician. On Monarch Ridge, in the southeastern part of the Garfield quadrangle, Crawford (1913, p. 60) obtained *Helicotoma* sp.? and undeterminable cephalopods about 50 feet above the base, and 10 feet higher poorly preserved specimens of *Dalmanella*, probably *D. testudinaria*, were found. In addition, he reports silicified specimens of *Orthoceras* sp. from horizons ranging from the top of the formation down to about 80 feet above the base. Near the west-central part of the quadrangle a specimen of an endoceratid siphuncle was collected by Dings on the northwest slope of Bald Mountain from about 75 feet above the base of the formation. About 25 miles southeast of Monarch, along Kerber Creek in the Bonanza mining district, Burbank (1932, p. 11) reports the following fossils from the lower limestone member (Manitou dolomite of present usage) of the Tomichi limestone of Crawford (1913): sponge, cystid columnals, crinoid columnals, orthoid brachiopod (probably referable to *Taffia*), *Diphragmoceras?* sp., *Helicotoma* sp., and *Hormotoma* sp. At Fossil Ridge, about 6 miles west of the Garfield quadrangle, Worcester (Crawford and Worcester, 1916, p. 56) reported the following fossils from the lower part of the Yule limestone (Manitou dolomite of present usage): *Dalmanella* f. *D. testudinaria* (Dalmen)?, *D. hamburgensis* Walcott, *Reticularia* sp. (?), and *Lingula* sp. (?). Johnson (1944, p. 319–320) obtained the following fossils from the same ridge above Boulder Lake, cystoid plates and columnals, *Manorthis hamburgensis* (Walcott), cross sections of small, low spiral gastropods, fragments of a brachiopod suggesting a *Dalmanella*, and possible algal growths.

HARDING QUARTZITE

The Harding quartzite, of Middle Ordovician age, is a relatively thin formation, but it extends the entire length of the belt of Paleozoic rocks. The rock is a useful horizon marker in the section of predominant limestone and dolomite between the Sawatch and Belden formations, even though it is poorly exposed at places and can be traced only by float fragments. Many mining men unfortunately refer to this formation as the "Parting quartzite," although it is not equivalent to the Parting quartzite member of the Chaffee formation so well known in the Leadville region.

The thickness of the Harding reaches a maximum of about 38 feet in the Monarch district and decreases toward the northwest to about 10 feet in the Tincup district. All but the lower beds was removed by erosion before deposition of the Fremont dolomite in the area between Quartz Creek and the north border of the quadrangle. Slightly irregular unconformable surfaces separate the Harding from the underlying Manitou and overlying Fremont formations.

The Harding is almost entirely a quartzite and is white, pink, brown, gray, or bluish black. Weathered surfaces are usually pink or brown and commonly show small blotches of hydrated iron oxide. Grain size ranges from fine to coarse, although medium-grained rock predominates. Most of the quartzite, particularly northwest of the Tomichi district, shows a characteristic sprinkling of coarse rounded quartz grains in an otherwise fine- to medium-grained rock. The lower part of the Harding, from Quartz Creek north to the map boundary, locally contains thin beds of sandstone, calcareous sandstone, and shale. The shale and calcareous beds are mostly green or greenish gray.

The best and thickest exposure of the Harding is along the South Arkansas River east of Garfield, where the following section was measured:

Section of Harding quartzite three-quarters of a mile east of Garfield

Fremont dolomite.
Unconformity.

	Feet
Harding quartzite:	
Quartzite, bluish-black, weathered surface brown to black, medium-grained, finely disseminated pyrite grains, beds 6 to 20 inches thick	11.0
Quartzite, bluish-gray, slightly iron-stained surfaces, fine-grained, beds 8 to 26 inches thick	6.5
Quartzite, white, vitreous, light-gray streaks and bands, chiefly medium-grained but some beds fine-grained and containing scattered rounded grains as much as 1½ mm. Rare shaly partings and shaly quartzite beds 1 inch or less thick. Beds 2 to 20 inches thick	17.5
Quartzite, light bluish-gray, weathered surface gray, coarse-grained, beds 4 to 12 inches thick	2.5
	37.5

Unconformity.
Manitou dolomite.

The Harding sandstone was first named and described by Walcott (1892, p. 153) for sandstone and shale beds, then presumed to be of Silurian age, exposed in the Harding quarry at Canon City, Colo. In the Monarch and Tomichi districts, the Harding quartzite was originally included with the beds termed Tomichi limestone by Crawford (1913, p. 57–59), but Kirk (1930) has shown it to be correlated with the Harding. Kirk (1930) has likewise established the age of the Harding at Canon City and elsewhere in Colorado as Middle Ordovician.

Fossil fish remains have long been known from the Harding (Walcott, 1892), and they occur at many localities. In the Garfield quadrangle fragments of small fish plates are widely distributed, especially in the Tincup district. Quartzite rich in fish plates is well exposed in a small pit about 25 feet east of the old road to the El Capitan mine at a point 600 feet southeast of the mine.

FREMONT DOLOMITE

In the past the Fremont dolomite of Middle and Late Ordovician age has been called the Fremont limestone. In the Garfield quadrangle the Fremont is a dolomite, and in this report will hereafter be referred to as the Fremont dolomite. It has about the same wide and patchy distribution as the Harding quartzite, on which it rests unconformably. The Fremont is separated from the overlying Devonian Chaffee formation by an erosional unconformity expressed by considerable local variation in thickness of the Fremont, and locally by a slight angular discordance between the two formations. In the Monarch and Tomichi districts the thickness ranges from 100 to 135 feet and in the Tincup district, about 15 miles to the northwest, from 40 to 100 feet. Only 15 feet is present in a section exposed near the base of a prominent west-facing cliff 2,000 feet south of Graphite Basin, or about 2 miles southeast of the Tincup district. East of Whitepine, in the Tomichi district, the following thicknesses were measured: 117 feet on the main tunnel level of the Akron mine, 105 feet immediately west of the Breadwinner mine, and 135 feet on West Point Hill.

The Fremont is characteristically a bluish-gray, somewhat mottled, massive, crystalline dolomite which weathers dark gray. In places it is a pronounced cliff-maker. Most of the formation is highly dolomitized although at a few localities, particularly in the Monarch district, some layers are limy dolomite or dolomitic limestone. Locally the basal few feet are sandy. Near large igneous intruded bodies the rock has been metamorphosed to medium- to coarse-grained, white to light-gray marble. Black chert nodules are rare. In the absence of fossils, isolated outcrops of Fremont dolomite are difficult to distinguish from those of the Manitou dolomite. The absence of chert, and a mottled light- to medium-gray surface help to identify the Fremont, but these criteria are not conclusive.

The Fremont dolomite was recognized in the Garfield quadrangle by Kirk (1930, p. 457), Goddard (1936, p. 560), and Johnson (1944, p. 322). It was included as the upper part of the Tomichi limestone by Crawford (1913, p. 56–61) in the Monarch and Tomichi districts, and following Crawford's nomenclature, by Burbank (1932, p. 9–11) in the Bonanza district. In the Gold Brick district Crawford and Worcester (1916, p. 54) included the Fremont dolomite as the third unit in the lower fossiliferous member of their Yule limestone.

Fossils in a fairly well preserved state are rather common in the lower 60 feet. Crawford (1913, p. 60) obtained *Receptaculites oweni* and *Halysites catenulatus*. Additional fossils collected during the present investigation from the top of Monarch Hill are *Halysites gracilis* and *Streptelasma* sp.

CHAFFEE FORMATION

The Chaffee formation, of Late Devonian age, is present wherever lower Paleozoic rocks are preserved. In most places the formation is rather poorly exposed, particularly the upper part which is commonly concealed beneath debris from the overlying Leadville limestone. Erosional unconformities of low relief separate the Chaffee from the underlying Fremont dolomite and the overlying Leadville limestone.

The Chaffee formation is 150 to 250 feet thick in most parts of the quadrangle except locally north of Quartz

Creek where all beds between the Manitou and Belden are cut out by a channel of pre-Pennsylvanian age. A maximum of about 300 feet was found southeast of Monarch high on the northwest slope of Monarch Ridge near its northern end. Rather abrupt changes in thickness are common. In a distance of about half a mile in the Whitepine area the formation thins from 228 feet in the Akron tunnel to 130 feet near the Breadwinner mine on Lake Hill.

The Chaffee formation is lithologically the most varied of all the lower Paleozoic formations. The two members, the Parting quartzite member and the overlying Dyer dolomite member, recognized at most places in the Sawatch and Mosquito Ranges, can be separately distinguished in the Garfield quadrangle but they are poorly defined. At every locality where thicknesses could be determined, the Dyer member is thicker than the Parting member.

The Parting quartzite member consists chiefly of light-gray dolomitic limestone with subordinate beds of dolomite, limestone, shaly limestone, limy shale, shale, dolomitic or limy sandstone, and quartzite. Locally the carbonate beds have been metamorphosed to marble. The individual beds are shades of red, green, brown, or gray, but a tan or light yellowish-brown color on weathered surfaces is a characteristic feature of the Parting and of the overlying Dyer as well. The lithology varies considerably within short distances; individual beds are lenticular, and the rocks intergrade. The basal 10 to 15 feet at most places consists of alternating thin beds of greenish to reddish shale and limestone or shaly limestone. In the Tincup district this basal unit contains much red shale and is known to prospectors as the Fairview shale (Hill, 1909, p. 35–36). Overlying the basal shaly unit are beds that range greatly in lithology from place to place but consist chiefly of dolomite, dolomitic limestone, or limestone containing one or more "sandy beds." The "sandy beds" may be represented by quartzite, sandy limestone, sandy dolomite, dolomitic sandstone, or limy sandstone, all of which are usually crossbedded. Individual beds range from a few inches to as much as 30 feet thick, although the hard quartzite beds are generally thinner and have a maximum thickness of about 10 feet. The "sandy beds" are less abundant in the northern half of the mapped area than in the southern part, and more of them are in the form of quartzite. The top of the Parting member is placed at the top of the highest prominent "sandy bed."

The Dyer dolomite member consists chiefly of dolomitic limestone with subordinate limestone, and minor pure dolomite, and rare sandy and shaly material in thin beds, lenses, or streaks. From Middle Quartz Creek north through the Tincup district the basal bed of the Dyer is a mottled gray, slightly pinkish, granular limestone generally rich in brachiopods and crinoid stems. The beds above this are thin-bedded dolomite, dolomitic limestone, or limestone beds that contain locally a few scattered small nodules or thin lenses of chert.

The best exposure found is about 200 feet northeast of the El Capitan mine, in the northern part of the Tincup district, where the following section was measured:

Section of the Chaffee formation, Tincup district

Leadville limestone.	
Unconformity.	
Chaffee formation:	
Dyer dolomite member:	*Feet*
Limestone light- to medium-gray, beds commonly ranging from 1/16 to 1½ inches thick, weathered surface buff, local calcite seams and patches	38
Dolomitic limestone, light- to medium-gray, beds commonly ranging from ¼ to 1 inch thick, weathers to buff-colored wavy plates	60
Limestone, mottled gray and slightly pinkish, granular, abundant brachiopods and crinoid stems	17
Total Dyer	115
Parting quartzite member:	
Limy quartzite, white with much pink and brown stain, crossbedded	10
Dolomitic limestone, light pinkish-gray, finely crystalline, weathered surface has pronounced buckskin color. Chiefly based on float fragments; lower part may contain thin sandy beds	40
Interbedded shale and limestone; pink, red, and grayish-green shale and gray limestone, beds commonly 1/16 to ½ inch thick	15
Total Parting	65
Total Chaffee	180
Unconformity.	
Fremont dolomite.	

The beds assigned to the Chaffee formation in the Garfield quadrangle are regarded as of Late Devonian age (Kirk, 1931). This assignment is based upon paleontology, lithology, and stratigraphic position compared with other sections in Colorado. Kirk (1931, p. 232) and Johnson (1944, p. 329–330) had previously recognized Chaffee rocks in parts of the quadrangle. The Chaffee formation of this report corresponds to the lower part of the Ouray limestone as used by Crawford (1913, p. 62) in the Monarch and Tomichi districts, being equivalent to his units 1 through 9 and part of unit 10.

Most of the formation is devoid of fossils, but two fossiliferous limestone beds are present locally. The most fossiliferous one (locs. 2 and 3 in table below) lies at the base of the Dyer member in the northern half of the mapped area. The other (loc. 1) is in the Monarch district in the Parting member about 30 to 40 feet above the base. Fossils collected in the Garfield quadrangle by various members of the field party were submitted to P. E. Cloud, Jr., of the Geological Survey, who made the identifications given in the table below. Cloud (written communication) stated that they are very probably of Late Devonian age although the poor preservation of the fossils is quite inadequate for purposes of close identification and age determination.

Invertebrate fossils from the Chaffee formation

	Locality		
	1	2	3
Zaphrentis—like cup coral fragment	×	×	×
Pelmatozoan joints	----	×	×
Fragmentary starfish	----	----	×
Echinoderm fragments	----	----	×
Trepostomatous bryozoan	×	----	----
Bryozoan fragments	----	×	×
Camarotoechia cf. *C. contracta* (Hall)	×	----	----
Paurorhyncha endlichi (Meek)	×	×	----
Paurorhyncha?	----	----	×
Cyrtospirifer cf. *C. animasensis* (Girty)	×	----	----
sp	----	----	×
Unidentifiable spiriferoid brachiopod	×	----	×
Fragments of unidentifiable brachiopods	----	×	×
Athyris sp	×	----	----
Schuchertella?	×	----	----
Productella?	×	----	----
Schizophoria?	----	----	×
Coiled cephalopod	----	----	×

LOCALITY 1. Northwest slope of Monarch Ridge, about 700 feet northeast of the Eclipse No. 1 mine.
2. Duncan Hill, about 200 feet northeast of El Capitan mine, Tincup district.
3. Top of mountain south of Halls Gulch, west-central part of quadrangle, at center of sec. 35, T. 51 N., R. 81 W.

LEADVILLE LIMESTONE

The Leadville limestone of Mississippian age is present in almost all preserved sections of the Paleozoic rocks except at the site of the pre-Pennsylvanian channel north of Quartz Creek. In many places it is a pronounced cliffmaker, particularly the lower part of the formation. The Leadville rests unconformably on the Chaffee formation, and its contact with the overlying Belden shale is an erosional unconformity locally marked by irregular karst topography that developed before deposition of the Belden. This karst surface is particularly well developed in the southern part of the Tomichi district and is exposed in the workings of the Erie mine. On Lake Hill it is strongly indicated by the great local irregularity of the Leadville-Belden contact.

The thickness of the Leadville is 200 to 300 feet at most places, although it ranges from about 350 feet in the Tomichi district to zero north of Middle Quartz Creek. The variations in thickness are attributed to unequal erosion during the post-Leadville to pre-Belden time of erosion. In spite of the irregularity of the erosion surface, no angularity was observed between the Leadville and Belden formations; this contact, however, is generally heavily covered.

The Leadville consists of limestone and dolomite with some minor beds of dolomitic limestone, limy dolomite, and locally at the base, sandy or shaly beds. The color is predominantly gray or bluish gray, although some beds are nearly white, and others are black. The basal 2 to 20 feet generally consists of thin beds of limestone or shaly limestone, locally with a sandy zone a few inches to 3 feet thick at the base. The basal unit is overlain by massive beds of limestone or dolomite, the lower 50 feet of which generally contains one or more layers of depositional breccia.

In the Monarch district the Leadville limestone forms a dip slope on most of the northwest side of Monarch Ridge at its northern end. The approximate Chaffee-Leadville contact can be determined within a few feet on a small nose of the ridge at an altitude of about 11,400 feet and about 2,000 feet northwest of the Delaware mine. Here the basal Leadville consists of a few feet or less of light-gray dolomitic limestone containing sandy lenses. This is overlain by about 40 feet of black dolomite or limy dolomite that yields a strong fetid odor to the freshly broken rock. The dolomite is finely to coarsely crystalline, cherty, and locally contains light and dark patches of "zebra" type banding. At lower altitudes on Monarch Ridge, the black dolomite is seen to be overlain by a gray, dense, pure limestone averaging about 100 feet in thickness. Above this is 12 to 18 feet of light-gray cherty dolomite and then about 20 feet of black, cherty, crystalline limestone and dolomitic limestone. The top 85 to 100 feet of the Leadville is a white and gray, somewhat mottled, dolomite or limy dolomite locally containing abundant black chert nodules and lenses.

In the Tincup district about 15 miles northwest of Monarch, the Leadville has the same general lithologic characteristics as at Monarch; limestone predominates in the lower half of the formation, and dolomite with local cherty layers is more common in the upper half. However, individual beds of the Monarch district cannot be recognized with certainty at Tincup, nor even just across the Continental Divide from the Monarch district in the Tomichi district, where most of the Leadville has been metamorphosed to coarse marble.

For many years the early workers in neighboring areas included the Devonian limestones and dolomites with the Mississippian rocks, but Kirk (1931, p. 239) later separated them into the Chaffee formation and

Leadville limestone, the terminology used in this report. The Leadville corresponds to the upper part of the Ouray limestone as recognized by Crawford (1913, p. 62) in the Monarch and Tomichi districts.

Two richly fossiliferous zones were found in the Leadville. One is about 50 feet above the base and is particularly conspicuous in the northern part of the quadrangle on Duncan Hill where it locally contains abundant horn corals. The other, also locally rich in horn corals, is about 150 feet higher stratigraphically and is in the southeast part of the quadrangle. Fossils of this higher zone are particularly abundant in a black granular dolomite bed exposed on Lake Hill 200 feet west of the David H. mine. The table below gives the fossils collected in the quadrangle by the members of the field party and identified by James Steele Williams and Helen Duncan of the Geological Survey. Miss Duncan (written communication) states that most of the corals are fragmentary, that structures have been altered or obliterated by recrystallization and corrosion, and that most of the species and some of the genera are indeterminate, but the general aspect is Carboniferous. She further states that the specimens of *Caninia* appear to belong to a group of considerably more specialized species than has hitherto been observed in the lower Mississippian rocks of this continent, although species showing a similar degree of complexity are known from the lower part of the lower Carboniferous in other parts of the world.

Invertebrate fossils from the Leadville limestone

	Locality		
	1	2	3
Zaphrentoid corals	----	×	×
Caninia sp. indet	----	×	×
Syringopora aculeata (Girty)	----	×	----
surcularia (Girty)	----	×	×
Spirifer centronatus (Winchell)	×	----	----
sp. indet	----	×	----
Composita sp	×	----	----

LOCALITY 1. Top of Duncan Hill, Tincup district; collected 15 feet above base.
2. East slope of Duncan Hill, Tincup district; collected 50 feet above base.
3. Lake Hill, 200 feet west of David H. mine, Tomichi district; collected about 200 feet above base.

BELDEN SHALE AND MINTURN FORMATION

The rocks of Pennsylvanian and Permian(?) age as designated on the geologic map (pl. 1) are correlated with the Belden shale and Minturn formation as recognized by Tweto (1949) in the Pando area, about 15 miles north of Leadville. When the field work was begun, nomenclature of the Pennsylvanian and Permian(?) rocks of west-central Colorado was in a state of confusion, and as the generally poor exposures and incomplete sections in the Garfield quadrangle afforded an inadequate basis for subdivision, all the Paleozoic rocks above the Leadville limestone were mapped as a unit.

Although the Belden and Minturn were not mapped separately, it was nevertheless possible almost everywhere to recognize a lower division, the Belden shale, consisting chiefly of shale and limestone; and an upper division, the Minturn formation, consisting predominantly of clastic rocks, such as quartzite, grit, conglomerate, and micaceous and sandy shales. In the Monarch and Tomichi districts Crawford (1913, p. 66–70) used the term "Garfield formation" for the lower 2,600 to 2,800 feet of the Pennsylvanian section and applied the term "Kangaroo formation" to the uppermost 3,000 feet of beds. In the present usage, the Belden shale corresponds to the lower 1,100 feet of Crawford's Garfield formation, and the Minturn formation corresponds to the rest of the Garfield and all of the Kangaroo formation. The Minturn attains a maximum thickness of about 4,000 feet which gives a total thickness of about 5,100 feet for the Pennsylvanian and Permian(?) rocks, or 700 feet less than Crawford's total. Crawford estimated a total maximum thickness of about 5,800 feet, which, considering the uncertain and variable factors involved in the measurement of these beds, is not too great a divergence from the thickness given in the present report.

Belden shale.—The Belden shale is poorly exposed, particularly in the lower half, and it generally forms smooth grass-covered slopes. Almost everywhere the Belden lies on an uneven erosion surface on the Leadville limestone; in the Tomichi district this is locally a karst surface. North of Middle Quartz Creek the Belden shale lies on the Manitou dolomite over a distance of about three-quarters of a mile. Here the Devonian and Mississippian rocks are believed to have been eroded along an old river channel. The Belden, in the quadrangle, attains a maximum thickness of about 1,100 feet. About 25 miles northeast of Garfield near Trout Creek Pass the Belden shale (Weber formation(?)) attains a thickness of about 1,725 feet (Gould, 1935, p. 977, and Brill, 1944, p. 625).

The Belden consists typically of dark carbonaceous argillite or shale, thin beds of dark limestone, and a relatively few beds of quartzite, limy shale, and shaly limestone. At most places three fairly distinct units (lower, middle, and upper) can be recognized. The lower unit, 200 to 500 feet thick, consists chiefly of dark shale or argillite. At most places the basal 5 to 35 feet of the lower unit is chiefly or entirely coarse quartzite with local conglomeratic beds or lenses, although in a few places medium-grained quartzite or dark shale rest directly on the Leadville limestone. The middle unit, 400 to 700 feet thick, consists chiefly of limestone and shale in which either one or the other may predominate. The upper unit of the Belden, about 200 feet thick, contains more quartzite than the underlying beds. It grades into the overlying Minturn formation, and the contact is rather arbitrarily placed where quartzite and micaceous shales of the Minturn exceed limestone and shale of the Belden.

The shale of the Belden is typically dark gray to black, carbonaceous, and commonly contains small grains of marcasite. It ranges from a fairly soft fissile shale to a fairly hard argillite. Weathered surfaces are characteristically buff to reddish brown, and many are slightly pitted. Although some limestone beds are gray to bluish gray, most are dark gray. Weathered surfaces are light to medium gray. Individual beds may be a few inches to as much as 30 feet thick; some are massive, but others show bedding. Rocks gradational from shale to limestone, such as limy shale and shaly limestone, are present locally, but they are not nearly so common as limestone or shale. True sandstone is very rare but quartzite occurs throughout the Belden, particularly in the upper few hundred feet. Except for the quartzite at the base of the Belden, which is generally coarse-grained, most of the quartzite is medium-grained. Color ranges from dirty white to nearly black, although most of the rock is gray, brown, or greenish brown. Beds commonly range in thickness from 1 to 6 feet, but some are only a few inches thick and others are as much as 10 feet thick. Many are crossbedded. Some quartzite beds are graphitic, some are arkosic or micaceous, and a few are gritty. In addition to the common metamorphism of sandstone to quartzite and shale to argillite, many beds, particularly those near large intrusive bodies, have been converted into hornfels, epidote-garnet rock, marble, and graphite or graphitic shale.

Minturn formation.—The Minturn formation has been eroded from most of the Garfield quadrangle, but patches remain in three widely separated areas: northwest of Garfield in the vicinity of Kangaroo Gulch; high on the mountain about 1 mile south of the junction of Middle and North Quartz Creeks, in the extreme west-central part of the quadrangle; and high on the west slope of the Continental Divide a few miles southeast of the Tincup district. Not more than 1,000 feet of Minturn remains in the Quartz Creek and Continental Divide areas, but in the region northwest of Garfield at least 4,000 feet is preserved in a faulted syncline. Outcrops are few, and individual beds can rarely be followed more than a few hundred feet. The thickest part of the Minturn extends from the upper part of Taylor Gulch, due north of Garfield, westward to Columbus Gulch, where the sedimentary rocks are cut off by the Mount Princeton batholith. Because in most of this area there are wide talus slopes and few outcrops, little can be seen of the Minturn formation, and only a rough approximation of the thickness can be made.

The Minturn formation consists principally of quartzite and shale, with quartzite predominant. Most individual beds are between 2 and 20 feet thick, but some are as much as 50 feet thick. The quartzite is generally gray, with shades of brown or green, and is mostly coarse grained, although grain size locally varies from fine to very coarse. Many of the quartzites contain feldspar and white mica. Some of the more strongly metamorphosed quartzites show a pronounced fine banding or braiding due to the segregation of biotite along bedding planes, and the rock then resembles schist or gneiss, particularly on weathered surfaces. Some of the original sandstones were undoubtedly calcareous, as is indicated by calcium-bearing metamorphic minerals in some quartzites. A few beds are conglomeratic; the pebbles are mostly quartz or granite and range from a fraction of an inch to about 4 inches in maximum dimension. These conglomeratic beds, although nowhere abundant, are mostly confined to a zone 800 to 1,100 feet above the base. Most of the shale has been converted to argillite which is typically fairly hard and dark gray or black. A few bluish-gray or dark-gray limestone beds occur locally. Other rocks locally present include shaly limestone, limy shale, and micaceous shale. Many beds, probably originally shale, have been metamorphosed to hard, flinty hornfels.

It is noteworthy that maroon or reddish beds typical of parts of the Pennsylvanian and Permian rocks in most of Colorado are not present in the Garfield quadrangle. This probably merely reflects metamorphism, however, since the bleaching of reddish rocks to gray or green tones is one of the first metamorphic effects on redbeds.

Fossils and age.—No fossils were found in the Minturn formation, but in the Belden shale fossils, especially brachiopods, occur in limy shale, shale, or limestone beds at a number of places, particularly in the Monarch district on the southeast face of Syncline Hill at an altitude of about 10,250 feet; in the Tomichi district near the top of Lake Hill; and in a small ravine in the Tincup district a few hundred feet east of the small lake on Middle Willow Creek about 1,800 feet north of the lower Gold Cup mine workings. The fossil horizon on Syncline Hill is about 700 feet above the base of the formation, and on Lake Hill about 250 feet. The beds on Middle Willow Creek are probably several hundred feet above the base of the formation, although an accurate determination is not possible because the shale is in intrusive contact with Tincup quartz monzonite porphyry. Fossils probably occur in some of the limestone or shaly beds of the Minturn formation, but these beds are poorly exposed, and at many places fossils may have been destroyed during metamorphism.

The table below lists the fossils collected in the Garfield quadrangle during this investigation. Mackenzie Gordon, Jr., of the Geological Survey identified them.

Invertebrate fossils from the Belden Shale

	Locality		
	1	2	3
Conularia sp	×		
Polypora sp. indet			×
Orbiculoidea sp		×	
Spirifer sp., possibly *S. occidentalis* (Girty)		×	
Crurithyris sp. indet			×
Chonetes (*Lissochonetes*) *geinitzianus* (Waagen)	×		
(*Lissochonetes*?) sp. indet			×
Productus (*Dictyoclostus*) *coloradoensis* (Girty)	×		
(*Juresania*) *nebrascensis* (Owen)?	×		
Marginifera ingrata (Girty)			×
Brachiopod fragments and spines, indet	×		
Nuculopsis? sp	×		
Leptodesma? sp	×		
Schizodus sp	×		
Aviculopecten sp	×		×
Pelecypod fragments, indet	×	×	
Volsella? sp		×	
Pleurophorus? sp	×		
Aclisina? sp		×	
Gastropod fragments, indet	×		
Pseudorthoceras? sp	×		

LOCALITY 1. Southeast face of Syncline Hill, Monarch district; collected at altitude of about 10,250 feet.
2. Float fragments near above locality, and probably from beds a few feet higher stratigraphically.
3. Middle Willow Creek, Tincup district.

According to Gordon (written communication, 1950), the fossil assemblage appears to be typical of the Belden shale and suggests a middle Pennsylvanian or older age, although he states that most of the Pennsylvanian fossils are long ranging and it is relatively difficult to subdivide the Pennsylvanian stratigraphically on a faunal basis.

Since no definitely recognizable fossils were found in any of the Minturn rocks, it is impossible to determine the exact age. Most, if not all, of the Minturn is thought to be Pennsylvanian in age although some of the upper beds may be Permian.

MESOZOIC SEDIMENTARY ROCKS

Sedimentary rocks of Mesozoic age are restricted to an area of about 4 square miles in the extreme southwestern part of the quadrangle. They include three formations: the Morrison formation of Late Jurassic age, the Dakota sandstone of Early and Late Cretaceous age, and the Mancos shale of Late Cretaceous age. The Mesozoic rocks of this area form the border of a much larger mass that rests on granite and schist of pre-Cambrian age. The geologic map of Colorado (Burbank, Lovering, Goddard, and Eckel, 1935) shows a northwest-trending belt of Paleozoic rocks between the Morrison formation and the pre-Cambrian granite in the southwestern part of the Garfield quadrangle, but the present investigation has shown that this belt is absent and that the Morrison formation rests directly on the pre-Cambrian granite. The nearest locality where rocks of Mesozoic age rest on Paleozoic units is probably northeast of Almont, about 20 miles northwest of the southwestern corner of the Garfield quadrangle.

Along the northeastern border of the area of Mesozoic sedimentary rocks within the Garfield quadrangle, the beds strike northwest and dip 40° to 85° SW., averaging about 55°. The northwestern part of this area is a northwest-trending syncline which passes beyond the limits of the map.

MORRISON FORMATION

The Morrison formation consists of interbedded sandstones, shales, and limestones. The beds weather readily, and outcrops are few. The sandstones are typically fine- to medium-grained and a dirty white color. The shales are mostly greenish or reddish. The limestones are yellowish to gray. No fossils were found, but the lithology is typical of the Morrison formation as exposed at many places farther west. The Morrison appears to range from 250 to 375 feet in thickness, although accurate determinations could not be obtained.

DAKOTA SANDSTONE

As the Dakota sandstone is a resistant formation underlain and overlain by much softer beds, it forms hogbacks throughout most of its extent. The formation is composed chiefly of light-gray, crossbedded quartzose sandstone or quartzite. Most weathered surfaces are stained light brown to reddish brown. A conglomerate as much as 15 feet thick is present locally at the base, and many of the lower beds contain lenses or thin beds of conglomerate a few inches thick in an otherwise medium-grained rock. The upper part of the formation is poorly exposed, generally being covered by a thick layer of talus. Float fragments and a few small exposures indicate that it consists principally of gray sandstones, although a few shale beds may be present, as they are not uncommon in the upper part of the Dakota in this region. A bed of purplish-gray sandstone about 1 foot thick in the upper part of the Dakota contains abundant weathered feldspar grains scattered among medium-sized quartz grains. The thickness of the Dakota formation could not be determined with certainty because of the broad and thick belt of talus on the southwest side of the outcrop belt, but it is probably 150 to 200 feet. The thickest continuous exposure observed is 110 feet; it is on the northwest side of Eldorado Gulch.

MANCOS SHALE

The Mancos shale occupies most of the area of Mesozoic rocks. It weathers easily and forms low, smooth and relatively gentle slopes. The beds are exposed only at one place (the NW¼ sec. 12, T. 49 N., R. 4 E.) in the quadrangle, where a small cut near the base of the formation exposes a few feet of gray shale. Only the lower few hundred feet of the formation is present in the quadrangle, and these beds, as determined by float fragments, consist of light- to medium-gray shale and limy shale. A few miles southwest of the quadrangle formations equivalent to the Mancos shale (Benton shale, Niobrara formation, and Pierre shale) attain a maximum thickness of about 2,200 feet (Stark and Behre, 1936, p. 103).

TERTIARY INTRUSIVE ROCKS

A great succession of intrusive rocks of probable early Tertiary age occupy a larger area than any other group of rocks in the quadrangle. They form stocks, chonoliths, sills, dikes, and one small batholith of Mount Princeton quartz monzonite. The batholith extends within the quadrangle (pl. 1) from Whitepine north 15 miles to the boundary; north of the quadrangle it extends about 7 miles north to a point a few miles west of Buena Vista (Burbank, Lovering, Goddard, and Eckel, 1935). The smaller intrusive bodies, whose total combined areal extent is far less than that of the batholith, are chiefly clustered around the Tincup district or in a belt several miles wide that extends from the northern part of the Tomichi district northeast for about 8 miles to the eastern border of the quadrangle (pl. 1). Reconnaissance examinations by the writers west and north of the Tincup district and Crawford's mapping (Crawford, 1913, pl. 2) east of the quadrangle along Browns Creek have established that many of these smaller intrusive bodies extend several miles beyond the boundaries of the quadrangle. All the intrusive rocks of the Garfield quadrangle are part of a much larger group of intrusive bodies that are exposed at many places in western Colorado, particularly in the mineral belt that extends from the San Juan Mountains northeast for about 200 miles to the tungsten district west of Boulder. The Garfield region, near the middle of this belt, is believed to be one of the local centers of intrusion of which there were probably many.

Excluding the dike rocks, 11 distinctive types of intrusive bodies occur in the Garfield quadrangle. The relative ages of most of these bodies are clearly shown by crosscutting relations, by inclusions of one rock in the other, or by relation to major periods of faulting. The order of emplacement was: quartz diorite porphyry, Tincup quartz monzonite porphyry, rhyolite, quartz diorite, gneissic quartz monzonite, Mount Pomeroy quartz monzonite, andesite, Mount Princeton quartz monzonite, Mount Antero granite, quartz latite porphyry, and Mount Aetna quartz monzonite porphyry. The above names, based on the composition of the rocks, indicate that the rocks range in composition from rhyolite to andesite, although many are quartz monzonites; a summary of the composition is described in more detail under the heading of variation in composition. Textures range from aphanitic and fine grained in the rhyolite, andesite, and latite to coarse-grained gneissic quartz monzonite, although medium grain size predominates. Six of the 11 intrusive rocks are markedly porphyritic, but some others, notably the Mount Princeton quartz monzonite, are mostly equigranular with only porphyritic facies.

The dikes range in thickness from a few inches to about 1,000 feet, and in length from a few feet to one about 9 miles (dike along upper Chalk Creek valley), although most are 2 to 3 feet in thickness and 500 to 1,000 feet in length. Monzonitic and latitic dikes are the most abundant types, although a few are rhyolite or lamprophyre. Porphyritic texture is common to nearly all the dikes.

The age of the intrusive igneous rocks, as well as that of some younger extrusive igneous rocks to be described, is given under "age of igneous rocks" on page 33.

QUARTZ DIORITE PORPHYRY

Quartz diorite porphyry is exposed in the Tincup district where it forms a small stock and a larger, somewhat sill-like, irregular body. The stock, the southern body of this porphyry shown on plate 1, is pear shaped and about 3,000 feet long with a maximum width of about 2,000 feet at its southern end. The northern mass of porphyry extends in a northerly direction as an irregular belt nearly 2 miles long, and attains a maximum outcrop width of 1,300 feet. It thins to the north and probably pinches out a short distance beyond where it disappears beneath glacial moraine. Outcrops are rare, and no definite contacts are exposed at the surface, but the position of the porphyry body can be located fairly closely by float fragments except along the steep west slope of Duncan Hill, where the contact of the porphyry with the Manitou dolomite is concealed for a long distance by talus from the higher body of porphyry to the east. Information obtained from mine workings and the relation between the trend of the contact and topography, as contrasted with the same relations of bordering formations, disclose that the porphyry body dips steeply east or northeast, although locally the dip is concordant with the bedding of the Paleozoic strata.

The fresh quartz diorite porphyry is typically a medium-gray to greenish-gray, fine-grained rock in which white feldspar and dark hornblende phenocrysts are conspicuous. Weathered surfaces are light brown to dark reddish-brown, and chlorite is common along fracture surfaces. The phenocrysts generally constitute one-third to one-half the rock, although locally they are sparse. They are mostly dull to shiny white feldspar occurring as subhedrons generally ranging from 2 to 6 mm long. Striations can be seen on many of these grains. Much less conspicuous and abundant are somewhat smaller phenocrysts of hornblende and rarely biotite; in a few facies almost the only phenocryst is hornblende. The groundmass is rather uniformly fine grained, although in places it is of medium grain. Feldspar, hornblende, biotite, quartz, and an occasional small grain of sphene can generally be distinguished in hand specimens.

Microscopic examination of thin sections of the porphyry shows it to be porphyritic in varying degrees, with phenocrysts ranging from 0.15 to 8 mm long enclosed in a fine-grained hypautomorphic groundmass in which grain size commonly ranges from 0.2 to 1 mm. The most abundant mineral is plagioclase feldspar, averaging sodic andesine, but many grains, particularly the phenocrysts, show pronounced zoning and have cores of labradorite. Orthoclase was observed in all sections examined; it varies considerably in quantity, but is not abundant enough to class the rock as a quartz monzonite. Quartz, mostly in small anhedral grains, is widely distributed and constitutes about 8 percent of the rock. Common green hornblende and brown biotite are present in variable amounts, although hornblende is usually predominant. Together they constitute about 15 to 20 percent of the rock. Biotite is generally in small frayed grains in the groundmass, although a few euhedral grains occur as phenocrysts. Hornblende occurs both in groundmass and as phenocrysts, in the latter occurrence as subhedral blades commonly ranging from 2 to 6 mm long. The accessory minerals are magnetite, apatite, and sphene. Magnetite occurs as irregular grains, rarely in small octahedra, and as a secondary mineral formed from biotite or hornblende. Chlorite, epidote, and sericite are alteration products present in minor quantity in most specimens.

The quartz diorite porphry is probably the oldest of the Tertiary intrusive rocks, although conclusive evidence of its relative age was not found. Most, if not all, of the other Tertiary intrusions followed the major period of diastrophism that produced the northwest-trending Tincup-Morning Glim fault zone. In the West Gold Hill mine, however, fragments of quartz diorite porphyry have been dragged along bedding faults that are probably related to the Tincup thrust fault. The quartz diorite porphyry is thus earlier than many of the porphyries, but its relation to a few of the other early intrusive rocks, such as the Tincup quartz monzonite porphyry, the rhyolite, and the quartz diorite, is uncertain, as will be indicated in the discussions of these rocks.

TINCUP QUARTZ MONZONITE PORPHYRY

A quartz monzonite porphyry that differs markedly in physical characteristics from any other porphyry in the quadrangle occurs in five separate bodies along the west side of the quadrangle (pl. 1), from near the junction of North and Middle Quartz Creeks northward for at least 9 miles to the north end of Duncan Hill, where it passes beneath glacial moraine. This quartz monzonite porphyry is here designated the Tincup quartz monzonite porphyry from its type locality in a stock west of Napoleon Pass in the Tincup mining district (pl. 2A). The porphyry masses occur in several forms, such as a stock, sills, a large tongue or wedge-shaped body, and as two small irregular bodies with exposed lengths of less than half a mile.

The stock near Napoleon Pass is an oval-shaped body trending a little west of north with a width of about 1 mile and an exposed length of about 3 miles. Except locally along its southern and western borders, the stock is confined within the Belden shale and includes or partially surrounds many large and small areas of the shale. Most of the western border of the stock dips east and emplacement here has clearly been controlled by the east-dipping beds of the Belden shale (pl. 1), particularly those beds lying immediately or a short distance above the basal quartzite. Here the porphyry occurs commonly, but not everywhere, in the form of sills. The southern and eastern contacts of the stock are probably crosscutting and dip steeply, although on these sides no reliable data could be obtained.

One mile south of Cumberland Pass an easterly trending tongue or wedge-shaped body of porphyry 2 miles long cuts obliquely across the high ridge south of the Bon Ton mine. At its easternmost exposure, where it passes under glacial moraine, the thickness is about 500 feet, but at the extreme western edge, where it leaves the quadrangle, the thickness is about 3,500 feet. The porphyry body dips steeply to the south, probably 65° to 85°. The quartz monzonite porphyry cuts gneissic granite of pre-Cambrian age and encloses many small bodies of granite which are too small to show on the geologic map. The contact with the granite, although very rarely exposed, is sharp and shows a narrow chill border of porphyry. The emplacement of this body of porphyry was controlled to a large extent by a pre-existing easterly trending fault or fault zone, as indicated by remnants of a faulted band of sedimentary rocks bordering the porphyry on its southwestern edge, and by a strong gouge and fracture zone in the granite exposed at the porphyry and granite contact in a small prospect pit on the north border of the porphyry body near its eastern end, at an altitude of about 11,500 feet.

A sill of the Tincup porphyry is partially exposed for a length of 1½ miles on the northeast slope of the mountain immediately south of the confluence of North and Middle Quartz Creeks. At the western edge of the quadrangle its thickness is about 600 feet, but farther west the thickness is greater, according to Whitebread,[2] and in places the sill becomes irregular bodies that cut the bedding of the sedimentary rocks at high angles.

The Tincup quartz monzonite porphyry varies considerably in appearance from place to place, depending on the relative abundance of quartz phenocrysts as opposed to those of feldspar. The typical rock consists of very conspicuous phenocrysts of white feldspar, colorless to slightly smoky quartz, and less abundant dark hornblende in a light greenish-gray to grayish-green aphanitic groundmass. The phenocrysts generally exceed the groundmass in volume and locally constitute 65 percent of the rock. Quartz phenocrysts commonly range from 1.5 to 12 mm long and occur chiefly as strongly corroded and embayed grains, whereas feldspar occurs typically in subhedrons ranging from 1.5 to 7 mm long. Scattered blades and irregular grains of hornblende, mostly chloritized, are everywhere present in grains slightly smaller than those of feldspar. A prominent variant of the porphyry occurring locally at or near the borders of the larger bodies contains larger and more numerous quartz phenocrysts than the typical Tincup porphyry. Some of the phenocrysts are 20 mm long. They stand out conspicuously on weathered surfaces and give the rock the appearance of a pebbly sedimentary rock, a feature which is emphasized in a few places by a platy structure in the porphyry.

Microscopic examination shows that an average of about 60 percent of the feldspar phenocrysts are sodic andesine, and the others are orthoclase. The groundmass consists chiefly of microgranular quartz and orthoclase ranging in size from 0.005 to 0.1 mm. Most of the hornblende is altered to a fine-grained aggregate of chlorite, epidote, magnetite, and sericite. All specimens examined contain a little apatite and a few contain small grains of pyrite.

The Tincup porphyry of Tertiary age is probably older than the Mount Princeton quartz monzonite because it is cut by veins believed to be related to the Mount Princeton, and because indirect evidence indicates the porphyry was locally emplaced along a fault that was formed before the intrusion of the Mount Princeton batholith. This age relation is discussed in more detail under "Age of igneous rocks." The age of the Tincup in relation to porphyries older than the Mount Princeton is not known, but it, together with the quartz diorite porphyry, probably correlates in age with the first stage of porphyry intrusions in central Colorado, as suggested by Crawford (1924, p. 365–388).

RHYOLITE

A stock of rhyolite lies near the old town of North Star (pl. 5) about half a mile east of Whitepine, where it is poorly exposed over a distance of about 2,000 feet in two areas, one north and the other south of Galena Creek. The northern body is covered by moraine to the west and is cut off by the Star fault to the east; the southern body cuts the Manitou dolomite and is poorly exposed. The rhyolite is also exposed in the Akron tunnel and some of the higher mine workings vertically below the southernmost surface exposure. The Akron tunnel cuts the rhyolite for a distance of 1,640 feet, beginning about 1,750 feet east of the portal. The first 200 feet is characterized by interfingering bodies of rhyolite and Mount Princeton quartz monozonite in which relative age relations are difficult to determine, but about 200 feet farther east a dike of Mount Princeton quartz monzonite clearly cuts the rhyolite.

The rhyolite is a dense, white to light-gray aphanitic rock locally containing a few scattered small quartz phenocrysts and, less commonly, some of biotite and feldspar. Most of the rock has been so strongly silicified, impregnated with small grains of pyrite, and stained with limonite that the original mineral composition could not be determined. The rhyolite is highly shattered and weathers into small angular blocks whose surfaces are iron stained.

Because the rhyolite is cut by the Star fault, it is older than this fault, which, in turn, is almost certainly a branch fault related to the major Tincup-Morning Glim period of reverse faulting. The rhyolite is cut by dikes of Mount Princeton quartz monzonite and is thus the older, but there are no data available to establish the age of the rhyolite relative to Tertiary igneous rocks older than the Mount Princeton quartz monzonite.

[2] Whitebread, D. H., 1951, Geology of the Pitkin area, Gunnison County, Colo.: Colo. Univ., master's thesis.

QUARTZ DIORITE

Quartz diorite occurs in the southern part of the Garfield quadrangle as five rather widely separated stocks ranging in length from 500 feet to a little more than a mile. The largest stock is a northeast-trending body about 6,000 feet long and 1,200 feet wide situated at the eastern edge of the quadrangle at Cree Creek, where it cuts crystalline rocks of pre-Cambrian age and is partly covered by moraine. A small stock of quartz diorite having a maximum length of 1,500 feet penetrates Silver Plume(?) granite on the southeast slope of Banana Mountain about 1 mile west of Monarch. Near the head of Canyon Creek in the southwest part of the quadrangle are two small stocks about 500 feet across that stand out in bold relief, and a few thousand feet northeast is a larger body of quartz diorite on the west slope of Stella Mountain. This body intrudes the Silver Plume(?) granite and some of the lower Paleozoic strata and is in turn partly surrounded by Mount Princeton quartz monzonite. Although the contact of the quartz diorite and Mount Princeton quartz monzonite is not exposed, the Mount Princeton is the younger of the two, as indicated by inclusions of quartz diorite in the quartz monzonite near the contact.

The typical quartz diorite is a fine- and even-grained, greenish-gray rock, with weathered surfaces dull brown or brownish gray. In most hand specimens white or gray feldspar, biotite, and an occasional grain of quartz are readily identified. The relatively large content of biotite distinguishes the quartz diorite from the other Tertiary intrusive rocks in the Garfield quadrangle. In most of the rocks, grain size ranges from 0.5 to 1 mm, but some facies, and particularly the stock on Banana Mountain, are somewhat coarser, having many grains 2 to 3 mm long. Microscopic examination of thin sections shows that the rock is typically even-granular, xenomorphic, and the most abundant mineral is andesine. Orthoclase is present everywhere but in much smaller amounts than the plagioclase. Small amounts of quartz are also present in all specimens examined. Biotite, hornblende, and augite make up a large proportion of the rock. Their ratios vary somewhat, but biotite is generally most abundant. Accessory minerals are apatite, zircon, sphene, and iron oxide, probably magnetite or ilmenite or both.

The following table, taken from Crawford (1913, p. 133–134), gives a chemical and actual mineral analysis of the quartz diorite from the stock at Cree Creek in the Monarch district (Lost Mountain stock of Crawford).

The only certainty about the age of the quartz diorite relative to the other Tertiary intrusive rocks is that it is older than the Mount Princeton quartz monzonite, as was shown above. As a result of regional studies, Crawford (1924, p. 365–388) concluded that the quartz diorite of the Monarch and Tomichi districts, as well as that in other small bodies in central Colorado, were the first rocks intruded after a period of large-scale folding and faulting. The large-scale faulting is exemplified in the Garfield quadrangle by the Tincup period of deformation.

Chemical and mineral analysis of quartz diorite

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [Rosiwal method, by R. D. Crawford]	
SiO_2	57.39	Quartz	13.7
Al_2O_3	18.26	Orthoclase	18.9
Fe_2O_3	1.58	Plagioclase	39.8
FeO	5.10	Augite	6.0
MgO	1.51	Hornblende	4.1
CaO	6.52	Biotite	15.0
Na_2O	2.78	Iron ore	2.4
K_2O	4.59		
H_2O-	.20		99.9
H_2O+	.11		
TiO_2	1.11		
ZrO_2	.03		
P_2O_5	.11		
Cl	.05		
MnO	.88		
	100.22		

GNEISSIC QUARTZ MONZONITE

Gneissic quartz monzonite occurs as a stock and several small bodies surrounded by younger Tertiary intrusive rocks in the eastern part of the Garfield quadrangle. The largest body extends from the south slope of Mount Aetna northeast for 5 miles to the boundary of the quadrangle and is about a mile wide near Shavano (pl. 1). This body is the western half of a large stock lying east of the quadrangle (Crawford, 1913, pl. II) that has been cut near its center (approximately at the quadrangle line) by an apophysis of Mount Princeton quartz monzonite. On the geologic map, plate 1, two large inclusions of gneissic quartz monzonite in the quartz latite porphyry are shown on the east slope of Mount Aetna, and another large inclusion in the quartz latite porphyry lies northeast of the summit of Clover Mountain on the Continental Divide. About half a mile southeast of Billings Lake, near the head of North Fork, an inclusion about 1,000 feet long in andesite consists of Palezoic sedimentary rocks intruded by gneissic quartz monzonite.

The gneissic quartz monzonite crops out in many places and is especially well exposed in cliffs on the east-trending ridge north of Hunkydory Gulch. Here, as at most other places, the weathered surfaces are stained reddish brown or buff. The gneissic structure is evident in most outcrops. South of Shavano northeast strikes and moderate northwest dips prevail, but north of Shavano both strike and dip range widely (pl. 1).

The typical gneissic quartz monzonite is a very coarse-grained, light- to medium-gray rock having conspicuously large elongated phenocrysts of feldspar or feldspar and quartz lenses separated by wavy shreds, lenses, and bands of biotite. The same rock was perhaps equally well named quartz monzonite gneiss by Crawford (1913, p. 77), and the terms "gneissic augen quartz monzonite" or "quartz monzonite augen gneiss" might be applied equally well because of the abundant large feldspar phenocrysts, some as much as 3 inches long, in a finer grained, but still coarse, groundmass with a strong gneissic structure.

White to gray or rarely pink feldspar and quartz, biotite, and an occasional grain of magnetite can be identified in most hand specimens. The light minerals are in lenses generally 1 to 3 inches long and consist of a granular aggregate of quartz and feldspar or of feldspar alone. The feldspar is commonly granulated and lenticular, although some shows little or no granulation and has shiny cleavage surfaces. Most of the biotite occurs in narrow bands, lenses, or shreds and much of it is partly altered to chlorite. Biotite and magnetite form inclusions in much of the feldspar. Microscopic examination shows that the larger feldspar grains are orthoclase and microcline, but the smaller grains are mostly plagioclase, averaging sodic andesine. Quartz occurs typically as anhedral grains containing many liquid inclusions, and as a micrographic intergrowth on the borders of some of the orthoclase grains. Other minerals present are magnetite, sphene, and small amounts of apatite, zircon, and allanite.

The chemical analysis and calculated mineral composition of a specimen of the gneissic quartz monzonite from Jennings Creek valley is given in the following table, taken from Crawford (1913, p. 150–151).

Chemical and mineral analysis of gneissic quartz monzonite

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
SiO_2	67.90	Quartz	22.86
Al_2O_3	16.08	Alkalic feldspar	31.57
Fe_2O_3	.83	Andesine, Ab_2An_1	36.09
FeO	2.02	Biotite	6.52
MgO	.73	Titanite	.59
CaO	2.86	Magnetite	.70
Na_2O	4.08	Ilmenite	1.22
K_2O	4.11	Apatite	.31
H_2O-	.14		
H_2O+	.21		99.86
TiO_2	1.15		
ZrO_2	tr		
P_2O_5	.12		
Cl	.01		
MnO	none		
	100.24		

According to Crawford (1913, p. 149–150), the foliation in the gneissic quartz monzonite was produced by flow of a partly crystallized viscous magma and was not the result of dynamic metamorphism after intrusion and solidification of the magma, because gneissic structure is absent nearby in the older Pikes Peak granite on Missouri Hill, and Paleozoic sedimentary rocks intruded by gneissic quartz monzonite southeast of Billings Lake show no dynamic metamorphic effects The granular lenses of feldspar in association with large uncrushed feldspars indicate that movement of the magma occurred after crystallization had started and that the crystals which had formed with their long diameters at a high angle to the direction of flow were rotated and somewhat crushed, whereas those oriented in the same general direction as the flow were not crushed. The writers likewise attribute the foliation to flow of the magma for the same reasons.

The gneissic quartz monzonite is older than the Mount Pomeroy quartz monzonite, described later, because several small fragments of it were found included in the Mount Pomeroy near the summit of the mountain half a mile northeast of Billings Lake. Crawford (1913, p. 178), who evidently did not see this occurrence, tentatively placed the Mount Pomeroy as the older.

MOUNT POMEROY QUARTZ MONZONITE

The Mount Pomeroy quartz monzonite was named first the Pomeroy quartz monzonite by Crawford (1913, p. 79) for a stock, part of which is well exposed at its type locality on Pomeroy Mountain. The name was changed by the authors to Mount Pomeroy to conform with the U. S. Geological Survey requirements, because the name Pomeroy had been used elsewhere in the United States. The stock is exposed in an irregular belt, averaging about 1¼ miles in width, that extends from the vicinity of Chalk Creek Pass northeastward almost to the eastern boundary of the quadrangle (pl. 1). One outlying body of Mount Pomeroy quartz monzonite is exposed east of Brittle Silver Mountain, and two others are near the head of Browns Creek; all probably represent part of a once larger body of Mount Pomeroy that was fragmented and intruded by younger rocks.

The Mount Pomeroy quartz monzonite dips under the two younger intrusive rocks, the quartz latite porphyry and andesite, on the south side of the stock. The dip is 25° to 40° S. under the quartz latite porphyry, as is well shown on the high ridge a few thousand feet east of Hancock Lake, where the gently dipping contact between the lighter colored Mount Pomeroy and the overlying dark quartz latite porphyry can be seen from a long distance (pl. 3B). The attitudes of the contact of the quartz monzonite porphyry with the andesite were not discernible in outcrops, but the relation between this contact and the topography suggests a moderate to steep southerly dip. Along its northern border the Mount Pomeroy quartz monzonite is in contact with the younger Mount Princeton quartz monzonite for several miles. No dip was observed from outcrops, but the relationship between the topography and the contact indicates a southerly dip, varying from gentle to steep. The contact of Mount Pomeroy quartz monzonite with the younger Mount Antero granite at the east end of the stock is steep. The Mount Pomeroy stock has probably not been greatly eroded because near its southern and southwestern contacts the rock grades into a finer-textured and more silicic marginal facies.

The typical Mount Pomeroy quartz monzonite is a pinkish-gray, medium-grained rock, with weathered surfaces dull greenish gray or dull reddish brown. Chloritized hornblende and biotite, white, pink, and gray feldspar, quartz, and a few small pyrite grains can generally be seen in hand specimens. Some of the white feldspar shows albite twinning striations. Hornblende, the most abundant mafic mineral, is typically chloritized; this feature, combined with the pinkish tone, is characteristic of most of the rock and helps to distinguish the Mount Pomeroy from other Tertiary intrusive rocks, particularly the Mount Princeton quartz monozonite. Thin sections under the microscope show that the plagioclase ranges from calcic andesine to sodic labradorite and is considerably in excess of orthoclase; it occurs typically in subhedrons and anhedrons, many of which show combinations of Carlsbad and albite twins. Most of the orthoclase is micrographically intergrown with quartz. Other minerals recognized include magnetite or ilmenite, pyrite, and small amounts of zircon, apâtite, and sphene, as well as the occasional secondary minerals, epidote, calcite, and a clay mineral.

In many places bright brownish-red and brown iron oxide stain occurs along joints, particularly northeast of Hancock Lake, along the ridge for 2,000 feet north from its contact with the quartz latite porphyry, and also about half a mile northeast of Billings Lake, along the divide between North Fork and Grizzly Gulch.

The Mount Pomeroy quartz monzonite of Tertiary age is older than both the quartz latite porphyry and the Mount Princeton quartz monzonite. The relative ages are based upon the presence of fragments of Mount Pomeroy in the quartz latite porphyry, and locally a chilled border of Mount Princeton quartz monzonite where it is in contact with the Mount Pomeroy quartz monzonite. This chilled border is especially well exposed on the slope northwest of Pomeroy Mountain.

The table below, taken from Crawford (1913, p. 137–138), gives a chemical and mineral analysis of the Mount Pomeroy quartz monzonite from the Pride of the West tunnel on the east side of Pomeroy Mountain.

Chemical analysis and calculated mineral composition of Mount Pomeroy quartz monzonite

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
SiO_2	62.60	Quartz	17.46
Al_2O_3	18.16	Orthoclase	28.59
Fe_2O_3	.91	Labradorite (about Ab_1An_1)	40.52
FeO	2.72	Biotite	3.96
MgO	.96	Hornblende	6.94
CaO	5.30	Magnetite	.70
Na_2O	3.02	Ilmenite	1.52
K_2O	4.10		
H_2O-	.28		99.69
H_2O+	.34		
TiO_2	1.02		
ZrO_2	tr		
P_2O_5	.06		
Cl	.04		
MnO	.50		
	100.01		

The occurrence of sodic labradorite with an appreciably smaller quantity of orthoclase, and still less quartz, suggests that the rock is not a typical quartz monzonite and might be classed as granodiorite or possibly quartz diorite according to various definitions. However, in the foregoing calculation of the mineral composition of the rock Crawford (1913, p. 138), for reasons advanced and not duplicated here, states that the true ratio of orthoclase to plagioclase may be greater than given in the table.

ANDESITE

Andesite occurs as a large irregular stock or chonolith in the east-central part of the quadrangle, as four small outlying bodies, and in several dikes. The chonolith extends from a point 2 miles west of Shavano northeastward about 4 miles to the head of Browns Creek and averages about 1 mile in width. The andesite intrusion was emplaced between the older Mount Pomeroy and gneissic quartz monzonite masses, and in turn the andesite is cut off by younger intrusive rocks at its eastern and western borders. Along its western border the andesite dips on the average 30° SW. under the younger quartz latite porphyry (pl. 1). Its contact with older rocks is concealed. However, along the northern border the relation between topography and the trace of its contact with Mount Pomeroy quartz monzonite suggests a moderate southerly dip, and along its southern contact with gneissic quartz monzonite a nearly vertical dip is indicated. This led Crawford (1913, p. 160) to assume, perhaps justifiably, that the body of andesite, in the upper part at least, is a downward-pointing wedge-shaped chonolith.

Two small outlying andesite bodies are near the eastern boundary of the quadrangle about ½ mile from the main mass; two other small intrusive bodies are about 4 miles southwest of the chonolith. The dikes are generally small and most of them are confined to the area south of the chonolith.

The typical andesite is a dense, grayish-green to dark greenish-gray rock, with small phenocrysts of white or light greenish-gray feldspar. In the field some of the dark-colored andesite is very difficult to distinguish from the younger quartz latite porphyry. The andesite weathers into angular fragments commonly less than 1 foot long, with surfaces stained buff to reddish brown. The phenocrysts, although generally conspicuous, constitute on the average only about one-fourth of the rock. Most are in anhedral forms ranging from 1 to 3 mm long and a few show albite twinning striations. The only other minerals commonly recognized in hand specimens are epidote, chlorite, and small grains of disseminated pyrite.

The andesite is everywhere altered to propylite and at most places small grains of pyrite are disseminated throughout the mass. Most of the hornblende has been changed to epidote and magnetite, and biotite is characteristically bordered by a reaction rim of magnetite or entirely altered to chlorite, epidote, and magnetite. Many feldspar phenocrysts are strongly epidotized. On the mountain three quarters of a mile southeast of Billings Lake many joint surfaces of the andesite are coated with pyrite. Weathering of the pyrite has locally produced iron hydroxides of striking shades of red and brown, and this mountain southeast of Billings Lake is locally known as Calico Mountain because of its variegated and vivid colors.

Although conclusive evidence was not obtained, the authors believe that the propylitization and pyritization are genetically related to the magma that in part formed the andesite. This assumption is based upon the widespread occurrence of propylite and pyrite in the andesite, and these types of alteration locally extend into the bordering older rocks, especially the Mount Pomeroy quartz monzonite at the heads of North Fork and Cyclone Creek valleys. Whether the origin of this alteration was by deuteric or hydrothermal process or a combination of these two is not known, although the very common propylitization of andesite bodies throughout the world suggests deuteric alteration for propylites. It is fully realized that this local center of alteration in the Garfield quadrangle may merely reflect a period of alteration considerably younger than the andesite intrusion which was localized along accessible structures in this area; however, structural features necessary to localize this alteration throughout the entire body of andesite are absent.

The following table, taken from Crawford (1913, p. 162–163), gives the chemical analysis of a fairly fresh specimen of the andesite from near the head of Jennings Creek, and the mineral composition as calculated from the chemical analysis.

Chemical analysis and calculated mineral composition of andesite

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
SiO_2	57. 51	Quartz	13. 02
Al_2O_3	19. 18	Orthoclase	12. 79
Fe_2O_3	1. 76	Plagioclase (average $Ab_{10}An_9$)	53. 10
FeO	3. 39	Hornblende	4. 40
MgO	2. 44	Biotite	10. 66
CaO	6. 32	Magnetite	1. 62
Na_2O	3. 28	Ilmenite	3. 04
K_2O	3. 18	Pyrite	. 23
H_2O-	. 09	Apatite	. 93
H_2O+	. 09		99. 79
TiO_2	2. 02		
ZrO_2	none		
P_2O_5	. 41		
Cl	. 07		
FeS_2	. 23		
MnO	none		
	99. 97		

The andesite is older than the quartz latite porphyry, as shown by inclusions of andesite in the porphyry near their contact about 1¼ miles south of Billings Lake. It is also older than the Mount Antero granite because pegmatite dikes related to the granite cut the andesite on the ridge north of Browns Creek. The andesite contains blocks of gneissic quartz monzonite about half a mile southeast of Billings Lake and is therefore younger than the gneissic quartz monzonite. No clear-cut age relation between the andesite and Mount Pomeroy quartz monzonite was seen, but pyrite that is characteristically disseminated through the andesite and believed to be genetically related to the andesite penetrates the borders of the adjacent quartz monzonite, as previously noted, suggesting that the andesite is younger.

MOUNT PRINCETON QUARTZ MONZONITE

The Mount Princeton quartz monzonite of Tertiary age was named the Princeton quartz monzonite by Crawford (1913, p. 70) because of its excellent exposure at the type locality on Mount Princeton, the summit of which lies less than half a mile east of the northeast corner of the Garfield quadrangle. The authors, however, follow Stark and Barnes (1935, p. 475) in using the name Mount Princeton for this quartz monzonite, because the name Princeton had been used before Crawford's time for another rock unit in the United States. The Mount Princeton quartz monzonite is one of the largest bodies of Tertiary intrusive rocks in Colorado (Burbank, Lovering, Goddard and Eckel, 1935). It forms a small batholith roughly circular in outline with a maximum diameter of about 20 miles. Only the southern part of the batholith is present in the Garfield quadrangle, and it occupies a larger area than any other rock unit. The Mount Princeton quartz monzonite lies chiefly east of the Continental Divide, although the southernmost large apophysis of the batholith crosses the divide about 1½ miles north of Middle Quartz Creek and extends southward about 8 miles to Spring Creek, in the southernmost part of the Tomichi mining district, where it terminates rather bluntly as a tongue about a mile wide. Many of the highest peaks in the quadrangle are composed of this quartz monzonite, especially those north and west of Chalk Creek. In addition to the main mass, the Mount Princeton quartz monzonite forms many small outlying bodies and also forms a large northeast-trending body about 6 miles long and ¾ mile wide, extending from Middle Fork of South Arkansas River to the eastern boundary of the map. This body is probably an apophysis that connects to the northeast with the main batholith. The Mount Princeton quartz monzonite is of particular interest because most of the economically important ore deposits are believed to be genetically related to it.

The quartz monzonite is generally a fresh-appearing rock on weathered as well as newly broken surfaces, but in a number of places, especially in the southern part of the Tomichi district, highly weathered parts of the Mount Princeton are difficult to distinguish from the pre-Cambrian granite which it intrudes. Typically, the rock is gray and medium grained but locally is light gray, pinkish, or, rarely, white. Minerals recognized in hand specimens are white, gray, and pinkish feldspars, glassy quartz, fresh shiny black biotite flakes, many of which are in euhedral forms, dull-green hornblende, and in almost all specimens, a few small cinnamon-brown crystals of sphene.

The texture ranges from even-granular through slightly porphyritic, to a prominently porphyritic facies. The phenocrysts are white, gray, or pink feldspar, and some attain a length of 1½ inches. The Mount Princeton quartz monzonite east of Chalk Creek in the northern half of the mapped area is, in general, markedly more porphyritic than elsewhere. Here the phenocrysts are almost entirely pink potash feldspar, but west of Chalk Creek the phenocrysts of the locally porphyritic facies are about equally divided between potash and plagioclase feldspar. The groundmass of the porphyritic facies has a greater content of pink alkali feldspar and a smaller content of mafic minerals than the nonporphyritic facies. Thin sections show that plagioclase exceeds orthoclase. The plagioclase occurs typically in subhedral crystals ranging in composition from calcic andesine to sodic labradorite; many are zoned, and a few enclose biotite. Orthoclase is generally in anhedrons and poikilitically encloses all other minerals except quartz. Quartz varies locally in amount although it is everywhere present. Biotite and hornblende are commonly intergrown, and biotite slightly exceeds hornblende in amount. Sphene, in wedge-shaped and irregular grains, is the most abundant accessory mineral; others are apatite, zircon, black iron oxide, and occasional grains of pyrite.

The table below gives two chemical analyses and one actual mineral composition of the Mount Princeton quartz monzonite. The analysis of the rock from the gulch south of Williams Pass is from a composite sample of many chips of typical nonporphyritic rock collected over an area several thousand feet in length.

Chemical and mineral analyses of Mount Princeton quartz monzonite

Chemical analyses	1	2	Mineral composition by weight [By R. D. Crawford; Rosiwal method]	2
SiO_2	65. 37	67. 64	Quartz	18. 8
Al_2O_3	17. 04	14. 75	Orthoclase	25. 8
Fe_2O_3	2. 30	. 81	Plagioclase	42. 5
FeO	2. 16	1. 95	Hornblende	2. 9
MgO	. 63	. 94	Biotite	8. 2
CaO	3. 37	3. 98	Iron ore	1. 2
Na_2O	3. 76	3. 40	Titanite	. 6
K_2O	4. 20	4. 06		
H_2O-	. 06	. 13		100. 0
H_2O+	. 34	. 19		
TiO_2	. 48	1. 36		
ZrO_2	------	tr		
P_2O_5	. 21	. 20		
Cl	------	. 08		
MnO	. 08	. 27		
CO_2	. 08	------		
BaO	. 16	------		
	100. 24	99. 76		

1. Mount Princeton quartz monzonite, gulch south of Williams Pass, Quartz Creek district, Colorado. Leonard Shapiro, U. S. Geological Survey, analyst. Na_2O and K_2O determined with flame photometer by S. M. Berthold, U. S. Geological Survey.
2. Mount Princeton quartz monzonite, Taylor Mountain, Monarch district, Colorado. From Crawford (1913, p. 144-145). R. M. Butters, analyst.

There is little change in texture or composition of the Mount Princeton quartz monzonite as the border is approached, except locally, as on the ridge north of Pomeroy Mountain at the contact with the Mount Pomeroy quartz monzonite. Here the Mount Princeton is a granite porphyry that extends northward several hundred feet and grades into quartz monzonite.

From Whitepine northwest for about 9 miles the contact of the Mount Princeton batholith with rocks of pre-Cambrian and Paleozoic age roughly follows the older Tincup-Morning Glim fault zone, which was doubtless a zone of highly shattered rock that afforded easy access for emplacement of the Mount Princeton magma. Xenoliths of the older rocks occur near the borders of the Mount Princeton quartz monzonite. The inclusions range in size from small fragments a few inches long to large bodies nearly half a mile long. The larger xenoliths are mostly sedimentary rocks; several are shown on the geologic map 2 to 5 miles northwest of Whitepine along the west side of the batholith. The southernmost large inclusion, which is chiefly coarse marble, is about 4,000 feet from the west margin of the batholith.

Distributed through the Mount Princeton quartz monzonite are dark-colored bodies, generally oval, of which the vast majority range in length from 1 to 12 inches, although one about 100 feet long is 500 feet northeast of the portal of the 400-foot level of the Mary Murphy mine. The bodies are a fine-grained dark-gray aggregate consisting chiefly of feldspar, biotite, and hornblende; the mafic minerals constitute about a third of the rock. In most hand specimens a little quartz and an occasional grain of sphene can be recognized. The bodies grade into the surrounding quartz monzonite through border zones less than half an inch wide. There are two distinct types of bodies. One is even grained and one is porphyritic, with phenocrysts, chiefly of feldspar, forming about one-fourth of the rock. Both types have about the same composition, but the porphyritic variety is characterized by slightly narrower gradational border zones. The large inclusions are of the porphyritic type and are probably cognate inclusions; that is, fragments of chilled Mount Princeton quartz monzonite, as suggested by their large size and the fact that no other rock of this type was seen outside the borders of the Mount Princeton quartz monzonite. The even-granular bodies are believed to be basic segregations of the Mount Princeton magma because of their uniform size, even distribution through the Mount Princeton batholith, composition, and gradation into quartz monzonite. If the even-granular bodies were inclusions, they would be expected to be more abundant near the borders of the batholith and have a wide range in composition and size.

Dikes and apophyses extend out from the Mount Princeton batholith into the bordering rocks at places, notably near Boss Lake Reservoir and high on the ridge west of the head of Taylor Gulch. The quartz monzonite in such dikes is generally finer grained than that of the main body; it contains somewhat more biotite than the normal Mount Princeton quartz monzonite but is richer in potash feldspar and approaches granite in composition. Dikes of white, fine-grained, and sugary-textured granite aplite occur throughout the Mount Princeton batholith but are somewhat concentrated in a zone 1 to 2 miles wide along the west side of the batholith. A few extend out into the older rocks. Most of the dikes are only 1 inch to 2 feet thick and less than 50 feet long. Only the largest ones are shown on the geologic map. These have a northeast trend, but the hundreds of smaller dikes show no consistent trend. Pegmatite dikes related to the Princeton quartz monzonite are extremely rare; the few found are narrow bodies within aplite dikes or bordering dikes of quartz monzonite. They consist chiefly of quartz and microcline, with accessory biotite, hornblende, and muscovite; black tourmaline is present locally.

The Mount Princeton quartz monzonite is older than the Mount Antero granite, which clearly cuts the quartz monzonite high up in the sharp gulch of McCoy Creek, near the eastern border of the quadrangle. It is definitely younger than the Mount Pomeroy quartz monzonite and is probably younger than the andesite, because veins believed to be genetically related to the Mount Princeton quartz monzonite cut the andesite.

MONZONITIC AND LATITIC DIKES

Dikes of monzonitic and quartz monzonitic composition occur throughout most of the mapped area except in the region roughly bounded by the Continental Divide on the west and Chalk Creek on the east. The dikes included in this general grouping consist of monzonite, quartz monzonite, latite, quartz latite, and their porphyritic equivalents. Porphyritic quartz monzonite and porphyritic quartz latite are the most abundant. The dikes occur singly or in groups as on the slopes of Taylor Mountain and north of Waterdog Lakes.

Although some dikes can be traced half a mile or more, the vast majority range in length from 500 to 1,000 feet and are 5 to 25 feet thick. The dikes generally dip steeply, insofar as could be determined, and their strike varies according to the local structure, but northeast and northwest strikes dominate over easterly or northerly ones.

The monzonitic dikes are generally gray or greenish gray, with conspicuous and abundant phenocrysts of feldspar, quartz, or hornblende, depending upon the composition of the individual dike. The latite and quartz latite dikes are generally light- to medium-gray aphanitic rocks containing small phenocrysts of quartz or feldspar or both, although some are nonporphyritic. In general the latitic dikes are shorter and narrower than those of monzonite.

The relative ages among the different types of scattered dikes in this group were not determined, because at no place are crosscutting relationships exposed. Most, if not all, of the dikes were probably intruded after the Mount Princeton batholith and before the Mount Antero granite, because no dikes of this group cut rocks younger than the Mount Princeton.

RHYOLITIC DIKES

Rhyolitic dikes, including rhyolite, rhyolite porphyry, and pitchstone porphyry, are widely but sparsely distributed throughout the Garfield quadrangle.

They are most abundant in the vicinity of Taylor Mountain in the Monarch district and east of Whitepine in the Tomichi district but are not nearly so common as the older monzonitic dikes. Several of the rhyolitic dikes, such as some in the Whitepine area, one east of the Tincup district, and two a few miles east of St. Elmo, attain lengths of ½ to almost 1 mile, but many are less than 1,000 feet long. Most of the dikes are 5 to 20 feet thick, but some are less than a foot thick, and others locally swell to 50 feet. The dikes tend to follow local structure, but northeast and northwest strikes predominate over northerly or easterly ones. In the Whitepine area, the northerly trending rhyolite dike cut in the Akron mine was intruded along the Star fault zone which it locally fills and cuts across at low angles. Two long dikes several miles east of St. Elmo follow a northeast-trending fracture zone which is emphasized by several veins in the Mount Princeton quartz monzonite. The dip of the dikes is generally steep although some, such as those east of the Tincup district and near Chalk Creek, east of St. Elmo, dip as low as 20°.

The dikes are white to light-gray, dense rhyolitic rocks, either with or without phenocrysts of quartz or feldspar, although by far the greater number are porphyritic to some extent. Many have a platy fracture, and some are pinkish on weathered surfaces. A green or brownish, resinous pitchstone porphyry with feldspar and some biotite phenocrysts occurs locally as much as 2 feet thick along the borders of two rhyolite dikes cut in the Akron and Morning Star mines.

The rhyolitic dikes are probably rather closely related genetically to the Mount Princeton quartz monzonite. Crawford (1913, p. 167 and pl. II) regarded them younger than the Mount Aetna porphyry, but the present writers assign them an older age because: (1) at no place does rhyolite cut rock younger than the Mount Princeton quartz monzonite, (2) many of the dikes are cut or bordered by veins or altered and weakly mineralized zones that are believed to be genetically related to the Mount Princeton quartz monzonite, and (3) the wide distribution of the dikes suggests a genetic relation to a large widespread body such as the Mount Princeton batholith.

KERSANTITE DIKES

One long and several short, probably lamprophyric dikes, ranging from 1 to 100 feet wide, cut the Mount Princeton quartz monzonite north of Chalk Creek about 2½ miles northeast of St. Elmo (pl. 1). The rock is dark green to black, aphanitic or fine grained, and slightly porphyritic. As determined by microscopic analysis, the rock is composed chiefly of plagioclase and biotite, with subordinate magnetite and augite; thus it is technically a kersantite. The dikes strike northeast and dip 60° to 70° NW. At an altitude of 10,100 feet in Coal Camp Canyon one of the small kersantite dikes cuts and offsets a rhyolite dike and, therefore, this dike is younger than the Mount Princeton quartz monzonite and the rhyolite dike. The relation of the kersantite dikes to rocks younger than these two, such as the Mount Antero granite and the quartz latite porphyry, is unknown.

MOUNT ANTERO GRANITE

In the eastern part of the Garfield quadrangle a granite of Tertiary age occurs as two stocks, several small outlying bodies, and dikes. The granite is here named the Mount Antero granite because of its occurrence at its type locality on Mount Antero, the crest of which lies a few hundred feet east of the quadrangle boundary. The northern, and larger, stock (pl. 1) is about 3 miles long, extending from the west side of Mount Antero to a point about half a mile south of Browns Creek. The southern stock, 2 miles farther south, in the vicinity of North Fork South Arkansas River, is about 1½ miles long. Both stocks extend east beyond the quadrangle boundary, as shown on Crawford's geologic map (1913, pl. II), the northern one for at least 2½ miles, and the southern one for about 1,500 feet. Both stocks are irregular in plan and appear to have steeply dipping contacts. Granite dikes and small outlying bodies are exposed in the rocks adjacent to the northern stock. Pegmatite dikes related to the Mount Antero granite are restricted to the area in and around this intrusion.

The Mount Antero granite is light gray to nearly white, and weathered surfaces are a slightly glistening white, with local pinkish or brownish tones. It is typically medium grained and is composed mostly of feldspar and quartz, with subordinate small grains of biotite. Most of the quartz is conspicuously rounded and embayed. Locally the rock contains a few scattered pink feldspar phenocrysts, and some dikes and irregular border zones are fine grained, with scattered larger grains of feldspar and rounded quartz.

Microscopic examination shows that the feldspars are orthoclase, microcline, and albite. Microcline is sparse; the albite and orthoclase are present in about equal amounts. Quartz occurs in single anhedral grains, in clusters, and, to a minor extent, micrographically intergrown with orthoclase. Biotite, apatite, zircon, and sphene are accessory minerals. Most of the biotite is altered to chlorite, muscovite, or black iron oxide.

The following table, taken from Crawford (1913, p. 154–155), gives the chemical analysis and calculated mineral composition of the Mount Antero granite from near Browns Creek.

Chemical analysis and calculated mineral composition of Mount Antero granite

CHEMICAL ANALYSIS [R. M. Butters, analyst]	
SiO_2	74.27
Al_2O_3	13.67
Fe_2O_3	.48
FeO	.45
MgO	.12
CaO	.65
Na_2O	3.48
K_2O	5.90
H_2O-	.10
H_2O+	.04
TiO_2	.49
ZrO_2	.01
P_2O_5	.04
Cl	.02
MnO	none
	99.72

CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
Quartz	30.36
Alkalic feldspar [1]	65.48
Biotite	2.86
Ilmenite	.15
Titanite	.78
	99.63

[1] Orthoclase molecule 33.92
Albite molecule 29.34
Anorthite molecule 2.22
65.48

The granite and bordering rocks in the vicinity of Mount Antero and White Mountain to the south have long been known to mineral collectors as a source of fine specimens of beryl, phenacite, topaz, and other rare minerals; these occur in pegmatites, in small irregular beryl-rich zones in the granite, and in quartz veins. A more detailed description of these minerals and their occurrences is given under the heading of beryl in pegmatite, granite, and greisen.

The Mount Antero granite is younger than the Mount Pomeroy quartz monzonite, Mount Princeton quartz monzonite, and the andesite, because dikes of granite, or related pegmatites, cut these three rocks. The age relation of the granite to the distant quartz latite porphyry is not known.

QUARTZ LATITE PORPHYRY

The quartz latite porphyry occurs near the center of the Garfield quadrangle as one large irregular mass and several smaller bodies in the area extending from near the head of North Fork west across the Continental Divide almost to Tomichi Creek. The areal relations shown on plate 1 leave little doubt that the outlying bodies were once part of a single irregular intrusive body, best described as a chonolith, that was split, surrounded, and deeply embayed by the later Mount Aetna quartz monzonite intrusion. The original size of the chonolith was apparently about 9 square miles. Along the northern and part of the eastern side the contact of the quartz latite with older rocks dips 25° to 50° S. (pl. 3*B*) but elsewhere the dip is nearly vertical.

From Hancock Lake southeast along the contact for nearly 2 miles the basal part of the quartz latite porphyry consists of angular to rounded rock fragments in a quartz latite porphyry matrix. The breccia forms a belt 50 to 500 feet wide. The fragments in the breccia are chiefly quartz latite porphyry, andesite, and Mount Pomeroy quartz monzonite, mostly in somewhat rounded or oval forms ranging from a few inches to a foot long. These rounded fragments suggest strong abrasive action before incorporation by the latitic magma that followed. For a distance of about 2,000 feet on the northern end of the sharp ridge of Van Wirt Mountain, the quartz latite porphyry shows a pronounced fluxional platy structure, which, from a distance, imparts to the rock the appearance of a well-bedded sedimentary rock (pl. 2*B*).

The quartz latite porphyry typically forms high, jagged dark cliffs such as the prominent ones extending from Mount Aetna northwest to Van Wirt Mountain. It is the darkest of the Tertiary intrusive rocks and is mostly dark gray, although a medium-gray rock with a slight bluish tone is found locally. Phenocrysts 1 to 3 mm long compose about 40 percent of the rock; they are mostly white or gray feldspar and biotite and hornblende. A little quartz, a few pink feldspars, and small sphene crystals also can be recognized in most hand specimens. The groundmass is typically dark gray, dense, and aphanitic.

Miscroscopic examination shows that the most abundant phenocrystic mineral is plagioclase ranging in composition from calcic oligoclase to sodic andesine; many of the crystals are zoned and have a core of andesine bordered by oligoclase. A few orthoclase crystals are present. The feldspars are typically in subhedral or anhedral forms, and many are broken and embayed. Biotite, often in bent crystals, exceeds hornblende in quantity. Hornblende occurs as fresh or altered crystals, and, in common with the biotite, a few are bordered by small grains of black iron oxide, probably magnetite. Apatite, zircon, and particularly sphene are accessory minerals. The groundmass is typically a very fine-grained microgranular material containing some glass, but it is largely indeterminable. Dark dustlike inclusions are abundant. A few of the phenocrysts are surrounded by wavy and irregular, glassy flow bands.

Several features suggest that the quartz latite porphyry magma was introduced in pulsations into partly or completely solidified rock rather than continuously. At times the pulsations were probably relatively gentle, but at other times they are believed to have been violent and some material may even have been ejected at the surface. Features that indicate the pulsatory movement of the magma are: abrupt changes in the general physical appearance of the rock, local stringy patches, irregular zones of rock rich in both foreign and cognate inclusions, locally a conspicuous cemented breccia zone near the base, ruptured feldspar crystals, bent and broken mica flakes, and flow bands around some of the phenocrysts.

The quartz latite porphyry is younger than the andesite and Mount Pomeroy quartz monzonite, for it contains inclusions of these rocks. It is clearly older than the Mount Aetna quartz monzonite porphyry, because at many places dikes of Mount Aetna porphyry cut the quartz latite porphyry, and inclusions of the quartz latite porphyry are found in the Mount Aetna porphyry.

The following table, taken from Crawford (1913, p. 166–167), gives the chemical analysis and calculated mineral composition of a specimen of quartz latite porphyry from the Mohammed tunnel in Middle Fork South Arkansas valley, due west of Mount Aetna.

Chemical analysis and calculated mineral composition of quartz latite porphyry

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
SiO_2	64. 56	Quartz	14. 58
Al_2O_3	17. 36	Orthoclase	31. 14
Fe_2O_3	. 76	Plagioclase (average Ab_5An_2)	42. 66
FeO	1. 81		
MgO	. 73	Biotite	7. 28
CaO	3. 25	Hornblende	1. 93
Na_2O	3. 56	Magnetite	. 46
K_2O	5. 94	Titanite	. 98
H_2O-	. 41	Apatite	. 31
H_2O+	. 45		
TiO_2	. 61		99. 34
ZrO_2	tr		
P_2O_5	. 08		
Cl	. 01		
MnO	. 33		
	99. 86		

MOUNT AETNA QUARTZ MONZONITE PORPHYRY

A distinctive quartz monzonite porphyry occurring chiefly in the central part of the mapped area was named by Crawford (1913, p. 80) the Etna quartz monzonite porphyry. The name "Etna" had previously been used elsewhere in the United States for a rock unit, so the authors, following the U. S. Geological Survey requirements, have changed the name to "Mount Aetna quartz monzonite." The spelling of "Etna," it will be noted, has been changed to "Aetna" in order to conform to that used on the topographic base map of the Garfield quadrangle. As the name implies, the rock is exposed at its type locality on Mount Aetna, 3 miles north of Monarch, where it occurs as an irregular stock extending about 3 miles northwest to the headwaters of Tomichi Creek. A smaller stock, probably connected at depth with the larger mass, centers around Deer Gulch, west of Vulcan Mountain, and about a mile farther south, a still smaller stock lying adjacent to a body of andesite cuts across the valley of Bonanza Creek. Two long dikes radiate from the main stock (pl. 1). The longer, near the west side of the stock, extends from upper Tomichi Creek valley almost 10 miles northeast across the Continental Divide to a point about a mile beyond St. Elmo where it apparently pinches out in Mount Princeton quartz monzonite. Less than a mile to the northeast, however, another dike having the same general trend as the longer one is exposed for about a mile, and the two probably connect at depth. The dike pinches and swells, ranging in width from about 50 to 1,000 feet. Most of the dike is vertical but in the vicinity of St. Elmo it dips about 50° NW. The other large dike extends from the south side of Mount Aetna 4½ miles northeast to the border of the map, and Crawford (1913, pl. II) shows it extending about 2 miles farther, almost to Browns Creek. The southern dike on the east side of Jennings Creek is apparently a branch from the main dike, the junction of the two being concealed beneath glacial moraine a few thousand feet northeast of Shavano. The main dike dips steeply northwest, and the width ranges from 200 to 600 feet.

The Mount Aetna quartz monzonite porphyry is the coarsest grained porphyry in the Garfield quadrangle and is readily distinguished in the field from all other rocks. It is light, medium, or pinkish gray, and weathered surfaces are generally dull gray with local buff to brown iron-stained areas. Large pink and white feldspar phenocrysts are especially conspicuous. The largest and most abundant phenocrysts are pink or rarely gray, subhedral or euhedral crystals of orthoclase ½ to 1 inch long. A few are zoned, with a white border about a pink core, and carlsbad twins can be detected in some. White plagioclase (andesine) phenocrysts average much smaller than those of orthoclase and commonly range from ⅛ to ½ inch in length, although a few reach lengths of 1 inch or more. Some show carlsbad and albite twinning in hand specimens. Most of the plagioclase crystals are somewhat irregular in outline, and a few are rounded and embayed. The groundmass of the large pink and white feldspar phenocrysts is a granular aggregate of medium-grained minerals which in turn occurs in a groundmass of very fine grained material. The medium-grained aggregate consists of plagioclase, quartz, biotite, hornblende, and sphene, all of which can generally be recognized in hand specimens.

Deviations from the typical lithology of the Mount Aetna porphyry are slight and are chiefly expressed by a greater proportion of groundmass and by smaller phenocrysts. The dikes commonly contain somewhat more hornblende than the porphyry in the stocks, and the groundmass is a little finer grained. In parts of the dikes, pink feldspar crystals, some of which attain lengths of 2 to 3 inches, locally show parallel or subparallel orientations; their long axes are alined with the strike of the dike and plunge at low angles toward the main stock. This orientation can be seen especially well in the wide dike exposed on the north side of Brittle Silver Basin. A few small, fine-grained, dark, rounded or oval segregations are widely scattered in the Mount Aetna porphyry, and inclusions of the older rocks, particularly quartz latite porphyry, occur locally near the margins of the larger masses. No pegmatite or aplite dikes genetically related to the porphyry were found. The Mount Aetna porphyry somewhat resembles the Lincoln porphyry of the Leadville region, but the Mount Aetna is coarser than most specimens of the Lincoln seen by the authors.

Large feldspar phenocrysts are rarely found in the Mount Aetna porphyry near the contact with the older rocks, and this suggests that they were not of intratelluric origin, although the parallelism of the phenocrysts in parts of the dikes indicates that some movement of the magma occurred locally before complete solidification. The large phenocrysts and coarse texture indicate a magma of low viscosity, probably rich in mineralizers, and suggest that cooling was slow.

The Mount Aetna porphyry of Tertiary age is clearly younger than the quartz latite porphyry, as shown above, but it is older than the volcanic breccia, which contains a few fragments of Mount Aetna porphyry on the west side of the Continental Divide about half a mile south of Monumental Peak.

Microscopic examination of the typical Mount Aetna porphyry shows that the plagioclase is calcic andesine, and some crystals are zoned. Quartz occurs both as embayed phenocrysts and as part of the groundmass, and it is also occasionally intergrown with orthoclase. Orthoclase phenocrysts contain inclusions of biotite, hornblende, plagioclase, and sphene. Orthoclase also constitutes a large part of the groundmass. Biotite and hornblende are common in the groundmass as are much smaller amounts of sphene, black iron oxide, zircon, and apatite.

The following table, taken from Crawford (1913, p. 158–159), furnishes a chemical analysis and calculated mineral composition of the Mount Aetna quartz monzonite porphyry from Clover Mountain.

Chemical analysis and calculated mineral composition of Mount Aetna quartz monzonite porphyry

CHEMICAL ANALYSIS [R. M. Butters, analyst]		CALCULATED MINERAL COMPOSITION [By R. D. Crawford]	
SiO_2	66.71	Quartz	21.84
Al_2O_3	15.04	Orthoclase	32.42
Fe_2O_3	.92	Plagioclase	30.35
FeO	1.74	Biotite	7.95
MgO	1.53	Hornblende	3.60
CaO	2.92	Magnetite	.70
Na_2O	3.37	Ilmenite	.76
K_2O	5.04	Titanite	1.37
H_2O-	.34	Apatite	.31
H_2O+	.43		
TiO_2	1.29		99.30
ZrO_2	none		
P_2O_5	.20		
Cl	.04		
MnO	.46		
	100.03		

ORIGIN AND INTERRELATIONS OF THE INTRUSIVE ROCKS

As a result of regional studies extending far beyond the Garfield quadrangle Crawford (1924) has postulated, quite logically, that the Mount Princeton batholith and several other smaller bodies of quartz monzonite are probably merely the exposed upper irregularities in the roof of a much larger batholith of quartz monzonite that underlies the region extending from the Monarch and Tomichi districts northeast to Montezuma—a distance of about 85 miles. Within and bordering this region Crawford likewise noted similarities among various porphyries, quartz diorite bodies, and other relatively small intrusive bodies, which led him to the conclusion that many of these smaller bodies, as well as the quartz monzonite batholith, belong to a single petrographic province. He has shown that some of the bodies were emplaced before the batholith and that others followed its emplacement.

The present study of the Garfield quadrangle furnishes additional data regarding the origins and interrelations of the intrusive rocks in this part of the petrographic province. In the age sequence of the Tertiary intrusive rocks from the early quartz diorite porphyry through the Mount Antero granite it is notable that there are three groups of rocks each showing a general progressive change from basic or intermediate composition to more acidic types. This grouping is based largely upon a change in chemical composition as related to age in each group and is shown by the reappearance of granite, rhyolite, or quartz monzonite immediately preceding an intermediate to basic intrusive type, such as andesite or quartz diorite. The uncertainty of the relative ages of a few of the igneous bodies, particularly some of the smaller intrusive ones, might change their positions slightly in the age sequence, but the age relations already established are sufficient to define the main series. The above three series of intrusive rocks that range in composition from basic or intermediate types to acidic ones strongly suggest that differentiation in the magma reservoir took place at depth and probably extended over a long period of time. It is likely that all these bodies were originally derived from an underlying batholith as postulated by Crawford and stated above; however, an additional explanation is necessary to account for the three series of compositional changes. A likely explanation is that parts of the magma were separated from the batholith, perhaps as a result of early tectonic movement, and differentiation took place in the separated magma reservoirs independently from the main batholith.

In these comparatively shallow reservoirs differentiation by subtractive processes of crystal settling or crystal zoning during fractionation (Bowen, 1928) and a later filter press mechanism (Harker, 1909, p. 323), which removed part of the partially crystallized body, could have occurred several times. In the Front Range of Colorado Lovering and Goddard (1938) explain a differentiation series from diorite through quartz monzonite to granite porphyry by subtractive differentiation in relatively shallow hearths. In support of part of this theory as applied to the rocks exposed in the Garfield quadrangle, it has been shown that some of the intrusive bodies, especially in the Tincup and Quartz Creek districts, were emplaced both before and after two major periods of faulting, and furthermore that emplacement of the Mount Princeton batholith followed the most intense period of Tertiary deformation. There is evidence of a sort to indicate that this threefold differentiation and emplacement occurred over a long period of time. The variations in rock texture, such as fine, coarse, and porphyritic, suggest intrusion under variable temperature and pressure conditions, although the part played by mineralizers in the magma may have been an important factor in determining the type of texture in the rock. Temperature and pressure conditions were likely influenced by such factors as faulting, uplift, and prolonged periods of erosion, which in total probably extended over a long period of time.

TERTIARY EXTRUSIVE ROCKS AND TUFF

Two types of extrusive rock and a water-laid tuff of Tertiary age crop out near the south-central part of the Garfield quadrangle in the vicinity of Brittle Silver Basin and in the Tomichi mining district. The extrusive rocks are a volcanic breccia and a flow breccia, which are equivalent to rhyolites or quartz latites in composition.

VOLCANIC BRECCIA

Volcanic breccia is confined to a small area less than 2 miles wide in the Tomichi district, where it extends from Vulcan Mountain on the Continental Divide to Tomichi Valley. The largest continuous body lies high on the west slope of Vulcan Mountain and surrounds or partly surrounds large masses of broken and metamorphosed Paleozoic sedimentary rocks. In many places the boundary between volcanic breccia and the adjoining broken sedimentary rock must be drawn arbitrarily. Most of the area shown as landslide north of Fort Scott Gulch consists of slumped blocks and masses of volcanic breccia, and at many other places in this general area there are breccia patches too small to show on the geologic map. The contacts of the breccia cut irregularly across several types of rock, but at no place could the dip of the contact be determined.

The typical breccia has a dense, light to medium greenish-gray matrix surrounding angular or subangular inclusions of rocks of many types. Although the inclusions range from minute particles to masses several hundred feet long, the most common and conspicuous sizes range from 1/8 inch to 2 inches. Greenish-gray to dark-green fragments of altered rock of the Belden shale and Minturn formation are especially conspicuous. The character of other fragments varies locally, but within a short distance it is usually possible to recognize inclusions of pre-Cambrian granite, quartz monzonite, quartzite, limestone, shale, hornfels, chert, iron-stained quartz, and pink feldspar.

Microscopic examination shows that the matrix is largely glass and broken grains of orthoclase, plagioclase, and some quartz. Some of the less altered plagioclase grains are oligoclase, but most are too altered for accurate determinations. Chlorite, epidote, a clay mineral, and calcite are common alteration products. The composition of the matrix is probably that of a rhyolite or quartz latite.

Fragments of the Mount Aetna porphyry in the volcanic breccia establish that the volcanic breccia is younger than this porphyry. The volcanic breccia now exposed is extrusive, and it probably represents the first major extrusion in the Garfield quadrangle.

FLOW BRECCIA

Brittle Silver Mountain, on the divide between Tomichi and Middle Quartz Creeks, is capped by an erosional remnant of flow breccia that does not occur elsewhere in the mapped area. The remnant is nearly circular, has a diameter of almost 1,000 feet, and a thickness of about 200 feet. Most of the flow breccia rests on an irregular but gently north-dipping surface of iron-stained and chloritized Mount Princeton quartz monzonite, but the eastern part rests for a short distance on the Mount Aetna porphyry. The flow structure is pronounced, and, although locally irregular and wavy, it is about horizontal. Good exposures are uncommon except in the high and difficultly accessible cliffs on the south side.

The typical flow breccia is a pinkish-gray rock consisting of many small angular particles of rock and mineral in a streaky aphanitic matrix. The particles constitute about half the rock and most of them range from 1 to 3 mm long, although a few are as much as an inch. Those most commonly seen in hand specimens are dark dense porphyry, hornfels, quartz, white and pink feldspars, chlorite, epidote, and hornblende. The hornfels, porphyry, and some of the feldspar and epidote are included foreign material, but the others—quartz, chlorite, and hornblende—are, in large part at least, related to the magma and are typically contained in a streaky groundmass of fine-grained and glassy rock. Microscopic examination shows that the matrix is glass in which are abundant phenocrysts, chiefly of oligoclase, orthoclase, and some quartz and biotite. The composition is probably that of a rhyolite or quartz latite. The pronounced flow structure, pinkish color, and small size of the fragments in the flow breccia distinguish it from the volcanic breccia described above. The character of the flow breccia, its probable originally small areal extent, and its proximity to a much larger mass of volcanic breccia to the south, strongly indicate, but do not prove, that the flow is closely related genetically to the volcanic activity that produced the volcanic breccia. The flow breccia likely represents the last, relatively quiet stage of this volcanism.

WATER-LAID TUFF

Small erosional remnants of flat-lying water-laid tuff are poorly exposed near the mouth of Deadman Gulch, along the extreme southern border of the Garfield quadrangle. The tuff is exposed on the north side of the road cut immediately west of Deadman Gulch, and at several places along the slope to the north, tuff remnants rest on the Silver Plume(?) granite. Only a small patch of this tuff lies within the Garfield quadrangle, but a short distance to the south it is exposed in horizontal beds at many places in road cuts along the old Monarch Pass road and the road to Sargents. The highest exposure of tuff on the old Monarch Pass road is about 225 feet above the beds at Deadman Gulch; this indicates that the tuff was originally at least this thick before erosion. Along the main road to Sargents, which follows the east side of Tomichi Valley, tuff beds can be seen in road cuts as far as 5 miles south of the exposure at the mouth of Deadman Gulch. Reconnaissance along the lower slopes on the west side of Tomichi Valley disclosed that the tuff beds have been largely eroded on this side of the valley; the only outcrop seen was near the floor of the valley a few miles south of Deadman Gulch. The beds in all exposures observed are horizontal or else dip only a few degrees, generally toward the valley floor.

The tuff is a poorly consolidated, dull-white to light-gray, fine-grained, thin- and well-bedded rock that contains many fossiliferous beds and lenses a fraction of an inch to 2 inches thick. A few large fragments of older rocks are present locally in lenses or as isolated cobbles. These are generally subangular and rarely exceed 6 inches in length; they are mostly pre-Cambrian crystalline rocks, although one exposure in a road cut on the old Monarch Pass road reveals fragments of a fresh quartz monzonite porphyry that is different from any rock observed in the mapped area to the north. Thin sections of the typical tuff show that about 65 percent of the rock is a dense mixture of glass and calcite; the rest consists of anhedral grains, 0.02 to 0.15 mm long, of quartz and minor sodic andesine, with a little orthoclase, biotite, hornblende, epidote, and chlorite. The rock is probably of rhyolitic or quartz latitic composition.

Fossils collected near Deadman Gulch were identified by T. C. Yen of the U. S. Geological Survey as broken fragments of the genera *Lymnaea* and *Fluminicola.* These gastropods, according to Yen, represent a fresh-water environment of late Tertiary, possibly Pliocene, age.

The tuff beds lie within and immediately north of the area shown on the geologic map of Cross and Larsen (1935, pl. 1) as "undifferentiated volcanics mostly of pre-Conejos age, but include some Conejos and some Sheep Mountain." The age of these rocks as shown on their map is Miocene(?). The water-laid tuff beds, however, are probably younger than the large area of volcanic rocks shown by Cross and Larsen, and as the fossils indicate, are probably of Pliocene age. Reconnaissance in Tomichi Valley suggests that the tuff beds rest on the Miocene(?) undifferentiated volcanic rocks, although no definite and clear-cut relation could be found. During Pliocene(?) time a large fresh-water lake evidently occupied Tomichi Creek valley, at least from Sargents northward for 6 or 8 miles to Deadman Gulch.

AGE OF IGNEOUS ROCKS

The exact geologic age or ages of the various intrusive and extrusive rocks in the Garfield quadrangle that have been described in this report are not known. On plate 1 they are shown as Tertiary in age without question even though the youngest strata that some of these bodies cut are of Pennsylvanian and Permian(?) age, except for one monzonitic dike in the southwestern corner of the quadrangle which cuts the Mancos shale of Late Cretaceous age (pl. 1). However, an unquestioned Tertiary age for the intrusive and extrusive rocks seems justified because of the widespread occurrence of many similar igneous bodies in western and southwestern Colorado that are of known Tertiary age (Emmons, 1894; Cross and Larsen, 1935), and others that are shown on geologic maps as of Tertiary age even though they cut rocks older than Paleocene (Burbank, Lovering, Goddard, and Eckel, 1935; Vanderwilt, 1937, pl. 1).

In the Garfield quadrangle an early stage of intrusion has been postulated for the quartz diorite porphyry, Tincup porphyry, and rhyolite by their relation to structures that formed before the main period of thrust faulting. Crawford (1913, p. 75) believed that the quartz diorite (part of this early intrusive group) is one of the oldest, if not the oldest, of the intrusive rocks of the Monarch and Tomichi districts by correlating it with a similar diorite in the Elk Mountains (Emmons, 1894) which is of post-Laramie age. In the present report the authors have tentatively shown (pl. 1) that the 11 main intrusive bodies from quartz diorite porphyry through Mount Aetna quartz monzonite porphyry range in ages from Paleocene to Oligocene. This age range is based upon the assumption that these intrusive bodies required a considerable amount of time for emplacement, as indicated by the fact that some preceded and others followed the major period of thrust faulting, and that sufficient time elapsed to permit three periods of mineralization and possibly three main periods of magmatic differentiation.

As previously pointed out by Crawford (1913, p. 75–76), the extrusive bodies of rhyolitic breccias are considerably younger than the intrusive bodies, for they were erupted after erosion had removed much of the probably thick original cover of the plutonic bodies in the northern part of the Tomichi district (pl. 1). The breccias are therefore tentatively assigned to a younger epoch, the Miocene, partly on the basis of an erosion interval and partly because the Miocene epoch elsewhere in Colorado, particularly in the southwestern part of the State, was characterized by extensive flows and breccias, some of which are rhyolite (Cross and Larsen, 1935, p. 50–54). Fossils in the water-laid tuff strongly indicates that these beds were deposited during the Pliocene epoch.

QUATERNARY DEPOSITS

GLACIAL MORAINE

Glacial moraine is widespread in the Garfield quadrangle, and the floor and lower slopes of almost every long valley are at least partly covered by it. The moraines are by far the most common in and along the sides of long U-shaped valleys, although there are several areas where patches of morainal debris are high up on the slopes or on top of ridges. Although considerable care and time were spent in outlining the areas of moraine, only major areas of continuous or nearly continuous moraine are shown; and great preference has been given to showing bedrock geology rather than the surficial deposits, particularly in many of the high glacial valleys. The most extensive glacial deposits are in the valleys and tributaries of Chalk Creek, West, Middle, and East Willow Creeks, North and Middle Quartz Creeks, Tomichi Creek, Fooses Creek, and North Fork of the South Arkansas River. Some of the higher deposits are in hanging valleys, such as those north of Chalk Creek a few miles east of St. Elmo, or in broad basins such as the areas around Waterdog Lakes, west of Monarch, and north of Halls Gulch, in the western part of the quadrangle.

The surface of many of the moraines is uneven with kettles, hummocky knobs, and lake basins, although very large areas are merely thin deposits spread out on the valley floors and extending high up on the sides of the glacial valleys. In general the thicknesses as disclosed in prospects and shafts are not great, generally less than 20 feet. Crawford (1913, p. 29) states that the greatest thickness on record (in part of the area covered in this report) is 56 feet cut by a shaft west of Monarch, and no greater thickness than this was found by the authors elsewhere in the quadrangle. The material composing the moraines is chiefly subangular fragments of the various rocks along the course of each individual glacier, although in most places Mount Princeton quartz monzonite and pre-Cambrian granite predominate.

Most of the glacial deposits are ground moraine and only in a few places do distinct topographic forms of end or lateral moraines occur. Mirror Lake, northeast of the Tincup district, formed behind an end moraine of a small glacier that moved north down East Willow Creek valley. No end moraine is preserved in Tomichi Valley although the large glacier that occupied this valley probably terminated near the present junction of Canyon and Tomichi Creeks. The end morainal material here was undoubtedly carried away by melt waters flowing through the narrow outlet of the bordering steep-walled canyon. Most of the large glaciers terminated beyond the borders of the mapped area. Locally, remnants of lateral moraines bulge out along the valley walls and in places block older stream-cut tributary valleys, but generally these ridges have slumped toward the valley floor.

GLACIOFLUVIAL DEPOSITS

Glaciofluvial material deposited by streams fed by former glaciers is present in some of the glacial valleys, but, except where these deposits are fairly broad belts of considerable extent, they have not been delineated on the geologic map. North of Cumberland Pass the road to Tincup is in glaciofluvial material for several miles along West Willow Creek, and farther north, beyond the limits of the map, the glacial outwash debris spreads out into a very much wider belt that extends from Tincup northwest into Taylor Park. The upper part of the deposit along West Willow Creek is well exposed in a road cut about 1,500 feet south of the north border of the map. Here the deposit is at least 50 feet thick and consists largely of rounded to oval-shaped pebbles and cobbles of gneissic granite ranging from 1 to 8 inches long, with a little sand and silt, and a few boulders as much as 3 feet long. Limestone, dolomite, marble, chert, and porphyry are minor constituents of the deposits.

LANDSLIDES

Three fairly large areas of landslide occur in the mapped area, and all show the typical hummocky landslide topography. The largest area about 2 miles northeast of Whitepine, extends in a northerly direction a little more than a mile. Here rock on the lower slope of Monumental Peak has slid west or southwest toward Tomichi Creek. The rock is chiefly a mixture of volcanic breccia, Paleozoic sedimentary rocks, and pre-Cambrian granite. Several small prospect pits were dug in parts of this slide material, chiefly in blocks of mineralized sedimentary rock that had slid westward from the mineralized area immediately north of Fort Scott Gulch.

Two fairly large areas of landslide are shown on the geologic map near South Fork of South Cottonwood Creek, in the northern part of the quadrangle. The smaller area is a chaotic mass of Mount Princeton quartz monzonite; the larger area consists of black schist and Mount Princeton quartz monzonite that slid from the steep slope of Emma Burr Mountain toward the cirque at the head of South Cottonwood Creek. In both the Cottonwood and Tomichi regions the landslides resulted from slippage along steep slopes that had been formed locally by the alpine glaciers.

On Monarch Ridge, particularly southeast of the Madonna No. 6 portal, some large masses of sedimentary rock have slid northwest down the hill. One such mass is especially noticeable a few hundred feet up the slope from the Madonna portal, where steeply dipping beds of the Devonian Chaffee formation overlie steeply dipping beds of Ordovician age cut in the tunnel a short distance below the surface.

TALUS

Talus is present on many of the steep slopes. The larger areas that are completely covered by talus are delineated on the geologic map, but many small areas and a few of the larger ones where there is little doubt regarding the character of the underlying rock are not shown, as the purpose of this investigation was to map bedrock insofar as possible. The largest area of talus extends for several miles in an easterly direction on the north slopes of Taylor Mountain and Missouri Hill. Small rock glaciers occur at a few places; the largest is about a mile east of Cumberland Pass, in the northwest part of the quadrangle, where a crescent-shaped area about half a mile wide, with characteristically hummocky surfaces, consists of large and small angular blocks of Tincup porphyry. Talus cones and rock streams are likewise common. Talus cones are conspicuous along Chalk Creek valley east of St. Elmo. A very prominent rock stream that can be seen from far away extends as a narrow belt down a sharp valley on the south slope of Mount Aetna and at its base passes into a talus cone. Rock from the top of Mount Aetna has traveled down this rock stream for a distance of a little more than 1 mile and through a vertical distance of slightly more than 3,000 feet. The road up Middle Fork skirts the base of the lower part of the rock stream at an altitude of about 10,765 feet and here affords a striking view up this valley toward Mount Aetna.

ALLUVIUM

Alluvial deposits are uncommon, because the streams of this mountainous region have high gradients which favor erosion rather than deposition. The widest belt of alluvium is along Tomichi Creek at the southern boundary of the Garfield quadrangle where it attains a width of 4,000 feet although a short distance to the north the belt narrows to a few hundred feet. A small area of alluvium, derived from the easily eroded Mancos shale, borders Hot Springs and Stridiron Creeks in the extreme southwest part of the quadrangle. There are several places along Chalk, Fooses, West Willow, and Middle Quartz Creeks, where narrow belts of alluvium are present locally, but these are included on the geologic map with the glacial deposits. These alluvial deposits are only a few hundred feet wide at most, and they typically support a heavy growth of willows. Alluvial fans and cones are widely distributed. Remnants of older alluvium that probably formed during or shortly following the Pleistocene glaciation are preserved at a few places in small basins.

STRUCTURE

The structure of the rocks of the Garfield quadrangle is moderately complex with folds, faults, and fractures of diverse trends. The dominant structures trend northwest, and of these the most pronounced is a thrust fault of large displacement that extends diagonally across the quadrangle. Deformation occurred during pre-Cambrian, Late Cretaceous or early Paleocene (Laramide orogeny), and early(?) Tertiary. The structures are discussed on the following pages on the basis of the age of the rocks in which the structural features were observed.

STRUCTURE OF THE PRE-CAMBRIAN ROCKS

Only a very general examination of the structure of the pre-Cambrian rocks in the Garfield quadrangle was made, because a detailed study was not an objective of the present investigation. Such a study would have required at least two more field seasons of work, which was not warranted economically as most of the ore bodies are in Paleozoic sedimentary rocks or in veins in the Tertiary Mount Princeton batholith.

Remnants of the oldest group of pre-Cambrian rocks, the gneisses and schists, occur in three widely separated areas (pl. 1). The largest of these areas, the quartz-hornblende schist in the northwestern part of the quadrangle, is part of the northeast limb of a northwest-trending anticline that probably developed in large part during pre-Cambrian deformation and was later (Laramide) modified and cut off on the west by the Tincup fault and still later in the Tertiary period, on the east, by the Mount Princeton batholith. The eastern part of the schist dips, on the average, 45° NE., but the western side passes locally into broad open flexures that were probably formed during the later period of Tincup faulting. In the gneiss and schist area centering around Middle Quartz Creek the scattered foliation readings indicate broad steep folds that pass into smaller northwest-trending folds near the western border of the quadrangle. In the southeastern part of the quadrangle the gneisses and schists occur in two small areas separated by 3 miles of younger granites. The rocks in both areas are deformed and locally injected by intruded granitic bodies, and no structural correlation can be made between the two separated areas. In the southern area the foliation averages a northwest strike and moderate to steep southwest dip. The structural relation of the two areas to the wide belt of schists and gneisses that lies east of the quadrangle is not known, but exposures in many road cuts indicate that the rocks in this belt are complexly folded and faulted.

Among the granites of pre-Cambrian age, only the gneissic granite in the northwest part of the quadrangle shows foliation. This ranges from conspicuous to very faint, and in some fairly large areas it is absent. The few readings obtained show a northwest strike, with moderate to steep northeast dips. The foliation probably formed during the pre-Cambrian before the intrusion of the Pikes Peak and Silver Plume(?) granites, because the latter granites do not show strong foliation except local primary foliation near their borders.

STRUCTURE OF THE PALEOZOIC AND MESOZOIC ROCKS

The structure of the sedimentary rocks, particularly those of Paleozoic age, is complex. Folds and faults on both large and small scale are present in every large patch of sedimentary rocks from the Monarch to the Tincup district. Unraveling of the structure is complicated by the many unconformities within the Paleozoic system and made difficult by the many large areas of poor exposures. The unconformities cause considerable range in the thickness of the formations, and marked thickening or thinning of rock sections cannot always be attributed to faulting or folding.

Although the Paleozoic sedimentary rocks have been invaded by large Tertiary intrusive bodies and have been eroded to a series of discontinuous patches, enough of them remain to bring out clearly the dominant northwest trend of the folds and especially the faults (pl. 1). The major faults outline a broad zone that more or less coincides with the belt of sedimentary rocks. The fault zone, characterized by northeast-dipping reverse faults, extends diagonally across the Garfield quadrangle from southeast to northwest for at least 35 miles to the Aspen district (Burbank, Lovering, Goddard, and Eckel, 1935). Southeast of the Garfield quadrangle this fault zone, if present, is obscured in the pre-Cambrian rocks or hidden beneath Tertiary volcanic rocks for about 20 miles, but the northwest-trending fault in the Kerber Creek area west of Villa Grove, which brings pre-Cambrian rocks on the northeast against Carboniferous strata on the southwest (Burbank, 1932, pl. 3), may be the southern extension of the same major fault zone.

The Mesozoic rocks are preserved only in a small area in the southwest part of the Garfield quadrangle outside the belt of Tertiary intrusive bodies. They are also outside the belt of most intense deformation, although the moderate to steep dip of the beds on the northeast side of a syncline and the local strike faults show the area to be at least moderately deformed.

FOLDS

Several major folds can be recognized in the erosional remnants of the sedimentary rocks. The major period of folding which produced the fairly broad regional anticlines and synclines antedated the period of major faulting, although some of the minor cross-cutting faults and bedding slips are doubtless products of the period of folding. In this region where post-Paleozoic erosion has been profound, the folded strata now preserved are chiefly in the synclines or remnants of the limbs of downfaulted anticlines. In several areas large drag folds were formed along major faults, such as the Powderhouse, Lake, Hawkeye, Madonna, and Mayflower faults. These drag folds are primarily a product of the stage of faulting, although the faults themselves may have had their inception in earlier folds.

In the southern part of the quadrangle three synclinal folds are preserved in the area extending east from about Lake Hill in the Whitepine area to the eastern border of the map (pl. 1, section *C—C′*), and Crawford (1913, p. 88 and pl. II) shows two smaller ones 2 miles farther east, near Maysville. In the Whitepine area east of Lake Hill a gently north-plunging syncline is cut off obliquely at its northern end by the Morning Glim fault (pl. 1). In the block of sedimentary rocks centering around Garfield the major structure is essentially the east limb of a large syncline whose southern half passes into minor folds. The east limb is part of an older syncline than the present one. The western limb of the original large syncline has been cut off by the Lake fault, probably in the axial part of the original syncline, and the beds were dragged up on the east side of the Lake fault creating the sharp syncline of Syncline Hill. This sharp syncline is strikingly seen from many points, especially from the northern part of Monarch Ridge. This local structure, imposed upon the broader folded area, can be traced about a mile from South Arkansas River over Syncline Hill to a point southeast of Boss Lake Reservoir where it is obscured by glacial debris. At its south end this fold also passes under surficial deposits, and farther south it is lost in the confusion of faults on the lower west slope of Monarch Ridge, although the local steep westerly dip of the overturned beds adjacent to the Hawkeye fault may represent the southern part of the fold.

High on the mountain a mile southeast of Garfield, a synclinal fold has been preserved between two northwest-trending faults (pl. 1, section *C—C′*); the anticline between this fold and the northwest-dipping beds at the north end of Monarch Ridge has been removed by erosion south of Garfield, but evidence of this north-plunging anticline is reflected in beds preserved just north of Garfield, even though later faults have displaced the strata locally.

A broad anticline, probably with many small folds, once connected the strata of the Whitepine area with those of the Monarch-Garfield area. The crest of this anticline was probably not far from the Continental Divide, for a small patch of Sawatch quartzite and Manitou dolomite (too small to show on the geologic map) remains on the Continental Divide west of the largest of the Waterdog Lakes.

About 2½ miles northwest of Whitepine, at the head of Canyon Creek, is the southern end of a series of patches of Paleozoic strata that extends northwest more than 12 miles into the Tincup district. These strata dip northeast and form the northeast limb of a broad northwest-trending anticline, the southwest limb of which is partly preserved south and west of the junction of North and Middle Quartz Creeks. The Sawatch quartzite of the northeast and southwest limbs of this large fold is separated by about 3 miles in the area extending northeast from near this junction. Three miles north, in the area around Halls Gulch, the broad anticline passes into a series of smaller northwest-trending open folds cut by many faults, chiefly of the reverse type, and a little farther north, this fold unit is cut off by the Athens fault.

In the Tincup district the beds west of the Tincup fault dip northeast and form the northeast limb of a broad northwest-trending anticline, the probable southwest limb of which is exposed for a short distance at the extreme western border of the map about three quarters of a mile southwest of Cumberland Pass. The strata here are bordered on the east by a northerly striking fault, but west beyond the border of the map they pass into a small synclinal fold.

FAULTS

The individual faults and faulted areas are classified and described below with respect to major structural units and geographic location. The major divisions considered are the Tincup-Morning Glim fault zone, the Quartz Creek graben, the Bald Mountain area, and the Garfield region. The age relations of the various fault systems are summarized at the end of the discussion.

TINCUP-MORNING GLIM FAULT ZONE

The Tincup thrust fault in the northwest part of the quadrangle was first described by Stark (1934, p. 1004–1007). The Morning Glim reverse fault, in the southern part of the Tomichi district, was mapped by Crawford (1913, pl. II). The present investigation has shown that the Morning Glim fault is an extension of the Tincup fault zone and that the original fault has been cut out for 8½ miles by the Mount Princeton batholith, forming the two disconnected segments. In the discussion of the Mount Princeton quartz monzonite, it was noted that emplacement of the southwestern edge of the batholith was controlled in large part by the weak Tincup fault zone.

The Tincup fault strikes variably northwest but maintains a general N. 15° W. trend. The dip averages 30° NE. but ranges from 10° to 40°. With the possible exception of a small exposure near the point where the fault is cut by the Mount Princeton batholith, no exposures of the fault contact were found, and strikes and dips must be calculated from the relation of trace to topography. The Tincup fault extends for a little more than 5 miles along steep slopes west of the Continental Divide, in the northern part of the quadrangle. Dark quartz-hornblende schist (pre-Cambrian) has been thrust southwestward over sedimentary rocks of Pennsylvanian and Permian(?) age (pl. 1, section *A—A′*). If it is assumed that the Sawatch quartzite, before erosion, lay just above the schist as exposed on the hanging wall of the fault, the throw of the fault would be a minimum of 3,200 feet and the dip slip would be about 2 miles. However, both the throw and dip slip are probably very much greater, for it is likely that erosion has removed a thick section of pre-Cambrian rock and the basal Sawatch quartzite lay at a much higher position. This is indicated by the fact that a short distance north of the quadrangle boundary lower Paleozoic units are exposed along the Continental Divide at an altitude of about 13,000 feet.

The Tincup fault has no topographic expression except near the northern edge of the quadrangle, just south of where the fault disappears beneath glacial debris, where a sharp gulch about 6 feet deep and 500 feet long marks the fault.

The southern part of the Tincup fault zone, in the Tomichi district, is known as the Morning Glim fault. This fault cuts across a northerly trending syncline and brings pre-Cambrian granite in fault contact with beds that range in age from Ordovician to Pennsylvanian. Although the fault is exposed only at its southeastern end, where it dips 55° NE., its position can be determined fairly closely through most of the Tomichi district from distribution of float fragments and from many prospect pits and mines. None of the old mine workings are accessible, however, and the dip and character of the fault zone or fault surface cannot be observed. Locally the position of the fault in relation to topography suggests considerable variation in strike and dip, and in some places the dip may be vertical or steeply to the southwest. From Galena Creek north to the glacial deposits along Tomichi Creek, the fault trends N. 25° W., but south of Galena Creek the trend averages N. 45° W. About a mile east-southeast of Lake Hill, at the head of No Name Creek, the Morning Glim fault enters pre-Cambrian granite and disappears beneath slope wash where it could not be traced farther. The throw of the fault east of Lake Hill is a minimum of 2,300 feet. The fault zone is commonly marked at the surface by silicified and iron-stained country rock, in places as much as 200 feet wide.

The Star fault (pls. 1 and 5), ½ to 1½ miles west of the Morning Glim fault, is a northerly striking and eastward-dipping reverse fault along which pre-Cambrian granite has been thrust over the Paleozoic rocks of West Point Hill. This fault is of considerable economic importance because several profitable mines are situated along it, notably the Akron mine. The fault can be readily traced on the surface, chiefly by pits and old mine workings, from the glacial deposits high on Porcupine Ridge southward for a little more than 1 mile to a point a short distance south of the ridge between West Point Hill and Lake Hill, where it is cut by younger Mount Princeton quartz monzonite, although farther south it undoubtedly extends into the granite. The dip of the fault as determined from mine workings ranges from about 40° to 80° E. in the Akron mine, although locally the dip is steeply to the west. The throw of the fault diminishes from about 900 feet near where last seen to about 500 feet a short distance south of Galena Creek. Rhyolite porphyry dikes intruded part of the fault, but renewed movement occurred on the fault after intrusion. The fault is marked by a strong breccia and gouge zone in places attaining a width of 120 feet.

About a mile south of West Point Hill, two small patches of Sawatch quartzite are preserved on the west, or downthrow, side of a fault that strikes about N. 18° W. These two patches were delineated entirely by shallow prospect pits and float fragments. A definite fault was not observed, but the elongated outlines of the quartzite patches and strong iron stain along their northeast borders indicate that they are bounded by a fault rather than being merely erosional patches of quartzite resting normally on granite. This fault, as well as the Star fault, is undoubtedly a subsidiary fault of the Morning Glim zone and the Star fault may be a branch of the Morning Glim fault.

QUARTZ CREEK GRABEN

A large down-faulted block, here called the Quartz Creek graben, lies in the western part of the quadrangle in the vicinity of North Quartz Creek (pl. 1, section *B—B′*). The graben trends east and is bounded on the north by the Athens fault and 5¼ miles to the south by the Powderhouse fault. Both faults are cut off at their eastern ends by the northerly trending Tincup and Bald Mountain faults. The extent of the graben west of the Garfield quadrangle is not known, but reconnaissance along the trend of the Powderhouse fault indicates that this fault extends at least 2 miles farther west.

At no place can the Athens fault be seen at the surface, although several caved mine workings and slumped prospect pits mark its general course. The trend of the fault in relation to topography indicates a nearly vertical dip through all but the western part of its course where a moderate southerly dip is indicated. West of North Quartz Creek, the fault brings pre-Cambrian granite against Belden shale (Pennsylvanian); east of the creek the fault is concealed for a long distance under glacial debris and then enters a sharp valley which it follows east toward the intersection with the Tincup fault. This valley is the only local topographic expression of the Athens fault. The eastern part of the fault has a throw between 1,500 and 2,000 feet; in its western part the minimum throw, as indicated in section *B—B′*, plate 1, is about 1,400 feet.

The Powderhouse fault, situated at the south side of the graben, trends eastward along the south side of Powderhouse Gulch. The fault is everywhere concealed, but bordering outcrops delineate its position fairly closely. Locally, drag along the fault has tilted the beds steeply to the northeast. Pre-Cambrian granite and lower Paleozoic strata on the south side of the fault have been brought into contact with beds of the Minturn formation. The fault probably dips steeply north, and the throw is a minimum of 3,000 feet.

A series of northwest-striking reverse faults cuts the pre-Cambrian granite and folded Paleozoic units on the mountain south of Halls Gulch, repeating the lower units at four places. The fault 1 mile east of the western border of the map offsets the Sawatch quartzite a little more than 3,000 feet horizontally, and the others show offsets ranging from 100 to 2,000 feet. These faults probably formed as a result of compressive stresses acting on the earlier folded rocks as they were being wedged between the Athens and Powderhouse faults.

FAULTS OF THE BALD MOUNTAIN AREA

The Powderhouse fault is cut off on the east by the Bald Mountain fault which trends north and in turn is offset by the younger, northeast-trending Stridiron fault (pl. 1). The Bald Mountain fault dips west at an unknown but probably fairly steep angle and brings rocks of pre-Cambrian age on the east in contact with Paleozoic units on the west through most of its length. At its north end it is concealed by the broad belt of glacial deposits in Middle Quartz Creek valley, and its southern extension into the granite could not be traced far. North of the junction with the Powderhouse fault, the throw of this fault is at least 3,000 feet. The nearly vertical Stridiron fault, south of Bald Mountain, strikes about N. 45° E., and extends from the upper valley of Stridiron Creek northeast for at least 1 mile and then apparently dies out in pre-Cambrian gneiss. This fault offsets the Bald Mountain fault and lowers the Paleozoic rocks on its southeast side about 600 feet.

FAULTS OF THE GARFIELD REGION

Faults in and bordering the large area of folded Paleozoic rocks centering around Garfield have a dominant northwest strike, although the fault with the greatest displacement in this area, the Lake fault, strikes nearly north. In addition to the faults shown on the geologic map, there are many small ones, chiefly bedding slips. There has also been some movement almost everywhere along the contact between the Manitou dolomite and the underlying crystalline rocks, but most, if not all, of this movement probably took place during the period of folding and before the main period of faulting.

Two of the chief faults in this area are the Madonna and Mayflower, which bound a narrow fault block. These two faults are of special economic importance because the ore bodies of two large and rich mines, the Madonna and Eclipse, were concentrated along them. The Madonna fault is mainly a reverse fault with a steep southwest dip, although locally the dip is northeast. Its maximum throw of about 350 feet occurs at a point about 750 feet southeast of the Madonna No. 6 portal, and the throw diminishes markedly to the southeast. The Mayflower fault is concealed by slope wash and talus throughout most of its course up the slope of Madonna Ridge and little is known about it other than what can be seen in one short drift in the Madonna mine and what can be learned from the records of old mines now inaccessible. In the Madonna mine the fault dip ranges from 85° NE. to 60° SW. and averages vertical. Crawford (1913, p. 93) states that the Mayflower fault was seen by him in a prospect tunnel above the Madonna No. 5 tunnel where the strike is N. 50° W., and the dip 70° SW. The position of the strata bordering the Mayflower fault indicates a hinge fault because a slight offset of the beds on the southwest side of the fault indicates that they are down at the southeastern end and a marked offset at the northwestern end indicates that here the beds are up.

The Lake fault, west of Monarch, can be traced 1½ miles from the glacial debris along South Arkansas River north across Syncline Hill to a point about 1,200 feet north of Boss Lake Reservoir, where it is cut off by the Mount Princeton quartz monzonite. The fault brings pre-Cambrian granite on the west against Paleozoic units that dip steeply east. The lower beds have been greatly reduced in thickness, probably by squeezing. The fault is not exposed at the surface, but Crawford (1913, p. 91–92) saw it in the Monarch Contact tunnel (inaccessible in 1951) where the dip ranges from 56° to 80° W. This is accordingly a reverse fault and the throw is a minimum of 3,500 feet west of Syncline Hill.

There is a possibility that the Lake fault continues a long distance south under the glacial deposits of the South Arkansas River valley, but it is more likely that the Hawkeye fault is the southern extension of the Lake fault. Records of diamond drilling done in the Madonna No. 6 mine workings suggest that the Madonna fault is offset by the Hawkeye fault. Surface mapping indicates that the Hawkeye fault is, in turn, offset to the northwest by the Mayflower fault; thus the Hawkeye might very logically be the offset southern part of the Lake fault, as indicated on the geologic map.

About 2 miles north-northeast of Garfield, near the head of Cree Creek, the sedimentary rocks are apparently offset about 1,000 feet by a northwest fault that is concealed beneath the glacial debris in the valley (fig. 8). The offset of the sedimentary rocks on the slopes of the valley is too great to be explained entirely by a fold as suggested by Crawford (1913, p. 125).

STRUCTURE OF THE TERTIARY ROCKS

A relatively mild type of deformation compared to the Laramide orogeny is believed to have occurred in early(?) Tertiary time soon after the emplacement of the Mount Princeton batholith. The chief effects of this deformation are a series of dominantly north- to northeast-trending fractures that are especially abundant in the eastern half of the quadrangle in the Mount Princeton quartz monzonite and rocks older than the quartz monzonite. Many of the fractures were later filled by vein material and a few by dikes. The moderate to steep dip of the fractures indicates that they were formed by dominantly vertical forces. The strike of the fractures suggests that the directions in which the opposing horizontal forces acted were chiefly northeast and southwest.

The absence of widespread and large displacement of the vein-filled fractures and offset of contacts between younger intrusive bodies indicate that significant deformation ceased after the early(?) Tertiary movement.

STRUCTURAL CONTROL OF THE TERTIARY INTRUSIVE BODIES

The size, shape, and position of some of the Tertiary intrusive bodies have resulted from structures that formed before the emplacement of the magmas. The two main kinds of structures affecting the intrusion are faults and fractures of probable early Tertiary age and the much older foliation of the pre-Cambrian schists and gneisses. Some of these structures produced large-scale effects, but others produced relatively minor features. One of the most outstanding examples in the Garfield quadrangle of a structure that guided the invading magma was the Tincup-Morning Glim fault zone. This fault, which has a large displacement and which probably shattered the bordering rocks over a wide zone, was an easy conduit for the southwestern part of the Mount Princeton batholith. Here the fault zone has been rather closely followed for a distance of 8½ miles from Whitepine to a point 3 miles southeast of Cumberland Pass (pl. 1). Another fairly large body of igneous rock that has been irregularly emplaced along a fault is the elongated body of Tincup porphyry 1 mile south of Cumberland Pass, which extends from the western border of the quadrangle east for 2 miles. Two examples of smaller intrusive bodies along faults occur south and southwest of the Athens fault in the same region as the elongated body (pl. 1). The northern small body follows a northwest-trending fault, probably for about 1,000 feet, before branching away from the fault. The southern intrusive body apparently was emplaced near the northwestern end of one of the reverse faults near Halls Gulch. Here the part of the intrusive body now exposed does not have the pronounced elongated shape as do the other two bodies of the same porphyry to the north. Perhaps strong fractures normal to the strike of the fault may have caused the relatively blunt termination of the body against the fault. The Star fault in the Tomichi district (pls. 1 and 5) was the governing structure along which a thick rhyolite porphyry dike was emplaced. This relation is especially well observed in the Akron mine (pl. 7) where the dike in large part fills the fault zone although locally it deviates from the main fault.

In the east-central part of the quadrangle several Tertiary intrusive bodies form conspicuous belts, 1 to 1½ miles wide and 4 to 6 miles long, that trend N. 50° to 60° E. (pl. 1). The bodies that show this trend are andesite, Mount Antero granite, gneissic quartz monzonite, Mount Pomeroy quartz monzonite, and a wide and long dike of Mount Aetna porphyry. A conclusive explanation is not at hand to account for this marked northeast trend of so many separate intrusions. However, the northeast foliation in the pre-Cambrian rocks to the southeast along the valley of North Fork may reflect a similar trend in the older rocks to the north that lie beneath the northeast intrusive belt. These foliation planes, if present under the intrusive bodies, could have yielded weak northeast-trending zones along which the earliest of the Tertiary intrusive bodies (gneissic quartz monzonite and Mount Pomeroy quartz monzonite) were emplaced. Emplacement of some of the younger group of Tertiary intrusive rocks (andesite, Mount Antero granite, and dike of Mount Aetna porphyry) was also probably controlled in part by the northeast foliation in the crystalline rocks in this area and also by the positions of the earlier emplaced northeast-trending bodies (pl. 1), notably the andesite intruded between the older Mount Pomeroy and gneissic quartz monzonite bodies. Besides the foliation planes, it is likely that northeast-trending fractures in the invaded rocks played a large, if not the main, part in controlling the trend of the intrusive bodies. No detailed study was made of the fracture patterns in the surrounding pre-Cambrian rocks, but a similar northeast trend of some dikes in the older rocks to the south suggests such a cause.

Bedding planes in the Paleozoic strata controlled the emplacement of some Tertiary intrusive bodies, such as the sill of Tincup porphyry between the Leadville limestone and Belden shale along South Quartz Creek valley. In the Tincup district, to the north, the structure that controlled the emplacement of the main stock of Tincup porphyry could not be determined, but part of the western side of the porphyry was emplaced along bedding planes in the Paleozoic strata.

CHRONOLOGY OF MAIN PERIODS OF LATE CRETACEOUS AND TERTIARY FAULTING AND INTRUSION

Several relations between the larger fault systems and the principal intrusive bodies afford some idea of the sequence between major periods of deformation and intrusion. The first period of strong faulting produced the east-trending Quartz Creek graben, and the Tincup porphyry was later intruded into it. The next period of deformation probably came after the intrusion of the rhyolite and quartz diorite and was the most intense. It was marked by strong northeast-southwest compressive forces that thrust pre-Cambrian crystalline rocks southwest over upper Paleozoic sedimentary rocks and formed the Tincup-Morning Glim fault zone and probably the Bald Mountain fault. It is believed that the Tincup deformation cut off the eastern end of the earlier Quartz Creek graben, even though the offset parts of the graben faults could not be found east of the Tincup fault. This apparent absence of the offset graben faults is readily explained by the very poor exposures in the pre-Cambrian rocks and the later obliteration of large areas of pre-Cambrian rocks by the Mount Princeton batholith (pl. 1). The Tincup deformation was followed by a period of adjustment or settling of the displaced blocks during which the Stridiron, and also probably the Lake-Hawkeye faults, were formed with principally northerly or northeasterly trends. Succeeding this period of adjustment several small stocks and the Mount Princeton batholith were emplaced. The batholith engulfed and obliterated structures in the older rocks over a large area, and, around its margins, it invaded all types of rock, locally forming minor faults. Following crystallization and at least the partial cooling of the Mount Princeton batholith, fissures were formed and many of these were later filled by dikes and veins, which extend as a prominent belt northeast for 13 miles from upper Tomichi Creek valley nearly to the northeast corner of the quadrangle (pl. 1). The Mount Antero stock was emplaced after the Mount Princeton batholith and its related dikes and veins were formed. Still later small stocks of quartz latite porphyry and Mount Aetna porphyry were intruded about 2 miles west of the Antero stock, and probably at a considerably later time in this same area volcanic breccia and flows emerged on the eroded surfaces of the quartz latite and Mount Aetna stocks. No major deformation is known to have occurred in the Garfield quadrangle after the Tincup period of faulting, although minor movement probably took place locally along many of the earlier faults and fissures.

CONTACT METAMORPHISM

The Mount Princeton quartz monzonite, of all the many Tertiary intrusive rocks, is the only one that produced widespread and pronounced contact metamorphic effects on the Paleozoic sedimentary rocks, and the following descriptions apply to this period of metamorphism.

By far the most pronounced effect of the Mount Princeton intrusion on the sedimentary rocks is a recrystallization, or marbleization, of the limestone and dolomite beds of the Manitou, Fremont, Chaffee, and Leadville formations. Except in a few small areas, these strata lying within half a mile of the main batholith or its large eastern apophysis are marbleized, and in the Taylor Gulch area pronounced marbleization extends as far as 1½ miles from the outcrop of the quartz monzonite. The limy beds of the Belden and Minturn formations are, on the average, far less marbleized than older ones, for reasons explained in a later paragraph. The areas of strongest metamorphism are the upper part of Cree Creek valley, the head of Taylor Gulch, the western part of the Whitepine area, and the eastern edge of the belt of sedimentary rocks extending from near Stella Mountain 7½ miles northwest to Graphite Basin.

The marble ranges from fine grained to very coarse grained. Although there are many exceptions, generally the Leadville and Chaffee formations are coarser grained and more thoroughly marbleized than the Fremont and Manitou formations. The marble is predominantly white, although locally bluish, buff, gray or black. The latter is graphitic marble. The purest marbles are composed only of calcite or dolomite grains, but in many places, particularly in Taylor Gulch and near the head of South Quartz Creek, silicates are present. Wollastonite occurs in the limestone marble at the Garfield quarry in bunches with a radiating structure. Serpentine is locally abundant, especially in the area from Stella Mountain northwest to the divide between Middle and South Quartz Creeks. It was formed mostly from the alteration of dolomite, although part of it on Stella Mountain was derived from olivine, an earlier metamorphic mineral, as shown by remnants of olivine that accompany some of the serpentine. The large inclusion of marble in quartz monzonite on the south slope of Stella Mountain (pl. 1) shows serpentine associated with olivine, magnetite, calcite, and garnet. Much serpentine occurs as veins or irregular patches in the marbleized xenolith south of Middle Quartz Creek, shown on the geologic map as a patch of undifferentiated Paleozoic rock. Many of the marbles contain sparse grains of diopside, and locally this mineral is abundant, notably as a bed about 6 feet thick west of the Victor mine in the Whitepine area, and also associated with phlogopite in a marble on the north slope of West Point Hill. Diopside locally replaces chert nodules, especially in the Manitou beds of the Cree Creek area. Garnet occurs sparingly with the marble, but it is much more common in the calcareous shaly and sandy beds.

The contact metamorphism of the sandstone, shale, shaly limestone, and limy shales of the Belden and Minturn formations has produced marked changes. The shale passes through stages of minor baking to argillite, graphitic shale, graphite (in Graphite Basin), and hornfels, especially cordierite hornfels. The sandstones were everywhere converted to quartzite containing local assemblages of contact metamorphic minerals. The impure limy rocks display the greatest variety of minerals and in many places pass into a hard dense hornfels, as readily seen high on the slopes east of North Quartz Creek, parts of Syncline Hill, and along the ridge extending west from the head of Taylor Gulch. The most common minerals in the impure limy or shaly beds are garnet (andradite), epidote, diopside, and calcite. Many individual beds are composed largely of either garnet or epidote or both, and some attain a thickness of at least 30 feet, as for example a garnet bed at the head of Taylor Gulch, and epidote beds in the Cree Creek area. The quartzite beds contain variable quantities of biotite, magnetite, tremolite, diopside, garnet, and epidote. The laminae of biotite give the rock the appearance of a gneiss or schist.

Two very irregular but nevertheless distinct mineralogic and lithologic zones can be recognized in the metamorphosed sedimentary rocks bordering the Mount Princeton batholith. Rocks within about 2,000 feet of the batholith are almost everywhere characterized by epidote, garnet, diopside, and locally magnetite and olivine, the latter mostly altered to serpentine. Hard flinty hornfels, graphitic shale, and coarse-grained dolomite and limestone marbles are the typical rocks. Outward from this zone of silicated and high-temperature minerals is an irregular zone, locally as much as 1½ miles wide, in which the characteristic rocks are coarse- to fine-grained dolomite and limestone marbles, slightly indurated shale, and argillite. Locally, tremolite and wollastonite are abundant in the marble.

The metamorphic zones described above are the result of pyrometasomatic processes related to the Mount Princeton magma, and in turn the two zones are chiefly an expression of the distances from the batholith. In places, however, faults, fractures, and bedding slips afforded easy access to the heat, solutions, and vapors, and the shape of the metamorphic zone was modified accordingly. Only to a very slight extent was the marbleization of the limestones and dolomites caused by folding and faulting, because strongly folded and faulted beds distant from the quartz monzonite are rarely marbleized. The occurrence at many places in the Garfield quadrangle of unaltered, or only slightly altered, limestone beds alternating with hard quartzites seems best explained by relative permeabilities. Hot solutions and gases from the bordering Mount Princeton batholith moved more readily through the porous sandy beds than through the limestone beds, and almost all the sandy beds were transformed to quartzite.

In the Whitepine area the marbleization of the rocks has been controlled chiefly by the earlier formed Star fault and the blanketing effect of the lower shale beds of the Belden shale. Here the pronounced area of marble occurs west of the Belden strata and extends from near Tomichi Creek south to an east-west line about at Spring Creek. Except at the north end of this area near the contact with the Mount Princeton batholith, the limestone beds of the Belden show little or no recrystallization, although the underlying Leadville limestone is extensively marbleized. This variation in metamorphism is further indicated by a common development of contact metamorphic minerals in the quartzite beds at the base of the Belden, such as occur in the Erie and Eureka-Nest Egg mine workings. The beds of Ordovician to Mississippian age between Spring Creek and the Morning Glim fault are mostly unmetamorphosed, except that marble has locally formed in irregular masses in the Leadville and Chaffee formations along the Morning Glim fault 1,000 to 2,000 feet southeast of the Annie Hudson mine. It therefore seems likely that heat, solutions, and vapors from the Mount Princeton batholith migrated upward and to the south along the Star fault, but the lower shale beds of the Belden were nearly impervious to the metamorphic agents.

ORE DEPOSITS

LOCATION OF MINING DISTRICTS

The following mining districts lie wholly or partly within the Garfield quadrangle: Tincup, Quartz Creek, Tomichi (Whitepine), Monarch, and Chalk Creek. All districts except Monarch and Chalk Creek are west of the Continental Divide. The Tincup district, which is in the northwest part of the quadrangle, is about 5 miles long and 1½ miles wide and extends approximately from an east-west line through Cumberland Pass north to the town of Tincup, one-third of a mile north of the map border, although the most productive part of the district extends from about three-fourths of a mile north of Cumberland Pass to the north end of Duncan Hill. The Quartz Creek district adjoins and lies south of the Tincup district. It is a fairly large, rather vaguely defined district chiefly bordering North Quartz Creek in the mapped area, but extending several miles west and southwest beyond the junction of North and Middle Quartz Creeks. About half of the district lies within the Garfield quadrangle.

The Tomichi, or Whitepine, district is about 6 miles long by 4 miles wide and centers around the old and now completely dilapidated town of Tomichi, at the junction of Tomichi and Robbins Creeks. In recent years most of the production has been from the southern part of the district, in the Whitepine area. Brittle Silver Basin and Stella Mountain are regarded as part of the Tomichi district, although they might be considered part of the Quartz Creek or Chalk Creek districts, as Brittle Silver Basin is in the Quartz Creek drainage area, and the diggings are continuous over the Continental Divide into the Chalk Creek district. The Monarch district is in the southeast corner of the quadrangle and embraces the mines east of the Continental Divide and north to and including the headwaters of Middle and North Forks of the South Arkansas River; it is bounded on the west by the Tomichi district and on the north by the Chalk Creek district. The Chalk Creek district, as the name implies, lies in the area drained by Chalk Creek.

HISTORY OF MINING

The early prospectors moved into the Arkansas River valley in 1859 or 1860 (Henderson, 1926, p. 107) and by late 1860 most of the stream valleys in the Garfield quadrangle had been prospected for placer gold. The first reported discovery was on Willow Creek in the Tincup mining district (Poet, 1932, p. 30). From 1860 to 1870 placer mining was the chief activity, but some lode deposits were doubtless discovered and worked. The earliest information on a lode mine in the quadrangle is given by Raymond (1877, p. 314) who reported that in 1875 Chapman and Riggins were building a mill of 10-ton capacity in Chalk Creek valley to treat ores from their mines, one of which was the Mary Murphy. According to Crawford (1913, p. 195, 224), ore was first discovered in the Monarch district in 1878 and in the Tomichi district in 1879. The first lode mine in the Tincup district was the Gold Cup, discovered in 1878 (Poet, 1932, p. 31).

Between 1878 and 1882 most of the larger ore deposits in the region were discovered. During this period of discovery and development, many towns were established. Some of these were Tincup, Hillerton, and Virginia City in the Tincup district; Pitkin in the Quartz Creek district; Maysville, Monarch, Garfield, and Shavano in the Monarch district; Whitepine and Tomichi in the Tomichi district; and Forest City (later renamed St. Elmo), Alpine, Romley, and Hancock in the Chalk Creek district. The population of these towns fluctuated considerably depending upon the development of the mines and new discoveries in other parts of the State. In 1951, only Pitkin, Monarch, Garfield, St. Elmo, and Whitepine had permanent residents.

In 1883, according to Crawford (1913, p. 196), A. Eilers organized the Colorado Smelting Co., which took over the Madonna mine, in the Monarch district. The railroad, which had been built to Maysville in 1881, was extended to Monarch, and the Colorado Smelter was built at Pueblo, Colo., to process the ore. The Madonna mine furnished basic ore for fluxing with siliceous ores from other districts in Colorado.

The Denver, South Park & Pacific Railroad, a narrow-gage line, reached Alpine in 1880. In 1881 the railroad was extended to St. Elmo and in 1882 to Quartz and Pitkin west of the Continental Divide, thus making railroad transportation available to the Chalk Creek and Quartz Creek mining districts. Ore from the Tincup district was first hauled by wagon over Tincup Pass to the railroad at St. Elmo, and later over Napoleon Pass to the railroad at Quartz. That part of the railroad within the quadrangle was abandoned in 1910.

The greatest period of activity in all the mining districts was from 1883 to 1893. Nearly all the production during this period was from lode mines, but a few placer mines were still operated in the Tincup district. Many of the larger mining companies operated mills. Small smelters were built in most of the districts but were mostly unsuccessful. In 1893 the price of silver dropped from $1.27 per ounce to $0.70 per ounce (Poet, 1932, p. 32) and as a result most of the mines were closed and the towns abandoned.

In 1904 renewed interest in gold resulted in a second boom in the Tincup district; the production came primarily from the Gold Cup mine. In the Chalk Creek district, the Mary Murphy mine increased its production, but in other districts production was small. From 1908 to 1912 an attempt was made to use gold dredges in the Tincup district, but the project was a failure (Poet, 1932, p. 33), and since then there has been very little activity in this district.

With the start of World War I there was renewed activity in most of the mining districts. In the Monarch district the Madonna, Garfield, and Eclipse mines were again in production, as were several smaller properties. The Morning Star and Akron mines were the major producers in the Tomichi district, and the Mary Murphy mine in the Chalk Creek district. A small quantity of tungsten and molybdenum was produced from some mines in the northern part of the Quartz Creek district.

Between 1924 and 1940 there was only intermittent activity in the Monarch, Tomichi, and Chalk Creek districts, and a small amount of placer mining was done in the Tincup district. At the start of World War II a few mines were reopened in the Monarch and Tomichi districts. The important producing mines in the Monarch district during this period were the Garfield and Hawkeye, and in the Tomichi district, the Akron and Erie. Most of the mines closed shortly after the end of the war, although the Akron was still in production in 1952.

PRODUCTION

The value of the ore produced from the mining districts in the Garfield quadrangle is estimated to be about $30,000,000, as shown in the table below:

Approximate value of ore produced from the mining districts in the Garfield quadrangle, Colorado

District	Value, 1901–49, from production records	Estimated value before 1901	Total value
Monarch	$4,195,000	$9,000,000	$13,195,000
Tomichi	4,137,000	2,500,000	6,637,000
Chalk Creek	5,330,000	600,000	5,930,000
Tincup	56,000	3,000,000	3,056,000
Quartz Creek	226,000	400,000	626,000
	13,944,000	15,500,000	29,444,000

The value of the ore produced in the various districts before 1901 (the year in which accurate statistical data were first assembled) is based upon specific as well as very general information obtained from many sources. In the Monarch district, almost 50 percent of the total output came from the Madonna mine; in the Chalk Creek district, the Mary Murphy group of mines (Mary Murphy, Lady Murphy, Lady Catherine, Iron Chest, Tressa C) has accounted for at least 75 percent; in the Tincup district, the Gold Cup mine has produced about 50 percent of the total value of ore recovered.

The following table gives the production of gold, silver, copper, lead, and zinc by districts from 1901–49.

The total value of tungsten and molybdenum ore produced from the northern part of the Quartz Creek district is probably not more than $25,000. Tweto[3] reports that tungsten and molybdenum ore valued at $16,000 was shipped from the Ida May claim during World War I and about 25 tons of sorted molybdenum ore said to average 4.5 percent MoS_2 was shipped from the Molybdenite mine. Small lots of tungsten, most of it picked from dumps and float, were produced from time to time since 1918 and shipped to the mills of Boulder County. In 1948 a shipment of 21 tons of tungsten ore was made from the Complex mine, but the value is not known.

ORE BODIES

The ore deposits in the Garfield quadrangle are of two main classes: replacement deposits in the sedimentary rocks, and vein deposits in sedimentary, intrusive and pre-Cambrian rocks. On the basis of the value of the ores produced, the vein deposits are nearly equal in value to the replacement deposits, but this is due largely to the output from a few veins on the Mary Murphy group of claims which have accounted for about 75 percent of the total value from all vein deposits in the quadrangle.

REPLACEMENT DEPOSITS

The replacement deposits are chiefly in limestone and dolomite of the Manitou, Chaffee, and Leadville formations, although a few are in quartzite. Most of the deposits are in the Monarch, Tomichi, and Tincup mining districts in the larger areas of sedimentary rocks near or adjacent to the Mount Princeton batholith.

Most of the ore bodies, especially the larger ones, occur either as bedded replacement deposits or as irregu-

[3] See footnote 1 on p. 4.

Production[1] of gold, silver, copper, lead, and zinc from the mining districts within the Garfield quadrangle, 1901–49

[Compiled from records of A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo.]

District	Crude ore produced (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
Tincup	4,133	1,031	41,860	1,200	165,369	9,520
Quartz Creek	8,688	1,185	297,336	4,934	16,722	5,359
Tomichi	101,855	1,298	614,690	434,106	23,307,927	29,629,737
Monarch	123,010	11,589	1,083,716	1,933,608	13,271,340	15,560,686
Chalk Creek	317,369	111,003	1,014,686	1,099,574	18,903,595	14,602,272
Total	555,055	126,106	3,052,288	3,473,422	55,664,953	59,807,574

[1] Production in terms of gross metal content of ore.

lar deposits along premineral faults and fractures. Locally the bedded or blanket-type deposits and those associated with faults intergrade, and some irregular replacement bodies seem to conform neither to bedding nor prominent fissures. In all types of replacement bodies the outline between ore and wall rock is very irregular. Most of the ore shoots pinch and swell; the swells may be very irregular or as lenses. Many shoots are connected by iron-stained joints or iron-stained bedding planes.

Bedded replacement deposits are especially important economically in the Tincup district; ore deposits in the Gold Cup, Silver Cup, Tincup, Robert E. Lee, Drew, El Capitan, and West Gold Hill mines are of this roughly tabular form. The ore bodies commonly plunge northeast down the gentle to moderate dip of the beds. Most of the ore mined in the district lies along the contact of a gray limestone and overlying dolomite in the Leadville formation about 150 feet stratigraphically below the top, although some ore bodies occur at stratigraphically lower positions, as near the base of the Leadville, in limy beds immediately above and below the top quartzite bed of the Parting member of the Chaffee formation, at the top of the Fremont dolomite, and in the Manitou dolomite. In the Tomichi district, the principal bedded deposits are in the Erie and Eureka-Nest Egg mines. Here the ore bodies are in the upper part of the Leadville limestone at or near the contact with the overlying Belden shale. In the Monarch district, small bedded replacement bodies have been mined from all of the calcareous formations, but the most favorable host rock is the Manitou dolomite, particularly the lower part, at or near the contact with the underlying pre-Cambrian crystalline rocks. Both the Lilly and Garfield mines obtained ore from this zone.

The largest blanket ore body so far discovered in the quadrangle is in the Gold Cup mine, where a fairly continuous mineralized body extends along the strike of the beds for a distance of about 1,000 feet and down dip for about 800 feet. This body contained several rich shoots (Goddard, 1936, p. 573) which ranged from 30 feet to several hundred feet in length, 10 feet to 60 feet in breadth, and 1 foot to 7 feet in thickness, averaging about 3½ feet.

Some important replacement deposits are so clearly related to premineral faults that they warrant special mention, particularly since three economically important mines are of this class. In the Monarch district the Madonna ore body lies adjacent to the Madonna fault, and the Eclipse ore body is associated with the Mayflower fault. In the Tomichi district, most of the ore in the Akron mine is in the sedimentary rocks along the west side of the Star fault. In the Quartz Creek district the ore in the Maid of Athens, Citizen, and Ben Franklin mines probably lies in the sedimentary beds near or adjacent to the Athens fault.

Although many ore shoots along faults are small lenses or pods measured in inches, some attain large dimensions. In the Madonna mine the main ore body, although irregular and not an entirely continuous ore shoot, extended for a pitch length of about 2,000 feet, a maximum breadth of 80 feet, and a maximum thickness of 40 feet. The ore shoots in the Akron mine occur chiefly along the west side of the Star fault, and the largest of these was mined for a pitch length of about 300 feet, a breadth of about 150 feet, and an average thickness of 8 feet. Most of the ore shoots along faults plunge moderately to steeply toward the Mount Princeton batholith.

The mineralogy of the replacement deposits varies somewhat in details but in general all deposits are markedly similar. The chief sulfide minerals are galena, sphalerite, pyrite, and some chalcopyrite; as a rule pyrite and galena are more widely distributed than chalcopyrite or sphalerite. A large part of the pyrite is gold-bearing, and practically all of the galena carries some silver values, in places large amounts. Pyrrhotite occurs locally in the Garfield mine in association with other sulfides. Minor amounts of enargite, tetrahedrite, and tennantite are found in the ores of a few mines in the Tomichi district. The sulfides form fine-grained to moderately coarse-grained masses, small pods, lenses, or discrete grains disseminated in limestone or dolomite. Pyrite in the form of cubes, pyritohedrons, or irregular grains, is by far the most abundant and widely distributed metallic mineral, and locally it forms nearly pure masses either remote from the other sulfides or as an irregular border to the other sulfides. Sphalerite varies from light green to dark brown although a brown resinous variety is most typical. Almost everywhere the gangue is marbleized limestone or dolomite, generally with some quartz or silicified limestone. In a few places earlier formed contact metamorphic minerals make up part of the gangue. Quartz is more abundant in the ore of the Tincup district than in either the Tomichi or Monarch districts.

The oxidized ore of the replacement deposits is typically yellowish to reddish brown and ranges from soft, porous, and earthy to a hard, dense, almost flinty, material. The chief ore minerals of the oxidized zone are cerussite, residual patches or grains of galena, and free gold. Other minerals, some of which are locally of considerable economic importance, are smithsonite, calamine, anglesite, cerargyrite, argentite, cuprite, malachite, azurite, chrysocolla, wulfenite, and residual grains of sphalerite, chalcopyrite, and pyrite. Cerussite is white to dark gray and occurs as patches, seams, and as crystals as much as half an inch long lining cavities. In places, especially in the Tincup district, galena is coated or seamed by cerussite or anglesite or both. Free gold is contained in limonite, and also probably in some pyrite. The gangue is chiefly limonite or a mixture of limonite and quartz. The relative proportions of quartz and limonite vary greatly, although some limonite occurs in all the oxidized bodies. Locally calcite, dolomite, silicified limestone, and altered country rock accompany the typical gangue minerals.

The order of deposition of the chief primary minerals began with quartz and pyrite, and was followed by sphalerite, chalcopyrite, and galena. A study of polished sections of the ore from the Tomichi district shows pyrite cut or replaced by chalcopyrite, sphalerite, and galena; sphalerite by chalcopyrite and galena; chalcopyrite by sphalerite and galena; and galena by sphalerite. This indicates that chalcopyrite, sphalerite, and galena were deposited almost simultaneously, and a slight variation in conditions caused one or the other to deposit first. Galena formed about simultaneously with the other two but its deposition probably continued after that of chalcopyrite and sphalerite had stopped. Quartz was deposited during and after the main sulfides formed. Locally calcite and dolomite seams cut the sulfides and quartz.

In the Tincup district, where the oxidized ores can best be observed on some of the mine dumps, the order of formation of the oxidized minerals seems to have been cerussite, malachite, chrysocolla, calamine, and drusy quartz. Locally small crystals of wulfenite rest on drusy quartz.

The depth of the zone of oxidation in the Garfield quadrangle is variable, ranging from almost zero to about 1,000 feet, and the bulk of all ore mined so far was at least partially oxidized. As a rule the ore in the replacement deposits is more thoroughly oxidized and oxidation extends to greater depths than that in the vein deposits. This can be explained in part by the fact that most of the veins are in areas that have been intensely glaciated, and consequently much of the oxidized material, which formed before the time of glaciation, has been removed. Furthermore most of the ore-bearing veins cut igneous and metamorphic rocks which are less permeable to the oxidizing solutions than are the sedimentary rocks.

In the larger bedded replacement bodies nearly all the ore is oxidized, and the zone of partial oxidation locally extends down the dip of the beds for 1,000 feet. However, in these larger bedded bodies the dip of the strata containing the ore is generally only a little steeper than the surface slope above, and few, if any, parts of the mine workings are more than a few hundred feet vertically below the surface. In the Madonna mine partially to completely oxidized ore bodies plunge northwest for a distance of about 2,000 feet, but at no place are they more than 1,000 feet vertically below the surface of the slope of Monarch Ridge.

In general, conclusive evidence of secondary enrichment in the replacement deposits is notably lacking. However, Crawford (1913, p. 218–220), from a study of the values of the Madonna mine and an examination of ore from parts of this mine, concluded that in the process of oxidation, the ores of the higher levels lost part of their gold and silver, and that these were redeposited in part in the oxidized zone at a lower level in the mine. The removal of much pyrite and possibly sphalerite in the higher levels resulted in ores richer than average in lead. In the Gold Cup mine, however, reports have it that the reverse is true—the upper levels were rich in gold and low in silver and lead, but at depth both lead and silver values increased and gold decreased.

Localization of the ore bodies of the replacement deposits has been governed by the composition of the beds, by permeability, by structure, or by a combination of these. Some shoots, such as those in carbonate rock immediately below quartzite, shale or granite, were apparently formed by a trapping of the ore solutions beneath these less permeable beds. Other shoots, such as those that lie at the contact of limestone and dolomite in the Leadville limestone in the Tincup district, probably formed in the more soluble and therefore probably more permeable limestone in preference to the dense dolomite. At many places structures have clearly controlled the migration of the ore solutions. The Madonna ore shoot along the Madonna fault, the Eclipse ore shoot along the Mayflower fault, and the Akron ore shoot along the Star fault are typical as well as important economic examples of the localization of ore by faults. Ore concentrated in small folds occurs locally, such as in the old North Star workings of the Akron mine. Bedding-plane slips and brecciation along bedding planes have localized ore bodies at many places by affording channels for the ore solutions.

A somewhat separate group of replacement deposits that are rich in magnetite occur at many places in the Garfield quadrangle in limestone and dolomite beds at or near contacts with intrusive rocks. All of these, with the exceptions of the two deposits mentioned below, are very small bodies near or bordering the Mount Princeton batholith. Magnetite and some hematite and limonite are associated with contact metamorphic minerals such as garnet, epidote, diopside, and serpentine. Some of the iron deposits carry a little gold, silver, and copper. In the Tincup district, the Cumberland mine and several small opencuts nearby produced some iron ore for flux many years ago. The ore occurs in a layer of limestone of the Belden shale that lies between the quartz diorite porphyry and the Tincup porphyry (pl. 1). Most of the iron ore is magnetite in small octahedra, commonly twinned, in a gangue of quartz, calcite, garnet, diopside, serpentine, and tremolite. One specimen of magnetite-rich ore seen on the Cumberland mine dump contained a few minute grains of chalcopyrite. Copper stains are common along many joint surfaces. The Iron King mine in the Tomichi district is in metamorphosed limy beds of the Belden shale at the north end of the Morning Glim fault, near where the fault is cut off by the Mount Princeton batholith (pl. 1). The ore varies from a compact magnetite with seams and specks of limonite to scattered grains of magnetite in a gangue of epidote, garnet, chlorite, quartz, calcite, serpentine, and tremolite. Some pyrite and secondary copper stains occur locally. The mine workings were badly caved and slumped when visited in 1950, and the contact between igneous and sedimentary rocks could not be seen. Crawford (1913, p. 305) reports that in 1910 the mine showed a face of magnetite about 30 feet high. He also states that it was reported to him that 2 tons of rich copper ore in the form of cuprite was shipped from the surface near the deposit, but no other workable copper ore has been found in this vicinity.

All the replacement deposits previously described are believed to be genetically related to the magma that produced the Mount Princeton batholith, as described later under "Origin and relative ages of mineralization."

VEIN DEPOSITS

Veins are widely distributed but are most abundant in the north-central part of the quadrangle (pl. 1). The veins are of four classes: pyritic quartz, hubnerite-molybdenite, quartz-fluorite, and quartz-beryl-pyrite. These groupings are a classification based chiefly upon the most abundant or significant minerals present, although it is in part a genetic classification as described under "Origin and relative ages of mineralization." The pyritic quartz veins locally contain minerals that have yielded most of the gold, silver, copper, lead, and zinc. The total value of tungsten, molybdenum, and beryl ores that have been produced is very small.

PYRITIC QUARTZ VEINS

The pyritic quartz veins are the most important economically of the four classes of veins, for they locally contain concentrations of valuable minerals, especially sphalerite, argentiferous galena, gold, chalcopyrite, cerussite, anglesite, and smithsonite. They are also by far the most numerous and widely distributed of the four. Most of the pyritic quartz veins are east of the Continental Divide (pl. 1). The principal vein zone extends from upper Tomichi Creek valley northeast almost to the corner of the quadrangle, a distance of about 13 miles, and in this zone the greatest concentration of veins in the quadrangle centers around the Mary Murphy mine, south of St. Elmo. Smaller clusters of veins center half a mile south of Taylor Mountain, and around upper North Fork, Grizzly, and Baldwin Creek valleys.

Most of the veins strike north to N. 35° E., although some strike northwest and still fewer strike nearly east. West and northwest dips, ranging from 50° to 90°, are by far the most common. In length and thickness the veins range from stringers a few feet long and a fraction of an inch thick to veins about a mile long and 10 feet thick. In some places closely spaced veins, or vein zones, are 50 feet wide. The largest number of veins, however, on which substantial prospecting has been done are 500 to 1,000 feet long and 1 to 3 feet thick.

The veins are chiefly in fissures in the Mount Princeton quartz monzonite along the eastern border of the arm of the batholith that extends into the Garfield quadrangle. Some veins cut rocks older than the Mount Princeton quartz monzonite and are as much as 2 miles distant from the batholith. Those in the sedimentary rocks generally follow bedding planes. Very few pyritic quartz veins, as well as veins of any other class, are in rocks younger than the Mount Princeton, such as the quartz latite and Mount Aetna porphyries and the volcanic breccia. There is no apparent relation between the composition and physical properties of the vein matter and the country rock.

With few exceptions the veins are poorly exposed at the surface and have no topographic expression. Most prospects and mines were started either in small outcroppings, or along iron-stained fissures, or near a local concentration of float fragments of vein matter. Of the many veins found in the quadrangle only a relatively small proportion has proved to be of significant economic importance. Few veins have been explored to a depth of more than a hundred feet below the surface, and many only a few feet, but nearly all veins not concealed in large part by heavy talus or glacial deposits have been prospected at fairly short intervals. The most notable exception to the above statements is the Mary Murphy vein which has been worked through a vertical range of about 2,200 feet from the surface outcroppings on Chrysolite Mountain to the Golf tunnel level (pl. 1) in Chalk Creek valley. Parts of this mine as well as several others were accessible when visited, but most of the information concerning the veins was necessarily obtained from shallow prospect pits, mine dumps, and a few outcrops.

As the classification of these veins implies, they are composed chiefly of quartz and pyrite, with quartz almost everywhere greatly in excess of pyrite. A few veins, generally short and narrow, consist only of quartz and others of pyrite. Most of the quartz is medium to coarse grained, white, and vuggy. The vugs range from a fraction of an inch to several inches across and are lined with well-formed quartz crystals, some as long as 2 inches. Along some veins a fine-grained, and in places brecciated, gray quartz occurs in bands, ½ inch to 6 inches wide, between the wall rock and white quartz, or as irregular patches in the white quartz. Locally in other veins, white vuggy quartz is cut by fine-grained gray quartz.

Pyrite, either singly or with other sulfides, is contained in the quartz as irregular patches, bands, or disseminated grains, and it is locally disseminated for several feet into the wall rock. Pyrite ranges from minute specks to crystals an inch across, and occurs as irregular grains, cubes, and pyritohedrons. Some pyrite is copper-bearing and some is reported to contain free gold. The principal sulfide minerals, in addition to pyrite, are sphalerite, galena, and chalcopyrite, which may occur singly or in combination with each other, although sphalerite and galena are commonly closely associated. Chalcopyrite is generally far less abundant than the other principal sulfides and occurs mostly in scattered grains. Sphalerite varies from yellowish brown to the black iron-rich variety, marmatite. Both sphalerite and galena range in grain size from fine to coarse and are generally in anhedrons. Most of the galena is silver-bearing. Accessory sulfides found locally in small amounts are tetrahedrite, enargite, argentite, greenockite, molybdenite, and tenorite.

The common ore minerals of the oxidized zone are cerussite, smithsonite, anglesite, and residual grains of galena. Others of local occurrence are malachite, azurite, chrysocolla, calamine, psilomelane, and pyrolusite. Native silver, native copper, cuprite, and cerargyrite are rare. The gangue is limonitic quartz and limonite. Free gold probably occurs in some of the limonite.

Gangue minerals other than quartz, pyrite, and limonite occur in a few veins, mostly in the Mary Murphy area. This group of minor gangue minerals includes calcite, rhodochrosite, rhodonite, barite, and fluorite. White, and in places pinkish, calcite in fine to coarsely crystalline form is especially common in the Mary Murphy and most of the surrounding veins; it is also in a few other veins many miles distant. Rhodonite and rhodochrosite occur chiefly as a tough fine-grained mixture with quartz, which forms stringers, lenses, and pods, a fraction of an inch to several inches in thickness, near the center of the veins. Pods of rhodochrosite occur locally in the Mary vein. Barite occurs in only a few widely scattered veins, such as the Kickapoo vein north of St. Elmo, the Lilly vein west of Whitepine, and the Bill Short vein near Tomichi. Although barite generally is rare, it is locally abundant in some parts of these veins. Fluorite is a rare gangue mineral confined to the Mary vein and few others close by.

In the great majority of veins scattered throughout the quadrangle the only minerals present are quartz, pyrite, sphalerite, galena, and chalcopyrite, and these show fairly consistent paragenetic relations with each other. The first stage of succession was the crystallization of gray quartz with some pyrite; this was followed by a second stage characterized by white quartz and locally much pyrite; the third stage was the crystallization of sphalerite, galena, and chalcopyrite, probably chiefly in this general order but with some overlap. Quartz and locally a small amount of pyrite accompanied and in some places continued forming after the main sulfides had formed as stage four. In many veins the first stage, represented by gray quartz and pyrite, is absent. The position in the sequence of rhodonite and rhodochrosite, which occurs in the Mary Murphy veins, is not clear, although scanty evidence indicates that they crystallized in part before and in part simultaneously with the main sulfides. Calcite in the Mary Murphy and Stonewall veins formed after the sulfides of stage three, but before stage four. In a few other veins calcite was the last mineral formed. Barite in the Kickapoo vein crystallized at about the same time as the sulfides of stage three, but in the Lilly and Bill Short veins it crystallized after the sulfides and before the last stage of quartz. Scanty evidence indicates that some fluorite formed with and some after the main sulfide stage.

Most of the veins are bordered by altered zones from a few inches to about 2 feet thick. The width of the altered zone is at many places roughly proportional to the width of the vein, although some shear zones either with or without pyrite-quartz veinlets are altered over a width of as much as 50 feet. Extending outward from many veins in the Chalk Creek district is a zone of silicified and pyritized country rock, which is locally separated from the vein by a thin band of argillized rock. Pyrite commonly extends beyond the zone of silicification into a zone in which most minerals in the country rock, except quartz, are altered to sericite and hydromica. Overlapping the sericite-hydromica zone and extending beyond is an outer zone in which the ferromagnesian minerals of the country rock are partly or completely changed to chlorite. Most of the veins at the head of North Fork are bordered by a zone of argillized and pyritized rock which locally and irregularly grades outward into chloritized country rock.

The ore shoots of the pyritic quartz veins range in size from small isolated pods to bodies as much as 1,000 feet in length, although if judged from the records and a few of the shoots that were seen, most are 25 to 100 feet in pitch length and 10 to 50 feet in breadth. The largest shoot so far found is in the Mary Murphy mine where one shoot in the Mary vein has an average pitch length of about 1,000 feet, a breadth of 700 feet, and an average thickness of 4 feet.

Little is known definitely of the causes of the localization of ore shoots in the veins, although changes in strike or dip of the veins are known to have localized some shoots. In the Mary Murphy mine, for example, some ore shoots coincide with changes in strike of the veins.

Oxidized vein material is chiefly confined to those veins exposed on high slopes, above the reach of the glaciers. Most of the oxidation is believed to have occurred before glaciation. Later the glaciers removed some, if not all, of the oxidized parts of the veins and protected them from further extensive oxidation by a blanket of debris. For these reasons the unoxidized parts remain in the strongly glaciated areas, as along valley floors. In many glaciated areas, as at the head of North Fork and Chalk Creek valleys, the readily oxidizable sphalerite occurs as fresh grains only a few feet below the surface. The veins high on Chrysolite Mountain are strongly oxidized because they extended above the glaciers. The Mary vein is almost completely oxidized to a depth of 300 feet, and partially oxidized to a depth of 700 feet.

The most important effect of supergene alteration has been the removal of most of the sphalerite and pyrite. This has resulted in a residual concentration of the less soluble galena or its oxidized products, cerussite and anglesite. Gold content was reportedly highest in the strongly oxidized parts of the Mary vein; this probably reflects a residual concentration of gold from auriferous pyrite.

Field evidence for any important supergene sulfide enrichment of the ore bodies is lacking, and it is not known to the authors that any mine has produced secondary sulfides in quantity. It is reported that a few mines along pyritic quartz veins obtained sulfides characteristic of supergene sulfide enrichment, such as argentite, covellite, and chalcocite, but they were sparsely distributed and the range in depth was short.

The most productive veins have been those of the Mary Murphy group in the Chalk Creek district, which have yielded ore valued at about $12,000,000. The Jimmy Mack mine on the Mack vein in the Tincup district ranks next with an estimated value to its ores of $700,000. The value of ores produced from all other pyritic quartz veins is small. Although only a very few of the many veins in the Garfield quadrangle are entirely lacking in ore minerals, most of the ore shoots discovered have been too small or of too low grade to warrant profitable mining.

A genetic relation between nearly all of the pyritic quartz veins and the magma that formed the Mount Princeton batholith is strongly suggested and is described in some detail under "Origin and relative ages of mineralization." It is especially noteworthy that all of the pyritic quartz veins except a very few near Mount Aetna are in the Mount Princeton batholith or in the bordering rocks that are older than this batholith.

HUBNERITE-MOLYBDENITE VEINS

The hubnerite-molybdenite veins are chiefly on a high ridge that lies north of North Quartz Creek and west of Cumberland Pass in the Quartz Creek mining district, although a few veins, mostly short and narrow, are as much as 1¼ miles south of Cumberland Pass. The main group near Cumberland Pass is in an easterly trending belt about 1¼ miles long and half a mile wide (pl. 1). This area comprising about a square mile was studied and mapped by planetable method by Ogden Tweto in 1943, and a large part of the following descriptions of the veins and the tenor of the ores is from his report.[4]

The veins range widely in strike, although the strongest and most persistent molybdenite veins strike nearly east, and the hubnerite veins all strike northeast except the Complex vein south of Cumberland Pass, which strikes northwest. The dips of the veins, insofar as could be determined, are generally rather flat, and three of the largest ones, the Mammoth, Bon Ton, and Complex, dip only 40° to 45°. Many veins are only 100 or 200 feet long, although the Mammoth-Orient veins, which are probably the same, have a total length of about 1,700 feet. Widths range from a few inches to about 5 feet, and the average is 1½ to 2 feet. Most of the veins are in fissures in pre-Cambrian gneissic granite, although one at the north end cuts Sawatch quartzite and may extend into the Manitou dolomite. A few narrow and short veins, not shown on plate 1, are in the Tertiary Tincup porphyry south of North Quartz Creek. There is marked similarity in both the molybdenum- and tungsten-bearing veins throughout their vertical range of exposures, which in the case of the former is about 1,000 feet, and for the tungsten-bearing veins about 600 feet.

Some postore movement has occurred locally along

[4] See footnote 1 on p. 4.

the veins and in a few places veins, such as the Bon Ton and Orient-Mammoth, are offset a short distance by north- or northwest-trending faults.

The veins consist chiefly of quartz, some pyrite, and minor amounts of molybdenite, hubnerite, tetrahedrite, chalcopyrite, sphalerite, galena, and a few other minerals of rare occurrence. Except for a few local pyritic lenses, quartz constitutes more than 95 percent of the vein filling by volume. The veins are roughly banded, and three successive generations of quartz can be identified at some places by slight differences in texture and in the degree of brecciation. The earliest quartz is light gray to white and sugary; the next is massive, vitreous, milky quartz; and the youngest quartz, aside from barren comb quartz lining vugs, is a colorless, glassy, coarse-grained quartz in which crystal outlines are detectable, and much of which is vuggy. Although all three of the main types of quartz are locally brecciated, the sugary quartz is more strongly brecciated than the others. Molybdenite and hubnerite occur together in many veins, but each is generally restricted to bands or streaks in a gangue of different varieties of quartz; the former to the sugary or milky vitreous quartz, and the hubnerite to the coarsely crystalline, colorless quartz. Hubnerite in the Complex vein, however, is in a white quartz gangue, although this quartz may be the same generation as the colorless quartz of the Cumberland Pass area because it is both coarse-grained and somewhat glassy. Where the two main types of quartz are in the same vein, hubnerite-quartz usually lies along one wall and the molybdenite-quartz along the other wall.

The chief tungsten mineral is a light-brown, probably low iron-content hubnerite that occurs typically as slender prisms ½ inch to 2 inches long. The larger crystals tend toward a tabular form. Tweto [5] found one crystal 5 inches long in quartz float on the talus slope north of the Ida May mine. Associated with the hubnerite are chalcopyrite, tetrahedrite, galena, sphalerite (variety marmatite), pyrite, and the secondary minerals chalcocite, covellite, bornite, and cuprite. A very small amount of scheelite-powellite occurs as small grains or coatings among the comb quartz crystals of vugs on the ridge west of Cumberland Pass; in the Complex vein, considerable scheelite occurs bordering hubnerite and tetrahedrite.

The chief molybdenum mineral is the sulfide, molybdenite, which occurs generally in disseminated fine grains in the sugary quartz, and in the milky quartz as coarser grains in the forms of tufts, streaks, and irregular small veinlets of platy crystals, some as much as a quarter of an inch long. In most of the veins, except those that contain a tungsten streak, pyrite is the only other sulfide associated with the molybdenite. Most of the molybdenum now exposed in the upper parts of the veins is in the yellowish secondary mineral, ferrimolybdite.

Definite paragenetic relations of all the main minerals of the tungsten-molybdenum veins could not be determined with absolute certainty because all mines were caved, the veins are poorly exposed at the surface, and, except at the Complex mine, the mine dumps had been well picked over. However, the order of deposition of the principal vein material was probably in the following main stages: (1) quartz, molybdenite, and some pyrite; (2) quartz, hubnerite, pyrite, chalcopyrite, and tetrahedrite; (3) scheelite; (4) quartz, sphalerite, galena, and minor amounts of pyrite, chalcopyrite, and barite; (5) quartz.

During stage one, quartz was formed in two generations. Molybdenite and pyrite were deposited with the second generation of quartz and probably with the first also. In stage two, chalcopyrite and tetrahedrite are clearly younger than either hubernite or pyrite, but the age relation between chalcopyrite and tetrahedrite could not be determined in the specimens studied. Examination of many specimens of the vein material on the Complex mine dump showed scheelite bordering many grains of hubnerite and tetrahedrite and extending into vitreous white quartz. A few grains of both hubnerite and tetrahedrite are clearly "veined" by scheelite. The foregoing relations among hubnerite, tetrahedrite, and scheelite show that tungsten mineralization occurred both before and after tetrahedrite was deposited. The second period of tungsten mineralization formed the calcium tungstate, scheelite, probably by the action of calcium-bearing hydrothermal solutions on the earlier formed hubnerite. Apparently tetrahedrite was a very favorable host mineral for the deposition of scheelite. The principal deposition of sphalerite and galena is believed to have occurred during the fourth stage listed above. Barite occurs locally in some of the Complex mine ore associated with sphalerite and galena. The barren quartz of stage five cuts all other minerals and is typically vuggy; it is probably a continuation of the quartz deposition of the preceding stage.

Most of the feldspar of the pre-Cambrian granite throughout the Cumberland Pass area is altered to white or light-gray clay minerals, and some of the veins are bordered by more intensely altered zones. The Mammoth vein, as exposed in a cut east of the tunnel, consists of about 2½ feet of massive quartz and 2½ feet of brecciated molybdenum-bearing quartz separated by 4 to 6 inches of iron- and molybdenum-stained gouge. On the hanging wall the vein is bordered by 4 feet of intensely argillized granite seamed by quartz,

[5] See footnote 1 on p. 4.

beyond which is bleached, less altered granite. On the footwall side of the vein is 3 feet of intensely argillized granite, followed by 1 to 1½ feet of sheeted and less altered rock, and this by 3 to 5 feet of sheared and quartz-seamed granite, which in turn is bordered by a black recrystallized gouge zone a few inches to 3 feet thick. Along the Bon Ton vein the bordering granite of the hanging wall is sericitized and impregnated with pyrite for 4 or 5 feet, and the footwall for 12 to 15 feet.

The width of the molybdenum-bearing quartz in the veins averages 1½ to 2 feet, and the tungsten streaks are much narrower, rarely exceeding 1 foot, and most are 1 to 2 inches wide. According to Tweto[6] the average tenor of the molybdenum veins is not precisely known but probably does not exceed 0.5 percent MoS_2, and the average tenor of the better tungsten veins is probably 2½ percent WO_3. Tweto recognized that tungsten ore bodies of this grade are small and scattered, and exploration work along veins since Tweto examined them in 1943 indicates that ore of this grade is probably very rare. Some gold, probably in the pyrite, is present in small quantities in many of the veins, and silver is probably present in the galena and tetrahedrite. The only assay data available for these metals were from a 21-ton shipment of hand-cobbed ore from the Complex mine in 1948; it assayed 0.02 ounce of gold and 21.10 ounces of silver per ton, as well as 13.50 percent lead, 17.55 percent zinc, and 2.10 percent copper. The amount of tungsten was not reported, but examination of many specimens of this hand-cobbed ore before its shipment indicates a tenor of about 1 to 3 percent WO_3, and a sphalerite and galena content far above the average for the veins of the Cumberland Pass area.

The hubnerite-molybdenite veins are characterized by a rather high-temperature assemblage of minerals. They probably represent the center of a mineralized area bordered by deposits of somewhat lower temperatures, such as the lead-silver-gold-copper-quartz veins of the Jimmy Mack, Indiana, and Deacon mines to the north in the Tincup district, and veins of similar mineral assemblages to the south near the Athens fault. The veins are believed to have been deposited from hydrothermal solutions genetically related to the magma that formed the Mount Princeton batholith as discussed under "Origin and relative ages of mineralization."

QUARTZ-FLUORITE VEINS

Veins composed chiefly of quartz and fluorite with little or no sulfides are rare. With two exceptions, they are all in a northeast-trending belt 1¾ miles long and ¼ mile wide, extending from a point about ¾ mile south of Tomichi Pass across the west side of Central Mountain and beyond into Brittle Silver Basin (pl. 1). The exceptions are a vein about 4 miles west of Brittle Silver Basin in South Quartz Creek valley and a short and narrow vein (not shown on pl. 1) about 2 miles southeast of Brittle Silver Basin on the east slope of Vulcan Mountain. The veins in the Brittle Silver Basin belt are in Mount Princeton quartz monzonite, quartz latite porphyry, and Mount Aetna porphyry, whereas the quartz-fluorite vein in South Quartz Creek valley cuts pre-Cambrian granite and the vein on Vulcan Mountain cuts volcanic breccia.

Although some veins are short and narrow stringers, most extend at least 500 feet; one on the north side of Brittle Silver Basin can be traced for about 3,500 feet, and the vein in South Quartz Creek valley probably has a total length of about a mile, as indicated on plate 1. Strike and dip vary considerably, but the strike of most of the veins ranges from N. 20° W. to N. 20° E., and moderate to steep westerly dips are dominant. The thickness usually ranges from 1 to 5 feet, and there is much local pinching and swelling. Many veins change within a distance of 50 feet to a zone, locally as much as 25 feet wide, of argillized country rock containing many narrow quartz or quartz-fluorite veinlets of diverse attitudes. Parts of some veins are bordered by a thin gouge selvage; others, such as the northern part of the vein exposed in the Day Star prospect, may be bordered by a zone of gouge and breccia as much as 3 feet thick. Insofar as it could be determined the gouge and breccia formed before the introduction of the vein material. The veins are poorly exposed and have no distinct topographic expression. They have been explored mostly by shallow pits, although the Day Star tunnel followed a typical quartz-fluorite vein along strike for several hundred feet. At the southern end of this tunnel the vein is about 225 feet below the surface and here, as well as elsewhere in the mine, its texture and mineral composition are the same as at the surface.

The typical vein filling is white quartz and white fluorite in variable amounts, although quartz is generally far in excess of fluorite and in places forms the entire vein filling. Within a distance of a few feet some of the quartz changes to colorless or gray and the fluorite to colorless or blue, green, and purple shades. Quartz is locally banded with fluorite but in many more places it forms a crusted network of veinlets surrounding angular to subangular fragments of altered country rock a fraction of an inch to about 2 inches long, or as a lining in vugs; many of the vugs have been partly to completely filled with fluorite. Locally, small white calcite crystals rest on fluorite or quartz crystals. Metallic minerals are present in a few places, generally

[6] See footnote 1 on p. 4.

in very subordinate amounts in the quartz gangue. Pyrite in the form of small cubes, pyritohedrons, or irregular grains is the most abundant sulfide, although small grains of galena, greenish resinous sphalerite, and rarely chalcopyrite are present locally. Small amounts of brittle silver, probably stephanite, have been reported in Brittle Silver Basin, but none was observed in specimens now remaining on the prospect dumps, and the specific location of its reported occurrence could not be found.

The paragenetic history of the vein filling began with local introduction of small amounts of quartz into fissures containing irregularly brecciated fragments of country rock. This was followed by a somewhat later period of movement that brecciated the quartz and probably some more country rock. Following these stages the main constituents of the veins formed in the following order: quartz, pyrite, sphalerite and galena, chalcopyrite, fluorite, and calcite. Some quartz continued to crystallize after fluorite formed, as shown by some stringers of quartz cutting fluorite.

Insofar as it could be determined from the poor exposures, the rock bordering the veins is everywhere altered for a distance of a few inches to several feet, and some zones as much as 25 feet wide consist of many veinlets in altered rock. The Mount Aetna porphyry and Mount Princeton quartz monzonite, which are the most abundant wall rocks, have been altered to a whitish or light-green rock. Plagioclase and most of the potash feldspar are altered to a white clay mineral or minerals, although some pink potash feldspar, especially the phenocrysts of the Mount Aetna porphyry, is unaltered. Biotite is altered to chlorite, and this type of alteration extends a little farther from the vein than the argillic alteration. In a few places the veins are bordered by irregular patches of sericitized rock ranging from a fraction of an inch to 2 inches in width.

The veins are unoxidized. No important production of metals nor of fluorite has been made from veins of this type. The ore shoots of the metallic metals so far disclosed in prospecting appear to have had a maximum length of only a few feet. Most, if not all, of the ore was evidently of too low grade for profitable mining, particularly in this area remote from adequate transportation. The fluorite is likewise of no present economic importance because of its low grade and irregular distribution.

The quartz-fluorite veins are believed to have formed during the last main stage of mineralization in the Garfield quadrangle, as discussed on a following page.

QUARTZ-BERYL-PYRITE VEINS

A few veins composed chiefly of quartz, beryl, and pyrite occur in the extreme eastern part of the quadrangle, especially along the divide separating Browns Creek and Baldwin Gulch. The veins fill premineralization fractures in the Mount Antero granite, the andesite, and Mount Pomeroy quartz monzonite. Most of the veins are too short and narrow to show on the geologic map, plate 1, as they commonly range from 5 to 50 feet in length and 1 to 12 inches in thickness. The California vein, however, attains a maximum thickness of 3 feet and is tentatively projected for a distance of 650 feet. The veins range widely in strike, and the dips are everywhere steep. Insofar as it could be determined from poor exposures, all veins adhere closely to the wall rock.

The vein filling is typically white quartz with subordinate amounts of beryl, pyrite, molybdenite, magnetite, and muscovite. Pyrite and beryl are the most persistent of the minor vein minerals, although parts or all of some veins are entirely quartz or quartz and pyrite. Several other minerals occur locally in small amounts, such as fluorite, ferrimolybdite, and fine crystals of wolframite. In addition to the minerals listed above, Adams (1953) and Landes (1934) found topaz, rutile, tourmaline, and the uranium-titanium mineral brannerite in these veins. Quartz occurs near the borders of the vein as fine-grained anhedrons, but in the center of the vein it is coarse grained and locally vuggy. Light-green to bluish-green beryl crystals, a fraction of an inch to 6 inches long, are intergrown with coarsely crystalline quartz or line vugs. Pyrite cubes, 1 to 5 mm in size, are scattered through the fine-grained quartz. Molybdenite usually occurs in fine-grained quartz as streaks or as small crystals in vugs near the border of the veins. Some molybdenite is disseminated for a distance of a few inches into the country rock adjacent to the veins. Fine-grained magnetite forms streaks and narrow lenses near the borders of the veins. Flakes of muscovite 1 to 10 mm across are intergrown with beryl and coarse quartz.

The paragenesis of the main vein minerals, as determined chiefly from megascopic examinations of many specimens from the dump of the California mine, was apparently in the following main stages: (1) quartz (fine-grained) and magnetite; (2) quartz (coarse-grained), beryl, and muscovite; (3) quartz (fine-grained), molybdenite, and pyrite.

Locally the country rock bordering the veins is silicified and pyritized. The silicified rock extends for a distance of a fraction of an inch to a maximum of about 1½ inches, and small pyrite grains locally are disseminated for as much as a foot from the vein. Chloritic alteration of the Mount Pomeroy quartz monzonite extends a few feet beyond the silicified zone of the California vein. The small andesite body northeast of the California mine is everywhere intensely argillized.

This alteration is not believed to be genetically related to the many veins in this area, and it probably represents an older period of alteration related to the pyritic quartz veins.

The quartz-beryl-pyrite veins are of very little economic importance; a very small quantity of gem beryl has been recovered. Pods of molybdenite rarely exceed a length of 1 foot and the ore is of too low grade to warrant profitable mining. Wolframite is very rare and occurs as isolated crystalline aggregates.

The veins are probably closely related genetically to the beryl pegmatites of the Mount Antero granite as discussed in more detail in a following section dealing with the origin of the beryl pegmatites.

ZONING OF THE ORE DEPOSITS

The only evidence found of zoning of ore deposits in the quadrangle is in the Tincup and Quartz Creek districts, as previously noted by Goddard (1936, p. 566) and Tweto.[7] There the relatively high-temperature tungsten-molybdenum veins near Cumberland Pass seem to lie at the center of a large mineralized area embracing the Tincup district and at least the part of the Quartz Creek district lying within the quadrangle boundary and extending as far south as the junction of Middle and North Quartz Creeks. Roughly zoned around this core of tungsten-molybdenum veins are deposits of silver, lead, zinc, and gold, which are characteristic of lower temperatures. There is some evidence of a silver-lead-copper zone between the "tungsten core" and the wide outer zone, although the erratic distribution of silver, gold, lead, zinc, and some of the copper in the outer zone prevents clear-cut definition of the intermediate silver-lead-copper zone tentatively recognized by Tweto.[7] No definite vertical zoning of the primary ore minerals was recognized within the vertical range of surface and underground exposures.

STRUCTURAL AND STRATIGRAPHIC CONTROL

Several types of structure have governed localization of ore bodies, particularly in the sedimentary beds. Likewise some stratigraphic zones were especially favorable host rocks for replacement deposits, and in places a combination of stratigraphic and structural control is evident. Some of these features are described in detail in the descriptions of specific mines that follow.

Minor concentrations of ore occur locally along the axes of small folds, such as the small ore bodies in the eastern part of the Akron mine (fig. 4). The folds, probably in combination with minor fractures, locally guided and confined the ore-bearing solutions. In many places faults have clearly been the major channels for ore-bearing solutions. Some of the largest and richest ore bodies of the quadrangle are located in favorable stratigraphic zones along faults with moderate displacement, such as the rich Madonna ore body along the Madonna fault (pl. 11), the Eclipse ore body along the Mayflower fault, and the Akron ore body along the Star fault (pl. 7 and fig. 3). Small faults, particularly bedding slips, have localized many of the smaller ore bodies; the ore found in the West Gold Hill mine serves as a good example of ore concentrated along a bedding slip. Bedding slips along the Manitou-granite contact and in the lower beds of the Manitou dolomite on the east side of Taylor Gulch probably localized ore in the Garfield, Alaska, and Lilly mines.

There are certain stratigraphic zones in the sedimentary rocks that are more favorable than others for ore concentrations; these are the basal part of the Manitou dolomite, the upper part of the Manitou dolomite immediately below the Harding quartzite, the upper part of the Fremont dolomite directly below the basal shaly beds of the Chaffee formation, the upper 200 feet of the Leadville limestone, and locally, at least in the Whitepine area, the limestone and quartzite beds at the Leadville-Belden contact. Some of these zones that lie in a thick series of limestone and dolomite may represent beds with an inherently greater permeability than others. It is noteworthy, however, that most of the favorable ore zones are in dolomite rather than limestone. Since all the sedimentary rocks in the Garfield quadrangle had been at least moderately deformed before the introduction of the ores, it is possible that deformation produced greater permeability in the dolomites than in the limestones, as postulated by Rove (1947) in his general study of the physical characteristics of ore horizons. Rove (1947, p. 191–192) recognizes that the chemical difference between dolomite and limestone plays a significant role in effecting replacement, but he emphasizes the importance of making these rocks accessible to ore-bearing fluids as a preliminary requisite to replacement. Under favorable conditions of deformation of interbedded limestone and dolomite, the fracturing of the dolomite, as contrasted to the flowage of the limestone, produces far greater permeability in the dolomite beds and therefore makes the latter readily receptive to ore-bearing fluids.

Other ore zones in the Garfield quadrangle lie beneath relatively impervious shaly beds that probably acted as a local barrier to the ore solutions, as for example the thick shale and argillite beds at or near the base of the Belden shale, and the relatively impervious

[7] See footnote 1 on p. 4.

basal shaly beds of the Chaffee formation. This barrier effect of the shale on ore deposition may be the result of inherent differences in permeability between shale and the underlying carbonate rocks or it may be that premineralization fractures and faults of small displacements in the lower beds did not continue strongly into the overlying shale. Thick premineralization clayey gouge zones have acted locally as impervious barriers; for example the thick gouge along the eastward-dipping Star fault, which has largely confined the ore bodies to fractured beds along the western side of the fault.

BERYL IN PEGMATITE, GRANITE, AND GREISEN

Beryl occurs in the Garfield quadrangle in a group of closely related rocks and veins in the Browns Creek area at the eastern border of the quadrangle (pl. 1). None of the occurrences of beryl is, at present, of economic interest other than to gem and mineral collectors. Beryl in quartz veins has already been described under "Vein deposits," and all of the other occurrences are described below. In order to simplify the general groups, beryl in miarolitic cavities is described with the pegmatites.

Beryl pegmatites.—All of the beryl pegmatite bodies and beryl in miarolitic cavities in the quadrangle are in the Mount Antero granite on the west slope of Mount Antero and on the ridge separating Baldwin Gulch and Browns Creek. Only one pegmatite body is exposed in the Mount Antero granite south of Browns Creek; it is similar to the others but no beryl was seen in it.

The pegmatite bodies occur in irregular, rounded, and tabular, or dikelike forms. They range from 6 inches to 10 feet in width and from 3 feet to 100 feet in length. The dips, insofar as could be observed, are steep, and the strikes range widely.

The textures and composition of the bodies differ greatly. The textural terms and classification of zones used here are those of Cameron, Jahns, McNair, and Page (1949, p. 16, 20); that is, the outermost zone of a pegmatite body (in contact with the country rock) is termed the "border zone," the next zone inward the "wall zone," the innermost zone is termed the "core," and any zone or zones between the core and wall zone is termed the "intermediate zone," or zones. Each zone has a characteristic texture and usually a characteristic mineral assemblage. Most of the pegmatite bodies of the Mount Antero granite have a border zone, ranging from ¼ inch to 2 inches in width, composed of fine-grained feldspar, quartz, and muscovite. The contacts of most border zones with the granite are gradational for as much as 1 inch. Some pegmatite bodies, especially the dikes, have a fine-grained or aplitic border zone, and the contacts with the granite are sharp. The pegmatite wall zones are fine grained to medium grained and make up most of the volume of the body. The common minerals in the wall zones are quartz, orthoclase, microcline-perthite, albite, and muscovite and minor amounts of beryl, phenacite, and fluorite. Some pegmatite bodies have cores of white, vuggy, medium-grained quartz. One body may contain one or more cores. The core or cores occur at or near the center and range in length from 1 inch to 5 feet and in width from ½ inch to 2 feet. The contact of the core with the wall zone is usually gradational for a distance no greater than an inch. Lining the vugs or intergrown with the core may be microcline-perthite, smoky quartz, muscovite, albite, fluorite, and these beryllium minerals: beryl, phenacite, and bertrandite.

Miarolitic cavities are sparsely distributed throughout the Mount Antero granite north of Browns Creek. The cavities are ellipsoidal to round, ranging from 1 inch to 3 feet across and averaging 3 to 6 inches. The larger cavities are most abundant on the west slope of Mount Antero, 600 to 1,000 feet below the summit, in an area along and east of the boundary of the quadrangle. The miarolitic cavities are lined with a quartz-feldspar zone, ½ to 1 inch wide, which is coarser grained than the enclosing granite. The contact of the cavity lining with the granite is gradational for as much as an inch. Partially embedded in the lining and projecting towards the center of the cavity are coarse euhedral crystals of microcline-perthite, clear or smoky quartz, albite, muscovite, beryl, phenacite, fluorite, and topaz. Adams (1953 p. 99), Switzer (1939, p. 794), and Over (1935, p. 28) have reported calcite, bertrandite, apatite, garnet, rutile, ilmenorutile, monazite, columbite(?), and cyrtolite as occurring in the pegmatite bodies and in miarolitic cavities in granite.

Switzer (1939, p. 799) determined the following general sequence of crystallization for the minerals in the pegmatite bodies: microcline, beryl, smoky quartz, muscovite, phenacite, albite, fluorite, bertrandite, colorless quartz, calcite, sericite, and limonite.

Beryl granite.—On the west and southwest slopes of Mount Antero are several bodies of beryl-bearing granite. Those within the quadrangle range in width from 2 inches to 10 feet and in length from 6 inches to 25 feet. Reconnaissance a few hundred feet east of the quadrangle on the south and southwest slopes of Mount Antero revealed bodies of beryl-bearing granite as much as 10 feet wide and at least 50 feet long. All of the beryl-bearing granite bodies in the quadrangle are elliptical, and their long axes are oriented west or northwest. Beryl is most highly concentrated near the centers of the bodies and locally constitutes 90 percent of the rock by volume. The proportion of beryl diminishes towards the outer limits of the bodies, and the contacts of the bodies with the granite are gradational. Microscopic examination of the beryl granite shows highly fractured subhedral crystals of blue to white beryl as much as 2 inches long, enclosing subhedral crystals of albite and biotite and anhedral crystals of quartz. Accessory minerals are fluorite, garnet, magnetite, and pyrite.

Beryl greisen.—Two areas of Mount Antero granite within the quadrangle have been altered to greisen, and both contain some beryl. The larger area, lying 300 feet northeast of the California mine (pl. 1), is a poorly exposed body 1,400 feet long and 700 feet wide. The other area is on the ridge between Baldwin and Browns Creeks, about 3,000 feet farther northeast and is a north-trending zone about 1,000 feet long and 400 feet wide east of the contact of the andesite and granite. The greisen is a medium-grained, equigranular, gray rock composed primarily of quartz and muscovite. The contact of the greisen with unaltered granite is gradational for as much as 100 feet. Beryl, molybdenite, fluorite, and pyrite are sparsely disseminated in the greisen in grains 1 to 5 mm long, or line small vugs 12 mm or less in diameter.

Origin.—The occurrence of beryllium minerals in the Mount Antero granite, in pegmatite bodies and in miarolitic cavities in the granite, in areas of granite altered to greisen, and in quartz-sulfide veins cutting rocks adjacent to the granite leaves little doubt that the beryllium mineralization is genetically related to the magma that formed the Mount Antero granite. Detailed studies of the relations of the various types of deposits to one another were not made. Probably the beryl-rich granite, the pegmatite bodies, and miarolitic cavities are related to the pegmatitic phase of the crystallization of the granite.

The presence of sulfide minerals as well as beryllium minerals in the quartz-beryl-pyrite veins and in areas of granite altered to greisen indicates that these two types of beryl deposits were of the same origin and were probably formed by closely related hydrothermal solutions. No facts were observed that might relate the pegmatitic phase to the hydrothermal solutions, other than the similarity in mineral composition and areal distribution. These two facts, however, certainly indicate that all the beryl mineralization is in some way related to the formation of the Mount Antero granite.

Economic importance.—The beryl pegmatite bodies and miarolitic cavities of the Mount Antero region have been prospected by gem and mineral collectors, primarily for aquamarine and phenacite crystals. The exposed pegmatite bodies and miarolitic cavities have been carefully examined by collectors and are cut by many shallow prospect pits. Other than gem-quality aquamarine and phenacite, there has been no commercial production. The inaccessibility of the deposits, their small size, and apparently low grade (Adams, 1953, p. 113) limits, at present, their economic importance to gem and mineral collectors.

ORIGIN AND RELATIVE AGES OF MINERALIZATION

The vein, replacement, and beryl deposits are believed by the authors to have been formed chiefly from hydrothermal solutions that are genetically related to three of the Tertiary igneous bodies that are exposed in the Garfield quadrangle; namely, the Mount Princeton quartz monzonite, the Mount Antero granite, and the volcanic breccia.

In his studies of the southeastern part of the Garfield quadrangle Crawford (1913, p. 221–225) recognized several possible age relationships to the ore deposits of the Monarch and Tomichi districts, but in conclusion he expressed the belief (p. 225) that most of the veins and the replacement deposits were genetically related to the Mount Princeton batholith, and that it was not improbable that the replacement deposts were formed shortly before the fissure veins. From regional studies Crawford (1924, p. 384–385) later postulated that the Mount Princeton batholith underlies a large area to the northeast and it may likely have been the source for ores found in other mining districts. Although conclusive proof is not at hand, the authors agree with Crawford that most, although not all, of the ore deposits in the Garfield quadrangle are related to the Mount Princeton batholith.

Deposits related to the Mount Princeton quartz monzonite.—Deposits assigned to this genetic group include the hubnerite-molybdenite veins, the replacement bodies in sedimentary rocks, and most of the pyritic quartz veins. All these deposits cut the Mount Princeton quartz monzonite or rocks older than the Mount Princeton. Conclusive evidence is not at hand to establish definitely the genetic relations postulated above, although there is evidence of a sort. The magnetite-bearing replacement deposits are almost certainly related to the Mount Princeton batholith because of their proximity to this body and because of the contact metamorphic minerals that are present. It is noteworthy that these bodies also contain sulfides and seem to grade towards the more common "magnetite-free" sulfide bodies that are in the same structures at a greater distance from the batholith, as, for example, the deposits along the Morning Glim fault in the Tomichi district. The mineral composition—except for the relative amounts of quartz—and the distribution of the sulfide replacement deposits and pyritic quartz veins are much the same, and, therefore, both are believed to be related to the same period of mineralization. The hubnerite-molybdenite veins near Cumberland Pass are chiefly in pre-Cambrian granite but some that are too small to show on the geologic map cut the Tincup porphyry of Tertiary age, and, although the relation is not absolutely clear because of poor exposures, the veins appear to pass into pyritic quartz veins. The apparent zoning of the ore deposits of the Tincup and Quartz Creek districts around the hubnerite-molybdenite veins (see p. 53) would support the idea that the replacement deposits, pyritic quartz veins, and hubnerite-molybdenite veins are all related to the same general period of mineralization, although probably the introduction of each type was separated in time from the other.

Deposits related to the Mount Antero granite.—The origin of the beryl-bearing pegmatite bodies, granite, and greisen bodies and the quartz-beryl-pyrite veins has been discussed under "Beryl in pegmatites, granite, and greisen." If, as it seems very likely, these deposits are related to the Mount Antero granite, they are therefore younger than the deposits believed to be related to the Mount Princeton quartz monzonite.

Deposits related to the volcanic breccia.—The last period of mineralization in the Garfield quadrangle was relatively weak and occurred after the volcanic breccia was formed. The deposits thus formed are thought to be genetically related to the magma that formed this breccia. Veins assigned to this age group consist of all the quartz-fluorite veins shown on the geologic map, plate 1, and a few pyritic quartz veins that center around Mount Aetna. Many of the veins cut rocks, such as the quartz latite porphyry, Mount Aetna porphyry, and volcanic breccia, that are younger than either the Mount Princeton batholith or the Mount Antero granite.

The few pyritic quartz veins that belong to this age group could not be distinguished by physical characteristics or mineral content from those assigned to the older Mount Princeton, but the veins in the younger group are so poorly exposed that their characteristics are obscure. The absence of distinguishing features might, quite logically, suggest that all pyritic quartz veins in the quadrangle formed after the volcanic breccia; however, there is evidence of a sort to suggest that there were at least two periods of pyritic quartz mineralization. About half a mile north of Brittle Silver Basin a pyritic quartz vein that strikes northeast and dips northwest has apparently been cut off at its northeast end by a dike of Mount Aetna porphyry (pl. 1). The field evidence here is not absolutely clear because of poor exposures, but from what can be observed, the dike apparently cuts off the end of the vein. If it does, this would establish the fact that there were two ages of pyritic quartz veins. Those that formed before the intrusion of the Mount Aetna porphyry, as previously discussed, are believed to be related to the Mount Princeton batholith, and the younger and much less abundant group that cut rocks of post-Mount Princeton age, including the volcanic breccia, are believed to be genetically related to the breccia magma. Another factor which suggests, although certainly does not prove, that most of the pyritic quartz veins are related to the Mount Princeton batholith, is the widespread distribution of these veins in an irregular zone bordering the batholith (pl. 1); in conjunction with this statement it should be noted that definitely established post-Carboniferous mineralization of this small region is largely confined within the boundaries of the Garfield quadrangle. Furthermore, a large body of magma, such as formed the batholith, would be a likely source of large quantities of ore-bearing solutions necessary to cover this mineralized area.

MINES AND PROSPECTS

The locations of the mines and larger prospects are shown on the geologic map (pl. 1), and the geologic setting of many of these is more clearly shown on the large-scale maps of the Tincup district (pl. 4), the Whitepine area of the Tomichi district (pl. 5), and the Cree Creek area of the Monarch district (fig. 8). A detailed map by Tweto [8] of the surface geology of the tungsten-molybdenum area near Cumberland Pass is a helpful reference.

The mines and prospects are described by districts on the following pages. Usually the mines with the larger production are described first, and the others follow in outline form; the mines in both groups are arranged in alphabetical order. Most of the mines have been inaccessible for many years, and many of the descriptions are summaries of a combination of published descriptions, information obtained locally from residents, and the results of the writers' field observations. By far the most fruitful source of published information is that of Crawford (1913, p. 234–310) for the many mines and prospects of the Monarch and Tomichi districts. The authors have also drawn freely from the mine descriptions of Goddard (1936, p. 571–591) in the Tincup district, and Tweto [8] in the Cumberland Pass area. It will be noted in the following descriptions that production figures are generally divided into those before and after 1901, because systematic recording of mine production data for this re-

[8] See footnote on p. 4; pl. 1.

gion was first begun by the Federal Government in 1901. Unless otherwise stated, the data on production since 1901 have kindly been furnished by A. J. Martin of the Economics Division, Statistics Branch, U. S. Bureau of Mines, Denver, Colo.

In the outline descriptions for some of the mines it will be noted that the ore and sulfide minerals are presented as a list with no specific statement made regarding the character of the typical ore that has in the past yielded the values. This omission is due to the absence of definite data for these mines. The minerals in these instances are listed in accordance with their apparent relative abundance; the most abundant is given first. This has been determined largely from material seen on the mine dump or this material in combination with old records, and it should be recognized that these data may not reflect the typical mineralogy of the ore bodies that were once mined.

The only mines in which any substantial amount of work was being done during the course of the present investigation are the Akron and Erie mines of the Tomichi district, the Madonna, Lilly, and Garfield mines of the Monarch district, and the Mary Murphy and Stonewall mines of the Chalk Creek district.

TINCUP MINING DISTRICT

CHIEF ECONOMIC AND GEOLOGIC FEATURES

The Tincup is chiefly a silver-lead district, although considerable gold was obtained from many of the mines, such as the Gold Cup, West Gold Hill, Tincup, and Deacon mines, and probably others. Copper, zinc, and iron have also been produced in commercial quantities. Probably no attempt was made in the early days to mine zinc because of a lack of smelting facilities, even though zinc may have been found. Practically all the mines were badly caved when visited, and very little production has been recorded in the past 50 years.

Ore occurs in the Tincup district chiefly as bedded replacement deposits and in fissure veins. The fissure veins of economic importance occur along the southwestern border of the area shown on the geologic map of the Tincup district (pl. 4). The Jimmy Mack, Deacon, and Indiana mines are reported to have obtained most of their output from veins. The veins are reported to range in thickness from 2 to 6 feet and to strike north to northeast, with steep to moderate dips either to the east or west. Probably none of the veins exceeds 1,000 feet in length, although heavy slope wash and talus prevent tracing them on the surface, and reliable mine data could not be obtained for these inaccessible mines. Most of the other mines in the district have obtained ore from bedded replacement deposits, which are by far the most important economically, although the rich ore from the Jimmy Mack mine is a notable exception. The replacement deposits are in limestone or dolomite and commonly conform in general to the attitude of the enclosing strata, although some smaller bodies or parts of the larger deposits pass into irregular replacement deposits and locally follow fault fissures. The most productive stratigraphic zone is the upper part of the Leadville limestone at the contact of a gray to bluish-gray limestone with overlying darker gray dolomitic limestone. The ore bodies of the Gold Cup mine, the richest in the district, with a production valued at more than $1,000,000 (Goddard, 1936, p. 554), were in this zone, as were those of the Robert E. Lee, Silver Cup, and Sylvan Dell mines. The ore of the Tincup and Drew mines was chiefly in a bed about 100 feet lower stratigraphically than that in the Gold Cup. Ore in the West Gold Hill mine came from the lower part of the Manitou dolomite, where it was localized along a bedding slip, and in the El Capitan mine the ore replaced the Fremont dolomite for a few feet immediately below the basal shale and limestone beds of the Chaffee formation. Minor productive zones include the top of the Manitou dolomite, limestone beds immediately above and below the main quartzite beds in the Parting quartzite member of the Chaffee formation, and the lower 50 feet of the Leadville limestone. The quartz diorite porphyry and the Tincup quartz monzonite porphyry intruded the country rock before the ore deposits were formed but apparently these porphyries did not influence ore deposition, as did the Tertiary porphyries of the Leadville mining district (Emmons, Irving, and Loughlin, 1927, p. 189). However, the authors believe that the contact between carbonate rock and the porphyries has not been explored sufficiently in the Tincup district to warrant its complete condemnation.

The primary sulfide minerals—galena, sphalerite, chalcopyrite, pyrite, and, less commonly, tetrahedrite—occur in the deeper parts of some of the mine workings, but most of the ore mined from both the veins and replacement deposits was oxidized. The chief ore minerals of the oxidized deposits are cerussite, calamine, and anglesite, locally accompanied by cerargyrite, argentite, malachite, azurite, or chrysocolla. All these are typically contained in a brownish gangue of porous limonite, limonitic quartz, or jaspery limonite. Small residual masses of galena occur in much of the oxidized ore. No specific data are available regarding the occurrence of gold. It probably occurs in the free form in limonite and in some of the sulfide minerals; locally, pyrite has been reported to carry much gold. Silver is generally contained in galena, although cerargyrite and argentite have been reported locally.

According to information obtained by Goddard

(1936, p. 565–568), the ore shoots of the replacement bodies are commonly 30 to several hundred feet in length, 20 to 50 feet in breadth, and generally not more than 8 or 10 feet thick. He further states that all the ore was at least partly oxidized, and much of it was completely oxidized. The ore at the bottom of the Gold Cup shaft, a depth of about 500 feet, was partially oxidized. Little information is available regarding the size of the ore shoots in the vein deposits. It is reported that partial oxidation extends to about the same depth on veins as in the replacement deposits.

A small tonnage of iron ore has been produced from the Cumberland mine and immediate vicinity, about half a mile southeast of the Jimmy Mack mine (pl. 1). The ore minerals are magnetite and some hematite in a gangue of typical contact metamorphic minerals. The ore occurs at the contact of the Leadville limestone and quartz diorite porphyry.

Although no major placer mining has been done for about 75 years in the Garfield quadrangle, minor operations along Willow Creek and Tincup Gulch have produced a few ounces of gold from time to time.

GOLD CUP MINE

The Gold Cup (Gold Cup Republic) mine is on a prominent north-trending ridge about three-quarters of a mile east of Duncan Hill at an altitude of about 11,400 feet (pl. 1). It has been by far the largest producer in the Tincup district. According to Lowry Englebright (oral communication, 1949) the Gold Cup was located sometime in the seventies by Messrs. Hull and Herd who shortly afterward sold it to a group of men living in New York. The New York group mined the rich oxidized ore bodies near the surface until 1883, after which the mine was shut down for awhile and later was operated intermittently by lessees. Sometime before 1903 all or part interest in the property was acquired by the Reynolds-Morse Corp. of Denver. The property was leased to I. L. Johnson who worked it intermittently from about 1904 to 1926. In 1904 the old inclined shaft was abandoned and the equipment moved to Middle Willow Creek where an adit was started and driven southwestward toward the lower mine workings. From 1926 to 1936 the property was leased by J. W. Belcoe and a Mr. Momb who reportedly did some work in the lower tunnel. From 1936 to 1950 little or no work was done.

A complete record of production from the Gold Cup mine has not been preserved. It is generally reported, probably about correctly, that the gross value of output is about $1,500,000, mostly obtained before 1883. The chief values were in silver, lead, and gold. The local newspaper, the Tincup Miner, reported the production for 1883 as 800 tons, valued at $88,000, and for 1890, ore valued at $58,395, of which $3,900 was for gold, $50,424 for silver, and $4,071 for lead. Production was intermittent from 1902–1935 when a total of 2?4 tons of crude ore yielded 111 ounces of gold, 18,520 ounces of silver, 264 pounds of copper, and 21,777 pounds of lead. The tenor of most of the ores ranged from about 30 to 1,800 ounces of silver and 0.5 to 4 ounces of gold to the ton. According to Mr. Englebright (oral communication, 1949) some silver ore first mined near the surface ran as high as 3,000 ounces to the ton.

Figure 2 shows most of the mine workings and outlines of the stoped areas. Only a few hundred feet of the mine workings were accessible when visited in 1949. Entrance to the oldest workings was from two adits north of the inclined shaft; the adits are now almost covered by dump material. The inclined shaft bears N. 56° E. for about 925 feet down the dip of the beds; it has an average slope of 30° and its base is 456 feet lower than the portal. Nine main levels extend from the shaft; most of the stopes are above level 7. About 3,000 feet northeast of the shaft and about 600 feet lower an adit near Middle Willow Creek has been driven S. 60° W. for about 2,200 feet where it intersected the main Gold Cup ore zone, which here, however, was only weakly mineralized.

The principal mine workings are in the Leadville limestone about 150 feet below the overlying Belden shale. The most important ore zone is at the contact of a gray to bluish-gray limestone and overlying dolomite or dolomitic limestone. The Willow Creek adit was driven about 1,820 feet through the Belden shale, which contained at least two thick sills of Tincup porphyry, before reaching the top of the Leadville limestone. The beds strike N. 10°–35° W., and dip 20°–40° NE. According to G. H. Garrey (oral communication, 1949), the tunnel intersected several nearly vertical premineral fissures that trend north and northeast; most of these do not contain sufficient ore to be productive, but Garrey believes that they were the channels through which the mineralizing solutions spread out along favorable contacts or ore horizons. It is reported that locally a low-angle or bedding fault lies along the contact of the limestone and dolomite of the main ore zone. The limestone and dolomite contact in the Willow Creek adit was seen by Goddard (1936, p. 574) who states,

> The contact, as exposed at the breast of the tunnel, is cut and offset by a N. 70° E. fault, the displacement being about 30 feet eastward on the south side. In the contact plane adjacent to the fault there is about 1 to 1½ feet of gougy limonitic, siliceous material, which contains a small amount of ore. The fault zone is 2 to 3 feet wide and consists of sheared and brecciated limestone, which is stained with limonite and con-

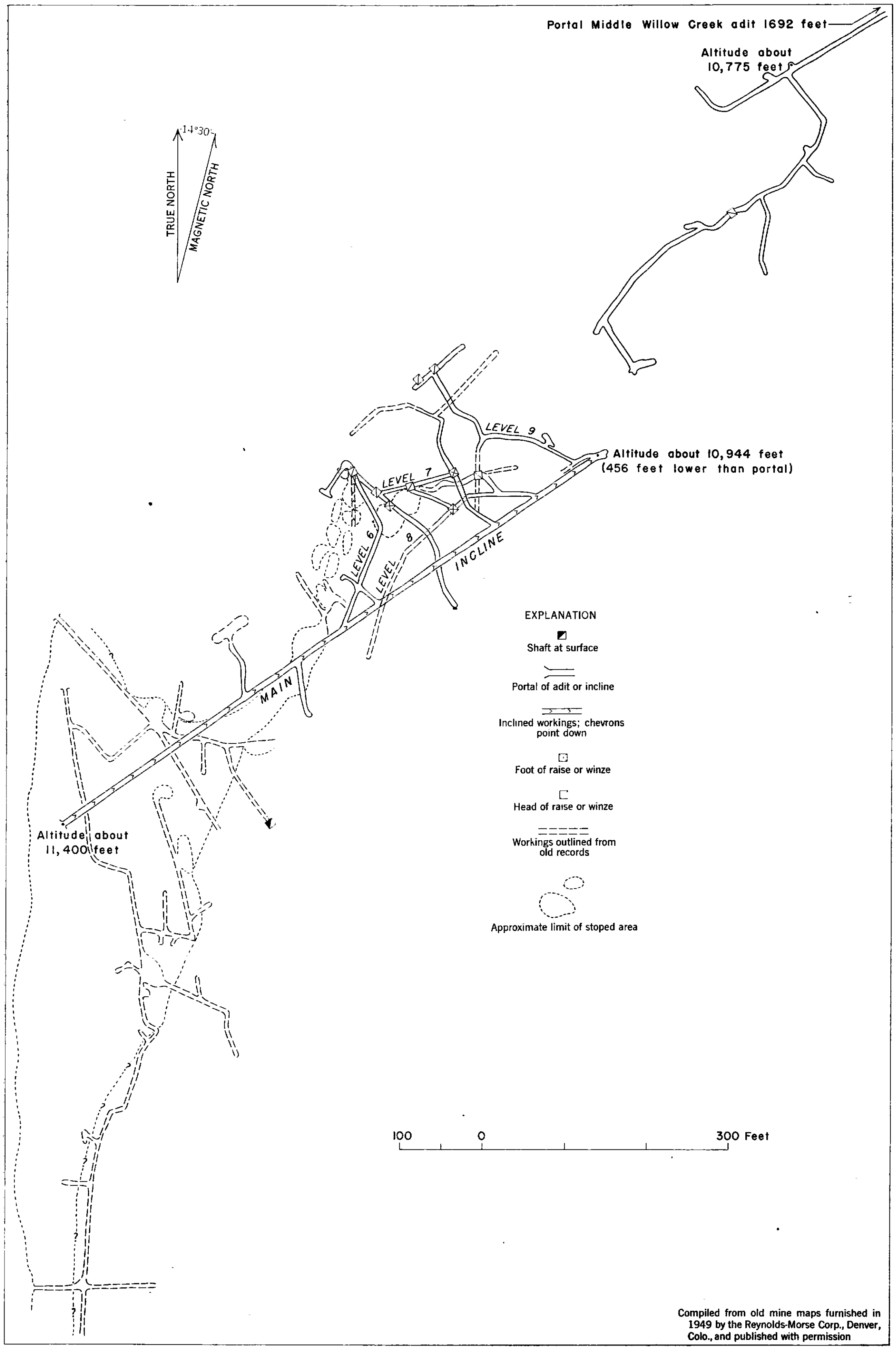


FIGURE 2.—Map of the upper and part of lower workings of the Gold Cup mine, Tincup mining district.

tains calcite seams. Throughout the last 360 feet of the tunnel there are several brecciated bedding planes and numerous nearly vertical fissures of northeast trend which contain quartz, limonite, and small amounts of ore, but there are no ore bodies of commercial size.

Most of the ore mined was oxidized and contained cerussite, cerargyrite, limonite (gold-bearing), residual grains of silver-bearing galena, anglesite, malachite, and locally calamine, azurite, and chrysocolla. The primary minerals, in addition to galena, are pyrite (gold-bearing), chalcopyrite, tetrahedrite, and sphalerite. The typical ore is a mixture of limonite and sugary, jaspery, or cellular quartz, and contains seams and irregular patches of cerussite and anglesite, in places bordering and cutting galena. Locally, some fractures and cavities are filled with calamine, malachite, and chrysocolla. Many cavities are lined with quartz crystals. Calcite, a minor gangue mineral, was the latest mineral deposited.

The main ore bodies are of the bedded replacement type. The largest mineralized area extends from a point about 250 feet north of the portal of the inclined shaft south for about 900 feet (fig. 2). This area was worked from near the surface northeast down the dip of the beds for a slope distance of about 500 feet. Beyond this point about 10 smaller ore bodies are clustered north of the incline, and at a still lower level, and to the northeast, a little ore occurs in the Willow Creek adit in north- and northeast-trending fissures. Individual ore shoots are reported to have ranged from 30 feet to several hundred feet in length, 10 to 60 feet in breadth, and 1 to 7 feet in thickness. According to Mr. Englebright, the gold ore did not extend down far from the surface, and below the gold zone the shoots graded into very rich silver chloride ore, which in turn gave way at depth to silver-bearing galena.

OTHER MINES AND PROSPECTS

BLISTERED HORN TUNNEL

Development.—Tunnel bears east into hill and has been driven about 1,800 feet; reportedly reached lower Paleozoic units. Portal caved when visited in 1948. Raise of about 375 feet connects with lower workings of Jimmy Mack mine. Amount of drifts unknown but probably small. Tunnel started in 1902 and work abandoned in 1920.

Production and tenor.—No record of any production before 1906. The recorded production from 1906 to 1950 is 788 tons, although this might be ore from the Jimmy Mack mine. The 788 tons yielded 64,117 pounds of lead, 9,583 ounces of silver, 78 ounces of gold, and 149 pounds of copper.

Veins.—Several northeast-trending and steeply dipping veins cut in tunnel. Both oxidized and primary ore on dump.

Wall rock.—Chiefly gneissic granite; some quartzite and dolomite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, cerussite, calamine, malachite, azurite, and chrysocolla.

Gangue minerals.—Quartz and limonite.

CUMBERLAND

Development.—Adit (caved when visited in 1948) bearing east, and several pits and cuts. Small amount of workings.

Production and tenor.—No complete record of production before 1901; in 1883 produced 530 tons of ore valued at $13,250; tenor reported to be 6 ounces of silver and 2 ounces of gold to the ton, and 64 percent iron. No production recorded from 1901–50.

Ore body.—Replacement body in limestone bed in Belden shale that lies between the quartz diorite porphyry and Tincup quartz monzonite porphyry. Extends irregularly along strike of bed for several hundred feet, locally 10 feet thick as exposed in 1949 and reported as much as 38 feet thick in mine.

Ore and sulfide minerals.—Magnetite, hematite, limonite, malachite, and chalcopyrite. Gold and silver probably in limonite and chalcopyrite.

Gangue minerals.—Calcite, quartz, garnet, diopside, serpentine, and tremolite.

DEACON

Development.—Shaft (caved when visited in 1949) about 150 feet deep. Extent of underground workings reported to be small.

Production and tenor.—No complete records available of production before 1901. No production recorded 1901–50. Some good silver-lead-gold ore. Average tenor $50 a ton, and some as high as 6 ounces of gold to the ton.

Vein.—Strike N. 5° E., dip nearly vertical, length 400 feet (?), width 2 to 3 feet.

Wall rock.—Manitou dolomite.

Ore and sulfide minerals.—Cerussite, galena, and free gold.

Gangue minerals.—Quartz and limonite.

DREW

Development.—Inclined shaft (caved when visited in 1949) 200 feet deep and at least 500 feet of lateral workings.

Production and tenor.—No complete records available of production before 1901. No production recorded 1901–50. A shipment in 1881 of 7 tons gave returns of 82 ounces, 127 ounces and 676 ounces of silver to the ton for the three classes of ore; single assays ran as high as 3,454 ounces. In 1882 a 25-ton shipment assayed $200 a ton, and in 1883 an 87-ton shipment returned $8,700, or an average of $100 a ton. In 1883 mill run of ore when sorted ran 50 to 150 ounces of silver to the ton and 20 percent lead.

Ore bodies.—Bedded replacement deposits in the upper part of the Leadville limestone.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Cerussite, galena, calamine, free gold, malachite, and chrysocolla.

Gangue minerals.—Quartz, limonite, and calcite.

EL CAPITAN

Development.—Inclined (18° SE.) shaft (inaccessible when visited in 1947) and about 1,000 feet of underground workings.

Production and tenor.—Ore produced to end of 1883 valued at $60,000 to $80,000. No record, and possibly no production, 1884–1900. From 1901–50, only recorded production is 68 tons in 1918–19. In 1882 tenor reported to be $50 to $700 a ton, and in 1883 ore averaged $100 a ton. A 250-ton lot contained 50 ounces of silver per ton. In 1883 mill run ore reported to average 1 ounce of gold per ton. The 68 tons of ore produced in 1918–19 yielded 6,746 pounds of lead, 2,267 ounces of silver, 12 ounces of gold, and 12 pounds of copper.

Ore body.—Bedded replacement deposit 4 to 10 feet thick at top of Fremont dolomite along its contact with overlying shale and limestone of basal Chaffee formation. Beds dip 15°–20° E.

Wall rock.—Limestone, dolomite, and shale.

Ore and sulfide minerals.—Galena, pyrite, cerussite, calamine, anglesite, malachite, and free gold probably associated with the pyrite. Cerargyrite and argentite have been reported but are scarce.

Gangue minerals.—Quartz, silicified limestone, and limonite.

INDIANA

Development.—Shaft (caved when visited in 1949) about 250 feet deep. Extent of underground workings are not known but estimated to be about 1,000 feet, judging from size of dump.

Production and tenor.—No records available of production before 1901. No production recorded 1901–50. Reported to have shipped a small amount of good-grade ore which carried silver, lead, and a small amount of gold.

Vein.—Strike N. 30° E., dip 55° NW., length 425 feet (?).

Wall rock.—Limestone and dolomite of Chaffee formation, and quartz diorite porphyry.

Ore and sulfide minerals.—Cerussite, galena, and free gold.

Gangue minerals.—Quartz and limonite.

JIMMY MACK

Development.—A 435-foot shaft (inaccessible when visited in 1949) inclined 70° E.; six levels which range from 150 to 350 feet in length; and a 400-foot winze on the 300-foot level that connects with the lower Blistered Horn tunnel.

Production and tenor.—Records of production before 1901 are incomplete; nearly all production before 1894. Total value reported to be about $700,000. From 1901 to 1950 only recorded production was in 1907 when 152 tons of ore yielded 55 ounces of gold, 977 ounces of silver, and 14,396 pounds of lead. Tenor ranged from about $60 to $130 a ton; highest assay was from ore mined in 1883, which ran 6,385 ounces of silver and 0.5 ounce of gold to the ton.

Vein.—Strike N. 25°–30° E.; dip 70° SE.; width 3½–6 feet.

Wall rock.—Dolomite, limestone, and quartzite of Manitou, Harding, Fremont, and Chaffee formations.

Ore and sulfide minerals.—Cerussite, anglesite, and some galena and gold. Gold probably in limonite.

Gangue minerals.—Quartz and limonite.

NAPOLEON

Development.—Adit bearing about N. 35° E. at portal, and several short prospect adits and shallow pits. Mine workings probably total about 500 to 700 feet, judging from size of dump.

Production.—No records available before 1901. No production recorded 1901–50.

Ore bodies.—Replacement deposits in the Leadville limestone.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, cerussite, calamine, and smithsonite.

Gangue minerals.—Limonite, calcite, and quartz.

NATIONAL

Development.—Shaft 90 feet deep, 3 northeast-bearing adits, and 1 adit, south of shaft and 200 feet lower, that bears northwest. All mine entrances caved when visited in 1948.

Production and tenor.—No records available before 1901. No recorded production 1901–50. Locally reported that no ore shipped since 1890.

Ore bodies.—Reported to be replacement deposits in Leadville limestone about 150 feet stratigraphically below top of formation.

Wall rock.—Limestone, dolomite, and some porphyry.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and malachite.

Gangue minerals.—Calcite, quartz, and some limonite. Quartz mostly brecciated.

ROBERT E. LEE

Development.—Shaft (caved when visited in 1949) and an estimated total of 1,200 feet of workings.

Production and tenor.—Records of production before 1901 incomplete; reported value in 1887 was about $9,000 and in 1890 it was $5,898. Recorded production 1901-50 is 38 tons of crude ore that yielded 1 ounce of gold, 2,535 ounces of silver, and 15,600 pounds of lead.

Ore bodies.—Bedded replacement deposits in the upper part of the Leadville limestone in a higher stratigraphic zone than ore in the Gold Cup mine.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Cerussite, galena, calamine, gold, malachite, and chrysocolla.

Gangue minerals.—Quartz, limonite, and calcite.

ROBERT E. LEE NO. 2

Development.—Shaft inclined to east (badly caved at collar when visited in 1949). Extent of workings not known, but probably not more than 500 feet.

Production.—No records available before 1901. No production recorded 1901–50.

Ore body.—Probably replacement deposit in upper part of Leadville limestone.

Ore minerals.—None seen on dump although some limonite may contain gold.

Gangue minerals.—Limestone and dolomite.

SILVER CUP

Development.—Adit bearing about S. 50° E. at portal and two shafts (all badly caved when visited in 1948). Reported to have been stoped irregularly for about 1,500 feet (probably both north and south from shafts).

Production and tenor.—Production included with that of Gold Cup, and probably most, or all, production before 1894. Reported to have been high-grade silver-lead-gold ore.

Ore body.—Bedded replacement deposit in Leadville limestone about 150 feet stratigraphically below top.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Cerussite, anglesite, cerargyrite, smithsonite, calamine, galena, and free gold.

Gangue minerals.—Quartz, limonite, and calcite.

SYLVAN DELL

Development.—Shaft (caved when visited in 1947). Extent of underground workings could not be ascertained, but probably small, considering size of dump.

Production.—None on record. May have had small production before 1894.

Ore body.—Probably bedded replacement deposit in upper part of the Leadville limestone.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Probably cerussite, smithsonite, calamine, and galena.

Gangue minerals.—Quartz, limonite, calcite, and dolomite.

TINCUP

Development.—Vertical and inclined shafts (both caved when visited in 1949) and an estimated total of 1,200 feet of lateral workings.

Production and tenor.—Records of production before 1901 are incomplete; in 1883 production of 400 tons valued at $60,000 and in 1890 recovered $1,100 in gold, $14,222 in silver, and $1,131 in lead for total of $16,453. Tenor of 450 tons shipped in 1881 averaged $180 a ton; 450 tons shipped in 1882 averaged $178 a ton; in 1883 tenor ranged from 50 to 380 ounces of silver to the ton and about 60 percent lead. Recorded production from 1901–50 is 125 tons; no production since 1914.

Ore bodies.—Bedded replacement deposits in Leadville limestone chiefly in a stratigraphic zone somewhat lower than ore in the Gold Cup mine.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Cerussite, galena, calamine, gold, malachite, azurite, and chrysocolla.

Gangue minerals.—Quartz, limonite, and calcite.

WEST GOLD HILL

Development.—Workings consist of an adit bearing east for 300 feet, an inclined (8°–23°E.) stope 225 feet long connected to surface by incline 140 feet long, and 130 feet of crosscuts.

Production and tenor.—No records available of production before 1901. Recorded production 1901–50 is 2,493 tons that yielded 650 ounces of gold and 1,374 ounces of silver. No production recorded since 1908. Gold principal metal and reported to be high grade locally.

Ore body.—Bedded replacement deposit in Manitou dolomite about 35 feet above Sawatch quartzite.

Ore minerals.—Gold (in limonite), cerussite, malachite, chrysocolla.

Gangue minerals.—Quartz, limonite, silicified limestone, calcite.

Ore shoot.—Pitch length 250 feet, breadth 15 to 25 feet, thickness 7 to 15 feet, pitches east about 15°. Shoot in breccia zone of bedding fault. Breccia zone cut by several northerly trending and steeply dipping faults; all faulting before ore deposition. Faults caused localization of ore shoots.

QUARTZ CREEK MINING DISTRICT

CHIEF ECONOMIC AND GEOLOGIC FEATURES

In the part of the Quartz Creek district that lies within the Garfield quadrangle the chief values have been in silver and lead, although some gold, copper, zinc, molybdenum, and tungsten have been produced in commercial quantities. Molybdenum and tungsten are confined to the northern part of the district, chiefly near Cumberland Pass. The only mine in the Quartz Creek district that was even partly accessible in 1950 was the Complex (pl. 1), which lies about on the southern border of the area that contains molybdenum and tungsten. Ore occurs in the Quartz Creek district in fissure veins and in replacement deposits in limestone and dolomite.

The veins are chiefly in pre-Cambrian gneissic granite in the northern part of the district, north of the Athens fault (pl. 1). Most of the veins contain the tungsten and molybdenum minerals hubnerite and molybdenite. The veins range widely in strike, although the strongest and most persistent molybdenum veins strike nearly east, and the tungsten veins all strike northeast, except the Complex vein which strikes northwest. The dips of the veins, insofar as could be determined, are on the whole rather flat, and three of the largest ones, the Mammoth, Bon Ton, and Complex, dip only 40° to 45°. The lengths of most of the veins, determined from poor exposures at the surface, are only 100 to 200 feet long, although the Mammoth-Orient veins, which are probably the same, have a total length of about 1,700 feet. Widths range from a few inches to about 5 feet, and the average is 1½ to 2 feet.

In the southern part of the Quartz Creek district the ore deposits of known economic importance all lie west of North Quartz Creek, principally in a belt a little less than 2 miles long extending from the Silent Friend mine north to the Athens fault (pl. 1). Very little is known of these deposits except what can be learned from study of the mine dumps, their surface locations, and records of past production of some of the mines. The Silent Friend mine apparently explored a replacement deposit in the Fremont dolomite. The old workings clustered around the Maid of Athens mine, south of the Athens fault, may have obtained ore from replacement deposits in the upper part of the Leadville limestone and the thin limestone beds of the Belden shale, although the positions of the openings to some of the mines suggest that part of the ore, at least, came from northwest-trending veins along minor fractures formed during the movement on the Athens fault. The many prospects along the Athens fault indicate that ore was locally concentrated in the limy beds on the south side of the fault.

Some of the ore on the mine dumps is oxidized and forms a brown, porous limonitic quartz locally containing a few patches of galena and some cerussite, but most of the ore now seen on the dumps shows fairly fresh primary sulfides, including galena, sphalerite, pyrite, and chalcopyrite, in a white to gray, fine to cryptocrystalline quartz gangue, or less commonly in a limestone, dolomite, or marble gangue. Some barite is associated with the gangue quartz at the Maid of Athens mine. Malachite, azurite, and chrysocolla occur locally in minor amounts, and tetrahedrite and polybasite are reported from some mines. By far the greatest values have been in silver and lead, although some fairly rich gold ore has been found locally, and a small production of copper has been made.

GRAPHITE MINES

Graphite has been produced from mines in Graphite Basin, which is 1½ miles S. 70° E. from Cumberland Pass at an altitude a little above 11,000 feet (pl. 1). According to A. L. Pearson (oral communication, 1948), prospecting was first done in this area for silver many years ago, but much later the area became known for its graphite, and during World War I about 78 cars (narrow gage) of graphite were shipped. No mining has been done since then. In 1948 the property was held by A. E. Woodruff of Greeley, Colo.

All mine workings were caved at their entrances when visited in 1948. The principal workings are on the north side of the stream. The main adit enters the hill on a bearing of about N. 5° E. A lower adit 80 feet S. 20° E. of this probably enters the same workings as the main adit. Another adit about 100 feet N. 50° E. from the main adit bears north into the hill. The extent of the underground workings is not known, but the size of the dumps indicate about 2,000 feet of workings. The mine south of the stream and about 850 feet from the others was worked through an adit bearing about due south. The size of its dump indicates about 1,000 feet of workings.

The country rock is carbonaceous shale, dark limestone, and a few beds of quartzite of the Belden shale. Disseminated pyrite is common in the shale and limestone.

The graphite is amorphous except for occasional flaky streaks. According to Mr. Pearson, there are three graphite seams ranging from 18 inches to about 15 feet in thickness. The thickest seam, the one mined on the south side of the stream, averaged about 45 percent carbon, and the other two averaged 85 to 95 percent carbon.

The main adit to the mine on the north side of the stream enters the hill along a fault that strikes N. 14° E. and dips 82° E. Above the portal to this adit is a small exposure of slickensided, black carbonaceous shale and graphite about 6 feet thick that lies between quartzite and gray recrystallized limestone.

MAID OF ATHENS MINE

The Maid of Athens mine, at an altitude of about 11,000 feet, is a mile northwest of the mouth of Halls

Gulch, and several hundred feet north of a stream tributary to North Quartz Creek. According to A. L. Pearson (oral communication, 1948), mining began in 1897. The last period of active operation was between 1915 and 1917. The property was held in 1948 by persons living in Canada, according to Harold Koster, of Salida, Colo.

The mine entrances were all badly caved when visited in 1948. The main entrance apparently was by a shaft, reported to be about 200 feet deep, although three adits, all bearing northwest, are within a distance of 150 feet from the shaft. The underground workings, which must have been fairly extensive, judging from the size of the dump, extended northwest to the boundary of the Citizen claim. The earliest work was done on the northwestern part of the claim, and entrance was obtained by another shaft of unknown depth.

The country rock is black argillite, dark-gray limestone, and some gray quartzite of the lower part of the Belden shale. Exposures are poor, but one limestone bed 125 east of the main shaft strikes nearly east and dips about 40° N. The limestone is strongly jointed; the joints are vertical and strike N. 12° W.

The mine entrance is only a few hundred feet south of the strong Athens fault which brings pre-Cambrian granite on the north against Pennsylvanian rocks on the south, and it is probable that a large part of the underground mine workings were in a wide fault zone. Most of the rock on the mine dump is brecciated and cemented by calcite and quartz.

The ore, according to Mr. Pearson, was mostly silver-bearing galena, although it contained some gold, probably in pyrite, and some zinc in the form of smithsonite. The ore shoots were chiefly in the limestone beds adjacent to a narrow dike of Tincup porphyry. Mr. Pearson stated that the ore occurs as irregular "veinlike" bodies ranging in width from an inch or less to large "cavelike" bodies. Mineralized material on the dump is gray to black silicified limestone with minor patches and irregular veinlets of white quartz, both commonly iron stained. Most of it has many small vugs and narrow cracks lined with minute quartz crystals which give a shiny appearance to some of the rock. One specimen on the dump showed white barite intergrown with white quartz. Some of the gray silicified rock has been brecciated and recemented by a later generation of white quartz. Pyrite and galena are common in small grains, and minor amounts of chalcopyrite and copper stain are present.

SILENT FRIEND MINE

The Silent Friend mine is half a mile southwest of the mouth of Halls Gulch on the steep east slope of the mountain about 1,000 feet above North Quartz Creek. According to A. L. Pearson (oral communication, 1948) the mine was originally located by a Mr. Stoller, probably in the seventies or eighties, and the last work of any consequence was in 1890. In 1917 the mine was reopened by Elmer Wiley, but no ore was shipped. The total value of the ore produced, as estimated by Mr. Pearson, was $400,000 to $500,000, with values mainly in silver and lead.

Entrance to the mine, which was caved when visited in 1948, was by an inclined shaft bearing west-northwest, and reported to be 300 to 400 feet long. The size of the dump indicates a moderate amount of underground workings, probably the equivalent of about 2,000 feet of tunnel. The ore occurred in dolomitic limestone of the Manitou formation bordering, but not in, a northwest-trending reverse fault, probably the fault shown on the geologic map, plate 1, 500 feet west of the mine.

According to Mr. Pearson, the ore shipped in the early days consisted chiefly of silver-bearing galena, a little gold-bearing pyrite, and minor amounts of cerussite and anglesite. Most of the ore was from caves in the dolomitic limestone. Some ore on the dump contains, in addition to the minerals mentioned above, considerable light-green and brown sphalerite, chalcopyrite, secondary copper stains, and a little tetrahedrite, all in a quartz and calcite gangue.

OTHER MINES AND PROSPECTS

BEN FRANKLIN

Development.—Shaft (caved when visited in 1948), reported to be "not deep." Extent of underground workings unknown.

Production and tenor.—Total value of ore produced estimated by A. L. Pearson to be $40,000 to $50,000. From 1901 to 1950 the only recorded production was in 1911, when 9 tons of ore yielded 455 ounces of silver, 30 pounds of copper, and 374 pounds of lead. This was the first mine in this area, and ore reported to be rather low-grade silver-lead.

Veins.—None indicated on surface but probably along or adjacent to the Athens fault.

Wall rock.—Argillite, limestone and dolomite beds of Belden shale; gneissic granite, and quartz monzonite porphyry.

Ore and sulfide minerals.—Pyrite, galena, and chalcopyrite.

Gangue mineral.—Quartz.

BON TON

Development.—Crosscut adit bears about N. 10° W. for 600 feet. At 285 feet from portal a drift extends 220 feet westward and 200 feet eastward, stoped about 150 feet of this distance. At about 200 feet and 60 feet from the portal, two drifts extend east 140 and 100 feet, respectively. Portal was caved when visited in 1949.

Production.—No records available before 1901. Only recorded production from 1901 to 1950 was in 1913–22 when 1,980 tons of crude ore was produced, which yielded 133 ounces of gold, 3,527 ounces of silver, 3,665 pounds of copper, and 2,529 pounds of lead. A few tons of molybdenum ore produced during World War I assayed 1 to 3 percent MoS_2.

Veins.—Bon Ton: Strike, averages N. 67° E.; dip, 38°–63° SE.; width, 2½ to 5 feet; made up of quartz with stringers and disseminations of pyrite, chalcopyrite, and molybdenite. Vein offset in places by north-trending faults. Two narrow east-trending veins south of Bon Ton vein are weakly mineralized.

Wall rock.—Gneissic granite.

Ore and sulfide minerals.—Pyrite, chalcopyrite, molybdenite, gold, and silver; no galena reported in veins but smelter returns of mine indicate its presence.

Gangue mineral.—Quartz.

CITIZEN

Development.—Three shafts and one adit, all badly caved at collar or portal when visited in 1948. Main shaft about 300 feet deep. It is reported that workings connect with those of Maid of Athens mine.

Production and tenor.—No record available before 1901. Recorded production 1901–50 is 3,135 tons (mostly from 1902–06), which yielded 579 ounces of gold, 148,072 ounces of silver, 517 pounds of copper, and 4,247 pounds of lead.

Veins.—Probably quartz vein or veins in the Belden shale adjacent to or in the Athens fault, although none exposed at surface.

Wall rock.—Argillite, limestone, and dolomite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, chalcopyrite, malachite, and chrysocolla.

Gangue minerals.—Quartz and silicified limestone.

COMPLEX

Development.—Adit bears northeast for 300 feet to vein; about 500 feet of drifts; several prospect shafts and pits on ridge northeast of adit portal. Mine workings extend upward for 150 to 200 feet from adit level; partly accessible when visited in 1948.

Production and tenor.—No records available for production before 1901, although mine first worked in 1879. From 1901 to 1950 recorded production is 24 tons. A 21-ton shipment of hand-cobbed ore made in 1948 assayed 0.02 ounce of gold and 21.10 ounces of silver per ton, 13.50 percent lead, 17.55 percent zinc, and 2.10 percent copper. The tungsten assays, if made, were not available.

Vein.—Strike N. 15°–40° W., dip 40°–55° SW., length about 500 feet and width averages 4 feet.

Wall rock.—Gneissic granite.

Ore and sulfide minerals.—Hubnerite, scheelite, tetrahedrite, galena, sphalerite, pyrite, chalcopyrite, covellite (stain), malachite, azurite, and chrysocolla. Cerargyrite reported from old workings.

Gangue minerals.—Quartz and scarce calcite.

Changes in depth.—Reported that values in upper workings mostly in tungsten.

EMMA H.

Development.—Two shafts, each probably less than 50 feet deep, on a northwest-trending vein. Both shafts inaccessible when visited in 1949.

Production.—No records available before 1901. Only production between 1901 and 1950 was shipment of 11 tons in 1913 which contained 1 ounce of gold, 205 ounces of silver, and 348 pounds of copper.

Vein.—Emma H.: Northwest-trending vein 400 feet long, average width 1 to 3 feet.

Wall rock.—Gneissic granite.

Ore and sulfide minerals.—Sparse molybdenite and pyrite, and probably chalcopyrite and tetrahedrite.

Gangue mineral.—Quartz.

FLUORSPAR LODE

Development.—Several shallow prospect cuts and pits.

Production.—None as late as 1950. Prospected for fluorite.

Veins.—Veinlets ¼ inch to 4 inches wide in lode 6 feet wide. Strike northeast and steep northwest dip. Vein may have a length of 5,000 feet as shown on plate 1, but poorly exposed.

Wall rock.—Argillized Silver Plume (?) granite.

Ore and gangue minerals.—Quartz and fluorite, commonly banded. Most of quartz brecciated before introduction of fluorite. Fluorite varies from white to blue, green, and purple.

HUBNERITE LODE

Development.—Four short adits and several prospect cuts. All adits caved when visited in 1948 except one that had been driven south 65 feet to a poorly mineralized east-trending vein. Estimated total underground workings 600 to 700 feet.

Production and tenor.—Records of production before 1901 incomplete, although it is reported that the veins were worked in the seventies for gold and silver. No production recorded 1901–48. In 1943 a sample of the ore from the western adit, obtained from pieces showing the full width of the tungsten streak, assayed 2.52 percent WO_3.

Veins.—Poorly exposed. Several northeast-trending veins reported and tentatively projected on plate 1. Vein exposed in adit strikes N. 85° E., and dips 80° S. Widths range from 12 to 24 inches. Tungsten streaks are 4 to 8 inches wide and reportedly lay on one side of the veins.

Wall rock.—Altered gneissic granite and locally altered schist or Sawatch quartzite.

Ore and sulfide minerals.—Pyrite, chalcopyrite, hubnerite, tetrahedrite, galena, sphalerite, chalcocite, covellite, bornite, and locally a trace of molybdenite.

Gangue minerals.—Quartz and some limonite.

IDA MAY

Development.—Workings consist of 60-foot shaft, an east-trending adit, and several shallow shafts and pits. Adit and 60-foot shaft caved when visited in 1949.

Production and tenor.—Workings reported to have produced $18,000 in gold and silver. Two or three cars of tungsten ore containing 11 percent WO_3 and valued at $16,000 was produced during World War I. Sample of 2-inch streak picked from dump assayed 19.10 percent WO_3.

Veins.—Group reportedly includes 3 north- to northeast-trending tungsten veins 150 to 500 feet long that appear to range from 2 to 6 inches wide, float indicates maximum width of 18 inches; 3 tungsten-molybdenum veins and several molybdenum veins 100 to 200 feet long, having average width of 1½ to 2 feet. Ida May veins contain some sulfides.

Wall rock.—Gneissic granite.

Ore and sulfide minerals.—Relatively abundant molybdenite, hubnerite, pyrite, chalcopyrite, cerussite, and some tetrahedrite, galena, marmatite, covellite, bornite, cuprite, and molybdenum stain.

Gangue mineral.—Quartz.

LADY FRANKLIN

Development.—Adit bearing about S. 45° W. at portal (caved when visited in 1948). Extent of mine workings not known but probably total about 1,000 feet.

Production.—No record available before 1901, but probably small production. No production recorded 1901–50.

Ore bodies.—Probably replacement bodies in Leadville limestone adjacent to a northwest-trending fault.

Wall rock.—Dolomite and limestone.

Ore and sulfide minerals.—Some material on dump contains sparse pyrite, chalcopyrite, and galena.

Gangue minerals.—Silicified limestone, calcite, and limonite.

MAMMOTH

Development.—One 130-foot adit along east-trending vein that was cut near portal. Adit inaccessible when visited in 1949.

Production.—No records available before 1901. No production recorded 1901–50. Average grade of vein believed to be about 0.8 percent MoS_2 throughout width of 30 to 40 inches.

Vein.—Strike, N. 75° E.; dip, 40°–50° S.; length, 900 feet, possibly longer; width, averages 4 feet. Vein cut off by a fault about 100 feet west of portal, and Orient vein may be offset part of Mammoth.

Wall rock.—Quartz, intensely altered gneissic granite, and gouge and breccia.

Ore and sulfide minerals.—Molybdenite and sparse pyrite.

Gangue minerals.—Quartz and country rock.

MOLYBDENITE

Development.—Workings consist of a crosscut adit bearing N. 30° W. for 140 feet, an 85-foot drift on vein, and an opencut 100 feet long. Mine last operated in 1917–18. Portal of adit caved when visited in 1949.

Production and tenor.—No records available of production before 1901. In 1917 and 1918 shipment of 400 tons hand-sorted ore averaged 4.5 percent MoS_2. A 3-foot sample cut in 1943 from vein in opencut assayed 0.81 percent MoS_2.

Vein.—Molybdenite: Strike, N. 80° W; dip, 57°–67° S.; 3 feet of quartz in opencut contains disseminations and stringers of pyrite and molybdenite, and traces of chalcopyrite. Thickness of molybdenite vein in underground workings reported from few inches to 1½ feet.

Wall rock.—Sheared and altered gneissic granite.

Ore and sulfide minerals.—Molybdenite, pyrite, and chalcopyrite.

Gangue mineral.—Quartz.

MORNING GLORY

Development.—Two adits bear northwest; caved at portal when visited in 1949.

Production and tenor.—Records of production before 1901 incomplete, although it is reported that in the eighties two carloads of native copper were obtained from boggy ground near the portal of the upper adit. No production recorded 1901–50. Assays of 100-pound samples taken from the two dumps in 1943 ran 0.08 percent and 0.20 percent MoS_2.

Ore body.—Zone of disseminated molybdenite, pyrite, and chalcopyrite covered at surface by moraine. Most pieces on dumps contain a little molybdenite as thin faces on joints and to a lesser extent as disseminated flakes.

Wall rock.—Gneissic granite.

Ore and sulfide minerals.—Molybdenite, pyrite, and chalcopyrite.

Gangue.—Wall rock.

OCCIDENT

Development.—Adit bears S. 75° E. for 300 feet. Vein intersected 110 feet from portal, drifted on for 15 feet. Adit inaccessible when visited in 1949.

Production and tenor.—No production known. Sample of 6-inch hubnerite vein taken in 1943 assayed 1.45 percent WO_3.

Vein.—Occident: Strike, N. 22° E.; dip, 75° W.; length, 600 feet at surface; width, 6 inches of quartz containing hubnerite on hanging-wall side, and 6 to 12 inches of soft, sheared granite containing abundant sulfides.

Wall rock.—Gneissic granite, altered and sheared.

Ore and sulfide minerals.—Hubnerite, pyrite, chalcopyrite, chalcocite, covellite, and trace of molybdenum stain.

Gangue minerals.—Quartz and wall rock.

PORCUPINE

Development.—Tunnel bears N. 35° W., 1,100 feet through West Gold Hill, completed about 1880. Both portals caved when visited in 1949. Some later development work done on vein cut by tunnel near southeast portal.

Production.—Records of production before 1901 incomplete, although some silver produced. No production recorded 1901–50. Sample of hand-sorted material on dump in 1943 assayed 0.13 percent MoS_2.

Ore bodies.—Fault breccia containing silver and disseminated sulfides. Near southeast portal tunnel cuts strong northwest-trending vein containing molybdenum.

Wall rock.—Gneissic granite and a breccia, probably consisting chiefly of fragments of the Sawatch quartzite.

Ore and sulfide minerals.—Silver, molybdenite, and sulfides, probably including pyrite and galena.

Gangue minerals.—Quartz and wall rock.

TOMICHI MINING DISTRICT

CHIEF ECONOMIC AND GEOLOGIC FEATURES

The early production from the Tomichi district was principally oxidized silver and lead ore, but later primary lead and zinc ore became the most valuable. Although some gold, silver, and copper are recovered, the district now primarily produces zinc and lead. A small tonnage of iron ore was obtained many years ago from a magnetite deposit at the Iron King mine, northeast of Whitepine.

The ore deposits vary considerably in metallic content, mineral assemblages, form, and occurrence. In general, however, the deposits in the Paleozoic sedimentary rocks are of the replacement type in limestone and dolomite; those in all the other rocks are fissure veins. The vein deposits occur in the northern two-thirds of the district and continue north of Brittle Silver Basin into the Chalk Creek district. The chief replacement deposits lie east of Whitepine in an area of about 1 square mile in the northwest half of the patch of folded and faulted strata of Paleozoic age preserved in a syncline (pls. 1 and 5). Most of the past mining operations in the district were concentrated in the area east of Whitepine, and in another area 2 miles northeast, near the junction of Deer Gulch and Tomichi Creek. Of the many mines in the district, only five were accessible, even in part, at the time of this investigation.

Among the vein deposits only the pyritic quartz veins are of significant economic importance, although a few quartz-fluorite veins occur in the northern part of the district. The pyritic quartz veins range from irregular stringers a fraction of an inch wide to well-defined veins 6 feet thick, but most of those on which mines are located are from 1 to 4 feet thick. Some extend a hundred feet or less, but others attain a length of about half a mile. Although the attitudes of the veins vary considerably, most veins have a northerly strike and steep westerly dip (pl. 1), and most are in the Mount Princeton quartz monzonite. The vein filling is typically white vuggy quartz and sparse to very abundant pyrite, some chalcopyrite, and local shoots of galena and sphalerite. The galena is commonly silver-bearing; gold reportedly occurs in some of the pyrite and in native form in some of the oxidized ore. Several other minerals occur locally, as greenockite, chalcocite, azurite, malachite, tennantite, tetrahedrite, anglesite, cerussite, and native silver. Barite occurs in the quartz gangue of the Lilly and Bill Short mines.

The depth of oxidation is not known precisely but is not great, as indicated by fresh sulfides in the vein quartz exposed in many shallow prospect pits. The information available indicates that none of the mines on veins were more than a few hundred feet deep.

The replacement deposits, which are confined to the Whitepine area, occur in two rather distinct forms. The most important one economically is replacement along fault zones; the other is replacement along bedding. The replacement deposits along faults are chiefly confined to the Star fault (pl. 5), a northerly striking and easterly dipping reverse fault of considerable displacement. Rhyolite porphyry dikes follow and locally cut across the fault. The principal ore shoots occur on the western or footwall side of the fault, in dolomite or limestone near the porphyry. Some extend 100 feet west of the fault. Individual ore shoots range from a length of a few feet to at least several hundred feet, and most show a steep northeasterly plunge. The most favorable host rock is the Manitou dolomite, although other limestone and dolomite beds, especially the Leadville limestone, contain replacement deposits along this fault zone. Bedded and somewhat irregular replacement deposits occur at several positions in the sedimentary beds lying between the Manitou dolomite and the Belden shale, but the most productive zone lies at the top of the Leadville limestone, immediately below the basal quartzite or argillite beds of the Belden shale. The Erie and Eureka-Nest Egg mines (pl. 5) obtained ore from irregularly spaced east-dipping shoots at this position.

Some of the ore near the surface is strongly oxidized, but there is little oxidation below a depth of 100 feet. Most of the ore mined at depth and in the more recent operations consists of a granular aggregate of sphalerite, galena, and variable amounts of pyrite and chalcopyrite. The galena is commonly silver-bearing, and gold is locally contained in the pyrite. The sulfides are chiefly in a gangue of marbleized limestone or dolomite with variable amounts of quartz or silicified limestone. Much of the gangue of the deposits lying immediately below the Belden shale contains earlier formed contact metamorphic minerals such as epidote, diopside, magnetite, and andradite garnet.

AKRON MINE

The portal of the Akron tunnel is a few hundred feet south of Whitepine and 300 feet east of the road along Tomichi Creek (pl. 5). The tunnel extends east about 3,500 feet to a point where it intersects the main workings of the Akron mine. *Section B—B′*, plate 5, approximately follows the course of the tunnel.

In 1901 the North Star, Tenderfoot, May, and Mazeppa mines (pl. 6) were incorporated into the Akron Mining Co., and the Akron tunnel was started from about the level of Tomichi Creek and was driven eastward to undercut these mine workings. The tunnel was completed to its intersection with the North Star-Dividend shaft in 1903, and from 1903 to 1937 the mine operated intermittently. In 1937 the Callahan Zinc-Lead Co. acquired control and is operating the mine.

The following table gives the recorded production of the mine from 1901 to 1950. This production came from ore shoots of the North Star, May, Mazeppa, and W. and A. mines. The production for 1924, 1942, and since 1943 includes production of the Erie mine and possibly others.

When last examined in 1951 the mine was accessible through the Akron tunnel, the Mazeppa shaft, and a raise from the 350 level to the Tenderfoot tunnel. The Akron tunnel, the main haulageway, is 3,450 feet long, and about 5,500 feet of drifts and crosscuts connect with it, excluding the Morning Star development drift. Above the tunnel level are five main levels designated as the 75, 100, 150, 250, and 350 levels which have a total of about 6,000 feet of drifts and crosscuts (pls. 6 and 7, and fig. 3). In 1951 the Callahan Zinc-Lead Co. was mining and doing development work primarily on the 150, 250, and Akron tunnel levels. The chief work was the Morning Star development drift that was being driven south from the Akron level, parallel to, and a short distance west of, the Star fault, to explore the area below the old workings of the Morning Star mine (pl. 6).

Production of the Akron mine, in recovered metal, 1901–50

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published by permission of the owners.]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1901	1,500	75	12,000	----------	----------	----------
1903	163	9	1,102	----------	229	----------
1905	700	52	7,000	----------	210,000	----------
1906	85	----------	1,354	----------	22,632	----------
1916	3,301	14	7,490	4,931	216,926	143,205
1919	1,500	1	444	----------	17,455	----------
1920	5,523	----------	11,713	----------	997,448	521,800
1924 [1]	9,762	107	58,546	----------	3,806,380	4,613,051
1927	1,167	19	9,206	3,263	494,183	353,934
1928	1,427	20	10,207	2,641	514,031	725,983
1929	389	7	2,943	526	125,986	159,804
1930	108	1	293	28	33,740	51,520
1931	118	1	1,608	611	81,155	----------
1941	92	2	805	----------	34,386	45,791
1942 [1]	380	3	1,865	1,379	105,521	144,981
1943	3,941	40	21,597	20,681	597,870	910,479
1944 [1]	5,768	68	21,545	43,794	794,269	1,151,837
1945 [1]	6,176	63	22,896	24,035	782,659	1,083,396
1946 [1]	4,220	28	14,266	47,746	730,251	1,071,976
1947 [1]	8,001	58	48,554	12,607	2,853,740	3,315,862
1948 [1]	18,158	89	85,312	31,468	4,016,293	5,153,685
1949 [1]	14,676	67	60,578	39,073	2,737,872	3,755,978
1950 [1]	12,342	----------	72,836	----------	1,578,650	2,426,660
Total	99,497	724	474,160	232,783	20,751,676	25,629,942

[1] Akron, Erie, and other ore combined.

The Akron mine workings, the most extensive in the district, expose all the formations occurring in the district (pl. 5) except the Belden shale. Highly altered Silver Plume(?) granite is exposed in the hanging wall of the Star fault on the Akron level (pl. 7), Akron-Morning Star development drift, 150 level, and 250 level (pl. 6 and fig. 3). The Manitou dolomite—the host rock for the main ore bodies of the Akron mine—is exposed on all levels of the mine, both on the hanging and foot walls of the Star fault. On the footwall of the fault the Manitou dolomite is shattered, silicified, and locally mineralized and, although at most places the beds are difficult to distinguish, in general they strike northerly and dip 40°–70° E. The Manitou dolomite on the hanging wall of the fault, as exposed on the Akron level (pl. 7), is shattered, folded, and recrystallized. The Harding quartzite, Fremont dolomite, Chaffee formation, and Leadville limestone are only exposed by the easterly trending drift into the hanging wall of the Star fault on the Akron level. In general, the beds strike northerly and dip 30°–45° E.

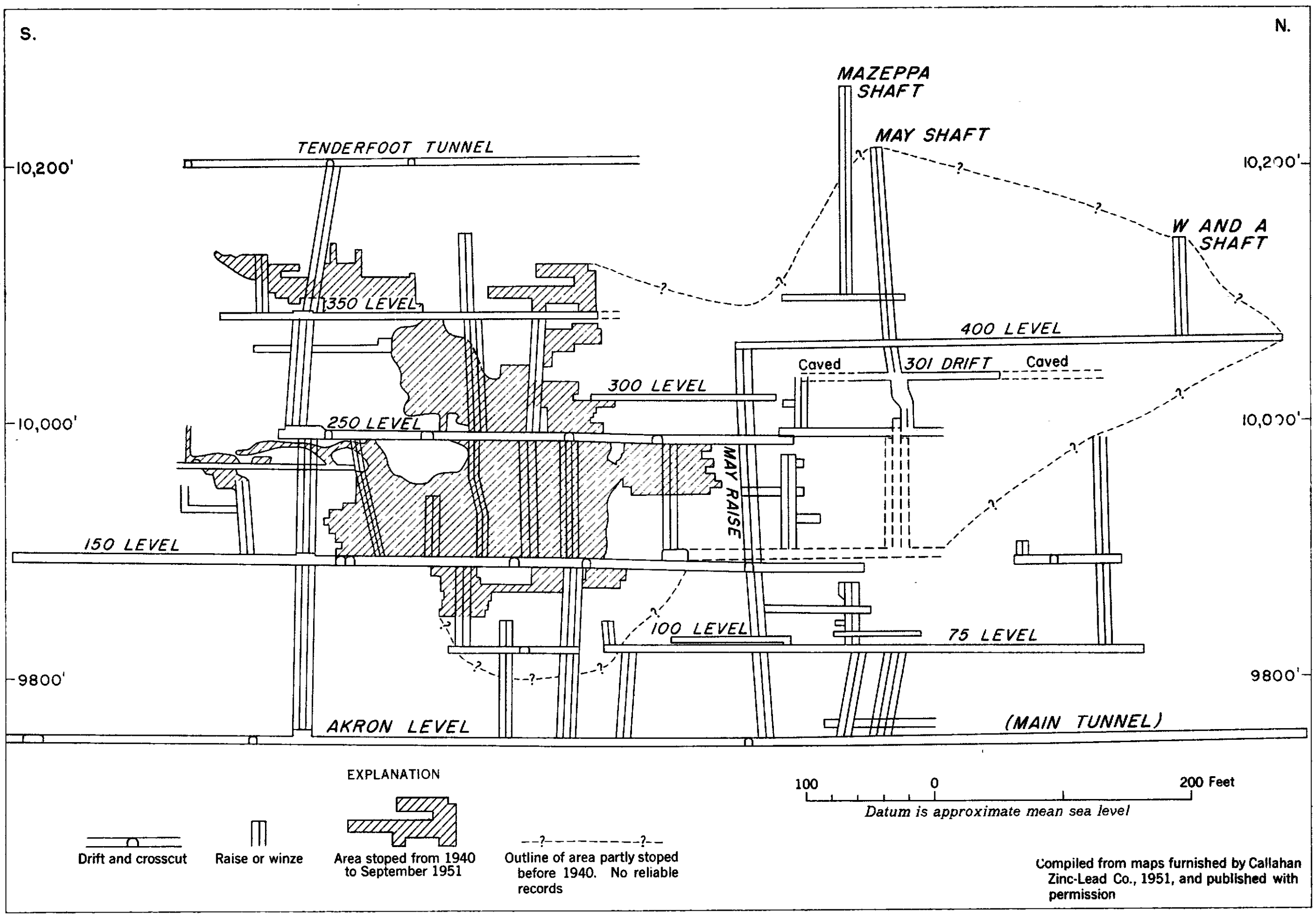


FIGURE 3.—Vertical projection of workings along the Star fault, Akron mine.

A rhyolite body is exposed west of the Star fault in the Akron tunnel, Akron level, 150 level, and 250 level. This rhyolite is highly sericitized and silicified and is difficult to distinguish from the altered Manitou dolomite on the footwall of the Star fault. Shenon and Full,[9] because of the intense alteration of this body, were not sure of its origin and so termed it simply the Akron formation. The rhyolite body intruded the Manitou dolomite before the formation of the Star fault.

The Mount Princeton quartz monzonite is exposed only in the Akron mine in the Akron tunnel.

A rhyolite porphyry dike, younger than the rhyolite body and the Mount Princeton quartz monzonite, is exposed throughout the main workings of the mine (pl. 7 and fig. 3). This dike, and branches of it, intruded the Star fault zone and locally the foot and hanging walls of the fault. At the contacts the rhyolite porphyry dike may grade into pitchstone porphyry, and in the vicinity of the ore bodies the dike has been altered to a dark-gray clay.

The chief structure is the Star fault, a reverse fault which strikes northerly and dips 40°–80° E., with an average dip of 60° E. Where exposed in the Akron tunnel (pl. 7), the Star fault is a 110-foot breccia and gouge zone containing 90 feet of altered rhyolite porphyry. The displacement along the fault could not be measured in the mine; at the north end of the mine workings Manitou dolomite has been thrust from the east over the rhyolite body, and at the south end, Silver Plume(?) granite has been thrust from the east over Manitou dolomite. The Star fault was formed, and much of the shattering of the Manitou dolomite and the rhyolite body occurred, before the intrusion of the rhyolite porphyry dike and before mineralization. Some faulting occurred after the rhyolite porphyry dike was emplaced, as indicated by 1 to 12 inches of gouge that occurs locally along the contact of the dike.

The ore occurs in a wedge of Manitou dolomite, 20 to 100 feet in width, between the Star fault on the east and the rhyolite body on the west (pl. 7). Most of the

[9] Shenon, P. J., and Full, R. P., 1946, Akron mine, Callahan Zinc-Lead Co., Tomichi mining district, Gunnison County, Colo.: Private report made to Callahan Zinc-Lead Co.

ore has come from near the Star fault on the east side of the wedge of Manitou dolomite, but in late years considerable ore has been produced from the west side of the wedge near the contact of the Manitou dolomite and the rhyolite body. In general, the ore bodies in both zones are elongated parallel to the Star fault, dip 40°–80° E., and plunge north. They range in pitch length from 50 to 300 feet, in breadth from 10 to 200 feet, and in width from 2 to 75 feet.

The ore near the Star fault is composed of large masses of coarse- to fine-grained sphalerite and galena and small disseminated grains of pyrite and chalcopyrite. Much of this ore averages better than 30 percent of combined zinc and lead. The contacts between the ore bodies and the country rock are sharp. Locally the rhylite porphyry dike, within the Star fault, is the hanging wall of the ore bodies, and is separated from the ore by 1 to 12 inches of gouge.

In the zone of ore bodies near the contact of the Manitou dolomite and the rhyolite body, the ore is composed of 1- to 6-inch bands of sulfides in a gangue of clay and silicified Manitou dolomite. Individual sulfide bands consist of layers of nearly pure galena and sphalerite alternating with layers of sphalerite mixed with pyrite and chalcopyrite. The average ore assays 10 to 15 percent combined zinc and lead. Where the ore bodies in this zone are in contact with the rhyolite body, the contact is sharp and commonly there is 1 to 6 inches of gouge along the contact. The contacts of the ore bodies with the Manitou dolomite, however, are gradational, the contact being dependent upon the ratio of gangue and pyrite to the ore minerals.

Oxidized ore has not been mined from the Akron mine, although it has been found above the 350 level. It consists of siliceous limonite and calcite containing cerussite and residual grains of galena. Oxidized ore was produced from the North Star, May, Mazeppa, and W. and A. mines before their incorporation into the Akron mine.

The tenor of the ore produced from the Akron mine is best shown by records of the Callahan Zinc-Lead Co., which show that the average grade of 58,803 tons of crude ore produced between 1925 and 1950 was 6.04 ounces of silver per ton, 11.43 percent lead, and 14.96 percent zinc.

ERIE MINE

The Erie mine is about 1,200 feet east-northeast of the town of North Star on the south side of Galena Creek (pl. 5). It may be reached by a good road that joins the Galena Creek road about 1,500 feet northeast of the town. The mine is owned by the Callahan Zinc-Lead Co.

The Erie claim, according to Crawford (1913, p. 284), was located in 1882. The mine is reported (Crawford, 1913, p. 303) to have yielded ore worth $16,399 in 1891. No records are available on the mine from 1892 to 1901, and from 1902 to 1950 the mine was operated intermittently. Before 1943 all mining was done through the Erie shaft. In 1943 the Callahan Zinc-Lead Co. extended the Silver Trowel tunnel, now called the Erie tunnel, to the no. 4 level of the Erie shaft. Since 1944 all the mining has been done through this tunnel. The following table gives the recorded production of the mine from 1901 to 1947. Included is some production from the Eureka-Nest Egg, May, Mazeppa, North Star, and Spar copper mines. In 1942 and since 1947 all production has been included with that of the Akron mine.

Production of the Erie mine, in recovered metal, 1901–47

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published with permission of the owners]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1907	38	------	1,344	------	21,000	19,508
1913	80	------	423	150	9,371	18,265
1917	3,690	54	15,207	63,362	539,965	614,619
1918	1,000	3	6,912	215	282,821	346,157
1921	48	------	860	------	42,302	------
1923	7,207	34	12,592	146	1,422,150	3,587,054
1925	4,618	67	34,957	7,800	1,295,466	1,434,203
1926	2,732	66	22,157	11,402	862,064	932,049
1944	5,768	67	21,408	43,794	794,269	1,151,837
1945	6,176	63	22,896	24,035	782,659	1,083,396
1946	4,220	28	14,266	47,746	730,251	1,071,976
1947	2,234	17	15,338	43,293	267,524	875,609
Total	37,811	399	168,360	241,943	7,049,842	11,134,673

The mine was first worked through the Erie shaft, which was caved in 1949. According to Shenon and Full[10] the shaft is vertical for 90 feet from the surface and then inclined for 230 feet. Extending from the shaft are six levels. The Erie tunnel intersects the no. 4 level, and only the nos. 4 and 3 levels were accessible in 1949. Plate 8 is a modification of a similar map prepared by Shenon and Full for the Callahan Zinc-Lead Co. The map shows that the accessible mine workings consist of about 4,000 feet of drifts and crosscuts.

The country rock is the Leadville limestone, which here is largely limestone marble and dolomitic limestone marble, and the Belden shale. The Belden shale is composed of interfingering beds of conglomeratic quartzite, quartzite, and argillite. It was deposited on an irregular surface of the Leadville limestone. The formations strike northwesterly and dip 25° to 50° NE. Cutting the formations and the ore bodies are many small northwesterly to northeasterly striking fractures

[10] See footnote 9 on p. 69.

that dip steeply east or west. The displacement, if any, along these fractures is small. At the south end of the no. 4 level is a fault zone about 70 feet wide. In this zone are blocks of quartzite as much as 4 feet in length, cemented with coarsely crystalline calcite. This fault zone could not be found on the surface, and the displacement could not be determined.

The most extensively mineralized zone is along the contact of the Leadville limestone with the overlying Belden shale. This mineralized zone is about 600 feet long and averages 8 feet wide on the no. 4 level (pl. 8). A second mineralized zone is 10 to 30 feet southwest of the zone along the contact, or 5 to 30 feet lower stratigraphically. Both mineralized zones approximately parallel the bedding of the Leadville formation in both strike and dip. The zones are mineralized and altered wherever they are exposed in the mine, but only locally was the mineralization extensive enough to form ore. The contacts between the ore and country rock are gradational for 2 to 4 feet. Ore minerals also occur in small fractures in the country rock and in the quartzites and argillites of the Belden shale.

The ore minerals in the mine and on the dumps are oxides and primary sulfides. Oxidized ore minerals were found on the dumps of the Eureka-Nest Egg mine, which is believed to have worked extensions of the Erie ore zones, and the early production of the Erie mine was probably from the oxidized zone. The primary sulfide minerals in the Erie mine are galena, sphalerite, pyrite, and chalcopyrite. Fine- to coarse-grained galena occurs as irregularly shaped masses 1/4 to 4 inches in length. The sphalerite is red to black, and mostly fine grained. The pyrite and chalcopyrite occur as disseminated fine grains in the country rock and as fine to coarse grains associated with the galena and sphalerite. Magnetite is locally associated with the ore; it occurs as irregularly shaped masses, 1/2 inch to 6 inches in length.

The ore occurs in shoots which plunge northward. The largest shoot was stoped from the No. 3 level, a few feet northwest of the shaft, to the No. 6 level, a pitch length of about 250 feet. This stope ranges in length from 40 to 200 feet and averages about 6 feet in width. Other smaller shoots, to the north and south of the main shoot, were stoped on both mineralized zones. Most of these range from 20 to 80 feet in stope length, 5 feet in width, and were stoped for a pitch length of 50 to 100 feet.

In the two mineralized zones in the Leadville limestone, the ore minerals are associated with a dense, hard, yellowish-green rock which contains epidote, diopside, garnet, and magnetite. Small amounts of ore minerals are found in the quartzites and argillites of the Belden shale associated with a sugary quartz gangue. The ore minerals in small fractures in the Leadville limestone are associated with calcite and quartz gangue.

In 1950 the Callahan Zinc-Lead Co. estimated that the mine contained 250 tons of measured ore, 1,000 tons of indicated ore, and 5,000 tons of inferred ore. The tenor of the measured ore was estimated at 5 percent lead and 19 percent zinc. That of the indicated and inferred ore, 3 percent lead and 12 percent zinc. Pillars in the old stopes account for the measured ore.

EUREKA-NEST EGG MINE

The Eureka-Nest Egg mine is on the north slope of Lake Hill at an altitude of about 10,700 feet. It is reached by a poor road which climbs southward up the hill from the Erie mine and Galena Creek (pl. 5).

The Eureka-Nest Egg mine was one of the earliest mines in the Tomichi district. Crawford (1913, p. 284) reports that in 1879 the first ore was discovered in the district, and in that year the Nest Egg and probably the Eureka claims were located. The reports of the Directors of the Mint give the production from this mine for the years 1887, 1888, and 1890 as follows:

Production of Eureka-Nest Egg mine for 1887, 1888, and 1890 [1]

Year	Gold	Silver	Gold and silver	Copper	Lead	Total
1887			$19,493		$18,840	$38,333
1888		$18,100			28,952	47,052
1890	$6	796		$26	14	842
Total	6	18,896	19,493	26	47,806	86,227

[1] Reports of the Directors of the Mint upon the statistics of the production of the precious metals in the United States for the calendar years of 1887, 1888, and 1890.

The following table gives the production of this mine from 1901 to 1950:

Production of Eureka-Nest Egg mine, 1901–50

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published with permission of the owners.]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1917	35	1	198	24	10,548
1918	11		61		4,080
1933	108	2	1,833		87,146
Total	154	3	2,092	24	101,774

The mine was worked through several shafts, which were caved when visited in 1950. No maps are available; so the extent of the underground workings is not known. The shafts were started in the Belden shale 100 to 200 feet east of the contact between the Belden shale and the Leadville limestone. Most of these shafts went through the Belden shale and into the Leadville limestone, because material from both formations is found on the dumps. The Belden shale dips 25°–35° E., a dip which means that the shafts would reach the Leadville limestone at depths of 50 to 100 feet.

The Leadville formation in the vicinity of the mine consists of limestone marble and dolomitic limestone marble and the Belden shale of interfingering beds of conglomeratic quartzites, quartzites, and argillites. The irregularity of the contact between these formations, where observed east of the shafts, indicates that the Belden shale was deposited on an uneven erosion surface of the Leadville limestone. The formations are cut by many short northeast- to northwest-trending fractures, which dip steeply east or west. The displacement along these fractures is believed to be small.

On the dumps, the oxidized ore minerals cerussite and anglesite are found associated with galena in vuggy, iron-stained quartz gangue. Galena crystals averaging about one-fourth inch in diameter are coated with a very thin band of anglesite which in turn is coated with a band of cerussite. Cerussite also occurs as fine white crystals lining small vugs. Galena, sphalerite, chalcopyrite, and pyrite, accompanied by epidote and garnet, are found in irregular-shaped masses in fine-grained quartzite and in partially silicified dolomitic limestone marble. Most of the ore, as in the Erie mine (p. 71), is believed to have been produced from the upper Leadville limestone at or near its contact with the Belden shale, and very little was produced from the quartzites of the Belden shale.

MAY, MAZEPPA, AND W. AND A. MINES

The May, Mazeppa, and W. and A. mines were incorporated into one mine, the Akron, shortly after their discovery. The shafts are 300 to 600 feet southeast of the old town of North Star (pl. 5). The mine was owned in 1952 by the Callahan Zinc-Lead Co.

Very little information is available on the history and production of the mine. Shenon and Full[11] report that the May shaft was the first of the three shafts started. The following table gives the only production figures available on the mine. According to Shenon and Full, the mine closed in 1907, and very little if any work was done from 1907 to 1937, when the Callahan Zinc-Lead Co. acquired control. Any production of the mine since 1903, when the Akron tunnel was completed, would have been included with that of Akron mine.

The workings of the mine were caved when visited in 1950, except for the Mazeppa shaft. The following information was obtained from the report of Shenon and Full.[11] The May shaft extends from the surface to the 400 level of the Akron mine (fig. 3). The Mazeppa shaft extends from the surface to a sublevel about 20 feet above the 400 level. This shaft is maintained as an escape manway for the Akron mine and a conduit for power cables to the mine. The W. and A. (Woodworth and Allen) shaft extends from the surface to the 400 level. The 400 level includes about 600 feet of workings, and at its south end is the May raise which connects it with the main workings of the Akron mine. The ground above the 400 level is believed to have been stoped from the May shaft to the W. and A. shaft.

Production of the May, Mazeppa, and W. and A. mines, 1888, 1890, and 1891 [1]

Year	Gold	Silver	Lead	Totals
1888	$300	$11, 636	$2, 640	$14, 576
1890		129, 792	218, 339	348, 131
1891		305, 200	274, 915	580, 115
Total	300	446, 628	495, 894	942, 822

[1] Reports of the Directors of the Mint upon the statistics of the production of the precious metals in the United States for the calendar years of 1888, 1890, and 1891.

The country rock is white and gray dolomitic limestone marble of the Manitou dolomite, and a rhyolite porphyry dike. The subsurface geology is not known because the workings were caved or timbered, and there were no geologic maps available. The shafts were started in the hanging wall of the Star fault that has locally been intruded by a rhyolite porphyry dike. The dike and fault dip east. Shenon and Full report that the ore was produced from west of the rhyolite dike; that is, from the footwall of the fault. No specimens of the ore were found on the dumps, but the ore was probably the same as that of the Akron mine (p. 70), which worked the lower part of the same ore body.

MORNING STAR MINE

The Morning Star mine is 500 to 1,000 feet northwest of the saddle between West Point Hill and Lake Hill at an altitude of about 10,500 feet (pl. 5). The lower tunnel, the only part of the workings accessible in 1951, is reached by a road which goes south from the Galena Creek road at the old town of North Star. The mine was owned in 1952 by the Callahan Zinc-Lead Co.

Production was first reported in 1907, and the mine was operated intermittently from then to 19?5. In 1951 the lower tunnel was reopened and some of the workings rehabilitated (pl. 9). The following table gives the production from 1901 to 1950.

[11] See footnote 9 on p. 69.

Production of Morning Star mine, in recovered metal, 1901–50

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published by permission of the owner]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1907	117	----------	3, 394	----------	51, 472	49, 137
1908	350	----------	10, 151	----------	154, 000	147, 000
1910	463	10	8, 960	3, 181	171, 773	176, 815
1911	803	12	13, 800	3, 564	281, 157	508, 569
1912	360	2	6, 850	1, 159	125, 039	255, 752
1913	75	2	1, 806	763	23, 063	39, 425
1914	677	9	10, 917	79	27, 226	358, 250
1916	136	3	2, 072	----------	38, 908	68, 172
1926	163	70	1, 376	484	55, 942	68, 964
1927	424	4	5, 768	1, 494	127, 308	183, 340
1929	40	----------	495	199	15, 878	22, 431
1933	194	2	2, 744	1, 018	65, 486	67, 098
1934	79	----------	1, 064	391	52, 103	41, 794
Total	3, 881	114	69, 397	12, 332	1, 189, 355	1, 986, 747

The mine was originally accessible through an inclined shaft and two tunnels (pl. 6). The shaft extends from the surface, altitude about 10,600 feet, to about halfway between the upper and lower tunnels. The upper tunnel, N. 55° W. 250 feet from the shaft, extends into the hill for about 600 feet; it is connected to the shaft by a short crosscut. The lower tunnel, N. 35° W. 650 feet from the shaft, goes into the hill about 720 feet where it divides into two drifts. The total workings on this level are about 2,500 feet. Below the lower tunnel level, and connected with it by two winzes, is a winze level with about 1,250 feet of drifts and crosscuts.

The country rock associated with the ore is dolomite and limestone marble of the Chaffee and Leadville formations. The sedimentary rocks are cut by an eastward-dipping rhyolite porphyry dike which invaded both the Star fault zone and the sedimentary rocks in the footwall of the fault. Where the dike invaded the footwall of the fault, blocks of marble are east of the rhyolite dike in fault contact with the Silver Plume(?) granite. Where the dike is confined to the fault zone, it is in direct contact with the granite. The dike and Star fault dip 45°–65° E.

According to Crawford (1913, p. 300), the ore occurs in limestone blocks in fault contact with the granite east of the rhyolite dike and in limestone west of the dike. He reports seeing sulfide ore bodies 1 to 6 feet wide west of the dike and one ore body east of the rhyolite dike 6 feet wide and extending 100 feet upward with a dip of 47° E. In the workings accessible in 1951 ore was seen east of the rhyolite dike in a zone of brecciated and silicified limestone or dolomite marble about 15 feet in width (pl. 9).

Oxidized and primary sulfide ore minerals are found on the dumps and in the mine. It was reported to Crawford (1913, p. 301) that lead carbonate extended about 100 feet down from the surface and that a body of oxidized ore 1 to 5 feet thick extended upward 50 feet from the upper tunnel level. The ore exposed in the lower tunnel consists of galena in a siliceous iron-stained gangue. Ore from the dumps contains small patches of galena with fine-grained galena and yellow sphalerite in a white or gray dolomitic limestone marble. Associated with the galena and sphalerite are small amounts of fine-grained pyrite and chalcopyrite. Crawford (1913, p. 301) reports that an ore sample taken from near the bottom of the shaft, which is about halfway between the upper and lower tunnel levels assayed 0.14 ounce of gold and 19.10 ounces of silver per ton, 22.7 percent lead, and 45.0 percent zinc.

NORTH STAR MINE

The North Star mine is a few hundred feet north of the Morning Star and about 1,200 feet southeast of the old town of North Star (pl. 5). The mine may be reached by a poor road which joins the Galena Creek road about 700 feet east of North Star. The Callahan Zinc-Lead Co. owned the mine in 1952.

The North Star mine was one of the first mines in the Tomichi district. According to Crawford (1913, p. 284), the North Star claim was located in 1879. Burchard (1882, p. 464) reports that ore was shipped from the mine in 1881 and 1882. In 1883, according to Burchard (1883, p. 308), the mine was being worked through seven shafts, and the ore produced averaged 140 ounces of silver per ton and 50 percent lead. For 1884 Burchard (1884, p. 217) reports the mine was producing 4 to 6 carloads of ore per week. From 1884 to 1900 there are no records available on the production of the mine. In 1901 the Akron Mining Co. started operating the North Star and other mines in the district. The production of the mine from 1901 to 1950 is included with the production of the Akron mine.

The mine was worked in the early days through several inclined and vertical shafts. Two of these shafts, the North Star and North Star-Dividend shafts (pl. 5), reached a considerable depth. No information is available on the workings of the North Star shaft, but the workings of the North Star-Dividend shaft are shown on plate 6, and figure 4 is a composite geologic map of the lower workings of the North Star-Dividend shaft. None of the workings were accessible when visited in 1950.

The country rock is white, gray, or brown limestone marble or dolomitic limestone marble of the Manitou dolomite. The following information on the geology is quoted from the report of Shenon and Full.[12]

> The North Star ore is found along the nose of a pitching anticline as irregular replacement bodies in the Tomichi limestone [Manitou dolomite of this report], and along cross-cutting fractures not far above the Sawatch quartzite. The writers mapped three mineralized beds and several cross-cutting fractures where-

[12] See footnote 9 on p. 69.

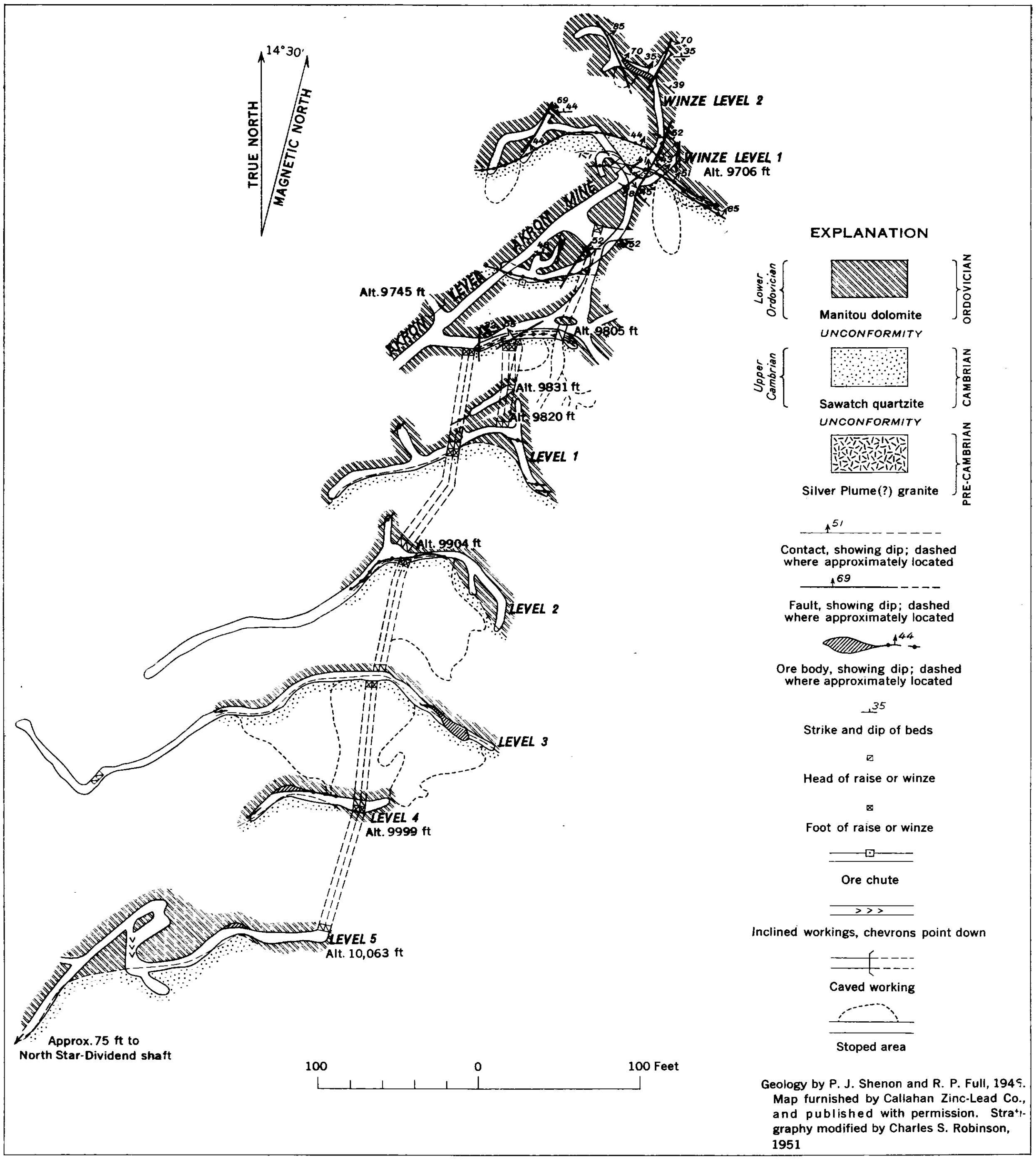


FIGURE 4.—Geologic map of part of the North Star-Dividend shaft levels.

as Michael Clapp [former manager of the mine] reports four ore bearing horizons. The most persistent and regularly mineralized horizon is immediately above the Sawatch quartzite. None of the stopes were long; for the most part, less than 50 feet, and the thickness was generally less than 3 feet. The only North Star stope seen by the writers was less than three feet wide.

The ore in crosscutting fractures is found near the crest of the anticline. The best example seen by the writers is called the T. N. stope. The ore occurred along the intersection of a steeply dipping northeast fracture with a limestone bed, located about 35 feet stratigraphically above the Sawatch quartzite. The stope trends S. 25° W. at an angle of about 35°. Where the writers saw the stope it was more or less circular in cross section and ranged from 6 to 8 feet in width and from 8 to 10 feet in thickness. The cross fracture along which the ore occurred in the T. N. stope can be seen in the Akron tunnel 25 feet northeast of the winze, where it is weakly mineralized.

The ore seen in the lower levels was a mixture of galena, sphalerite, and pyrite, generally in a banded arrangement with certain bands commonly containing more of one mineral than another; thus layers of nearly solid galena often alternate with layers composed largely of sphalerite and pyrite. The writers saw the end of one ore shoot. The sulfides cut out within a length of 10 feet and gave away to calcite, iron oxide, and manganese oxides.

Oxidized and primary sulfide ore minerals are found on the dumps of the shafts. Cerussite, calamine, and smithsonite occur in a soft white dolomitic gangue, locally limonitic. Fine- to coarse-grained galena and pyrite are found in the dolomitic limestone country rock and in coarsely crystalline calcite veins. Fine-grained sphalerite is associated with the galena, and there is a small amount of chalcopyrite associated with the pyrite. Most of the rocks on the dumps are iron stained, and small amounts of azurite, malachite, and chrysocolla are found as stain on some of the rocks.

SPAR COPPER MINE

The Spar Copper mine includes the Morning Glim, Ensign, and Parole tunnels, which were driven at different levels to intersect the same vein. They are at altitudes of from 10,400 to 10,600 feet on the east slope of the Tomichi Creek valley, about three-fourths of a mile northeast of Whitepine (pl. 5). The Morning Glim tunnel may be reached by a poor road which joins the Galena Creek road about 2,000 feet northeast of the town of North Star. The Parole tunnel may be reached by a road which joins the Tomichi Creek road about 3,800 feet northeast of Whitepine. Trails connect the Ensign tunnel with the Morning Glim and Parole tunnels. The mine property includes the Morning Glim and Spar patented claims that in 1950 were owned by C. A. Tutt of Colorado Springs, Colo., and the Jersey, Snowden, Ensign, Iron Duke, and Bob Lee patented claims owned by the Callahan Zinc-Lead Co.

The production records are incomplete and partly contradictory. Leech (1890, p. 134) reported the mine produced silver valued at $698 and lead valued at $428 in 1890. The following table gives the production of the mine from 1901 to 1950 as reported to the U. S. Bureau of Mines. Some production from this mine has

Production of the Star Copper mine, in recovered metal, 1901–50

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published by permission of the owners]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1907	125	10	3,879	13,690	----------
1908	58	5	2,000	5,485	----------
1912	45	3	1,964	4,920	5,625
1913	41	3	1,529	3,072	6,483
1916	58	4	2,993	5,725	744
1917	1,104	14	9,336	21,086	7,416
1940	14	----------	362	1,103	4,043
Total	1,445	39	22,063	55,081	24,311

been included with that of the Erie, Eureka-Nest Egg, May, Mazeppa, and North Star mines.

Shenon and Full[13] report that according to a Mr. Dyrenforth, a former operator of the mine, the mine produced a total of about 4,800 tons of ore. Of this, according to Dyrenforth, 2,300 tons was oxidized copper-silver ore, assaying 7 percent copper and 5 ounces of silver per ton, produced from the Morning Glim tunnel; and 2,500 tons, averaging 20 percent lead, 30 percent zinc, 10 ounces of silver, and 0.04 ounce of gold per ton, came from the Parole tunnel. According to Shenon and Full,[13] J. E. Dick shipped 320 tons of ore from the mine in 1925–26, which averaged 0.4 percent copper, 12 percent lead, 22 percent zinc, 10 ounces of silver, and 0.047 ounce of gold per ton. The production as reported by Shenon and Full was not credited by the U. S. Bureau of Mines to the Spar Copper mine, and probably was included by the operators with shipments from other mines.

All the tunnels were caved in 1950, and the following discussion is based on earlier reports. The Morning Glim, Ensign, and Parole tunnels are successively lower levels driven to work the Spar Copper vein. Crawford (1913, p. 303) states that the Morning Glim tunnel is about 1,200 feet long, and that the Parole tunnel, after cutting the Morning Glim fault, continues along the Spar Copper vein for about 500 feet. Shenon and Full[13] report that the Ensign tunnel is about 365 feet long.

The mine workings are on both sides of the Morning Glim fault. This fault strikes northerly and dips steeply east with Silver Plume(?) granite on the east having been thrust over the Belden shale on the west—a vertical displacement of at least 1,400 feet. The ore of the Spar Copper mine was produced from two localities, a vein in the granite east of the Morning Glim fault, and replacement deposits in the limestone marbles of the Belden shale west of the fault. The vein is not exposed at the surface, but its trend may be followed for about 300 feet by a series of caved prospect pits and shafts. According to Crawford (1913, p. 304), the vein, as exposed in the Parole tunnel, is about 3½ feet wide, and includes ore about 1 foot wide. The ore occurs in lenticular bodies on either side of the vein or in small stringers in the vein. The vein has been followed in the Parole tunnel for about 500 feet. Vein matter on the dumps shows veinlets of banded quartz and pyrite, and minor amounts of galena, sphalerite, tetrahedrite, and chalcopyrite occurring as narrow bands or lining small vugs, in altered granite. The

[13] See footnote 9 on p. 69.

galena is coarse- to fine-grained and may or may not have small grains of sphalerite intermixed with it. Chalcopyrite and tetrahedrite occur, lining small vugs or as fine grains intermixed with the other metallic minerals. Crawford (1913, p. 304) found a little enargite and also reported native copper. The feldspars and ferromagnesian minerals in the granite, within and along the vein, have been altered to yellow clay. Where veinlets of quartz and pyrite cut the altered granite, the rock on either side is silicified and pyritized for 1 to 10 inches from the veinlet.

The ore in the limestone marbles of the Belden shale west of the fault contains galena, sphalerite, pyrite, and chalcopyrite in a matrix of white to blue-gray limestone marble. The Belden shale in the vicinity of the mine is composed of limestone marble and interbedded shale and quartzite. The ore minerals are fine grained and occur as disseminated grains in the marble or in 0.1 to 1 inch aggregates in a quartz, barite, and calcite gangue.

TENDERFOOT MINE

The Tenderfoot mine is about 700 feet south of the old town of North Star at an altitude of about 10,200 feet (pl. 5). A poor road goes west from the portal of the mine about 300 feet and joins a road that runs north to the town of North Star. The mine was owned in 1952 by the Callahan Zinc-Lead Co.

Very little information was available on the history and production of the mine. The Tenderfoot ore body was presumably discovered while the Tenderfoot tunnel was being driven to its intersection with the North Star-Dividend shaft. L. B. Stitzer reported to Shenon and Full [14] that the mine produced a large quantity of high-grade ore. The production of the mine has been included with that of the Akron mine.

The Tenderfoot tunnel was driven about 800 feet to the North Star-Dividend shaft. Several short drifts, totaling about 580 feet, were driven from both sides of the tunnel. When visited in 1950, the tunnel was caved about 270 feet from the portal. The geologic map of the mine, figure 5, was modified from one prepared for the Callahan Zinc-Lead Co. by P. J. Shenon and R. P. Full.[14]

The tunnel starts in the Manitou dolomite, which here is a white and gray limestone marble and dolomitic limestone marble. About 250 feet south of the portal, it cuts the Star fault, which brings the Silver Plume(?) granite in contact with the Manitou dolomite. A rhyolite porphyry dike intruded along the fault zone. The west contact of the dike was mapped by Shenon and Full [14] in a drift south of the tunnel as dipping 75° E. East of the dike is the Silver Plume(?) granite, followed by northeastward-dipping Sawatch quartzite, and Manitou dolomite. The Sawatch quartzite and Manitou dolomite are folded into a syncline plunging to the northeast. According to Shenon and Full, most of the ore was produced from a pipelike ore body just west of the trough of the syncline. The ore was in the Manitou dolomite about 130 feet stratigraphically above the Sawatch quartzite. Shenon and Full report that this ore body was stoped upward for at least 40 feet, and for a length of from 10 to 20 feet. There are no records available on the mineral content of the ore, and no ore specimens were observed on the dump. Presumably the ore was mined for lead and zinc.

[14] See footnote 9 on p. 69.

VICTOR MINE

The Victor mine is on the south side of West Point Hill, at an altitude of about 10,600 feet, and is 600 feet south of the Morning Star shaft. The mine is reached by a poor road which passes the Morning Star and North Star mines, and joins the Galena Creek road about 700 feet east of the old town of North Star (pl. 5). In 1952 the mine was owned by the Callahan Zinc-Lead Co.

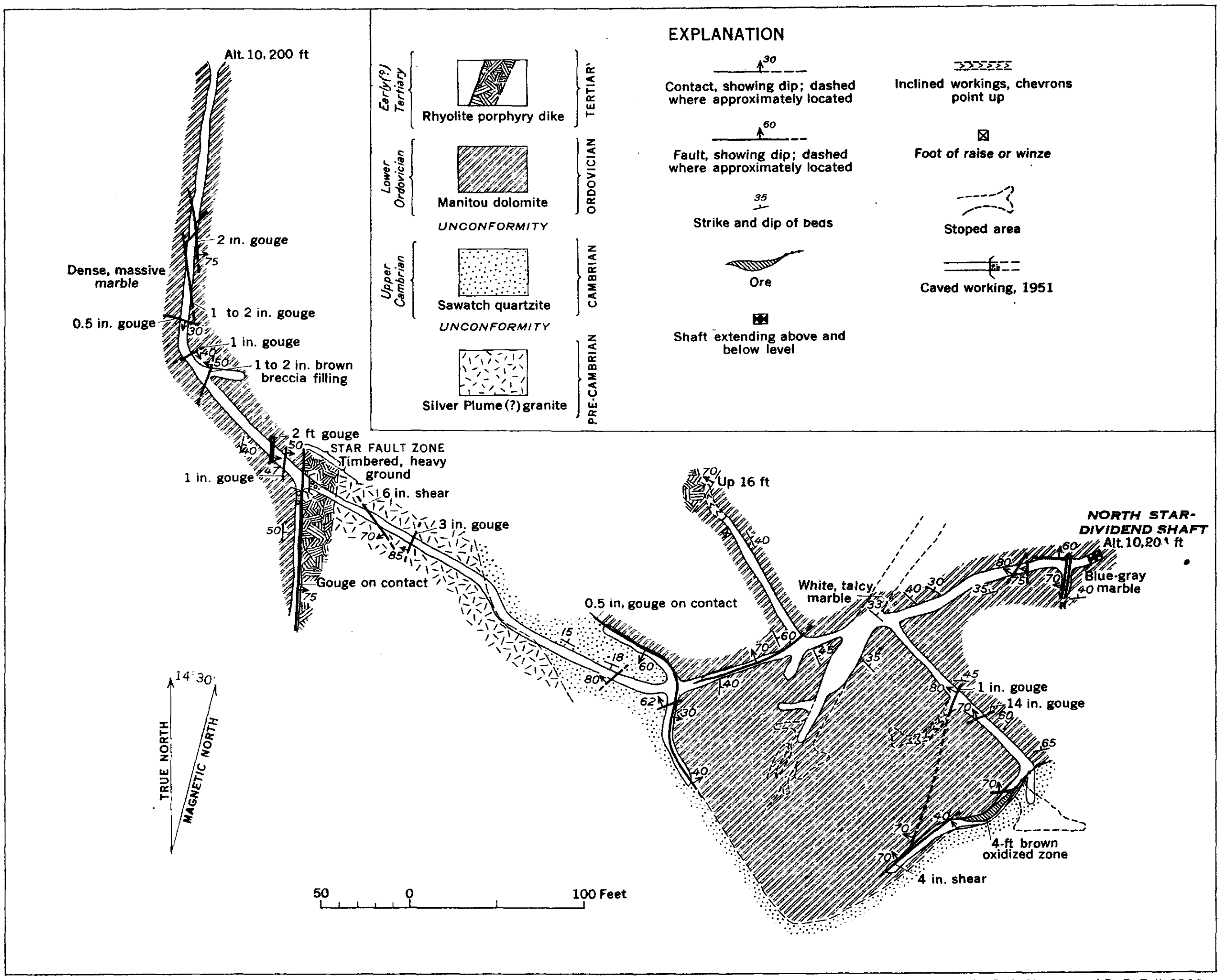
The Victor claim, formerly called the Beta, was one of the earliest in the Tomichi district. Crawford (1913, p. 284) reports that it was located in 1882 and that the production (p. 300) of the mine before 1911 was about $500,000. The following table gives the production from 1901 to 1950.

Production of the Victor mine, in recovered metal, 1901–50

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published by permission of the owners]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1906	100		1,800		40,000	37,508
1909	74	2	4,640	48,324	17,425	
1916	41		285	84	3,983	10,998
1917	47	1	458	474	4,082	11,000
1919	221		2,175	309	75,764	149,592
1920	251				55,344	106,840
1923	475	5	6,889	1,642	262,485	24,168
1924	166	2	2,220	1,462	76,048	24,883
Total	1,375	10	18,467	52,295	535,131	364,989

The mine workings were caved when visited in 1950. Old maps obtained by the Callahan Zinc-Lead Co. show that the mine was worked by an inclined shaft and a tunnel. The inclined shaft, about 300 feet in length, bears about due east and is inclined 45°. Along the shaft at 40- to 50-foot intervals are six levels with a total of 300 feet of workings. No maps were available of the Victor tunnel, but according to Crawford (1913, p. 300), the tunnel was driven 200 to 300 feet before 1911.



Geology by P. J. Shenon and R. P. Full, 1946. Map furnished by Callahan Zinc-Lead Co., and published with permission. Stratigraphy modified by Charles S. Robinson

FIGURE 5.—Geologic map of the Tenderfoot tunnel.

The country rock is dolomitic limestone marble of the Leadville formation, which dips about 50° E. About 100 feet east of the shaft, the Star fault brings the Silver Plume(?) granite against Leadville beds. A rhyolite porphyry dike occupies most of the fault zone and locally cuts into the limestone in the footwall of the fault, leaving blocks of limestone east of the dike in fault contact with the granite. The dip of the fault and dike ranges from 45° to 65° E.

Crawford (1913, p. 300) describes the occurrence of the ore as follows:

The largest orebody hitherto discovered in the mine extended from the surface to a depth of 182 feet and was just west of the porphyry dike that may be seen in the Morning Star mine. The longest drift of ore has a length of 300 feet. The greatest thickness of the ore body was 8 feet. The ore was chiefly silver-bearing lead carbonate and averaged $62 a ton in value. A few years ago a tunnel, which was driven 200 or 300 feet, cut a body of sulphide ore about 75 feet below the surface on the east side of the porphyry dike—that is, between the porphyry and the granite. This ore was in or near the Star fault. Of the four carloads shipped from the tunnel the best ran 93 ounces silver per ton, 26 percent lead, and 6 percent copper.

Oxidized ore found on the dumps contains cerussite, calamine, and smithsonite, with associated small patches of galena in a gangue of vuggy, iron-stained quartz. The most abundant primary ore mineral is galena, found as disseminated grains or small patches in dolomitic limestone marble. Associated with it is a small amount of yellow or brown sphalerite, a little pyrite, and some chalcopyrite. Crawford (1913, p. 300) reported that specimens from the tunnel carried galena, tennantite, and pyrite. Most of the rocks of the dump are heavily iron stained, and some azurite and malachite occur as stain on these rocks.

WEST POINT MINE

The West Point mine is on the north slope of West Point Hill, at an altitude of about 10,200 feet, just west of the lower Morning Star tunnel (pl. 5). It may be reached by a trail from the lower Morning Star tunnel. In 1952 the mine was owned by the Callahan Zinc-Lead Co.

Very little information is available on the history, production, or workings of the mine. Crawford (1913, p. 299) reports that several tons of ore were removed when the adit was being driven and that in 1912 the owners reported shipping a carload of silver-lead carbonate ore. As shown on plate 6, the workings, which were caved when visited in 1950, consist of a tunnel about 1,100 feet long and a raise 900 feet from the portal. Crawford (1913, p. 299) states that the tunnel was driven in granite for about 300 feet and then in limestone for 200 feet, but detailed mapping in the vicinity of the mine has shown that the adit was started in Manitou dolomite and intersected a shear zone about 300 feet from the portal. (The shear zone may be followed on the surface by a series of caved prospect pits and shafts.) The adit is then believed to have followed the shear zone to its intersection with the granite.

In most of the Tomichi district the Sawatch quartzite directly overlies the granite but locally Manitou dolomite may be in contact with the granite because the Sawatch quartzite was removed by erosion before deposition of the Manitou dolomite. The latter must be the case in this mine, for Crawford (1913, p. 299) states that some ore was removed from a raise at the contact of the granite and limestone (Manitou dolomite of this report). A favorable locality for deposition of ore would be in the fractured limestone or dolomite at the intersection of the shear zone with the contact between the Manitou dolomite and the granite.

Ore found on the dump contains pyrite, chalcopyrite, and sphalerite as disseminated grains and in small veinlets in the dolomite marble and granite. A small quantity of galena is associated with the sphalerite. Ore minerals in the dolomite marble are accompanied by a little epidote, diopside, and calcite, and in the granite by some phlogopite. Most of the granite on the dump is altered, the feldspars to sericite and the ferromagnesium minerals to hydromica.

OTHER MINES AND PROSPECTS

ALWILDA TUNNEL

Development.—Adit, bearing N. 71° W. at portal. Caved when visited in 1950. Reported in 1910 to be about 1,000 feet long.

Production.—No records before 1901. No production recorded 1901–50.

Vein.—Tunnel driven to cut Silver Cord and Lilly veins, but probably did not reach them.

Wall rock.—Mount Princeton quartz monzonite.

ANNIE HUDSON

Development.—Adit bearing S. 80° E. at portal (caved when visited in 1949), and several prospect pits and short adits. Estimated underground workings total 1,000 feet.

Production and tenor.—No records available of production before 1901. No production recorded 1901–50. Total production probably small. Ore stacked at portal in 1910 assayed 41.00 percent zinc and carried 5.25 ounces of silver to the ton.

Ore body.—Replacement body in limestone of the Belden shale along the Morning Glim fault zone.

Wall rock.—Dolomite, limestone, and marble containing some specularite, magnetite, serpentine, and tremolite.

Ore and sulfide minerals.—Smithsonite, calamine, and galena.

Gangue minerals.—Quartz and limonite.

BEN BOLT

Development.—Shaft (inaccessible when visited in 1949), and probably only a small amount of level workings.

Production.—Little, if any; no recorded production 1901–50.

Vein.—Strike N. 75° E., dip 75° N., length 1,800 feet on surface, width 6 to 18 inches.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and some chalcopyrite on dump.

Gangue mineral.—Quartz.

BILL SHORT

Development.—Adit bears northeast, and estimated total workings of about 2,000 feet. Mine accessible for a few hundred feet when visited in 1949.

Production and tenor.—Records of production before 1901 unavailable. The only production recorded from 1901 to 1948 was in 1935 when 14 tons of ore yielded 158 ounces of gold, 357 ounces of silver, 157 pounds of copper, 712 pounds of lead, and 1,879 pounds of zinc.

Vein.—Strike northeast, dip 60°–75° NW., length at least 700 feet.

Wall rock.—Altered Mount Princeton quartz monzonite and some altered Silver Plume(?) granite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, chalcopyrite, and rare greenockite.

Gangue minerals.—Quartz and barite.

BREADWINNER

Development.—Shaft, caved when visited in 1950. Total mine workings small, judging from size of dump.

Production and tenor.—No records available before 1901. No production recorded 1901–50. One assay of ore from dump gave 37.70 percent zinc.

Ore body.—Bedded replacement deposit at contact of Fremont dolomite and Chaffee formation.

Wall rock.—White dolomite marble of Fremont dolomite and shaly limestone of Chaffee formation.

Ore and sulfide minerals.—Calamine, cerussite, smithsonite, and galena.

Gangue minerals.—Banded sugary quartz and limonite.

CONGRESS TUNNEL

Development.—Adit, caved 50 feet from portal when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Ore body.—Bedded replacement deposit in Leadville limestone at contact with Belden shale.

Wall rock.—Limestone marble of Leadville limestone and quartzite and argillite of Belden shale.

Ore and sulfide minerals.—Sphalerite, galena, pyrite, and chalcopyrite.

Gangue minerals.—Calcite, dolomite, and some epidote, diopside, and garnet.

DAVID H.

Development.—Three shafts, caved when visited in 1950, but reported not deeper than 100 feet. Extent of underground working unknown but probably small.

Production.—No records available before 1901. Only recorded production from 1901 to 1950 is 512 tons in 1901–03 which yielded 5 ounces of gold, 20,304 ounces of silver, and 184,791 pounds of lead.

Ore bodies.—Replacement bodies along steeply dipping, northerly striking fractures.

Wall rock.—White and gray dolomite marble and tremolite-bearing marble of the Leadville limestone.

Ore and sulfide minerals.—Cerussite, calamine, smithsonite, and galena. Tetrahedrite and stephanite reported.

Gangue minerals.—Dolomite and calcite.

DAY STAR

Development.—Entered by adit bearing S. 3° W.; three drifts total 640 feet, and one crosscut 102 feet.

Production.—Probably none. No production recorded 1901–50.

Veins.—One main vein and two short and narrow veins. Main vein strikes on the average N. 23° W., dips 53° W. to vertical, exposed for 410 feet in mine, and traced for total length of 1,900 feet at surface, width 1 inch to 7 feet, with average of 2 feet. Locally bordered by gouge and breccia zone as wide as 3 feet.

Wall rock.—Mount Princeton quartz monzonite and Mount Aetna quartz monzonite porphyry. Locally altered for distance of 8 feet or less.

Minerals.—Quartz, fluorite, and scarce pyrite, chalcopyrite, and calcite. Stephanite (brittle silver) has been reported as occurring in small quantity.

DEFIANCE

Development.—Shaft and short adit (both inaccessible when visited in 1949); small workings.

Production.—No complete records available before 1901, but it is reported that several carloads of ore shipped in early eighties. No production recorded 1901–50.

Vein.—Not exposed and no data available.

Wall rock.—Silver Plume(?) granite.

Ore and sulfide minerals.—Pyrite, sphalerite, and probably others.

Gangue mineral.—Quartz.

DENVER CITY

Development.—Shaft, inclined 55° N. 71° E., 200 to 250 feet deep, and an adit several hundred feet long. Shaft and adit caved when visited in 1950.

Production.—Only production before 1901 was in 1888–90, which totaled $5,239, of which $442 was in gold, $2,659 in silver, $1,786 in copper, and $352 in lead. Most of the production from shaft. No production recorded 1901–50.

Ore body.—Bedded replacement deposit along contact of Fremont dolomite and Chaffee formation.

Wall rock.—Massive white dolomite marble of Fremont dolomite and shaly limestone of Chaffee formation.

Ore minerals.—Cerussite, smithsonite, calamine, and malachite.

Gangue minerals.—Limonite and quartz.

FORT SCOTT

Development.—Two adits (inaccessible when visited in 1949) and several prospect cuts and pits. Extent of underground workings not known; most of dump washed down gulch.

Production and tenor.—Records of production before 1901 incomplete, but mine reported to have shipped 10 or 12 carloads of chiefly gold and silver ore. No production recorded 1901–50.

Vein.—Probably northerly trending vein zone; not clearly exposed.

Wall rock.—Altered volcanic breccia.

Ore and sulfide minerals.—Pyrite (probably gold-bearing) and probably galena, but none seen on dump.

Gangue.—Altered volcanic breccia and some quartz.

HIAWATHA

Development.—Shaft (inaccessible when visited in 1949) about 100 feet deep, and an estimated total of 250 feet of level workings.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Trend N. 12° W., length 900 feet as traced on surface.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite and rare galena and sphalerite on dump.

Gangue mineral.—Quartz.

IRON KING

Development.—Adit, caved when visited in 1950.

Production.—No production recorded 1901–50. Several carloads of iron ore and 2 tons of cuprite reported to have been shipped before 1910.

Ore bodies.—Replacement deposits in limestones of the Belden shale along or near Morning Glim fault. The fault dips steeply eastward. The deposits are reported to range from 5 to 40 feet in thickness and to extend for several hundred yards.

Wall rock.—Limestone, quartzite, and argillite of the Belden shale, and Silver Plume(?) granite.

Ore and sulfide minerals.—Magnetite, limonite, cuprite, and pyrite.

Gangue minerals.—Quartz, calcite, epidote, chlorite, amphibole, pyroxene, and garnet.

ISABEL

Development.—Adit, bearing N. 9° W. at portal. Caved when visited in 1950.

Production.—No records before 1901. No production 1901–50.

Ore body.—Replacement deposit in Manitou dolomite in hanging wall of Star fault, which dips steeply eastward.

Wall rock.—Hanging wall of fault white to gray limestone and dolomite marble. Footwall is altered rhyolite body.

Ore and sulfide minerals.—Cerussite and galena.

Gangue minerals.—Quartz and limonite.

LEGAL TENDER

Development.—Adit bearing northeast at portal (caved when visted in 1949), and several prospect cuts and pits. Estimated workings total about 1,500 feet.

Production.—No records available before 1901. No production recorded 1901–50.

Ore body.—Probably irregular replacement deposits in limestone; partly oxidized.

Wall rock.—Chiefly silicified limestone and volcanic breccia.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, cerussite, smithsonite, anglesite, and sparse chalcopyrite and malachite.

Gangue minerals.—Silicified limestone, quartz, and limonite.

LEWISTON-PET

Development.—Two shafts (inaccessible when visited in 1949) within 30 feet of each other, several pits and cuts, and an unknown but probably small amount of underground workings.

Production and tenor.—Record of production before 1901 incomplete, but it is reported that very high grade ore was shipped in the eighties. In 1887 production of gold valued at $2,000 and silver at $500. No production recorded 1901–50.

Veins.—At least two northeast-striking veins, probably a minimum length of 500 feet for each.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, chalcopyrite, and some tetrahedrite on dump. Free gold and silver reported.

Gangue mineral.—Quartz.

LILLY

Development.—Shaft (inaccessible when visited in 1949) reported to be 200 feet deep. At depth of 150 feet drift extends north for 300 feet and south for 150 feet; at 200 feet, drift extends north for 40 feet and south for 120 feet.

Production and tenor.—Production to 1910 valued at $40,000. None recorded 1911–50. Ore was all tetrahedrite, which assayed as much as 200 ounces of silver per ton.

Vein.—Strike about N. 10°–15° E.; dip reported to be steep. Width 8 inches to 5 feet.

Ore bodies.—On 150-foot level the ore extended nearly the length of drift toward the north, but only pyrite was found in the south drift. On 200-foot level, vein weakly mineralized in north drift, but no shipping ore.

Wall rock.—Mount Princeton quartz monzonite and Silver Plume(?) granite.

Ore and sulfide minerals.—Tetrahedrite, galena, pyrite, and chalcopyrite.

Gangue minerals.—Quartz and barite, the latter especially common on the 200-foot level.

MAGNA CHARTA TUNNEL

Development.—Adit bearing N. 35° W. at portal (caved when visited in 1949) reported to be about 4,000 feet long.

Production.—No ore shipped.

Veins.—Cut several northerly trending veins.

Wall rock.—Mount Princeton quartz monzonite.

Minerals in vein.—Quartz, pyrite, and sparse galena, sphalerite, chalcopyrite, tetrahedrite, and calcite.

MAID OF ERIN-SILVER PICK

Development.—Shaft, caved when visited in 1950.

Production.—No records available before 1901. Only production recorded from 1901 to 1950 was in 1916 when 55 tons were produced and yielded 1 ounce of gold, 1,240 ounces of silver, 277 pounds of copper, and 11,049 pounds of lead.

Ore body.—Replacement deposit in Manitou dolomite, either at the contact with the overlying Harding quartzite or with the underlying Sawatch quartzite. The mine is in a small fault block separated from the adjacent formations by two eastward-trending faults (pl. 5).

Wall rock.—White to gray limestone and dolomite marble of the Manitou dolomite, and quartzite of the Harding quartzite and possibly Sawatch quartzite.

Ore minerals.—No ore minerals on the dump; ore was probably oxidized.

Gangue minerals.—Probably limonite and quartz.

PRINCETON TUNNEL

Development.—Adit bearing about N. 80° W. at portal (caved when visited in 1949). Probably total length about 1,500 feet.

Production.—No record available before 1901. No production recorded 1901–50.

Vein.—Intersected eastern part of Ben Bolt vein. Width 1 foot.

Wall rock.—Mount Princeton quartz monzonite; hanging wall strongly argillized (?).

Ore and sulfide minerals.—Pyrite, galena, and coating of chalcocite on pyrite.

Gangue mineral.—Quartz.

SILVER CORD

Development.—Shaft reported 140 feet deep (inaccessible when visited in 1949), and several prospect pits.

Production.—Before 1910, one carload of ore that averaged 85 ounces of silver per ton and 40 percent lead. No production recorded 1911–50.

Vein.—Strikes about N. 10° W.; traced on surface for about 1,200 feet. Vein material on dump shows a local width of at least 10 inches.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Silver-bearing galena, pyrite, and scarce chalcopyrite.

Gangue minerals.—Quartz and barite.

SILVER DOLLAR (ALICE)

Development.—Adit bearing N. 60° W. at portal (inaccessible when visited in 1949). Little data available about workings, but reported to have intersected and drifted along the Ben Bolt vein.

Production.—No records available before 1901. Only recorded production from 1901 to 1950 was in 1916 when 98 tons of ore yielded 188 ounces of silver, 1,376 pounds of copper, and 11,886 pounds of lead.

Vein.—Ben Bolt vein; where intersected by tunnel strikes N. 65° E. and dips 75° NW.; width 18 inches; splits to southwest into two veins, 6 inches and 8 inches wide, separated by 3 feet of quartz monzonite.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, chalcopyrite, and some copper stain.

Gangue mineral.—Quartz.

MONARCH MINING DISTRICT

CHIEF ECONOMIC AND GEOLOGIC FEATURES

Most of the principal mines in the Monarch district are situated on Monarch Ridge, about half a mile south of Monarch, and in an area north of Garfield extending from Taylor Gulch west to Columbus Gulch. Outlying groups of mines are situated high up in Middle Fork and North Fork valleys, in Hoffman Park, and near the source of Cree Creek. Most of the mines in the district were caved at their entrance when visited, and of the seven mines that could be entered, most were only partly accessible.

The district has produced silver, lead, zinc, gold, and copper, listed in order of probable value. Because a large part of the output was made before reliable and fairly complete records were kept, it is possible that the total value of lead may exceed silver. The relatively small value of the zinc is accounted for in part by the fact that there were no zinc smelters in Colorado during the early, and greatest, period of activity. According to Crawford (1913, p. 199), ores produced before 1913 from Monarch Ridge yielded chiefly lead, silver, gold, and zinc, with some copper in the Madonna and Eclipse mines; Taylor Gulch ores were copper, silver, gold, lead, and zinc; Columbus Gulch ores were silver, gold, and lead; the mines of North Fork produced chiefly silver and lead ore. The ore produced since Crawford's figures were compiled in 1913 has materially increased the total value of zinc, especially in the Monarch Ridge and Taylor Gulch areas where it probably ranks third, exceeded only by silver and lead.

The ore deposits of the Monarch district consist of replacement deposits in limestone and dolomite, and of veins. The replacement deposits have been overwhelmingly the most productive. They occur in bedded and irregular forms and along faults. The bedded and irregular replacement deposits occur locally in all of the formations that contain limy beds, but they are particularly characteristic of the basal 50 feet of the Manitou dolomite, and in many places rest on granite.

The largest ore bodies mined occur as replacements in limestone or dolomite beds along faults, as those on the Madonna fault in the Madonna mine, and on the Mayflower fault in the Eclipse mine. In the Madonna mine some ore occurs in pre-Cambrian rocks on the southwest side of the Madonna fault, but most of it is in sedimentary rocks on the northeast or downthrow side of the fault in shoots that dip northwest a little steeper than the enclosing beds and lie adjacent to the faults. According to Crawford (1913, p. 241), the main ore body forms an irregular but practically continuous shoot having a pitch length of about 1,900 feet and a vertical height of nearly 1,500 feet. Ore shoots in the Eclipse mine have the same northwest plunge as those in the Madonna, and the ore solutions probably migrated chiefly along the Mayflower fault and spread out along the dolomite beds where deposits were formed mostly in shoots near the granite-Manitou contact and just beneath the Harding quartzite.

The bedded replacement deposits are especially well developed on the east sides of Taylor Gulch and Cree Creek valley, where they have been mined in the Garfield, Lilly, and Clinton mines. The ore occurs chiefly in lower beds of the Manitou dolomite that dip steeply west. Many of the ore shoots plunge north.

Most of the ore obtained from the replacement deposits has been oxidized, although primary sulfide minerals were reached at varying depths in all the deeper mines. The oxidized ore is typically brown, soft, porous limonite containing variable amounts of cerussite, calamine, smithsonite, and occasional patches or grains of galena. The common primary sulfides are pyrite, galena, sphalerite, and chalcopyrite. Pyrrhotite is present in part of the ore in the Garfield mine.

Most of the veins in the Monarch district occur in the Mount Princeton quartz monzonite and the Belden and Minturn formations, although there are a few in sedimentary rocks older than the Belden, in crystalline rocks of pre-Cambrian age, and in Tertiary intrusive rocks other than the Mount Princeton quartz monzonite. Veins in the Belden shale and Minturn formation generally strike north to northeast and commonly fill bedding faults that dip steeply west. Most of the veins in the Mount Princeton quartz monzonite strike northeast and dip steeply northwest. In length the veins range from a few feet to as much as 4,000 feet on the Columbus vein (pl. 1), and the thickness of the more persistent veins ranges from 1 to 4 feet, although the Columbus vein is reported to range from 6 to 20 feet.

The unoxidized parts of the veins consist characteristically of variable proportions of galena, sphalerite, and pyrite, and generally lesser amounts of chalcopyrite, in a gangue of white vuggy quartz. Silver is present in nearly all the sulfide ores, and gold is present locally and in variable quantities. Oxidized vein matter is typically brown, somewhat porous limonite or limonitic quartz, accompanied locally by cerussite, smithsonite, calamine, secondary copper stains, and patches or grains of galena. Oxidation is not nearly so pronounced or deep in the veins as in the replacement deposits. The veins in the sedimentary rocks are more deeply altered than those in the crystalline rocks; many are extensively oxidized to depths of several hundred feet, whereas most of the veins in the crystalline rocks contain fresh sulfides at or a few feet below the surface.

Several ore deposits in the Monarch district are associated with minerals characteristically developed by contact metomorphism. All these deposits are near the head of Taylor Gulch or in Cree Creek valley, near a large body of Mount Princeton quartz monzonite which has irregularly metamorphosed the bordering sedimentary rocks to the southeast for as much as half a mile. Silver ore is reported to be associated with magnetite in the Mountain Chief mine, sphalerite is associated with diopside and andradite near the New York mine, and silver, copper, lead, and gold are associated with garnet in the Clinton mine.

GARFIELD MINE

The Garfield mine is on the east side of Taylor Gulch at an altitude of about 10,500 feet. The mine was probably first worked in the late eighties; it passed through various ownerships until acquired in 1935 by a group of men who organized a company known as The Garfield Mines, about 70 percent of the stock of which was held by S. E. and W. E. Burleson of Salida, Colo. The property consists of 17 patented claims and a mill site.

No records were kept of the production before 1901, but it was probably not more than a few thousand tons. The total production [15] from 1901 to 1948 was 12,244 tons of crude ore that yielded 1,468 ounces of gold, 106,239 ounces of silver, 372,220 pounds of copper, 579,624 pounds of lead, and 1,737,933 pounds of zinc. The greatest annual production was in 1946. Zinc ore was first shipped in 1944.

[15] Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. Published by permission of the owners.

The mine has been worked through two adits, spaced about 1,400 feet apart (pl. 1), which start in the Leadville limestone and bear east to the contact of the pre-Cambrian granite and Manitou dolomite. The principal ore bodies developed thus far are reached from the south adit level. The north adit, about 200 feet higher, has been driven more recently. It connects with a raise in the north end of the south adit workings. The geologic map and section (pl. 10) show the workings of the south adit level. Raises and winzes connect with workings that are mostly less than a hundred feet vertically from the main adit level. The north adit crosscut bears northeast for about 350 feet and then nearly east for about 525 feet to connect with a 210-foot raise from the south adit workings. From the head of the raise a drift has been driven for about 350 feet, on an average bearing of N. 10° W., along or close to the contact of the granite and limestone. About midway along this drift, a raise of 70 feet was made to cut the upward extension of a northward-pitching ore body found in the drift. At a point in the drift about 80 feet north of this raise, this ore body was being worked in an underhand stope when the mine was visited in 1949.

Both crosscut adits begin in steeply dipping beds of Leadville limestone and to the east successively cut the Chaffee, Fremont, Harding, and Manitou formations. In the eastern part of the crosscuts the beds are overturned and dip steeply east. Most of the limestone and dolomite has been metamorphosed to marble. Bedding slips with a fraction of an inch to 4 inches of gouge are common. There are few folds; the most prominent one is in the south adit about 220 feet west of the granite and limestone contact where the beds have been dragged along a northwesterly trending fault. The contact of the Silver Plume(?) granite and Manitou dolomite dips steeply, generally being overturned and dipping to the east; almost everywhere that it is exposed it shows some movement along the contact.

The important ore bodies all occur in the Manitou dolomite at or a few feet west of the granite. In the south level workings are three main ore shoots: (1) at the Old South winze, (2) at the Middle winze, and (3) at the Big winze (pl. 10). In the higher north adit workings, two small north-plunging shoots have so far been worked. All are replacement bodies that closely follow the bedding of the Manitou dolomite or the contact of granite and dolomite. The lengths and breadths of the main ore shoots are shown on the section, plate 10. The maximum thickness of the ore shoots is 12 feet, although some sulfide minerals are disseminated for a few feet beyond the ore. The ore is oxidized to a depth of about 325 feet below the surface, and generally oxidized ore is above the main level of the south adit and primary ore is below it.

The sulfides are chiefly pyrite, sphalerite, galena, chalcopyrite, and pyrrhotite. Pyrrhotite and pyrite were most abundant in the ore shoot developed through the Old South winze, and sphalerite was especially abundant in the lower part of the shoot developed through the Middle winze. The oxidized ore consists of cerussite, residual grains of galena, copper carbonates, and some anglesite, calamine, and smithsonite. Free gold is probably contained in some pyrite and limonite.

MADONNA MINE

The Madonna mine is half a mile south of Monarch on the steep northwest slope of Monarch Ridge. The property consists of 19 patented claims, 3 mill sites, 4 unpatented claims, and part interest in 7 other patented claims. It is owned by the Utze Lode Co., of which Harold R. Koster of Salida, Colo., is treasurer and mine manager.

The mine has had a long history. It was discovered by surface indications high on Monarch Ridge about 1878 by Messrs. Smith and Gray. They soon sold it to a company that erected a small smelter at the foot of the ridge, but this enterprise failed because of the lack of siliceous ore needed to flux the basic ore of the Madonna and because of the high cost of coke. In 1883 the mine was purchased by Anton Eilers and his associates. They were instrumental in getting the narrow-gage railroad extended from Maysville to Monarch. The Madonna mine was the principal reason for the establishment in 1883 of the Colorado Smelter at Pueblo, and for many years the Madonna mine supplied a large part of the ores treated there. The Madonna mine was worked continuously from 1883 to 1894, under the management of Eilers, by the Colorado Smelting Co., which included the former operators. After 1895 the mine was worked intermittently by various lessees until the Utze Lode Co. acquired the property in 1945 from the Eiler family. In 1908 the mine was leased to the Monarch-Madonna Mining Co., which started driving a lower tunnel, no. 6 level, which in 1953 was the principal means of access to the mine. From 1945 to 1953 the Utze Lode Co. did considerable exploratory work on and below the no. 6 level and produced some ore.

The Madonna mine has produced the second largest tonnage and value of ore of any mine in the quadrangle, being surpassed only by the Mary Murphy in the Chalk Creek district. The total value of the Madonna ore has been about $6,000,000, of which lead accounts for about $3,575,000, silver $1,430,000, zinc $735,000, gold $225,000, and copper $35,000. These figures were obtained by adding the values obtained by Crawford (1913, p. 239) for the period 1883–1901 to the value of the production recorded by the Bureau of Mines for the period 1902–51. The production figures [22] for this latter period were kindly furnished by A. J. Martin, Statistics Branch, Economics Division, Denver, and the values calculated by the authors. Production was greatest during the period 1883–94, when two-thirds of the total was produced. Most of the rest was obtained during the period 1902–20. In the past 30 years, somewhat less than 2,500 tons of crude ore has been mined.

The mine workings, as of 1950, consist of seven adit levels, numbered 0 to 6, eight intermediate or sublevels, many raises and winzes, and at least 12,000 feet of drifts and crosscuts. The vertical distance from the zero, or surface, level to the lowest workings, the 384-foot sublevel, is about 1,525 feet. The old mine workings from zero to the no. 5 level have been largely or entirely inaccessible for many years. Access to the mine and haulage of ore for the past 35 years have been chiefly through the no. 6 level, the portal of which is only a short distance above the valley floor and is easily reached. Plate 11 shows the outline of the main ore bodies and the mine workings, and the principal geologic features from the no. 6 level down to the 384-foot sublevel. To avoid confusion, most of the old workings above the no. 6 level are not shown on this map but they may be seen on plate XXI of the report by Crawford (1913).

The mine workings are chiefly in dolomitic limestone of the Manitou and Fremont formations and in the Harding quartzite. Except where small erosional remnants of Sawatch quartzite are present, the Manitou rests unconformably on an undulating surface of the pre-Cambrian rocks, principally the Silver Plume(?) granite. The rocks are folded and faulted on both a large and small scale; most, if not all, deformation occurred before the introduction of the ore-bearing solutions. The regional strike of the beds is northeast and the dip is 25°–50° NW. Drag along the Hawkeye, Madonna, and Mayflower faults formed local synclines and overturned beds, such as seen in the main drift and first crosscut on the no. 6 level. The main structure is the Madonna fault, which strikes northwest and dips steeply southwest, although locally the dip is northeast. The fault has a displacement of about 300 feet at a point southwest of the first crosscut on the no. 6 level. The displacement apparently decreases rather markedly to the southeast as indicated by the offset of the beds bordering the fault near the top of Madonna Ridge. Drill-hole records combined with surface and underground mapping indicate that the northeast-trending Hawkeye fault offsets the Madonna fault for a distance of about 200 feet as shown on plate 11.

The ore shoots are contained in and border the Madonna fault, chiefly in limestone or dolomite of the northeast, or footwall, side of the fault. The few shoots that are in the hanging wall tend to follow stratification planes, but those in the footwall are in more broken ground and are irregular. The main mineralized body (pl. 11), which is almost a continuous ore shoot, has a pitch length of about 1,900 feet. It consists of several large shoots and many smaller ones. All shoots are irregular, and most plunge northwest at angles ranging from 25° to 48°, generally a little steeper than the dip of the beds. The largest shoot extends from no. 1 level to no. 3 level and is chiefly in the Fremont and Manitou formations, although part of the ore is in and bordering irregular patches of the Harding quartzite. On no. 3 level this shoot was mined for a maximum breadth of 80 feet and a stope length of 200 feet. Continuous, or nearly continuous, shoots extend from the surface to no. 4 level, and from about 200 feet below no. 5 level to about 200 feet below no. 6 level. The main shoot on no. 6 level ranged in breadth from 5 to 11 feet, and this same shoot 150 feet vertically below no. 6 level had a maximum breadth of 17 feet. Thicknesses vary greatly from place to place; the maximum is about 40 feet. From no. 1 level to no. 4 level the ore body lay about 100 feet above the underlying granite. Below no. 4 level it gradually approached the granite, which it reached at no. 6 level. Diamond drilling done intermittently during the past few years indicates a body of mineralized ground containing fresh pyrite, sphalerite, and sparse galena and chalcopyrite in the basal Manitou at its contact with granite. This body is about 250 feet northwest of sublevel 384 and lies about 125 to 225 feet lower. It is apparently close to the Madonna fault.

Practically all of the ore mined to date has been oxidized. It grades from limonite, rich in ore minerals, to barren limonitic and iron-stained wall rock; locally the wall rock contains disseminated grains of galena. In places the contact of the ore with limonite is sharper than the contact between limonite and unaltered wall rock. The principal ore minerals are cerussite, free gold, smithsonite, calamine, cerargyrite, argentite, residual grains of silver-bearing galena, and malachite. The gangue is chiefly limonite, locally accompanied by limestone, dolomite, and quartz.

The tenor of the ore varied considerably but in general, according to Crawford (1913, p. 242), the ore of the main shoot from the surface to no. 3 level, was chiefly yellowish cerussite which carried 5 to 7 ounces of silver per ton, 25 to 30 percent lead, and much iron; between levels 3 and 5 it was mostly brown limonite

[22] Published by permission of the owners.

which carried 5 to 7 ounces of silver per ton, 2 to 10 percent lead, and, on part of the no. 5 level, a few hundredths of an ounce of gold per ton. From no. 5 level to about 100 feet below no. 6 level, iron and lead remained fairly uniform while gold and silver increased steadily although irregularly. About 150 feet below no. 6 level the ore carried high values in silver and gold, some lead, and 10 to 25 percent excess silica. Locally, on the lower levels a high-grade streak of ore, 1 to 6 inches wide, accompanied the lower-grade bodies. The streak consists of a brown variety of ore composed chiefly of small cerussite crystals in limonite, and a dark-brown to black, earthy or sooty, variety containing much cerargyrite, small grains of argentite and pyrite, and small crystals of cerussite and quartz. A specimen of the first variety assayed (Crawford, 1913, p. 242) 10.40 ounces of gold and 756.40 ounces of silver per ton, and 48.0 percent lead; the second variety 65.10 ounces of gold and 5,974.90 ounces of silver per ton, and 24.30 percent lead.

Most of the zinc ore came from irregular bodies composed of smithsonite and calamine in a gangue of limonite that are below the no. 4 level and lie under and in contact with the silver and lead-bearing limonite. Some zinc ore, not mined in the early days, may remain in the higher levels, as indicated by material on the upper dumps. The principal copper shoot occurred below the main silver-lead shoot from no. 4 level to about 50 feet below no. 5 level. It bottomed at the contact of the granite and limestone, although an arm of this irregular shoot extended about 300 feet horizontally from the main silver-lead shoot. The copper ore, chiefly malachite in limonite, carried 1½ to 12 percent copper, some silver and lead, and, locally, gold.

Some additional work has been done in the Madonna mine since 1950 when it was last examined for this report. The internal shaft on no. 6 level has been deepened to 600 feet. At a depth of 470 feet a crosscut has been driven northeast for about 185 feet, and at a depth of 590 feet a crosscut has been driven about 500 feet on a bearing of N. 59° W. No ore in commercial quantities was cut, although a few pockets of fresh sulfide minerals, mostly pyrite with sparse sphalerite and chalcopyrite, and rare galena, were found. In April 1953, the date of this writing, work stopped in the mine and the lower levels were permitted to flood.

OTHER MINES AND PROSPECTS

ALASKA

Development.—Main shaft (caved when visited in 1950) in 1910 down 110 feet, and about 1,000 feet of drifts at 30, 60, and 100 feet below surface.

Production and tenor.—Records of production before 1901 incomplete, but most of production from 1886 to 1888. In 1898 about one carload of ore shipped. A few tons ran $37 in gold and 14 ounces of silver per ton, 18 percent lead, and 32 percent iron. Recorded production from 1901 to 1948 totaled 412 tons of ore that yielded 43 ounces of gold, 1,050 ounces of silver, 1,335 pounds of copper, 35,496 pounds of lead, and 51,485 pounds of zinc.

Ore bodies.—Replacement deposits in Manitou dolomite at or near contact with pre-Cambrian granite.

Wall rock.—Dolomite, granite, and gouge material.

Ore and sulfide minerals.—Galena, cerussite, and limonite.

Gangue minerals.—Limonite and some quartz and calcite.

Ore shoots.—Main shaft sunk on east-trending streak of ore about 45 feet west of granite. Main shoot 10 to 18 inches wide, extends 30 feet along north-trending drift, and pitches about 20° N.

ALPHA

Development.—Adit (caved when visited in 1950) bearing about N. 73° E. at portal. An estimated 175 to 200 feet of underground workings.

Production.—Records before 1901 incomplete, although a total of about 20 tons of silver-lead ore reported shipped from Alpha and Beta mines. No production recorded 1901–50.

Ore body.—Probably in a northerly-trending vein, although none exposed at surface.

Wall rock.—Mostly quartzite of the Minturn formation.

Ore and sulfide minerals.—None seen on dump; probably chiefly silver-bearing galena.

APRIL FOOL

Development.—Gently inclined adit bearing about N. 40° W. (caved when visited in 1950). Small workings indicated by size of dump.

Production.—Records before 1901 incomplete, but reported to have produced at least three carloads before 1890. No production recorded 1901–50.

Ore body.—Replacement body in Manitou dolomite at or near contact with Silver Plume(?) granite.

Wall rock.—Limestone, dolomite, and granite.

Ore and sulfide minerals.—Probably cerussite, smithsonite, calamine, and galena in limonite.

Gangue minerals.—Limonite and calcite.

BEN HILL

Development.—Shaft (inaccessible when visited in 1950) in 1909 was 275 feet deep with drifts at 125, 175, and 225 feet below surface. Longest drift runs 125 feet north on 175-foot level.

Production and tenor.—Records before 1901 incomplete, but reported ore value about $12,000; mostly shipped during the eighties. No production recorded 1901–50. Average tenor of galena ore from 175-foot level was 85 ounces of silver per ton and 73 percent lead; carbonate ore in same shoot averaged 22 to 28 ounces of silver per ton and 30 percent lead.

Vein.—Ben Hill. Strike N. 15°–20° E., dip 50°–65° W., length about 1,800 feet as tentatively projected, width 3 feet locally. Locally, postore bedding fault.

Wall rock.—Quartzite, shale, and limestone of Belden shale.

Ore and sulfide minerals.—Chiefly galena and cerussite.

Gangue minerals.—Quartz and some limonite.

Ore shoots.—Northward-pitching shoot extending from about 125-foot level to 175-foot level, and ore spotty down to 225-foot level. On 175-foot level shoot of galena 3 feet wide, bordered by lead carbonate.

BETA

Development.—Shaft (caved when visited in 1950) and an estimated 200 feet of underground workings.

Production.—Records before 1901 incomplete, although a total of about 20 tons of silver-lead ore reported shipped from Alpha and Beta mines. No production recorded 1901–50.

Vein.—Probably a northerly trending vein; heavy talus in area and vein not exposed.

Wall rock.—Mostly quartzite of the Minturn formation.

Ore and sulfide minerals.—None seen on dump; probably chiefly silver-bearing galena.

BLACK TIGER

Development.—Adit bears about S. 35° W. at portal (caved when visited in 1950), and an estimated total underground workings of about 300 feet.

Production.—Records before 1901 incomplete, although 8 or 10 carloads of lead-silver ore reported shipped in 1881. No production recorded 1901–50.

Ore body.—Replacement deposit in Manitou dolomite a few feet above Silver Plume(?) granite.

Wall rock.—Dolomite.

Ore and sulfide minerals.—Cerussite, galena, malachite, chrysocolla, and chalcopyrite(?).

Gangue minerals.—Limonite and quartz.

BONNIE BELLE

Development.—Adit (caved when visited in 1950) bearing northwest and leading to a shaft 146 feet deep, in 1909. Extent of underground workings not known, but probably small.

Production.—Records before 1901 incomplete, but some ore reported shipped in the eighties. No production recorded 1901–50.

Vein.—Probably a northward extension of the Ben Hill vein.

Wall rock.—Quartzite, shale, and limestone of Belden shale.

Ore and sulfide minerals.—Chiefly galena and cerussite.

Gangue minerals.—Quartz and some limonite.

Ore shoot.—Northward-plunging shoot 6 feet thick cut in shaft at 60-foot depth, extended down 40 to 50 feet and had a stope length of 60 feet.

BRIGHTON

Development.—Shaft (inaccessible when visited in 1950) reported to be 100 feet deep and to have 30-foot drifts to north and south.

Production and tenor.—About 100 tons of ore that had a mill value of $40 per ton produced about 1881. No reports of any production since then.

Vein.—Probably a northward extension or branch of the Columbus vein.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and chalcopyrite.

Gangue mineral.—Quartz.

CLINTON

Development.—Opened by three northeast-bearing adits and a shaft distributed on surface through vertical range of 240 feet (fig. 8). All inaccessible when visited in 1950. Total underground workings estimated to be about 2,000 feet.

Production.—First opened in the early eighties and operated for a few years. Reopened and worked from 1901 to 1904 when yielded chiefly silver, gold, copper, and lead valued at about $12,000. No record of production since 1904.

Ore bodies.—Replacement bodies in the Manitou dolomite 6 to 8 feet from the pre-Cambrian granite.

Wall rock.—Skarn, marble, dolomite, and limestone.

Ore and sulfide minerals.—Cerussite, gold (probably in limonite), malachite, azurite, psilomelane, and sparse calamine, pyrite, and chalcopyrite.

Gangue minerals.—Skarn, limonite, quartz, and calcite.

Ore shoots.—Northward-dipping shoots; one extended 300 feet vertically and attained a maximum width of 8 feet.

COLUMBUS

Development.—Worked through several adits distributed up Columbus Gulch through a vertical range of about 500 feet. All underground workings inaccessible when visited in 1950; from size of dumps, workings estimated to total at least 5,000 feet.

Production.—Records before 1901 incomplete, although reported value of ores about $300,000 chiefly silver and copper. From 1901 to 1950 only recorded production was in 1919 when 44 tons of ore yielded 1 ounce of gold, 641 ounces of silver, and 448 pounds of copper.

Vein.—Strike N. 10° W. to N. 10° E., dip steep, length about 3,000 feet as traced on surface, width reported to be 6 to 20 feet but this probably includes altered country rock. Reportedly oxidized to depth of 200 feet.

Wall rock.—Altered Mount Princeton quartz monzonite and metamorphosed beds of the Minturn, chiefly quartzite, argillite, and hornfels.

Ore and sulfide minerals.—Pyrite, sphalerite, azurite, malachite, argentite(?), some native copper and gold-bearing limonite.

Gangue minerals.—Quartz and limonite.

DARLING

Development.—A shaft estimated to be about 150 feet deep, and southwest of it an adit bearing about N. 75° E. and estimated to be about 300 feet long (all underground workings inaccessible when visited in 1950).

Production.—No records available before 1901. From 1901 to 1950 the only recorded production is 12 tons of ore in 1902 that yielded 26 ounces of silver and 1,214 pounds of lead.

Vein.—Not exposed at surface; probably a short and narrow northeast-trending vein.

Wall rock.—Somewhat altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Silver-bearing galena and sparse pyrite.

Gangue mineral.—Quartz.

D'BYRON

Development.—Several pits and short adits, all badly caved when visited in 1950. Main adit bears about N. 12° E., and estimated total workings on it about 200 feet.

Production.—Records before 1901 incomplete; one carload of ore reported shipped in early days. No production recorded 1901–50.

Veins.—Several short and narrow veins reported in area, although the only one exposed is a 10-inch wide vein at portal of main adit; it strikes N. 12° E., and is vertical.

Wall rock.—Mount Aetna quartz monzonite porphyry; chloritic and argillic(?) alteration extends about 6 feet on each side of vein.

Mineralogy of veins.—Only pyrite and white vitreous quartz seen in vein and on dumps. No record of metallic content of ore.

DELAWARE

Development.—Gently inclined adit bearing about N. 35° W. (caved when visited in 1950), and an estimated total of about 750 feet of underground workings.

Production and tenor.—Records before 1901 incomplete. No production recorded 1901–50. Reported to have produced in "early days" about 600 tons of ore, which averaged about $20 a ton, with chief values in silver and lead.

Ore body.—Replacement deposit in Manitou dolomite.

Wall rock.—Limestone, dolomite, and granite.

Ore and sulfide minerals.—Probably cerussite, galena, and smithsonite, and rare gold in limonite.

Gangue minerals.—Limonite and calcite. Manganese oxide reported at bottom of incline, but it carried no values.

DESDEMONA

Development.—Opened by adit (caved when visited in 1950), bearing about N. 55° W., leading to shaft reported to be 118 feet deep in 1910, and lateral drifts totaling 160 feet.

Production.—No records available before 1901, and no production recorded 1901–50.

Vein.—Probably a southward extension of the Ben Hill vein.

Wall rock.—Quartzite, shale, and limestone of Belden shale.

Ore and sulfide minerals.—Chiefly galena and cerussite.

Gangue minerals.—Quartz and some limonite.

ECLIPSE

Development.—Worked through the discovery shaft (about 125 feet deep) and four main adits. The vertical distance between the shaft and the portal of the lowest adit, no. 4, is about 900 feet, and the horizontal distance is about 2,100 feet. The workings, which probably total 8,000 to 10,000 feet, have been largely or entirely inaccessible for many years.

Production and tenor.—Records of production before 1901 incomplete. The recorded production from 1901 to 1950 was obtained intermittently from 1902 to 1926, when 4,925 tons of ore yielded 86 ounces of gold, 6,577 ounces of silver, 17,510 pounds of copper, 222,271 pounds of lead, and 2,002,367 pounds of zinc.[17] It is stated that the net receipts from 1887 to April 1911 were $585,670, and that the greater part of the total output from this mine was produced before 1887. The

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total value to 1950 is therefore about $1,000,000 to $1,250,000. Before 1893, the ore shipped carried 25 to 50 percent lead; later some ore only carried 5 percent. Silver averaged about 8 ounces per ton; the highest reported was 28 ounces per ton.

Ore bodies.—Replacement deposits chiefly in the upper and lower beds of the Manitou dolomite.

Wall rock.—Dolomite, Silver Plume (?), and Harding quartzite.

Ore and sulfide minerals.—Silver-bearing cerussite and galena, smithsonite, calamite, malachite, and probably rare sphalerite, pyrite, and chalcopyrite in lower workings. Gold probably in limonite.

Gangue minerals.—Chiefly limonite and dolomitic wall rock.

Ore shoots.—Two main and separate shoots; one in dolomite immediately below the Harding quartzite and the other in dolomite along its contact with granite. Both plunge northwest about 30° to 45° and lie along and to the northeast of the Mayflower fault. Pitch lengths: Upper shoot about 1,200 feet; lower shoot about 1,400 feet. Lower shoot attains a maximum breadth of 80 feet and thickness of 25 feet. Zinc and copper accompany lead and silver in the lower shoot.

EVENING STAR

Development.—Shaft and at a lower elevation an adit that bears about S. 25° W. at portal (both inaccessible when visited in 1950). Estimated total workings 1,500 feet.

Production and tenor.—Production records incomplete before 1901, although about 600 tons of ore valued at $20 a ton reported. Only recorded production for 1901–50 was in 1917 when 67 tons of ore yielded 3 ounces of gold, 464 ounces of silver, 607 pounds of copper, and 19,432 pounds of lead.

Ore body.—Replacement deposit in Manitou dolomite near contact with granite. Maximum breadth reported is 50 feet.

Wall rock.—Limestone and dolomite of Manitou dolomite and Silver Plume (?) granite.

Ore and sulfide minerals.—Galena, cerussite, smithsonite, and some gold-bearing limonite.

Gangue minerals.—Limonite and calcite.

EXCHEQUER

Development.—Shaft about 150 to 200 feet deep and adit bearing about N. 35° W. at portal (both inaccessible when visited in 1950).

Production.—A small tonnage, if any.

Mineralized body.—Limonitic quartz, and iron-stained limestone and argillite in Belden shale.

GOLDEN AGE

Development.—Adit (caved when visited in 1950) bearing N. 35° W. at portal. In 1909 workings were 550 feet of crosscut and a drift 40 feet long. Size of dump indicates little or no extension since then.

Production.—Records before 1901 incomplete, although reported that two carloads of ore shipped. No production recorded 1901–50.

Ore body.—About 3 feet wide in a shear zone; probably quartz veinlets in mineralized country rock.

Wall rocks.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite (probably gold-bearing) and galena.

Gangue minerals.—Quartz and altered quartz monzonite.

GULCH

Development.—Two adits (inaccessible when visited in 1950) one bearing south and other S. 30° W. at portals. An estimated 150 feet of workings from each adit.

Production.—Records before 1901 incomplete. During period 1887–89 yielded gold and silver ore having a coinage value of $2,380 and $13,054, respectively. No production recorded 1901–50.

Vein.—Attitude and dimensions could not be obtained in this area of heavy talus.

Wall rock.—Probably chiefly quartz latite porphyry.

Ore and sulfide minerals.—Gold-bearing pyrite, silver-bearing galena, sphalerite, chalcopyrite, and some manganese oxide stain.

Gangue minerals.—Quartz and wall rock.

HAWKEYE

Development.—Main adit (Hawkeye, or Hawkeye no. 2) bears about S. 45° E., and about 200 feet lower and to the north, Hawkeye no. 3 adit bears about S. 50° E. Both adits caved at portals when visited in 1950. Underground workings total 6,000 to 8,000 feet and include drifts, crosscuts, inclines, and several raises and winzes.

Production and tenor.—No records available of production before 1901. Production recorded from 1901 to 1950 totals 7,532 tons of ore that yielded 127 ounces of gold, 34,798 ounces of silver, 2,019 pounds of copper, 1,901,364 pounds of lead, and 274,688 pounds of zinc.[18] Mine last produced ore (601 tons) in 1944. In 1912 tenor of ore was about $14 a ton, with values chiefly in lead and silver.

Ore bodies.—Replacement deposits in Manitou dolomite at or near contact with granite.

[18] Published by permission of the owners.

Wall rock. — Limestone, dolomite, and Silver Plume (?) granite.

Ore and sulfide minerals.—Cerussite, galena, secondary copper minerals, and silver- and gold-bearing limonite.

Gangue minerals. — Calcite, limonite, and some quartz.

Ore shoots.—Plunge 25°–40° NW.; two shoots known to have been mined had pitch lengths of about 300 feet, maximum breadths of 30 feet and 66 feet, and maximum thicknesses of 7 feet and 8 feet.

HERCULES

Development.—Adit (caved when visited in 1950) bearing about S. 75° E. at portal; estimated total underground workings about 750 feet.

Production.—None reported or recorded.

Vein.—No data available and no vein exposed in this vicinity, but probably a narrow and short northeast-trending vein; on dump maximum width of vein material is 6 inches.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and sparse chalcopyrite and chalcocite.

Gangue mineral.—Quartz.

INDIANAPOLIS

Development.—Adit about 100 feet long, and near portal a shallow winze (adit filled with ice when visited in 1950).

Production.—About a carload of ore reported shipped before 1901. No production recorded 1901–48, although some from here might have been included with that from the New York or Iron Duke mines.

Vein.—Indianapolis: strike, about N. 45° E.; dip, moderate to steep to the northwest; length, about 500 feet. Vein along bedding.

Wall rock.—Iron-stained quartzite, argillite, and skarn of the Minturn formation.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, cerussite, and malachite.

Gangue minerals.—Quartz, limonite, and skarn.

INGERSOLL

Development.—Shaft (caved when visited in 1950) and several prospect pits. Estimated total underground workings 400 feet.

Production.—Records before 1901 incomplete, but one carload of ore reported shipped. No production recorded 1901–50.

Ore body.—Replacement deposit in Ordovician rocks.

Ore and sulfide minerals.—Galena and cerussite.

Gangue minerals.—Limonite and calcite.

Hematite prospect.—Prospect shaft (caved) in Fremont dolomite about 300 feet southeast of Ingersoll main shaft. On dump abundant specular hematite in plates as much as an eighth of an inch long and some limonite. Reported to be 40 feet thick; not exposed at surface. No known production of iron.

IRON DUKE

Development.—Shaft (inaccessible when visited in 1950) with estimated underground workings of about 150 feet, and several prospect pits.

Production.—No records before 1901. Recorded production from 1901 to 1948 included with that of New York mine. Total production probably small.

Vein.—Iron Duke: strike, N. 10° E.; dip, 68° W.; length, about 500 feet as indicated on surface; width, 8 inches in the Neglected adit. Vein along bedding.

Wall rock.—Quartzite and hornfels of the Minturn formation.

Ore and sulfide minerals.—Malachite, chrysocolla, galena, smithsonite, and cerussite (?).

Gangue minerals.—Limonite, quartz, and wall rock.

JEWELL TUNNEL

Development.—Adit bears N. 40° W. for 972 feet (inaccessible when visited in 1950). One short drift to north reported. Driven to cut New York and Indianapolis veins at depth (about 700 feet below New York adit) but reportedly did not reach them.

Production.—None.

Veins.—None other than narrow stringers reportedly cut.

LAST CHANCE

Development.—Small workings, entered by adit (caved when visited in 1950) bearing northwest at portal.

Production.—No records available before 1901. Recorded production from 1901 to 1950 is 24 tons ore that yielded 939 ounces of silver and 5,341 pounds of lead. No production since 1912.

Ore body.—No data available, and no vein exposed at surface. May be irregular limonitic replacement in limestone bed in Belden shale.

Ore and sulfide minerals.—Probably silver-bearing cerussite and some galena.

Gangue mineral.—Limonite.

LILLY

Development.—Opened through a shaft which was later reached by a crosscut adit. Adit is about 800 feet southeast of shaft and about 350 feet lower; it bears S. 80° E. for about 300 feet to the granite and limestone contact and then north along or near this contact for at least 2,250 feet. Four main levels are above and at least two levels, spaced 100 feet apart vertically, are below the main crosscut adit. Most of mine workings inaccessible in 1950. An aerial tramway about 7,200 feet long formerly carried the ore to Garfield.

Production and tenor.—During the period 1888–1900 about 4,000 tons of ore was produced. The recorded production from 1901 to 1949 is 10,418 tons of ore that yielded 351 ounces of gold, 92,905 ounces of silver, 987,776 pounds of copper, 1,392,273 pounds of lead, and 7,696 pounds of zinc.[19] The gross value of all ore produced is about $250,000. The largest yearly output was in 1909 when 1,832 tons of ore were produced, having a gross value of $26,121. Most of the ore averaged 9 to 10 percent copper.

Ore bodies.—Replacement deposits in the lower 50 feet of the Manitou dolomite.

Wall rock.—Dolomite, quartzite, granite, and locally monzonite porphyry.

Ore and sulfide minerals.—Silver-bearing cerussite and galena, crysocolla, chalcopyrite, pyrite, cuprite, smithsonite, calamine, sphalerite, and some gold, probably in pyrite and limonite. Most of the pyrite is copper-bearing.

Gangue minerals.—Chiefly limonite and dolomitic wall rock.

Changes in depth.—Fairly complete oxidation extends 200 feet below surface.

Ore shoots.—At least 8 ore shoots cut on main adit level over a distance of 1,500 feet, and all plunge 20°–50° N. Limonite streaks and limonitic dolomite generally connect the individual shoots; one of the largest shoots measured about 100 feet in pitch length, 30 feet in breadth, and a maximum of 10 feet in thickness. The shoots are chiefly localized along premineral bedding slips, especially in the Manitou dolomite at or near its contact with erosional remnants of Sawatch quartzite 1 to 6 feet thick that rest on pre-Cambrian Silver Plume(?) granite.

LITTLE ORPHAN ANNIE

Development.—Several prospect cuts and an adit (inaccessible when visited in 1950) bearing S. 10° W. at portal. Estimated 150 feet of underground workings.

Production and tenor.—Small tonnage. A small shipment many years ago reportedly returned 47.6 ounces of silver per ton and 24 percent lead. Only recorded production from 1901 to 1950 was in 1908 when less than half a ton of ore was shipped.

Vein.—Strike, N. 15°–20° W.; dip, steep to the west; length, traced 600 feet on surface; width, vein zone locally 3 to 4 feet wide.

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Wall rock.—Altered Mount Pomeroy quartz monzonite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and some chalcopyrite.

Gangue minerals.—Quartz and wall rock.

MACEDONIAN

Development.—Adit (inaccessible when visited in 1950) bears N. 60° E. at portal. In 1910 had been driven about 1,300 feet to a narrow pyrite vein. Shallow shaft about 1,350 feet northeast of adit portal.

Production.—Records before 1901 incomplete, although a small quantity of good-grade ore reported taken from the shallow shaft. No production recorded 1901–50.

Vein.—At shaft, strike, N. 5° E.; dip, 75° W.; length, about 500 feet as traced by poor exposures on surface; width, vein zone locally several feet.

Wall rock.—Altered Mount Aetna quartz monzonite porphyry.

Ore and sulfide minerals.—Pyrite, galena, and anglesite.

Gangue minerals.—Quartz and wall rock.

MAJOR

Development.—Two shafts and an adit bearing about N. 70° E. at portal (all inaccessible when visited in 1950), and an estimated 2,000 feet of underground workings.

Production and tenor.—Records of production before 1901 incomplete, although probably about 500 tons. Production from 1901 to 1950 included with Shamrock mine and totals 329 tons ore that yielded 80 ounces of gold, 1,189 ounces of silver, 44,852 pounds of copper, and 60,499 pounds of lead. Early production averaged $15 a ton net value.

Ore bodies.—Replacement deposits in Manitou dolomite near a monzonitic dike.

Wall rock.—Limestone and dolomite.

Ore minerals.—Azurite, malachite, chrysocolla, maleconite, cerussite, and gold-bearing limonite.

Gangue minerals.—Limonite and calcite.

Ore shoots.—One copper shoot reported to be about 6 feet across.

MARSHALL TUNNEL

Development.—Adit bearing about S. 25° E. at portal (caved when visited in 1950), and an estimated total workings of about 1,000 feet. Portal in Chaffee formation.

Production.—None.

Mineralized bodies.—It is reported that only a few very small and poorly mineralized bodies were cut. On dump is some limonitic Manitou dolomite with veinlets of calcite and quartz, and rare streaks of cerussite(?).

MASON

Development.—Worked through two adits bearing about S. 80° W. at portals and a shaft inclined 50° S. 10° W. (all entrances caved when visited in 1950). Estimated total workings 750 feet.

Production and tenor.—Records of production before 1901 incomplete. The only recorded production from 1901 to 1950 was during 1909 and 1910 when a total of 94 tons of ore yielded 2 ounces of gold, 1,516 ounces of silver, and 25,229 pounds of lead. Value of all ore reported to be about $75,000, and most of production in the eighties.

Ore bodies.—Chiefly oxidized ore in pockets ranging from a few inches to several feet in width. Some ore bodies at the contact between sedimentary rocks and volcanic breccia.

Wall rock.—Volcanic breccia and metamorphosed Paleozoic rocks.

Ore and sulfide minerals.—Cerussite, psilomelane, and some galena, pyrolusite, and gold.

Gangue.—Wall rock and limonite.

MAVERICK TUNNEL

Development.—Adit (caved when visited in 1950) bearing about N. 80° E. at portal. An estimated 1,500 feet of workings. Adit in about 650 feet in 1910.

Production.—No production recorded 1901–50.

Vein.—Probably reached Beta vein about 300 feet below collar of Beta shaft.

Ore and sulfide minerals.—Pyrite, some chrysocolla, and locally manganese oxide stain on vein matter on dump.

Gangue mineral.—Quartz.

MAY QUEEN

Development.—Several short adits (all inaccessible when visited in 1950) along or near vein; total underground workings estimated at 400 feet.

Production.—Small tonnage of ore reportedly shipped in the late seventies or early eighties. No production recorded 1901–50.

Vein.—Strike, N. 20°–25° E.; length, about 800 feet as traced on surface; width, 12 inches.

Wall rock.—Altered Mount Pomeroy quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, and sparse galena and chalcopyrite.

Gangue mineral.—Quartz.

MICHIGAN GROUP

Development.—A group of patented claims north of the May Queen mine on which are several prospect cuts and pits and five main adits (all inaccessible when visited in 1950) bearing north or northeast at portals. About 150 to 300 feet of workings on each adit.

Production.—Records before 1901 incomplete, and no production recorded 1901–50. It is reported that the total production is about 200 tons of ore, mostly from the northernmost workings, and probably before 1901.

Veins.—At least four northerly trending veins, dipping steeply west. Widths, 2 to 20 inches of quartz, locally in altered zones 4 to 6 feet wide. Heavy talus covers most of veins.

Wall rock.—Altered Mount Pomeroy quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and some chalcopyrite.

Gangue minerals.—Quartz and some calcite.

MISSOURI BOY

Development.—Several shallow shafts and two adits on the Missouri Boy, Mockingbird, Independence, and Bay State claims. All workings inaccessible when visited in 1950.

Production.—Records before 1901 incomplete, although ore valued at about $3,000 reported from shaft on Missouri Boy claim. Only recorded production from 1901 to 1950 came from adit on Independence claim and was 9 tons of ore that yielded 28 ounces of gold, 13 ounces of silver, and 600 pounds of copper.

Veins.—One or more north-northwest trending veins, probably no more than a foot wide. Vein matter partly oxidized.

Wall rock.—Chiefly pre-Cambrian Silver Plume(?) granite.

Ore and sulfide minerals.—Chalcopyrite, galena, pyrite, malachite, calamine, and rare sphalerite.

Gangue minerals.—Quartz and some limonite.

MOHAMMED

Development.—One long and two short adits, and several prospect shafts. Main adit bears N. 70° E. (inaccessible when visited in 1950) about 700 feet to vein. Estimated total of 1,500 feet of underground workings.

Production.—None reported or recorded, although probably a small tonnage taken out before 1901.

Vein.—Strike, N. 20°–35° W.; dip 75° NE.; length, about 1,500 feet as traced on surface; width, vein zone about 5 feet.

Wall rock.—Silicified and argillized quartz latite and Mount Aetna quartz monzonite porphyries.

Ore and sulfide minerals.—Pyrite,, galena, and sphalerite.

Gangue minerals.—Quartz and wall rock.

MONARCH CONTACT

Development.—Shaft about 60 feet deep and an adit bearing N. 37° W. In 1912, adit extended 117 feet to Lake fault, thence north along fault about 600 feet; additional workings from adit total about 200 feet. Portal caved and almost obliterated by highway when visited in 1950.

Production and tenor.—No production. Assays of three samples yielded, respectively, 0.18, 0.10, and 0.08 ounce of gold per ton, 173.50, 9.60, and 173.50 ounces of silver per ton, and 14.10, 0.40, and 0.20 percent lead; not assayed for zinc.

Ore bodies.—Small patches in fractured wall rock and thin seams in Manitou marble and Silver Plume (?) granite along Lake fault. Pyrite in gouge.

Ore and sulfide minerals.—Pyrite, galena, and sphalerite.

Gangue.—Fault rubble.

MOOSE

Development.—Several prospects and two short adits bearing southwest (inaccessible when visited in 1950); estimated total workings 400 feet.

Production and tenor.—Records of production before 1901 incomplete, although it is reported that 3 carloads of ore shipped in the eighties netted $165 per ton. The only recorded production from 1901 to 1950 was during period 1909–13 when 14 tons of ore yielded 16 ounces of gold, 859 ounces of silver, and 1,141 pounds of lead.

Veins.—Several northerly trending veins reportedly cut in workings; main vein is vertical, strikes north, and is 4 feet wide.

Wall rock.—Mount Aetna quartz monzonite porphyry and quartz latite porphyry.

Ore and sulfide minerals.—Gold-bearing pyrite and silver-bearing galena.

Gangue minerals.— Banded and vitreous quartz, and rare calcite.

MOSS FLOWER (HALF MOON)

Development.—Entered by an adit bearing about N. 30° E. at portal (inaccessible when visited in 1950), with an estimated 500 to 750 feet of underground workings.

Production.—No records available before 1901. Only recorded production from 1901 to 1950 was in 1917 when 90 tons of ore yielded 2 ounces of gold, 328 ounces of silver, 20,000 pounds of lead, and 34,000 pounds of zinc.

Vein.—Probably a northeast-trending, steeply dipping vein parallel to bedding of Minturn formation.

Wall rock.—Probably chiefly quartzite.

Ore and sulfide minerals.—Pyrite, sphalerite, silver-bearing galena, and sparse chalcopyrite.

Gangue mineral.—Quartz.

MOUNTAIN CHIEF

Development.—Adit bearing about north at portal, a shaft, and several surface cuts. All underground workings inaccessible when visited in 1950, but estimated to total about 500 feet.

Production and tenor.—Records of production before 1901 incomplete, and no production recorded 1901–50. Reported to have yielded in early days some very high grade ore. At a somewhat later time it is reported that 20 tons of ore had a gross value of $10,600.

Ore bodies.—Replacement deposits in Leadville limestone.

Wall rock.—Marble.

Ore and sulfide minerals.—Probably chiefly silver-bearing galena and cerussite.

Ore shoots.—Main shoot in a pocket mostly within 70 feet of surface; thickness ranged from a few inches to 3 feet.

NEGLECTED

Development.—Several hundred feet of digging and shallow shafts along vein, and a lower adit on the Iron Duke claim bearing about N. 70° W. was being driven in 1950 and was in about 98 feet. Adit cut Iron Duke vein at 32 feet from portal.

Production.—No records available before 1901, and no production recorded 1901–48. Probably produced small tonnage of hand-sorted ore.

Vein.—Neglected: strike, N. 5°–20° E.; dip, 55°–70° W.; width, 1 to 3 feet; length, about 500 feet as traced on surface. Vein along bedding slip, and some post-vein movement.

Wall rock.—Graphitic shale, hornfels, and quartzite of Minturn formation. Locally vein bordered by a few inches of gouge.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, malachite, chrysocolla, and sparse chalcopyrite.

Gangue minerals.—Quartz, wall rock, and sparse limonite.

NEW YORK

Development.—Main adit opens on New York no. 2 claim and bears N. 39° W. for a reported distance of 1,105 feet (caved at 1,005 feet when visited in 1950). At 215 feet from portal, drifts on Iron vein 110 feet northeast and 100 feet southwest; at 358 feet, drifts on New York vein 63 feet northeast and about 410 feet southwest to where it pinches. A little beyond cave-in (1,005 feet) Indianapolis vein reported cut in an up-raise where it was faulted, although a crosscut to the west cut only a weakly mineralized zone at the projected position of this vein. New York vein stoped upward about 150 feet and for a length of about 340 feet. Iron vein stoped a distance of 130 feet. An aerial tramway formerly connected with tramway at Lilly mine.

Production and tenor.—No records available of production before 1901, which was probably small. Recorded production [20] from 1901 to 1948, including some ore from the Iron Duke mine, is 2,000 tons of ore that yielded 41 ounces of gold, 60,840 ounces of silver, 105,334 pounds of copper, 570,402 pounds of lead, and 224,464 pounds of zinc. Ore from the Iron vein was chiefly low-grade zinc. From 1911 to 1914 most of the ore from the New York vein had a net value of about $35 per ton. No production since 1937.

Veins.—Veins are along bedding. Chief vein is the New York: strike, N. 35°—67° E.; dip, 58°—73° NW.; width, a few inches to 7 feet; length, about 500 feet as exposed in mine. Iron vein: strike, N. 33° E.; dip, 55°—60° NW.; length, 210 feet as exposed in mine.

Wall rock.—Iron-stained quartzite, argillite, and skarn of the Belden shale.

Ore and sulfide minerals.—Chiefly galena, sphalerite, pyrite, cerussite, and malachite; some smithsonite, calamine, azurite, tenorite, and gold (probably in limonite and pyrite).

Gangue minerals.—Limonite, skarn, quartz, and calcite.

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Development.—Adit (inaccessible when visited in 1950) bears about N. 50° W. at portal. In 1909, adit in 1,300 feet and about 500 feet of drifts on Ben Hill vein.

Production.—None known.

Vein.—Cut Ben Hill vein about 350 feet below collar of Ben Hill shaft.

Wall rock.—Brecciated limestone of Belden shale.

Sulfide mineral.—Probably a few scattered grains of galena.

Gangue mineral.—Quartz.

PAYMASTER

Development.—Adit bearing about S. 50° E. at portal (inaccessible when visited in 1950). Extent of underground workings not known, but probably totals at least 500 feet.

Production.—No records available before 1901. From 1901 to 1950 only recorded production was in 1926 and 1927 when 116 tons of ore yielded 502 ounces of silver, 50,339 pounds of lead, and 58,668 pounds of zinc.

Ore bodies.—Replacement deposits in Ordovician rocks.

Wall rock.—Limestone and dolomite.

Ore and sulfide minerals.—Cerussite, smithsonite, calamine, and some galena.

Gangue minerals.—Calcite, limonite, and some quartz.

PRIDE OF THE WEST

Development.—Adit 1,150 feet long bears N. 69° W. A drift 650 feet from the portal extends north and south from the adit and has a total length of 125 feet. The south extension has a small amount of stoping.

Production.—Only record of production was in 1911 when a trial shipment of concentrates from the drift yielded 36.9 ounces of silver per ton, 47.1 percent lead, 26.5 percent zinc, and 17.7 percent iron.

Veins.—Many west-dipping veins were intersected by the adit; most are less than 4 inches wide and are poorly mineralized where exposed. The vein in the drift is 2 feet wide where cut by the adit but narrows to 3 inches at the north face of the drift and to 1 inch at the south face. The combined lead-zinc content of the part of the vein exposed in the stope is estimated to be 3 percent.

Wall rock.—Mount Pomeroy quartz monzonite.

Ore and sulfide minerals.—Pyrite, silver-bearing galena, and sphalerite.

Gangue minerals.—Quartz and sparse calcite.

RAINBOW-EAGLE BIRD

Development.—Worked through two adits bearing northeast and two shafts (all inaccessible when visited in 1950). Total of underground workings estimated to be 1,500 feet.

Production.—Records before 1901 incomplete, although value of ore reported to be about $16,000. The only recorded production from 1901 to 1948 was in 1918 when 7 tons of ore yielded 5 ounces of gold, 529 ounces of silver, 99 pounds of copper, and 2,064 pounds of lead.

Ore body.—Bedded replacement deposit, locally 18 to 24 inches thick, in Fremont dolomite.

Wall rock.—Limonitic dolomite marble.

Ore and sulfide minerals.—Galena, silver-bearing manganese oxides, chiefly psilomelane, gold-bearing limonite, and some malachite(?).

Gangue minerals.—Limonitic marble and some quartz.

SHAMROCK

Development.—Shaft and an adit 900 feet long bearing about N. 82° E. (all inaccessible when visited in 1950), and several drifts, raises, and winzes.

Production and tenor.—Records of production before 1901 incomplete, although probably produced about 500

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tons. See Major mine for production from 1901 to 1950, for it is included with this mine. One carload of ore carried 1.58 ounces of gold and a few ounces of silver to the ton. No production since 1922.

Ore bodies.—Mostly in pockets in the Harding quartzite near a monzonitic dike.

Ore minerals.—Azurite, malachite, chrysocolla, melaconite, cerussite, and gold-bearing limonite.

Gangue minerals.—Quartzite, limonite, and calcite.

SILENT FRIEND

Development.—Entered through four adits distributed over a vertical distance of about 400 feet (pl. 1). Mine workings have been inaccessible for many years and no mine maps available. Workings total many thousands of feet. On the lowest, or no. 4, level a winze at least 140 feet deep has been sunk.

Production and tenor.—Most of the output was before 1901, for which no records are available. The only recorded production from 1901 to 1950 was during the period 1909–16 when 564 tons of ore yielded 5 ounces of gold, 1,500 ounces of silver, 337 pounds of copper, 109,808 pounds of lead, and 128,947 pounds of zinc. It is estimated that the gross value of all ore produced is about $250,000. Some ore in the main shoot ran 20 ounces of silver to the ton and about 70 percent lead.

Ore bodies.—Replacement deposits chiefly in the lower 60 feet of the Manitou dolomite.

Wall rock.—Dolomite and granite.

Ore and sulfide minerals.—Chiefly galena, cerussite, and smithsonite; some anglesite, calamine, and malachite, and probably a little free gold in limonite.

Gangue minerals.—Limonite and wall rock.

Ore shoots.—Main shoot followed a somewhat spiral course in lower 60 feet of Manitou dolomite and averaged a plunge of about 45° N. 35° W.; pitch length, 1,000 feet; maximum breadth, 50 feet; thickness, averaged about 10 feet.

SONG BIRD

Development.—Two adits bearing about S. 20° W. at portals (caved when visited in 1950) and many prospect cuts. Estimated several hundred feet of underground workings in each adit.

Production and tenor.—Records of production before 1901 incomplete, although reportedly some rich silver ore mined as early as 1878. No production recorded 1901–50.

Ore bodies.—Probably in shoots in short and narrow veins in Fremont dolomite.

Wall rock.—Dump material mostly marble and skarn.

Ore and sulfide minerals.—Not known for certain; probably chiefly silver-bearing galena and cerussite.

STEMWINDER

Development.—Two adits (caved when visited in 1950) bearing northwest. An estimated 300 feet of workings in each.

Production.—Records before 1901 incomplete, although about a carload of ore reported shipped. No production recorded 1901–50.

Ore bodies.—Near the surface in pockets or narrow veins in upper part of Belden shale.

Ore and sulfide minerals.—Galena, cerussite, and rare anglesite.

Gangue minerals.—Limonite and quartz.

THIRTY-SIX-THIRTY

Development.—Shaft (caved at collar when visited in 1950) and several prospect pits and shallow shafts. Estimated total underground workings about 300 feet.

Production.—Records before 1901 incomplete, but some ore reported shipped. No production recorded 1901–50.

Ore body.—Replacement deposit of unknown dimensions.

Wall rock.—Manitou dolomite.

Ore and sulfide minerals.—Probably chiefly silver-bearing galena and some cerussite.

Gangue minerals.—Limonite and dolomite.

TOM CAT

Development—An adit bearing S. 67° E., started in 1910, and several small prospects. Adit portal caved when visited in 1951. Total mine workings probably not more than 1,000 feet.

Production.—No records available before 1901. No production recorded 1901–50. About 500 pounds of ore piled near portal contains an estimated 30 percent lead.

Veins.—Probably followed narrow quartz vein southeast to its junction with the northerly trending vein prospected 600 feet east of portal, as shown on plate 1.

Wall rock.—Andesite which has been argillized, sericitized, and silicified.

Ore and sulfide minerals.—Chiefly pyrite and galena; some anglesite, cerussite, malachite, and azurite.

Gangue minerals.—Chiefly quartz; some calcite, limonite, epidote, and stringers of gypsum.

TWEED

Development.—An upper adit bearing N. 30° E. at portal and, to the south and about 75 feet lower, another adit bearing about N. 35° W. at portal (both inaccessible when visited in 1950), and several pits and short adits. Estimated underground workings total 2,500 feet.

Production and tenor.—No records available of production before 1901, and none recorded 1901–50. Very thin seams of high-grade gold ore reportedly found in prospects along Middle Fork Creek.

Veins.—Main workings cut one or more veins; none exposed at surface. On dump some vein material 5 inches thick.

Wall rock.—Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite (copper-bearing), sphalerite, and galena on dump.

Gangue minerals.—Quartz and sparse calcite.

UNCLE SAM (CYCLONE CREEK AREA)

Development.—Adit, bearing N. 28° E. at portal. Caved when visited in 1951.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—No vein exposed at surface. Reported in 1910 that adit followed a narrow quartz vein.

Wall rock.—Adit started on or near contact of Mount Pomeroy quartz monzonite and andesite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and chalcopyrite.

Gangue minerals.—Quartz, and some calcite, and silicified Mount Pomeroy quartz monzonite and andesite.

UNCLE SAM (HOFFMAN PARK AREA)

Development.—Adit enters near contact of Mount Princeton and Mount Aetna formations on bearing of N. 52° W. (caved about 150 feet from portal when visited in 1950); estimated 400 feet of workings. To the northwest and about 75 feet higher is a caved shaft.

Production.—Some ore reported shipped before 1901. No production recorded 1901–50.

Vein.—Strike, N. 42° E.; dip, 80° NW.; width, including altered rock, is 6 feet; length, about 400 feet as traced on surface.

Wall rock.—Altered Mount Aetna quartz monzonite porphyry.

Ore and sulfide minerals.—Chiefly chalcopyrite, sphalerite, and pyrite; some malachite and chalcocite(?).

Gangue mineral.—Quartz.

CHALK CREEK MINING DISTRICT

CHIEF ECONOMIC AND GEOLOGIC FEATURES

The mines and prospects of the Chalk Creek district are distributed chiefly in three areas: (1) Browns Creek area in the east (pl. 1), (2) Baldwin Gulch area, 3½ miles southeast of St. Elmo, and (3) the largest and most important, a belt ½ mile to 2 miles wide and about 10 miles long that extends from the Continental Divide northeast across Chrysolite Mountain to the northeast corner of the quadrangle. Only a few of the mines were accessible in 1951, and a large part of even such extensive workings as the Mary Murphy group of mines could not be entered during the course of this investigation. The ores of the district contain gold, lead, zinc, silver, and a little copper. Lead and zinc values are nearly equal, and their total exceeds the value of gold. The Mary Murphy mine has yielded at least 75 percent of the total output from the district.

Most of the ore was mined from pyritic quartz veins in the Mount Princeton quartz monzonite, although veins in other rocks have been productive. The veins generally strike northeast and dip steeply. They range from mere stringers a fraction of an inch thick and less than 50 feet long to lodes 50 feet thick and more than a mile long, although most are separate veins 1 to 3 feet thick. Galena and sphalerite occur in variable amounts in the pyritic quartz, chiefly in streaks 1 to 12 inches wide. Some chalcopyrite generally accompanies pyrite. The gangue is chiefly white vuggy quartz, although calcite, rhodonite, rhodochrosite, barite, and fluorite occur locally.

Strongly oxidized ore and vein matter are largely confined to the veins on the west slope of Chrysolite Mountain, where complete or nearly complete oxidation extends to a depth of about 400 feet, and partial oxidation to about 900 feet. Elsewhere, veins exposed in shallow prospect pits show little or no alteration of the sulfides. As in the Monarch district, the deeper oxidized zones are above the height of glaciation. The oxidized ore is typically brown, porous limonite or limonitic quartz with variable amounts of cerussite, calamine, smithsonite, and patches or grains of galena. Free gold reportedly occurs in much of the ore.

ALLIE BELLE MINE

The Allie Belle mine is about a mile south of the old town of Romley and about 300 feet east of the road between Romley and Hancock. No information was available on the history or production of the mine before 1900. Production from 1901 to 1950 was 381 tons, which yielded 26 ounces of gold, 11,723 ounces of silver, 591 pounds of copper, 17,183 pounds of lead, and 320 pounds of zinc.

The mine was worked through two adits of which only the lower was accessible when visited in 1950. Old records show that the upper adit, which is 350 feet S. 64° E. from the lower adit, was driven N. 55° E. along a vein for about 750 feet. In 1950 about 2,000 feet of the lower adit level was accessible (fig. 6).

The country rock is Mount Princeton quartz monzonite. Locally the lower adit workings cut dark fine-

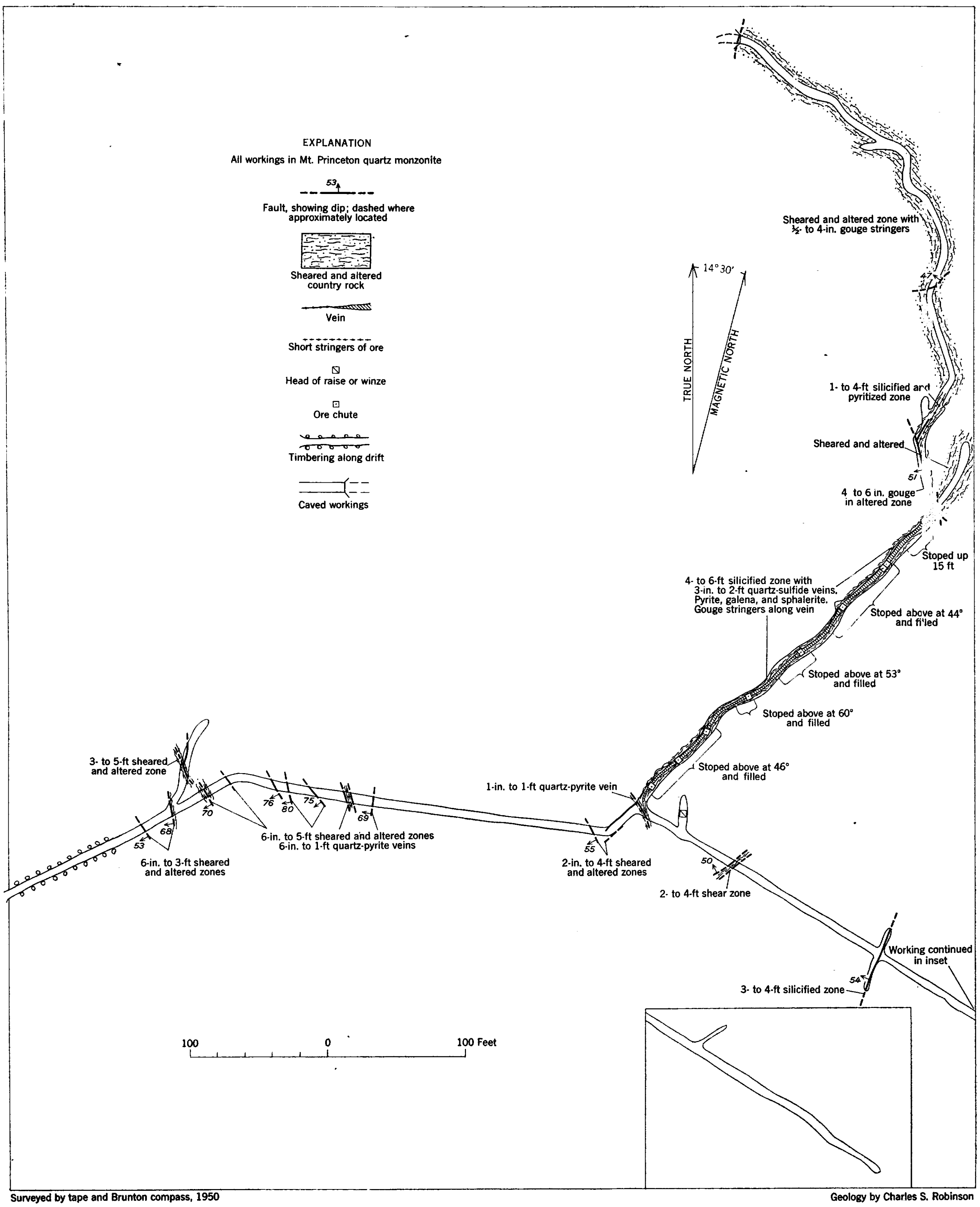


Figure 6.—Geologic map of the lower tunnel of the Allie Belle mine, Chalk Creek mining district.

grained porphyritic bodies believed to be cognate inclusions in the Mount Princeton quartz monzonite.

The vein is exposed at the caved portal of the upper adit and in the lower adit workings. It strikes N. 45°–55° E. and dips 50°–60° N. It consists of 3 to 6 feet of highly brecciated and altered country rock cut by many quartz stringers 1 inch to 2 feet in width and gouge seams 1 inch to 1 foot in width. The vein has been faulted at its north and south ends on the lower adit level (fig. 6). As indicated by the drag, the vein should have been faulted southeasterly at both ends. The extension of the vein at the south end has not been found, and the vein found northwest of the north fault is believed to be another vein and not the faulted extension of the main vein.

Pyrite, galena, sphalerite, and chalcopyrite, in this order of abundance, occur in the quartz stringers. Pyrite in fine grains is also disseminated for 6 inches to 1 foot in the adjacent wall rocks. Galena occurs in stringers or irregular masses, and associated with it is a small amount of brown to black sphalerite and a few fine grains of chalcopyrite. Quartz is the only gangue mineral. At the edges of the vein it is in fine-grained gray bands and contains fine-grained disseminated pyrite. In the center of the vein the quartz is medium grained, white, and vuggy and contains galena, sphalerite, and chalcopyrite.

Locally the vein was wide enough and rich enough to be stoped. In the lower adit, the stopes range from 10 to 70 feet in length and from 2 to 6 feet in width. The heights could not be determined for the stopes were caved or backfilled.

The country rock is altered for 4 to 10 feet on either side of the vein. Along the quartz veins, the country rock is silicified and pyritized for 1 inch to 1 foot. Beyond the silicified zone, the rock is altered to sericite and hydromica, with decreasing intensity the greater the distance from the vein.

CALIFORNIA MINE

The California mine is on the north side of Browns Creek valley near the east border of the quadrangle at an altitude of 12,500 feet. The mine may be reached by a trail 8 miles long that starts in the Arkansas River valley and goes up Browns Creek, or by another trail 7 miles long extending from Alpine up Baldwin Gulch and over the ridge into Browns Creek (pl. 1).

The California property consists of three claims: the California, Utah, and White Rock Extension, owned by George G. Furman of Farmington, N. Mex. The mine was developed as a molybdenum mine, and a few sacks of ore were shipped during World War I. There is no recorded production since then, and the mine has been idle for many years.

The mine was inaccessible when visited in 1951 but has been described by Worcester (1919, p. 35):

> All the development work, with the exception of some shallow surface cuts and location shafts, has been done on the California claim. In the summer of 1917 the workings consisted of: an open cut with a 50-foot drift on the vein; an inclined shaft 50 feet deep, near the open cut, but apparently not on the vein; a crosscut tunnel, that was started 50 feet vertically below the open cut and was run 98 feet to the vein; and drifts from this tunnel, one 30 feet westerly on the vein and another 120 feet to the east. Small stopes, only 2 or 3 feet above the normal roof of the tunnel, have been run for 75 feet, on the east drift. Mr. W. B. Lowry reported in June 1918 that since July 1917 the drift has been continued on to the east 15 feet to a fault, and 130 feet beyond, where the vein was recovered.

All the workings start in Mount Pomeroy quartz monzonite but the description by Worcester suggests that part of the workings should extend into the small body of Mount Antero granite northeast of the mine. The material on the dump is Mount Pomeroy quartz monzonite and vein material.

Where the California vein crops out a few feet northeast of the shaft, it is 2 feet wide, strikes N. 55° E., and dips 80°–90° W. The vein cannot be followed for more than a few feet on account of the heavy talus. Worcester (1919, p. 36) states that the vein, as disclosed in the mine, ranges from 1½ to 3 feet in thickness and the average dip is 80° N.

The California mine contains the most varied mineral assemblage of any of the quartz-beryl-pyrite type veins. Vein material on the dump consists mostly of white, fine- to coarse-grained quartz and varying and much smaller quantities of molybdenite, molybdite, pyrite, magnetite, beryl, and muscovite. In addition to these, Landes (1934, p. 693) reports tourmaline, and Adams (1953, p. 100), brannerite.

According to Worcester (1919, p. 36), the richest molybdenum ore occurs in streaks 1 to 2 inches thick and 6 inches to 2 feet in length near the walls of the vein. In many places pockets of molybdenite and molybdite, containing 20 to 30 pounds, occur between beryl and quartz crystals. Although there are streaks and pockets of rich ore, in general the vein is of low grade.

The Mount Pomeroy quartz monzonite has been sericitized for 1 to 3 feet and silicified for 1 to 6 inches on either side of the California vein. Fine-grained pyrite and molybdenite are disseminated in the silicified country rock.

IRON CHEST MINE

The Iron Chest mine is on the northwest side of Chrysolite Mountain at an altitude of about 11,950 feet (pl. 1). It may be reached by a wagon road which starts at St. Elmo and climbs south about 2¼ miles to the mine. The mine was owned in 1951 by T. Stark.

No information is available on the history or production of the mine before 1900, but it is believed that most of the ore produced was mined between 1875 and 1900. The following table gives the recorded production of the mine from 1901 to 1915. Any production since 1915 has been included with that of the Mary Murphy mine.

Production of the Iron Chest mine, 1901–15

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)
1902	450	200	4,600		
1913	123	66	1,500	1,482	8,326
1914	218	158	5,143	53	5,396
1915	201	53	2,083		7,367
Total	992	477	13,326	1,535	21,089

Most of the mine workings were inaccessible when visited in 1950. According to old maps of the Mary Murphy Gold Mining Co., the mine was originally accessible through several short adits about 50 feet apart in elevation, and a main adit and shaft about 400 feet below the crest of the ridge to the south of the mine. The shaft is about 280 feet deep; off it are three levels totaling about 2,000 feet of drifts. About 400 feet of the lowest shaft level was accessible through the Mary Murphy mine. The main adit level has about 500 feet of workings. The extent of the workings above the main adit level is not known.

The Iron Chest mine worked the northern extension of the Pat vein of the Mary Murphy mine. The vein is a filled fissure in the Mount Princeton quartz monzonite, and ranges in width from 1 foot or less to 6 feet. It can be followed on the surface for about 4,000 feet and has been followed underground in the Iron Chest and Mary Murphy workings for about 2,000 feet. The vein ranges in strike from N. to N. 50° E. and dips 60°–85° E. Locally the vein is bordered by gouge stringers 1 inch to 2 feet thick.

Only primary sulfide ore minerals were seen on the lowest shaft level, but oxidized ore was observed on the dumps of the upper adit levels. This consists of cerussite, smithsonite, and anglesite in a limonite or limonitic quartz gangue, and minor psilomelane, pyrolusite, malachite, azurite, and chrysocolla as stain or in small vugs. The primary sulfide minerals are, in order of abundance, sphalerite, galena, pyrite, and chalcopyrite. The sphalerite and galena occur intermixed in stringers or irregular masses from an inch or less to 4 feet wide, and as disseminated grains in the gangue. Chalcopyrite is sparsely disseminated in the sphalerite and galena. Pyrite is most abundant in the quartz gangue and disseminated in the wall rock. A small quantity of pyrite is associated with the other sulfides.

The principal gangue mineral is quartz. It occurs, with some disseminated pyrite, as gray, fine-grained bands at the borders of the veins, and as white, medium-grained, vuggy quartz containing sulfides near the centers of the veins. A fine-grained mixture of rhodonite and rhodochrosite occurs in those sections of the vein that contain abundant sulfides. Calcite is present in vein material on the dump of the shaft.

The country rock is altered on either side of the vein as seen on the lowest shaft level. At the contact of the quartz vein and country rock, the country rock has been silicified for 1 to 6 inches. Disseminated in the silicified country rock and extending beyond is fine-grained pyrite. Beyond the silicified zone the minerals of the country rock have been altered to sericite and hydromica with decreasing intensity away from the vein. The width of alteration could not be observed in the Iron Chest mine, but in the Mary Murphy mine it ranged from 5 to 20 feet.

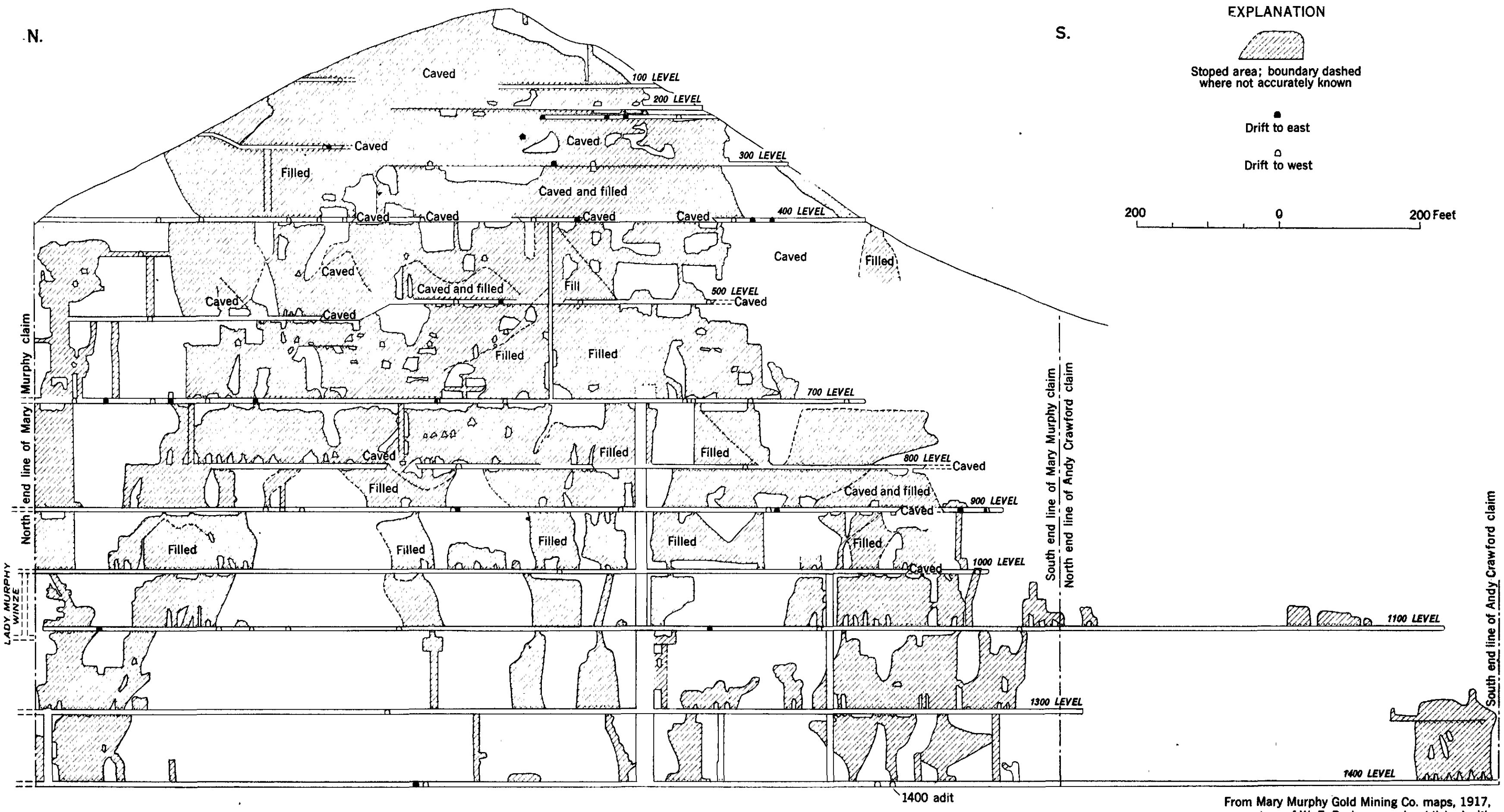
MARY MURPHY MINE

The Mary Murphy mine is on the southwest side of Chrysolite Mountain about 2 miles south of St. Elmo (pl. 1). The main tunnel, no. 14 or 1400 level, may be reached by the road up Pomeroy Gulch. The mine in 1952 was leased to S. E. Burleson and W. E. Burleson of Salida, Colo.

The Mary Murphy was one of the first mines developed in the Chalk Creek district. Raymond (1887, p. 282) reports that the mine was in operation in 1875. Records of production before 1901 are unavailable, but the mine is believed to have been in operation continuously from 1870 to 1925. Between 1925 and 1951 the mine was operated intermittently. The table on page 100 gives the recorded production from 1901 to 1949.

Old maps show that the mine was worked through 14 main levels and several intermediate levels. Plates 12 and 13 and figure 7 were reproduced from maps of the Mary Murphy Gold Mining Co. and show the workings as of 1917. The mine was originally accessible from the surface by tunnels at the 100, 200, 300, 400, 700, 1,100 (Lady Murphy tunnel), 1,400, and 2,200 (Golf tunnel) levels. When visited in 1950, only the Lady Murphy and the 1,400 level tunnels were open. Geologic maps were made of the mine workings accessible in 1951. Two of these, plates 14 and 15, which show the typical geology, are included with this report.

The veins are filled fissures in the Mount Princeton quartz monzonite. Most of the faulting took place before the deposition of the ore; gouge seams 1 inch to 3 feet wide occur on one side or on both sides of the veins, and in many places, the veins cut the adjacent gouge seams. Some postore faulting has displaced the veins;



From Mary Murphy Gold Mining Co. maps, 1917, courtesy of W. E. Burleson, and published with permission

FIGURE 7.—Section along Mary vein, Mary Murphy mine, projected into vertical plane.

many faults of small displacement cut the veins throughout the mine (pls. 14, 15).

Production of the Mary Murphy mine, 1901–49

[Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colo. No production recorded for years not listed. Published by permission of the lessors]

Year	Crude ore (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1901	10, 261	3, 794	45, 662	-----	-----	-----
1902	16, 465	14, 818	57, 782	-----	-----	-----
1903	11, 661	5, 758	34, 134	-----	-----	-----
1904	4, 807	949	6, 438	-----	142, 761	-----
1906	700	427	24	-----	146, 474	68, 606
1907	2, 000	1, 375	12, 666	11, 960	196, 860	56, 240
1908	1, 900	1, 320	6, 130	-----	150, 000	140, 000
1909	68	75	1, 231	409	6, 208	-----
1910	513	525	9, 767	3, 142	48, 500	-----
1911	1, 308	1, 623	19, 572	20, 487	178, 479	-----
1912	3, 220	3, 767	33, 202	41, 690	368, 126	-----
1913	43, 426	14, 698	148, 110	147, 736	2, 841, 168	1, 494, 835
1914	56, 895	14, 493	141, 356	246, 494	3, 366, 434	1, 960, 851
1915	60, 588	14, 152	121, 159	406, 263	4, 001, 582	4, 119, 283
1916	5, 887	8, 589	75, 575	228, 778	2, 576, 602	2, 670, 878
1917	36, 602	5, 481	47, 015	72, 700	1, 198, 503	1, 455, 934
1918	29, 554	5, 232	55, 036	74, 157	1, 091, 934	1, 739, 347
1919	16, 381	2, 737	27, 087	30, 237	453, 209	-----
1920	2, 235	1, 486	33, 616	14, 140	237, 486	-----
1921	2, 069	1, 535	25, 045	7, 575	191, 486	-----
1922	1, 164	931	9, 543	9, 585	587, 948	-----
1923	818	741	11, 393	6, 593	103, 473	29, 070
1924	374	385	6, 023	982	48, 065	-----
1932	63	36	643	-----	2, 574	-----
1933	203	125	1, 709	175	13, 733	-----
1934	913	1, 319	9, 662	-----	94, 560	-----
1935	976	1, 200	8, 741	16, 126	93, 855	18, 480
1936	1, 134	1, 316	9, 236	22, 430	224, 086	326, 356
1937	991	822	8, 028	22, 164	207, 866	280, 733
1938	248	137	1, 778	5, 123	61, 071	71, 608
1939	129	139	1, 511	1, 211	29, 630	13, 937
1940	114	74	757	741	28, 780	13, 699
1941	91	129	613	2, 033	19, 821	39, 540
1942	50	39	417	816	7, 764	10, 920
1944	36	11	321	472	5, 853	11, 614
1949	370	16	136	-----	8, 077	13, 413
Total	314, 214	110, 254	971, 118	1, 394, 219	18, 732, 968	14, 535, 344

Five main veins and several smaller ones were worked in the mine. The most important was the Mary vein, which crops out on the ridge above the mine (pl. 1) and can be traced for 6,000 feet on the surface. It was followed underground for about 5,000 feet and is known to have been mined from the surface to the 1,400 level. Possibly the 1,500 and Golf tunnel levels intersected this vein. The Mary vein strikes N. to N. 35° E.; the average is about N. 20° E. It dips 75°–90° W. from the surface to the 900 level, and from 75°–90° E. below this level. The width ranges from 6 inches to 20 feet and averages 3 feet.

On the 900 level, 300 to 350 feet east of the Mary vein, is the West Pat vein, and 50 to 75 feet east of the West Pat is the East Pat. The 900 level is the lowest level on which these two veins were worked. Old maps indicate that these two veins intersect near the 400 or 500 level. On the ridge above the mine 100 to 200 feet east of the Mary vein, a single vein, the Pat, crops out. This vein can be traced for about 4,000 feet on the surface. The West and East Pat veins, as measured in the mine, strike N. 10°–50° E. and dip 60°–85° E.

On the 900 level and west of the Mary vein, 80 and 150 feet, respectively, are the Morley and Nelson veins. On the 1,100 level about 200 feet west of the Mary vein and on the 1,300 level about 260 feet west, a vein believed to be the Nelson is exposed. About 100 feet below the crest of the ridge above the mine, a vein west of the Mary, probably the Morley, intersects the Mary vein. These veins strike N. to N. 50° E. and dip 70°–85° W.

Maps of the old workings indicate that these main veins converge in the upper workings and to the south, and diverge with depth and to the north. Where the veins diverge other veins occur between the main veins, usually as offshoots of the main veins. In the upper workings where the veins were closest together are many cross veins, which are reported to have yielded small amounts of relatively rich ore.

Oxidized and primary sulfide ore was produced from the mine. Above the 400 level most of the ore was oxidized. Between the 400 and 900 levels the ore is partially oxidized, and below the 900 is primary sulfide ore. Because the main workings above the 900 level are inaccessible, little is known of the oxidized and partially oxidized ore. Ore on the dumps of the upper levels contains cerussite, smithsonite, and anglesite, commonly with a few grains of galena, in a limonitic vuggy quartz gangue. Psilomelane, pyrolusite, malachite, azurite, and chrysocolla occur as stain or in small vugs. Below the 900 level, the veins consist of brecciated and silicified Mount Princeton quartz monzonite cut by quartz or quartz-rhodonite-rhodochrosite stringers containing varying quantities of sulfides. The sulfides in the veins are, in order of abundance, sphalerite, galena, pyrite, and chalcopyrite; pyrite is the most abundant sulfide in the wall rock adjacent to the veins. Quartz is the chief gangue mineral. It occurs as fine-grained gray quartz containing disseminated pyrite, at the borders of the veins, and as massive, white, medium-grained, vuggy quartz near the centers. A very fine grained mixture of rhodonite and rhodochrosite is almost everywhere present in those parts of the veins that contain abundant sulfides. Locally rhodochrosite, calcite, barite, and fluorite occur in the veins.

A megascopic study of the veins and the paragenetic relations of their minerals to each other indicates that the order of deposition was:

1. Fine-grained gray quartz and disseminated pyrite.
2. Medium-grained, white, vuggy quartz, accompanied by rhodonite and rhodochrosite, sphalerite, galena, and chalcopyrite; probably in this order but with considerable overlap.
3. Medium-grained white quartz. This stage probably just a continuation of the quartz deposition of stage 2.
4. Calcite, barite, and fluorite. These gangue minerals are barren and, therefore, probably followed stage

2, but their position in the sequence of deposition could not be determined.

The quartz monzonite adjacent to the veins has been altered from a few inches to hundreds of feet on either side of the veins in proportion to the width of the veins. At the edges of the veins the quartz monzonite is silicified for 1 inch to 10 feet. In the silicified wall rock and extending beyond the zone of silicification is disseminated fine-grained pyrite. At the edge of the silicified zone the wall rock may be argillized from 1 inch to 1 foot, and extending beyond the argillized or silicified zone, the alteration minerals of the wall rock are sericite and hydromica, with a decreasing intensity the greater the distance from the vein. Overlapping and extending beyond the zone of sericitization may be a zone of alteration in which the ferromagnesian minerals have been altered to chlorite or epidote or both.

The largest ore shoot in the mine, and the largest of any in the vein deposits of the quadrangle, is on the Mary vein. Figure 7, a vertical section of the Mary vein, shows the stoped areas as of 1917 and gives an idea of the size of the ore shoots in this vein. The vein was stoped from the surface to the 900 level, a vertical distance of 700 feet, for an average stope length of 1,000 feet. Below the 900 level the ore body is less well defined. At the north end of the mine is an ore shoot extending from the 900 level to the 1,400 level, a pitch length of about 450 feet and breadth of 300 feet. About 200 feet south of the raise from the 1,400 level to the 900 level, an almost vertical ore shoot extends between these levels (380 feet) and has an average stope length of about 250 feet. Between these two main ore shoots below the 900 level are several smaller ones ranging from 20 to 150 feet in pitch length, and from 5 to 100 feet in breadth. From what could be observed in the accessible parts of the mine, the stopes ranged in width from 2 to 20 feet.

Although the records show that considerable ore has been produced from this mine since 1917 when the stope map (fig. 7) was made, the map is still believed to give a fairly accurate picture of the ore shoots. From what was observed in mapping the accessible parts of the mine, the mining since 1917 was primarily on veins other than the Mary and in removing "high grade" pillars in the old stopes. A 1,500 level was added to the workings of the mine since this map was made but there are no stopes below the 1,400 level.

Old stope maps of the Pat, Morley, and Nelson veins show that those veins were stoped from the surface to the 700 level, a vertical distance of about 530 feet, for an average stope length of 600 feet. Part of the Morley was stoped to the 900 level and the Nelson to the 1,300 level.

So little of the mine was accessible that a study of the structural factors that might have controlled the deposition of the ore could not be made. The maps (pls. 12, 13, and fig. 7) show, however, that the largest ore shoots, at least along the Mary vein, occur where the vein dips west and between two sharp changes in strike. From the surface to the 900 level, in the center of the mine, the Mary vein dips from 75°–90° west. Below the 900 level the dip of the vein changes to the east. The largest ore shoots were mined from above the 900 level. This, in part, may only be an apparent relationship; the ore above the 900 level is partly oxidized and, therefore, richer, and a narrower width of vein might be mined profitably. Two abrupt changes in strike occur along the Mary vein; one about 180 feet north of the south end line of the Mary Murphy claim and the other 80 feet south of the north end line. At the south end, the vein changes strike from N. 30° E. to due north, and then there is a gradual change in strike through a distance of 1,100 feet from due north to N. 25° E. The abrupt change at the north end is to due north again. These changes in strike make a roll in the vein to the east. The largest ore shoots occur between the two sharp changes in strike.

OTHER MINES AND PROSPECTS

BIG BONANZA

Development.—Shaft, inclined N. 67° W. at 58°. Caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Strikes N. 5°–15° E. and dips 40°–60° W. Brecciated and silicified Mount Princeton quartz monzonite cut by 1- to 6-inch quartz-sulfide veinlets. Vein traced on surface for about 300 feet.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz and silicified Mount Princeton quartz monzonite.

BLACKHAWK

Development.—Adit, bearing S. 73° E. at portal. Caved when visited in 1950.

Production.—No records available before 1901. Recorded production for 1901–50 was 170 tons, which yielded 23 ounces of gold, 3,380 ounces of silver, 1,500 pounds of copper, 22,126 pounds of lead, and 42,006 pounds of zinc. Most of this produced between 1909–13.

Veins.—Two veins exposed in cliff about 1,000 feet east of portal. Veins 4 to 10 feet wide of quartz and brecciated and silicified Mount Princeton quartz monzonite. Veins range in strike from north to N. 30° E. and dip steeply east or west. Veins traced about 500 feet on surface. They are possibly the extensions of the Pat and West Pat veins of the Mary Murphy and Iron Chest mines, covered by heavy talus in the intervening area.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, chalcopyrite, cerussite, smithsonite, and copper and manganese stains.

Gangue minerals.—Quartz, rhodonite, rhodochrosite, and silicified Mount Princeton quartz monzonite.

FLORA BELLE

Development.—Adit, bearing N. 75° E. at portal, caved when visited in 1950. Reportedly about 1,000 feet of workings.

Production.—No records before 1901. Recorded production 1901–50, mostly in 1910–19, was 406 tons, which yielded 13 ounces of gold, 6,757 ounces of silver, 206 pounds of copper, and 9,863 pounds of lead.

Vein.—No data available and not exposed at surface.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Sphalerite, galena, pyrite, and chalcopyrite on dump.

Gangue minerals.—Quartz and silicified Mount Princeton quartz monzonite on dump.

KENTUCKY

Development.—Shaft, caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Stonewall vein. Ranges in strike from north to N. 30° W. and dips 40°–80° W. Vein may be followed on surface for about 2,000 feet, and ranges in width from 5 to 30 feet. Locally, heavy gouge seams on either foot or hanging wall of vein.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz, calcite, and silicified Mount Princeton quartz monzonite.

KICKAPOO

Development.—Adit, bearing S. 89° E. at portal. About 600 feet of accessible drifts in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Strikes N. 30°–50° E. and dips 60°–80° NW. Ranges in width from 5 to 40 feet. Traced on the surface for 1,500 feet.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Barite, quartz, and silicified Mount Princeton quartz monzonite.

LITTLE BONANZA

Development.—Shaft, inclined N. 66° W. at 70°. Caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50. On dump 3 to 4 tons of ore which would average 5 to 10 percent combined lead-zinc.

Vein.—Strikes N. 20°–40° E., dips 60°–80° W. Brecciated and silicified Mount Princeton quartz monzonite 4 to 10 feet in width, cut by 4- to 18-inch quartz-sulfide veins. Vein traced on surface for 1,000 feet by a series of prospect adits and pits.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Sphalerite, galena, pyrite, and chalcopyrite.

Gangue minerals.—Quartz and silicified Mount Princeton quartz monzonite.

LITTLE JESSIE

Development.—Adit, bearing N. 87° E. at portal. Adit goes in about 115 feet where it intersects vein. About 200 feet of drifting along vein.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Strikes N. 20°–40° E., averages N. 25° E. Dips are vertical to 65° W.; locally dips steeply east. Vein 1 to 5 feet wide of quartz and brecciated and silicified Mount Princeton quartz monzonite. On west side of vein 1 to 4 inches of gouge. About 250 feet from portal, vein offset about 4 feet by fault.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz and silicified Mount Princeton quartz monzonite.

Ore shoot.—About 20 feet long, 2 to 4 feet in width, and stoped up about 20 feet at 65°.

MATILDA

Development.—Three main adits and several prospects. Only the upper and lower adits were accessible in 1951. The upper adit bears S. 5° W. for 250 feet on a narrow vein. The lower adit is about 1,200 feet north of the upper workings and bears S. 55° W. for 135 feet on a narrow vein; 25 feet in from the portal a tight, south-trending vein was drifted on for 60 feet. The intermediate adit, having an estimated 150 feet of workings, is about 300 feet north of the upper main adit and bears south along the same vein.

Production and tenor.—No records available before 1901. From 1901–51 the only production recorded was a 2-ton test-shipment in 1930 that yielded 1 ounce of gold, 16 ounces of silver, and 1,137 pounds of lead.

Veins.—The vein in the upper two adits is 1 to 6 inches wide and about 1,500 feet long. Strike, N. 5° E.; dip, 60°–70° W. The vein in lower adit is 1 to 6 inches wide; strike, N. 55° E.; dip, 65° W. Parts of the vein now exposed in the mine contain sparse sulfide minerals.

Wall rock.—Silicified and sericitized Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite and silver-bearing galena.

Gangue minerals.—Quartz, some barite and calcite, and rare fluorite.

NORTH POLE

Development.—Adit bears S. 75° W.; estimated 400 feet of workings. Adit caved at portal when visited in 1951.

Production.—No records available before 1901. No production recorded 1901–50.

Veins.—Adit was probably driven to intersect veins exposed at surface about 300 feet west of portal, as shown on plate 1. Only trace of vein material on surface of dump.

Ore and sulfide minerals.—Traces of anglesite and pyrite.

Gangue mineral.—Quartz.

OVERLAND

Development.—Shaft and four adits. Adits numbered 1 to 4 starting at one nearest shaft. Bearing of adits at portals: no. 1, S. 20° E.; no. 2, S. 10° W.; no. 3, S. 14° W.; no. 4, S. 14° W. All workings caved when visited in 1951.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—Strikes N. 20° W. to N. 20° E. and dips 65°–90° W., locally dips steeply east. Vein 1 to 5 feet wide of quartz, and brecciated and altered Mount Princeton quartz monzonite. Vein well exposed for 500 feet south of shaft and at portal of adit no. 3. Total length of vein about 3,000 feet.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz, gypsum, and silicified Mount Princeton quartz monzonite.

PORTLAND

Development.—Main adit, bearing N. 80° E. at portal, and many small prospect adits and pits. All workings caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—No data available and no vein exposed at surface.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—On dumps galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz, rhodonite-rhodochrosite, and silicified Mount Princeton quartz monzonite. Vein material heavily stained by manganese.

ST. ELMO QUEEN

Development.—Adit, bearing N. 63° W. at portal, caved when visited in 1950.

Production.—No records available before 1901. Only recorded production 1901–50 was 20 tons in 1932, which yielded 16 ounces of gold, 198 ounces of silver, and 1,789 pounds of lead.

Vein.—No data available and no vein exposed at surface.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and chalcopyrite on dump.

Gangue minerals.—Quartz, calcite, and silicified Mount Princeton quartz monzonite on dump.

STANLEY

Development.—Adit, bearing S. 19° W. at portal. Caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—No data available and no vein exposed at surface. Adit probably driven to intersect Big and Little Bonanza veins.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and chalcopyrite on dump.

Gangue minerals.—Quartz and silicified Mount Princeton quartz monzonite on dump.

STONEWALL

Development.—Shaft (caved when visited in 1950), and tunnel 600 feet long. About 150 feet of drifts along vein accessible at end of tunnel.

Production.—No records available before 1901. Only production [21] recorded in 1946, 1947, and 1949, when 267

[21] Published by permission of the owner.

tons of ore yielded 17 ounces of gold, 590 ounces of silver, 37 pounds of copper, 40,770 pounds of lead, and 13,264 pounds of zinc.

Vein.—Strikes north to N. 30° W., dips 40°–80° W. as exposed in workings, about 30 feet wide. Traced on surface for about 2,000 feet. Mineralized zone consists of brecciated and altered Mount Princeton quartz monzonite cut by many quartz and calcite veins 1 inch to 3 feet wide and 1-inch to 1-foot gouge seams. On foot and hanging walls 1 to 3 feet of heavy gouge.

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and chalcopyrite.

Gangue minerals.—Quartz, calcite, and altered wall rock.

TILDEN

Development.—Four shafts, four adits, and several shallow prospects. All of the larger workings were inaccessible when visited in 1951. Combined workings of the four shafts estimated to be 2,500 feet.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—No data available and no vein exposed at surface. Vein material on dump contains both primary and secondary minerals; some pieces have high content of pyrite and galena.

Wall rock.—Mount Princeton quartz monzonite, highly altered next to veins and along fractures.

Ore and sulfide minerals.—Pyrite, galena, chalcopyrite, magnetite, anglesite, cerussite, malachite, azurite, and pyrolusite.

Gangue minerals.—Quartz, barite, calcite, and fluorite.

TOM PAYNE

Development.—Adit bearing S. 77° W.; estimated 1,500 feet of workings. Caved at portal when visited in 1951.

Production.—One carload ore reported shipped before 1913. About 3 tons of vein material near portal in 1951.

Veins.—No data available and no vein exposed at surface. Surface of dump contains pieces of quartz, as much as 12 inches across, and 50 percent pyrite and 5 percent combined galena and sphalerite. Probably reached veins (shown on pl. 1) 500 to 800 feet to the west.

Wall rock.—Andesite; silicified adjacent to vein.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and sparse chalcopyrite.

Gangue mineral.—Quartz.

TRESSA C.

Development.—Shaft about 400 feet deep and adit bearing S. 2° E. at portal. All workings caved when visited in 1950.

Production.—No records available before 1901. No production recorded 1901–50.

Vein.—No data available and no vein exposed at surface. Probably the extension of the Nelson vein of the Mary Murphy mine (pl. 12).

Wall rock.—Altered Mount Princeton quartz monzonite.

Ore and sulfide minerals.—Sphalerite, galena, pyrite, chalcopyrite, smithsonite, malachite, and chrysocolla. Heavy manganese stain.

Gangue minerals.—Quartz, rhodonite, rhodochrosite, and silicified Mount Princeton quartz monzonite.

MISCELLANEOUS NONMETALLIC DEPOSITS

By far the most important nometallic product mined in the Garfield quadrangle is limestone for flux. The large quarry of the Colorado Fuel & Iron Corp. at Monarch supplies a large tonnage of pure limestone to the steel plant at Pueblo. The limestone quarried is a bed about 100 feet thick that overlies a black dolomite near the base of the Leadville limestone. The limestone dips about 40° NW., about parallel to the slope of the hill. In the past the Garfield quarry, near the town of Garfield (pl. 1), has supplied limestone for flux from the same bed and shipped it to smelters at Salida and Pueblo, and for use in sugar refineries in the Arkansas River valley.

A small quantity of marble has been produced from a small quarry northeast of the Exchequer mine in Taylor Gulch in the Monarch district, but most of the marble is too coarse grained and too remote from adequate transportation to be competitive as a building stone.

During World War I several hundred tons of amorphous graphite was produced from two mines in Graphite Basin, about 1½ miles east of Cumberland Pass (pl. 1). These mines have been described on page 63.

FAVORABLE AREAS FOR FUTURE PROSPECTING

As a result of the studies made in the Garfield quadrangle, several areas appear promising for discovery of any or all of the valuable metals previously found in the quadrangle. The favorable areas must be delineated by purely geologic considerations rather than by extensions from known or indicated ore bodies, because most of the mines are inaccessible and the records are generally poor.

A favorable area in which substantial ore bodies may occur is just east of the southern extension of the Lake fault, from the Monarch Contact tunnel about S. 5°–10° E. for about 2,000 feet toward the Madonna mine No. 6 portal. (See pl. 1.) This area, although covered by glacial debris, is probably characterized by complex faulting where the Lake, Mayflower, and Madonna faults meet, and this faulted zone could very likely have been the locus of ore deposition. A significant economic obstacle for exploration here in the valley is the glacial debris, which may be quite thick. Crawford (1913, p. 255) reported that 56 feet of surficial material was cut above the limestone bedrock in a prospect shaft a few hundred feet southwest of the Monarch Contact adit (pl. 1), and it is likely that farther south near the center of the valley the thickness is greater. Other obstacles are a likely heavy flow of water from the porous glacial till and the high cost of hoisting ore through a shaft rather than the less costly method of undercutting the ore by a tunnel.

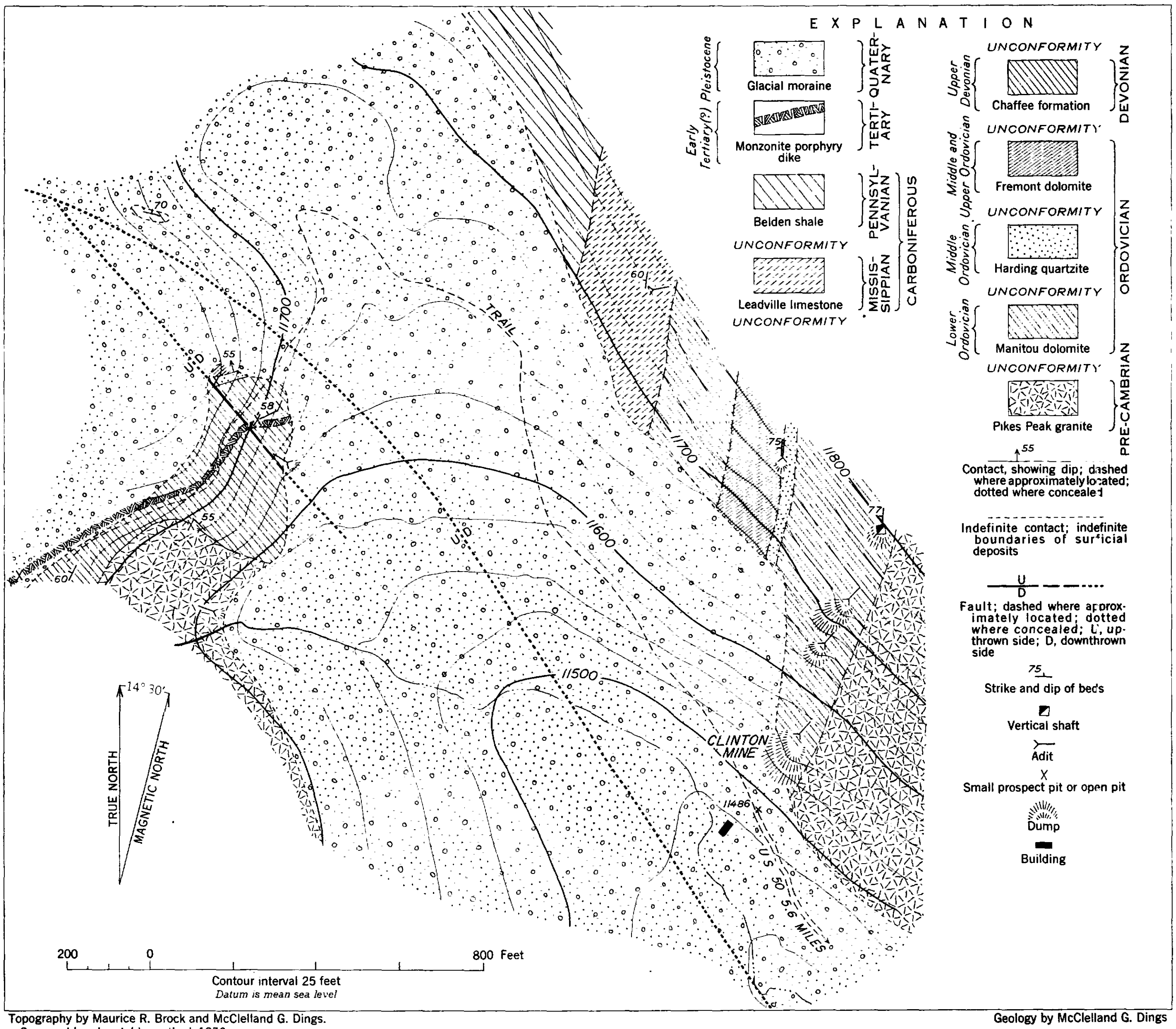
Another area favorable for exploration, although it presents somewhat the same economic problems as does the area north of the Madonna mine, lies high in Cree Creek valley near the Clinton mine (fig. 8). Here a northwest-trending fault is evidently concealed beneath the glacial deposits in Cree Creek valley. Considering the known deposits on each side of the valley, and the tendency for large ore bodies to form where large faults cut limestone beds, as in the Monarch and Whitepine districts, the possibility of ore in commercial quantities along the fault seems good. The most favorable stratigraphic zone is the Manitou dolomite, especially near, or at, its contact with the granite. This zone could probably be found by drilling or bulldozing on the downthrown side of the fault at a point about 400 feet southwest of the Clinton mine, and on the upthrown side at a point about 800 to 1,000 feet west-northwest of the mine. The sharp folds in the beds adjacent to the fault would likely increase rather than diminish the possibilities for concentration of ore in this area by forming structural traps for the ore solutions, such as occurred in folded beds east of the Star fault (fig. 4) in the Akron mine. The depth of glacial debris and soil in this vicinity is not known but it is probably not more than about 35 feet.

The upper 150 feet of the Leadville limestone, particularly at its contact with the overlying Belden shale, has been very slightly explored in Taylor Gulch, and this area, from the lower Garfield tunnel northward for about a mile, is worthy of further exploration. The beds dip steeply west, and the contact of the Leadville and Belden lies on the west side of the valley where it is covered in very large part by slope wash and talus.

The uppermost 175 feet of the Leadville limestone has been extensively explored in the Tincup district where it has yielded a large quantity of ore from the Gold Cup mine south to the Robert E. Lee no. 2 shaft, but from here south for about half a mile it has been inadequately explored by a few small prospects, and it warrants closer and more thorough exploration.

Although a rumor persists in the Tincup district that ore is not found in quantity at the contact of the porphyries and the sedimentary rocks, the authors believe from facts obtained by a study of the surface geology and distribution of prospects and mines that this is not necessarily true, and that such contacts have been inadequately explored. The porphyries in general dip more steeply to the east than the sedimentary beds, and it is quite possible that undiscovered ore bodies might lie against both the quartz diorite and Tincup porphyries at their western margins in the area extending from an east-west line a little south of the Jimmy Mack mine north to the far end of Duncan Hill. In this same general area it is likewise recommended that additional exploration be carried on for possible bedded replacement deposits immediately beneath the Harding quartzite or the basal shaly beds of the Chaffee formation.

Near Whitepine in the Tomichi district an area that warrants additional exploration is along the Morning Glim fault for a distance of about 1,000 feet northwest and 3,000 feet southeast of the Parole mine (pl. 5). This area seems promising because some good ore was obtained near this fault in the old Parole workings, and because large faults elsewhere in the Garfield quadrangle, and especially in the Akron mine nearby, have been highly productive.



Topography by Maurice R. Brock and McClelland G. Dings. Surveyed by planetable method, 1950

Geology by McClelland G. Dings

FIGURE 8.—Geologic map of the Cree Creek area, Monarch mining district, Chaffee County, Colo.

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