UNITED STATES DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary
GEOLOGICAL SURVEY
W. C. Mendenhall, Director

Bulletin 884 — 8 8 6

GEOLOGY AND MINERAL DEPOSITS

OF THE SNOWMASS MOUNTAIN AREA

GUNNISON COUNTY, COLORADO

BY

JOHN W. VANDERWILT

Prepared in cooperation with the

STATE OF COLORADO, COLORADO METAL MINING
FUND, COLORADO MINING ASSOCIATION
and GEOLOGICAL SURVEY BOARD
OF COLORADO

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1937

CONTENTS

III

689153

ILLUSTRATIONS

GEOLOGY AND MINERAL DEPOSITS OF THE SNOWMASS MOUNTAIN AREA, GUNNISON COUNTY, COLORADO

By John W. Vanderwilt

ABSTRACT

The Snowmass Mountain area is in the Elk Mountains, immediately north of the Crested Butte and Anthracite quadrangles, in the extreme northern part of Gunnison County, Colo. Mineral deposits were recognized in the early seventies; in early literature the area is referred to as the Rock Creek mining district, but it is now known as the Crystal River district.

The maximum relief is a little over 5,000 feet, with rugged divides and steep slopes on which the geologic features are well exposed by glaciation and subsequent stream erosion.

Pre-Cambrian gneiss, the Paleozoic formations common to central Colorado, Jurassic and Cretaceous formations, and intrusions of Tertiary age are exposed in the area. The gneiss is composed largely of feldspar and biotite and is typical of the pre-Cambrian over large areas in the Sawatch Range, to the east. Sawatch quartzite (Cambrian), 219 to 278 feet thick, rests on the gneiss and is in turn overlain by 81 to 151 feet of Manitou (Ordovician) dolomite. Several feet of Harding quartzite and 60 to 63 feet of Fremont limestone constitute the upper part of the Ordovician. No Silurian is present. The Parting member, the basal part of the Devonian Chaffee formation, is composed of about 54 feet of shales, shaly limestones, and dolomites and several feet of quartzite. The upper part of the Chaffee formation, the Dyer dolomite member, is 72 to 97 feet thick and is overlain by 170 to 274 feet of Leadville (Mississippian) limestone. The lower part of the Leadville is interbedded dolomite and limestone through an interval of about 40 feet, above which the formation is a massive limestone. On the Leadville limestone rests the Hermosa (?) formation (Pennsylvanian), composed of 1,228 to 1,316 feet of limestone, sandstone, shale, and rocks of intermediate composition. A breccia of chert and quartzite fragments in shale forms the basal bed of the Hermosa and rests on an erosional unconformity. Above the Hermosa are more than 3,000 feet of Pennsylvanian (?) and Permian strata (Maroon formation), terminated at the top by a strong angular unconformity at the base of the Entrada sandstone (Jurassic), 30 to 40 feet of which in places underlies the Morrison formation (Jurassic), which is about 400 feet thick. Dakota (?) quartzite (Cretaceous), 100 to 150 feet thick, rests on the Morrison, and above the Dakota (?) are Mancos (Cretaceous) shales. Only the lower part of the Mancos shale is present.

All the formations are well developed except the Harding quartzite and Fremont limestone, both of which are relatively thin and represent the

1

northernmost exposures of these beds in central Colorado. The formations can be satisfactorily correlated with those of neighboring areas, including Glenwood Springs, the Crested Butte quadrangle, and the Aspen mining district.

The igneous rocks in the area are of Tertiary age. The oldest are dikes and sills of intermediate composition, after which stocks of granodiorite (Snowmass Mountain) and albite granite (Treasure Mountain) came into place. The albite granite and granodiorite may represent differentiates of a common batholith. The relative ages of the stocks are not known.

The dikes and sills are small. They are confined largely to the southern part of the area and represent the northern ends of dikes and sills of the Anthracite and Crested Butte quadrangles. The dike rocks are all porphyritic and consist of quartz monzonite similar to the Lincoln porphyry of the Mosquito Range, gabbro, lamprophyric rocks, and white felsitic rock. All are more or less altered, and identification is not always possible.

The granodiorite is a stock covering about 40 square miles, most of which lies north of the area. It forms rugged peaks, of which Snowmass Mountain is a representative example. The rock is medium-grained and very uniform in appearance over large areas. It is composed of quartz, orthoclase, oligoclase, and biotite. Marginal facies of the granodiorite are quartz diorite and albite rock in which all the feldspar is albite. The quartz diorite occurs opposite the Maroon formation and is confined to a zone not more than a few hundred feet wide. The albite rock, not to be confused with the albite granite of Treasure Mountain, occurs in a zone several hundred feet wide opposite the Mancos shale and in the area where the intrusion has cut across the Elk Mountain fault zone. The principal minerals are albite and quartz with much biotite and some calcite. The complete absence of veins of any kind and the presence of limestone inclusions has led to the belief that the albite granite was formed in the magmatic stage of the intrusion by mineralizers, probably water and carbon dioxide, derived from the sedimentary rocks. The chief role of the sedimentary inclusions would be to furnish mineralizers in sufficient volume and concentration to cause the concentration of the albite molecule during the magmatic stage; ordinarily the concentration of mineralizers is effected relatively late, as albitization more commonly occurs after a magma is almost completely solidified. The early existence of an albitic magma finds support in the occurrence of albite-aplite dikes and other albitic dikes and sills in the Aspen district.

The albite granite is exposed over a relatively small area, but the areal extent of associated metamorphic rocks is proof of the stocklike nature of the mass. The intrusion arched the formations in the form of an elongate dome and at the same time cut across 1,500 to 2,000 feet of strata. The granite is a pink medium-grained rock composed of quartz, orthoclase, albite, and a small amount of biotite. The marginal facies is porphyritic, with phenocrysts of pink orthoclase and quartz in a pale-pink to white groundmass. Biotite is entirely lacking in places in this marginal porphyritic facies, which ranges in width from a few inches to several hundred feet. The bulk of the mass is well crystallized, and at the crest of the stock pegmatites of orthoclase and quartz are common. The granite is virtually unaffected by metamorphism.

The outstanding structural features, named in order of their relative age, are an angular unconformity at the base of the Jurassic; the Elk Mountain fault zone; the granodiorite stock, of which Snowmass Mountain is a part; and the Treasure Mountain dome, formed by the intrusion of a stock of albite granite.

The beveled edges of the beds below the unconformity at the base of the Jurassic trend N. 40°–50° W. and dip 20°–28° NE., relative to the base of the

Jurassic reduced to a horizontal plane. The surface of the unconformity is remarkably uniform.

The Elk Mountain fault zone trends northwest across the area. Along it the Maroon red beds are thrown up against and above 1,000 feet of overturned Mancos shale. The structure is continuous to the northwest with the Grand Hogback fold, on the flank of the White River Plateau; to the southeast it extends at least as far as the Gunnison River. The strike in the area is northwest. It changes to nearly west for several miles northwest of the area, and beyond that it changes to more nearly north. Thrust or reverse faulting is confined to the Snowmass Mountain area; farther northwest the beds lie in a monoclinal fold with normal faults. Local variations in structural detail are dependent on the changing curvature along the strike of the fault zone; the beds are steepest in the areas between the points of maximum curvature. Three large stocks of granodiorite are localized along the Elk Mountain fault zone— Whitehouse Mountain lies to the southeast, Snowmass Mountain within the mapped area, and Mount Sopris to the northwest of the area.

The granodiorite of Snowmass Mountain cuts across the Elk Mountain fault zone; however, the main mass of the stock lies on the northeast side. Where the intrusive mass cuts across the strike of the beds along the fault zone the rocks are crushed and broken for a width of several hundred feet; elsewhere the beds are arched and the bedding is cut at a small angle.

An intrusion of granite brought about the exposure of pre-Cambrian gneiss and all the earlier Paleozoic beds, for it arched the beds into a sharp dome and thus brought them within reach of erosion. Treasure Mountain marks the crest of the dome, which is 3 to 5 miles wide and 5 to 6 miles long, with its major axis trending northwestward. Only a relatively small area of the albitic granite is exposed, but the extent of metamorphism suggests a wider distribution of the granite at depth. All the formations below the Dakota (?) quartzite are uniformly metamorphosed, whether close to the contact or several thousand feet from it. The principal changes are from shale to hornfels, from sandstone to quartzite, from dolomite beds to serpentinized rock that contains much diopside, and from limestone to white marble. In addition, epidote, andradite garnet, and hedenbergite are common in places. The formation of serpentine and diopside has been controlled so closely by the composition of individual beds that these minerals constitute a guide for the identification of horizons in the metamorphic areas.

The area has been glaciated at two stages. The first or high stage is marked by cut-rock benches near the heads of the valleys and by glacial boulders several hundred feet above the benches that were traced as far as Redstone, 12 miles northwest of the area. The second stage filled the lower parts of the present valleys. At the heads of the valleys continuous glaciation may have occurred.

Among the ore deposits zinc-lead ores predominate, although copper-silver and native silver ores also have been productive. The deposit of Colorado Yule marble has been and promises to continue to be commercially more productive than the metals. The total value of the output of metals has been about $500,000, and that of marble several million dollars. Authentic data on production are lacking for both industries. The bulk of the metals came from four mines—the Eureka mine, on Treasure Mountain, and the North Pole mine, in North Pole Basin, both of which produced copper-silver ore; the Black Queen mine, on Sheep Mountain, which produced considerable native silver ore; and the Lead King mine, which produced lead-zinc ore and some silver ore. All the marble has come from one quarry, which was opened in 1908.

Ore deposits are confined to the structural dome of Treasure Mountain and are concentrated on the northeast flank of the dome in a faulted and fissured zone 1 to 3 miles wide and 8 miles long. The zone contains sedimentary beds of Pennsylvanian, Permian, Jurassic, and Cretaceous age. The granite that formed the dome has cut out all the early Palezoic beds in this part of the dome, but they are present on the crest of the dome and to the southwest. All the beds were metamorphosed prior to sulphide deposition.

The process of mineralization included three major stages, each of which graded into the succeeding one—first, intrusion of the granite of Treasure Mountain, which caused faulting and metamorphism of the overlying Paleozoic and Cretaceous beds; second, deposition along faults and related fractures of large amounts of quartz with locally much pyrite, some specularite, and barite; and last, deposition of sphalerite, chalcopyrite, galena, and silver-bearing tetrahedrite with a gangue of pyrite, fluorite, quartz, and calcite, Evidence of relationship between the first and second stages is suggested by more intense metamorphism where faults are large and numerous and by the common occurrence of hedenbergite in metamorphosed beds and in bands with quartz in veins. The second and third stages were more directly related than the first two, and they were separated by a period of fracturing. The rising solutions followed fault fissures, virtually all of which contain at least some quartz, and also spread out from the fissures along certain horizons to form bedded or blanket deposits. The early quartz, however, is virtually confined to veins, which are particularly numerous and conspicuous in the Dakota (?) quartzite; very little, if any, was deposited along beds. The quartz veins invariably pinch out on passing from quartzite into shale (hornfels). The workable shoots of sulphide occur in veins and in replacement bodies along beds. Blanket deposits are characteristic of the four mines that produced most of the ore.

Zoning is suggested, with copper-silver deposits centering on Treasure Mountain and North Pole Basin and with lead-zinc and silver deposits occurring to the northwest and southeast. For future prospecting the bedded or blanket types of deposits are recommended rather than the conspicuous quartz veins, which seem to have been preferred by the prospector. Veins are promising only where they intersect limy beds known to be favorable for ore.

Marble was recognized as early as 1880, but substantial development and production did not begin until 1908 or 1909, after the railroad was built to Redstone for developing coal deposits on Coal Creek. The marble quarry is near Marble, 13 miles from Redstone, and is in recrystallized Leadville (Mississippian) limestone. This formation is uniformly recrystallized to a white marble throughout its extent along the Crystal River and Yule Creek. Local development of metamorphic minerals, distribution of bands of chert and dolomite, and location are factors that control the possible commercial value of a particular outcrop. An abundant reserve of marketable material is indicated. Quarrying is complicated by the presence of joints, chert bands, and irregular masses of dolomite. These features are so closely related to the grain of the marble that quarrying of rectangular blocks is difficult and attended by a large percentage of waste. Nevertheless the quarry is noted for its ability to furnish blocks of large dimensions.

The marble is sold for exterior and interior building and for statuary and decorative use. Much of the marble is finished in the mill at Marble, and considerable unfinished marble, particularly statuary and decorative stock, is shipped. The bulk of the marble goes to western markets, but some is sent to eastern markets. The quarry and mill are owned and operated by the Vermont Marble Co., of Proctor, Vt.

INTRODUCTION

LOCATION AND ACCESS

The Snowmass Mountain area, comprising about 64 square miles, has an irregular outline and, as shown in figure 1, lies between meridians 107° and 107°10′ west longitude and parallels 39° and 39°7′30″ north latitude. The Aspen quadrangle joins the area on the east and the Anthracite quadrangle on the south, but to the west and north the topography is not mapped. The town of Marble, at the western edge of the area, is connected with Glenwood Springs by highway and railroad and is thus easily accessible from the north. From Crested Butte, the nearest railroad station to the south, a
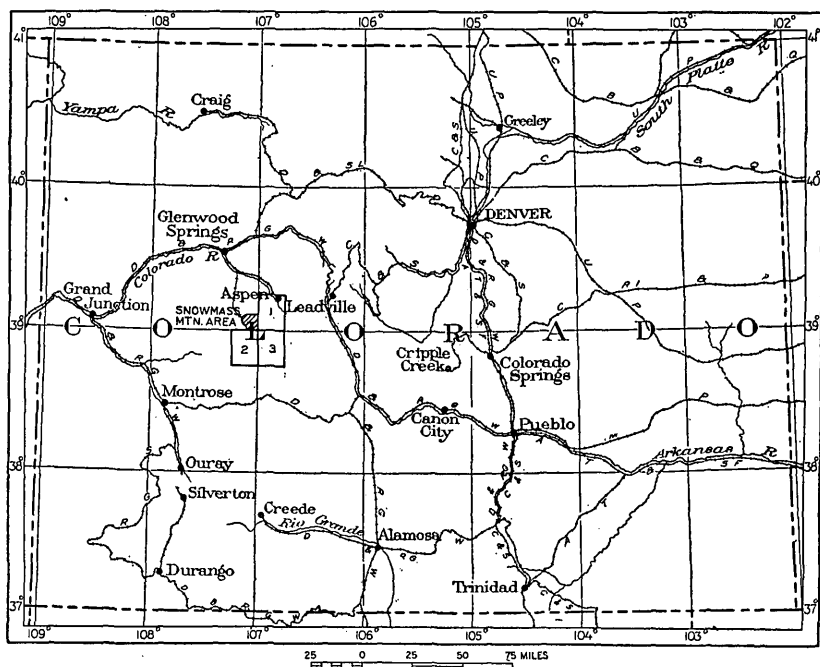
FIGURE 1.—Index map showing location of Snowmass Mountain area. 1, Aspen quadrangle; 2, Anthracite quadrangle; 3, Crested Butte quadrangle.

road leads over Schofield Pass into the southeastern part of the area, but the old wagon road that formerly connected the northwestern and southeastern parts of the area has deteriorated to a trail that is passable with difficulty for horses.

PHYSICAL FEATURES

The Snowmass Mountain area includes a part of the Elk Mountains, a relatively small but nevertheless a very prominent range in the Southern Rocky Mountain province. The geomorphic forms

are only in part controlled by the structure and relative resistance of the rocks to erosion. Snowmass Mountain is composed of granodiorite, and Maroon Peak of flat-lying sedimentary rocks, but both are about equally rugged and both reach altitudes of more than 14,000 feet. The divides are narrow, and most of them are more than 12,000 feet in altitude, but a few are less than 11,000 feet. The principal valley is that of the Crystal River, which lies at an altitude of 9,000 feet in the central part of the area and 1,000 feet lower at Marble, at the western margin. The gorges are the result of severe glaciation and are as imposing as the peaks and serrated ridges; they usually head in cirques with large accumulations of talus from the oversteepened cliffs. Locally the gorges broaden to form relatively wide and attractive valleys or parks, such as Schofield Park and Lead King Basin. The Crystal River, which is tributary to the Roaring Fork of the Colorado River system, flows west and north and drains all the area except two small parts— an area to the northeast that is drained by Snowmass Creek, which flows north to Roaring Fork, and an area to the southeast that is drained by the East River, which flows south to the Slate River.

A view from any high peak includes several flat-topped hills. These flat surfaces are composed of quartzite, shale, and other sedimentary rocks, as well as Tertiary igneous rocks, and apparently are remnants of former erosion surfaces. Glacial boulders occur 1,000 to 1,500 feet above the floor of the valley of the Crystal River fully 12 miles northwest of Marble. A regional study of geomorphic forms would doubtless reveal a long history of erosion. Postglacial streams have cut narrow V-shaped canyons, some of which are as much as 200 feet deep and 200 feet wide, in the resistant Dakota (?) quartzite. These striking canyons represent marked erosion, but they are insignificant as compared with the valleys, rock terraces, and other forms carved by glaciers.

CLIMATE AND VEGETATION

The climate of the Snowmass Mountain area is subject to the wide range of temperature and precipitation common in mountainous districts of high altitude. Much snow accumulates during the long winter, and there is considerable rain during the summer. On south slopes and on most untimbered slopes even at high altitudes and in the lower valleys the snow is usually melted by late May, whereas at high altitudes on north slopes and on those protected by timber the snow remains until late June. Small permanent ice banks are found at the head of Bear Basin and also a short distance southeast of the Yule-Slate Creek Pass. Snowslides are common and are especially frequent in the Crystal River canyon between Marble and Crystal, where slides come from the high steep slopes

of Treasure Mountain.[1] Snowslides also occur almost yearly in the valley of East River below Emerald Lake, where they come from the northeast face of Mount Baldy. It is not uncommon for ice and snow accumulated by snowslides to block the road in these two places until middle or late July, and in some years these banks of ice remain throughout the summer.

May and June, the spring season, have many warm sunshiny days, but the nights remain cold. A rainy season usually begins early in July and continues well into August. During this season the rainfall at times becomes general, but more often it consists of local thunder showers, which center over the higher peaks. A little snow falls and melts immediately on the higher peaks through the summer, but late in August snow becomes more common than rain, and in September snow is expected at altitudes as low as that of Marble. The period October to April is generally considered the winter season. There are, however, many delightfully warm clear sunny days until well into December, and most of the winter precipitation comes after that month. Weather records are not available, and the range of temperature is not known, but 20° to 30° below zero is probably not uncommon, as these temperatures are recorded in neighboring areas. During the summer 70° to 80° is considered warm, and at Marble 85° is regarded as unusual.

Many of the slopes are covered with spruce and fir as high as 11,600 feet in altitude. The thickest growth is always on north slopes, and it continues to slightly higher altitudes there than on the slopes facing in other directions. Thick groves of quaking aspen grow in the valley of the Crystal River from Crystal to a point several miles downstream from Marble. The growths of aspen are particularly luxuriant in Mancos shale soil on slopes below 10,000 feet. During the rainy season the open grassy slopes are tinted yellow, red, or blue, or combinations of these colors, by flowering vegetation. Relatively large areas of smooth grassy slopes at and above timber line, which ranges from 11,500 to 11,700 feet, afford excellent grazing for sheep.

PREVIOUS WORK

Evidence of mineralization was recognized in this region at least as early as 1875. Holmes,[2] of the Hayden Survey, mapped this area and in his report referred to the "lead-silver mineralization" on Treasure Mountain. He recognized the intrusions of Treasure Mountain and Snowmass Mountain, but naturally his report does not include detailed

[1] Treasure Mountain, a primary triangulation point, is approximately at the crest of the Treasure Mountain dome and must not be confused with Treasury Mountain, also a primary triangulation point, about 2 miles to the southwest.

[2] Holmes, W. H., [Report on the geology of the northwestern portion of the Elk Range]: U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., p. 67, 1876.

descriptions. The Anthracite-Crested Butte folio describes the district adjoining this area on the south and contains brief reference to the area of Snowmass Mountain; its description of the intrusive rock of the White Rock Mountains of the Sawtooth Range is in general applicable to the intrusive rock of Snowmass Mountain. A few references to mines and to attempts at mining were made in mining magazines from 1880 to 1890, and, after the development of the large deposit of marble in Yule Creek, references to the marble industry were made in several trade journals, but none of these publications contain more than brief references to geologic conditions. A preliminary report on the geology of Galena Mountain, situated in the southern part of the area, has been published,[3] and the stratigraphy of the formations found on Yule Creek has been described.[4] These recent descriptions are based on the same field work as this report.

FIELD WORK AND ACKNOWLEDGMENTS

This report is based on a little over 2 months of field work in 1930 and 5 months in 1931. Two weeks was spent in 1932 in studying that part of the Snowmass Mountain intrusion which lies north of the area included in this report and the intrusive rock of Mount Sopris, which constitutes the north end of the Elk Mountains. In 1932 several days was also used to trace the northwest continuation of the Elk Mountain fault.

In 1930 J. B. Reeside, Jr., visited the area while studying the Triassic in western Colorado, and I wish to thank him for his help, especially in verifying the identification of the horizon of the Niobrara limestone in the Mancos shale. During the field season of 1931 B. S. Butler visited and studied the area for several days and aided materially in solving field problems. G. F. Loughlin visited the area during the field season of 1932, examined critical places, and gave particular attention to the Yule Colorado marble quarry, and I am indebted to him for his aid and advice, both in planning the field work and the report. Without his assistance the production figures of the marble quarry and the list of buildings in which the marble has been used would have been incomplete. I am also indebted to G. W. Bain, consulting geologist of the Vermont Marble Co., for supplying results of recent studies of the physical properties of the marble. It is difficult to acknowledge satisfactorily the benefits derived from discussions with colleagues of the Geological Survey and in particular those of the Golden office, as well as those not connected with the Survey. I wish to thank Dr. R. D. Crawford, of
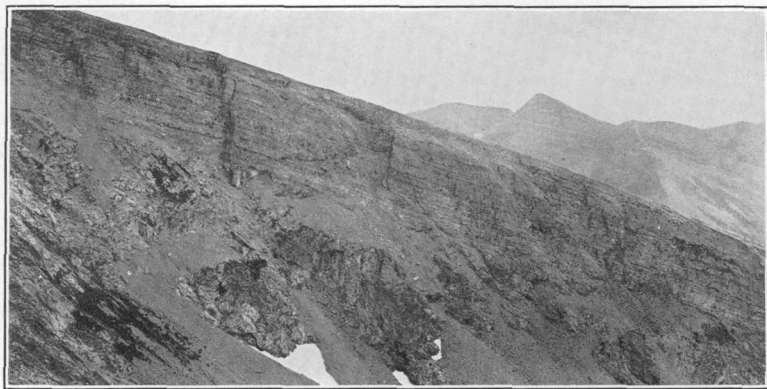
A. RIDGE OF CAMBRIAN (SAWATCH) QUARTZITE FORMING THE WALL OF A CIRQUE
ON THE SOUTHWEST FLANK OF TREASURE MOUNTAIN.
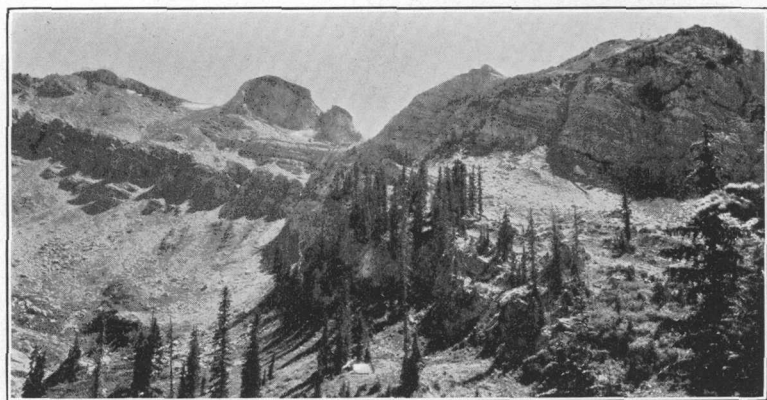
B. CHARACTERISTIC BLUFF OF ORDOVICIAN (MANITOU) DOLOMITE ON THE SLOPE
SOUTHEAST OF WHITEHOUSE MOUNTAIN.

The lower continuous ledge is Manitou dolomite and the upper bluff is Mississippian (Leadville) lime-
stone.   Between these two formations lie upper beds of Ordovician and Devonian age that form less
conspicuous outcrops.
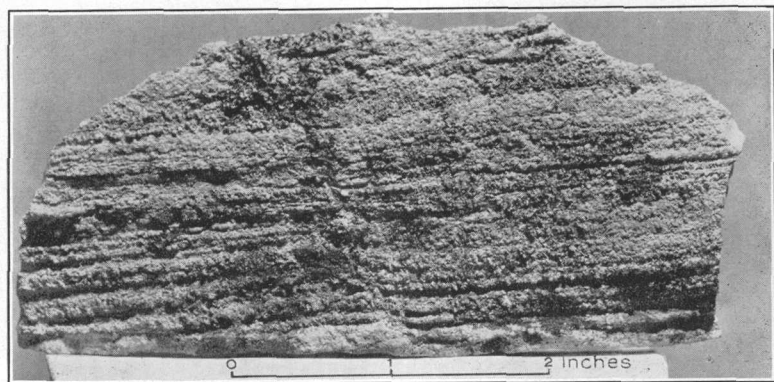
C. BANDING CHARACTERISTIC IN OUTCROPS OF WEATHERED SURFACES OF
MANITOU DOLOMITE.
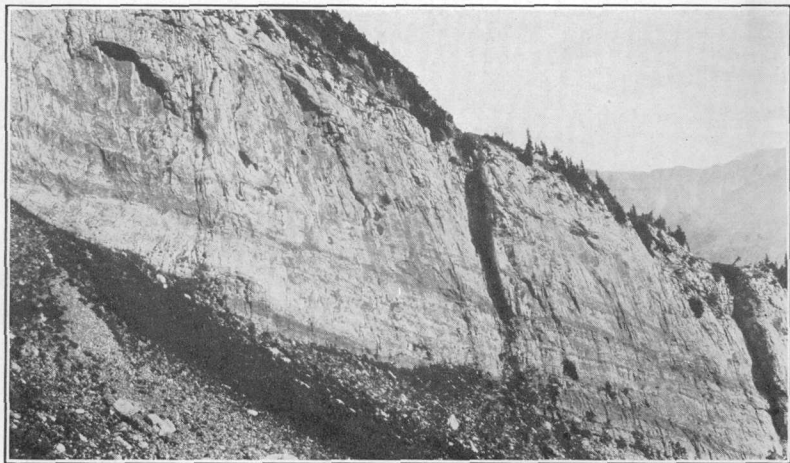
A. INTERBEDDED DOLOMITE, DOLOMITIC LIMESTONE AND LIMESTONE IN THE LOWER PART OF THE MISSISSIPPIAN (LEADVILLE) LIMESTONE ON EAST SLOPE OF WHITEHOUSE MOUNTAIN.

Total thickness about 200 feet.   A little Dyer (Devonian) dolomite is exposed in the lower right corner.
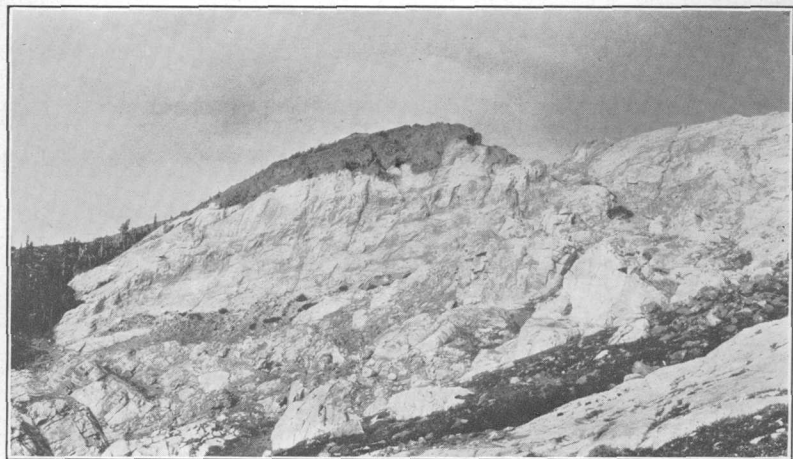
B. BEDDING BROUGHT OUT BY WEATHERING OF UPPER PART OF MISSISSIPPIAN (LEADVILLE) LIMESTONE CALCITE MARBLE SOUTHEAST OF SADDLE SOUTH OF WHITEHOUSE MOUNTAIN.

The erosion-surface contact between marble and overlying Hermosa (?) Pennsylvanian beds is also shown.

the University of Colorado, for the opportunity to examine his collection of Tertiary igneous rocks and for his advice on several problems related to them.

Appreciation and thanks are here expressed to the residents of Marble and Crested Butte whose cooperation made field work more effective as well as more pleasant and whose information concerning old and nearly forgotten claims and mine workings was a decided help.

I was ably assisted in both geologic mapping and examination of prospects during most of each field season by H. C. Fuller.

GEOLOGY

SUMMARY

Pre-Cambrian gneiss, Paleozoic, Jurassic, and Cretaceous sedimentary rocks, and Tertiary intrusions of granodiorite and quartz monzonite crop out within the limits of the area. (See pl. 1.) Tertiary sedimentary formations are not present.

The important structural features of the area are (1) the Elk Mountain fault, which extends northwestward across the area and along which Permian on the east moved, by reverse faulting, against overturned Cretaceous (Dakota? and Mancos) and Jurassic (Entrada sandstone and Morrison formation) on the west; (2) the Snowmass Mountain stock of granodiorite along the Elk Mountain fault, intrusive into the Maroon beds; (3) the Treasure Mountain dome, formed by the intrusion of Tertiary granite; and (4) an angular unconformity at the base of the Jurassic, representing the elimination of 5,000 to 8,000 feet of Paleozoic and Mesozoic sedimentary beds. Outside the Snowmass Mountain area some of these features are to be found in neighboring scattered localities, but all of them are not known to be concentrated in a small area.

PRE-CAMBRIAN GNEISS

Distribution.—Pre-Cambrian gneiss is exposed only on the north and south flanks of Treasure Mountain up to an altitude of about 13,000 feet. It does not extend down to the bottom of the valley of the Crystal River on the north side but it extends down to Yule Creek on the south side and continues along it. The nearest pre-Cambrian outcrops in other areas are 18 to 20 miles to the east, where they form the western flank of the Sawatch Range east and southeast of Aspen. In these areas and in general on the Sawatch Range the gneiss is similar to that found on Treasure Mountain.

General features.—The gneiss is a medium-grained gray rock in which biotite, feldspar, and quartz predominate. Just below and east of the crest of Treasure Mountain the gneiss is locally stained

conspicuous bright reds and yellows owing to slight alteration of the biotite. Elsewhere the rock is unaltered and has dark-colored outcrops. A few small pegmatite dikes were observed in the valley of Yule Creek. Irregular masses of pegmatite are more abundant than the dikes, but they are invariably small, and nowhere were they estimated to constitute more than 5 or 10 percent of the rock.

The laminated and banded structure typical of gneiss is well developed, but it is highly contorted and without marked parallelism except that the bands dip generally 60° to 75° or more. On the south flank of Treasure Mountain, near the group of lakes, strikes of N. 40°–60° W. and dips of about 75° NE. predominate. Similarly northwest strikes also appear to predominate in the valley. As this strike is approximately parallel to the axis of the dome it would not be affected much by the uplift, but the dip, which is now 60°–75° NE., would have been essentially vertical before the uplift. In addition to being contorted the bands and laminae are not uniformly spaced. In places over small areas the rock is massive and more like granite·than gneiss.

Under the microscope the gneiss shows quartz, orthoclase, plagioclase, biotite, muscovite, some microcline, and small amounts of chlorite, apatite, titanite, and magnetite. The quartz and orthoclase appear in their normal habits. The plagioclase is only locally present and was identified as oligoclase ($Ab_{85}An_{15}$). The biotite is usually brown, but green biotite is also present, and both colors in a single grain are not uncommon. Some of the biotite is very pale brown and appears to grade into colorless mica or muscovite. Like the biotite the muscovite occurs in bands, both alone and with biotite. Chlorite replaces biotite.

In thin section the gneiss just below the Cambrian quartzite below the Skyline mine does not show evidence of granulation or any undulatory extinction of either feldspar or quartz; however, a specimen collected near the crest of the dome from the iron-stained gneiss mentioned in an earlier paragraph shows evidence of deformation. There the orthoclase and to some extent the quartz show granulation, and the larger grains have very strong wavy extinction. This relation suggests greater strain near the crest than on the flank of the dome, but further study is necessary because the observations made were too few to warrant a conclusive interpretation of the differences noted.

PALEOZOIC SEDIMENTARY ROCKS

REGIONAL SETTING

The Paleozoic sedimentary rocks, ranging in age from Cambrian to Permian, are exposed in many places in central Colorado in a zone with a northwesterly trend. This zone includes the northern

part of the Sangre de Cristo Mountains to the southeast and the Sawatch Range and the White River Plateau to the northwest. The Snowmass Mountain area is situated on the extreme western margin of this belt, opposite the Sawatch Range. In this zone over large areas the stratigraphy is characteristic and in general similar. The most pronounced variations in lithology occur in the Pennsylvanian and Permian rocks. The pre-Pennsylvanian rocks are not only more uniform in development but they also include the most productive ore-bearing belts in the Leadville and Aspen areas and in consequence have been studied in greater detail than the younger members of the Paleozoic. The extent of the Paleozoic rocks to the west is unknown: for many miles only Jurassic and younger formations are exposed, and these beds rest directly on pre-Cambrian granite and gneiss over large areas to the south and southwest as far as the San Juan Mountains, where Paleozoic formations are well developed and exposed.

The nearest neighboring areas in which the Paleozoic formations of the region are exposed and have been described are (1) Cement Creek, in the Crested Butte quadrangle, to the southeast, described by Eldridge,[5] and (2) the Aspen district, to the east, described by Spurr.[6] An excellent section of Paleozoic formations is found at Glenwood Springs, and in this area the pre-Pennsylvanian rocks have been described by Kindle,[7] who, however, does not include the Pennsylvanian or Permian rocks in his discussion. Recently the pre-Pennsylvanian sections of Cement Creek and Glenwood Springs were described by Vanderwilt and Fuller.[8]

METAMORPHISM

By the metamorphic action of the granite several of the familiar lithologic features of the sedimentary rocks on the Treasure Mountain dome have been obliterated, and certain unfamiliar features, which occur in their stead, are confusing unless the observer is familiar with the local effects of metamorphism. Limestones of the Leadville and Hermosa (?) formations have been recrystallized to white marble, of which the Yule Colorado marble is of commercial importance. Silicates, such as serpentine, diopside, actinolite, and andradite, have developed in abundance, especially in dolomite and in siliceous beds. Shale, particularly in the Hermosa (?) formation,

---

[5] Eldridge, G. H., Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

[6] Spurr, J. E., Geology of the Aspen mining district, Colo.: Geol. Survey Mon. 31, pp. 1–33, 1898.

[7] Kindle, E. M., The Devonian fauna of the Ouray limestone: Geol. Survey Bull. 391, p. 9, 1909.

[8] Vanderwilt, J. W., and Fuller, H. C., Correlation of Colorado Yule marble and other early Paleozoic formations in Yule Creek, Gunnison County, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 7, pp. 439–464, 1935.

has been changed to hornfels, which forms steep cliffs instead of the usual covered slopes. The conspicuous and striking red color of the Maroon rocks has been altered to a drab gray. These changes are marked in their effect on the character and appearance of the outcrops of some of the sedimentary formations. The fundamental character of the section, however, has remained unchanged, and original composition can be inferred readily from the alteration products. All that is really lost comprises the original color, the texture, chiefly of the calcareous rocks, and the soft character of shale.

The sequence and important stratigraphic features that are to be described are summarized in the following table:

Paleozoic sedimentary rocks of the Snowmass Mountain area

Age	Formation		Thickness (feet)	Character
Unconformity—				
Permian and Pennsylvanian (?)	Maroon formation.		2,200–2,700	A series of sandstone, shale, feldspathic sandstone, and feldspathic grit, which is usually conglomeratic. The grit occurs in the upper part, and sandstone with shale in the lower part. Thin and slightly fossiliferous beds of limestone occur at irregular intervals. The formation is red in the eastern part of the area where unaltered, and, owing to metamorphism, gray on and around Treasure Mountain.
Unconformity (?)—				
Pennsylvanian.	Hermosa (?) formation.		1,228–1,316	Gray hornfels, quartzite, and partly marbleized limestone. A few beds are fossiliferous. A characteristic conglomerate 5 to 20 feet thick occurs at the base.
Unconformity—				
Mississippian.	Leadville limestone.		170–274	White medium-grained calcite marble, which is usually massive. Chert is common in the upper part, and there is some dolomite in the lower part.
Unconformity—				
Devonian.	Chaffee formation	Dyer dolomite member.	72–97	Gray and fine-grained dolomite marble. Well bedded.
		Parting member.	54	Calcite and dolomite marble, with interbedded shale and quartzite. Variable along the strike.
Unconformity—				
Ordovician.	Fremont limestone.		60–63	White medium-grained massive calcite marble.
	Harding quartzite.		4–5	Fine-grained gray quartzite.
	Manitou dolomite.		81–151	Gray to buff dolomite marble, well bedded, with some chert locally in upper part; usually contains much serpentine.
Unconformity—				
Cambrian.	Sawatch quartzite.		219–278	Gray fine-grained quartzite, usually well bedded. Upper part contains inter-bedded shale and limestone.
Unconformity—				

Total thickness 4,088–4,938 feet.

CAMBRIAN (SAWATCH QUARTZITE)

Distribution.—All the exposures of the Paleozoic formations except the Maroon are confined to the flanks of the Treasure Mountain dome. The general distribution of these formations is therefore

very much the same.   Cambrian (Sawatch quartzite) lies in a narrow continuous band along the crest of the dome.   Along the valley of the Crystal River the Cambrian beds have been cut out by the granite of the intrusion that formed the Treasure Mountain dome.   In the vicinity of Twin Bridges the quartzite is found within a few hundred feet of the bottom of the valley, and in Bear Basin, to the southeast, the outcrops are nearly 3,000 feet above the valley.   On the southwest side of Treasure Mountain the formation has a continuous oval outcrop from the crest of the mountain into and across Yule Creek near its head, paralleling the stream down the valley first on the south and then on the north side for 5 or 6 miles before swinging back up the slope toward the crest.   For 3 or 4 miles along Yule Creek upper beds of the formation are cut out by an angular unconformity at the base of the Jurassic.

The lower part of the Cambrian is a thick quartzite member that forms prominent cliffs and bluffs, but the upper part has poor outcrops because of the shaly beds and thin-bedded limestone it contains. The Cambrian is normally overlain by a thick cliff-forming dolomite of Ordovician age.   The steep bluff above the covered slope of the upper part of the Cambrian is an easily recognized topographic feature.

Lithologic character and thickness.—The best sections are found at the head of Yule Creek and on Treasure Mountain below the Skyline mine, southeast of Whitehouse Mountain.   The two localities are only about 5 miles apart, and the general lithology of the formation is the same, but thicknesses differ slightly.

The measurements obtained of this formation are as follows:

Section of Cambrian quartzite at head of Yule Creek and on Treasure Mountain

Feet

2. Quartzite, limestone, dolomitic limestone, and shales interbedded, gray and thin-bedded.   Quartzite is predominant at head of Yule Creek and dolomite on Treasure Mountain.   Yule Creek, 91 feet; Treasure Mountain, 90 feet_____   90–91
1. Quartzite, gray and fine-grained.   Well bedded with strata 6 inches to 4 feet thick.   A few calcareous zones in which the rock is a quartzitic sandstone. Yule Creek, 187 feet; Treasure Mountain, 128 feet_ 128–187

The lower member (1) is uniformly fine-grained except for a basal conglomerate observed locally due east of the summit of Treasure Mountain.   The conglomerate is only a few feet thick and consists of well-rounded quartz pebbles 1 inch or less across in a matrix of fine quartz sand.   The calcareous beds are in reality sandstones with some calcite as matrix; they occur at irregular intervals and range from a few inches to 10 feet in thickness.   They are as

a rule not numerous and can be distinguished in outcrop from the more resistant quartzite by their greater tendency to disintegrate. A typical cliff of the lower member of the Cambrian quartzite with its characteristic bedding is shown in plate 2, *A*. The bedding surfaces are well developed but are so uneven that strikes and dips are usually difficult to obtain from small exposures.

The upper member (2) is not well exposed except on very steep and virtually inaccessible slopes. On Treasure Mountain it is generally marked by a zone covered with tabular fragments as much as 2 inches thick of quartzite, sandy dolomite, hornfels, and marble. At the head of Yule Creek the individual beds of quartzite, impure limestone, dolomite, and shale (hornfels) are thicker than on Treasure Mountain. Some of the purer quartzites of this upper member (2) are similar in color and texture to the quartzite of the lower member (1), but the thickness of a bed or aggregate thickness of several successive beds of purer quartzite in the upper member is rarely as much as 5 feet, whereas in most places the lower member is essentially pure quartzite.

The lithology of the quartzite of the Cambrian is typical and is best developed in the lower half or two-thirds of the formation. The upper part of the Cambrian is generally a highly siliceous member ranging from a shaly to a dolomitic zone which everywhere contains interbedded quartzites lithologically like the quartzite below. The upper boundary of the Cambrian is well defined by the marked lithologic change from siliceous beds below to dolomite above. Locally some of the thin dolomites of the upper part of the Cambrian are similar to the overlying Ordovician dolomite, and in places the boundary between the two cannot be definitely placed in a zone that is usually less than 15 feet thick.

ORDOVICIAN

Distribution.—The Ordovician beds of this area consist of a thick marbleized dolomite overlain by quartzite and white calcite marble. The band of the Ordovician parallels the Cambrian beds, but it is not continuous along the crest of the Treasure Mountain dome. Only remnants of the basal dolomite (Manitou) are present here, and all the Ordovician is cut out for 3 or 4 miles along Yule Creek by the erosion that produced the angular unconformity at the base of the Jurassic. The Manitou formation is also found high on the dome both at the northwest end toward Whitehouse Mountain and at the southeast end near Treasury Mountain. Conspicuous bluffs mark the outcrop of the formation (pl. 2, *B*). The lower parts stand out markedly above the covered slopes produced by the weak upper member of the Cambrian. The upper 60 feet of the Ordovician formation usually crops out in a prominent ledge which is conspicuous

because of the whiteness of the marbleized Fremont limestone, and because the overlying Parting member of the Chaffee formation (Devonian) forms covered slopes. (See pl. 2, *B*.)

Lithologic character and thickness.—A complete section of the Ordovician is exposed along Yule Creek above the Yule Colorado marble quarry, and although the general character of the formation is well brought out, the exposures are not good for detailed measurements. The best exposed sections of the Ordovician as well as of the Cambrian were found at the head of Yule Creek and high above the Crystal River on the flank of Treasure Mountain southeast of Whitehouse Mountain. The measurements obtained are:

Section of Ordovician at head of Yule Creek and on Treasure Mountain

Ordovician:
  Fremont limestone: *Feet*
    5. Limestone marble, white, medium-grained, and
        massive; 6 to 10 feet of dark-gray marble at
        base. Yule Creek, 63 feet; Treasure Moun-
        tain, 60 feet_____ 60–63
  Harding quartzite:
    4. Quartzite, gray and fine-grained; dolomitic
        and shaly in places. Yule Creek, 4 feet;
        Treasure Mountain, 5 feet_____   4–5
  Manitou dolomite:
    3. Dolomite marble, gray to bluff. Bedding well
        developed and individual beds generally less
        than 12 inches thick. In places chert is
        found in upper 10 feet. Much serpentine is
        present and develops a characteristic band-
        ing or ribbing on exposures across bedding.
        Yule Creek, 81 feet; Treasure Mountain,
        151 feet _____ 81–151

The Manitou dolomite (3), except for its thickness, is uniform throughout the area. The rock is recrystallized and contains abundant green and black serpentine and some yellow serpentine as well as diopside developed in irregular stringers parallel to the bedding. The serpentine is everywhere most abundant in the lower part of the dolomite. The numerous parallel stringers of serpentine produce on weathered surfaces perpendicular to the bedding a grooved and ribbed pattern and a conspicuously thin-banded rock (pl. 2, *C*), not found in other beds, which serve to identify this formation. It could not be determined to what extent this banding has been controlled by or expresses the original bedding of the rock. The grooves are 2 to 3 millimeters deep and are oriented nearly parallel to the bedding. On Treasure Mountain serpentine is abundant only in the lower beds, and diopside is predominant in the upper part, although it is inconspicuous owing to its white color. At the head of Yule Creek serpentine is abundant throughout the

formation. In places the lower 15 to 20 feet is sandy and contains a few sandstone beds as much as 2 inches thick, and in the upper 20 to 30 feet chert nodules, irregular in form and distribution, are locally developed along the bedding. The remainder of the formation does not show quartz sand or chert, but an original siliceous content can be inferred from the presence of the serpentine.

The Harding quartzite (4) is very inconspicuous in outcrops but is apparently continuous throughout the area. The grain is slightly finer than in the Cambrian quartzite. The sediments apparently contained impurities, like clay and iron, as the rock usually contains a little pyrite and also enough serpentine to give the quartzite greenish tints. Locally the rock is more nearly hornfels than quartzite. The Fremont limestone (5), above the Harding, is a white medium-grained marble very similar to the Yule Colorado marble (Mississippian) and like it forms ledges that stand out in contrast to the darker beds that lie immediately above and below it. The Fremont marble, however, is only 60 feet thick and in outcrop need not be confused with the Yule Colorado marble, which is fully three times as thick.

DEVONIAN (CHAFFEE FORMATION)

Distribution.—The Devonian Chaffee formation consists of two members, neither of which forms prominent or conspicuous outcrops. The lower member, 50 to 60 feet thick, is made up of thin-bedded shales (hornfels), marbleized dolomite, and quartzite and usually forms covered slopes. The upper member is dolomite, which forms the base of the more prominent cliffs of the overlying Mississippian (Leadville) limestone. In localities where both Ordovician and Mississippian formations are well exposed the Devonian can be recognized between the two. (See pl. 2, *B*.)

The outcrops of Devonian beds parallel those of the Ordovician. They are found high on the Treasure Mountain dome, at the northwest end toward Whitehouse Mountain and at the southeast end on the west slope of Treasury Mountain. The Devonian has been removed by erosion from the southwest and northeast flanks of the dome. On Yule Creek it is absent for 3 or 4 miles along the angular unconformity at the base of the Jurassic, and in the valley of the Crystal River it is cut out by the Tertiary granite.

Lithologic character, subdivisions, and thickness.—The upper part of the Dyer dolomite member is well exposed along Yule Creek just above the Yule Colorado Marble Co.'s quarry. The upper boundary occurs in the stream directly below the quarry. The Parting member is fairly well exposed about three-quarters of a mile above the quarry in the channel of the stream. If the trolley is operating from Marble to the quarry this locality is the most accessible one

for seeing the Devonian beds. The outcrops are not continuous, however, and the thickness cannot be satisfactorily measured. At the head of Yule Creek and on Treasure Mountain the following measurements were obtained:

Section of Devonian at head of Yule Creek and on Treasure Mountain

Devonian:
    Chaffee formation:
        Dyer dolomite member: *Feet*

	Feet
11. Dolomite marble, light gray weathering to pale buff, fine-grained and well-bedded strata a few inches to 5 feet thick. Lower 20 feet appears to be more calcareous than dolomitic. Yule Creek, 97 feet; Treasure Mountain, 72 feet	72–97

Parting member:

	Feet
10. Quartzite, gray, fine-grained. Pyrite along joints	5
9. Limestone marble, white, fine-grained, massive; 10-inch shale band near middle	12
8. Shale, dolomitic, black, dense. In places weathered surfaces are distinctly greenish	2
7. Limestone marble, dolomitic, light gray to white, fine-grained, in beds 1 to 4 feet thick, with a persistent sandy shale near middle	18
6. Shale and limestone, interbedded, gray. The shale is altered to brown, green, and gray. Outcrops poor	17
	54

The rocks identified as the Parting member of the Chaffee formation (6–10) are the only ones above the Cambrian and below the Pennsylvanian that contain an appreciable quantity of shale. In this member, which averages nearly 55 feet in thickness, there is about 36 feet of limestone and dolomite, 14 feet of shale, and 5 feet of quartzite. The quartzite occurs as a single bed at the top. Although individual beds vary along the strike, the Parting member as a whole is uniform throughout the area.

The Dyer dolomite marble (11) above the Parting member forms brown to buff cliffs. It is a little more massive than the dolomite marble (3) of the Ordovician. In places the beds are thin, but they average 2 to 5 feet in thickness. The dolomite marble appears fairly uniform from top to bottom, but the beds near the bottom effervesce more readily with acid than the beds in the upper part. The higher calcium-carbonate content which is thus indicated may have developed as a result of dedolomitization due to the formation of magnesian silicates, chiefly diopside.

The base of the Devonian is readily fixed, as the Fremont lime-stone below forms prominent outcrops of massive white marble be-low the Parting member of interbedded limestone and shale, which forms poor outcrops. The top of the Devonian is not so evident. The marbleized buff dolomite (Dyer member) for the most part is quite unlike the white marble of the overlying Yule Colorado marble (Mississippian), but between the two are 50 to 100. feet of inter-bedded calcite and dolomite marble.

In this report the top of the Devonian has been arbitrarily placed at the bottom of the lowest bed of calcite marble, because this con-tact is everywhere sharp, whereas the dolomite above this horizon varies in thickness and locally appears to grade into calcite marble, so that well-defined limits are lacking.

DEVONIAN-MISSISSIPPIAN BOUNDARY

The lack of a definite boundary between the Devonian and Mis-sissippian formations in the Snowmass Mountain area requires special comment, as two recent papers describe definite boundaries in other areas. In older geologic reports it is generally considered that the boundary is indefinite and is therefore usually not indicated. Gibson,[9] in 1925, was the first to fix the top of the Devonian in the Red Cliff district tentatively at the base of a certain quartzite bed which contained breccia fragments of limestone. In 1929 Behre,[10] apparently unaware of Gibson's conclusion, as he did not refer to it, used a similar quartzite-breccia bed as the base of the Mississippian in the Mosquito Range and Leadville district. In 1931 Kirk[11] stated:

> The exact separation of the Devonian from the Mississippian is usually attended with difficulties, *usually owing to the lack of good exposures.* The boundary can always be drawn within a vertical distance of a few feet, how-ever, and usually with precision. * * * The basal 25 feet or so of the Mississippian *seems* invariably to carry one or more bands of limestone breccia. The lowest of these is *usually* near the base of the Mississippian. *Often* there is a sandstone at the base of the Mississippian.[12]

The first statement implies that the chief difficulty arises from lack of good exposures, but the words "seems", "usually", and "often" used in the second part of the quotation certainly qualify if they do not contradict the contention of the first. D. P. Rohlfing,[13] who is well acquainted with the detailed geology of the Aspen district, does not find the boundary between Devonian and Mississippian easy to

[9] Crawford, R. D., and Gibson, Russell, Geology and ore deposits of the Red Cliff dis-trict, Colo.: Colorado Geol. Survey Bull. 30, pp. 37–38, 1925.
[10] Behre, C. H. Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colo.: Colorado Sci. Soc. Proc., vol. 12, no. 3, p. 41, 1929.
[11] Kirk, Edwin, The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, p. 223, 1931.
[12] Italicizing by J. W. V.
[13] Personal communication.

recognize. For practical purposes the miner at Aspen usually regards the contact at the top of the dolomite as the top of the Devonian and the true limestone as Mississippian.

In a study of this problem in the Aspen district [14] I have described a sandy zone present in all the sections studied, which can be correlated well with the sandy beds referred to above by Gibson and Behre. At Aspen all the Devonian below these sandy beds is dolomite, and the overlying Mississippian formation consists of an upper limestone member and a lower dolomite member, usually with interbedded limestone. Dolomite interbedded with limestone just below the Leadville limestone has been found on Cement Creek, at Glenwood Springs, and on Treasure Mountain and is therefore not a local feature. The limestones and dolomites on Treasure Mountain, because of metamorphism, are easily recognized by their color difference, calcite marble being white and dolomite marble buff. Ordinarily, however, the interbedded dolomite and limestone cannot be distinguished in the field unless acid tests are made. This fact is not generally appreciated, probably because the massive limestone is easily distinguished by inspection. At any rate the division between dolomite below and limestone above has been described as abrupt, without mention of an interval where the two are interbedded.

For the reasons given above the top of the Devonian on Treasure Mountain is placed at the base of the lowest limestone bed. The dolomites above this horizon do not contain the same kind of metamorphic minerals or as many as the Devonian dolomite below, and this suggests a difference in composition of these beds. (See pp. 20–21.) The correlation is arbitrary at best and must be considered so as long as the variations in lithology and composition are not known in detail or are not clearly understood.

MISSISSIPPIAN (LEADVILLE LIMESTONE)

Distribution and character.—The Mississippian (Leadville) limestone has been metamorphosed to a massive bed of white marble whose outcrops are conspicuous because of the prominent white cliffs they usually form. (See pl. 2, *B*.) It has the same general distribution as the older Paleozoic beds, although good exposures of the marble are more numerous. Complete sections are exposed at the head of Yule Creek, along Yule Creek in the vicinity of the quarry of the Yule Colorado Marble Co., and at the northwest end of

[14] Vanderwilt, J. W., Revision of structure and stratigraphy, and its bearing on the ore deposits of the Aspen district, Pitkin County, Colo.: Econ. Geology, vol. 30, pp. 223–241, 1935.

Treasure Mountain near Whitehouse Mountain. (See pl. 3, *A*, *B*.)
The sections measured are as follows:

Section of Mississippian Leadville limestone at head of Yule Creek and on Treasure Mountain

Mississippian:
    Leadville limestone: *Feet*
        14. Limestone (calcite) marble, white, medium-
            grained, and massive. Irregular t h i n
            bands and nodules of chert in places,
            especially near top. Locally dolomite beds
            1 foot thick were observed. Yule Creek,
            176 feet; Treasure Mountain, 127 feet_____ 127–176
        13. Dolomite and dolomitic limestone marble, gray
            to buff, fine-grained, and massive. Yule
            Creek, 68 feet; Treasure Mountain, 22 feet_ 22–68
        12. Limestone (calcite) marble, gray and white
            banded, medium-grained, and massive. Some
            dolomite. Yule Creek, 30 feet; Treasure
            Mountain, 21 feet_____ 21–30
                                          170–274

The formation measured 166 feet in thickness at the quarry on Yule Creek and 239 feet about 2,000 feet southeast of the quarry. The range in thickness of more than 100 feet can be attributed either to the fact that the base is not definitely recognizable or to irregularities of the unconformity at the upper boundary, which is sharply and clearly defined. A lack of well-defined bedding in the marble makes it difficult to compare angular relations between it and the overlying Pennsylvanian (Hermosa?) beds or to determine how uneven the unconformity may be.

In the lower 20 to 30 feet (12) banding is rather pronounced (pl. 3, *A*). The darker bands are of about the same grain, and they appear similar except that they are dolomitic in places. The bands are irregularly spaced, 4 to 6 feet apart, 3 to 8 feet thick, and 100 to 1,000 feet in length. The relations suggest that the white marble is bleached gray dolomitic marble, but the banding may be an expression of indistinct bedding and differences in original composition. Bed 13 is largely dolomite, which weathers buff and also stands out in bands, which are clearly an expression of the bedding. The banding referred to in beds 12 and 13 is well shown on plate 3, *A*, and also brought out on plate 2, *B*. The dolomite marble is invariably finer-grained than the calcite marble. It is slightly less dense than the dolomite of the Devonian but is otherwise so similar that the two are not easily differentiated. The dolomite included in the lower part of the Mississippian does not contain as many secondary silicates as are commonly found in the older beds of dolomite. No ser-

pentine was observed, and diopside was found only locally, although both of these silicates are abundant in lower beds of dolomite. It could not be definitely determined whether this difference was attributable to a difference in the original composition of the dolomite or to other conditions that controlled the formation of the silicates. The influence of original composition, however, is strongly suggested by the fact that the calcite marble in the lower part of the Leadville limestone does not contain magnesian silicates, which are found in both Mississippian and Devonian dolomite.

The upper 127 to 176 feet of the Leadville limestone (14) is a single bed of medium-grained white marble. This marble is usually massive, as shown in plate 3, *A*, but bedding surfaces are brought out in some places by weathering, as shown in plate 3, *B*. The marble has a well-developed schistosity, called "grain" by quarrymen, parallel to the bedding. This "grain" is very evident in quarrying the marble, and in thin sections it resembles the structure characteristic of schist. Gray chert in thin lenses or discontinuous stringers and in beds as much as 2 feet thick is present locally throughout the formation, but the chert appears to be most abundant in the zone from which the Yule Colorado marble (formerly called Colorado Yule marble) has been quarried. This zone also contains chert or flint in the form of irregular nodules, some of which contain fragments of small cup corals, the only fossils found in the Paleozoic section below the Pennsylvanian beds.

This calcite marble, like that in the lower part of the formation, does not contain either serpentine or diopside. Locally, however, brown andradite garnet replaces the marble at the upper contact. At the head of Yule Creek garnet as much as 30 feet thick is found along the contact, and on the west slope of Treasury Mountain irregular patches of the garnet cross the entire formation.

PENNSYLVANIAN (HERMOSA? FORMATION)

Distribution.—A series of interbedded limestone, shale, and sandstone metamorphosed to marble, hornfels, and quartzite of Pennsylvanian age lies unconformably on the Mississippian. These beds crop out around Treasure Mountain in the form of a crescent open along Yule Creek, where they are cut out by the angular unconformity at the base of the Jurassic from a point near the head of Yule Creek down to the vicinity of the quarry of the Yule Colorado Marble Co. Complete sections are found on Whitehouse Mountain, at the northwest end of the Treasure Mountain dome, and on Treasury Mountain, at the southeast end. Between these two localities along the valley of the Crystal River some of the lower beds have been cut out by the intrusion of granite. These beds are correlated with the

Hermosa formation of southwestern Colorado and are herein called Hermosa (?) formation.[15]

Lithology and detail of section.—The sections found in the area are not well suited for stratigraphic study, owing to the metamorphism of the rocks. The purer limestone, shale, and sandstone can be recognized as marble, hornfels, and quartzite. Intermediate rocks, such as calcareous or shaly sandstone and sandy shale, when indurated look alike and resemble a fine-grained quartzite. The shaly or sandy character of limestone may or may not be evident after alteration. These complications, however, are partly offset by the fact that the indurated beds form excellent and continuous exposures.

The beds definitely identified by fossils as Pennsylvanian consist of thick limestone members interbedded with only fine-grained clastic material; they are overlain by several hundred feet of fine-grained sandstones and shales devoid of limestone and of fossils. These fine-grained sandstones and shales appear to grade into the undoubted Pennsylvanian below and also into the Maroon formation above. The Maroon conglomerate and sandstone strata contain only thin lenticular beds, none of which seem to be either continuous or confined to any particular part of the formation. In the absence of fossils the section is mapped on a lithologic basis. The boundary between the Hermosa (?) and Maroon formations, chosen for convenience of mapping, is the top of the highest thick limestone bed. This arbitrary boundary is not very definite, as the upper limestone beds may be lenticular or may grade into sandy or shaly beds so that given beds cannot be traced continuously for any great distance. The Hermosa (?) as mapped, therefore, is as likely to exclude certain Pennsylvanian beds as it is to include Permian beds.

Measurements were made both on Treasury Mountain and on Whitehouse Mountain, at the southeast and northwest ends of the Treasure Mountain dome, and the results are given below.

Section on north and northeast slopes of Treasury Mountain

Maroon formation.
Hermosa (?) formation: *Feet*
    14. Quartzite, gray, fine-grained. Some beds are shaly__   79
    13. Conglomerate, marbleized limestone, and a few
        quartz pebbles in a sandy limestone matrix_____   45
    12. Quartzite, gray, shaly, much altered_____   12
    11. Conglomerate, marbleized limestone, and a few
        quartz pebbles in a sandy limestone matrix____   12
    10. Quartzite, shaly, sandy hornfels, and a little lime-
        stone. Much altered_____   162

[15] Vanderwilt, J. W., Stratigraphy of Pennsylvanian Hermosa formation in Elk Mountains, Gunnison County, Colo.: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 11, pp. 1668–1677, 1935.

*Section on north and northeast slopes of Treasury Mountain—*Continued

Hermosa (?) formation—Continued.   *Feet*
  9. Conglomerate with white limestone marble pebbles
      1 to 3 inches across in a light-gray limestone mar-
      ble matrix_____   68
  8. Hornfels, sandy, containing much specularite and
      epidote and some tourmaline. Possibly some py-
      rite and chlorite_____   30
  7. Conglomerate, white limestone marble pebbles 1 to
      3 inches across in a light-gray limestone marble
      matrix _____   45
  6. Hornfels, gray to greenish gray, and shaly quartz-
      itic sandstone. Shows much epidote, some gar-
      net, and abundant specularite along joints_____   280
  5. Limestone, gray to black, marbleized, with inter-
      bedded fine-grained sandstone and some shale.
      Some of the limestone is sandy or shaly and some-
      what micaceous. Much epidote along bedding
      planes and joints_____   260
  4. Hornfels, gray, with alternating beds of gray and
      white marbleized limestone. Hornfels sandy in
      places_____   76
  3. Quartzite, dark gray, fine-grained, sandstone, and a
      little hornfels interbedded_____   33
  2. Limestone, white and gray, well marbleized, mostly
      massive, with a few thin beds in part replaced
      by yellow serpentine_____   102
  1. Quartzite, gray green and black, hornfelsic, with
      much garnet and epidote. Upper half contains al-
      ternating beds of recrystallized limestone. Loc-
      ally conglomeratic with angular fragments of
      chert and quartzite_____   24
Leadville limestone.   _____
                                           1,228

Section measured on east face of Whitehouse Mountain

Jurassic quartzite.
Hermosa (?) formation: *Feet*
  (l) Gray marbleized limestone and quartzite in-
      terbedded_____   19
  (k) Conglomerate, pebbles of granite or gneiss
      1 to 3 inches in diameter, chert, and red
      clay in a sandy matrix_____   14
  (j) Hornfels, gray, sandy, grading upward into
      shaly and quartzitic sandstone. All sand
      is fine-grained. Contains (V. S. 336F)
      Chaetetes milleporaceus and *Amplexus?*____   115
  (i) Limestone, gray to white, marbleized; thin-
      bedded, with bedding planes irregular and
      wavy. Some of lower beds are fossilifer-
      ous, showing cross sections of cup corals,
      brachiopods or pelecypods, and crinoid
      stems, which are very difficult to collect.
      Upper 20 feet is shaly_____   180

Section measured on east face of Whitehouse Mountain—Continued

Hermosa (?) formation—Continued.   *Feet*

    (h) Sandstone and shale like (b). Upper 30 feet
        grades upward into a gray marbleized
        limestone _____   100

    (g) Conglomerate, marbleized limestone pebbles
        averaging 1 to 2 inches across in a matrix
        of medium-grained sandstone_____   12

    (f) Quartzite, medium- to fine-grained, gray, 10
        to 20 feet thick, interbedded with hornfels
        of equal thickness_____   122

    (e) Quartzite, gray, fine-grained. Beds well de-
        veloped 6 inches to 4 feet thick, average
        12 to 18 inches. Lower 45 feet is calcare-
        ous and shows some cross-bedding_____   235

    (d) Limestone, gray, marbleized, with irregular
        beds of quartzite or shaly sandstone as
        much as 6 inches thick which constitute 15
        to 25 percent of the unit. The quartzite is
        fine-grained and limy. Contains cup corals
        and other fossils (V. S. 161–0–1), 65 feet
        above base: *Solenomya radiata, Solenomya*
        anodontoides, Clinopistha radiata var. *levis,*
        Cardiomorpha missouriensis, Aviculipecten
        rectilaterarius, Pseudorthoceras knoxense;
        (V. S. 161–0–2), about 20 feet below top;
        *Spirorbis*_____   130

    (c) Hornfels, gray, interbedded with 10 to 20 per-
        cent of limestone in lower half and 50 per-
        cent in upper half_____   161

    (b) Limestone, gray, marbleized, thin-bedded;
        contains 5 to 10 percent of interbedded
        quartzite and hornfels. In the upper 40
        feet sandstone and shale increase to about
        50 percent of the rock_____   208

    (a) Conglomerate; angular blocks 1 to 2 inches
        across of chert and quartzite in a dense
        black hornfelsic quartzite matrix_____   2–20

Leadville limestone.
                                                 1, 298–1, 316

G. H. Girty,[16] who identified the fossils listed above, made the following statement concerning them:

The fauna of the siliceous shale (V. S. 161–0–1) is of a character most disadvantageous for age determination, for the fossils are none too well preserved and represent only pelecypod types, many of which can be identified even generically only upon characters that are not very trustworthy. This is more true of the fauna under consideration than of most pelecypod faunas, for it has been necessary to identify these fossils with types that are relatively little known. In spite of this fact I can hardly doubt that the age of this fauna is Pennsylvanian (possibly Pottsville). This interpretation is to some extent corroborated by the presence of the calcareous specimens (V. S. 161–0–2), especially by the one which contains so many shells of *Spirorbis* * * *, for

---

[16] Personal communication.
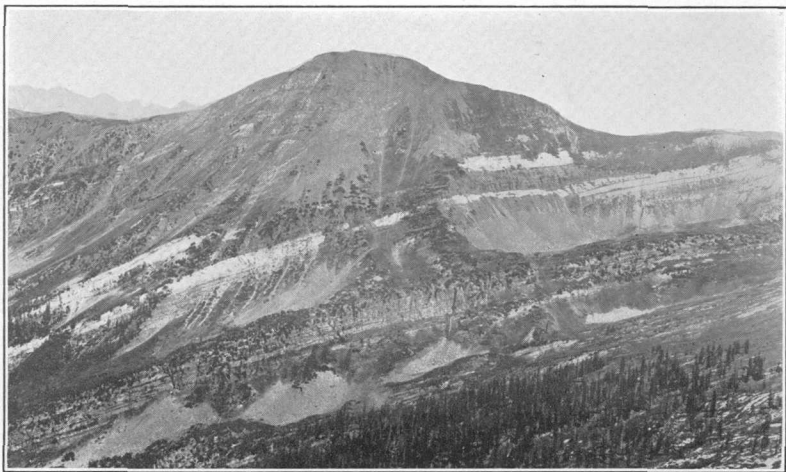
A. PROMINENT WHITE HERMOSA (?) PENNSYLVANIAN CONGLOMERATE CONSISTING OF WELL-ROUNDED LIMESTONE PEBBLES IN A LIMESTONE MATRIX, BOTH OF WHICH ARE WELL MARBLEIZED.

West slope of Crystal Peak east of Bear Basin. The conglomerate forms beds 7 and 9 of the Treasury Mountain section on p. 25.
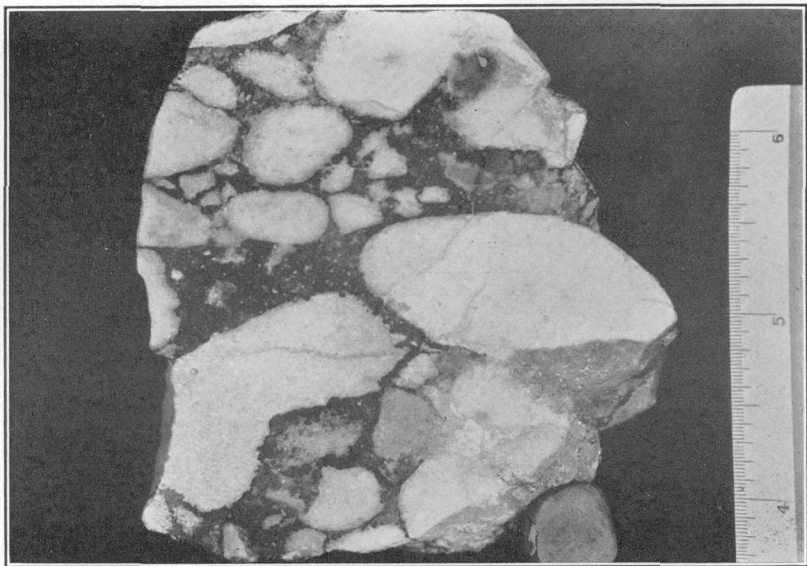
B. LIMESTONE (MARBLE) CONGLOMERATE OF THE HERMOSA (?) FORMATION SHOWN IN *A.*
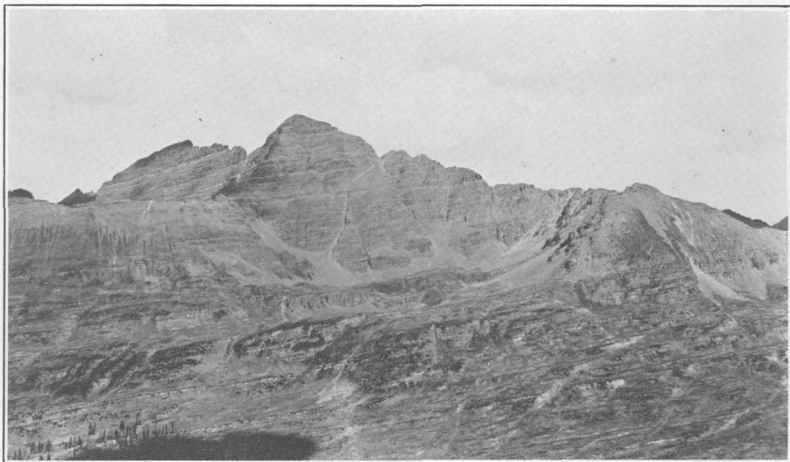
A. TYPICAL EXPOSURE OF UNMETAMORPHOSED MAROON STRATA ON EAST FACE
OF MAROON PEAK.

The relative hardness of sandstone and more shaly beds is expressed by erosion features.
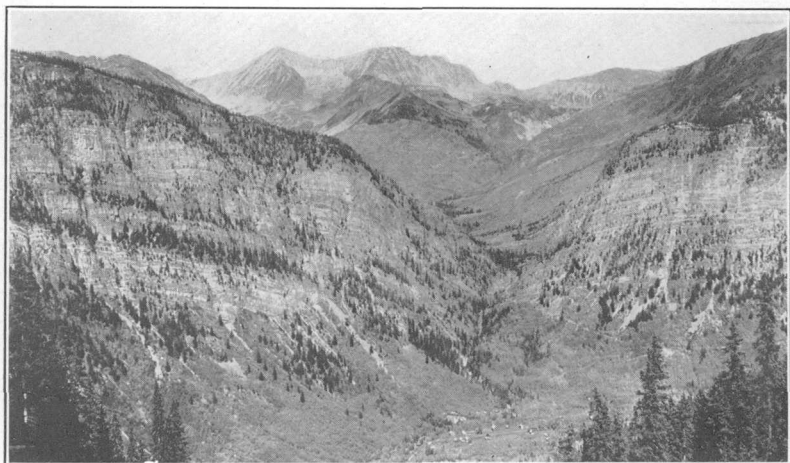
B. TYPICAL EXPOSURE OF METAMORPHOSED MAROON STRATA, LOOKING UP THE
NORTH FORK OF THE CRYSTAL RIVER INTO LEAD KING BASIN.

Sheer cliffs are characteristic where shaly beds have been changed to hornfels.   Cliffs at right (Mineral
Point) and left (east end of Sheep Mountain) are capped by Jurassic rocks.   Town of Crystal in
foreground and Snowmass Mountain in background.

although we find *Spirorbis* in marine faunas these minute worm tubes are especially abundant in rocks of nonmarine origin where they are associated with plant remains indicating an environmental condition that is rare if not wholly unknown in our Mississippian rocks. * * * *Chaetetes milleporaceus* is, so far as known, confined to the Pennsylvanian, and it chiefly occurs in the earlier faunas of that epoch.

These two sections are given in columnar form in figure 2, which shows the limestone beds in the section. The difference in detail of the two sections is largely attributable to lensing of beds and variation along their strike, although a minor part of the difference is also due, no doubt, to the fact that metamorphism has been more intense on Treasury Mountain than on Whitehouse Mountain, making it difficult to recognize either equivalent or similar units.

The conglomerate at the base is consistently present throughout the area and is particularly well developed and exposed in the vicinity of the Yule Colorado marble quarry and on Whitehouse Mountain. It fills depressions 10 to 20 feet in width and depth in the top of the Mississippian (Leadville limestone), making an irregular contact, which is fairly well shown on plate 3, *B*. The thickness ranges from 2 to 20 feet or more, not including a certain thickness added locally in the depressions. The conglomerate consists of angular to subrounded fragments, some of which are 12 inches across but which average less than 3 inches, of chert and fine-grained quartzite in a fine-grained black dense matrix that was originally shale or sandy shale. A similar conglomerate was observed in mine workings in both Aspen and Smuggler Mountains,[17]

FIGURE 2.—Columnar sections of Pennsylvanian beds measured on Whitehouse Mountain (A) and on Treasury Mountain (B). The numbers and letters correspond to those used for detailed descriptions in text (pp. 22–24).

in the Aspen area, at the contact between the Pennsylvanian and older

[17] Vanderwilt, J. W., Revision of structure and stratigraphy and its bearing on the ore deposits of the Aspen district, Pitkin County, Colo.: Econ. Geology, vol. 30, pp. 223–241, 1935.

formations. A conglomerate is also found at this horizon in the Gold Brick district [18] and in the Ouray area [19] (the base of the Molas formation), and according to the descriptions cited it practically matches the conglomerate described here, suggesting similar conditions at the beginning of Pennsylvanian time in these rather widely separated areas.

The several limestones, sandstones, and shales commonly change by gradation from one into another, although well-defined boundaries are also present. Most of the limestones effervesce quite readily with cold dilute hydrochloric acid, but some seem to be dolomitic. The conglomerates of Treasury Mountain (7, 9, and 13) are rather unusual rocks. Two of the beds (7 and 9) are to be seen on the slopes on the south side of North Pole Basin and on the east side of Bear Basin as very conspicuous white bands (see pl. 4, *A*), each of which, as seen from a distance, resembles the Yule Colorado marble (Mississippian). The conglomerate consists of well-rounded pebbles of white marble in a white marble matrix. On fresh fracture the pebbles and matrix do not stand out in great contrast, but on weathered surfaces the pebbles remain white while the matrix turns gray to black, which emphasizes the structure of the rock. (See pl. 4, *B*.) The conglomerates are not continuous; they are thin in the section near Treasury Mountain and apparently lacking in the section from the east face of Whitehouse Mountain.

Age.—The age of the formation based on fossil evidence, according to Girty, is Pennsylvanian (possibly Pottsville). The formation in general is slightly fossiliferous, but few of the fossils are well enough preserved to be reliable indicators. In addition to the fossils listed in the detailed section (pp. 23–24) *Amplexus?* sp. and *Lophophyllum?* sp. were collected at the head of Yule Creek. Fragments of cup corals and brachiopods are fairly common, and an intensive search would undoubtedly yield considerable diagnostic material.

PERMIAN AND PENNSYLVANIAN(?) (MAROON FORMATION)

Distribution.—A series of maroon to red sandstones, grits, and shales, with numerous strata of gray conglomerate, commonly referred to as the "red beds", lie above the Hermosa(?) formation in the Snowmass Mountain area. They are found on the Treasure Mountain dome, where they have the same general areal distribution and structural relations as the underlying beds, and in the northeastern part of the area, east of the Elk Mountain fault. These beds on the Treasure Mountain dome, though not actually continuous in outcrop, without doubt are at the same stratigraphic horizon

---

[18] Crawford, R. D., and Worcester, P. G., Geology and ore deposits of the Gold Brick district, Colo.: Colorado Geol. Survey Bull. 10, pp. 63–64, 1916.

[19] Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc. Proc., vol. 12, no. 6, pp. 161–162, 1930.

as the red strata lying east of the Elk Mountain fault, which are a part of the Maroon formation of the Anthracite and Crested Butte quadrangles. The Maroon as defined in the Anthracite-Crested Butte folio contains some beds included in the Hermosa in this report, but the lower limit as established by Spurr in the Aspen district corresponds to the base of the Maroon described on the Treasure Mountain dome.

In the northeastern part of the area this formation composes the crest of the Elk Mountains between the granodiorite of Snowmass Mountain, to the north, and of the White Mountains, to the south, in the Crested Butte quadrangle only a few miles southeast of this area. These beds occur in continuous exposures beyond the limits of the area to the northeast as far as the Aspen district, about 10 miles distant. To the southwest the Maroon formation is bounded by the Elk Mountain fault, along which the beds have been thrown up into contact with Jurassic and Cretaceous (Dakota? and Mancos) formations. The base of the Maroon is not exposed along the fault, and the beds are closely folded and crushed and in places overturned throughout a zone that is locally over 4,000 feet wide.

Lithologic character and thickness.—The area does not offer a section suitable for detailed measurement or study of the stratigraphy of the Maroon formation. On Treasure Mountain an unknown thickness has been removed along the unconformity, and the beds are altered. In the northeastern part of the area not only are both base and top of the formation absent but no specific horizon can be traced far or correlated with horizons elsewhere. Along the fault the beds are overturned, and in addition they may be duplicated. The best and most continuous exposure of the formation occurs on the west slopes of Maroon Peak (pl. 5, *A*), fully 3,000 feet east of the fault zone, where 4,000 feet of strata, dipping 5°–10° E., appear to lie in normal position. How great a thickness of Maroon beds there may be below these strata is not known. East of Maroon Peak the beds, with an easterly dip, appear to be continuous as far as the Aspen district, 10 miles away. This necessarily represents a great stratigraphic thickness, but the acutal amount was not determined. In the Crested Butte area Eldridge [20] recorded 2,500 feet of the "red beds", but in the northern part of the Snowmass Mountain area, along Copper Creek, I measured only 1,000 feet. As all these beds are missing along Yule Creek under an unconformity in the southern part of the Snowmass Mountain area, it would seem that the "red beds" now found in the Crested Butte area represent a remnant of the original series, which increases in thickness toward Maroon Peak and Aspen, to the north. The thickness of the "red

[20] Eldridge, G. H., Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

beds" in the Aspen district, according to Spurr,[20a] is estimated at 6,600 feet, 2,600 feet of which he called Triassic. However, in Woody Creek, just north of the Aspen district, the "red beds" are about 9,000 feet thick.[21]

On the Treasure Mountain dome the greatest thickness of the Maroon formation occurs in the vicinity of Crystal, where it is about 2,400 feet thick, as exposed along the North Fork of the Crystal River just north of the town. (See pl. 5, *B*.) The full section of the beds does not crop out in a position advantageous for study, and as many lithologic features are much changed by metamorphism, a detailed measurement was not attempted. In general, above the limestone taken as the top of the Hermosa (?) formation the section shows 300 to 400 feet of hornfels, which is very sandy in places and the lower beds of which are like some of the hornfels interbedded with the limestones below. These beds make conspicuous cliffs on the north face of Whitehouse Moutain and are well exposed on the south slope of Sheep Mountain. They are also present on Crystal Mountain but not in a position favorable for study. The upper beds of hornfels contain some medium-grained sand, and this grades upward into medium-grained feldspathic sandstone 200 to 300 feet thick, which in places is conglomeratic. These beds are very well exposed on the north, east, and west slopes of Galena Mountain, along the trail on the South Fork of the Crystal River northeast of Crystal Peak, and along the road just east of Lizard Lake. Upward the medium-grained feldspathic sandstones grade into beds of coarser feldspathic grits and conglomerates 1,500 to 1,800 feet thick. The conglomerate is composed of marbleized limestone, some quartzite, chert, and a few pre-Cambrian pebbles of granite or gneiss 1 to 3 inches across in a matrix of medium- to coarse-grained feldspathic sandstone. In the vicinity of Treasure Mountain the conglomerates are practically confined to the north side of the Crystal River on the south slopes of Mineral Point and Sheep Mountain. Farther south they have been eliminated by the erosion represented in the angular unconformity below the Jurassic.

The Maroon beds are known to change rapidly even in short distances along the strike, and a definite sequence of stratigraphic units has not been recognized. On Copper Creek, only a few miles southeast of the area of this report, in the Crested Butte quadrangle, the following series of red beds assigned to the Maroon in the Anthracite-Crested Butte folio were found overlain by Jurassic sandstone:

[20a] Spurr, J. E., op. cit. (Mon. 31), p. 38.

[21] Johnson, J. H., personal communication.

Section on Copper Creek

Feet

35. Red sandstone, medium- to coarse-grained, feldspathic, micaceous, and cross-bedded. This interval contains beds of conglomerate that are almost evenly spaced and have the following thicknesses: 1–14 feet, 1–10 feet, 2–5 feet, and 9–3 feet. The conglomerates are invariably white to gray and contain pebbles chiefly of limestone, but some of chert quartz and a few of pre-Cambrian granite and gneiss_____ 234
34. Red sandstone, medium-grained_____ 207
33. Conglomerate, white to gray, like bed 35_____ 6
32. Red sandstone, medium-grained_____ 66
31. Conglomerate, like bed 35_____ 2
30. Red sandstone, medium-grained and thin-bedded_____ 35
29. Conglomerate, like bed 35_____ 10
28. Red sandstone, medium-grained and thin-bedded_____ 91
27. Conglomerate, like bed 35_____ 6
26. Red sandstone, fine-grained, mottled with gray, and some shaly beds_____ 84
25. Conglomerate, like bed 35_____ 11
24. Red sandstone, fine-grained, thin-bedded, some beds gray, and micaceous_____ 34
23. Conglomerate, like bed 35_____ 20
22. Red to gray sandstone, fine- to medium-grained, thin to massive bedding, micaceous, and shaly in places___ 202
21. Gray sandstone streaked with red, medium- to fine-grained, containing mica, feldspar, and shaly beds____ 23
20. Gray shale, sandy and micaceous_____ 8
19. Gray sandstone, fine-grained, micaceous, and massive___ 6
18. Gray shale, sandy and micaceous_____ 5
17. Limestone described as top of Hermosa (?) formation in a preceding paragraph.

1, 050

This section probably represents only a small part of the original thickness of the Maroon formation but shows the change upward from finer-grained sandstones and shales into sandstones and conglomerates similar to the sequence described along the valley of the Crystal River.

CORRELATION OF PALEOZOIC FORMATIONS

The Paleozoic sedimentary rocks exposed on the Treasure Mountain dome are surrounded by Cretaceous formations. The Maroon formation east of the Elk Mountain fault forms continuous outcrops to the Aspen district, but outcrops of older Paleozoic formations are 15 to 30 miles distant. A few fossils were found in the Hermosa(?) formation, a few corals in the Leadville, and no fossils in lower formations, so that correlation is limited to lithologic and stratigraphic features. Due allowance must be made for the changes in lithology produced by metamorphism. Original textures and color contrasts have been obliterated, but the original mineral compositions

of quartzite, limestone, and shale are almost unchanged, and dolomites are easily identified by the serpentine and diopside they contain. Everywhere the fundamental character of the section is recognizable, and by matching columnar sections of neighboring areas satisfactory correlations can be made. A correlation of the pre-Pennsylvanian formations has been made thus by Vanderwilt and Fuller,[22] and their chart, revised and enlarged to include columnar sections from Aspen and Leadville, is shown in figure 3. The Hermosa(?) and Maroon formations are not included in the chart, because complete sections of these formations were not available. However, their lithology is very characteristic, and they are tentatively correlated with typical Hermosa and typical Maroon.

Ordinarily the Cambrian quartzite cannot be mistaken easily for any other formation. Owing to metamorphism, however, the Dakota (?) quartzite (Cretaceous), the Parting member of the Chaffee formation (Devonian), the Harding quartzite (Ordovician), and the Entrada sandstone (Jurassic) are all dense quartzites that could be confused in poor outcrops with the Cambrian quartzite. The exposures on Treasure Mountain are excellent, and their correlation as shown in figure 3 is without question.

The Ordovician here as elsewhere in Colorado is recognized by its stratigraphic position above Cambrian quartzite and below the Parting member of the Devonian. The two upper formations, Harding quartzite and Fremont limestone, are not found anywhere north of the Snowmass Mountain area. They are thin formations but very persistent within the area. Kirk[23] has shown the Harding sandstone to be present throughout the region between its type locality, near Canon City, and Cement Creek. Treasure Mountain, about 15 miles north of Cement Creek, is the northernmost place at which the Fremont limestone and Harding sandstone have been recognized.

The base of the Devonian Chaffee formation is well marked by its Parting member, which is one of the best horizon markers in the Paleozoic section in Colorado. The Parting member has in the past been referred both to Ordovician and Devonian age. Kirk[24] recently included it with the Devonian. The Parting is remarkably uniform in thickness, for so thin a member, over relatively large areas. Its rapid changes in lithology along the strike are in marked contrast to the uniformity of other formations and constitute a means for identification. The name "Parting" has been too much associated

[22] Vanderwilt, J. W., and Fuller, H. C., Correlation of Colorado Yule marble and other early Paleozoic formations on Yule Creek, Gunnison County, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 7, pp. 439–464, 1935.

[23] Kirk, Edwin, The Harding sandstone of Colorado: Am. Jour. Sci., 5th ser., vol. 20, pp. 456–466, 1930.

[24] Kirk, Edwin, The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, pp. 222–240, 1931.
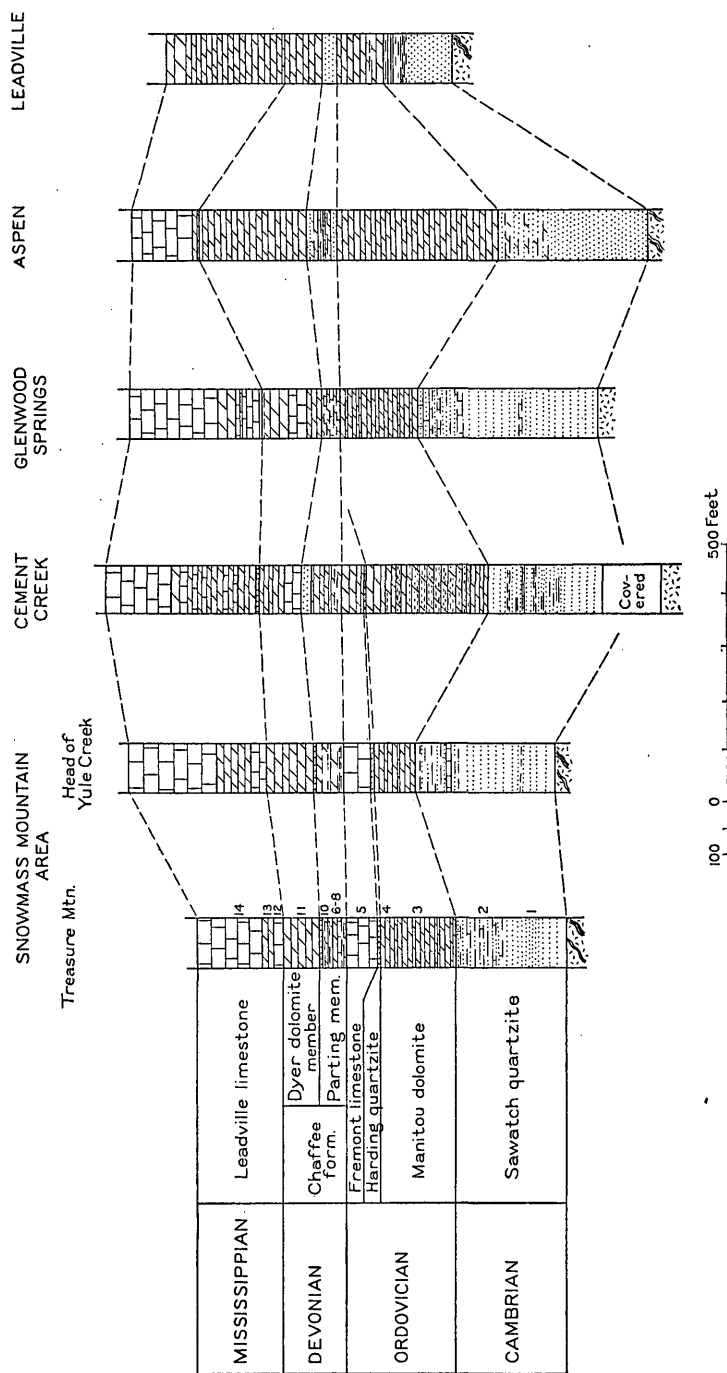
FIGURE 3.—Correlation of pre-Pennsylvanian rocks found on Treasure Mountain dome with those of neighboring areas. The numbers correspond to those used for detailed descriptions in text (pp. 13–20).

with quartzite, particularly in the Leadville district, where, as Loughlin [25] has pointed out, the shale and limestone components have attracted little or no attention. The prevailing notion that the Parting must be largely quartzite has led in places to mistaking the Harding sandstone as well as other sandstone beds for the Parting. The Parting member need not be confused with any other member if its true lithologic character is considered. The description of nearly every section from central Colorado clearly shows that the Parting is present but not everywhere primarily quartzite; in the sections that I examined in the field shale and limestone were generally more prominent than the published descriptions would lead one to believe. The importance of this member has been pointed out by many writers, but even so it seems to be underemphasized rather than overemphasized. The Parting and Dyer dolomite members are readily matched with similar members in other areas, as shown in figure 3.

The Mississippian (Leadville) limestone is readily recognized wherever it is found in association with the overlying shaly limestones of the Pennsylvanian Hermosa (?) formation. The base of the formation is less distinct, but the sandy beds used for correlation occur without much question at the same horizon in the areas where they could be located.

The correlation of Pennsylvanian rocks with the Hermosa formation of southwestern Colorado is based on fossil evidence and lithologic similarity. The red beds are continuous with the typical Maroon formation in the type area, on Maroon Creek and in the Aspen district. The Maroon formation was formerly regarded as Pennsylvanian because of its fauna, but more recently David White, in studying the flora along the Colorado River at Minturn and at Red Cliff, has concluded that the red beds are chiefly if not wholly Permian. The Permian beds as defined by White are continuous with the Maroon in the Aspen district.

The gradation from Pennsylvanian to Permian formations in this area seems apparent from the descriptions of the sections. In the Aspen area [26] the base of the Maroon formation is marked by a gypsum bed that crops out along the Roaring Fork Valley and on the west and south flanks of the White River Plateau. The gypsum is present about 12 miles northwest of Treasure Mountain on the west side of Mount Sopris, and a little gypsum was found in the saddle between Snowmass and Hagerman Peaks, where the beds are much disturbed and altered near the contact of the granodiorite. On Treasure Mountain it is not present, nor could it be found in areas to the south or southeast.

[25] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: Geol. Survey Prof. Paper 148, pp. 30, 31, 1927.

[26] Spurr, J. E., Geology of the Aspen mining district, Colo.: Geol. Survey Mon. 31, pp. 33–37, 1898.
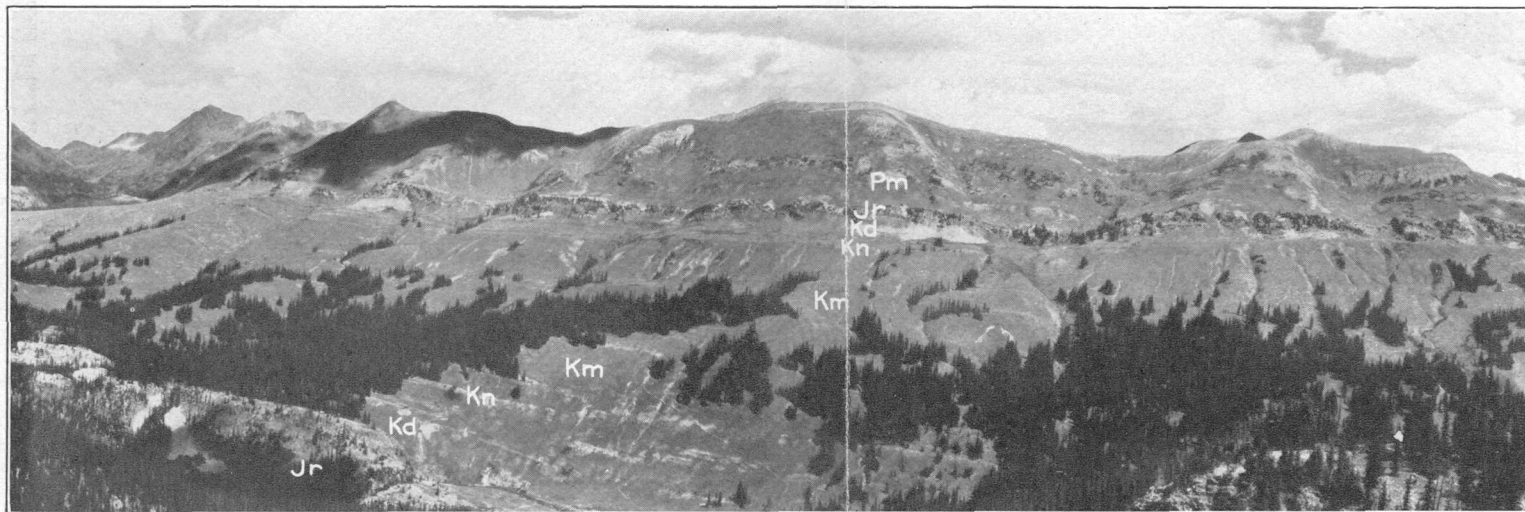
A. JURASSIC ROCKS AND CRETACEOUS DAKOTA (?) QUARTZITE AND MANCOS SHALE OVERTURNED ALONG ELK MOUNTAIN FAULT AND IN THEIR NORMAL POSITION ALONG THE CRYSTAL RIVER ON THE NORTHEAST FLANK OF TREASURE MOUNTAIN DOME.

View northeast of Galena Mountain.   Triangulation point Crystal (altitude, 12,492 feet) is on high point near center of panorama.   Km, Mancos shale; Kn, limestone of Niobrara age in the Mancos; Kd, Dakota (?) quartzite; Jr, Jurassic rocks; Pm, Maroon beds.
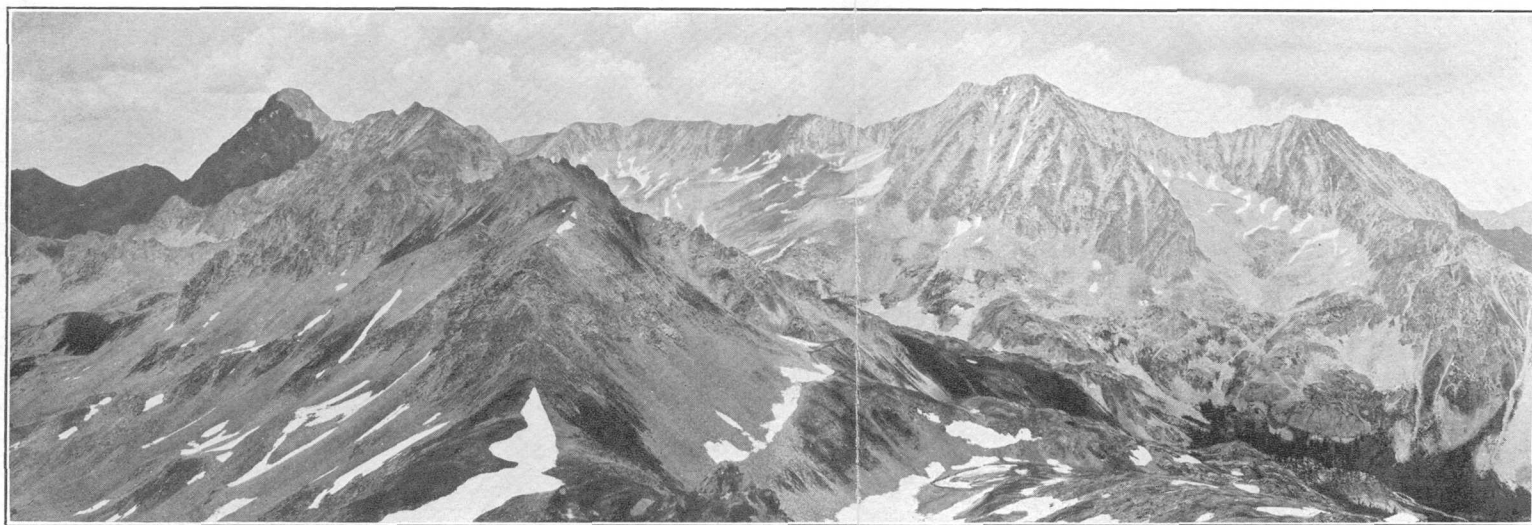
B. RUGGED TOPOGRAPHY AND HIGH RELIEF FORMED BY RESISTANCE TO EROSION OF ROCK OF THE SNOWMASS MOUNTAIN INTRUSION.

Snowmass Mountain is high peak at right.   High peak at left is Capital Peak, which is north of the limits of the area.   View from the west.

MESOZOIC SEDIMENTARY ROCKS

JURASSIC FORMATIONS

GENERAL DESCRIPTION

The Mesozoic sedimentary rocks in the Snowmass Mountain area include four formations—the Entrada sandstone and Morrison formation, of Upper Jurassic age, and the Dakota(?) quartzite and Mancos shale, of Upper Cretaceous age. The Dolores formation (Triassic and Jurassic?) of nearby regions has not been recognized in the Snowmass area, though it is present near Aspen and along the lower part of the Crystal River.

The Entrada sandstone, the basal formation of the Mesozoic of the general region, is present in the area northwest of the Snowmass area along the Crystal River, and it is present also toward the east, in the vicinity of Aspen. It is not known to occur in the area to the south and west along the Gunnison River. To the west for many miles Tertiary strata cover the horizon of the Entrada, and its presence or absence is not known. A somewhat similar discontinuous sandstone forms the basal part of the Morrison formation at many places in the general region and is particularly difficult to separate from the Entrada where both are more or less metamorphosed. It is possible that in the Snowmass area only the basal sandstone of the Morrison is present, though it is more probable that the two sandstones occur and that they have been confused. The zone of quartzite that lies across the beveled edges of the Paleozoic strata contains quartz grains of two sizes so characteristic of the Entrada in other areas, and on this evidence it is assignable to the Entrada, although Morrison sandstone may be associated with it in places. This sandstone zone and the overlying Mesozoic beds crop out in a continuous band around the Treasure Mountain dome. These formations are also found in an overturned position along the west side of the Elk Mountain fault, where the section between the lower part of the Mancos shale and the Maroon formation is essentially complete except for local squeezing and minor faulting. (See pls. 1 and 6, A.)

ENTRADA SANDSTONE

Distribution.—The sandstone zone that in adjacent regions is known to include Entrada sandstone and the immediately overlying Morrison formation was until recently commonly included under the name †"Gunnison formation." [27] The general distribution of the

---

[27] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

entire Jurassic sequence is briefly outlined above. Locally the Snow-mass Mountain intrusion has cut across the Elk Mountain fault zone and has eliminated the Jurassic (see pl. 1), which, however, continues along the fault on the northwest side of the intrusion for several miles beyond the limits of this area. To the south, south-east of the divide north of Mount Belleview, the Jurassic rocks have been cut out under a thrust surface of the fault.

The most accessible sections that probably include both the En-trada sandstone and the Morrison formation are (1) just northwest of Lizard Lake on the road from Marble to Crystal and (2) along the trolley track about half a mile northwest of the Yule Colorado marble quarry. Good exposures also occur along the trail from Crystal to Lead King Basin and just below or northwest of Scho-field Park. The Entrada sandstone as recognized in the Snowmass Mountain area may include some areas of sandstone of Morrison age.

Lithologic character and thickness.—The Entrada sandstone, which is normally composed of well-sorted white quartz sand, re-sembles other sandstones of the Jurassic in general appearance. Where exposures are sufficiently good it can be recognized easily. The Entrada of western Colorado and eastern Utah is distinguish-able from other sandstones of the Jurassic by the fact that in places some layers of the rock contain grains of two sizes.[28] The larger grains are subangular to well rounded, have frosted surfaces, and are commonly ·from 25 to 28 millimeters in maximum dimension. These large grains in any particular specimen are three to five times as large as the smaller ones. The two sizes of grains are not present in every layer but can usually be found on any good outcrop and afford a reliable means of identifying this sandstone, which other-wise resembles sandstones found at higher horizons in the Jurassic as well as some of those in older and younger formations. This character of two sizes of grains has been found at every exposure examined in the Snowmass area, and it supports the identity of the Entrada sandstone. On the Treasure Mountain dome the normal sandstone has been metamorphosed to a dense quartzite. The quartzite, 15 to 45 feet thick, is not conspicuous and resembles other quartzites except for the presence of grains of two sizes.

Age and correlation.—The Entrada sandstone and the immediately overlying Morrison formation compose the †Gunnison formation of the Anthracite-Crested Butte folio. Recent regional stratigraphic studies [29] have resulted in identifying the Entrada sandstone of south-eastern Utah over considerable areas in western Colorado and in Gun-nison County. Because of the thinness of the whole zone of sand-

[28] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., Correlation of the Jurassic forma-tions of parts of Utah, Arizona, New Mexico, and Colorado: Geol. Survey Prof. Paper 183, p. 7, 1936.

[29] Idem, pp. 16–21, 23, 26–28.

stone at the base of the Mesozoic, the sandstone has not been separated from the Morrison formation in mapping, though it is deemed worth while to recognize the probable presence of the Entrada in the sequence of rocks of this area.

The Entrada sandstone at its type locality in eastern Utah lies between formations that carry marine invertebrate faunas of Upper Jurassic age [30] and is therefore definitely assigned to the Upper Jurassic. There is no reason to doubt the Jurassic age of the Entrada sandstone of the Snowmass area, and it is so assigned.

MORRISON FORMATION

Lithologic character and thickness.—The Upper Jurassic Morrison formation consists of variegated shales, interbedded sandstones, and some limestones. It has a very characteristic development over large areas and when taken in its entirety need not be confused with any other formation. Different parts of the formation, however, vary in their development and in the persistency and thickness of individual beds and members, so that correlation of different members must be attempted with caution. Throughout the Elk Mountains the variations within the formation are less than they are in the western part of the State, and for this reason satisfactory correlation of exposures is not difficult.

A complete section suitable for detailed measurement was not found within the Snowmass area, but an excellent section of the Morrison formation and the underlying Entrada sandstone on the divide on the north side of Copper Creek in the Crested Butte quadrangle, only a few miles to the southeast, was studied. The section is given in detail not because individual strata are considered important but to bring out the composition of the formation.

The formation is divided into two lithologic units, as indicated below by 1 and 2, each of which is readily recognizable throughout the Snowmass Mountain area. It is underlain by Permian "red beds" and overlain by Dakota(?) quartzite.

Section measured on the divide on the north side of Copper Creek east of Gothic, Crested Butte quadrangle

Morrison formation: *Feet*

2. Shale, green, maroon, and gray variegated. Six lenses of gray limestone 2 to 6 inches thick_____ 67

Sandstone, fine-grained, gray, with some interbedded shale _____ 14

Shale, maroon to yellow_____ 11

Sandstone, gray to red, fine-grained_____ 8

Shale, greenish gray and gray to buff_____ 11

Sandstone, fine-grained, gray_____ 12

[30] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., op. cit., pp. 7, 8.

Section measured on the divide on the north side of Copper Creek east of Gothic, Crested Butte quadrangle—Continued

Morrison formation—Continued.   *Feet*

Shale, maroon and green, with red sandstone interbedded _____ 24

Sandstone, gray, fine-grained_____ 13

Shale, red to gray and green; upper part sandy_____ 35

Shale, gray, sandy_____ 16

Shale, calcareous, gray, alternating with beds of sandstone and some limestone_____ 45

Limestone, gray, dolomitic_____ 3

Shale, gray _____ 9

Limestone, gray, dolomitic_____ 5

Shale, gray to red, calcareous, with thin beds of limestone_____ 19

Limestone, gray_____ 12

Shale, gray to red, calcareous_____ 5

Limestone, dolomitic, gray mottled with red_____ 4

Shale, calcareous, gray, in places mottled red_____ 12

Sandstone, calcareous, gray, fine-grained, well bedded__ 27

1. Limestone, gray, dense, in beds 2 to 14 inches thick; 10 feet of dolomite at base_____ 30

Sandstone, calcareous, gray, fine-grained_____ 5

Shale, sandy, green to brown_____ 12

Entrada sandstone: Sandstone, brown to gray, fine-grained, well bedded, upper part calcareous and slightly friable_____ 30

Permian red beds (Maroon formation).

                                    438

The limestone unit 1 varies in composition and thickness but seems to be widespread in its occurrence. On Copper Creek the limestone is relatively pure and thick. In the Snowmass Mountain area this unit ranges from 15 to 30 feet in thickness and contains much interbedded shale, but although the relative proportion of limestone to shale varies greatly, some limestone is present throughout the Snowmass Mountain area. The limestone very commonly contains fossil algae in some of its beds and in a few places contains poorly preserved fresh-water fossils (*Unio?*). Fossil algae are not considered reliable for correlation over long distances, but in this area they were found useful, as they are consistently present and have not been found at any other horizon.

Unit 2, above the limestone, is largely shale and as a unit is readily recognized by its thickness and its variegated colors of green, red, and maroon. The limestones and sandstones found in the shale are lenticular; the lenses are not confined to any one stratum nor are they better developed at one horizon than at another.

Along the Elk Mountain fault within the area studied these two lithologic units of the Morrison are well exposed and normal in their development except, of course, that the formation is overturned, so that the shale sequence 2 lies below the limestone unit 1.

On the Treasure Mountain dome the Morrison formation has been metamorphosed. Instead of limestone there is white marble, and instead of partly covered slopes of variegated shales there are bold cliffs of gray to pale-green hornfels. In spite of these changes the two units are very good horizon markers. The marble zone (unit 1) is also characteristic, and when associated with the bed of Entrada quartzite, below, it cannot be confused easily with any other unit either in younger or older beds. The upper unit (2) of gray to pale-green hornfels is no less characteristic than the variegated shales it represents. Beds of similar hornfels are found both in the Pennsylvanian and in the Permian, but they are thin in contrast to the hornfels of the Morrison formation.

Age and correlation.—The Morrison formation composes the upper and principal part of the †Gunnison formation of the Anthracite-Crested Butte folio. The work of recent years by several geologists, chiefly by A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., has resulted in identifying the Morrison formation over large areas west of the Front Range in Colorado, though its type locality is near the town of Morrison, on the east side of the Front Range. The formation has also been delimited throughout much territory in northwestern New Mexico and southeastern Utah.

The age of the Morrison formation is now generally accepted as Upper Jurassic.

CRETACEOUS FORMATIONS

DAKOTA (?) QUARTZITE

Distribution.—A thick series of quartzite beds rests on the Morrison formation (Upper Jurassic) and is in turn overlain by the black Mancos shale. The quartzite crops out parallel to the Morrison formation around the Treasure Mountain dome and along the Elk Mountain fault. The most accessible exposure occurs along the road from Marble to Crystal. However, many excellent outcrops occur in numerous places along both Yule Creek and the Crystal River. The quartzite occurs at the horizon of the Dakota sandstone to the east, and for that reason it is here tentatively called Dakota (?) quartzite.

Lithology and thickness.—The Dakota (?) quartzite consists largely of relatively pure fine-grained quartzite with shale partings and some shaly beds in places. On the divide on the north side of Copper Creek, the Dakota (?) quartzite is 205 feet thick. The distribution of the shale in the section on Copper Creek is shown in the following section:

Section of Dakota (?) quartzite on Copper Creek, Crested Butte quadrangle

Feet

Quartzite, fine-grained, light gray, usually stained pale brown.
    Well-developed bedding 2 to 12 inches thick_____ 49
Shale, sandy, gray_____ 11
Quartzite, as above_____ 13
Shale, sandy, gray_____ 5
Quartzite, as above_____ 3
Shale, sandy, gray_____ 18
Quartzite, as above_____ 7
Shale, sandy, gray_____ 4
Quartzite, as above_____ 95
                                                           ———
                                                           205

At the base of the formation is a characteristic conglomerate ranging in thickness from 4 feet to the vanishing point, composed of well-rounded pebbles of white, gray, black, yellow, and red quartz or chert. The pebbles average a quarter of an inch across and are set in a fine-grained matrix of quartz sand. This conglomerate proved very useful in recognizing the base of the Cretaceous quartzite in the Snowmass Mountain area.

Near the head of Yule Creek and in the vicinity of the quarry of the Yule Colorado Marble Co., where this quartzite is best exposed, it is 160 feet thick.

The basal conglomerate is not absolutely continuous but is so persistent as to constitute a very convenient marker of the base of the Dakota (?) quartzite. In one place it was noted about 5 feet above the actual base of the quartzite. The lithology of the quartzite is uniform, and the shale, which is concentrated in the central part of the formation, is appreciably less than in the section on Copper Creek. In places shale beds are almost entirely lacking, but some shale partings are invariably present at irregular intervals throughout the formation. As a rule the upper few feet of the quartzite is shaly, and a few thin beds of quartzite occur in the Mancos shale several feet above its base; so the change from Dakota (?) quartzite to Mancos shale is gradational through a zone ranging from 2 to 10 feet in thickness.

MANCOS SHALE

DISTRIBUTION

A great thickness of dark-gray to black shale overlies the Dakota (?) quartzite. This shale surrounds the Treasure Mountain dome and also occupies the area between the dome and the Elk Mountain fault. To the north and east it is cut off by the intrusion of Snowmass Mountain and the Elk Mountain fault, but to the west and south it extends for many miles beyond the limits of the area. The upper part of the Mancos shale is not found within this area,

although it occurs only a few miles northwest of Marble, on the west side of Carbonate Creek, and in the Anthracite quadrangle, to the southwest.

The Mancos shale is a uniform dark-gray to black shale that readily weathers to clay. Except for a single bed of limestone of Niobrara age there are no lithologic subdivisions that can be mapped. Eldridge [31] gave 2,800 feet as the thickness of this formation immediately south of Mount Baldy, in the southern part of the area, and recognized in the lower part two members, which he called Benton shale and Niobrara limestone. On the north slope of Mount Baldy the lower 2,000 feet of the Mancos shale is present, but elsewhere within the area the thickness is less, the upper part having been eroded.

Lower shale member.—The lower shale member of the Mancos shale occupies the interval above the Dakota (?) quartzite and below the limestone member and is believed to be in part the equivalent of the Carlile shale east of the Front Range. This member is 200 to 500 feet thick and in the Snowmass area is slightly less calcareous and more siliceous but nevertheless lithologically similar to the shales above the limestone member. The lower 40 to 60 feet around the Treasure Mountain dome has been metamorphosed slightly and as a result is more massive and resistant to weathering than the overlying shale. The indurated shale forms conspicuous ledges, which upon weathering turn grayish and superficially resemble the limestone member. These beds are also present with the overturned beds along the Elk Mountain fault. Along the fault the beds are unaltered, and the lower part of the shales is noticeably more siliceous than the upper part, which is rather carbonaceous in places. The lower shales are less calcareous than the shales found above the limestone member.

Limestone member.—The limestone member of the Mancos shale as here mapped is a characteristic bed and is of economic importance as well. Reeside visited the area in 1930 and collected fossils from the limestone and from the shale below the limestone on the east side of Schofield Park. His identifications and remarks follow:

15398. Slope northeast of Schofield Park, limestone 500 feet above the Dakota (?):

    Globigerina sp.

    Ostrea congesta Conrad.

    Inoceramus deformis Meek.

This fauna is widespread in the lower part of the Niobrara and its equivalents.

---

[31] Eldridge, G. H., Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

15400. A few hundred feet south of the Hercules Ajax mine, Schofield Park, shale 400 feet above Dakota (?):

> Inoceramus fragilis Hall and Meek.
> Scaphites warreni Meek and Hayden.
> Prionocyclus wyomingensis Meek.

This fauna is widespread in the upper part of the Carlile and its equivalents. We found nothing to show the upper limit stratigraphically of the beds above the limestone and cannot say how much of the Mancos shale they represent. It seems possible that beds of Montana age may be present on the hillside that we visited.

The limestone member is 20 to 40 feet thick and consists of limestone beds 6 to 12 inches thick with interbedded shale. The limestone is gray, and some of the strata contain numerous fragments of *Inoceramus deformis*. A few nearly complete specimens of these fossils were found, but they are not common. The limestone, though relatively thin, is easily traced. Even on well-covered slopes its approximate position is usually marked by the characteristic slabs of limestone that formed as strata broke up through weathering.

Within the area the limestone has been locally called the "Lead King lime", probably because it marks the ore zone in the Lead King mine, in Lead King Basin. The term has also been applied by prospectors to the indurated lower part of the shale member, probably because the true relations were not recognized.

ALTERATION

The Cretaceous shales around the Treasure Mountain dome are not so intensely altered as the beds below the Dakota (?) quartzite. The shale is not changed to a hornfels, like the Jurassic shales just below the Dakota (?) quartzite, nor does it contain contact-metamorphic minerals, such as those found in the older formations. However, it is sufficiently indurated to make fairly good road material. In the southern part of the area the shales are indurated to a siliceous slate with a blocky fracture (see pl. 7, *A*); the unaltered shale readily disintegrates to clay that is very gummy and sticky when wet. In the northern part of the area the degree of induration is much less; the greater degree of alteration represented in plate 7, *A*, is believed to be due to the intrusions that occur in the Ruby Range, not far to the south.

AGE AND CORRELATION

The age of the black shales has been long established as Cretaceous on fossil evidence, and as the shales form continuous outcrops into the Anthracite quadrangle there is no problem of correlation.

TERTIARY IGNEOUS ROCKS

The Tertiary igneous rocks comprise the granodiorite of the Snowmass Mountain stock, only a part of which lies within the area,

granite of the Treasure Mountain stock, and dikes and sills of intermediate composition. These igneous rocks have not been described previously, but the rock of Snowmass Mountain is similar to the rock of White Rock Mountain, which lies to the southeast in the northern part of the Crested Butte quadrangle, and is probably related to it. White Rock Mountain has been described as diorite, by Cross [32] and much later as granodiorite by Knopf.[33] Some of the dikes and sills are continuous with Cross' group of "porphyrites" of the laccoliths, dikes, and sills in the Anthracite quadrangle. The granite found on Treasure Mountain has not been described and, so far as could be ascertained, is limited to this one area.

Both granodiorite and granite are younger than the series of dikes and sills in the southeastern part of the area, which, though numerous, are small individually and in total volume.

Each stock, as well as the group of dikes and sills, occurs as a unit without apparent direct relation to the other, and each stock and the dikes as a group are described separately.

DIKES AND SILLS

Gabbro porphyry, quartz monzonite porphyry, and lamprophyric rock are represented in the group of dikes and sills, most of which are confined to a zone in the southeastern part of the area. There are also a few dikes and dikelike apophyses related to the stocks, and these will be included in the description of the stocks. The only other dike outside the main zone is a dike of gabbro on Meadow Mountain, in the northwestern part of the area. Rock mineralogically similar to this gabbro is not found in the main zone of the dikes and sills to the southeast.

GABBRO PORPHYRY

Character.—The gabbro porphyry is a dark to almost black rock with chlorite and many small inconspicuous striated feldspar phenocrysts. The plagioclase crystals (Ab_4An_6) are 2 to 3 millimeters across and are partly replaced by calcite, which is also abundant throughout the groundmass. The groundmass is well crystallized and consists chiefly of laths of labradorite with some magnetite, 0.2 by 0.6 millimeter. The magnetite grains are commonly surrounded by calcite and shreds of secondary biotite. The chlorite, of the variety antigorite, is very pale green to colorless, showing either very weak or no pleochroism, and appears to replace both calcite and the secondary quartz. Primary ferromagnesian

[32] Cross, Whitman, Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), 1894.

[33] Knopf, Adolph, Recent developments in the Aspen district, Colo.: Geol. Survey Bull. 785, pp. 11–12, 1926.

minerals are lacking. Some quartz and scattered grains of pyrite are present.

Distribution.—Gabbro porphyry was found only on Meadow Mountain and to the west on Arkansas Mountain in an isolated area, so that its relation to the other dikes is not clear. The dike is discontinuous and was either faulted after intrusion or else the magma followed an irregular fracture. The outcrops are inconspicuous in the black shale, and the dike may extend farther west on Arkansas Mountain than is shown on the map.

QUARTZ MONZONITE PORPHYRY

Character.—The quartz monzonite dikes are porphyries; they can be divided into three groups—(1) a nearly white felsite showing only phenocrysts of quartz with very inconspicuous feldspars; (2) a gray rock with numerous phenocrysts of white feldspar 3 to 5 millimeters across in which quartz phenocrysts may or may not be present; and (3) a gray rock like that in the second group, but with conspicuous orthoclase phenocrysts 20 to 40 millimeters across spaced at intervals of 2 to 6 inches through the rock, which is lithologically like the Lincoln porphyry in the Mosquito Range.

Under the microscope the felsite and the finer gray rock show quartz and orthoclase in the groundmass and phenocrysts of plagioclase too much sericitized or replaced by calcite for satisfactory identification. The coarser variety is also altered, but in one section plagioclase ($Ab_{65}An_{35}$) was identified. The quartz grains are rounded, and some show halos. The large orthoclase crystals show only little alteration and contain numerous inclusions of quartz and plagioclase with some titanite and possibly hornblende. Chlorite is abundant throughout the rock and has largely replaced the biotite. Magnetite is not abundant, but its scarcity may be due to alteration, as leucoxene is common. Some pyrite is generally present.

Distribution.—The quartz monzonite dikes and sills are concentrated in the southeastern part of the area in a zone which trends northeastward. The porphyritic felsite on Mount Belleview is a small stocklike body that has bleached and indurated the Mancos shale, and in places in the southeastern part of the mass it is highly brecciated. The other occurrences are in the sills on Yule and Rock Creeks and, outside the main zone of dikes and sills, on Meadow Mountain, in the northern part of the area. The gray porphyritic rock with medium-sized phenocrysts occurs chiefly as sills and is confined mostly to the vicinity of Emerald Lake and the western slope of Mount Belleview. The coarser porphyritic rock with conspicuously large orthoclase phenocrysts occurs mostly in dikes that strike northeastward, parallel with the main zones of dikes and sills. The mass north of Mount Belleview shows some bleaching of the shales

along the contact zone, which is nearly vertical wherever exposed, and may therefore be a small stock. Quartz and feldspar crystals are well developed in a large sill east of Snowmass Creek, northeast of the limits of this area, but the sill is not known to occur farther to the east or north on the west side of the Sawatch Range. To the south and southeast the laccoliths in the Anthracite and Crested Butte quadrangles contain similar rocks.

LAMPROPHYRIC ROCKS

The dikes of lamprophyric rock are not numerous, and they are generally small. They range in width from 2 to 8 feet and make only inconspicuous outcrops that cannot be traced far along the strike. The lamprophyric rocks in neighboring areas have not been described. In the Anthracite and Crested Butte quadrangles certain facies of the "porphyrite" or of the dike rocks of the Ruby Range as described by Cross [34] may be the equivalent of the lamprophyres of this report. In the Aspen district, to the northeast, a sill described by Knopf [35] as diorite porphyry has a groundmass of quartz and albite and may be related to the lamprophyric rocks.

Character.—The lamprophyric rocks are uniformly fine-grained, are dark gray to black, and may or may not show phenocrysts. The phenocrysts are augite, hornblende, biotite, in some places feldspar, and more rarely quartz. All these rocks show evidence of alteration, and pyrite and calcite are common both in the lamprophyric rocks that appear least altered and in those that are bleached to a greenish gray. Alteration is not always apparent in hand specimens, but examination of thin sections shows that on the whole the lamprophyric rocks are more altered than the dikes of quartz monzonite.

In thin sections of the less altered lamprophyres oligoclase, augite, quartz, magnetite, hornblende, biotite, and some titanite and apatite were observed, together with such alteration products as calcite, pyrite, chlorite, biotite, epidote, augite, colorless garnet, dark-brown tourmaline, and possibly quartz. Colorless, nonpleochroic augite crystals 1 to 2 millimeters across are the most common phenocrysts, and pale-brown hornblende and biotite are next in order. The feldspar and quartz are generally confined to the groundmass, but plagioclase phenocrysts are rather common in a few places, although they are too much replaced by calcite to permit identification. A single quartz phenocryst was observed in one thin section. The groundmass consists of small laths of oligoclase with some interstitial quartz and is less altered than the phenocrysts. The amount of interstitial quartz was estimated at less than 5 percent, but it is not certain that all this quartz is primary; quartz in veinlets and lenticles is present. The

---

[34] Cross, Whitman, op. cit. (Folio 9).
[35] Knopf, Adolph, op. cit. (Bull. 785), pp. 7–8.

oligoclase shows albite twinning, and its maximum index of refraction is 1.544, which indicates a composition of about $Ab_{85}An_{15}$. The magnetite is present in small anhedral grains throughout the groundmass. Titanite and apatite were not found in any of the thin sections examined.

This rock has been classified as lamprophyric because in mineral composition it is close to lamprophyre. The sodic plagioclase and small amounts of quartz suggest a composition related to that of bostonite. However, the abundance of ferromagnesian minerals would seem to indicate a closer affinity to lamprophyre.

Alteration.—Calcite, chlorite, and pyrite were present in every thin section examined. Some of the calcite is in veinlets, but more generally it is disseminated through the rock, and in places it is so abundant that weathered surfaces of the rock show characteristic pits, owing to differential weathering. The chlorite is felted, is pale green to colorless, and is only slightly pleochroic, if at all; it partly or completely replaces the ferromagnesian minerals and to some extent replaces calcite. The pyrite occurs in euhedral grains scattered through the rock and does not show any relation to magnetite or other minerals that it may have replaced. In those places where epidote, garnet, and tourmaline are abundant in the area these minerals have also formed in the dikes, and locally they have completely replaced the primary minerals. Biotite regarded as secondary occurs locally in flakes and stringers in places in the groundmass, as sericite commonly occurs in feldspar. Where tourmaline and garnet are well developed augite may occur in an association strongly suggesting its secondary origin.

Relative age.—The dikes, with the possible exception of the gabbro porphyry dike, are the oldest Tertiary igneous rocks in the area. All the quartz monzonite and lamprophyric dikes have been metamorphosed by the Treasure Mountain stock of granite, and a dike of quartz monzonite with large orthoclase phenocrysts was found to be cut by the Snowmass Mountain intrusion and to be enclosed in it.

On the west slope of Mount Belleview a lamprophyric dike was found to cut a quartz monzonite porphyry sill containing large orthoclase phenocrysts. The sill in turn cuts quartz monzonite porphyry that is free from large orthoclase crystals, and the lamprophyric dike also cuts the stocklike mass of porphyritic felsite. Other age relations were not observed.

CORRELATION

The quartz monzonite porphyry with large orthoclase phenocrysts is continuous to the south in two places with rock described by Cross [36] that is common in several laccolithic intrusions occurring in

---

[36] Cross, Whitman, op. cit. (Folio 9).

the West Elk Mountains. A porphyritic felsite sill at the head of the Slate River in the Anthracite quadrangle continues into the head of Rock Creek. Several of the large laccoliths, including Gothic Mountain, only about 5 miles south of the main zone of dikes, are described by Cross as follows:

The rocks here called porphyrite are distinctly porphyritic rocks, exhibiting many white plagioclase crystals, with quartz, biotite, and occasionally hornblende, and, in most cases, very large glassy crystals of orthoclase, often 2 to 3 inches in diameter.

Cross also implies that the "porphyrites" show a sequence of intrusion, which, however, he does not discuss in detail.

In the Mosquito Range the Lincoln porphyry is quartz monzonite with large feldspar phenocrysts that lithologically and mineralogically resembles the coarser quartz monzonite porphyry referred to above, and on this basis they are tentatively correlated, although it must be remembered that the two areas are separated by a distance of nearly 40 miles, in which the rock is not known to occur.

GRANITE OF TREASURE MOUNTAIN STOCK

Treasure Mountain, in the southwestern part of the area, is a structural dome dissected by erosion so as to expose the structure in a striking manner. Holmes [37] briefly described the structural features of Treasure Mountain and on his geologic map showed its intrusive core. The granite is exposed both along the Crystal River on the north flank of the dome and in Yule Creek on the south flank not far from the central part of the dome. It is surrounded by sedimentary beds that separate it from all the other igneous rocks. It is the only post-Cretaceous granite known in the Elk and West Elk Mountains, which abound in intrusions of dioritic and monzonitic rocks.

GENERAL CHARACTER

The granite is a massive pale-pink rock that appears nearly white in outcrop, especially from a distance. In hand specimens the pink color is most pronounced in the well-crystallized porphyry facies, owing to the fact that in that facies the groundmass is more nearly white and the pink color is essentially concentrated in the orthoclase phenocrysts. The rock is generally medium- to coarse-grained and in addition to pink feldspar usually shows abundant quartz and some biotite.

A porphyritic marginal facies of the granite, which has phenocrysts of pink orthoclase in a fine-grained groundmass of the same composition, is present nearly everywhere along the contact but

---

[37] Holmes, W. H., [Report on the geology of the northwestern portion of the Elk Range] : U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., p. 67, 1876.

is best developed along the Crystal River, where it crops out over relatively large areas. The proportion of phenocrysts ranges from virtually nothing to perhaps 90 percent. Where they are most abundant the groundmass is recognizable only in thin section. The relative amount of quartz and pink orthoclase phenocrysts is not constant, and biotite or other ferromagnesian minerals are either very inconspicuous or in many places entirely lacking. The groundmass is very pale pink to white and granular but too fine-grained to distinguish the quartz from the orthoclase with a hand lens.

Irregular masses and small stringers of pegmatite composed of pink orthoclase and quartz and aplite dikes of the same composition occur in the granite. These pegmatites and aplites are common only in the upper part of Bear Basin and in Yule Creek; none were observed at lower altitudes along the Crystal River, where the porphyritic marginal facies or porphyry is well developed. All the thin sections show an abundance of quartz and orthoclase, considerable albite, and only minor amounts of either biotite or magnetite. A few grains of titanite and apatite were observed in thin section. In the granitoid facies the grain size averages 2 to 4 millimeters and the pink orthoclase crystals tend to be larger than this average, and the quartz grains smaller. The orthoclase is everywhere clouded and contains much perthitically intergrown albite, a small percentage of which is also found in separate grains. Biotite is green or brown and about equal in amount to magnetite, which occurs in small anhedral grains. The porphyritic phase found along the margin of the stock contains phenocrysts ranging from 1 to 5 millimeters in length, but in a given specimen the size is uniform. The quartz phenocrysts are generally rounded, in places conspicuous, and as a rule subordinate to the orthoclase. The orthoclase phenocrysts do not contain perthitically intergrown albite, which is so common in the granitoid facies. Albite is confined to the groundmass except for occasional anhedral phenocrysts. The groundmass is a well-crystallized uniform mosaic of quartz, orthoclase, and albite with an average grain size of about 0.1 millimeter. Several thin sections contained no biotite and magnetite; these minerals are nowhere abundant except in a few places near the contact with biotite gneiss or sedimentary rocks in which much biotite is present.

CHEMICAL COMPOSITION

A specimen for chemical analysis was selected in Bear Basin from the bottom of the gulch that was estimated to be at least 500 feet below the projected contact of the granite or top of the stock. The rock is pink and in hand specimen shows the typical quartz and pink orthoclase and a subordinate amount of biotite. The albite, mostly as perthite, is evident only under the microscope. A little

magnetite and pale-green biotite are present as well as a few grains of muscovite and a very little sericite.

Analysis of pink granite from Bear Basin

[J. G. Fairchild, analyst]

Analysis		Calculated mineral composition	
SiO_2	76.46	Quartz	32.5
Al_2O_3	12.58	Orthoclase	32.2
Fe_2O_3	.52	Albite	32.0
FeO	.59	Anorthite (mol.)	1.3
MgO	.13	Apatite	.1
CaO	.52	Titanite	.1
Na_2O	3.78	Magnetite	.8
K_2O	5.45	Biotite	1.1
H_2O-	None	CaO excess	.2
H_2O+	.48	H_2O (plus) excess	.3
TiO_2	.05		
CO_2	Trace		100.6
P_2O_5	.06		
MnO	.04		
BaO			
	100.66		

Beginning with orthoclase the minerals were calculated in the order given and, except the anorthite molecule, represent the minerals observed in thin section. The essential minerals quartz and feldspar constitute 98 percent of the rock; biotite and magnetite are the only visible accessory constituents. It is not evident where the excess water may belong, as the combined amount of sericite observed in thin sections and the small amounts of hydrated iron or manganese oxides that may be present can account for only a very small part of it. The cloudiness of the orthoclase could possibly be due in part to certain clay minerals, but 0.33 percent of water would imply about 2 percent of clay, and it should be accompanied by a corresponding excess of alumina.

The mineral and chemical composition show the rock to be a sodic granite or alaskite. Facies of the dioritic rock of the stock of White Rock Mountain and of the dike rocks of the Ruby Range are described by Cross [38] as granite, but chemical analyses or detailed petrographic descriptions of these granite phases are not available. Tertiary igneous rocks of similar chemical composition are found in several places in the State, and their analyses are shown for comparison in the accompanying table, which includes stocks, laccoliths, sills, flows, and a dike. The dike of bostonite is included because analyses of more siliceous rocks, such as rhyolite and alaskite of Tertiary age from the Front Range, have not been made.

[38] Cross, Whitman, op. cit. (Folio 9).

Chemical analyses of Tertiary igneous rocks in Colorado compared with analysis of granite from Treasure Mountain

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO₂	76.46	74.27	71.57	70.73	77.36	74.42	75.62	75.19	73.11	75.20	75.07	74.45	67.41
Al₂O₃	12.58	13.67	16.84	14.22	11.37	12.80	12.96	12.91	13.16	12.96	12.15	14.72	16.23
Fe₂O₃	.52	.48	.63	1.59	.31	.59	1.00	.88	.62	.37	1.62	.00	.85
FeO	.59	.45	.07	.59	.36	.83	.31	.68	.23	.27	Not det.	.56	1.14
MgO	.13	.12	.39	.00	.14	.04	.03	.00	.19	.12	.14	.37	.15
CaO	.52	.65	.31	.72	.30	.62	.39	.68	.54	.29	.86	.83	.14
Na₂O	3.78	3.48	3.05	4.96	1.38	2.20	3.80	3.72	2.85	2.02	4.12	3.97	3.95
K₂O	5.45	5.90	5.56	5.57	7.28	6.32	5.20	5.30	5.10	8.38	4.57	4.53	7.19
H₂O+	.48	.04	1.06	.32	.26	.94	.48	.47	4.05	.58	1.34	.66	.88
H₂O−	.00	.10	.28	1.16	.55	.55	.29	.21					.67
TiO₂	.05	.49	.34	.34	.16	.44	.21	.18				.01	.16
P₂O₅	.06	.04	.05	.03	.03	.02						.01	.05
MnO	.04		Tr.	.11	.03	.13	.04	.03	.14	.03	.05	.28	.16
ZrO₂		.01	.05	.04			.02	.02					.11
CO₂	Tr.		Tr.		.06	.21		.11					.56
Cl		.02	Tr.	.01	.01	.01	.01						
SO₃					.06	.01						Tr.	
S					.33		Tr.						
	100.66	99.72	100.05	100.39	99.97	100.47	100.37	100.36	99.99	100.02	99.92	100.38	99.65

1. Granite from Treasure Mountain stock.

2. Granite stock, Brown Gulch, Monarch district. Crawford, R. D., Colorado Geol. Survey Bull. 4, p. 154, 1913.

3. Rhyolite flow, Porphyry Peak, Bonanza, Colo. Patton, H. B., Colorado Geol. Survey Bull. 9, p. 25, 1915.

4. Quartz trachyte, sills and laccoliths, Grayrock Peak, Colo. Geol. Survey Geol. Atlas, Engineer Mountain folio (no. 171), p. 10, 1910.

5–8. Larsen, E. S., personal communication.

5. Rhyolite flow, Bachelor mine, Creede, Colo. Geol. Survey Prof. Paper 99, p. 57, 1917.

6. Rhyolite, irregular intrusion, Lake Fork, San Cristobal quadrangle, Colo. Geol. Survey Prof. Paper 99, p. 123, 1917.

7. Rhyolite flow, Big Spring Gulch, San Cristobal quadrangle, Colo. Geol. Survey Prof. Paper 99, p. 123. 1917.

8. Granite porphyry dike, about a quarter of a mile wide, in Alpine Gulch, San Cristobal quadrangle, Colo. Geol. Survey Prof. Paper 99, p. 123, 1917.

9. Pitchstone flow, Silver Cliff, Rosita Hills, Colo. Cross, Whitman, Geol. Survey 17th Ann. Rept., pt. 2, p. 324, 1896.

10. Rhyolite flow, Silver Cliff, Rosita Hills, Colo. Cross, Whitman, Geol. Survey 17th Ann. Rept., pt. 2, p. 324, 1896.

11. Nevadite, Summit County, Colo. Lagorio, A., Min. pet. Mitt., new ser., Band 8, p. 454, 1887.

12. Nevadite stock or laccolith, Chalk Mountain, Colo. Emmons, S. F., Geol. Survey Mon. 12, p. 349, 1886.

13. Bostonite dike, Idaho Springs, Colo. Ball, S. H., Geol. Survey Prof. Paper 63, p. 134, 1908.

MODE OF OCCURRENCE

Form of body of intrusion.—The attitude of the beds that overlie the granite is that of a symmetrical dome, which would seem to imply a domelike form for the top of the intrusive mass that caused the uplift. The top of the stock, however, is not parallel to the dip of the overlying sedimentary rocks. This is evident on the geologic map (pl. 1), which shows that the granite has cut across more than 1,000 feet of strata and an unknown thickness of pre-Cambrian gneiss. Close parallelism between the surface of the intrusion and sedimentary rocks is limited to the top of the stock; along the sides the surface of the intrusion dips more steeply than the sedimentary rocks.

A. INDURATED MANCOS SHALE ON WEST SLOPE OF CINNAMON MOUNTAIN, SHOWING TYPICAL MODE OF DISINTEGRATION INTO BLOCKY FRAGMENTS.
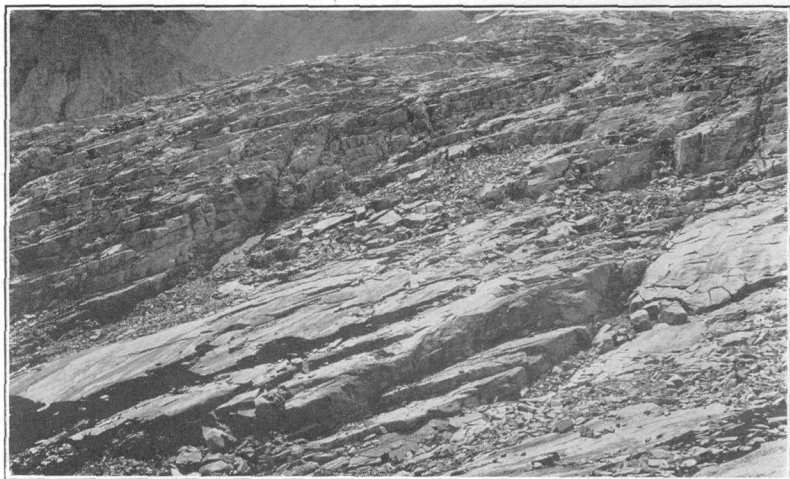
B. SHEET JOINTING IN GRANITE NEAR ITS CONTACT WITH SEDIMENTARY ROCK IN BEAR BASIN.

View looking south.   Treasure Mountain stock.
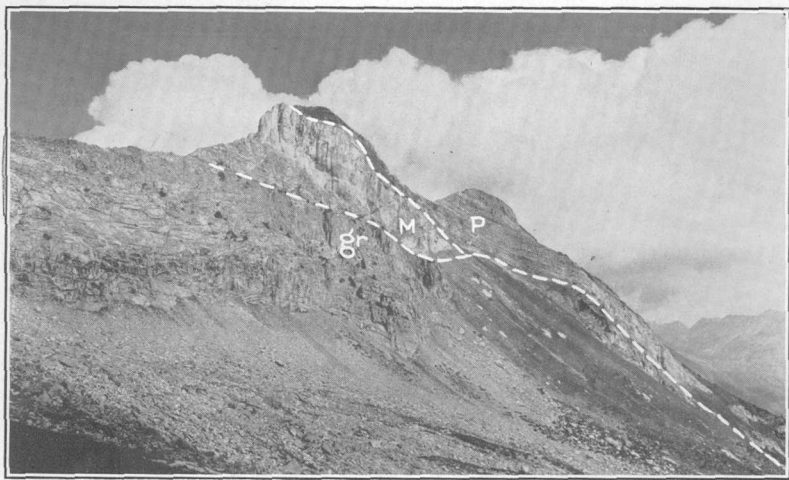
A. EAST SLOPE OF BIG BEAR MOUNTAIN SHOWING GRANITE CUTTING ACROSS THE BEDDING AT A LOW ANGLE.

gr, Granite; M, Mississippian (Leadville) limestone; P, Pennsylvanian (Hermosa (?) formation). See figure 4.
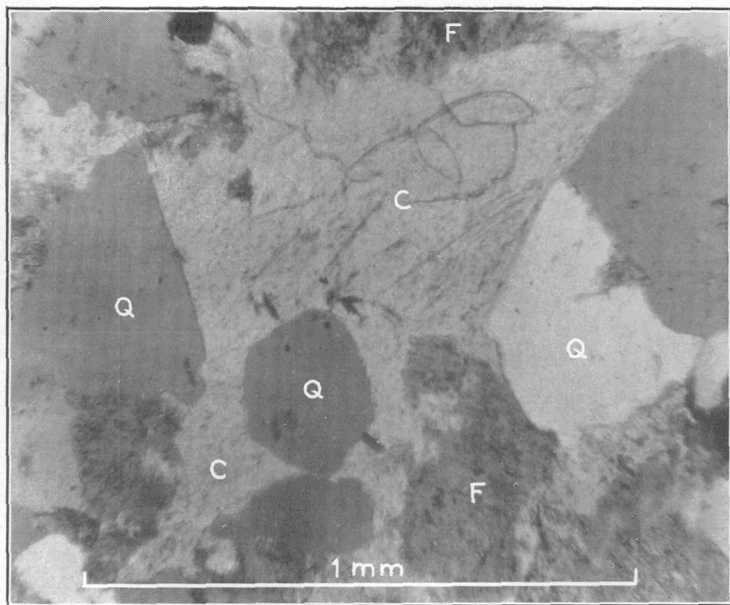
B. PHOTOMICROGRAPH SHOWING CALCITE IN GRANODIORITE OF SNOWMASS MOUNTAIN INTRUSION.

Q, Quartz; C, calcite; F, feldspar.

Joints or sheeted zones in the granite near and parallel to the contact also express the domelike form of the intrusion. The joints are spaced 2 to 6 feet apart, and in and near the margin of the granite their parallelism, an expression of contraction of the magma, is very marked. (See pl. 7, *B*.) In Bear Basin the joints dip northward and the granite is in contact with sedimentary rock. On Yule Creek, where the granite is in contact with gneiss, the joints dip southward and show no tendency to parallel the structure of the gneiss.

Emplacement.—The granite came into place without violence, as is indicated by (1) complete absence of inclusions in the granite, (2) lack of crushing or crumpling along the contact, (3) scarcity of small dikelike apophyses, and (4) absence of large intrusion faults even though the intrusion raised the strata to dips of 40°–50°.

The dome structure suggests a concordant intrusion, but there is also ample evidence of crosscutting. The granite is in contact with both gneiss and sedimentary rocks, and neither the schistosity of the
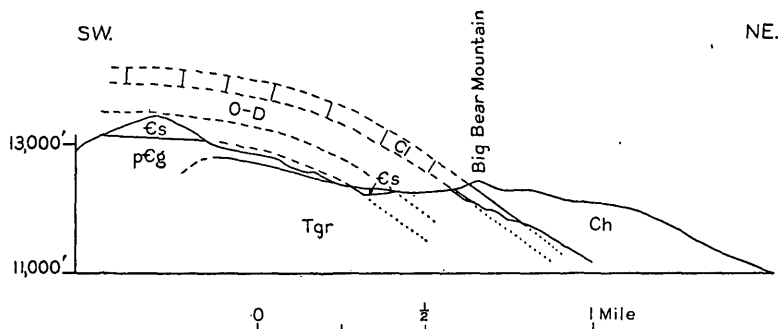
FIGURE 4.—Generalized section showing granite cutting across all the pre-Pennsylvanian formations and into pre-Cambrian gneiss. Cross section along ridge that extends north of Big Bear Mountain, shown in plate 10. Pre-Cambrian gneiss, ⊦€g; Cambrian quartzite, €s; Ordovician and Devonian formations, O–D; Mississippian (Leadville) limestone, Clm; Pennsylvanian (Hermosa? formation), Ch.

gneiss nor the bedding of the sedimentary rocks appears to have had much influence on the course of the advancing magma. In the area south and west of Twin Bridges (pl. 1) the granite cuts abruptly across the bedding of the sedimentary rock for several hundred feet, but in places it cuts across the bedding at low angles, as shown on the east slope of Big Bear Mountain (pl. 8, *A*). North of Big Bear Mountain the granite cuts across gneiss, as shown in figure 4. In places the surface of the contact is irregular, as shown by the small exposures of granite in gneiss on Yule Creek (see pl. 1), but elsewhere, as on the north flank of Treasure Mountain, the contact between granite and gneiss is a remarkably even curved surface. Parallelism between the contact and the schistosity of the gneiss is nowhere evident. These features do not furnish a clear picture of the conditions or the mechanics whereby emplacement was accom-

plished. Some of the relations appear to be contradictory; for example, (1) the absence of inclusions and the presence of a chilled marginal facies can be interpreted as indicating relatively low temperatures and high viscosity of the magma, although this interpretation is hardly compatible with the presence of pegmatite and the extent of the metamorphism caused by the granite, and (2) a quiet, easy emplacement that caused little or no crushing of rocks along the contact and an intrusion moving so slowly as to permit stretching without much faulting in the process of doming are not exactly in accord with the tremendous force necessary to lift so heavy a load.

Pegmatites, aplites, and porphyritic marginal facies.—Pegmatite and aplite are found in the same general areas, and they are most abundant in places on Yule Creek and near the crest of the intrusion in Bear Basin. The porphyritic marginal phase is best developed along the Crystal River, where a thickness of more than 500 feet has been exposed; near the crest of the stock it is thin or entirely lacking. Along the Crystal River where the porphyritic facies is so well developed no pegmatite or aplite was observed. These relations suggest that the northern part of the intrusion along the Crystal River is an apophysis, probably sill-like, which permitted the chilling of the rock; the more southerly and upper part of the intrusion with pegmatites and aplites would represent the part of the magma body with deep-seated connections.

Pegmatites are uncommon in the Tertiary stocks in Colorado, even where the intrusive body is relatively large. Their common occurrence in the granite on Treasure Mountain can be explained, first, because a granitic magma is more favorable for the formation of pegmatites than magmas of intermediate composition, and second, because the part of the intrusion exposed is the top of a stock or cupola, where mineralizers would tend to concentrate.

Metamorphism.—Metamorphism of the sedimentary rocks by the granite intrusion is discussed in detail in a separate section. It is referred to here because of its obvious bearing on the nature of the intrusion. Metamorphism is not confined to the immediate contact but extends to the limits of the outcrops of Dakota (?) quartzite and slightly beyond. (See pl. 1.) The principal changes produced are recrystallization of all limestones and dolomites, production of abundant serpentine, garnet, diopside, vesuvianite, and tremolite, induration of great thicknesses of shale to hornfels, and bleaching of great thicknesses of red beds to drab gray.

CONCLUSIONS

The arched gneiss and sedimentary beds over the intrusion are suggestive of a laccolith, but a deep-seated or plutonic type of stock, possibly representing the cupola of a batholith, must be

inferred to account for the crosscutting, the pegmatites, and the character and extent of metamorphism produced by the intrusion. Erosion has neither uncovered much of the intrusion nor cut into it deeply enough to reveal the form of more than the upper part of the stock. However, enough is exposed to show that the course of the magma was not strongly influenced by the structure of either the sedimentary rocks or the gneiss. The chilled marginal facies of the granite along the Crystal River and in the lower parts of Illinois, Chicago, and Bear Basins are believed to be related to a sill-like apophysis from the main body of the intrusion, the center of which lies to the south of Treasure Mountain, where the masses of pegmatite are common.

The conditions that prevented dikelike apophyses and permitted stretching rather than faulting of the beds as they were forced to take the form of an arch are not understood. Several factors, such as the load of overlying rock, viscosity, and rate of movement of the magma, are probably involved. The cover present at the time the magma came up seems to have been relatively thin, as only about 7,000 feet of Paleozoic and Cretaceous formations were arched by the intrusion, and if some of the early Tertiary beds now found to the west also covered the area, not more than 2,000 to 3,000 feet in thickness could be added. For additional thicknesses it would be necessary to assume that younger Eocene beds extended over the area, but even so a thickness comparable to great batholithic depths cannot be attained. If it is assumed that the inference of a relatively light load is correct and that an exceptionally high degree of viscosity is not in accord with the general granitoid textures and pegmatites present, it is necessary to postulate that the movement of the magma was very slow; otherwise faulting rather than stretching of the beds would have accompanied their uplift.

RELATIVE AGE AND CORRELATION

The Treasure Mountain stock is clearly younger than the quartz monzonite dikes correlated with the laccoliths, sills, and dikes in the Anthracite quadrangle, as these dikes have been altered by emanations that accompanied the intrusion of the stock. The relative age of the Treasure Mountain and Snowmass stocks has not been established. It has been stated that the granite of the Treasure Mountain stock is unique in the area, yet the variation in composition of the Snowmass Mountain stock suggests that the exposed part of the Treasure Mountain stock may represent a cupola or the upper part of a larger stock, which the Snowmass Mountain stock resembled before erosion had removed several thousand feet of material from its upper part.

The Treasure Mountain stock is of Tertiary age, as the dikes and sills that it has metamorphosed are correlated with the laccoliths which cut the Eocene rocks in the Anthracite quadrangle that were mapped as Ohio Creek and Ruby formations in the Anthracite-Crested Butte folio. Several intrusive and extrusive rocks of Tertiary age in neighboring mountains in Colorado similar in composition to the granite of Treasure Mountain (see p. 48) have been described, and the possibility of their correlation naturally suggests itself; however, chemical composition alone is not a reliable basis for correlation, as pre-Cambrian rocks of similar composition are known.

GRANODIORITE OF SNOWMASS MOUNTAIN STOCK

LOCATION AND ACCESS

The grandiorite in the northern part of the area shown on plate 1 is a part of a large stock that forms several peaks, among which Snowmass Mountain and Capital Peak, a few miles north of the area, are the most prominent. The stock is in the Elk Mountains, which, except the peaks of granodiorite, do not stand conspicuously apart from the surrounding country of high relief. The granodiorite has resisted erosion to such an extent that the area of the stock forms sharp divides and high peaks and is the source or head of several streams. This rugged topography (see pl. 6, *B*) is very characteristic and explains the general lack of roads closer than 2 to 8 miles, which makes access to the stock rather difficult. Fortunately Snowmass Mountain and vicinity lie in the Holy Cross National Forest, and the Forest Service has constructed and marked several trails across the area. These trails, together with numerous unmarked trails built by sheepmen, make many exposures of granodiorite accessible on horseback; other places of critical importance can be reached only on foot.

The easiest access to the intrusion is past Little Snowmass Lake by trail from Crystal, a ghost town which during the summer can generally be reached by automobile from Marble. Other tributaries to the Crystal River that head in the area of the intrusion and therefore afford access to it are Carbonate Creek, at Marble, and Avalanche Creek, about 18 miles north of Marble. Snowmass Mountain and Capital Peak can be reached from the north by following Capital Creek and Snowmass Creek, both of which join Roaring Fork about 15 miles west of Aspen.

RELATION TO NEIGHBORING STOCKS

The stock covers about 40 square miles and is ringed chiefly by Maroon red beds and Cretaceous (Mancos) shale. White Rock Mountain, nearly 15 miles to the southeast, and Mount Sopris, about

12 miles to the northwest, are intrusive stocks similar in occurrence and in the character of their rock, as pointed out by Cross in the Anthracite-Crested Butte folio. The three stocks constitute a large part of the Elk Mountains and are alined along a regional structure. Sedimentary rock completely separates each stock from the others, but their similar mode of occurrence and composition point to a common origin. A relationship between the granodiorite of Snowmass Mountain and the granite of Treasure Mountain, less than 5 miles to the south, can be theoretically inferred. The average compositions of the two are wholly unlike, but certain facies of the granodiorite suggest a differentiation which could produce a local granite facies like that of Treasure Mountain. Field evidence does not oppose such a relationship.

DIFFERENT ROCK VARIETIES

The rock of the Snowmass Mountain intrusion has not been previously described. Cross[39] stated that the rock of White Rock Mountain, to the southwest, is uniform over large areas, and he also described important variations in the amounts of quartz, hornblende, biotite, and augite. He said:

> In the average rock plagioclase strongly predominates over orthoclase, and biotite over hornblende. By a local increase in the amount of orthoclase, granitic facies (or modifications) are produced.

Cross does not discuss the areal distribution of the various facies, but his description is applicable to the stock of Snowmass Mountain.

The larger part of the Snowmass Mountain stock is medium-grained and very uniform in appearance and ranges from granodiorite to quartz monzonite. It grades into fine-grained quartz diorite and albite granite in a marginal zone 150 to 1,500 feet wide along the contact. The following descriptions of the variations in texture and composition and their relations to each other are based on a detailed study of exposures within the area. This study is supplemented by studies outside the area—in the southwestern part of the stock at the head of Carbonate Creek north of Marble and in the northern part of the stock on Avalanche Creek. No attempt was made to map each variety separately, because most of the stock lies outside of the area, and, moreover, as a whole it is not related to the cycle of mineralization that deposited the economic sulphides.

QUARTZ DIORITE

Distribution.—Quartz diorite occurs in the area northeast of Little Snowmass Lake but was recognized only after study under the microscope. Farther north, east, and west quartz is megascopically more

---

[39] Cross, Whitman, Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), 1894.

evident in the rock, and microscopic study indicates that this is a characteristic feature of quartz monzonite and granodiorite as compared with the diorite. Further field work would be necessary to determine its distribution, but present data suggest that quartz diorite is less extensive than other varieties.

Character.—The quartz diorite is a medium-grained gray rock in which hornblende or biotite and striated feldspar are generally recognizable without a lens. The relative amounts of hornblende and biotite vary noticeably, but the total amount of ferromagnesian minerals does not vary appreciably, and the rock is uniform in appearance from place to place. Quartz is not megascopically recognizable, and its apparent absence affords about the only means by which the diorite can be tentatively identified in hand specimens. At the margin or contact and for 50 to 100 feet from it the rock is finer-grained and darker than nearer the interior, but the same mineral constituents are present.

Under the microscope the medium-grained rock shows calcic plagioclase, quartz, biotite, hornblende, a little orthoclase, magnetite, apatite, titanite, and a little chlorite. The average grain size is 0.5 to 2.0 millimeters. The titanite and chlorite occur in scattered euhedral grains. The apatite tends to be associated with the magnetite and shows both euhedral and anhedral forms. The magnetite is scattered and occurs as individual anhedral grains or small aggregates. The hornblende is green with pleochroism X pale brown, Y green, Z darker green (than Y). The biotite is brown and anhedral and varies in amount relative to hornblende. Plagioclase predominates over all the other minerals. Near the margin of the stock the plagioclase shows euhedral outlines, and zoning is well developed, as is more characteristic of a hypabyssal rock or porphyry, but away from the margin the grains are anhedral with somewhat irregular and uneven albite twinning. The average composition of the plagioclase is that of andesine ($Ab_{55}An_{45}$), both near and away from the margin of the intrusion. Orthoclase is subordinate to quartz. The two minerals are interstitial to the plagioclase, and each constitutes not over 10 percent of the rock.

The chemical analysis below represents a specimen collected within 2 feet of the contact northeast of Little Snowmass Lake. In this area the quartz diorite is frozen to Weber (?) grits, and it is unaltered.

Chemical analysis of quartz diorite

[J. G. Fairchild, analyst]

Analysis (325A)		Calculated mineral composition	
SiO₂	56.83	Quartz	14.0
Al₂O₃	16.67	Orthoclase	8.7
Fe₂O₃	4.62	Albite	29.9
FeO	4.48	Anorthite	22.0
MgO	2.75	Biotite	23.2
CaO	6.45	Hornblende	15.1
Na₂O	3.56	Magnetite	4.1
K₂O	1.82	Titanite	1.4
H₂O −⎫	.88	Apatite	1.3
H₂O +⎭		Calcite	.2
TiO₂	.58	Al₂O₃	(−1.1)
CO₂	.07	H₂O	.8
P₂O₅	.59	MnO+BaO	.3
MnO	.21	FeO	.4
BaO	.09		
			101.4
	99.60		

NOTE.—Grain counts for determining mineral composition were not practicable because of the fine grain of the rock, but the mineral composition as calculated is in accord with the percentages estimated by observation.

ALBITE GRANITE

Distribution.—Albite granite occurs continuously along the shale contact west of Little Snowmass Lake in a zone 500 to 1,000 feet wide. Both field studies and a study of thin sections show that the albite granite grades into normal granodiorite of the stock at a distance of 1,200 to 1,500 feet from the margin.

Character.—The rock appears nonporphyritic and is fine-grained and gray. In outcrop and in hand specimen it resembles the fine-grained quartz diorite already described. Feldspar and ferromagnesian minerals, hornblende or biotite, are all that can be recognized with a hand lens.

Under the microscope the rock shows a completely crystalline texture with grains averaging 0.5 millimeter in diameter, and near the contact, in a zone about 150 feet wide, a porphyritic variety has developed. The minerals are quartz, sodic plagioclase, orthoclase (?), biotite, hornblende, magnetite, apatite, and titanite, with considerable calcite, some chlorite, and sericitic mica. The titanite, apatite, magnetite, hornblende, and biotite occur in about the same amount and manner as in the quartz diorite. The quartz is relatively abundant and occurs as an interstitial mineral with a smaller average grain size than the plagioclase. The plagioclase is clouded by sericitic mica and some calcite and does not have well-developed albite twinning. A low index of refraction is the chief optical property that gives a clue to the sodic composition of the feldspar. Calcite has replaced some of the hornblende and biotite and also occurs as an interstitial mineral and as inclusions or replacements in feldspar. The chlorite ranges from almost white and nonpleochroic to pale green with perceptible pleochroism, and in several thin sections varieties with abnormal interference colors were

observed. A chemical analysis shows the rock to contain much Na$_2$O and very little K$_2$O and makes it seem probable that the sericitic mica is paragonite instead of sericite, which is more generally expected in igneous rocks.

Chemical analysis of albite granite

[J. G. Fairchild, analyst]

Analysis (331B)		Calculated mineral composition	
SiO$_2$	60. 67	Quartz	13. 1
Al$_2$O$_3$	16. 76	Orthoclase	3. 1
Fe$_2$O$_3$	1. 52	Albite	55. 0
FeO	3. 64	Anorthite	None
MgO	1. 98	Biotite	[1] 16. 7
CaO	2. 96	Magnetite	2. 2
Na$_2$O	6. 48	Titanite	1. 2
K$_2$O	. 60	Apatite	. 9
H$_2$O—	} 1. 98	Calcite	3. 8
H$_2$O+		Siderite	. 9
TiO$_2$	. 50	Al$_2$O$_3$	1. 3
CO$_2$	2. 03	H$_2$O	1. 2
P$_2$O$_5$	. 40	MnO–BaO	. 1
MnO	. 04		
BaO	. 06		99. 5
	99. 62		

[1] Unidentified fibrous brown mineral resembling biotite in color.   Calculated as biotite with K$_2$O replaced by H$_2$O.

The albite granite was taken from the central part of a uniform zone of rock about 200 feet wide along the contact west of Little Snowmass Lake. Although there may be a considerable variation in composition from place to place in this apparently uniform zone, thin sections show that a small amount of orthoclase and a relatively large amount of calcite are characteristic of albite granite as a whole.

Alteration.—Calcite, sericitic mica, and to some extent chlorite found in the sodic granite can all be regarded as indicative of alteration; but veins were not observed anywhere in the granite. Sulphides have not been found in the granite, although a little pyrite was seen in some of the inclusions of marble. The replacement of ferromagnesian minerals was accompanied by a development of calcite intergrown with a brown fibrous and platy mineral that resembles brown biotite except that it lacks high absorption. The most characteristic mode of occurrence of calcite is interstitial to the silicates in irregular forms that are never veinlike, but it also occurs disseminated in the plagioclase. The chlorite replaces both biotite and hornblende, but more commonly it occurs isolated from the ferromagnesian minerals and magnetite. The sericitic mica is disseminated through the feldspar and so far as was seen had not replaced other minerals or been deposited in them.

The presence of calcite suggests hydrothermal alteration because it is commonly found in veins and is associated with sulphides. The alteration of the albite granite, however, is not accompanied by

the formation of the alteration products of veins, and instead of showing crosscutting relations the calcite is disseminated through the rock. I have interpreted the origin of the albite granite as due to mineralizers absorbed by the magma from the calcareous sedimentary rocks. Thus the mineralizers are secondary to the magma, but their behavior during the final stage of solidification of the magma would be analogous to that of residual primary mineralizers. The basis of these conclusions is given in the discussion of the origin of the different members of the Snowmass Mountain stock (pp. 64–67).

GRANODIORITE

Plagioclase, orthoclase, and quartz are the essential minerals throughout the bulk of the intrusion. Cross[40] classified a similar rock in White Rock Mountain as diorite. Knopf[41] has pointed out that the diorite of Cross would now be termed a granodiorite, and he applies this term to the rock of the White Rock Mountain stock. In the Snowmass Mountain area the relative amount of orthoclase with respect to plagioclase varies, and accordingly the rock ranges from quartz monzonite to granodiorite, and the relative volume of these two types is not known. The term "granodiorite" is used in this report for the rock of the Snowmass Mountain stock because the rock of White Rock Mountain, which shows a similar variation in composition, has been called granodiorite.

Distribution.—Granodiorite occurs throughout the main body of the intrusion and also in the relatively narrow protrusion southward along the Elk Mountain fault. The albite granite and the quartz diorite as described are confined to a zone along the margin which is small compared to the total width of 5 or 6 miles of the intrusion. The granodiorite is exposed in many bold cliffs and steep slopes above timber line. It also forms large accumulations of talus and rock streams. All these exposures are conspicuous because of the light color of the weathered rock, which stands out in contrast with the dark green of the timber-covered slopes and the red color of the surrounding Maroon formation.

Character.—The granodiorite is a nonporphyritic gray medium-grained rock in which quartz, feldspar, biotite, and hornblende can generally be recognized. The rock appears uniform over large areas and differs from the quartz diorite in its relative abundance of quartz recognizable with a hand lens and the predominance of biotite over hornblende.

Under the microscope the rock is seen to be completely crystalline, with the size of the grains ranging from 0.5 to 2.0 millimeters.

---

[40] Cross, Whitman, Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), 1894.
[41] Knopf, Adolph, Recent developments in the Aspen district, Colo.: Geol. Survey Bull. 785, p. 11, 1926.

Orthoclase, quartz, calcic plagioclase, biotite, hornblende, magnetite, apatite, and titanite were recognized, and some chlorite and sericitic mica are usually developed, but calcite may or may not be present. The titanite occurs in scattered grains more commonly anhedral than wedge-shaped. Apatite is present in small euhedral crystals scattered throughout the rock, included in the silicates, and as euhedral grains concentrated with the magnetite, which occurs in scattered areas or individual anhedral grains. Hornblende is common, although lacking in some of the thin sections. It is green with pleochroism X pale brown, Y green, Z darker green (than Y). Typical amphibole cross sections are well developed, but the laths are always without crystal terminations. Plagioclase is euhedral and shows somewhat irregular albite twinning in combination with carlsbad twins. Indices of refraction and extinction angles indicate the average composition to be that of oligoclase $(Ab_{75}An_{25})$. In some thin sections andesine $(Ab_{50}An_{50})$ occurs. Brown biotite generally predominates over hornblende, and it is euhedral. Orthoclase is always present, occurring in scattered grains and in irregular interstitial areas. The amount of orthoclase varies, but in no place does it appear to exceed the plagioclase, and generally it is definitely subordinate to that mineral. Quartz is also always present and like orthoclase occurs in scattered grains and in interstitial areas.

Several representative specimens of the granodiorite were studied in thin section, and one of these, collected 1,800 feet from the contact, was selected for the chemical analysis given below under 331L.

Chemical analyses of granodiorite

[J. G. Fairchild, analyst]

Analyses				Calculated mineral composition		
	331L	328D			331L	328D
SiO_2	66.19	59.68	Quartz		28.26	16.2
Al_2O_3	15.72	16.31	Orthoclase		14.45	8.6
Fe_2O_3	2.36	4.11	Albite		30.66	28.3
FeO	2.13	4.11	Anorthite		7.37	22.9
MgO	1.26	2.51	Biotite		10.19	4.2
CaO	2.58	6.36	Hornblende		.00	13.4
Na_2O	3.87	3.42	Magnetite		3.44	2.6
K_2O	3.60	2.12	Titanite		1.19	1.5
H_2O-	.93	.05	Apatite		.90	.9
H_2O+	--------	.65	Calcite		.45	.0
TiO_2	.49	.60	Al_2O_3		2.64	(−1.6)
CO_2	.20	.00	H_2O		.72	.6
P_2O_5	.40	.42	$MnO+BaO$		.23	.4
MnO	.02	.17	Fe_2O_3		.00	.1
BaO	.21	.18				
					100.24	100.2
	99.96	100.69				

Analysis 328D represents a specimen collected 225 feet from the contact with the Maroon formation; this rock is really a variety of the granodiorite that is close to quartz diorite in composition. The two rocks are similar in texture and in appearance except for

the presence of hornblende in one and biotite with more conspicuous quartz in the other. This difference is shown in the calculated mineral composition (norm), which includes only minerals actually identified in a thin section of the analyzed specimen, the albite and anorthite molecules combined representing the plagioclase. The minerals were calculated in the order in which they are shown in the table. Hornblende and biotite occur together, but more commonly only one is present. Rock showing only biotite forms the bulk of the stock.

CHANGES FROM MARGIN TOWARD CENTER

A discussion of the changes in texture and composition that occur between the margin and the center of the intrusion is given in an attempt to explain the origin of the albite granite and quartz diorite. The albite granite is contiguous to calcareous rocks, and the quartz diorite is contiguous to feldspathic rocks. Both of these rocks are confined to the fine-grained zone present along the border of the stock, and each rock grades into medium-grained granodiorite away from the margin.

The flow structure and micrographic texture related to the contact in general are also described. They are not related to the problem outlined above, and to set them apart they are grouped under structural and textural features and described first.

Structural and textural features.—A slight schistose appearance, due to hornblende and biotite oriented parallel to the contact, is common along the margin in the fine-grained rock. The best examples were found on the south slope of Snowmass Mountain. Orientation of phenocrysts in coarser-grained rock gives rise to an orthogneiss in places north of Snowmass Lake and at the head of Capital Creek, north of the area. Crushing is not evident in the finer-grained rocks that show flow structure, but some of the larger crystals, biotite in particular, show granulation in the orthogneiss. The orthogneiss has the appearance of a well-crystallized rock, but it contains fine-grained quartz and orthoclase interstitial to the plagioclase and biotite.

The rock at the margin appears nonporphyritic and differs somewhat in color and much in grain size from the rock away from the contact. In thin section, however, the marginal rock is seen to be porphyritic and shows phenocrysts of feldspar, hornblende, and biotite in a groundmass of feldspar and quartz. As a rule the texture of the groundmass is not uniform in a specimen; the grain size varies gradationally to the dimension of the phenocrysts, which accounts for the fact that the porphyritic structure is not evident in hand specimens.

Micrographic structure has a definite relation to the contact, being generally confined to a relatively narrow zone close to it. This

structure is particularly well developed along the western border of the sill-like extension of the granodiorite south of the Crystal River. In another place the structure could be found only in a zone between the limits of 2 and 15 feet from the contact. West of Little Snowmass Lake, however, the structure was found in specimens collected 100 to 150 feet from the contact but not in specimens collected either closer to the contact or farther from it. In the coarser-grained rock micrographic structure is either absent or shows only in a very few small interstitial areas.

The apparent limitation of micrographic structure to a narrow zone near the contact suggests the possibility that it might be used as a criterion for recognizing less obvious contacts within an intrusion, but a study of the relations in other places would first be necessary because the feature may be merely characteristic of certain intrusions. As the structure is a microscopic feature and may be limited to a narrow zone it is of no practical value unless a detailed microscopic study of the rock near the contact can be made.

Changes adjacent to feldspathic beds.—Adjacent to the Maroon red beds northeast of Little Snowmass Lake the fine-grained marginal facies of the intrusion is quartz diorite. In this area a fine-grained zone about 50 feet wide is manifest, and under the microscope a porphyritic structure is evident from the margin of the fine-grained zone to a point 150 feet from the contact. At 200 feet and farther from the contact the intrusive rock has a plutonic or completely crystalline texture. Several specimens, including a series collected at 2, 50, 150, 200, and 225 feet from the contact, were examined in thin section, and chemical analyses were made of the end members— specimen 325A, collected 2 feet from the contact, and specimen 328D, collected 225 feet from the contact.

Analyses of rocks adjacent to feldspathic sandstone

[J. G. Fairchild, analyst]

Analyses			Calculated mineral composition		
	325A	328D		325A	328D
SiO_2	56.83	59.68	Quartz	14.0	16.2
Al_2O_3	16.67	16.31	Orthoclase	8.7	8.6
Fe_2O_3	4.62	4.11	Albite	29.9	28.8
FeO	4.48	4.11	Anorthite	22.0	22.9
MgO	2.75	2.51	Biotite	3.2	4.2
CaO	6.45	6.36	Hornblende	15.1	13.4
Na_2O	3.56	3.42	Magnetite	4.1	2.6
K_2O	1.82	2.12	Titanite	1.4	1.5
H_2O-	.88	.05	Apatite	1.3	.9
H_2O+	------	.65	Calcite	.2	.0
TiO_2	.58	.60	Al_2O_3	(−1.1)	(−1.6)
CO_2	.07	.00	H_2O	.8	.6
P_2O_5	.59	.42	$MnO+BaO$	.3	.4
MnO	.21	.17	Fe_2O_3	------	.1
BaO	.09	.18	FeO	.4	------
	99.60	100.69		101.4	100.2

The outstanding change from the margin toward the center of the stock, as shown by the two specimens, is the increase in grain size, which is almost as marked in outcrop as it is in thin section. The rock is unaltered and in thin section shows plagioclase ($Ab_{45}An_{55}$), pale-green hornblende, brown biotite, orthoclase, quartz, magnetite, apatite, and titanite. Calcite was not recognized, although a small amount is suggested in one analysis. The chief differences observed in thin section are summarized below:

1. At the contact, represented by analysis 325A, the plagioclase, hornblende, and biotite crystals average about 0.1 by 0.3 millimeter, with more below than above this size, whereas 200 feet and farther from the contact the same minerals are 0.6 to 1.5 millimeters across.

2. Near the contact there is no definite groundmass. Quartz and orthoclase, about 10 percent of the whole, in grains measuring 0.03 millimeter, occupy interstitial areas. At 200 feet and more from the contact the quartz and orthoclase occur interstitially and in scattered grains nearly as large as those of the other minerals.

3. Near the contact zoning of plagioclase is characteristic, particularly in the larger grains; the smaller grains more commonly show uneven albite twinning. In the band between 50 and 150 feet from the contact the twinned grains increase in number, whereas the zoned grains show a corresponding decrease, and at a distance of 200 feet and more only the uneven albite twinning is found.

4. Titanite could not be found 2 feet or 50 feet from the contact, but it appeared in grains 0.05 to 0.1 millimeter across 150 feet and more from the contact.

5. Near the contact apatite occurs in small scattered euhedral crystals. From 150 to 200 feet from the contact the apatite in increasing amounts is associated with magnetite.

6. Flow structure occurs nearly everywhere in a zone near the contact, but the rock does not resemble the orthogneiss previously described. Orientation of biotite and hornblende can usually be seen in specimens from the zone about 50 feet from the contact, where it tends to be more evident than at the contact itself; 150 feet or more from the contact it is seldom recognizable. In some thin sections an orientation of crystals could be recognized as far as 200 to 225 feet from the contact.

Changes adjacent to calcareous beds.—Adjacent to the Cretaceous (Mancos) shale west of Little Snowmass Lake the fine-grained marginal facies of the intrusion is albite granite throughout a width of more than 1,000 feet. This wide zone of fine-grained albite granite is continuous to the west for about 5 miles. The change in texture from the margin toward the center is not a uniform change but is effected in successive zones, each maintaining a uniform texture, with gradational boundaries. For example, through a band about 100 feet wide along the contact no megascopic change could be detected, but beginning at 150 feet through a band about 10 feet wide there is a perceptible change to a slightly coarser texture. Again in the zone between 160 and 1,200 feet from the contact the lithology is uniform, but beginning at 1,200 feet through a width of about 200 feet the texture changes to that of the average of the plutonic facies of granodiorite found in the more central part of the stock. Evi-

dence of more than one intrusion was looked for, but, although exposures were good, only gradational changes from one facies to another were found.

Inclusions of marbleized limestone ranging from a few hundred to several hundred feet across occur in the zone of fine-grained rock, and near these inclusions, whether they are close to the contact or at a distance from it, the albite granite matches in texture and appearance the rock at the contact near the shale.

A series of specimens were collected at the contact and at 100, 150, 160, 500 to 800, 1,000, 1,050, 1,100, 1,300 to 1,400, and 1,500 to 1,700 feet from the contact for microscopic study and chemical analysis. Chemical analyses were made of two representative specimens—331B, at 100 feet from the contact, and 331L, at 1,800 feet.

Chemical analyses of granodiorite and albite granite

[J. G. Fairchild, analyst]

Analyses			Calculated mineral compositions		
	331L	331B		331L	331B
SiO_2	66.19	60.67	Quartz	28.3	13.1
Al_2O_3	·15.72	16.76	Orthoclase	14.5	3.1
Fe_2O_3	2.36	1.52	Albite	30.7	55.0
FeO	2.13	3.64	Anorthite	7.3	----------
MgO	1.26	1.98	Biotite	10.2	----------
CaO	2.58	2.96	Hornblende	----------	[1] 16.7
Na_2O	3.87	6.48	Magnetite	3.4	2.2
K_2O	3.60	.60	Titanite	1.2	1.2
H_2O-	} .93	1.98	Apatite	.9	.9
H_2O+			Calcite	.5	3.8
TiO_2	.49	.50	Siderite?	----------	.9
CO_2	.20	2.03	Al_2O_3	2.6	1.3
P_2O_5	.40	.40	H_2O	.7	1.2
MnO	.02	.04	$MnO+BaO$	.2	.1
BaO	.21	.06			
	99.96	99.62		100.5	99.5

[1] Calculated as biotite with K_2O replaced by H_2O; mineral not identified but resembles biotite in color.

The percentage of carbon dioxide and sodium oxide is high in the albite granite (331B), and that of potash and calcium oxide in excess of the amount required to balance the carbon dioxide is very low as compared with the percentages of these oxides in the other specimen. Specimen 331L was collected to represent the normal rock of the stock and to be compared with specimen 328D of the other series.

A mineral count of the albite granite, because of its fine-grained texture, did not prove satisfactory. In calculating the mineral composition from the chemical analysis the titanite and apatite in 331B were calculated first, and the remaining CaO was then calculated as $CaCO_3$, after which the remaining CO_2 was combined with FeO in $FeCO_3$.

The identity of calcite observed in thin section was checked by determination of refractive index and solubility in cold dilute hydrochloric acid (1:5) of grains isolated from powdered rock. The dilute

acid solution thus obtained gave a weak test for ferrous iron, which is the basis for believing that a ferrous carbonate molecule is present. The mica has been arbitrarily calculated because the identity of the platy or fibrous mineral, resembling brown biotite in color, is not definite; however, the average proportions of typical analyses are thought to be approximately represented in this specimen. Sericitic mica is not calculated separately, and the percentages of orthoclase as calculated may be slightly in excess of the true amount.

Each thin section shows plagioclase (albite or oligoclase) with or without orthoclase, quartz, biotite or hornblende, magnetite, apatite, and titanite. The textural differences are as great as in the series opposite the feldspathic rocks, but the differences in composition are more pronounced. The characteristic features of the specimens collected to represent the changes are summarized below:

1. At 0 to 150 feet from the contact the phenocrysts average 0.2 by 0.3 millimeter in size, but there is a noticeable change to 0.5 millimeter between 150 and 160 feet. From 160 to 1,200 feet the grain size gradually increases to 0.2 by 0.6 millimeter, with some 0.8 by 1.5 millimeters. About 1,300 feet and farther from the contact the grain size is uniform and averages about 0.5 by 1.5 millimeters. Some grains are over 2.0 millimeters across.

2. In the rock up to 100 feet from the contact about one-half of each thin section examined consists of well-defined groundmass with a grain size averaging 0.02 by 0.08 millimeter. At 150 feet there is no well-defined groundmass, and less than 10 percent of the grains are as small as 0.08 millimeter. From 160 to 1,200 feet there is no groundmass, although a small percentage of fine-grained interstitial quartz and orthoclase (0.05 to 0.1 millimeter) occurs in each thin section. At 1,300 feet the interstitial quartz and orthoclase constitute about one-third of the rock, forming a fairly well defined groundmass, which becomes poorly defined at about 1,500 feet and is lacking beyond 1,600 feet.

3. Plagioclase predominates and shows zoning, albite twinning, and albitic rims. At the contact there is little twinning, no zoning, and no albitic rims, but at 100 feet from the contact all these features are slightly developed, and from 160 to 1,200 feet they are characteristic features of the plagioclase. At 1,300 feet the zoning and albitic rims are lacking and the albite twinning is only poorly developed, but at 1,500 feet all three are present, and at 1,800 feet they are again rather well defined, although less conspicuous than in the zone between 160 and 1,200 feet.

4. Sericitic mica is common in each thin section and interferes with identification of the plagioclase. The identification of sericite is in doubt. Paragonite instead of sericite is suggested by the chemical analysis, which showed only 0.60 percent of K_2O in a rock containing an appreciable amount of the mica. The sericitic mica appears to be less abundant at a distance of 1,500 feet and more from the contact.

5. In every thin section quartz occurs in conspicuous amounts, either in the groundmass or as an interstitial mineral. It is noticeably fine-grained and subordinate to the plagioclase. The grain size of quartz increases more uniformly than that of the plagioclase. The change at 150 to 160 feet is scarcely evident, and at 1,200 feet it is not striking. The range of grain size from the contact to 1,200 feet is about 0.05 to 0.2 millimeter, and farther from the contact the range increases to 0.05 to 1.5 millimeters.

6. Orthoclase was not recognized from the contact to 160 feet, but from 500 to 1,200 feet some occurred as an interstitial mineral. From 1,300 to 1,800 feet orthoclase appears to be more common, but as all the feldspars are more or less clouded the relative amount of orthoclase that may be present could not be determined.

7. Magnetite is common throughout except at the very contact, where it is entirely lacking. From 100 to 1,800 feet the magnetite varies slightly in amount and grain size, but the change appears to be haphazard.

8. Pale-green hornblende, generally much altered, occurs in the zone from 150 to 1,200 feet. From the contact to 100 feet there is an alteration product believed to be a hydromica, which may represent altered hornblende. From 1,300 to 1,800 feet hornblende is lacking.

9. Brown biotite occurs in the zone from 150 to 1,800 feet and is partly altered. From 1,300 to 1,800 feet biotite is slightly altered, and some flakes are green. As with hornblende, the hydromica found from the contact to 100 feet may represent altered biotite.

10. Pale-green chlorite (penninite) is generally present, and in only a few thin sections is the alteration of biotite to chlorite evident; the chlorite commonly occurs isolated from other ferromagnesian minerals.

11. Titanite and apatite are uniformly present in small but easily recognizable amounts. The titanite is cloudy and appears altered at the contact.

12. Calcite is a common constituent but is more abundant near the contact and near inclusions than at a distance from sedimentary rocks. From the contact to 160 feet it is more abundant than from 160 to 1,200 feet, and at 1,800 feet it is present in some thin sections examined but not all, and the chemical analysis showed only 0.45 percent of calcite. The calcite near the contact replaces hornblende, biotite, and to some extent plagioclase, but its most characteristic habit both near and far from the contact is that of an interstitial mineral, as shown in the photomicrograph (pl. 8, *B*). The calcite does not form veins, and the closest approach to vein habit seen in thin section is the occurrence of a little calcite along a few small fractures in a quartz grain. Many fractured quartz grains without calcite were observed in thin sections.

ORIGIN OF ALBITE GRANITE AND OTHER ROCK VARIETIES

The several varieties of rock found in the Snowmass Mountain stock not only have a bearing on the differentiation of a magma but also offer a possible explanation for the development, under special circumstances, of a highly albitic rock. Figure 5 shows graphically the interrelations of the variations in composition to the contact and to each other. The magma at the time of intrusion had the composition of quartz diorite, similar to that found northeast of Little Snowmass Lake. (See fig. 5, specimens 325A and 328D.) In this area the rock is unaltered and undifferentiated, as the chilled and coarser-grained rocks show the same chemical composition. Furthermore, the quartz diorite is relatively poor in potash and silica, which are abundant in the grits or wall rock, and therefore appreciable assimilation did not occur. The albite granite (331B of fig. 5), on the other hand, contains calcite, and the calcite is most abundant near the contact of calcareous shales. Inclusions of marbleized limestone

are numerous. Obviously the albite granite does not represent the original composition of the magma.

In considering the origin of the albite granite it is important to review the following facts: (1) It has developed only where the intruding magma followed along and broke across the Elk Mountain fault zone and where magma came into contact with shale, (2) inclusions of marbleized limestone are common in the albite granite
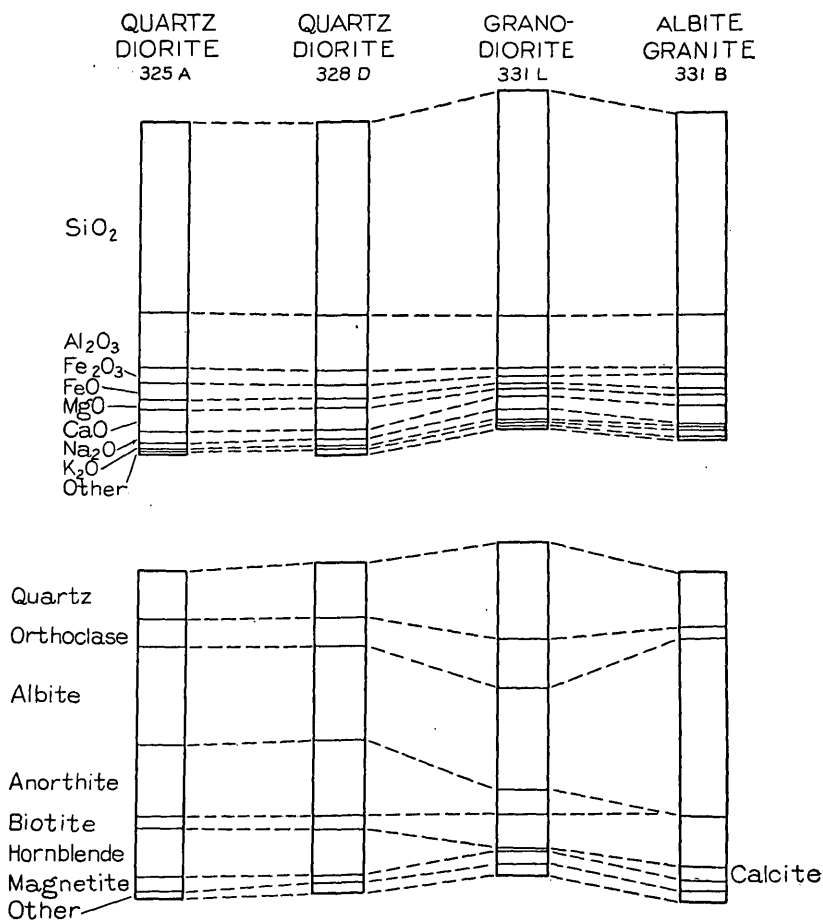

FIGURE 5.—Graphic presentation of rock varieties of Snowmass Mountain stock. 325A, Quartz diorite 2 feet from contact of feldspathic sandstone; 328D, quartz diorite 225 feet from contact of feldspathic sandstone; 331L, granodiorite 1,800 feet from contact of calcareous rocks; 331B, albite granite 100 feet from contact of calcareous rocks.

zone, (3) the inclusions at a distance from the margin are surrounded by individual zones of fine-grained albitic rock, (4) calcite is most abundant near the shale contact and near the marbleized limestone inclusions, and (5) the fine-grained zone is much wider opposite the shale than it is opposite the sandstones and grits of the Maroon formation. The Elk Mountain fault zone, with its broken and

crushed formations, furnished the inclusions found in the magma. The uniform contents of silica, alumina, titanium, and phosphate shown in the chemical analyses argue against assimilation or solution of the rock as a whole, but the presence and distribution of so large an amount of calcite can best be explained through absorption by the magma of carbon dioxide, either alone or in the form of calcite, from the sedimentary rock.

Calcite is so characteristic a mineral of veins that where it is present in an igneous rock it is generally regarded as a secondary mineral and a product of hydrothermal alteration. The calcite in the albite granite occurs like sericite in small particles in feldspar, in places it is disseminated through hornblende and biotite, and it is interstitial to quartz and orthoclase like a primary mineral. Cross-cutting veins of calcite were not seen in the field nor observed under the microscope. These features, together with the uniform texture and appearance of the albite granite, do not seem compatible with hydrothermal alteration in the ordinary sense—that is, alteration by circulating solutions that effect replacement, concentration of certain constituents, and leaching of others.

The development of albite granite is the result of a concentration of the soda at the expense of potash and lime without any marked variation in the amounts of other constituents except in the relative amount of ferrous to ferric iron. These changes are totally unlike those associated with ordinary hydrothermal alterations, and they have led me to the conclusion that the albitic magma was formed by gaseous transfer of material by volatile substances, including carbon dioxide and probably water, absorbed from the sedimentary rock.

The abundance of calcite in the albite granite in proportion to the proximity of calcareous rocks and the complete absence of calcite elsewhere afford strong evidence that carbon dioxide was derived from an outside source, and under the circumstances it is a natural supposition that water was absorbed also. Obviously residual primary mineralizers could have effected the changes described if they occurred in sufficient volume and concentration in the magma. However, in the ordinary course of events, as presumably it is the crystallization of a magma that causes the concentration of mineralizers, effective concentrations occur late rather than early, and the resulting differentiation or alteration, whether albitization or sulphide mineralization, is a late magmatic phenomenon that commonly affects the intruded rocks as well as solidified parts of the intrusion.

The existence of an albite granite magma is supported by evidence outside of the area. Albite-alaskite porphyry and albite-aplite porphyry dikes and sills of Tertiary age in the Aspen district are de-

scribed by Knopf.[42] These rocks are unique among Tertiary igneous rocks of the State that have been described, and they occur not far from the granodiorite stock of White Rock Mountain. A genetic relationship between the albite rocks described by Knopf and the albite granite facies of the granodiorite of Snowmass Mountain is naturally suggested.

To summarize briefly, the origin of the albite granite that seems most reasonable to me is as follows: The magma invaded a fault zone where the calcareous rocks were present in a broken condition, permitting ready absorption of the volatile constituents, such as carbon dioxide and water, which then became a part of the magma. Prior to and during crystallization of the magma these volatile constituents acted as mineralizers. Potash and calcium were removed, probably because the orthoclase and anorthite molecules were not stable under prevailing conditions, but the albite molecule, being stable, formed in abundance. The same method of reasoning indicates that the calcite molecule was stable, as it formed rather than anorthite. A greater stability of albite as compared with orthoclase and anorthite molecules in the presence of mineralizers is in accord with albitization in pegmatites and other rocks and also agrees with the conclusions of Bowen,[43] as well as others, in regard to the relative instability of the calcic plagioclase molecules. An abundance of calcite in areas where calcareous sedimentary rocks occur and an impoverishment of anorthite in the same areas are facts for which there is but one logical explanation—namely, Daly's theory of limestone syntexis.[44] In my opinion the evidence is so conclusive that much of the burden of disbelief must be borne by the skeptic. An outside source of mineralizers in no way minimizes the role of residual primary mineralizers of a magma, but it can account for a larger concentration of mineralizers at an early magmatic stage than would be expected if only primary mineralizers were available. The presence of carbon dioxide does not prove it to be an essential mineralizer; the volume of the volatile constituents, as well as their composition, must be taken into account. It is not unreasonable to imagine that the formation of albitic magma by a gaseous transfer of materials could proceed as readily as albitization and transfer of material by hydrothermal solutions. Thus the development of the albite granite resulted from normal physical chemical reactions that were made possible by a particular and somewhat unusual combination of circumstances.

---

[42] Knopf, Adolph. Recent developments in the Aspen district, Colo.: Geol. Survey Bull. 785, pp. 8–10, 1926.

[43] Bowen, N. L., The broader story of magmatic differentiation, briefly told: Ore deposits of the Western States (Lindgren volume), p. 114, Am. Inst. Min. Met. Eng., 1933.

[44] Daly, R. A., Igneous rocks and their origin, pp. 430–434, McGraw-Hill Book Co., 1914.

MODE OF OCCURRENCE

The Snowmass Mountain stock is rectangular in outline. It is 6 to 8½ miles across from east to west and 4 to 6 miles from north to south. The boundary within the limits of the Snowmass Mountain area is irregular, owing to the southward extension of granodiorite along a thrust-fault surface. The western part of the contact and the entire boundary outside the limits of the area are very regular and as a whole stand out in contrast with the very irregular ground plan of the White Rock Mountain stock, to the southeast, as described by Cross.[45]

The contact is well exposed high on the steeper slopes but elsewhere is generally obscured by surface cover produced by weathering. On the north and east sides of the stock the Permian grits dip away from the granodiorite, and the structure resembles that of a concordant intrusion; however, the intrusion cuts across the bedding in most places. East of Snowmass Mountain the bedding dips about 55° E., but the contact dips 65° to 75°. (See pl. 9.) South of Snowmass Mountain and at the north end of the neck of the long south extension of granodiorite the contact is well exposed and shows the sedimentary beds folded to vertical and overturned positions by the intrusion. (See pl. 10, *A*.) South of this fold (to the right in pl. 10, *A*) the outline of the contact is irregular because it dips to the south at a low angle, and it is exposed on an uneven erosion surface. The tongue of granodiorite that crosses the Crystal River apparently did not extend upward as high as the more central part of the stock and apparently represents a small apophysis intruded along the thrust-fault surface.

The contact north and west of Little Snowmass Lake, controlled by the Elk Mountain fault zone, is essentially vertical and crosses the strike of the Maroon formation. The Maroon is distorted and crushed, and its stratification has been obliterated throughout a zone several hundred feet wide. Farther west the contact along the shale is also nearly vertical and cuts across the bedding where exposed in Lost Trail and Silver Creeks. Along the contact the shale is crushed, and its stratification is not evident throughout a zone 500 to 1,000 feet wide, but beyond this the shale dips to the north, or toward the intrusion.

The intrusion of the granodiorite was accompanied by a bleaching of the red grits (Maroon) to a gray rock, and a little scattered epidote and garnet were formed. In a few places there are small concentrations of magnetite in the sedimentary rocks within the contact zone. This relatively weak metamorphism is in striking contrast to the strong alteration around the relatively small granite

45 Cross, Whitman, op. cit. (Folio 9).

intrusion of Treasure Mountain. The White Rock Mountain stock, nearly equal in size to the Snowmass Mountain stock, was the cause of pronounced metamorphism. Strong metamorphism around the granite of Treasure Mountain is in accord with the inference that the exposures represent the roof of the stock, where metamorphic effects would be greatest. Conversely, the relatively weak effects of metamorphism around the Snowmass Mountain stock are believed to represent rock alteration well below the top and on the flanks of the stock, where the concentration of rising emanations and therefore the degree of alteration would be less.

CORRELATION

The granodiorite cuts a quartz monzonite dike resembling the Lincoln porphyry and therefore, like the granite of Treasure Mountain, is later than the dikes. Direct evidence of the relative ages of the granodiorite and the granite is lacking, but indirect evidence suggests a possible genetic relationship. The soda-potash granite of Treasure Mountain is more like that of the granodiorite than that of the albite granite, and it could be a product of differentiation of a quartz diorite magma.

Snowmass Mountain, White Rock Mountain, and Mount Sopris are composed of the same kind of rock, and they are intruded close together along a fault zone; both points of similarity suggest very strongly that they belong to a single center of intrusion. Granodiorite similar in mineral composition to the stocks of the Elk Mountains is not common in any of the commercially important mineralized districts in Colorado, but this fact does not prove that the composition of the undifferentiated magmas was dissimilar. Had the different varieties of the Snowmass Mountain stock occurred as dikes, sills, or even stocks they could not be readily correlated on the basis of lithology with rock found in the parent stock.

In discussing the origin of the albite granite a genetic relationship with albite-alaskite porphyry and albite-aplite porphyry rocks of the Aspen district was suggested. The sequence of intrusion and faulting in the Aspen district given by Knopf[46] does not wholly support and at the same time does not necessarily vitiate a genetic relationship between the albitic rock of the Aspen district and the granodiorite intrusions of the Elk Mountains. Further studies would be justified to test, if possible, the validity of such a correlation.

Field data are scattered and relationships obscure, but it may develop eventually that the intrusions of the Elk Mountains, Treasure Mountain, and the West Elk Mountains can be referred to the same general eruptive period. Cross[47] held in 1894 that such a rela-

---

[46] Knopf, Adolph, op. cit. (Bull. 785), p. 13.
[47] Cross, Whitman, op. cit. (Folio 9).

tionship is reasonable for the laccolithic intrusions and dike rocks of the Ruby Range in the Anthracite quadrangle (West Elk Mountains). The variations in composition throughout this area, according to published reports, are no greater than those in the stock of Snowmass Mountain.

CONTACT METAMORPHISM
GENERAL FEATURES

Contact metamorphism is an outstanding feature of the granite stock of Treasure Mountain and in comparison is insignificant around the granodiorite stock of Snowmass Mountain. The difference may be due to differences in the composition of the magmas, but it may also be an expression of the particular part of the stock that is exposed. Treasure Mountain is the top of a stock, where metamorphic processes would be more concentrated and more intense than down along the flanks of a stock, as represented by Snowmass Mountain.

Metamorphism related to the stock of granodiorite is confined to a zone rarely over 100 feet wide along the contact, and at no place are the changes as thorough or as intense as on Treasure Mountain. The changes most commonly evident are the bleaching of some of the red beds, the development of small amounts of epidote, garnet, and diopside, chiefly in limestone pebbles in the Maroon grits, and the local concentration of small amounts of magnetite. The magnetite bodies are too small and too erratic in their occurrence to be of economic importance, and as sulphide mineralization has not occurred in the granodiorite its contact metamorphism will not be considered further.

Contact metamorphism on Treasure Mountain is described in some detail because it has a bearing on the search for ore, it caused the formation of the marble that constitutes the most important economic product in the area, and it is of scientific interest in that it represents metamorphism of an isolated intrusion that has not been complicated by subsequent changes. The relation of contact metamorphism to marble is obvious, and its bearing on the search for ore lies in the fact that without a proper understanding of it an accurate correlation of stratigraphic horizons cannot be hoped for; moreover, it is possible to mistake economically unimportant results of metamorphic alteration for indications of sulphide mineralization.

On Treasure Mountain all the sedimentary formations within the encircling outcrop of Dakota (?) quartzite are highly metamorphosed. Where the rim of quartzite is intersected and broken by faults, especially to the southeast, notable alteration of Mancos shale

has occurred. Elsewhere this shale is relatively unchanged except for a slight amount of induration, which has left it a little more resistant to the processes of weathering. The shale of the Morrison formation (Jurassic), on the other hand, even though its distance from the intrusion ranges from less than 1,000 feet to more than 10,000 feet, is uniformly metamorphosed everywhere around the intrusion to a greenish-gray hornfels. Likewise the recrystallization of the Mississippian (Leadville) limestone to white marble and changes in other sedimentary formations are everywhere remarkably uniform. The uniform alteration of the beds below the Dakota (?) quartzite and the lack of changes above it suggest that the quartzite acted effectively in limiting the extent of metamorphism. This tendency of a quartzite to limit metamorphic processes has not been previously described, but it is not unique. A similar relation is suggested in places in New Mexico, as in the Santa Rita district.[48]

Although the effects of metamorphism are so extensive as to have a regional aspect, the silicates developed are those commonly formed by contact metamorphism. Other outstanding features are the changes that are so characteristic of certain formations that they are distinct aids in correlation. The control of the composition of the rock over metamorphism is so marked as to suggest that the original elements of the rocks combined to form most of the contact minerals without the aid of introduced materials.

Before considering this conclusion further the evidence that supports it will be given in a detailed description of the contact metamorphism in the different kinds of rock. It is intended that this plan of treatment will bring out the metamorphic features that are useful to the prospector in correlating particular stratigraphic horizons.

PRE-CAMBRIAN GNEISS

Over most of the area of exposed gneiss no alteration of any kind was observed. At the very crest of the dome the gneiss is stained conspicuously red to yellow with the oxides of iron. An examination revealed a small amount of pyrite but nothing else to suggest metamorphism. The pyrite is apparently disseminated uniformly through the gneiss and is not abundant. Thin sections show some indication of granulation or shearing of the rock, but otherwise quartz and feldspar were unchanged. Unaltered biotite is present, but the localization of limonite and pyrite suggests alteration of a part of the mica. The pyrite may be related to the sulphide mineralization, which was later than contact metamorphism. However, some pyrite is commonly associated with the serpentine, and its true relation to metamorphism is not certain.

[48] Spencer, A. C., personal communication.

DIKES AND SILLS

The gabbro porphyry is least affected; it shows spots and occasional veinlets of calcite only a few millimeters across; otherwise it appears unaltered. In thin section, although the feldspar is fresh or only slightly sericitized, the ferromagnesian minerals are seen to be partly or completely replaced by combinations of calcite, chlorite, and magnetite. Locally both the primary and secondary magnetite are replaced by a mineral resembling leucoxene. In the more calcic rock, in which ferromagnesian minerals are plentiful, the chlorite is a very pale green, essentially nonpleochroic mineral with a low birefringence, suggesting a composition close to that of antigorite. It is not closely associated with magnetite, but instead it forms rims around the areas composed of calcite and quartz. In the quartz monzonite and lamprophyric rock the chlorite is penninite, which with associated magnetite replaces both biotite and augite. In most specimens replacement is complete, and except for a few remnants the identity of the primary mineral could not be ascertained. The feldspar and magnetite in quartz monzonite and lamprophyric rock, as in the gabbro, generally contain sericite and some calcite.

At the head of Rock Creek, within the zone faults, where metamorphism has been rather intense, the dikes and sills contain augite, black tourmaline, garnet (andradite), diopside, green hornblende, and epidote. Tourmaline occurs in small massive nodules, diopside and green hornblende as scattered crystals, and epidote as both scattered grains and veins. Brown to resinous garnet, some of which shows zoning and birefringence, and dark-green to black augite are most abundant and locally occur in small stringers or masses of irregular form that completely replace the rock.

SHALE

The Mancos shale, which overlies the Dakota(?) quartzite, is less altered than the shale below the quartzite. Above the quartzite the bedding planes of the shale are preserved, and its black color has been little affected, except locally. Along the fault zone in the southern part of the Treasure Mountain dome the shales are changed to a flinty hornfelsic rock sufficiently firm to serve as a surfacing for the road near Emerald Lake, whereas the unaltered Mancos shale is famed for its readiness to weather to clay that forms almost impassable sticky, muddy roads when wet. On Baldy and Cinnamon Mountains the Mancos shale is iron-stained from the weathering of pyrite, and it therefore appears much more altered than it really is. As pyrite is common everywhere through the Mancos shale its presence in this area cannot be definitely ascribed to contact meta-
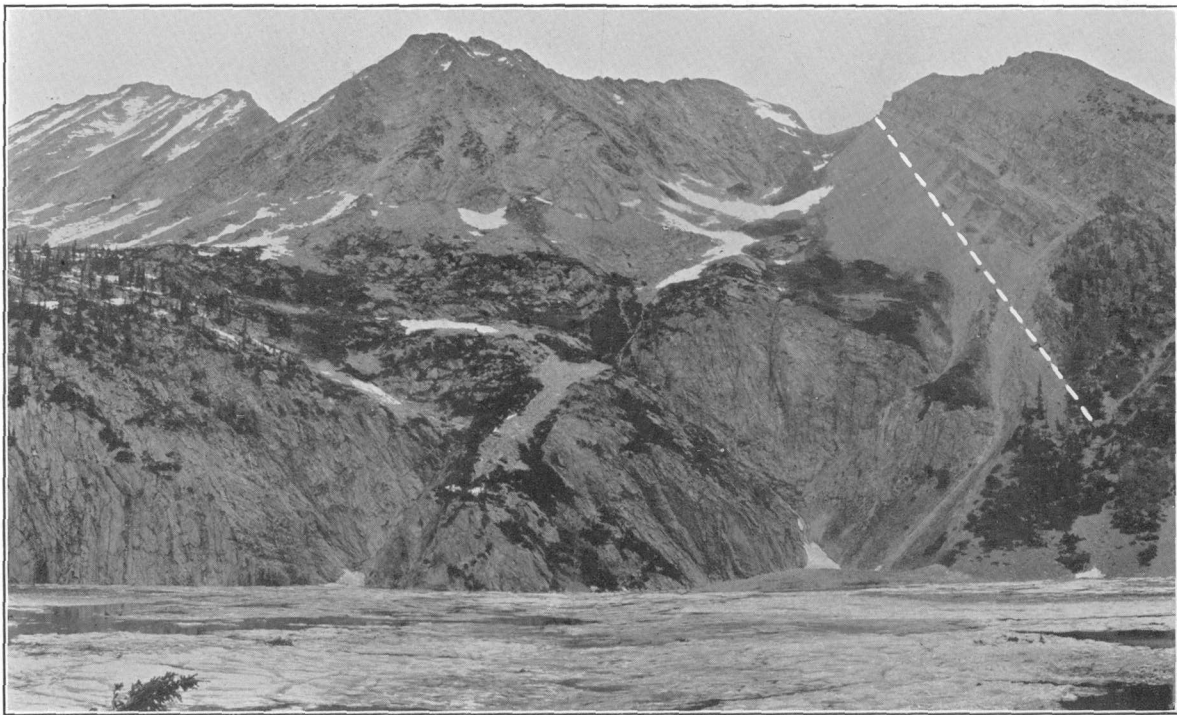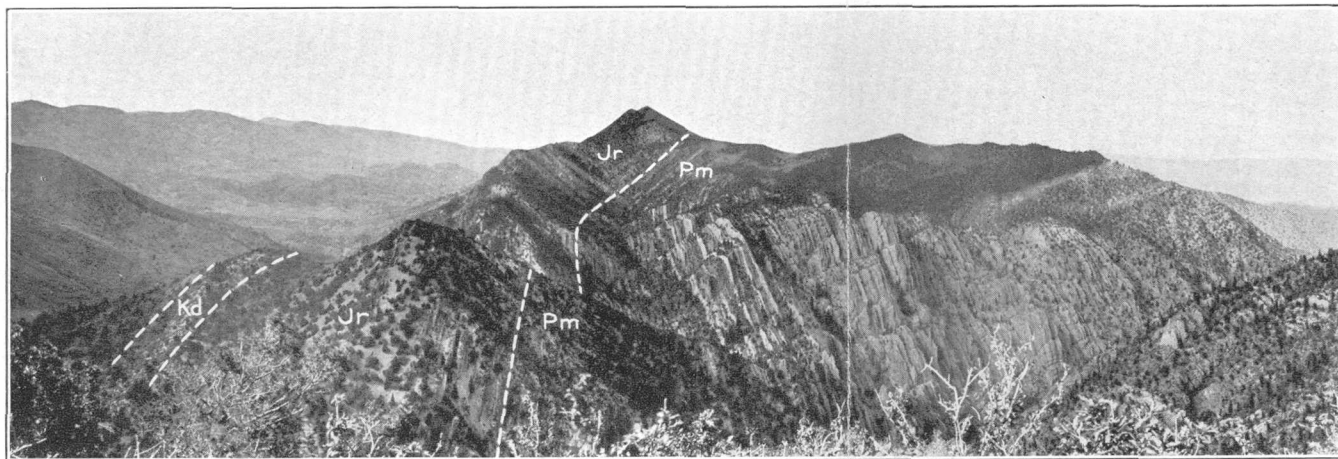
CONTACT OF GRANODIORITE OF SNOWMASS MOUNTAIN INTRUSION AND MAROON GRITS NORTH OF SNOWMASS LAKE.
Beds dip about 55° E. and the contact 65°–75° E.
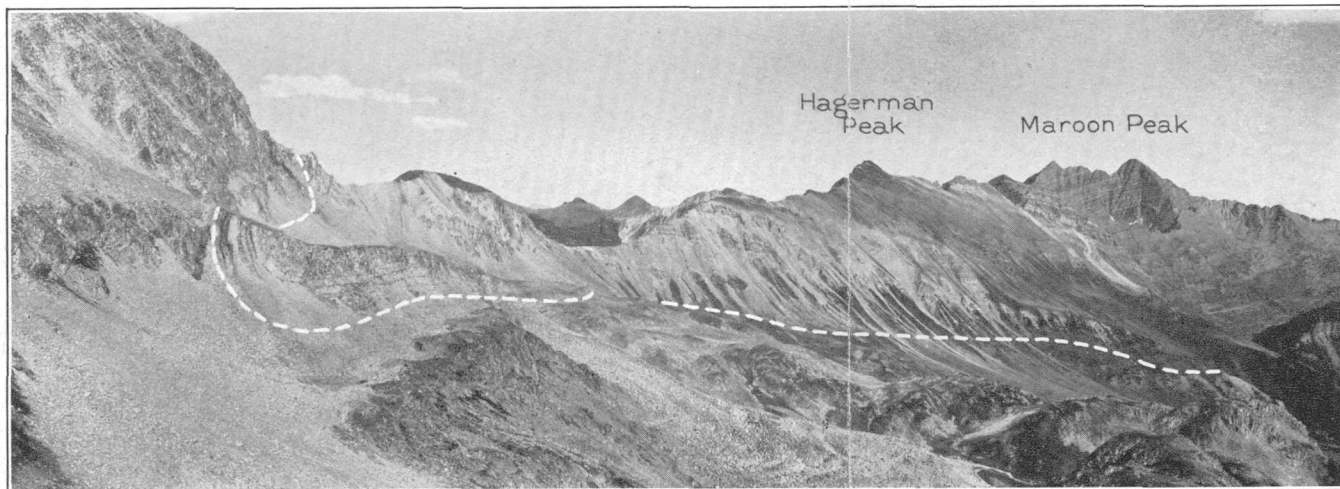
A. CONTACT OF GRANODIORITE OF SNOWMASS MOUNTAIN INTRUSION AND MAROON GRITS SOUTHWEST OF SNOWMASS LAKE.

View from west.   Snowmass Lake lies beyond low saddle to left of Hagerman Peak.

B. VIEW ALONG NORTHWARD CONTINUATION OF ELK MOUNTAIN FAULT ZONE ON THOMPSON CREEK ABOUT 15 MILES NORTHWEST OF MARBLE.

Vertical beds.   Kd, Dakota (?) quartzite; Jr, Jurassic rocks; Pm, Maroon red beds.   Longitudinal valley on left is in Mancos shale.
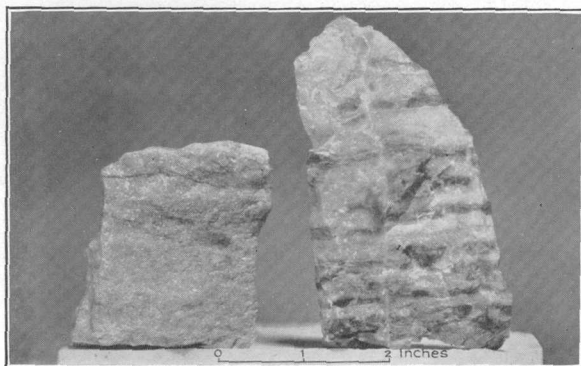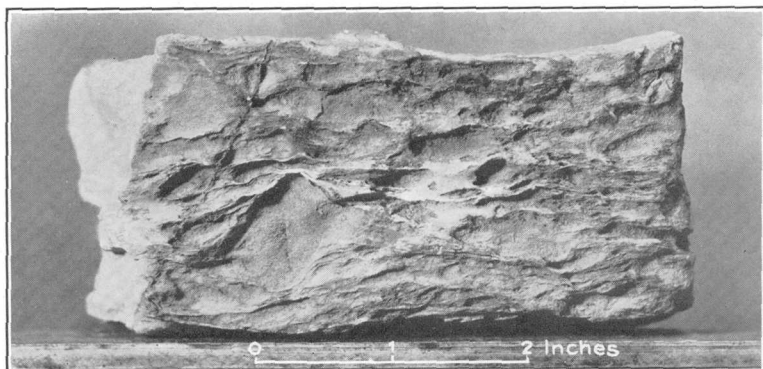
A. BANDED SERPENTINIZED MANITOU (ORDOVICIAN) DOLOMITE.

Dark bands are serpentine and light bands are carbonate.
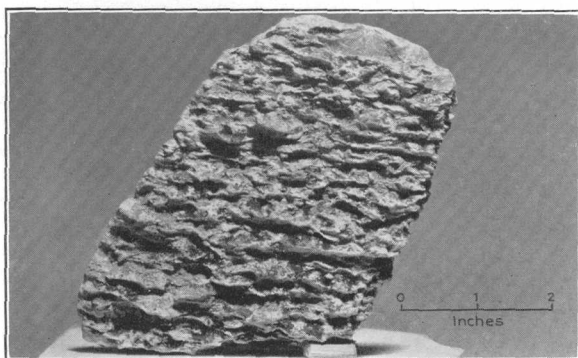
B. RIBBED PATTERN PRODUCED BY WEATHERING OF METAMORPHOSED DYER (DEVONIAN) DOLOMITE CONTAINING IRREGULAR BANDS OF DIOPSIDE.

The ribs are dolomite and the depressions between are calcite with diopside.
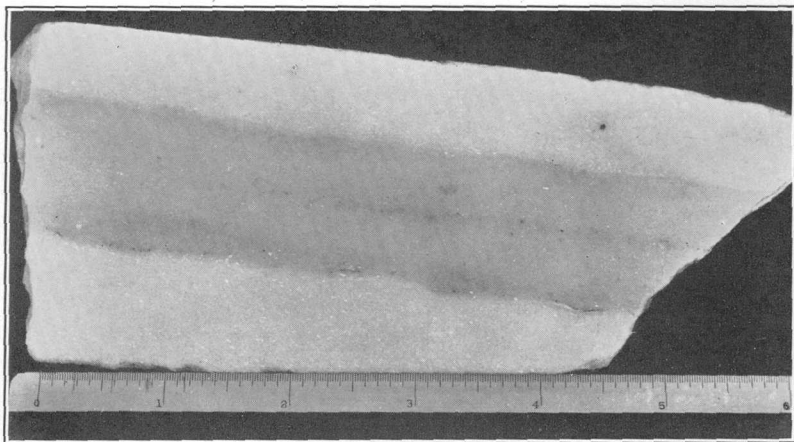

C. RIBBED PATTERN PRODUCED BY WEATHERING OF UNALTERED DYER (DEVONIAN) DOLOMITE FROM THE ALMA DISTRICT, PARK COUNTY, COLORADO.

Ribs are siliceous and depressions are dolomite.
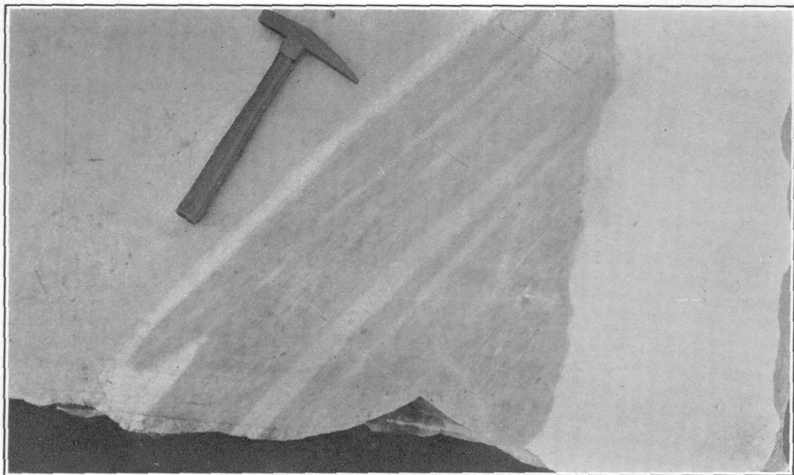
A. MARBLEIZED DOLOMITIC LIMESTONE IN MISSISSIPPIAN (LEADVILLE) LIMESTONE
ENCOUNTERED IN THE YULE COLORADO MARBLE QUARRY.

Gray patches contain partly recrystallized dolomite.

B. SILICIFIED (LIME) AREA IN MISSISSIPPIAN (LEADVILLE) LIMESTONE.

Gray band consists of quartz with inclusions of diopside (?).   Black spots are pyrite.

morphism, although such an origin is suggested by its relative abundance.

All the shales below the Dakota(?) quartzite have been altered to hornfels, a dense flinty rock that breaks into irregular angular frag-- ments. The color of the hornfels is invariably gray, usually a light shade, with a distinct greenish tint and without a trace of the original color. Hornfels from the Morrison (Jurassic) shales has a more characteristic green color than other hornfels, and this color is an aid in recognizing the Morrison horizon. From a distance the green color is not apparent, and the hornfels appears as a light to drab-gray rock.

Bedding planes have been entirely obliterated in most of the shales that do not contain sandy or limy partings. In the Cambrian and Pennsylvanian shales the effect of thin sandy and limy beds, further described under the heading "Sandy shale and shaly limestone", has been to preserve the bedding of the formations as a whole but not of individual strata of shale.

In thin section pronounced changes are evident. The flinty and finer-grained hornfels is too dense to permit identification of its constituents, although a mixture of crystalline components is apparent. The Morrison hornfels is uniformly of this type, although locally it contains numerous small black spots 1 to 2 millimeters in size that consist of colorless chlorite and a small amount of pyrite. The Hermosa(?) formation contains numerous strata of the fine-grained flinty hornfels, and on Bear Mountain it locally grades into coarse-grained rock composed almost entirely of pyroxene of the diopside-hedenbergite series. The change, which is gradational, microscopically as well as megascopically, is not accompanied by any variation in color.

QUARTZITE

The quartzites generally appear less altered than the other sedimentary rocks. In thin section relatively pure quartzite, such as the Dakota (?), shows the tightly knit quartz-grain contacts typical of true quartzite. The less pure quartzites, those of Cambrian (Sawatch), Ordovician (Harding), Jurassic (Entrada in particular), and Pennsylvanian (Hermosa?) age, are darker than the Dakota(?) quartzite and in thin section show secondary minerals interstitial to the quartz grains. The minerals coarse enough to be identified are augite, tremolite, epidote, sericite, and possibly biotite. Some calcite is generally present, but whether as an introduced product or as the original cementing material could not be determined.

Several thin beds in the Hermosa (?) formation have been altered to massive rock consisting almost wholly of augite. They resemble quartzite but obviously could represent either a limy sandstone or a

sandy limestone. The contact between the granite and quartzites was clearly defined in every exposure examined. Bain,[49] however, reports that many quartzite beds adjacent to the contact have been changed to feldspathic rock that is indistinguishable texturally or mineralogically from granite. Locally, as at the head of Yule Creek, garnet (andradite) with some pyroxene (hedenbergite) has entirely replaced as much as 15 feet of the massive beds of the basal Jurassic quartzite for more than 100 feet along the strike. The replaced quartzite occurs along the Mississippian (Leadville) limestone, which is itself also replaced by the garnet.

DOLOMITE

Dolomite was invariably recrystallized, and metamorphism developed serpentine or diopside and secondary calcite at the expense of dolomite. The metamorphosed dolomite is usually some shade of gray and is fine-grained with either serpentine or diopside sufficiently abundant to be readily recognized. In contrast, the marbleized limestones are coarse-grained and white and, except locally, are free from any metamorphic silicates. A little tremolite was observed, but nowhere is it quantitatively important, and garnet was found in only a very few places.

Serpentine is not confined to any one horizon, but is much more conspicuous and abundant in the Manitou (Ordovician) dolomite than in any other bed. It is gray, green, or yellow and occurs in irregular bands or stringers parallel to the bedding or disseminated evenly through the rock. Small but distinct veinlets both parallel to and cutting across the bedding are not uncommon. The banded serpentine shown in plate 11, A, is characteristic of the Manitou dolomite and is a means of recognizing this formation. At the head of Yule Creek individual bands of serpentine are fully half an inch thick and form an attractive rock that might be suitable as a building stone. Banded serpentinized dolomite of the Manitou is also well developed and is exposed on the north flank of Treasure Mountain on the slopes east and south of Whitehouse Mountain, but the outcrops are covered and do not extend down to the road along Crystal Canyon, where it is, however, represented by much float. Serpentine disseminated through dolomite is local in its development and can be recognized by the characteristic pitted surface produced by differential weathering. Fractured surfaces show the gray spots of serpentine in a groundmass of white calcite marble. The properties of the serpentine closely approach those of antigorite, although the fibrous habit of the mineral prevented the determination of all the diagnostic optical properties, and in places very small veinlets of serpentine were observed

[49] Bain, G. W., Roof of the Treasury Mountain granite (abstract) : Geol. Soc. America Preliminary list of titles and abstracts of papers to be offered at the forty-ninth annual meeting, Cincinnati, Ohio, p. 7, 1936.

that approached chrysotile both in index of refraction and in birefringence. In thin sections some of the disseminated serpentine showed slightly higher birefringence than the average for antigorite but otherwise appeared similar.

Diopside is as widespread and almost as abundant as serpentine. It is gray to white and as a result is not always conspicuous. Like serpentine, diopside has developed in all the dolomites, and, although the two minerals are found in the same specimen, diopside is most characteristic in those strata in which serpentine is less common. Diopside occurs in very irregular bands parallel to the bedding and is also widespread as a disseminated mineral. On weathered surfaces the irregular bands of diopside show a peculiar ribbed pattern. (See pl. 11, B.) The resistant "ribs" are dolomite, and the depressions mark areas of calcite and diopside. On freshly fractured faces the diopside is either inconspicuous or not evident and cannot as a rule be recognized megascopically. In thin section the coarser-grained diopside is readily recognized because of its high relief and its birefringence. The finer-grained diopside commonly occurs along the grain boundaries of the carbonate, where it is not easily recognized; several specimens examined in thin section appeared to contain only carbonate, and yet by dissolving the specimens in hydrochloric acid an appreciable percentage of diopside was found. The diopside has the common habit of forming essentially equidimensional grains in which cleavage is only poorly developed. It is replaced by serpentine where the two are associated, and very commonly it is also partly replaced by calcite. Lathlike crystals with characteristic pyroxene twinning and cleavage occur locally. The indices of refraction indicate a relatively pure diopside.

Calcite formed with both serpentine and diopside at the expense of the mineral dolomite, and locally veins of white calcite cut the recrystallized dolomite. Extensive replacement of dolomite by calcite may have occurred in the beds immediately below the Mississippian (Leadville) marble. Gillson [50] reports marked replacement of dolomite by calcite in contact metamorphism in the Pioche district, and this phenomenon may be more common than has been realized. It is possible that this may have a significant bearing on the characteristic sulphide mineralization in dolomite zones relatively distant from areas of contact metamorphism.

LIMESTONE

The Mississippian (Leadville) limestone is the outstanding formation in the area, and it has been recrystallized to an attractive white rock known commercially as the "Yule Colorado marble." The Fre-

---

[50] Gillson, J. L., in Westgate, L. G., and Knopf, Adolph, Geology and ore deposits of the Pioche district, Nev.: Geol. Survey Prof. Paper 171, p. 37, 1932.

mont limestone, the highest formation of the Ordovician, is also a white marble very similar in appearance to the Yule Colorado marble. In both formations metamorphic minerals are lacking over large areas; in fact, except for masses of garnet related to the upper contact, it can be said that silicates are essentially lacking in the pure calcite marble. The marble in direct contact with granite has become extremely coarse-grained.

Irregular masses of a grayish rock composed of fine-grained cloudy dolomite are encountered in the quarries of the Yule Colorado marble. They are termed "lime" by quarrymen and constitute an objectionable feature because of their color and the fractures they invariably contain. Two types of "lime" are present. (See pl. 12, A, B.) One type (pl. 12, A) has gradational and uneven boundaries, and masses of it range from a few inches to several feet across, with a definite tendency to elongation parallel to the bedding. The fractures are partly or wholly filled with calcite, which also replaces the walls, forming white bands across the dolomite. This replacement is evident only on large cut faces and not in thin sections. The cloudiness and the fine grain of the dolomite (0.05 to 0.10 millimeter) suggest that it is a primary texture, as the recrystallized dolomite consists only of aggregates of the clear colorless mineral. It is concluded that the rock was originally dolomitic and therefore slower to recrystallize completely.

The second type of "lime" differs in most respects, except color, from the first. It has a tabular form (pl. 12, B), with well-defined boundaries parallel to the bedding. Cross sections are lenticular, in places 4 feet long and about 1 foot thick. The larger masses show an interior consisting of calcite surrounded by an indistinct rim about an inch wide of a dense rock composed of granular quartz, calcite, and small amounts of tremolite. The boundary of each side of the rim is gradational, and the quartz occurs throughout its width, but the tremolite is confined to the outside border. The quartz grains, only a fraction of a millimeter across, show inclusions tentatively identified by their high index of refraction and birefringence as diopside.

The origin of this second type of "lime" is not clear, but local concentrations of sphalerite along the border suggest that mineralizing solutions formed them. These occurrences of sphalerite are not common; quarrymen reported only occasional occurrences of this kind during several years of quarrying. However, sphalerite in veins throughout the area is accompanied by silicification, and the presence of even a small amount of the sulphide suggests a similar relation.

Locally the Yule Colorado marble is veined by coarse gray calcite. The veins are irregular and are finer-grained at the margin than at the center. Also the gray calcite forms nodular masses 2 to 3 feet across and the matrix of white marble breccia. These several features are shown in plate 13, *A*. The coarse gray calcite was observed in the quarry near the upper part of the bed of marble. It occurs only locally, and its significance is not clear.

SANDY SHALE AND SHALY LIMESTONE

The Hermosa (?) and Maroon formations vary much in lithology and composition. Details of the original character of a particular metamorphosed stratum on Treasure Mountain can therefore only be inferred, but in spite of the changes it is evident that before metamorphism the Hermosa (?) formation in neighboring areas consisted of sandstone, shales, limestone, dolomites, and rocks of intermediate composition. There can be little question that the Maroon beds that are now gray were formerly red, as they are in neighboring areas. It has not been possible, however, to determine whether a metamorphosed sedimentary rock with one or more of the secondary silicates represents sandy shale, shaly limestone, or a rock of some intermediate composition. For this reason, and because they show a greater variation in metamorphic silicates than is found in the rocks of simpler composition, these formations are considered separately.

The Hermosa (?) formation contains numerous calcareous beds, many of which have an appreciable content of magnesium and have developed an abundance of diopside and serpentine as well as local small amounts of tremolite. These minerals are particularly conspicuous along cherty zones in calcareous rocks. In places in Bear Basin chert nodules in all stages of replacement by serpentine (antigorite) were found, and some of these nodules contain coarse antigorite crystals resembling mica in general appearance. Garnet and epidote are particularly characteristic of these intermediate sedimentary rocks. Individual beds of relatively pure dolomite, shale, and quartzite show the usual diopside and serpentine already described as occurring in rocks of these compositions. The general effect of metamorphism has been to accentuate the bedding by producing a particular combination of silicates that expresses the original composition of each bed. The result is that in outcrop the Hermosa (?) formation is distinctly banded; this banding and the limestone content set it apart as distinct from any other formation.

The Maroon formation contains an abundance of epidote and also some garnet. Epidote occurs through the entire formation in small amounts. It is found in the interstices between the grains and coating surfaces of joints and probably accounts for the loss of the

original red color of the formation. Garnet (andradite) is scattered throughout the formation and is commonly concentrated in limestone pebbles of the conglomerate, but garnet does not replace individual beds.

Locally the feldspathic sandstones, especially the fine-grained ones, resemble altered igneous rocks of intermediate composition even in thin section. The general effect of the changes has been to make the bedding stand out just as it does in the Hermosa (?) formation. However, the feldspathic content and the presence of conglomerates make the recognition of the Maroon formation easy.

INFLUENCE OF STRUCTURE ON METAMORPHISM

Proximity to the granite has had less influence on the character and degree of metamorphism than faults and sedimentary contacts. In places rock several thousand feet from the granite has been more completely replaced or recrystallized than rock in contact with granite.

Metamorphic minerals are concentrated in several places along contacts of sedimentary formations and locally along the contact between the granite and calcareous sedimentary rocks. These zones of metamorphism consist of beds of garnet 50 feet thick and of diopside with magnetite 10 feet thick. They therefore stand out in contrast to rocks showing the general changes previously described. Much massive yellow-brown to green garnet (andradite) has developed along and in the upper part of the Mississippian (Leadville) marble at the head of Yule Creek, and certain beds in the Maroon formation on the west slope of Treasury Mountain are also highly altered. The alteration of these beds may, however, be more closely related to small faults than to favorable contacts. The massive garnet averages only a few feet in thickness but may be as much as 50 feet thick, and in addition there are numerous irregular-shaped bodies of garnet in the upper part of the marble. The contact of garnet and marble is everywhere sharp, and nowhere does the marble contain veins or disseminated silicates. With the garnet there are small amounts of hedenbergite and epidote. The epidote coats the surfaces of vugs and is therefore a late mineral. The relative age of the hedenbergite is not certain, but it is intergrown with the garnet, and the two appear to be essentially contemporaneous. In the same area similar masses of garnet are found along some of the calcareous beds of the Hermosa (?) formation. The amount or intensity of replacement does not appear to be related directly to their proximity to the intrusion; in fact, the intrusive contact as a whole exhibits relatively little metamorphic action. It seems, therefore, that the concentration of the massive bodies of garnet or diopside with magnetite was largely dependent on or controlled by

certain favorable structural conditions and by permeability in the same degree that these features commonly control the formation of metalliferous deposits.

The slight metamorphism along the intrusive contact is dependent in part on the nature of the wall rock. For example, where the wall rock is gneiss or quartzite no indication of alteration was noted. Where the granite is in contact with the marbleized Leadville (Mississippian) limestone silicates have not formed, but the grain of the marble is invariably coarse, averaging 1.0 to 2.0 centimeters, whereas elsewhere it uniformly averages about 2 millimeters. Intrusive contacts between granite and dolomite, limestone, and mixed sedimentary rock show slight to marked changes. On Bear Mountain much biotite was found through a narrow zone in the Pennsylvanian sandstones, whereas along the north side of Crystal Canyon no unusual changes were noted. On the east side of Bear Basin, where the granite cuts across the Devonian dolomite, massive green diopside with some magnetite 3 to 10 feet thick is present.

The influence of faults on metamorphism is shown on Treasury and Galena Mountains and at the head of Rock Creek. In these areas manganiferous hedenbergite is characteristic and locally abundant in the veins along the faults, and the walls of the veins contain much diopside, garnet, and some tourmaline. The Mancos shales are noticeably more indurated along the fault zone on the northwest slope of Sheep Mountain and to the southwest on Rock Creek and on the west side of Emerald Lake. Garnet (andradite) is very common in the Maroon beds along this fault zone, whereas it is almost lacking at the west end of Sheep Mountain, outside of the fault zone. Just how much of the metamorphism can be attributed to the faulting cannot be determined, but the presence of hedenbergite and tourmaline in the veins along some of the faults indicates that solutions passed along them. The general effect of the faulting seems to have been to cause relatively strong alteration in places more remote from the intrusion than would have been affected had no faults been present.

The veins with manganiferous hedenbergite represent a transition between rock alteration due to metamorphic processes and the formation of veins containing sulphides. This relation is described in the section on sulphide mineralization.

ORIGIN OF METAMORPHIC SILICATES

Some of the metamorphic changes necessitate the introduction of metamorphic materials, and others are most logically explained by simple recrystallization. Thus limestone changed to marble and shale to hornfels by simple recrystallization, whereas the massive

beds of garnet along the sedimentary contacts and along faults could form only by the introduction of materials.

The origin of the silicates in the dolomites is more obscure, but the marked control of the composition of the rocks in general is significant. All the silicates in dolomite, shale, and intermediate rock can be theoretically accounted for by an increased activity of the connate water due to a rise in temperature, which would necessarily accompany the intrusion of the granite. It is difficult to evaluate the importance of material, if any, introduced by solutions, but if all the elements represented by the metamorphic silicates circulated freely the minerals should not be much more characteristic of one horizon than of another, and they could be expected to occur, in small amounts at least, in the limestones as well as in the dolomites. The diopside with calcite which developed the ribbed pattern in the Dyer (Devonian) dolomite, shown in plate 11, *B*, could readily have formed by recrystallization of a siliceous dolomite, shown in plate 11, *C*, and does not suggest introduction of much material. Dolomite of the Devonian is known to contain free silica, and yet free silica was not observed with the diopside and calcite in the metamorphosed dolomite of this age on Treasure Mountain, a fact which suggests that it was utilized to form the silicates.

Where solutions circulated freely, as along the faults, silica was introduced, and as the metamorphosed dolomite, limestone, and shale do not as a whole contain free silica the conclusion is that the solutions did not circulate freely through these rocks. Therefore little or no material was introduced, and the metamorphic minerals formed at the expense of those originally present in the rock. Along faults and contacts that were sufficiently pervious the solutions introduced elements, either with or without an exchange of material, to form massive bodies of andradite, diopside, and hedenbergite.

STRUCTURE

GENERAL FEATURES

The outstanding structural features of the area are the pre-Jurassic angular unconformity, the Elk Mountain fault, and the dome of Treasure Mountain. The faults along which mineralization occurred are a part of the dome structure and are therefore included with it. These features, except the faults related to the Treasure Mountain dome, have no bearing on the mineralization of the area, but they are of general interest in their relation to the geologic history not only of the Elk Mountains but also of the Sawatch Range and the White River Plateau.

As only one of the three structural features is important in relation to ore deposits, they are described in the order of their relative
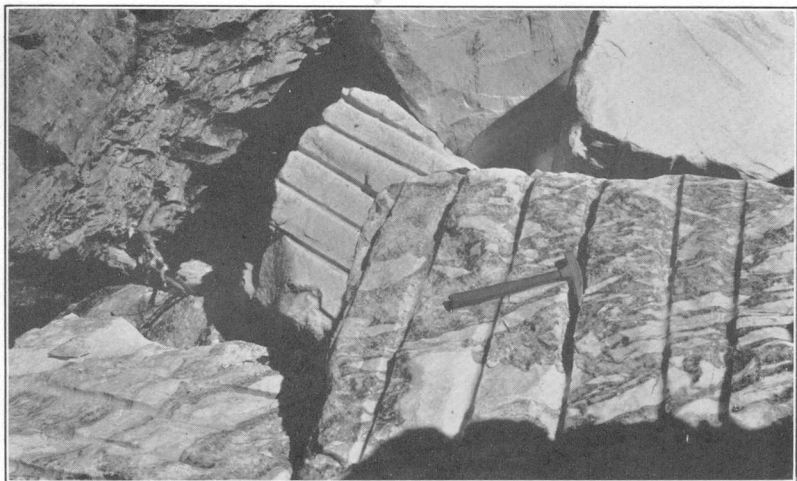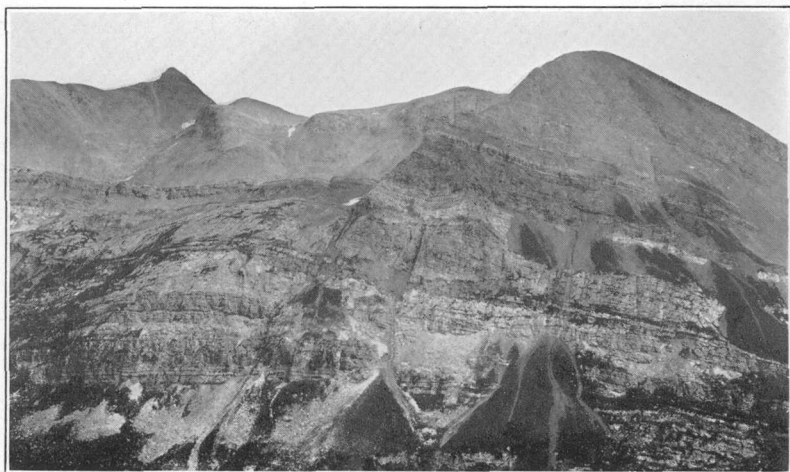
A. COARSE GRAY CALCITE OCCURRING IN VEINS AND AS MATRIX OF WHITE
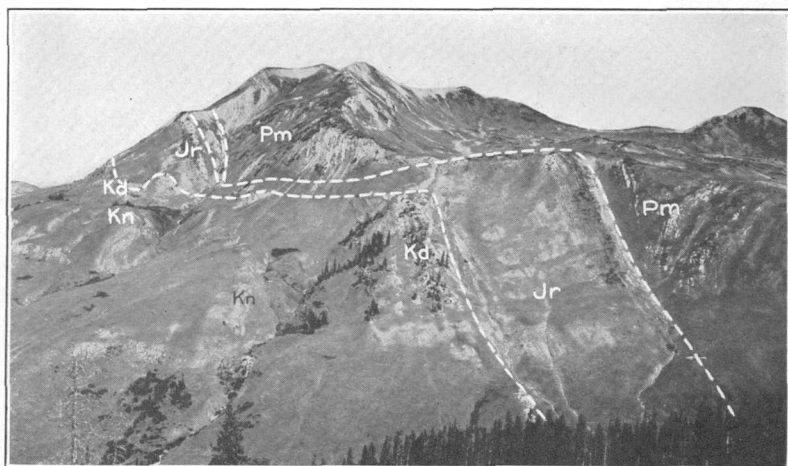MARBLE.

Found locally in upper part of the Mississippian (Leadville) limestone in the Yule Colorado marble
quarry.
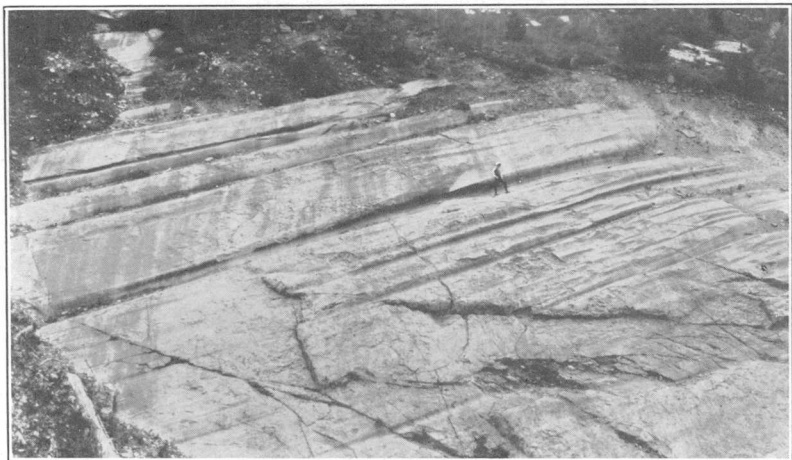
B. GLACIAL GROOVES IN DEVONIAN DOLOMITE IN YULE CREEK A LITTLE EAST OF
THE YULE COLORADO QUARRY.

A. ANGULAR UNCONFORMITY BETWEEN THE PALEOZOIC AND JURASSIC FORMA-
TIONS AS EXPOSED NEAR THE HEAD OF YULE CREEK ON THE SOUTH SIDE OF THE
VALLEY.

B. ELK MOUNTAIN FAULT ZONE EXPOSED ON NORTHWEST SIDE OF THE EAST FORK
OF ROCK CREEK EAST OF SCHOFIELD PARK.

Kn, Limestone of Niobrara age in the Mancos shale; Kd, Dakota (?) quartzite; Jr, Jurassic rocks; Pm,
Maroon formation.

geologic age. The pre-Cambrian structure is unknown. Within the area no evidence has been found of folding or faulting throughout Paleozoic time, as the Paleozoic beds show only disconformable contacts. Bain[51] has suggested that the marked linear structure of grains in the marbleized Leadville limestone and the presence of pebbles of identical rock oriented at random in overlying conglomerate beds of the Hermosa formation may imply a distinct deformation and therefore marbleization of the Leadville limestone in pre-Hermosa time, but, as no evidence of distinct folding at that time has been found anywhere in Colorado, it is difficult to prove sufficient deformation for the formation of marble. It must also be admitted that the Leadville limestone is dark blue throughout the State, except where affected by igneous intrusion or mineralizing solutions, and therefore that its white color in the Snowmass area is consistently attributed to the influence of the intrusive granite and associated mineralizing solutions.

The earliest period of folding is indicated by the angular unconformity at the base of the Jurassic. After this folding, quiet again prevailed through the period of erosion represented by the flat surface of the unconformity and continued through the deposition of the Cretaceous beds. Movements involving displacements of more than 7,000 feet along the Elk Mountain fault zone came at the end of the Cretaceous period and in early Tertiary time and produced the regional southwest dips west of the fault zone and the regional northeast dips east of it. The duration of these movements is not known, but after they ceased the granodiorite in the Elk Mountains and the granite of Treasure Mountain came into place. The intrusion of granite arched the overlying sedimentary beds and produced some faults and fractures, along which mineralization occurred as the closing chapter of a history of volcanic activity.

PRE-JURASSIC ANGULAR UNCONFORMITY

The presence of the angular unconformity at the base of the Jurassic is shown on the geologic map of the Crested Butte quadrangle (Folio 9). As the Jurassic (Gunnison formation of the map cited) cuts out the Paleozoic formations in an area of poor exposures where there is evidence of thrust faults, the true nature of the relations has been in some doubt. On Treasure Mountain the angular surface of the Paleozoic is well exposed in several places but probably better shown at the head of Yule Creek (pl. 14, A) than elsewhere. This surface ranges in dip from 20° to 28°. The lower figure was obtained by direct measurement in North Pole Basin, and the higher figure was calculated from the fact that formations 4,800 feet in total thick-

---

[51] Bain, G. W., oral communication.

ness are cut out from Lead King Basin to Yule Creek in a distance of 26,000 feet.

The present form of the surface of the unconformity is that of a dome conforming with the general shape of the Treasure Mountain uplift. The line of contact, however, is an even line wherever the surface is exposed, whether along or across the strike of the beds. Hunter [52] describes the base of the Jurassic along the Gunnison River as "remarkably sharp and straight" and regular except where disturbed by later faulting. Burbank [53] has noted a similar relation in the San Juan Mountains. From this evidence it is concluded that the surface on which the Jurassic was deposited was a well-developed peneplain.

An effort was made to determine the trend of the beveled edges of the Paleozoic beds across the pre-Jurassic surface. Direct observations are not easily interpreted because of the doming of Treasure Mountain. Along Yule Creek the trend of the beveled edges is about N. 50° W. A line drawn from this area to that of the Crested Butte quadrangle along the southwestern limits of the Paleozoic beds trends N. 40° W. These two figures are in fair agreement and mark the probable trend of the sedimentary formations that cropped out on the flat pre-Jurassic surface. This structure is parallel to that of the dominant trend of the more recent Rocky Mountains and is in accord with the general belief that the crustal disturbances of the later periods were probably controlled by the structure established much earlier.

STRUCTURE OF TERTIARY ROCKS

The Tertiary structural disturbances in the area are discussed in the order of their sequence, which is intrusion of dikes and sills along a northeastward-trending zone, regional diastrophism that made the Elk Mountain fault zone, and igneous intrusion that made the Treasure Mountain dome.

The dikes and sills are related to intrusions known to be younger than the Tertiary formations in the Anthracite quadrangle,[54] to the south, and the Elk Mountain fault zone involves the Tertiary beds in the Huntsman Hills and Grand Hogback, to the northwest.

NORTHEAST TREND OF EARLY DIKES

In the southeastern part of the area are several dikes of the Lincoln porphyry type with a northeast trend. This trend is parallel to and in line with that of many of the dikes of the Ruby Range, in the Anthracite quadrangle, to the southwest, but it has no recognized

[52] Hunter, J. F., Pre-Cambrian rocks of Gunnison River, Colo.: Geol. Survey Bull. 777, pp. 7–8, 1925.

[53] Burbank, W. S., personal communication.

[54] Eldridge, G. H., op. cit. (Folio 9).

local significance or importance. It is of interest because of its parallelism to the mineral belt from the San Juan Mountains to Boulder County. The structure is older than the Elk Mountain fault zone, as the dikes are displaced along that zone. The dikes are also faulted as well as altered by the intrusion of the granite of Treasure Mountain. This northeasterly trend is therefore the oldest recognized Tertiary structure in the area.

ELK MOUNTAIN FAULT ZONE

Principal features.—The Elk Mountains contain three large in-trusions of granodiorite along a zone of uplift, folding, and fault-ing. This zone will be referred to in this report as the Elk Moun-tain fault zone. (See pl. 1.) Hayden[55] discovered the zone in 1873 and described the overturned beds between Mount Belleview and Snowmass Mountain. His interest led him to have a special study made of the Elk Mountains in 1874 by Holmes,[56] who in his report described the structure in some detail as a "fault-fold." Holmes' analysis and interpretation are embodied in his illustrations reproduced on plate 15. Neither Hayden nor Holmes discussed the continuation of the fault-fold beyond the limits of the Elk Moun-tains proper. Hills[57] has pointed out that to the north and north-west the fault zone is continuous with the Grand Hogback fold, which in turn continues to the northwest and thence west along the south side of the Uinta Mountains to the Wasatch Mountains in Utah. In view of the fact that the structure was known to continue for many miles to the north it is surprising that Eldridge[58] in his description of the Crested Butte quadrangle did not consider more seriously its extension southward. He remarked in passing that certain overturned beds and sharp anticlinal folds resemble and are parallel in trend to the fault-fold of the Elk Mountains, but he made no effort to correlate the two, although the relation seems to be apparent. It remained for Burbank[59] to trace the fault zone from the Crested Butte quadrangle to a point a short distance south of the Gunnison River.

It is not feasible in a report of this kind to discuss in detail regional structure that extends for many miles beyond the limits of the area described. However, it is necessary to consider some of the regional aspects of the fault zone in order to bring out its relation to the large intrusions of granodiorite. In addition, there are certain

---

[55] Hayden, F. V., Geology of Elk Mountains: U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept., pp. 58–69, 1874.

[56] Holmes, W. H., Report on the geology of the northwestern portion of the Elk Range: U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., pp. 57–72, 1876.

[57] Hills, R. C., Orographic and structural features of Rocky Mountain geology: Colorado Sci. Soc. Proc., vol. 3, p. 409, 1891.

[58] Eldridge, G. H., op. cit. (Folio 9).

[59] Burbank, W. S., Geologic map of Colorado, 1936.

aspects that promise to throw light on Rocky Mountain structure and geologic history. Field work, particularly in the area to the south of the Elk Mountains, was insufficient to permit a detailed consideration of the regional nature of the fault zone, but as many facts as were observed and are known will be added to the more local description.

Local features.—On the slopes east of Schofield Park Maroon red beds occur above 800 to 1,000 feet of younger overturned strata. These younger strata include Entrada and Morrison formations (Jurassic), Dakota (?) quartzite (Cretaceous), and the lower 200 to 300 feet of the Mancos shales (Cretaceous), including the limestone of Niobrara age and the shale of Benton age. The strike of the overturned beds and the Maroon beds is parallel, and they all dip eastward. As seen from a distance, these strata lie in apparent conformable relations for a distance of more than 6 miles in the area between Snowmass Mountain on the north and Mount Belleview on the south. Throughout this distance (see pl. 6, *A*) the continuity of the exposures of the Entrada and Morrison formations, Dakota (?) quartzite, and limestone of Niobrara age in the Mancos shale does not give an impression of the great disturbance involved. Even a detailed examination of outcrops in most places shows only apparent conformable and normal depositional relations. True relations are shown, however, where the fault zone is traversed by an east tributary of Rock Creek. On the south side of this tributary near the saddle north of Mount Belleview (see pl. 1) the continuity of the Morrison shale and Dakota (?) quartzite is interrupted, and the faulted ends of these formations have been squeezed into a sharp isoclinal anticline that plunges very sharply to the south. On the north or opposite side of this valley the crumpled Maroon red beds are exposed (see pl. 14, *B*) as they appear east of the main zone of overturned Jurassic and Cretaceous beds. The close folding evident in plate 14, *B*, is as a rule not apparent on the beveled edges of the beds, which everywhere are essentially parallel. In most places, however, the Maroon strata dip 70°–85° E., whereas the overturned younger beds dip 55°–60° E. The cross section shown on plate 14, *B*, is therefore not a mere local feature.

The Maroon beds south of Snowmass Mountain that dip 75°–85° E. occupy a zone 3,000 to 4,000 feet wide. Adjacent to this zone on the east the Maroon beds have dips of only 20°–30°, which flatten to 5° or 10° on the west flank of Maroon Peak. Gentle easterly dips continue to the east and north without apparent interruption as far as the Aspen district, 10 to 15 miles distant. The boundary between the steeply dipping beds and the gently dipping beds marks a thrust-fault surface that was followed by the long tongue of granodiorite. In the southern part of the area the thrust

fault cuts out the steeply dipping Maroon beds, and in Rustler Gulch, just south of the area, it cuts out all the overturned formations as well as all the Mancos shale. At the head of Rustler Gulch faulted Maroon strata rest on Dakota (?) quartzite, and the thrust fault is intersected at a relatively steep angle by the granodiorite of White Rock Mountain. The Elk Mountain fault zone, including the overturned Jurassic and Cretaceous beds and the steeply dipping Permian beds in the northern part of the area, is over a mile wide; and to the south, in Rustler Gulch, where the overturned strata are cut out, the width of the fault zone is less than 200 feet.

Movement.—Three types of movement are represented in the Elk Mountain fault zone—first, vertical and horizontal displacements that resulted from the formation of a monoclinal fold; second, apparent reverse or upthrust faulting in which the horizontal and vertical components of movement were nearly equal; and third, thrust faulting in which the horizontal movement predominated. It is not possible to estimate the amount of displacement referable to each type of movement. In fact, the total combined displacement that has occurred along the Elk Mountain fault zone cannot be determined accurately because key beds are lacking. The series of beds (Maroon formation) with gentle easterly dips referred to above is more than 4,000 feet in total thickness near Maroon Peak, and beyond toward Aspen an additional thickness of several thousand feet appears to be present in an unbroken succession. Although a repetition of beds was not recognized it is not safe to infer without further study that repetition of beds could not have occurred. The Maroon beds west of the thrust fault are folded, and they stand nearly on end in a zone about 4,000 feet wide. In this zone repetition is suggested, as is shown on plate 14, *B*, but whether these beds represent the upper, middle, or lower part of the Maroon formation could not be determined. The lowest of the Maroon beds east of the thrust fault dip gently eastward and are 2,000 feet vertically above the Dakota (?) quartzite in Schofield Park. Holmes in 1874 estimated the vertical displacement at 8,000 to 11,000 feet, and Hills in 1890 estimated it at 8,000 feet. The great thickness of Maroon beds to the east implies a large displacement—in fact, if there is no repetition of beds there must be a relative uplift on the east of fully 12,000 feet.

The amount of horizontal movement of the upthrust is also difficult to ascertain. Holmes estimated it as not less than 6,000 feet, which is indeed a conservative figure, as the dip of the fault necessitates a horizontal component, normal to the strike of the fault, comparable to the vertical component. If, as seems probable, the isolated masses of Morrison shale and Dakota (?) quartzite along the thrust fault (see pl. 1) were dragged from the edges of the overturned beds north-

east of Mount Belleview there may be a north component of the thrust amounting to 1 or 2 miles. There is no other apparent source for these isolated slices of Morrison and Dakota (?) beds unless they are the continuation of the overturned strata to the west, which would also call for a large horizontal component. Evidence of faulting in the Mancos shale could not be found. Moreover, there is good reason, as originally stated by Holmes, for believing that the overturned formations constitute the eastern limb of a sharp syncline lying to the west. (See cross sections, pl. 1.) The amount of movement along the fault zone decreases and apparently dies out to the north, and it appears to increase to the south. This relation has been confused by the two large stocks of Snowmass and White Rock Mountains, both of which have been intruded along and across the faults and have thus complicated field relations. The Castle Creek fault at Aspen is very similar in many of its features to the Elk Mountain fault zone. Recent studies indicate that the fault near Aspen may be continuous with a zone of thrust faulting in the vicinity of Tincup and Pitkin,[60] about 60 or 70 miles to the south. Similarly the thrust faulting of the Elk Mountain fault zone also continues for some distance to the south.

Northward extension.—The fault zone in the Elk Mountains is part of a regional structure that extends northward unbroken to the Uinta Mountains. I followed this structure for a distance of more than 100 miles, to a point 20 miles northwest of Price Creek, a post office in Moffat County. Throughout this distance this zone is unbroken except for the intrusion of Snowmass Mountain, which cuts it out for 3 or 4 miles. The outstanding features observed in going northward are marked changes in strike (see fig. 6) and the progressive change from the area of thrust faulting and upthrusts accompanied by overturning of beds east of Schofield Park to an area of normal faulting in the limb of a well-developed monocline at Placeta, about 12 miles northwest of Marble. Farther north the structure changes to that of a sharp monocline with relatively little faulting.

The marked changes in strike (see fig. 6) are (1) from N. 30° W. in the area east of Schofield Park to nearly west in the area north of Marble; (2) from west to almost north near Placeta, continuing north for a distance of about 30 miles along the west side of the Crystal River and the Roaring Fork to Glenwood Springs; and (3) at Glenwood Springs to N. 70° W. for nearly 25 miles, beyond which it again curves more nearly north for 25 miles to a place where it crosses the White River west of Meeker. This section from Glenwood Springs to the White River is the Grand Hogback proper,

---

[60] Butler, B. S., Burbank, W. S., and Goddard, E. N., personal communication.

and for this distance the structure flanks the White River Plateau. North of the White River for 10 miles the strike changes to northeast, as if continuing around the plateau, but it abruptly veers back to N. 40° W. and maintains this course at least as far as a point 20 miles beyond Price Creek post office. The course beyond this point shown in figure 6 is taken from Hills' description, already
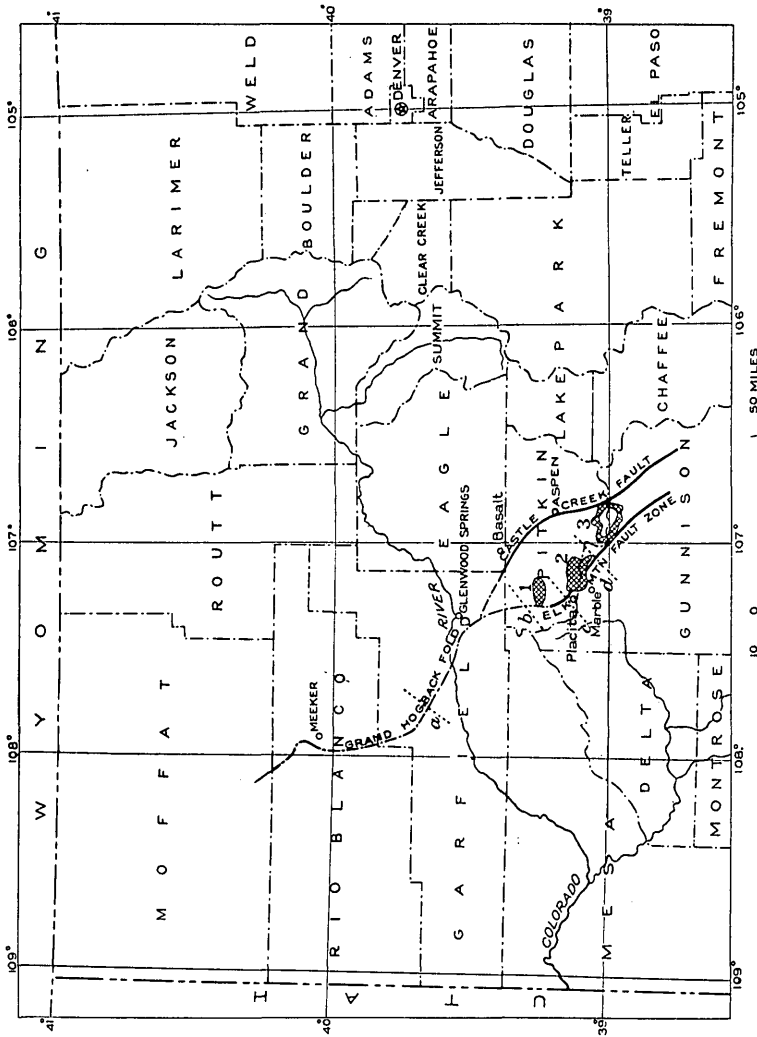

FIGURE 6.—Map showing the Elk Mountain fault zone and the Castle Creek fault at Aspen, in relation to the Grand Hogback monoclinal fold and to the intrusions of granodiorite in the Elk Mountains. 1, Mount Sopris intrusive; 2, Snowmass Mountain intrusive; 3, intrusion of White Rock Mountains and Sawtooth Range. Dotted lines at a, b, c, and d show approximately the positions of diagrammatic cross sections in figure 7.

cited. The course to the south continues along a line of disturbance across the Crested Butte quadrangle, described by Eldridge, and farther south, as mapped by Burbank. Because of the several changes in trend, an attempt to extend mapping of the structure beyond the limits covered by field observation is unwarranted.

The changes in the character of the faulting and folding from Schofield Park, where the fault zone is cut off by the stock of Snowmass Mountain, to the continuation of the structure on the west side of the stock near Placeta, on the Crystal River 12 miles northwest of Marble, are very striking. (See figs. 6 and 7, cross sections *c* and *d*.) From this place northward the structure is that of a sharp monoclinal fold with steep westerly dip. At Placeta much of the Mancos shale has been faulted out along a normal fault that has thrown the coal of the Mesaverde formation relatively close to the Dakota (?) quartzite. North of Placeta faulting was not recognized on the surface, but displacements of 100 feet are not uncommon in the old coal mines at Newcastle, west of Glenwood Springs.

An interesting feature is the relation between dips of the fold and fault and the curvature of the fault-fold zone. The dips are vertical where the strike changes from northwest to north and 40° to 60° where the strike changes from north to northwest at Glenwood Springs. Examples of the vertical dips are excellently exposed a few miles northwest of Placeta in the canyons of Coal and Thompson Creeks, where fully 5,000 feet of Permian, Jurassic, and Cretaceous beds combined (see pl. 10, *B*, and cross section *b*, fig. 7) are standing on end. A few miles north of Newcastle, where Rifle Creek crosses the Grand Hogback, about 7,000 feet of combined Cretaceous and Tertiary strata with vertical dips are well exposed.

Hills [61] believed that the monoclinal fold had everywhere been overturned as it is now seen in parts of the Elk Mountains. He assumed that along the Grand Hogback where overturned beds are not found the overturned part of the fold has been removed by erosion. Fortunately some of the upper part of the fold is preserved in the vicinity of Thompson Creek (see pl. 10, *B*), from which it is evident that overturning of the beds did not take place everywhere along the fold.

The upper part of the fold was found only on Thompson Creek, and the lower part was not found here or anywhere else.

The dip changes very abruptly from vertical to 40° or 50° in a sharp flexure without faulting, and the line of this flexure slopes eastward at about 20°. It could not be determined whether this feature is local or general. The westerly dips of 40° to 60°, common along the Grand Hogback fold, could well represent the upper part of the fold. It has been generally assumed that only the lower part of the monocline is present, but this assumption is not justified.

[61] Hills, R. C., Orographic and structural features of Rocky Mountain geology: Colorado Sci. Soc. Proc., vol. 3, p. 411, 1891.
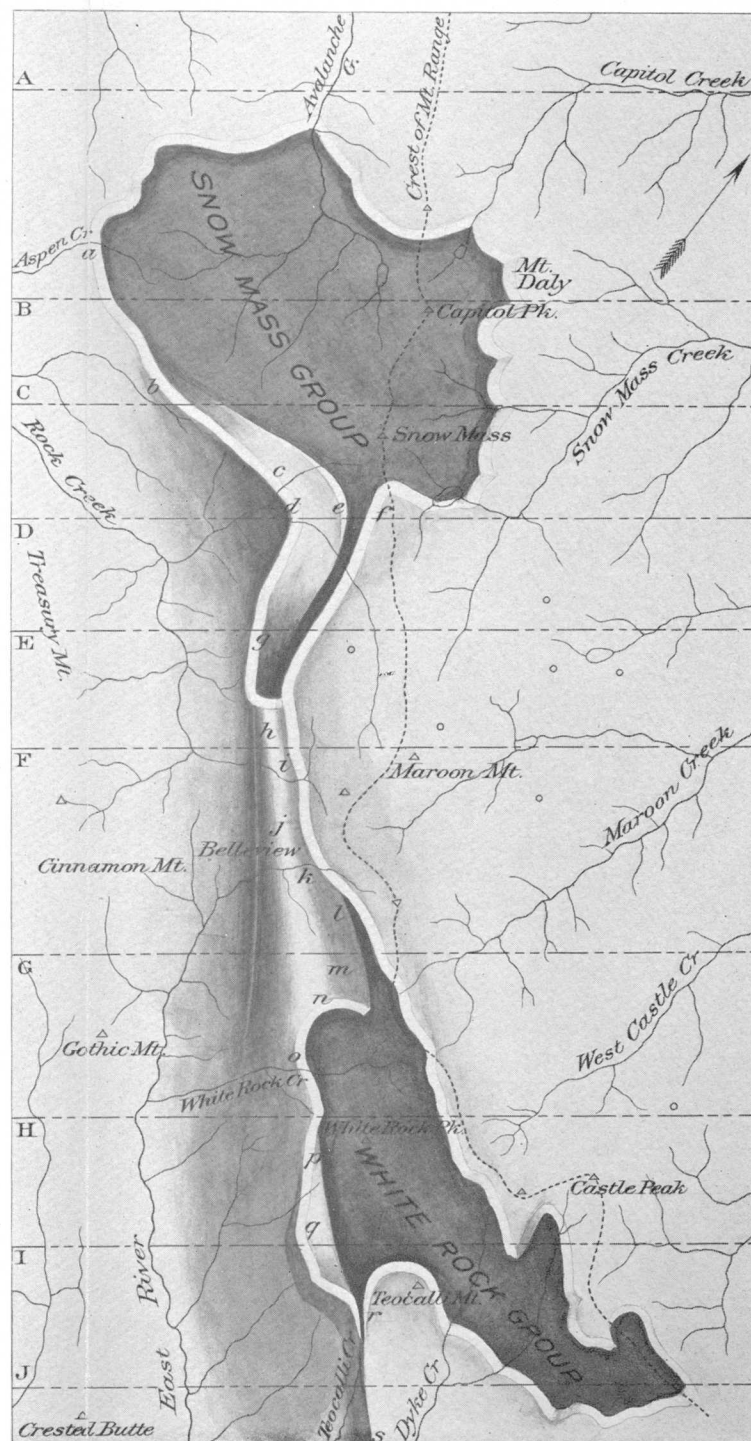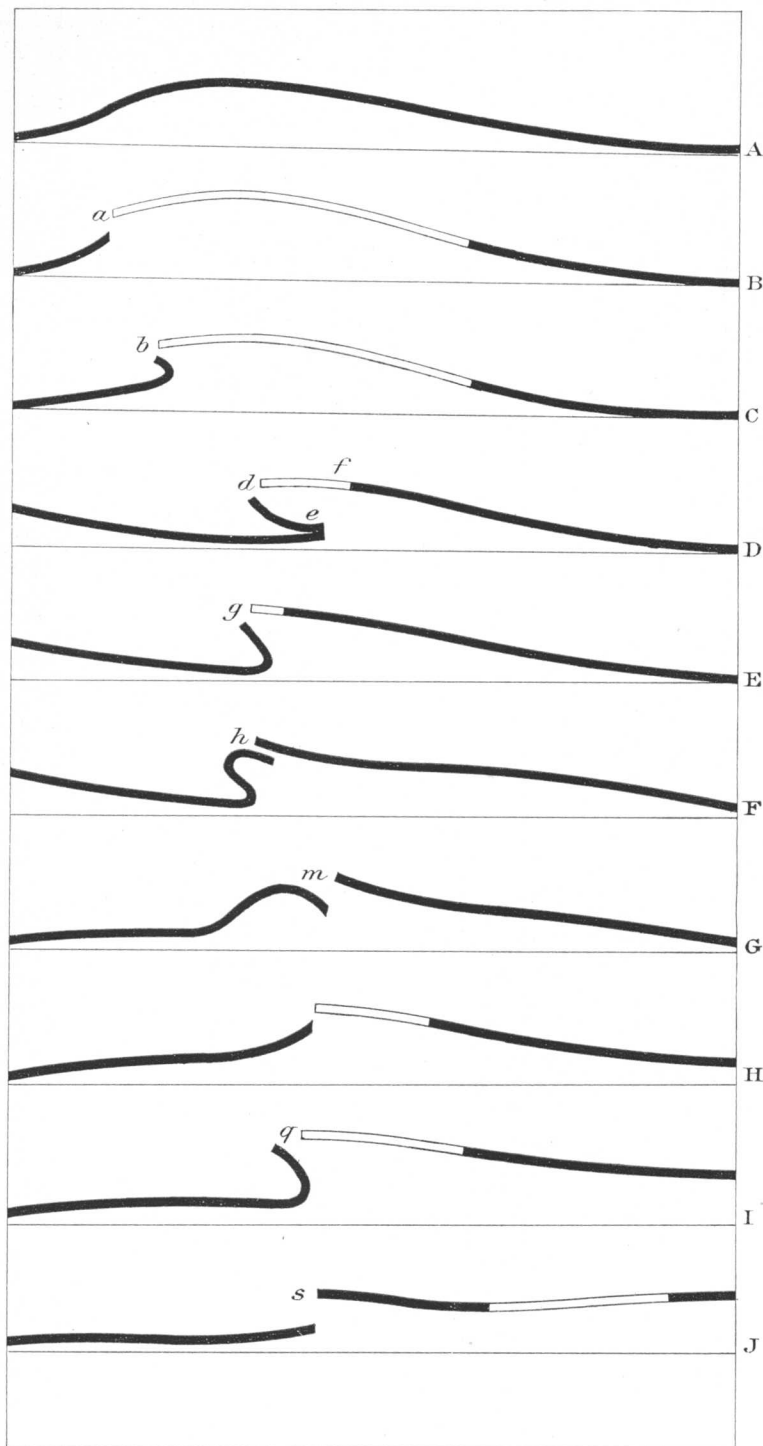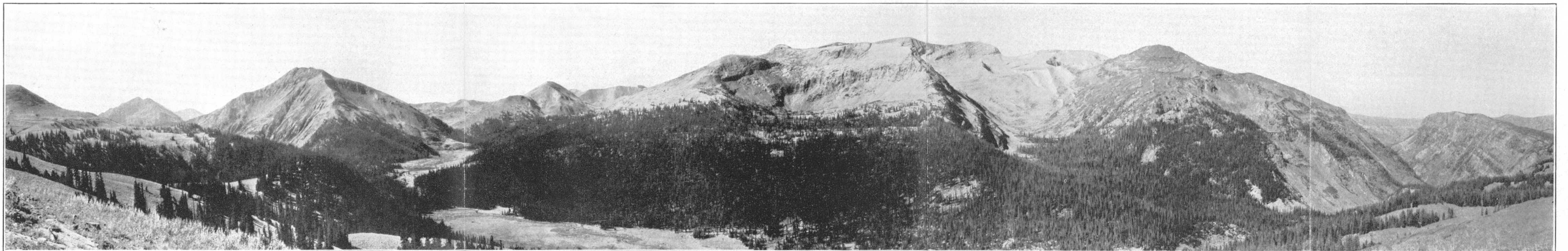
ELK MOUNTAIN FAULT ZONE ACCORDING TO HOLMES.

U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., for 1874, figs. 10, 11, 1876.

A. TREASURE MOUNTAIN DOME AS SEEN FROM THE NORTH.

Treasure Mountain in center, with Treasury Mountain on left. Crystal Peak on extreme left and Whitehouse Mountain on right. The cliffs in the right foreground are a part of the south face of Sheep Mountain.

B. TREASURE MOUNTAIN DOME AS SEEN FROM THE EAST.

Schofield Park in foreground.

A discussion of the relation of this zone of regional folding and faulting to structural features, such as the White River Plateau on the east and certain anticlines on the west, is beyond the scope of this report. It is mentioned, however, in order to point out that the Castle Creek fault at Aspen is very similar in many respects, including size, to the Elk Mountain fault zone.[62] The formations that are overturned in the Snowmass area are overturned in the same way along the Castle Creek fault near Aspen, and the fault changes to a monoclinal fold to the northwest. It continues northwestward from Aspen to Basalt along the valley of Roaring Fork. At Basalt the valley of Roaring Fork is northeast of the steeply dipping beds. A few miles below Basalt the valley veers to the southwest of the fold, which continues in a straight line and was traced to a point within 3 miles of the Grand Hogback fold, west of Glenwood Springs. There can be little doubt that the flexure, itself a monoclinal fold northwest of Basalt, is related to the monocline of the Grand Hogback. It appears, therefore, that the northwestward continuations of the Elk Mountain fault zone and the Castle Creek fault join south of Glenwood Springs and that the two represent a branching flexure. The data now available indicate that the relative movement of each of the two branches was about the same.

The features of the Elk Mountain fault zone and the Grand Hogback fold suggest probable stages of development that preceded the close folding and thrust faulting in the Snowmass Mountain area. The types of structure at different positions along the zone of deformation may be considered illustrative of stages in the development of the Elk Mountain thrust. First, a monoclinal fold developed (see fig. 7, a), owing to uplift of the area on the east with respect to the area on the west. During this stage the vertical component of movement was important, and locally normal faulting, such as that near Placeta (fig. 7, c), occurred. In the second stage the horizontal component of movement became relatively more important, and the upper limb of the monocline was arched into an anticline. Lastly the horizontal component became dominant as the beds broke along the line of flexing, and thrust movement was initiated along a surface essentially parallel to the bedding of the upper block (fig. 7, c). Each of the movements described represents the resolution of forces active during the period of development of Rocky Mountain structure.

---

[62] Vanderwilt, J. W., The revision of structure and stratigraphy of the Aspen district, Colorado, and its bearing on the ore deposits : Econ. Geology, vol. 30, no. 3, p. 231, 1935.
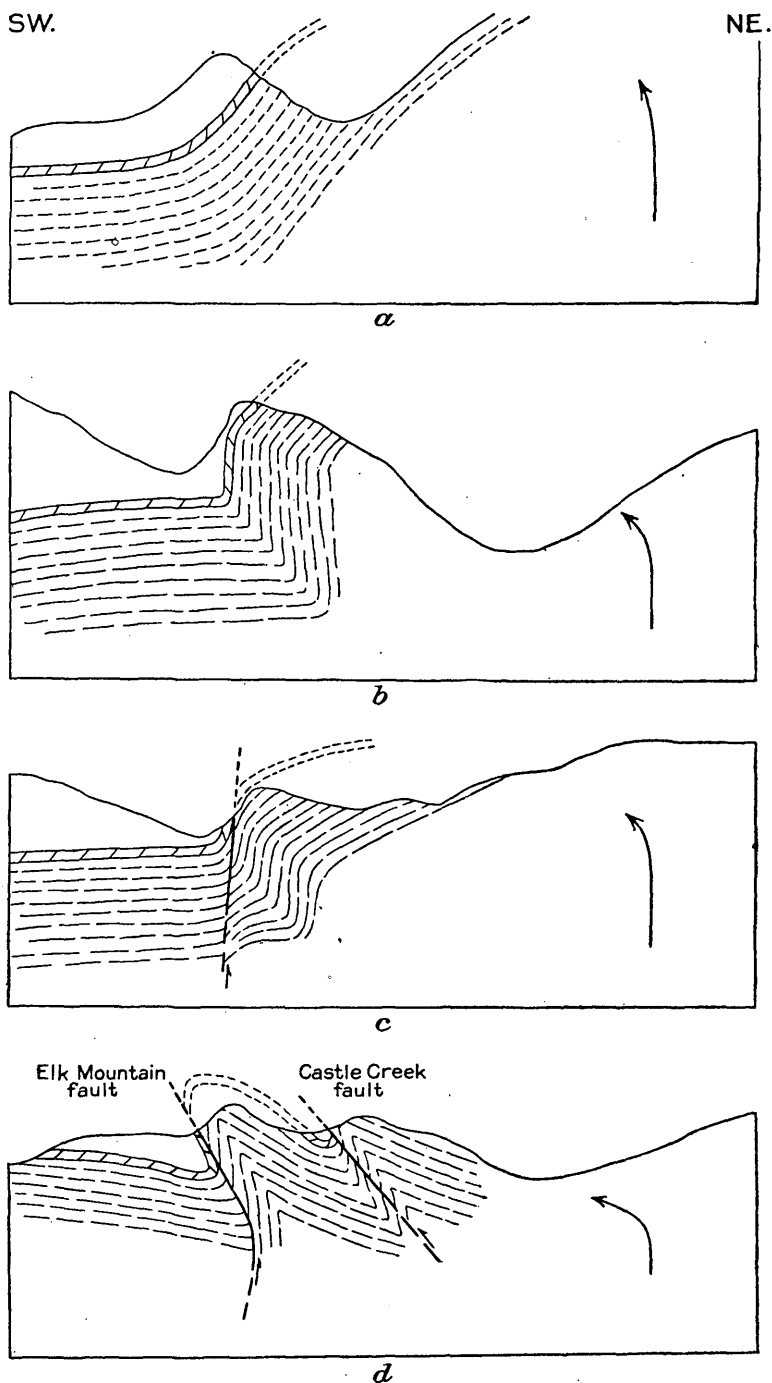
FIGURE 7.—Diagrammatic cross sections of structural types along the Elk Mountain-Grand Hogback zone of deformation. Approximate positions of cross sections, *a*, *b*, *c*, and *d*, are shown in figure 6. Arrows show relative amount and direction of movement. *a*, Vertical component dominant; *b* and *c*, horizontal component becoming important; *d*, horizontal component dominant, position of thrust faulting.

Relative age.—Hayden [63] in explaining the structure of the Elk Mountains says:

The Snowmass Range presents one of the most marked examples of the complete subversion of the strata by the elevation of the great group of granite peaks which formed the core of that range.

The following year Holmes [64] in explaining the structure wrote:

It will be seen, by reference to the figure and the sections opposite [see pl. 1], that the conditions along the east side are simple, there being a gradual and gentle dip from the crest of the range toward the valley of Roaring Fork, while on the west side there has been a gradual depression or downthrow, so to speak, amounting in many places to 7,000 or 8,000 feet; at the same time a combination of movements, principally lateral, have produced along the axis an immense wrinkle, a fold so abrupt that the beds are crushed and shattered and the several edges shoved past each other, as shown in the drawing and sections between e and n. It will not be difficult to imagine that while this was going on, the plastic mass beneath was assisting the movements and shaping the results, and that during the process it forced itself, or was forced, through the fracture line in the two great masses of Snowmass and White Rock groups.

Hills [65] about 16 years later agreed with Hayden and Holmes that the large intrusions of Mount Sopris and Snowmass and White Rock Mountains were contemporaneous with folding, even though he recognized the continuity of the structure to the northwest. He also believed that the Treasure Mountain dome was older and that subsequent to its formation it was tilted bodily by the uplift that resulted in the fault zone.

It is evident that the three intrusions of the Elk Mountains are alined along the regional structure. They apparently followed the line of weakness of the fault zone, which they also clearly intersect. South of Snowmass Mountain the granodiorite occurs along the surface of the thrust fault for fully 2 miles, and nowhere does the rock show any recognized effects of contemporaneous movement of the wall rock. West of this area the intrusive contact crossed the entire fault zone, which locally is wide, and forced its way beyond it for more than a mile into the weak Mancos shales. Just south of the limits of the area mapped, at the head of Rustler Gulch, the granodiorite of the White Rock Mountain group cuts abruptly across the fault zone in a similar manner. The crosscutting and the lack of faulting in the granodiorite indicate that the intrusion occurred after the final period of adjustment along the fault zone.

The age of the fault zone with respect to the Treasure Mountain dome has not been definitely established, but the field relations

[63] Hayden, F. V., Geology of Elk Mountains: U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept., p. 66, 1874.

[64] Holmes, W. H., Report on the geology of the northwest part of the Elk Range: U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept., p. 68, 1876.

[65] Hills, R. C., Orographic and structural features of Rocky Mountain geology: Colorado Sci. Soc. Proc., vol. 3, p. 413, 1891.

suggest that the dome is the younger. The evidence for this conclusion, included in the following description of the Treasure Mountain dome, is briefly as follows: The asymmetrical dips and faulting related to Treasure Mountain indicate that the regional dips of the sedimentary rocks formed by movements along the Elk Mountain fault zone existed before the dome was formed, and had there been any appreciable movement on the Elk Mountain fault zone subsequent to the formation of the Treasure Mountain dome late faulting in the dome would be expected.

TREASURE MOUNTAIN DOME

The general shape of the Treasure Mountain dome has already been brought out in the description of the form of the granite stock which is a part of it and to which it is due. (See pp. 48–50.) The part of the dome to be described further consists of the arched sedimentary formations. Its detailed form is of interest because it offers a clue to the relative age of the dome and it includes a system of faults that influenced the localization of sulphide mineralization.

SIZE AND FORM

. The dome is elliptical in ground plan (see pl. 1) and covers approximately half of the western part of the Snowmass Mountain area. The long axis trends northwest and is parallel to the Elk Mountain fault zone, which bounds it on the northeast. The Snowmass Mountain intrusion limits the dome at its northwest end, about a mile northwest of Marble. The southwest flank grades into the regional southwestward-dipping beds found in the adjoining area of the Anthracite quadrangle. The southeast end extends under Schofield Pass, and southeast dips are continuous as far as Emerald Lake. A little below this lake there is a slight reversal of dip that forms a small sharp fold, beyond which the southeast dips continue for nearly 2 miles before they flatten and are reversed by the large intrusion of White Rock Mountain, in the Sawtooth Range. These extreme limits give the dome a length of about 12 miles and a width of 9 miles. The dimensions given, although necessarily somewhat arbitrary, are believed to express the proper order of magnitude.

The structure of the dome is well exposed by erosion. The smooth curves of the arched formations can be seen from almost every direction. A striking view, however, can be had from Sheep Mountain to the north or from the higher slopes farther north. (See pl. 16, *A*.) This view and one from the east (see pl. 16, *B*) show the parallel relation between the topographic form and the structure of the arched beds, which is one of the most striking features of the Treasure Mountain dome.

The dips of the Jurassic and Cretaceous beds range between 40° and 50° along the lower part of Yule Creek and between 20° and 30° on the opposite side of the dome, along the Crystal River. The dips of the Paleozoic beds show an opposite relation—30° to 45° along the Crystal River and 20° to 25° along the upper part of Yule Creek. This difference is to be expected with the angular unconformity between Jurassic and Paleozoic formations and accordingly is not particularly significant. The asymmetric dips of the younger beds are of special interest because they offer a clue to the relative age of the intrusion with respect to the Elk Mountain fault zone. These asymmetric dips can be explained theoretically by asymmetric uplift of horizontal Jurassic and Cretaceous formations, or symmetric uplift of the horizontal Jurassic and Cretaceous formations with subsequent tilting of the entire dome, but it is in reality caused by symmetric uplift after the Jurassic and Cretaceous formations had acquired regional dips of 10°–15° SW.

FAULTS

A series of parallel faults has been developed parallel to the long axis, and, with one exception, they are on the northeast flank of the uplift. On Galena Mountain, a small area between latitudes 39° and 39°2' and longitudes 107°3' and 107°5', the faults were mapped in detail on a scale of 1:12,000.[66] In this area excellent exposures of two unfailing horizon markers—the Dakota (?) quartzite and the limestone in the Morrison (Jurassic) formation—permitted the recognition of a greater percentage of the displacements than is possible outside of this particular area. There can be little doubt that faults extend from Galena Mountain to Crystal Peak and from Crystal Peak to Sheep Mountain, but owing to the absence of horizon markers the displacements are not evident. Except for the presence of Jurassic beds on Crystal Peak the faults there would probably not have been recognized. On Sheep Mountain they could not be traced far from the outcropping rim of Dakota (?) quartzite. The faults are mineralized, and this is often an aid in tracing them; but mineralization has also occurred along fissures showing no appreciable displacement. Likewise, few faults are mineralized for their entire length. Projection of faults is therefore difficult, and it is not safe to map a fault much farther than it can be traced. The habit and nature of the faults and fractures are important because mineralization is largely confined not only to the zone of faults but in most places to the fractures themselves.

Characteristic features.—The faults can be divided into two broad groups—one having relatively few fractures, which have large

[66] Vanderwilt, J. W., Preliminary geologic notes on Galena Mountain, a part of Snowmass Mountain area, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 1, pl. 1, 1932.

displacements, and the other including numerous discontinuous fractures showing discontinuous displacements of not more than 15 or 20 feet. The smaller fractures are as a rule branches of the larger ones or are otherwise related to them. North to northwest strikes, steep easterly dips, and normal displacements are invariably shown by the larger faults and prevail throughout the zone. Some of the smaller faults have steep westerly dips and normal displacements. Apparent reverse faults were also observed near the larger faults on the ridge south and southwest of Galena Lake, and these account for small intervening horsts or upthrown blocks.

The number of faults and the amounts of displacement decrease to the southeast of Galena Mountain and to the northwest in the vicinity of Lead King Basin and Sheep Mountain. Sharp drag folds are common, especially along the larger faults, and are the cause of numerous branching faults, which will be referred to as "drag faults." Drag faults are almost invariably present on the footwall side, but on the hanging wall, even where strong drag is evident, they are unimportant or absent. On Sheep Mountain several faults are accompanied by a noticeable change in strike and dip of the beds on each side of some of the fractures. Except on the very rim of Dakota (?) quartzite the faults are poorly exposed, and the relations are therefore obscure; but the sharp changes in strike and dip are believed to be due to drag faults.

The several features referred to are shown by the Whopper fault, the largest in the area (pl. 1). Other details common to the entire zone are also shown by the Whopper fault, which is therefore selected for a detailed description.

Whopper fault.—The Whopper fault is named after the Whopper mine, on Whopper Creek. Its strike ranges from about north where it is crossed by the Brooklyn tunnel to fully 20° west of north on Whopper Creek, and the dip is 70°–80° E. It is well exposed on the surface for a little over 3 miles. The hanging wall has moved down relative to the footwall, and the displacement attains a maximum of about 600 feet in the vicinity of the Homestake tunnel, which follows the fault. The throw decreases both to the north and to the south. At each end the fault crosses limestone of Niobrara age, where the displacement is less than 50 feet, and beyond it is lost in the Mancos shales without any indication that it continues farther. A pronounced drag is shown in both footwall and hanging wall in the vicinity of the Brooklyn tunnel. Only on the footwall side, however, are drag faults present.

The drag faults branch from the main fault at angles of 15° to 20°. They invariably extend to the northwest, and their displacement is greatest next to the main fault. At distances of 1,500 feet or less from the main fault the displacement has generally decreased to

only a few feet, but a strong fissure usually continues for several hundred feet farther. It is common to find that a drag fault that is essentially vertical near its junction with the main fault changes to a dip of 60°–70° E. a short distance away from the fault. In addition, the strike curves so that the surface of a drag fault is slightly concave toward the main fault. Smaller fractures that branch from the drag faults are not uncommon. Some of the smaller fractures show displacement, and one or two were large enough to be shown on the map. The fractures are so numerous that it was considered impracticable to map those that do not show any displacement.

Lack of continuity.—The small fractures are not continuous in the Jurassic rocks. The faults immediately east of Galena Lake that offset the Dakota (?) quartzite from 5 to 20 feet cannot be traced in excellent glacially smoothed exposures of the Morrison formation, and the fractures are very inconspicuous in the quartzite. No evidence of extensions to the south in the Mancos shale could be found. Failure of faults to continue through the hornfels is interpreted to mean that the displacement occurred before the alteration of the shale—that is, the faults in the quartzite would be represented in shale by flexures or small fractures that were obliterated in the conversion of the shale to hornfels. Likewise the recrystallization of sandstone to a dense quartzite would tend to heal and make the fractures inconspicuous in this rock. This is in accord with the fact that faults are not found in the granite of Treasure Mountain; at the head of Yule Creek a fault was traced to a point within a few feet of the contact, but no sign of a continuation could be found in the granite.

Origin.—Maximum displacement nearest the crest of the dome and the fact that the displacement is such as would compensate the tension due to arching of the formations are regarded as proof that these faults were produced by the arching of the formations.

The presence of faults only along the northeast side of the dome is explained as follows: The granite of Treasure Mountain, symmetric in form, intruded and domed formations having a regional dip to the southwest, and consequently the strata on the northeast side of the uplift were folded so sharply that faulting resulted. On the southwest side of the dome the favorable regional dip made flexing without fracturing possible.

RELATIVE AGE

As the granite is younger than the dikes in the southern part of the area the dome also is younger. The dome is probably younger than the Elk Mountain fault zone, as it is superimposed on the regional southwest dips of the sedimentary formations, and the regional dips were produced by the diastrophism that formed the Elk Mountain fault zone.

The age of the Grand Hogback fold, the northern extension of the Elk Mountain fault zone, has been established as post-Bridger, and accordingly the Treasure Mountain dome is younger. It is possible, however, that the two are contemporaneous, as there is some evidence that the movement along the fault zone in the Elk Mountains was earlier than the movement in the vicinity of the Grand Hogback and to the north. For example, the Wasatch (lower Eocene) appears to dip less steeply than the Mesaverde (Cretaceous) beds in the Anthracite quadrangle, whereas in the vicinity of the Grand Hogback a similar angularity was not recognized.

The relative age of the dome and the intrusion of Snowmass Mountain is not known. Both appear to represent the last phases of igneous activity in the area, and they may be genetically related; if so, the intrusions were essentially contemporaneous.

SUMMARY

The structural features of Tertiary age show a sequence of intrusion and folding with faulting. The earliest Tertiary structure within the area is marked by the northeast trend of the earlier dikes. After this the Elk Mountain fault zone was active, as indicated by the faulted dikes. Whether this activity was merely a renewal of movement or marked the initial movement of the fault zone is not known. Later than the disturbance that produced the Elk Mountain fault zone, apparently after its latest movements, came the intrusions of granodiorite of Snowmass Mountain and White Rock Mountain and the granite of Treasure Mountain. The structural features were all formed in post-Cretaceous time, and along the Grand Hogback, the northward continuation of the Elk Mountain fault zone, there has been considerable post-Bridger (middle Eocene) movement. The sequence of events is in accord with the general belief that the Tertiary structural features originated at successive intervals and through an appreciable span of time.

GLACIATION

The glacial features in the Snowmass Mountain area are like those found in nearly every other high mountainous area in central Colorado, and they indicate strong glacial action in the Elk Mountains. These features will be considered under two divisions—deposition and erosion.

DEPOSITIONAL FEATURES

DISTRIBUTION AND RELATION TO TOPOGRAPHY

Glacial deposits in this area are not extensive. They consist chiefly of erratic boulders and a few poorly developed lateral moraines at

altitudes of 800 to 1,500 feet above the bottoms of the valleys. The floors of the valleys upstream are essentially free of morainic material. Below Marble the floor of the valley of the Crystal River consists of accumulations of soil and gravel, but moraines were not observed.

The distribution of the erratic boulders and moraines is shown on plate 1 (oversheet). Small lateral moraines occur at the west end of Sheep Mountain, northeast of Mineral Point, and also, though less well defined, on Yule Creek opposite the Yule Colorado marble quarry. At each of these places the moraines were found at altitudes of about 10,250 feet.

The erratic glacial boulders of granodiorite from Snowmass Mountain occur on benches or shoulders on the south slope of Sheep Mountain, which are ordinarily not clearly expressed by the contour lines on the map. Large blocks of hornfels of the Morrison formation were observed north of Marble and several hundred feet vertically above that village.

Boulders of white marble and gneiss 3 feet across that must have come from the vicinity of Treasure Mountain were seen 800 to 1,000 feet above the floor of the valley of Coal Creek opposite Redstone, about 12 miles down the valley northwest of Marble. Each variety of rock is readily recognized, and consequently little difficulty is encountered in locating the source of these glacial boulders. Several miles farther downstream and north of Redstone extensive gravel terraces, at altitudes of 500 to 800 feet above the stream, are believed to represent glacial outwash and therefore to mark the limit of the glacier that moved down the valley of the Crystal River. A brief reconnaissance did not reveal terminal moraines to mark this limit of the ice. As postglacial erosion has cut a valley about 500 feet deep and a quarter to half a mile wide, any moraine that may have been present would have been largely destroyed.

EROSIONAL FEATURES

CIRQUES, U-SHAPED VALLEYS, AND LAKES

The cirques with their precipitous walls at the heads of streams, the U-shaped valleys, the numerous lakes in rock basins, and the smooth, grooved surfaces of fresh bedrock are all indicative of recent mountain glaciation. Many examples of these features occur in the area. The cirques contain accumulations of talus, but rock streams have not developed. The cross sections of the valleys show the characteristic broad, shallow U shape. Below the junction of tributaries the depth relative to width and consequently the steepness of the walls are noticeably greater than in each branch some distance above the junction. A similar though less conspicuous relation is shown below the junction of the Crystal River and Yule Creek at Marble.

Most of the lakes are of the rock-basin type. Emerald Lake, south of Schofield, is partly dammed by talus, but the dam is shallow, and its removal would probably not drain the lake. Heavy timber conceals bedrock around the outlet of Big Snowmass Lake; however, bedrock is exposed only a few hundred feet downstream from the outlet. Lizard Lake is in a peculiar short valley transverse to the ridge that separates the Crystal River and Lost Trail Creek. This valley was formed by the ice flowing from the main valley of the Crystal River across the ridge and into Lost Trail Creek. Elko Lake represents a rock-bound basin tapped by a narrow postglacial channel. A plank dam across the channel impounds the water, making the lake as it now stands largely artificial. Little Snowmass Lake, Galena Lake, and the little unnamed lake high on the sides of Yule Creek Valley all have their outlets in solid rock. Numerous small depressions in bedrock are found on the terraces or benches along the valley near the head of the North Fork of the Crystal River. These depressions contain water during the greater part of the year, but many are too small to be shown on a map of this scale.

Rock outcrops smoothed by the ice are numerous along the valleys, and glacial striae are common. Remarkably deep and permanent glacial grooves in a dip-slope surface of dolomite occur on the east side of Yule Creek a short distance southeast of the marble quarry. These grooves, shown on plate 13, *B*, are cut parallel to the stream and are only a few feet above it, suggesting relatively little postglacial erosion in this locality.

GLACIATED ROCK TERRACES

Glacial rock terraces are very conspicuous at or near the heads of the valleys. The contour lines on the topographic map fail to bring out the prominence of the terraces, and several of the smaller ones are not shown at all. Some of the conspicuous glaciated terraces or rock-cut benches are shown on plate 1 (oversheet). They are characterized by polished and striated rock surfaces, rock-basin lakes, and water-filled depressions too small to be called lakes. The terrace shown on plate 17, *A*, is cut across Maroon red beds along a tributary of the North Fork of the Crystal River. A similar bench cut in gneiss is shown on plate 17, *B*. Glaciated terraces, benches, shoulders, or spurs are not peculiar to the Snowmass Mountain area. They are well developed in the Sawatch Range and are particularly well shown at the head of Roaring Fork, west of Independence Pass. They are present almost everywhere in the San Juan Mountains, according to Atwood and Mather,[67] who consider them features developed by stream erosion and later modified by the ice. Similar terraces in the European

---

[67] Atwood, W. W., and Mather, K. F., Physiography and Quarternary geology of the San Juan Mountains, Colo.: Geol. Survey Prof. Paper 166, p. 27, 1932.

Alps [68] have been interpreted as representing a stage of sluggish gla-
ciation preceding the more active glaciation that carved the inner and
relatively narrow U-shaped valley. The continuous slopes of rock
smoothed by ice from the bench down to the bottom of the valley,
shown on plate 17, *B*, are considered evidence that glaciation of the
benches and lower parts of the valley in this area was essentially con-
temporaneous.

HANGING VALLEYS AND CIRQUES

Hanging valleys and cirques are features so well known that they
scarcely require description. Attention is called to the concordance
of the valley occupied by Little Snowmass Lake with terraces at
Mineral Point, northeast of Galena Lake, and east of benchmark
10360 in Schofield Park. (See pl. 1, oversheet.) To these fea-
tures at altitudes of about 11,000 feet can be added the two hang-
ing valleys at the head of the North Fork of the Crystal River.
Although hanging valleys are found both higher and lower than
11,000 feet, those at this level stand out more prominently than the
others. Hanging cirques are striking features on the north side of
Treasure and Treasury Mountains, although they are not at all well
brought out on the map.

POSTGLACIAL EROSION

As the rate of stream erosion varies greatly with the gradient,
and as moving ice cuts a valley to an uneven gradient, a true pic-
ture of postglacial erosion is not easily obtained. This is well illus-
trated in the Snowmass Mountain area, where in places, particularly
above the junctions of larger tributaries, there are deep, steep-
walled canyons, but elsewhere only small channels. Above the
junction of the North and South Forks of the Crystal River each
branch has cut a sharp gorge about a mile long and 25 to 100 feet
deep. Sharp postglacial canyons are likewise found above the junc-
tions of Yule Creek, Lost Trail Creek, and the Crystal River. The
canyon along the Crystal River is 100 to 200 feet deep, with vertical
walls cut in the resistant Dakota (?) quartzite and the hard horn-
fels of the Morrison formation. The canyon of Lost Trail Creek,
in rocks of the same kind, is equally sharp, though not as deep or
wide. Along Yule Creek, with relatively soft Mancos shale at the
lower part, the walls of the canyon are not vertical, but they are
steep. These canyons represent headward cutting from the levels
of the overdeepened valley below the junctions of tributary glaciers,
and this fact must be taken into account in considering postglacial
erosion. Along the Crystal River west of Crystal—that is, between

---

[68] Penck, Albrecht, The origin of the Alps: Am. Geog. Soc. Bull., vol. 41, p. 68, 1909.

the sharp canyons referred to—the stream has cut less than 10 feet below the polished surfaces left by the ice. The glacial grooves along Yule Creek shown on plate 13, *B*, occur only a few feet above the stream. Along the Crystal River west of Marble the channel of the stream, even though in soft shale, is shallow, showing very little cutting since the ice filled the valley. The steep-walled, deep canyons therefore, represent a high rate of cutting due to the local and exceptional gradient left by glaciation. Taken as a whole post-glacial erosion is slight and has not materially altered the glacial features.

CONCLUSIONS

Two stages of glaciation are evident several miles below the heads of the valleys, and continuous glaciation seems to have occurred near the higher divides. The earlier stage is represented by the glacial boulders found in several places 800 to 1,000 feet vertically above the valley and as far down as Redstone; the later stage is represented by the U-shaped valleys. This is in accord with Spurr's interpretation of the geologic history of the Aspen area, on the western flank of the Sawatch Range,[69] and also with Capps' description of glaciation on the eastern flank of this range as well as in the Mosquito Fange.[70] In the San Juan Mountains Atwood and Mather[71] recognized three stages of glaciation with rather extensive interglacial stages.

In contrast to two entirely distinct stages of glaciation lower down the valleys, continuous glaciation occurred at the heads of the valleys near the higher divides, as is shown by the unbroken glacially polished rock slopes from the rock terraces down to the floors of U-shaped valleys.

ORE DEPOSITS

GENERAL SUMMARY

Treasury Mountain owes its name to the mineral deposits recognized on it prior to 1876. The first shipments of ore recorded were sent from the Eureka mine in 1883, and the next from the Black Queen mine about 1889. The North Pole and Lead King mines first produced about 1900. The total production is not known, but the mines are small, and none of them produced continuously. The Lead King mine, according to authentic records, produced about $250,000, chiefly in lead, and it is doubtful whether all other production would

[69] Spurr, J. E., Geology of the Aspen mining district, Colo.: Geol. Survey Mon. 31, p. 245. 1898.

[70] Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colo.: Geol. Survey Bull. 386, p. 15, 1909.

[71] Atwood, W. W., and Mather, K. F., Physiography and Quaternary geology of the San Juan Mountains, Colo.: Geol. Survey Prof. Paper 166, p. 82, 1932.

equal this amount. The production of individual mines, as far as it is known, is included in their descriptions below.

The marble industry on Yule Creek has been and promises to continue to be commercially more important than mining. The marble is recrystallized Mississippian (Leadville) limestone. A small quantity was marketed in 1896, and almost continual annual production has been made since 1908. Building stone has no logical place in the description of sulphide minerals and therefore the marble deposits are described separately after this section on ore deposits.

The ore consists of the base-metal sulphides, silver, lead, copper, and zinc. Invariably it has been referred to in the literature as "lead-silver ore", which, however, is only an expression of the greater economic interest in this particular ore. On the basis of quantity produced, zinc and lead ore with a minor amount of silver from the Lead King mine predominates. Next in order are silver from the Black Queen mine and copper-silver ore from the North Pole mine. These three types of ore are not representative of the deposits as a whole, because with relatively few exceptions all the prospects show sphalerite, chalcopyrite, and galena in fairly uniform propor-tions, and silver is not always present in commercially important amounts.

Mineral deposits are concentrated on the northeast side of the Treasure Mountain dome in a faulted and fissured zone that extends from Sheep Mountain on the northwest to Galena Mountain on the southeast. This zone is 1 to 3 miles wide and about 8 miles long and contains sedimentary beds of Pennsylvanian, Permian, Jurassic, and Cretaceous age. The granite of Treasure Mountain also extends into this zone. The intrusion of the granite formed the dome, and in the vicinity of the mineralized zone it has cut out the early Paleozoic beds, which, however, are present on top of the dome and to the southwest. Prior to ore deposition all the sedimentary rocks were metamorphosed by the granite, which itself was unaffected. The Yule Colorado marble is a product of metamorphism.

The characteristic occurrences of the sulphides are in veins and bedded replacement deposits.

Quartz is the predominant gangue mineral in the veins, and small amounts of fluorite are invariably present. Manganiferous heden-bergite is abundant in places, and small amounts of barite and cal-cite are found locally. Pyrite is usually present in appreciable amounts, and in the vicinity of Galena Mountain specularite is plen-tiful in the massive quartz veins. The economic sulphides sphalerite, chalcopyrite, and galena occur together but in varying proportions. Tetrahedrite is common in small amounts, but native silver has been recognized in only a few places. Gold occurs only in minor amounts, and economically it is less important than the other metals.

The minerals occur virtually in all proportions, but in the larger veins, some 40 feet wide, the bulk of the filling is quartz with pyrite or hematite. Quartz veins are particularly numerous and conspicuous in the Dakota (?) quartzite and to some extent in other quartzite beds, but few of the larger quartz veins contain concentrations of sulphides of possible commercial value, and the deposits generally pinch out on passing into shale (hornfels). It is estimated that fully 90 percent of the explored veins are in or very near the Dakota (?) quartzite.

The mineralogy of the bedded deposits is similar to that of the veins except that the beds do not contain the massive bodies of quartz common to veins, and specularite is much less abundant. The deposits are irregular in form, usually found along calcareous beds and in places localized along the intersection of a fracture and a bed. Some deposits are intermediate in form between bedded deposits and fissure veins.

Considered broadly a complete history of the mineralization includes the following three major divisions, each of which grades into the succeeding one: (1) Intrusion of granite, which also caused the faulting and the metamorphism of the country rock; (2) deposition of large amounts of quartz, locally with much pyrite, some specularite (hematite), and barite; (3) deposition of sphalerite, chalcopyrite, galena, and silver-bearing tetrahedrite (gray copper) with pyrite, fluorite, quartz, and calcite. The evidence of relationship between the first and second stages is suggested, first, by the fact that there has been more than average metamorphism, including the development of tourmaline, where faults are large and numerous, and second, by the presence of hedenbergite, one of the common and characteristic metamorphic minerals, intergrown with quartz in several veins.

The second and third stages are more directly and obviously related than the first two. The beginning of the third stage was marked by renewed movement along many of the older fractures, which shattered the quartz filling and afforded further access to the mineralizing solutions. Repeated reopening of the veins may have taken place during the second period. The distinctly banded character of the quartz veins may be due to repeated filling of successively formed openings, but as there is no essential difference in the character of the material deposited the detailed history has been obscured. During the third stage reopening of veins occurred again after some of the economic sulphides were introduced; they are locally veined by quartz. The mineralizing solutions were siliceous in all three divisions.

It appears that the prospectors preferred conspicuous quartz veins to the less conspicuous exposures of bedded deposits. However, the

Eureka and Black Queen ores occurred along sedimentary beds in which no large fractures were evident, and the Lead King ore came from the intersection of a relatively small vein and limestone of Niobrara age. It is concluded that bedded deposits are more favorable for prospecting than veins and that exploration of veins deserves little encouragement except at their intersections with calcareous beds known to be favorable for ore.

MINERALS

The minerals found in the veins and bedded deposits are discussed briefly in alphabetic order.

Adularia ($KAlSi_3O_8$).—Adularia was found in abundance in one thin section of a quartz vein in the Mancos shale east by south of the Brooklyn tunnel. The mineral was not observed elsewhere, but it does not seem likely that the occurrence is entirely confined to this locality. It was intimately associated with quartz and considerable fluorite, but sulphides were not present. In hand specimens adularia is not conspicuous and may be readily overlooked.

Aragonite ($CaCO_3$).—Radiating needles of aragonite occur in small amounts on chalcocite and line some of the cavities of calcite in the ore body of the Black Queen deposit. Aragonite was not observed elsewhere, and the small amount found in the Black Queen did not afford the opportunity to determine any genetic sequence or significance.

Argentite (Ag_2S).—Claims have been made that silver sulphide is present, but none was found in the course of this study in the area. It is reported in the Painter Boy mine, in the head of Washington Gulch just south of this area, and in mines in Rustler Gulch, in the White Rock Mountains.

Barite ($BaSO_4$).—Several prospects in the saddle southwest of Galena Lake and in the dump of the Inez tunnel west of Crystal show barite in quartz veins, and in places it is intergrown with specularite (hematite). This relation and the fact that it has not been recognized as a gangue with the later sulphides prove fairly well that barite preceded them. It is not present in sufficient quantity to be of commercial interest.

Calcite ($CaCO_3$).—Calcite is the chief gangue mineral in some deposits and is entirely lacking in others. It may be looked for in any vein but is more characteristic in the deposits that occur on the outer fringe of the mineralized area as outlined above. In the ore of the Lead King and Black Queen mines calcite is the chief gangue mineral. It is usually white, either coarse- or fine-grained, and in places weathers to brown and black surfaces, indicating manganese and iron content. Commonly calcite in the form of scalenohedrons lines cavities or vugs.

Irregular stringers and streaks of calcite are also common everywhere in the Mancos shale. This calcite seems to have been formed by a recrystallization of the calcite originally in the shale and is not related to sulphide mineralization. As a rule these calcite veinlets are too small to attract prospectors, but in one place a relatively large stringer was followed by a short tunnel. The calcite pinched out in a few feet and showed no sulphides.

Cerusite ($PbCO_3$).—Lead carbonate has been found or reported only in minor quantities. The characteristic lath-shaped water-clear crystals occur in the cavities of ore near the surface.

Chalcocite (Cu_2S).—Chalcocite is present only in small amounts, and it is rarely observed megascopically. On polished surfaces small areas of chalcocite replacing chalcopyrite are commonly seen. The chalcocite may therefore be a relatively important contributor to the copper content of chalcopyrite but by itself does not constitute an important ore mineral.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite in small amounts is widely distributed in the veins, and it is conspicuous in the blanket deposits of the Eureka and North Pole mines. It occurs in fine specks in some of the sphalerite, and it is intergrown with both sphalerite and galena, suggesting contemporaneous deposition. There is no indication that chalcopyrite has associated with it either silver or gold.

Chrysocolla ($CuSiO_3.2H_2O$).—The green copper silicate, superficially resembling malachite, occurs in several places. It is particularly common in veins on the east face of Crystal Peak, and it is also common in the North Pole mine. Chrysocolla does not constitute an ore mineral.

Fluorite (CaF_2).—Fluorite is widespread in its occurrence and may be considered one of the most characteristic and persistent of all the gangue minerals. It was found in every prospect that was examined in detail. As a rule the fluorite is colorless, and it is either mixed with the sulphides or lines cavities.

An abundance of fluorite was observed only in the Lead King mine, but here the relation of the fluorite to the sulphides does not appear to differ from that given above. In this mine the fluorite is coarse-grained, and it ranges from colorless to green and also from colorless to a deep pink.

Galena (PbS).—Galena is widespread in small amounts and in places constitutes ore. In places it is closely associated with sphalerite and chalcopyrite. Poorly crystallized galena occurs on the walls of the cavities (see pl. 18, *B*), and it occurs in the central part of the sulphide bodies, suggesting deposition during the later part of the period of sulphide mineralization.

It is commonly assumed by prospectors that the galena in the area is silver-bearing. Silver is generally present in some form, but the
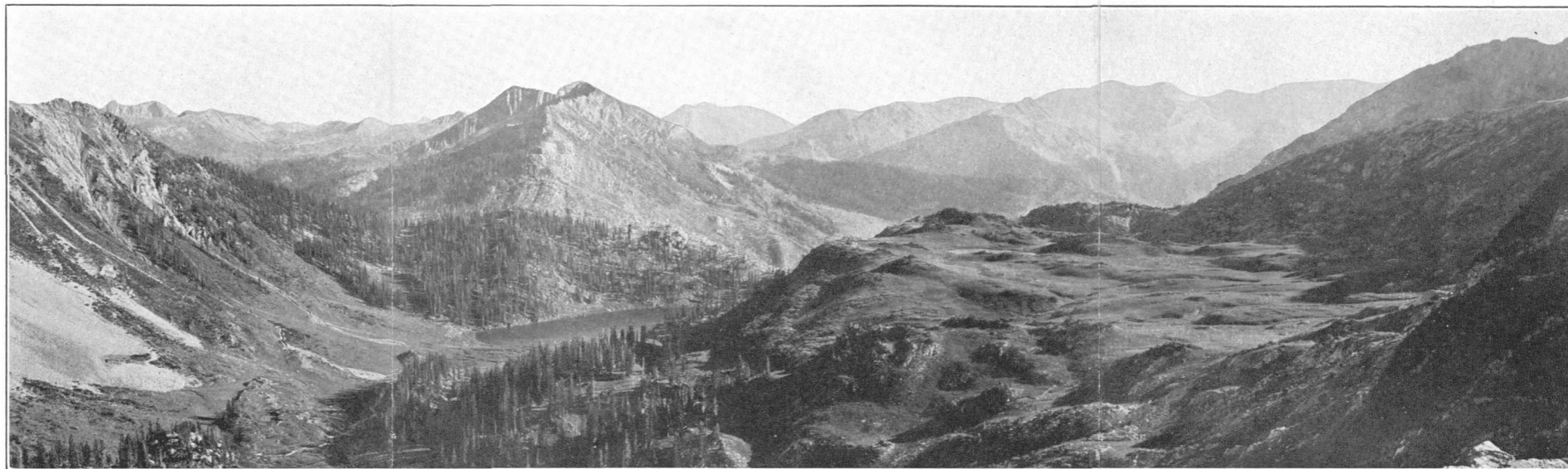
A. GLACIATED BENCHES ON MAROON RED BEDS NORTHWEST (RIGHT) AND SOUTHEAST (LEFT) OF LITTLE SNOWMASS LAKE.

Similar benches can be seen in the distance both to the left and to the right of Mineral Point (the peak that shows strata standing on end).   The altitude of this peak as shown on the topographic map is 12,503 feet.   The view is from the north.
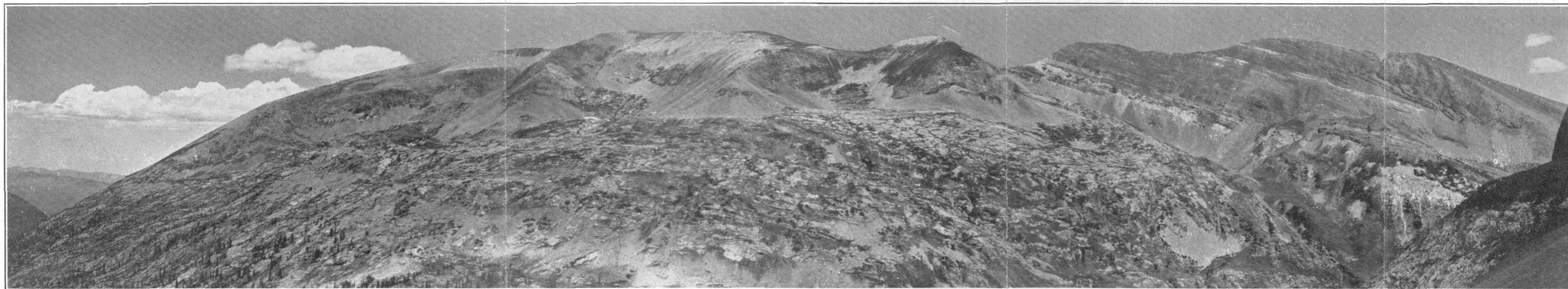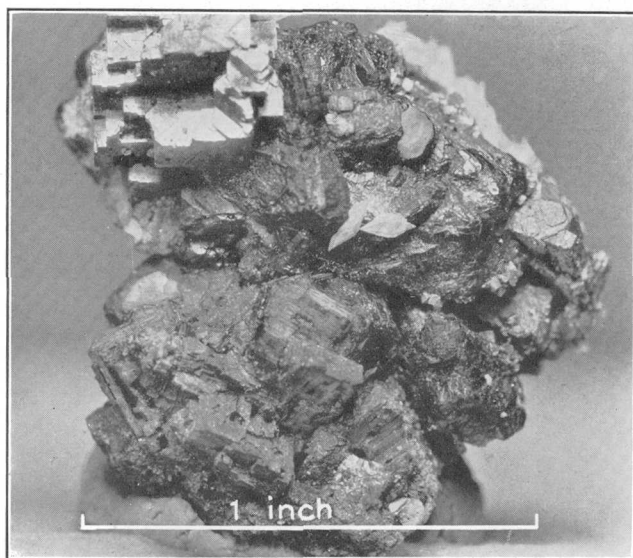

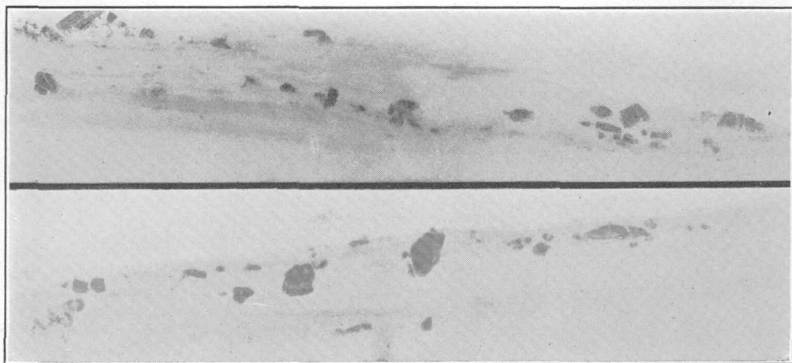*B.* GLACIATED BENCH CUT IN GNEISS ALONG YULE CREEK.

On this bench are three rock-basin lakes.   (See topographic map, area south of Treasure Mountain.)   View from south.
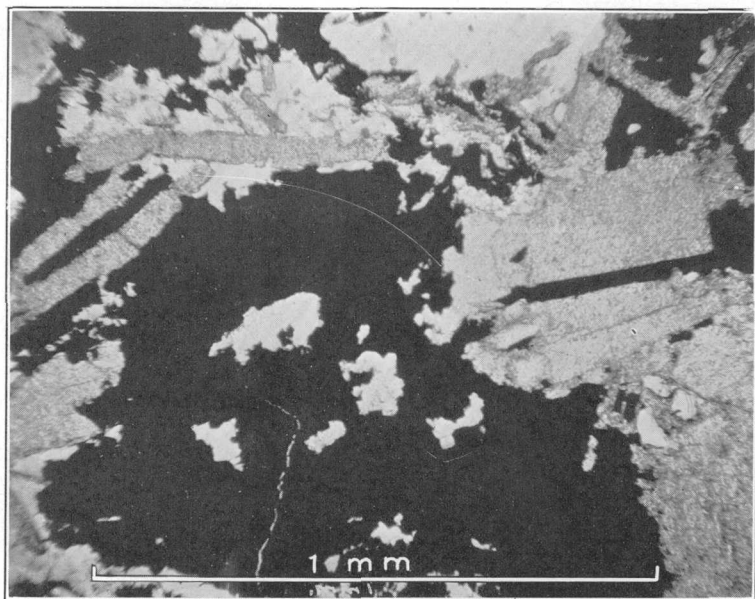
A. INTERGROWTH OF SPECULARITE (BLACK) AND BARITE (GRAY).

B. POORLY FORMED GALENA CRYSTALS FROM A CAVITY IN SPHALERITE.
Lucky Boy tunnel.

A. STRINGERS OF ANGULAR CHERT FRAGMENTS.
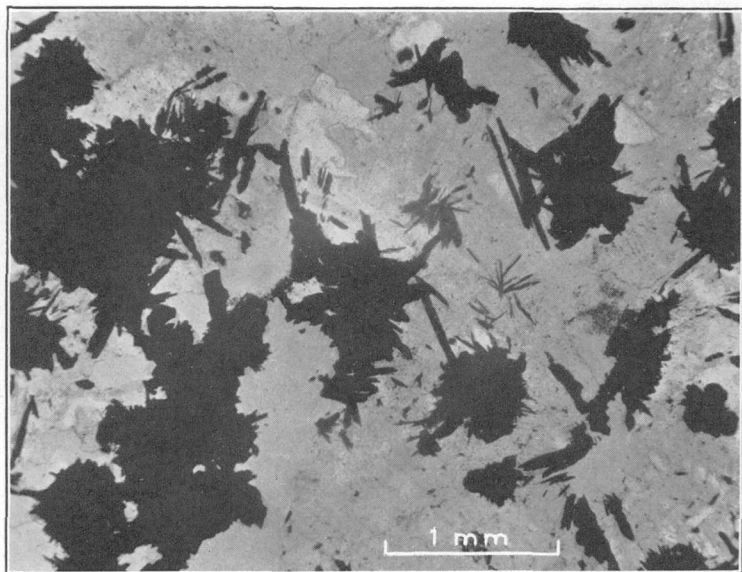
B. SEGREGATIONS OF SPECULARITE (BLACK) IN QUARTZ (GRAY).

amount of galena is not an indicator of the amount of silver that may be expected. The rich silver ores of the Black Queen have relatively little galena in them, and the high-grade galena ore from the Lead King mine contained only a moderate amount of silver.

Gold (Au).—Gold has not been important as an ore mineral. Many claims of high gold assays are made, but of 10 representative samples selected from as many veins by me and assayed at the Colorado School of Mines, only one showed an assay for gold and that only 0.02 ounce to the ton. G. Sessinghans [72] from many assays had one that ran 0.3 ounce and the rest showed either nothing or less than 0.02 ounce to the ton. H. W. C. Prommel [73] obtained an assay of 0.32 ounce from hand-sorted ore high in gray copper. C. C. McWilliams, of Marble, discovered a small quartz vein southeast of Lizard Lake in some of the vugs of which a small amount of native gold was found. This occurrence is obviously exceptional, and any claims of gold ores in the area should therefore require careful verification.

Hedenbergite (iron-bearing pyroxene).—Hedenbergite is readily recognized by its almost fibrous radiating structure. It is green on fresh surfaces and commonly black when weathered. Qualitative tests show the presence of appreciable amounts of manganese, which accounts for the black color of the weathered surfaces.

Hedenbergite is a characteristic metamorphic mineral in the area, associated with garnet as a product of alteration that clearly preceded the sulphide mineralization. It is also abundant as a gangue mineral in some veins and bedded deposits, particularly on Galena Mountain and in North Pole Basin. The relation of this mineral to the sulphide mineralization is not clear. As a rule it occurs in bands in massive quartz parallel to and along the walls of a vein. These bands do not appear as deposits along fractures but rather as if formed contemporaneously with the quartz. An early deposition of hedenbergite is suggested by its occurrence along the walls. This conclusion is supported by the fact that it was found to be cut by veinlets containing specularite, also an early mineral. As hedenbergite is a characteristic and common metamorphic mineral in the area, its presence in these deposits is interpreted as representing a transition between the contact metamorphism of the area and the formation of true veins.

Malachite $(CuOH)_2CO_3$.—The green carbonate of copper is common as stains and superficial coatings on weathered surfaces of copper-bearing ores. The amount of malachite stain is not a fair indication of the relative copper content of a deposit, because a very small amount of the mineral will produce a very showy effect. Mala-

---

[72] Personal communication.
[73] Private report.

chite is of no commercial importance in the area except possibly as an indicator of mineralization to aid in prospecting.

Molybdenite (MoS_2).—Molybdenite is not common and was not observed in any of the veins that carry sphalerite, chalcopyrite, and galena. It occurs in a small quartz vein in the gneiss, and a few flakes were noted near the contact in the granite of Treasure Mountain. Both occurrences are near the head of Yule Creek, and the amounts of molybdenite are too small to be of economic value.

Pyrite (FeS_2).—Pyrite is the most common sulphide present, and it is found everywhere, not only in the ore deposits but also disseminated through the country rock, particularly in the metamorphosed shales. Without exception the pyrite has been found to be barren. It occurs both as an early and as a late mineral in the fissure veins and bedded replacement deposits. The earlier pyrite is coarse to massive, and where later sulphides have been introduced it shows fractures filled with the later minerals. Pyrite is also veined and replaced by specularite.

The later pyrite, in small but well-formed cubes and invariably in association with quartz, is found in veins that cut the earlier pyrite and specularite. It is also in intimate association with the sulphides of economic importance. Like the earlier pyrite it is barren.

Pyrrhotite (FeS).—Pyrrhotite in grains less than 1 millimeter across was noted locally in Morrison hornfels and in dolomite marble. Identification is based on microchemical tests and the fact that the grains are magnetic. There is no apparent association between the pyrrhotite and the veins, and it is probably a product of metamorphism.

Quartz (SiO_2).—Quartz was one of earliest minerals to form and also one of the latest. Although it is the most abundant vein filling it is lacking in some deposits—for example, the Lead King, one of the most productive deposits in the area. In most veins the quartz is coarse-grained, and well-formed crystals lining the walls of cavities or open fractures are common. In the Black Queen mine jasperoid quartz is an abundant gangue mineral, but this is the only ore deposit in which jasperoid was noted. White jasperoid devoid of sulphides is conformable with the bedding of the Pennsylvanian formation at the head of Yule Creek.

Silver (Ag).—Native silver is reported in several localities, but it was found only in the Black Queen mine, where it is of economic importance. The silver occurs in two forms—(1) wire silver lining and filling small cavities in masses of pinkish-white calcite and (2) small plates attached to the walls of small seams or joints in black metamorphosed shale. The wire silver in the cavities of white calcite makes striking specimens, and it is claimed that this form of the metal constituted the principal ore. However, at the time I examined

the mine (1933) the plates of native silver along fractures in black shaly hornfels were much more conspicuous than the wire silver.

Specularite (Fe_2O_3).—Specularite, the crystalline form of hematite, is very common throughout the area both as a metamorphic mineral and as a vein mineral. As a metamorphic mineral it occurs scattered through all the ferruginous sedimentary rock in individual grains, in veinlets as thin as tissue paper, and in irregular segregations along bedding planes. In the lower part of the Jurassic rocks, apparently along a certain horizon, paper-thin segregations of specularite in the form of rosettes 1 to 2 inches across are common along bedding planes. The specularite formed by metamorphism is in places associated with epidote.

In veins specularite is abundant in the area that includes Galena, Treasury, and Crystal Mountains. The well-formed shiny crystals in white quartz attract the attention of prospectors and are sometimes mistaken for galena. Specularite occurs as disseminated crystals or clusters of crystals in massive quartz (see pl. 19, *B*) and partly fills vugs in vein quartz, where it forms spongy rather than massive aggregates. In places this spongy or drusy specularite is very common, and locally it is more abundant than the quartz in the vein.

Specularite was deposited before sphalerite, chalcopyrite, and galena, as it is intersected by veinlets containing these sulphides. Veinlets bearing quartz and specularite cut quartz with pyrite, indicating that it was one of the last minerals to be deposited before the economic sulphides were introduced. The intimate intergrowth of barite and specularite (pl. 18, *A*) indicates that these two minerals came in at about the same time, and as both also occur in the vugs they are regarded as late minerals of the earlier period, during which the massive quartz filled most of the open fissures.

Sphalerite (ZnS).—Zinc sulphide is present in most of the mineral deposits. It is generally more abundant than any of the other sulphides except pyrite. The color ranges from almost black, as on Yule Creek, through a deep resinous brown, as in the Lead King mine, to a clear yellow, as in the Black Queen mine. In most of the deposits sphalerite of the darker variety predominates.

On polished surfaces the sphalerite invariably shows numerous small inclusions of chalcopyrite, and it is intimately intergrown with chalcopyrite and galena deposited contemporaneously. Here and there sphalerite is cut by veinlets of the other two sulphides, showing that some of the chalcopyrite and galena was deposited after some of the sphalerite.

Tetrahedrite ($4Cu_2S.Sb_2S_3$).—Gray copper is present in small amounts in many of the deposits. It is regarded as an indication of a high silver content in any deposit in which it is found, but this is not a safe generalization, as the results of qualitative tests for

silver in tetrahedrite from different deposits ranged from very weak to fairly strong. In any particular deposit there appeared to be little variation. As a rule tetrahedrite is a silver-white mineral, but a dark-colored tetrahedrite, resembling argentite or chalcocite in color, was also found and gave a stronger qualitative test for silver than the lighter-colored varieties.

The mineral is present in only small amounts, and specimens showing definite age relations with other sulphides were not found. However, the general intimate associations indicate that it was deposited at the same time as the other sulphides.

CHARACTER

Mineralogically, particularly as regards the ore minerals, the ores of both the well-defined veins and the replacement deposits are approximately the same, but specularite and massive quartz are more conspicuous in veins than in the bedded deposits. Although the area is generally referred to as a producer of lead-silver, the ores are of the base-metal sulphide type. The lead-silver ores naturally attracted the attention of prospectors, whereas the quantitatively predominant lead-zinc ores have not been emphasized.

The veins of massive quartz have not been productive. The quartz itself is barren, and the sulphides occur in the quartz as irregular or narrow lenticular stringers that pinch out and reappear repeatedly in a short distance. This pockety character of the sulphide bodies in the veins is an unfavorable feature for economic development of the deposits. However, these sulphide veins and the quartz veins are so conspicuous and relatively so numerous that in the future as in the past they will continue to attract the less discerning prospectors.

Mineralization, not including metamorphism, has been essentially confined to the zone of faults along the northeast flank of the Treasure Mountain dome. This zone extends from Sheep Mountain and Lost Trail Creek on the northwest to a point slightly beyond Paradise Pass on the southeast. Northeast of this zone mineralization has not occurred far beyond the outcrop of the limestone of Niobrara age in the Mancos shale. The southwestern boundary of the zone is irregular and approximately follows a line extending from the head of Yule Creek across Crystal Peak to Marble. Only two mineral deposits, those of the Skyline prospect and a prospect in Yule Creek about a mile southeast of the marble quarry, lie outside of this boundary. However, the character of the sulphides and gangue minerals found in these two places suggests their relation to the deposits in the main zone of mineralization. Small segregations of magnetite are found near the contact of the Snowmass Mountain intrusion, but sulphides other than pyrite disseminated locally through the metamorphosed sedimentary rocks were not observed.

Oxidation is very shallow, as is characteristic of most glaciated areas. All outcrops of sulphides are stained with limonite, but the stain is superficial, and sulphides are common at the surface.

VEINS

The veins occur along faults and related fractures, and the vein minerals were introduced in two fairly distinct stages separated by an interval of fissuring. During the first stage of deposition of quartz varying amounts of pyrite, specularite, and some barite were deposited, and after a period of fissuring sphalerite, chalcopyrite, galena, small amounts of tetrahedrite and native silver, and pyrite with a gangue of calcite were introduced. The quartz veins, formed during the earlier period, range in width from a fraction of an inch along joints to 50 feet in places along the Whopper fault. In these veins vugs lined with relatively large quartz crystals are characteristic. Specularite and pyrite are unevenly distributed, and they are more commonly disseminated through the quartz; they also occur, specularite in particular, on the quartz prisms that line the vugs.

The second stage of mineral deposition followed a period of shearing which reopened some of the older quartz veins and also produced new fractures apart from the older ones. Thus the older quartz veins may or may not contain stringers of the ore minerals, and ore minerals are also concentrated in veins with little or no quartz. The sphalerite, chalcopyrite, and galena veins proper are very irregular in width, usually less than 6 inches. Although the several sulphides occur together, their proportions are not constant; it is common to find any one sulphide predominant in a given vein. The gangue minerals are quartz, calcite, and fluorite. Fluorite is persistent in its occurrence, though nowhere present in large volume, but quartz and calcite may occur in relatively large amounts or be entirely lacking.

The structure of the quartz veins is generally massive, although banded quartz and specularite occur in places. Banding is more characteristic of the ore. The most common arrangement, from margin to center, is quartz, sphalerite, chalcopyrite, and galena. Quartz, fluorite, and calcite, where present, are usually found along the more central part of the veins.

There is no apparent alteration of wall rock or its replacement by the vein minerals. The most prominent quartz veins are in the Dakota (?) quartzite or, as along the Whopper fault, bordering the quartzite, and they pinch down to insignificant width or disappear entirely in the overlying Mancos and underlying Morrison shales. The lack of replacement of wall rock and the general occurrence of prominent veins in quartzite, where open fractures would commonly form, are interpreted to mean that the quartz veins formed along open fissures.

In order to explain the absence of quartz veins in hornfels, it can be assumed that initial fissuring and faulting occurred before the hornfels was formed; fissures in the shale would be sealed and obliterated by contact metamorphism that changed the shale to hornfels. Fissures in quartzite and the harder grits survived metamorphism and became the channels for the solutions that formed the veins. Subsequent shearing which preceded the introduction of the sulphides and which fractured the early quartz veins also fractured the hornfels. Consequently the ore sulphides are found in all the formations, regardless of their original competence to maintain openings. The bearing of these structural and genetic relationships on the problem of finding ore is obvious.

BEDDED REPLACEMENT DEPOSITS

The bedded replacement deposits include all those formed parallel or nearly parallel to the bedding. The ores in the Eureka, North Pole, and Black Queen mines are replacement bodies along beds, and those of the Lead King mine and Mexican Cut occur along the intersection of a relatively poorly defined fracture and a bed. All the larger deposits are in this group, and the stratigraphic horizons at which they occur range in age from Devonian to Cretaceous, as shown in the following table:

> Cretaceous:
> > Limestone of Niobrara age in Mancos shale:
> > > Lead King mine.
> Jurassic:
> > Limestone 50 to 60 feet above base of Morrison formation:
> > > Mexican Cut.
> > Entrada sandstone (as mapped, may include some areas of sandstone of Morrison age):
> > > Prospect at head of Yule Creek.
> Permian and Pennsylvanian (?):
> > Maroon formation, calcareous beds:
> > > Black Queen mine.
> > > Eureka mine.
> Pennsylvanian:
> > Hermosa (?) formation:
> > > North Pole mine.
> Mississippian:
> > Leadville limestone, lower part:
> > > Skyline mine.
> Devonian:
> > Chaffee formation; Parting member:
> > > Prospects in Yule Creek.

The bedded deposits contain the same suite of minerals that is found in the veins, and their occurrence is also similar. Quartz is less abundant, and nowhere is it present in massive bodies comparable in size to the larger quartz veins. It is entirely lacking in the

Lead King mine, and it occurs as jasperoid in the Black Queen mine. In the Eureka and North Pole mines quartz is more plentiful. The North Pole ore body, more than any of the other bedded deposits, resembles a vein not only in the volume of the quartz but also in the banded and vuggy character of some of it. These features were not observed in any of the other bedded deposits.

The form of the ore bodies is as a rule irregular, owing to the uneven and incomplete replacement of particular beds. Most of the replacement deposits are in limestone or calcareous beds, but a few also occur in quartzite. It seems that in places the solutions followed bedding planes and spread into the rocks on each side. In other places the solutions followed a fractured bed, and replacement spread out from the fractures.

The extent of the bedded deposits is not known. In the North Pole mine a bed of ore is developed along the tunnel for a length of about 150 feet and an average width of 2 to 3 feet; in the Black Queen mine a greater length but less width is indicated. In the Lead King mine the ore lies along the intersection of a vein and a bed, and its horizontal dimensions are relatively small compared with its known vertical extent of about 200 feet. In each of these bedded deposits there is a possibility of a continuation beyond the explored limits, and in general the volume of mineralized rock is appreciably greater than in any of the explored veins.

GEOLOGIC CONTROL

For the convenience of the reader, the following discussion assembles and summarizes information that is scattered through the preceding sections of the report.

FAULTING AND METAMORPHISM

The formation of the mineral deposits was dependent on the existence of fractures that afforded access to solutions. This was particularly true during the early history of mineralization, when barren quartz filled the existing openings. The walls of these veins are sharply defined and show little or no replacement of wall rock, thus indicating that the solutions were not of the penetrating type that could pass through the pores of the rock. Under these conditions replacement would be proportional to the size and number of fractures in crushed or fissured zones.

The extensive metamorphism is believed to have a bearing on the problem. Faulting, metamorphism, and mineralization were all produced by the granite intrusion, and they occurred in general in the order mentioned. Metamorphism therefore had an opportunity to destroy some of the earlier fractures, especially in such rocks as shale, calcareous shale or sandstone, and limestone, in which exten-

sive recrystallization occurred. The surviving openings are found in the harder rocks, such as quartzite, and they are generally marked by quartz vein filling. The last period of shearing, which reopened many of the quartz veins, had an opportunity to affect all the metamorphosed rocks, including the calcareous rocks, and it prepared the way for the solutions that brought the ore. Virtually all the replacement deposits are related to fractures that originated during this later period of fissuring.

The larger concentrations of earlier quartz occur along the larger faults and near the junction of branching fractures. Furthermore, the quartz veins are generally in quartzite beds, and as the quartzite beds make good outcrops these quartz veins are so conspicuously exposed that they naturally have attracted much attention. The quartz veins are not, however, a favorable indication of ore, as the ore is dependent on later fractures, which are not confined to the early quartz veins or to the quartzite beds. The ore sulphides occur in veins and in bedded deposits formed by replacement, which is as dependent on the physical character and composition of the country rock as it is on the fracturing in the rock.

CHARACTER AND COMPOSITION OF ROCK

The more promising sulphide deposits are accompanied by an appreciable amount of replaced rock and occur in limestone and calcareous sandstone or shale. This relation seems to have been controlled by the manner in which these rocks fracture and by their solubility. In the Lead King mine the walls of the stopes show many intersecting veinlets of the sulphides, and the main body of the ore is reported to have been mostly a stockwork of veins with local massive bodies of sulphide. The amount of replacement cannot be determined, but the fracturing of the limestone and calcareous shale was obviously an important factor in permitting an infiltration of the solutions. In other mines replacement bodies of sulphides have formed at different stratigraphic horizons and in almost every variety of calcareous rock, but they do not occur in shale. The Lead King mine and the prospect called Mexican Cut are in limestones, whereas the Black Queen, North Pole, and Eureka are in more siliceous though still calcareous beds. Mineral deposits along a bed of quartzite of the Parting member are found in two places on Yule Creek. This mineralized stratum has attracted prospectors, but commercial ore bodies have not been found. The openings show that the sulphides are not strictly confined to the bed of quartzite, as they also occur along its contact with the overlying calcareous shales. A similar situation would be expected in the Pennsylvanian limestone beds and calcareous rocks within the mineralized zone. However, the beds at this horizon are not well exposed within the faulted zone, and they have not been fully explored.

ZONING

Pronounced zoning was not recognized in the mineralized zone along the northeast side of the Treasury Mountain dome. The only two mines from which there has been a regular commercial production of silver within the mineralized area are the Black Queen mine, near the northwestern limits of the zone, and the Painter Boy mine, at the southeast end. The Painter Boy is at the head of Washington Gulch, a few miles beyond the limits of the Snowmass Mountain area, just southeast of Cinnamon Mountain. In both of these mines lead and zinc are not quantitatively important as ore minerals, and calcite instead of quartz is the outstanding gangue mineral. The sulphide deposits occurring between these two mines—that is, from Paradise Pass to Crystal Mountain—consist of zinc-lead ores and are associated with much quartz. The ore at the Black Queen occurs in the Maroon grits, and that at the Painter Boy is related to the contact of a quartz monzonite sill in Mancos shale. The influence of wall rock or any other recognized factors cannot well account for the localization of the silver. Without doubt zoning offers the best explanation of the distribution referred to, but the number of deposits relative to the size of the mineralized area is so small that only a tentative conclusion is justified.

CONCLUSIONS

As the metals of chief value in the deposits are silver, lead, zinc, and copper, the ore bodies must be of considerable size and be favorably located for profitable mining. With one or two possible exceptions, the veins, as shown in numerous tunnels and shafts, are unfavorable for ore in great quantity. The bedded deposits are less numerous than the veins, and because of scant development their extent is uncertain, but the evidence available indicates that ore can be reasonably expected from them in greater quantity than from veins.

Crystal Canyon from Lead King Basin to Marble is accessible by highway to a railroad, and along this canyon on the east and south slopes of Sheep Mountain bedded deposits are shown in the Sheep Mountain and Lucky Boy tunnels. At the Lead King, Black Queen, and Black Eagle properties the ore is more closely related in form to bedded deposits than to fissure veins. Each of these occurrences is at a different horizon, although all are in limestones or calcareous beds overlain by shale or shaly members.

A further important consideration is the occurrence of sulphide replacement deposits within the zone of faults and fissures and apparently related to them. As this zone crosses Sheep Mountain (see pl. 1), the Hermosa (?) limestones that it intersects might contain

some beds favorable for ore. The limestones occur on the lower
part of the slõpe, where outcrops are concealed by talus and heavy
growth of vegetation, and as a result they have not been explored.

Detailed geologic work is essential in the immediate vicinity of
any prospect before any expenditure of money for development is
justified. The geologic map (pl. 1) and the text of this report bring
out the fundamental geologic factors and their possible bear-
ing on the mineral deposits. It is intended here to call attention
only to those parts of the area that appear to be the more favorable
for further prospecting. In doing this it is necessary to refer to
specific deposits, but even here it is very important that those inter-
ested should carefully study in detail the local geology before
deciding on further development.

MINES AND PROSPECTS

The deposits are described under two broad geographic divisions—
those in the northern part of the area, which are best accessible
through Marble, and those in the southern part of the area, which
are more easily reached by way of Crested Butte. These two di-
visions are subdivided into local areas in order to group together
neighboring prospects. Each mine and prospect described is in-
dexed on the geologic map (pl. 1). (See pp. 175–180 for list of
claims in numerical and alphabetic order.)

NORTHERN PART OF AREA

The northern part of the area includes Sheep Mountain, Lead
King Basin, Mineral Point, Bear Mountain tunnel, and Treasure
Mountain.

SHEEP MOUNTAIN

Sheep Mountain lies on the north flank of the Treasure Moun-
tain dome. It is a hogback with the Mancos shales on its relatively
gentle north slope, Dakota (?) quartzite and Morrison shales form-
ing its top, and Carboniferous formations on the steep south slope
that constitutes one wall of the canyon of Crystal River, intersected
north of the town of Crystal by the North Fork of the Crystal
River.

Black Eagle.—The Black Eagle mine is on the south slope of
Sheep Mountain at an altitude of 9,750 feet. It is on a good trail
that leaves the road at Lizard Lake. The workings consist of two
inclined shafts, both inaccessible, 25 feet apart and said to be 150
feet deep. The shafts follow the base of a limestone bed fully 75
feet thick that strikes N. 60° W. and dips 31° NE. The limestone
is well marbleized, and some beds show limestone pebbles. About
100 feet down the slope is a second and similar limestone bed, and

the two are believed to represent the limestone conglomerates so well developed near Crystal Peak and considered the top of the Hermosa (?) formation.

The total ore produced was one shipment [74] in 1894 of a small carload, which yielded about 165 ounces of silver to the ton. After this date no work was done. According to Mr. Nelson the ore came from the intersection of a steep vein and the base of the limestone. A small vertical fissure striking N. 67° W. is exposed at the collar of the west shaft, but it passes into the southwest wall of the shaft only 20 feet below the collar, and no fracture is evident at the east shaft. The limestone is not mineralized; therefore the shafts do not follow a vein but probably cut a fissure that has not been recognized at the surface. The dump shows sphalerite, galena, chalcopyrite, and pyrite with a calcite matrix. Native silver is claimed to be present, but I found none.

Black Queen mine.—The Black Queen mine is on the south slope of Sheep Mountain at an altitude of about 10,300 feet and is reached by trail from either Lizard Lake or Crystal. It has produced native silver, but records of total production are lacking. Mr. Nelson states that considerable ore had been mined before he first came to the district in 1890, and he has a record of a shipment during this period of 360 tons of ore averaging about 150 ounces to the ton, but this is only a small part of the total shipments. Mr. Nelson also has a copy of assays taken from the assay book of the Black Queen and Fargo mines, and according to this record the greatest periods of activity were 1889–90 and 1898–1904. The list records 162 assays that range from 1.0 to 3,291.8 ounces of silver to the ton and average 139.6 ounces. Two assays of native silver were not included in the average. A mill was built about 1903, but it proved unsuccessful, and from 1905 to 1932 the property was idle. Late in 1932 the mine was unwatered by Joe Juhan, of Denver, and in 1933–34 25 to 30 tons of ore was shipped that is reported to have averaged 30 to 50 ounces of silver to the ton.

Juhan reports a sample from the Black Queen mine that assayed 1 ounce of gold to the ton, but it is claimed that the value of the gold in the ore is equal to one-twentieth of the value of the silver. The assay record referred to above reports gold in 42 assays as follows, in ounces to the ton:

        4 assays_____ 1. 00–2. 00
        3 assays_____ 3. 00–4. 00
        14 assays_____ .02– . 08
        21 assays _____ .1 – . 2

The content of gold in 120 of the 162 listed assays was not reported.

---

[74] Nelson, W. P., Denver, Colo., personal communication.

It is evident that the gold is not uniform in its distribution, and the higher assays probably represent hand-picked specimens that cannot be regarded as representative of the ore; high silver does not mean an appreciable gold content.

The mine workings consist of an inclined shaft, which follows the dip of the bedding for about 600 feet, with laterals to the west, as shown in figure 8.

A mill was built at the foot of the slope, 1,500 feet vertically below the mine, and a tram connected the two. Subsequently the tram was removed, and the mill has fallen into decay.

The mineral deposit is in a siliceous limestone 3 to 4 feet thick about 100 to 150 feet stratigraphically above the horizon of the Black Eagle, to the west, and nearly an equal distance below that of the Evening Star, to the northeast. The limestone at the outcrop near
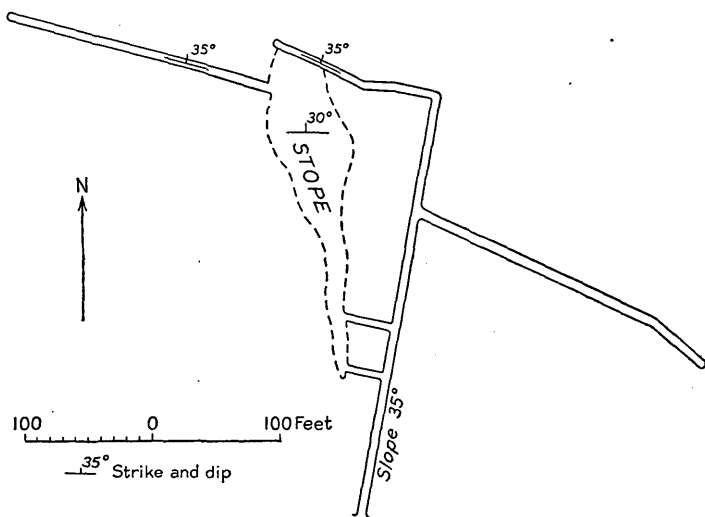
FIGURE 8.—Map of Black Queen mine.

the shaft has been partly replaced by vuggy quartz and shows manganese stain. Some fractures are evident, and one striking N. 7° E. and dipping 80° W. is exposed along the trail 60 feet southeast of the shaft. The ore, however, is not veinlike in form, and it is confined to the limy bed and to the overlying altered shale or hornfels, which forms the hanging wall of the stoped area. Stratigraphically higher and lower beds have not been prospected.

The deposit consists of small, scattered segregations of sulphides and native silver. Calcite is the characteristic gangue mineral, although fine-grained white quartz (jasperoid) is common. Some crystalline quartz is also present. Native silver is relatively common, as wire silver in calcite or in aragonite vugs and as platy grains along seams in the black hornfels that forms the hanging wall of

the mineralized bed. Gray copper is also reported as a source of silver, and it is claimed that the ore carries small amounts of gold. Small amounts of resinous pale-brown sphalerite and some galena are present but are not considered important parts of the ore. Pyrite is abundant throughout the mineralized bed.

Development has been confined to a single stratum, and any structural control that may have influenced the deposition of ore is not clear. The dip of the bed is not uniform, and the steepening or flattening of the bed may have influenced the ore-bearing solutions. Small but numerous fractures and flexures or folds, probably an expression of the northwestward-trending faults known to cross Sheep Mountain, may also have played an important part in localization of the ore. Further development is necessary to determine the significance, if any, of the structural features, and it would be worth while to examine their extension in other limestone strata. Inasmuch as the limestone is mineralized for several hundred feet along the strike and dip, additional work to develop a body of low-grade ore, or to discover new shoots of ore like the one mined, offers some promise.

Catalpa.—The Catalpa mine is about 600 feet north of benchmark 8656, near Twin Bridges, on the Crystal River road, where a small stream of warm water issues from a caved tunnel. A heavy growth of vegetation covers the surface, including the old dump, and conceals the character of the rock and ore that came from the tunnel. No sulphides were found, but the location is of interest because the water is relatively warm, having a temperature of about 68° F. Another interesting feature is the relatively high calcium-carbonate content of the water as indicated by deposition of lime along the stream. On the slopes below and away from the present course of the water are deposits of calcareous tufa, indicating a former spring. It may be that the tunnel intercepted the channel of such a spring.

Evening Star.—The Evening Star is on the south slope of Sheep Mountain, at an altitude of about 10,200 feet, northwest of the Black Queen mine. The workings consist of a tunnel 30 feet long running about N. 80° W. along the strike of the formation. About 10 feet in from the portal is a winze, inaccessible because of water, which apparently follows down the dip of a bed. Shipment of ore from this prospect has not been reported.

The beds are grits with a few impure limestones of the lower part of the Maroon formation. They strike about west and dip 35°–40° N. Mineralization occurred along a bed of limestone, forming an irregular body of sulphides ranging in thickness from a few inches to 12 inches. Massive dark-brown sphalerite, some galena, chalcopyrite, and much pyrite are exposed in the tunnel. The gangue consists of quartz, calcite, and some fluorite. All the sulphides show crushing and are veined by calcite and by quartz usually associated with pyrite.

Gold Pan vein.—The Gold Pan vein is about 100 feet south of the Marble-Crystal road 1½ miles east of Marble, and is opened by a shaft 30 or 40 feet deep. There have been no shipments of ore from this prospect.

The vein occurs in the upper part of the Dakota (?) quartzite along a fault. It strikes N. 56° W. and dips 75° NE. The hanging wall moved down with respect to the footwall, horizontally displacing beds about 25 feet, as shown in figure 9. This vein of massive quartz 2 to 8 feet wide is an excellent illustration of the massive quartz veins that commonly occur in the Dakota (?) quartzite. The vein does not continue far into the Mancos shale above or the Morrison shale below. The fault at the Gold Pan continues some distance into the Mancos formation, at least as far as the limestone member, and where exposed ramifying quartz stringers mark its course. The well-defined vein of quartz does not extend beyond the top of the Dakota (?) quartzite. In the opposite direction the fault cannot be traced far, and the quartz is not continuous far beyond Lost Trail Creek, where the vein joins a fracture that strikes N. 88° W. and dips 70° S. This fracture and several others both parallel and at right angles to the Gold Pan vein can be seen in the Dakota (?) quartzite and Morrison formation, which form dip slopes on the northwest side of Hat Mountain. Vein quartz, both as massive filling of fissures and as well-formed crystals projecting into open cavities along joints, is common along these fractures. Sparse grains of sphalerite, chalcopyrite, and pyrite are present, but as a rule the veins are barren.

EXPLANATION
37° Strike and dip
— — Vein
—— Fault
� Shaft
50   0   50 Feet
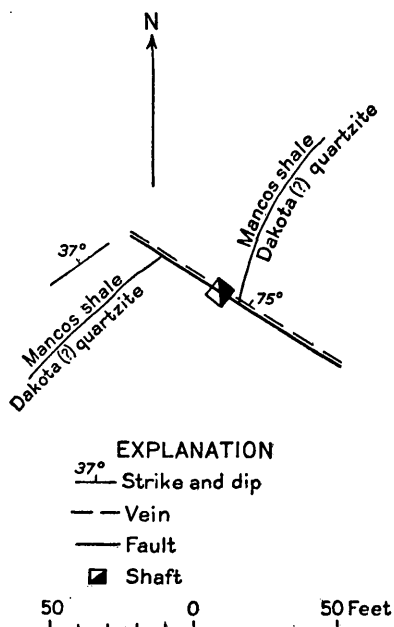
FIGURE 9.—Gold Pan vein and fault in Dakota (?) quartzite.

In the vicinity of the shaft the Gold Pan vein is 6 to 10 feet wide and consists chiefly of quartz with small amounts of sphalerite, galena, chalcopyrite, and a little gray copper (tetrahedrite). Both gold and silver are claimed from the specimens that show tetrahedrite, but as no shipments of ore have been made the value is not known. The sulphides are confined to a relatively narrow band in the otherwise barren quartz vein, and they are not continuous along the strike of the vein. According to reports they were found in the

upper part of the shaft but not at the bottom. At the bottom of the shaft a drift on the vein to the northwest is again supposed to have found sulphides, which suggests that the body pitches to the northwest, possibly along the Dakota(?)-Mancos contact in the hanging wall of the fault. The same contact in the footwall is not exposed, but it might also have had an influence on the deposition of sulphides. If so this would double the possibilities of the prospect, which though obviously small is favorably located and might therefore be capable of a small production at a profit. The intersection of this fault and the limestone of Niobrara age may also be mineralized. It is covered with soil, which supports a heavy growth of aspen trees and other vegetation, but the cover is relatively shallow and could be penetrated at a relatively low cost by trenching or with pits.

Inez tunnel.—The Inez tunnel is just west of Crystal, on the west side of the stream. It is readily accessible from the Crystal highway. Production of hand-picked ore is claimed, but the amount is probably small. There are over 1,500 feet of workings on the tunnel level and one stope (fig. 10). The stope, which was not accessible, was opened along the second vein and extends up to the surface. No work is known to have been done below the level of the tunnel.

The country rock consists of feldspathic quartzite and hornfels of the Hermosa (?) formation. The first vein encountered (see fig. 10) is chiefly quartz, is only a few inches wide, and illustrates very well the general character of the veins along joints that dip to the west, or in the opposite direction to the faults and large veins, and contain few or no sulphides. The second vein is more complicated. The rocks are much fractured, and vein calcite is plentiful in irregular stringers and masses over a width of 5 to 15 feet. The fractured zone with calcite is again exposed in the short connection between the two almost parallel drifts that extend to the northwest. The western drift follows a stratum that is mineralized but not enough to make ore. This bed loses its identity to the southeast, as it approaches the fractured zone, and a narrow fissure continues, as shown on the map. The veins in the eastern drift are small and unimportant.

The last 300 feet of the tunnel follows the bedding. On the east side of the fractured zone of abundant calcite the beds strike more nearly north than they do on the west side. As a change of strike commonly occurs on opposite sides of a fault the inference here is that a fault is represented by the fractured zone. The intersection of this zone and a favorable horizon would warrant prospecting if all the rocks in the tunnel were not of the highly siliceous kind that are unfavorable to sulphide mineralization. More promise would seem to be offered by crosscutting from the longer northwest drift to prove the presence or absence of the fractured zone than by extending the tunnel or its present drifts. If a fault is found, the
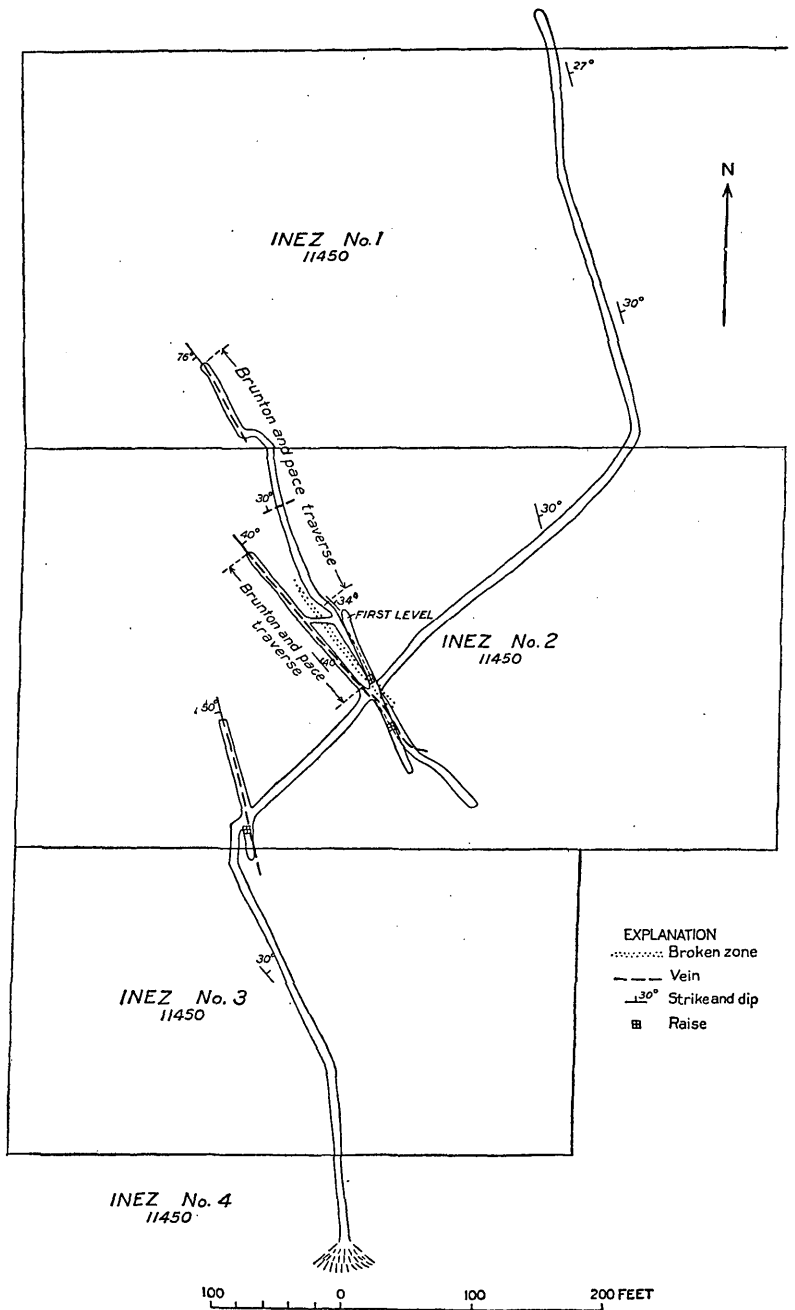
FIGURE 10.—Inez tunnel.

character and amount of mineralization would have to be the guide to further exploration.

Lizard Lake.—A few hundred feet east of Lizard Lake native gold was found by McWilliams & Brinkmeyer, of Marble. A few sacks of ore were shipped, but the yield is not known. The developments consist of a pit 6 to 8 feet deep on the vein and two crosscut tunnels. The first crosscut tunnel is 75 feet below the outcrop of the vein and about 90 feet long. The second tunnel, 395 feet long, is 700 feet to the south and about 200 feet lower, near the Crystal River. Both tunnels are new since 1930, and neither has intersected the vein. The lower tunnel has been abandoned, but the upper one was being continued when the prospect was last visited, in the summer of 1933.

The gold occurs in a vein in Maroon grits similar to the other numerous veins in the district. The vein strikes N. 25° W., is vertical, and has a width of about 2 feet. As exposed in the pit the vein consists of two or three stringers of vuggy quartz 2 to 4 inches wide in which the gold occurs probably as a surface concentration. Pyrite is present in the more solid quartz, but only limonite is associated with the gold. The fissure of the vein itself is not strong, and the quartz stringers could not be traced far. As small fractures consistently show a lack of continuity in beds that change as much in character as the Maroon grits, this particular vein is not encouraging. In addition the oxidized part of the vein, to which the native gold and relatively high grade ore are likely to be confined, will certainly be limited in depth by the water table some distance above the level of Lizard Lake. The gold content of the unoxidized parts of the vein cannot be given with certainty; it is probably not more than 0.01 to 0.03 ounce to the ton, the tenor common in the numerous similar veins in the area.

Lucky Boy.—The Lucky Boy prospect is half a mile west of Crystal on the north side of a valley at an altitude of 9,200 feet and is marked by a conspicuous light-colored dump. During 1906 or 1907 ten to twelve cars of zinc ore shipped by W. Porter Nelson [75] yielded 35 to 42 percent of zinc. The shipper was not paid for the other metals, which he said consisted of 2 percent of copper, 2½ percent of lead, and 5 to 6 ounces of silver to the ton. The developments consist of an upper tunnel 75 feet long and a second tunnel about 20 feet lower, 100 feet long. An incline connects the two.

Both tunnels and incline are along the same stratum in the upper part of a 75-foot limestone bed interbedded with shale and sandstone. The bed strikes N. 75° W., dips 31° NE., and is overlain by a limy shale 25 feet thick. Above the limy shale are grits typical

---

of the Maroon formation. Only thin, lenticular, impure beds are found above this horizon, which is therefore considered the top of the Hermosa (?) formation (Pennsylvanian).

In the upper tunnel 4 feet of the limestone is brecciated. Numerous veinlets of dark-brown sphalerite and much pyrite are found in this fractured stratum both parallel to the bedding and across it. On the surface the brecciated bed is exposed for fully 200 feet west of the tunnel, but it shows no sulphides. The easterly continuation is not exposed. Pyrite is relatively abundant along this zone in both the upper and the lower tunnel, but sphalerite, except locally, is present only in smaller amounts. Although sphalerite is the chief economic sulphide, small segregations of chalcopyrite as well as galena are present. Calcite is conspicuous with the galena, which commonly lines cavities in massive sphalerite. Scalenohedrons of calcite grow on both sphalerite and galena.

In the gully just south of the lower tunnel is a vein of massive quartz 18 to 24 inches wide in hornfels. The vein strikes N. 80° W., dips steeply to the north, and may represent a fault, although displacement could not be determined. It may be that this vein is a continuation of that noted in the Lucky Boy. In places the limestone has been silicified, and as quartz is also present with the sulphides a relation with the quartz vein is suggested. The vein where exposed is barren; but its intersection with the horizon of the Lucky Boy to the west would seem to justify consideration for prospecting.

The Lucky Boy vein, from which the shipments referred to above were made, has an average width of 2.8 feet. According to Mr. Nelson, an average assay of nine channel samples taken at intervals across this vein showed 7.9 percent of copper, 4.5 percent of lead, 24.0 percent of zinc, and 12.3 ounces of silver to the ton.

The location with respect to transportation facilities is favorable, and the chances for developing a paying ore body are therefore correspondingly better than those of many of the prospects in more inaccessible places. The extent of the mineralization both along the strike and down the dip in the vicinity of the tunnels should be determined.

Milwaukee-Undine group.—The Milwaukee-Undine group lies in the Dakota (?) quartzite along the top of Sheep Mountain, where there are several faults. (See pl. 1.) Along their strikes in both directions the faults are concealed by talus and vegetation, and horizon markers are generally absent. In addition to the faults, fissures without displacement are present. Both types of fractures have veins in places along their courses. Quartz veins are common in the Dakota (?) quartzite and show the same features found elsewhere in the area, and although accessible with difficulty, nearly all have been prospected; but all efforts seem to have been unsuccessful.

The veins show, in addition to quartz, much pyrite, some fluorite, and small amounts of sphalerite, chalcopyrite, and galena. The size and sulphide content of the veins are no greater than in many other places in the area, and their location is obviously more unfavorable. They therefore offer little or no encouragement for further prospecting.

Pioneer (Warrior) tunnel.—The Pioneer (Warrior) tunnel is on Lost Trail Creek on the west end of the north slope of Sheep Mountain. The tunnel exposes a strong quartz vein 1 to 6 feet wide along a fault in the Dakota (?) quartzite. The plan of the fault and the tunnel are shown in figure 11. Although the rocks are highly fractured and much quartz is present, there are very few sulphides other than pyrite. The prospect is typical of the quartz veins that occur in quartzite.
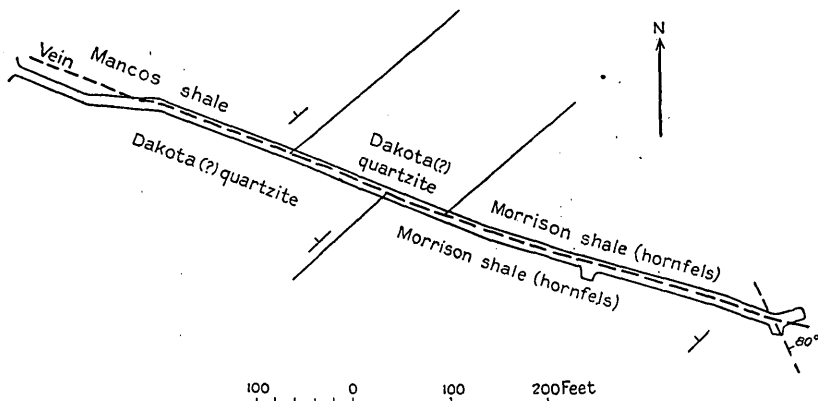
FIGURE 11.—Pioneer (Warrior) tunnel.

Sheep Mountain tunnel.—The Sheep Mountain tunnel is just west of Crystal, on the north side of the highway. Its purpose was to intersect "all" the veins on Sheep Mountain. Unfortunately, however, the tunnel is confined to a few beds (see fig. 12), and no crosscutting veins of any consequence were intersected. The tunnel followed slightly mineralized beds in country rock of quartzite and hornfels of the lower part of the Maroon formation. In the longer drift a fairly persistent bed of black shaly hornfels averaging 2 feet in thickness was believed by some to be the same bed that contains the ore in the Black Queen mine. Lithologically the beds are similar; both contain pyrite, small amounts of sphalerite, galena, and calcite veinlets. However, other similar beds are also present. It is therefore not safe to correlate any two of them if they cannot be traced continuously, a condition very difficult to fulfill on the slope of Sheep Mountain.

The south drift also followed a mineralized bed that showed an abundance of pyrite in a matrix of calcite and quartz and that con-
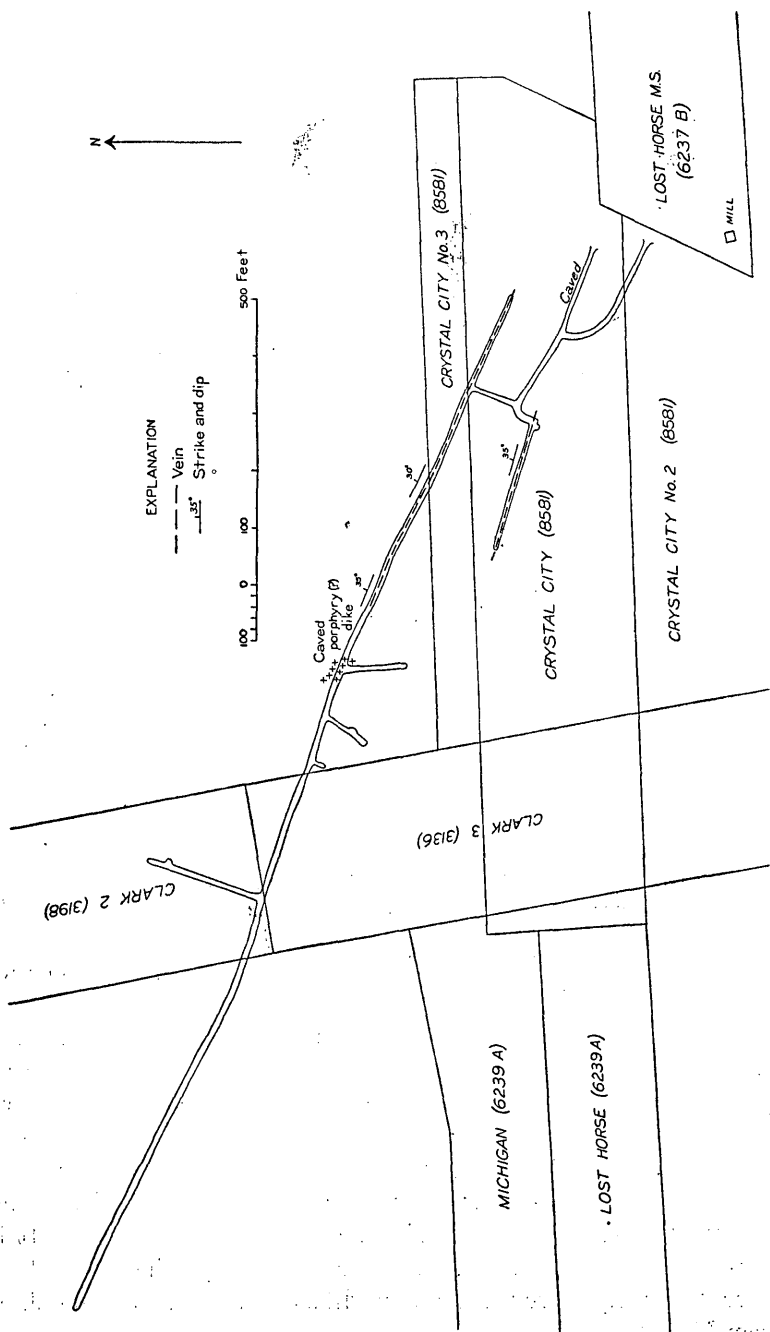
FIGURE 12.—Sheep Mountain tunnel.

tained sphalerite, chalcopyrite, and galena in small amounts. In several places along the drift the mineralized bed was stoped for 3 to

4 feet above the level of the drift, and these stopes are supposed to be the source of some of the ore treated in the old mill mentioned below.

A mill was constructed on the south side of the Crystal River opposite the tunnel portal, and some ore was treated but without success. According to reports some of the ore milled came from surrounding prospects. Whatever its source, the grade was too low for the inefficient methods of gravity separation employed. As a fair tonnage is represented, however, some effort is justified to determine the possibility of treating the ore with modern methods.

Tennessee of the Black Queen group.—The Tennessee of the Black Queen prospect is not connected with the Black Queen mine except by name. It is just north and about 200 feet vertically above benchmark 8656, near Twin Bridges, on the Crystal River road. Pieces of sphalerite, galena, and chalcopyrite lie scattered on the slope from the road up to the prospect. In 1929 [76] 5.19 tons of ore from the dump was shipped to the United States Smelting & Refining Co., Salt Lake City, and yielded assays showing 1.57 percent of copper, 8.25 percent of lead, 14.9 percent of zinc, 12.7 percent of sulphur, 5.0 percent of iron, and 11.5 ounces of silver to the ton.

The amount of development could not be determined, because all openings were caved. Nothing could be learned about the deposit beyond the fact that the sulphides common in the area were present.

LEAD KING BASIN

The Lead King Basin is a wide area along the valley of the North Fork of the Crystal River where it crosses soft Mancos shales 2 miles north of Crystal. The old road used for hauling ore from this locality is still passable, and it would cost relatively little to make the basin easily accessible to trucks. Several relatively prominent veins have been prospected in this locality, and among them is the vein of the Lead King mine, which is the largest in the entire area. All veins of any size that could be recognized are shown on the geologic map (pl. 1). The formations here dip northward. The outcrops of some of the veins are stratigraphically above the limestone of Niobrara age, which they must intersect a short distance below the surface. As the ore of the Lead King mine is related to this limestone it is surprising that the points of intersection of the limestone by the veins referred to above have not been more fully explored. A few shafts and tunnels, all caved, are located along some of the veins above the limestone. The depth to which these prospects extended is, of course, not known, but the size of each dump appears too small to represent an opening down to the lower part of the limestone, which is the horizon most favorable for ore, according to relations shown in the Lead King mine.

---

[76] Nelson, W. P., personal communication.

Lead King mine.—The deposit of the Lead King mine was not discovered until about 1902, or fully 25 years after ore was first recognized in the area. Authentic records credit the mine with a total production, chiefly in lead, of nearly $250,000.[77] This is by far a larger production not only than that of any other mine in the area but also than that of any other mine in the district.

The composition of the ore is best shown by smelter returns, which, according to settlement sheets of 46 carloads of ore of the early period of production, averaged 12.39 percent of copper, 19.87 percent of lead, 17.25 percent of iron, and 29.15 ounces of silver to the ton.

The smelters do not always give credit for zinc if the ore has been selected for lead, and lead-silver is often lost if the ore is selected for zinc. For this reason older smelter returns do not accurately represent the composition of the ore. Iron was regarded as beneficial in smelting. During 1912 and 1913, 530 tons of ore was shipped by Walter Brace under lease, and this is more representative of the composition of the ore than the earlier shipments. The smelter returns averaged as follows:

Smelter returns of shipments from Lead King mine, 1912–13

Ore	Tons	Silver (ounces per ton)	Lead (percent)	Copper (percent)	Zinc (percent)
Lead-silver	70.44	58.6	62.8	----------	1.1
Zinc	410.41	----------	1.3	----------	46.8
Chalcopyrite	49.52	10.7	3.8	11.0	18.1

Attempts to mill low-grade ore by gravity methods of mineral separation have not been successful, but flotation has not been tried. Below is a mill test of material taken from the dump.

Wilfley table test of material from dump of Lead King mine

[Made for the Crystal River Mining & Milling Co., Denver, Colo., Mar. 20, 1915, by the American Zinc Ore Separating Co.]

	Weight		Silver (ounces per ton)	Copper (percent)	Lead (percent)	Zinc (per cent)	Iron (per cent)	Insoluble (percent)
	Pounds	Per-cent						
Original	6,070	100.00	0.90	0.80	11.60	16.80	13.10	17.90
Wilfley concentrates	960	15.81	2.22	.30	42.20	6.30	19.40	1.34
Saving			[1]38.99	5.93	66.13	5.93	23.41	1.10
Static zinc	1,470	24.22	.48	.30	3.80	46.70	5.10	5.04
Saving			[1]12.92	9.03	7.93	67.33	9.43	6.82
Static iron	1,830	30.15	1.06	1.80	6.90	11.40	26.80	7.47
Saving			[1]35.51	67.85	18.80	20.45	61.68	12.60
Wilfley tails	1,570	25.86	.88	.40	2.90	5.50	2.70	46.60
Loss			[1]8.05	15.54	6.48	8.46	5.33	72.91
Wilfley slimes	240	3.96	1.36	1.20	11.20	12.80	8.10	31.60
Loss			[1]5.98	5.94	3.83	3.01	2.44	6.97

[1] Percent.

Ore crushed to 20 mesh. Sized in three sizes, 20–40, 40–80, and −80 mesh. The original percentage of lime was 5.60, and of static zinc 3.60.

---

[77] Henderson, C. W., Bur. Mines, Denver, Colo., personal communication.

About 1917 some dump ore was milled, and 138.5 tons of concentrates was produced, but they were not shipped until 1929. The average smelter returns, from the United States Smelting & Refining Co., Salt Lake City, showed 4.15 percent of copper, 5.85 percent of lead, 32.82 percent of zinc, and 7.60 ounces of silver to the ton.

The developments consist of a main tunnel about 600 feet long (see fig. 13, A), several raises and stopes, and two vertical winzes reported to be over 100 feet deep. Both winzes were filled with water and were inaccessible. The stopes, which are in ore, continue to the surface. Drifts connecting these stopes at higher levels are caved, and only 20 to 30 feet of the stoped area above the main tunnel could be examined.

Almost due east about 500 feet from the main tunnel and only a little above the level of the stream is a tunnel over 1,000 feet long, shown in figure 13, B. The purpose of this tunnel seems to have been to explore ground near the Lead King deposit, but it is too far from the favorable places to be effective. The veins intersected by this tunnel are weak and not commercially important.

Mancos shale, including the limestone of Niobrara age, forms the country rock; it strikes N. 70°–75° W. and dips about 30° NE. The limestone crops out in conspicuous and nearly continuous exposures from a point near the stream to a point well above and west of the mine. The shale is calcareous, grading into the limestone, which itself contains interbedded shale, and underground the two are difficult to distinguish. In the main tunnel the limestone is recognized in the crosscut near the end of the tunnel, but the position of its base could not be satisfactorily placed. It appears, however, that the stopes are just below or in the lower part of the limestone bed.

The sulphides that constitute the ore of the Lead King mine are typical of the area as a whole, but the gangue differs in that it consists entirely of calcite and fluorite; quartz and pyrite, which are so abundant elsewhere, are relatively scanty here. The ore minerals and gangue occur in irregular ramifying veinlets distributed in a zone essentially parallel to the bedding. Individual veinlets of massive sphalerite 1 to 3 inches wide are in the walls of the stope, but apparently their total volume was too small to constitute ore.

These veinlets show a fairly definite sequence of filling of fractures. Chalcopyrite, sphalerite, and fluorite either together or separately form the walls; calcite and galena are very characteristic along the more central parts. Calcite scalenohedrons lining vugs are common. The fluorite ranges from rose pink to green, and some is colorless.

Breccia occurs along the vein in places, particularly in that part of the floor of the stope accessible immediately above the tunnel.

The breccia consists of fragments of rock and a little sulphide cemented by fine-grained white calcite; it ranges in width from less

EXPLANATION
— — — — — Vein
$\underline{}^{65°}$ Strike and dip
⊞ Raise
⊠ Winze

100   0   100   200 Feet
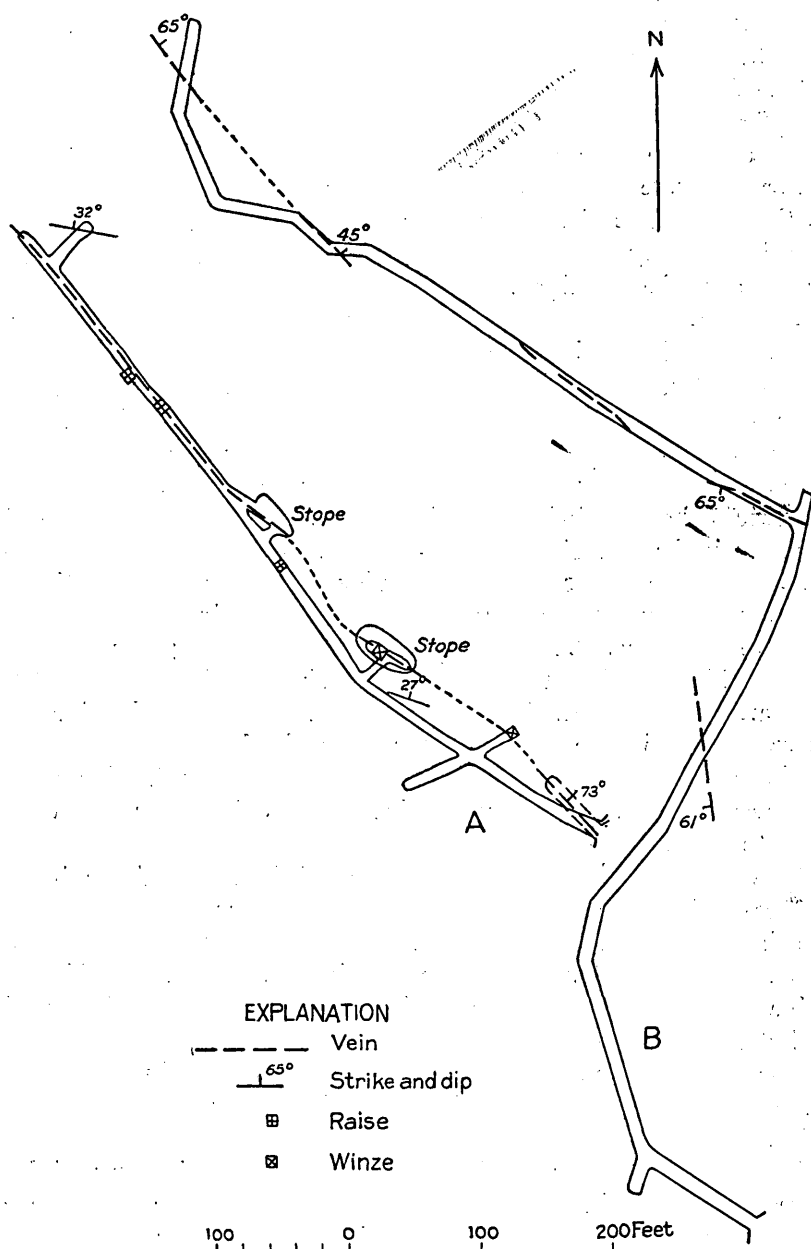
FIGURE 13.—A, Tunnel of Lead King mine; B, Lower barren prospect tunnel, Lead King mine.

than an inch to 12 inches. Northwest of the second stope in from the portal (see fig. 13, A) the breccia gives way to a calcite vein,

6 to 12 inches wide; this vein was followed by the tunnel to the face, where some breccia is again present. At the portal of the tunnel is a calcite vein 12 to 18 inches wide with several inches of chalcopyrite along each wall. This vein may be continuous with the breccia-filled fissure. However, a short drift just above the tunnel shows this vein to pinch to a width of a few inches in less than 30 feet.

The ore formed along the intersection of fissures and the lower part of the limestone member. The fracture intersected the bedding at a small angle, and its strike changes on passing from shale to limestone. As nearly as could be determined the first stope pitched about 50° NW. and the second stope about 65° NW. The two winzes, being vertical, do not approach the zone along the line of the pitch of the stopes. Old maps show the presence of some ore in both winzes, whereas from other sources barren massive pyrite is reported. If any ore is present its amount is probably small; otherwise it would have been mined. All reports agree that sulphides occur in these winzes, and this occurrence, insofar as it indicates a continuation of mineralization downward, argues for rather than against the presence of ore below the tunnel level. In view of the fact that no change in geologic conditions is evident at the tunnel level, below which there has been only scant development, further prospecting is justified. The stopes are at or in the lower part of the limestone member, and the top of this member, somewhere beyond the face of the tunnel, is also a favorable place for prospecting.

MINERAL POINT

Mineral Point as seen from Crystal is the top of a steep cliff, between the North and South Forks of the Crystal River. It is, however, the end of a ridge that forms the divide between these streams.

The lower part of the bold cliffs near Mineral Point is Maroon grit, and the upper part consists of Morrison shale and Dakota (?) quartzite. Mancos shale forms the crest of the ridge a short distance back of Mineral Point and the edge of the cliff. The quartzite along the top of the cliffs, as is common elsewhere in the area, is traversed by several fissure veins. The veins trend northwestward, and correlation of some of them on opposite sides of the ridge is suggested by their approximate alinement, but they cannot be traced through the overlying Mancos shale. Prospects on fissure veins are the Daisy, Belle of Titusville, and Burt.

Daisy.—The Daisy, north of Mineral Point, is a caved and inaccessible tunnel. The portal, at an altitude of a little more than 10,000 feet, is in Dakota (?) quartzite only a few feet below the Mancos

shale, and the tunnel runs along a fissure vein that trends N. 45° W. and dips 60°–70° SW. The fissure is without apparent displacement. Much of the dump is Mancos shale, and specimens showing sphalerite, chalcopyrite, galena, and some fluorite are present. Whether development was continued along the vein or along a contact is not known.

Belle of Titusville.—The Belle of Titusville is about a mile east of Crystal on the south slope of Mineral Point, at an altitude of about 10,000 feet and not far east of the Burt. It is reached by a short steep trail from the old road along the Crystal River. The developments consist of two tunnels (see fig. 14), one about 50 feet vertically above the other along a narrow fissure vein. The winze at the end of the upper tunnel connects with the lower tunnel. A small production of silver is claimed. The ore was run down a chute to the road below and hauled by wagon to a 10-ton mill located near the stream and operated by water power. The amount of silver produced is not known, but it cannot have been large.

The fissure vein of the Belle of Titusville is in Jurassic rocks, which strike N. 35°–40° W. and dip 25°–37° NE. The upper tunnel follows the vein. The lower tunnel after drifting on the vein for about 30 feet turns west and is off the vein for fully 200 feet before it swings back to intersect it at a winze that extends down from the upper tunnel. Wherever exposed the vein is

FIGURE 14.—Belle of Titusville tunnels.

less than 2 inches wide and consists largely of galena in calcite gangue. The ore is said to be of high tenor in silver, and according to reports this vein, though small, was continuous and constituted the source of the ore mined and milled. The developments along the vein do not give any evidence that it can be expected to be wider to the north, and with ordinary metal prices the vein is too small to be promising.

The vein strikes east of north and is not in accord with the trend of the faults and stronger veins in the area. In this respect the Belle

of Titusville vein is not entirely unique, but it represents the only vein with a northeast strike that has been developed to any extent.

Burt.—The Burt prospect is about a mile east of Crystal on the south slope of Mineral Point, at an altitude of about 10,250 feet, not far west of the Belle of Titusville. The same trail from the road along the Crystal River that leads to the Belle of Titusville continues on up to the Burt. Tunnels aggregating fully 1,000 feet in length have been made, but no ore was produced. Three tunnels
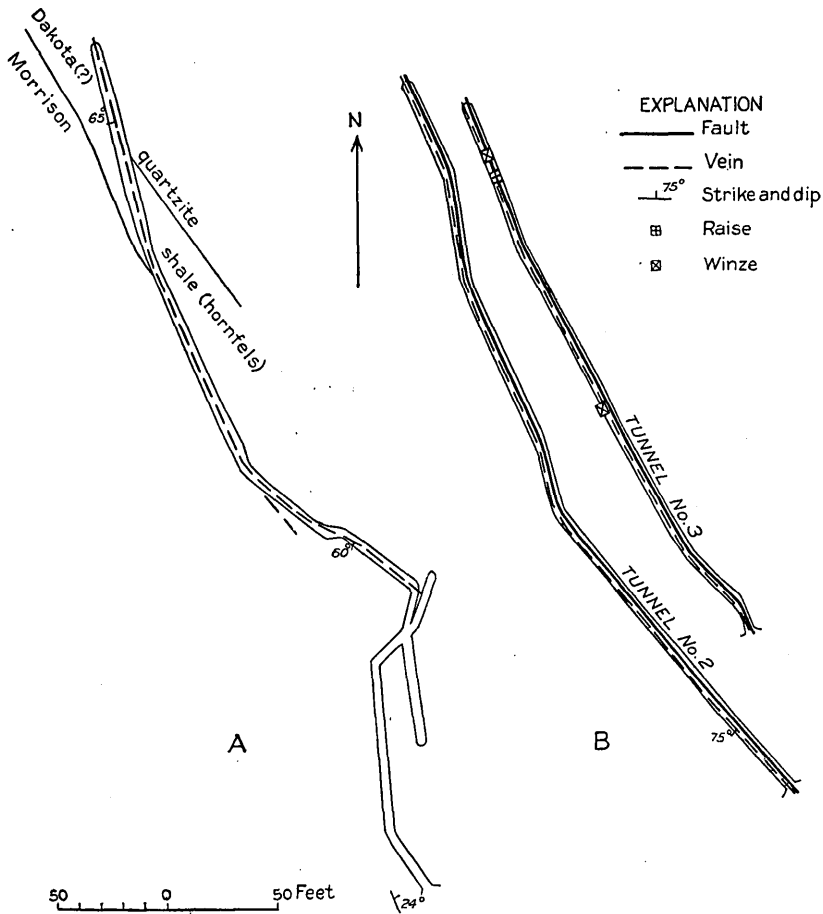
FIGURE 15.—Burt tunnels. A, Lowest; B, second and third.

were accessible and are shown in plan in figure 15. A fourth tunnel about 25 feet above tunnel 3 and on the same vein was inaccessible.

The tunnels follow two nearly parallel fault fissures in the Jurassic rocks and Dakota (?) quartzite. The fissures, which are only 30 to 40 feet apart, strike N. 30°–35° W. and dip 60°–75° SW. On each fault the hanging wall moved down and displaced the beds 10 to 20 feet vertically. The lowest tunnel follows the eastern fault, and the

three higher tunnels are on the western fault. The veins consist largely of quartz and average less than 12 inches in width, although locally they are 3 feet wide. The usual sulphides and fluorite are present. In tunnel 2 coarse vuggy quartz occurs along the fault, and sphalerite, chalcopyrite, and galena line the quartz vugs. Along the wall of this tunnel an area 6 feet across showed only sulphides, but this face represented a longitudinal section of a stringer less than an inch across. Between tunnels 2 and 3, where the vein is well exposed at the surface, the relations are shown better than underground. Here the quartzite is shattered through a width of 4 to 10 feet, and the vuggy quartz partly fills the fractures. The sulphides are confined to the vugs along the main zone of movement or fracturing, which is less than 2 feet wide. In view of the fact that the veins have been moderately well explored without encountering commercial bodies of ore, further expenditure for development does not seem justified.

BEAR MOUNTAIN TUNNEL

On the north slope of Bear Mountain at an altitude of 9,050 feet is a tunnel about 450 feet long, shown in plan in figure 16. It was planned to intersect a vein that carried much silver at the outcrops, several hundred feet above the tunnel level. The tunnel was not continued to its objective.

The Pennsylvanian Hermosa (?) formation crossed by the tunnel consists largely of calcareous shale, sandstone, and some limestone in contact with granite of the Treasure Mountain stock. As determined on the surface the beds strike northwest and dip northeast, but in the tunnel, owing to the broken rock, this attitude is not evident. Likewise the contact between sedimentary and igneous rock in the tunnel is indefinite. It appears to cut across the beds in places and to parallel them elsewhere along northerly dips that are as low as 25°. On the surface the trend of the contacts suggests that the igneous rock cuts across the beds at a steep dip.

The first vein in the tunnel is a narrow fissure that shows only weak mineralization. The second vein is 1 to 3 feet wide and shows quartz, pyrite, some fluorite, and a few small spots of sphalerite, chalcopyrite, and galena.

Although unimportant commercially, this tunnel is interesting be-cause it shows the local trend of veins, which is not evident from surface exposures. In addition the tunnel proves that mineralization was later than the intrusion of the Treasure Mountain stock.

TREASURE MOUNTAIN

The Skyline and Lead Bullet prospects are referred to Treasure Mountain for lack of any other reference point. As a whole the mountain lies outside the zone of faulting and shows very little sulphide

mineralization. The two prospects are of interest because they occur where other evidence of mineralization is lacking. The Skyline is of further interest because it represents the only occurrence in the entire
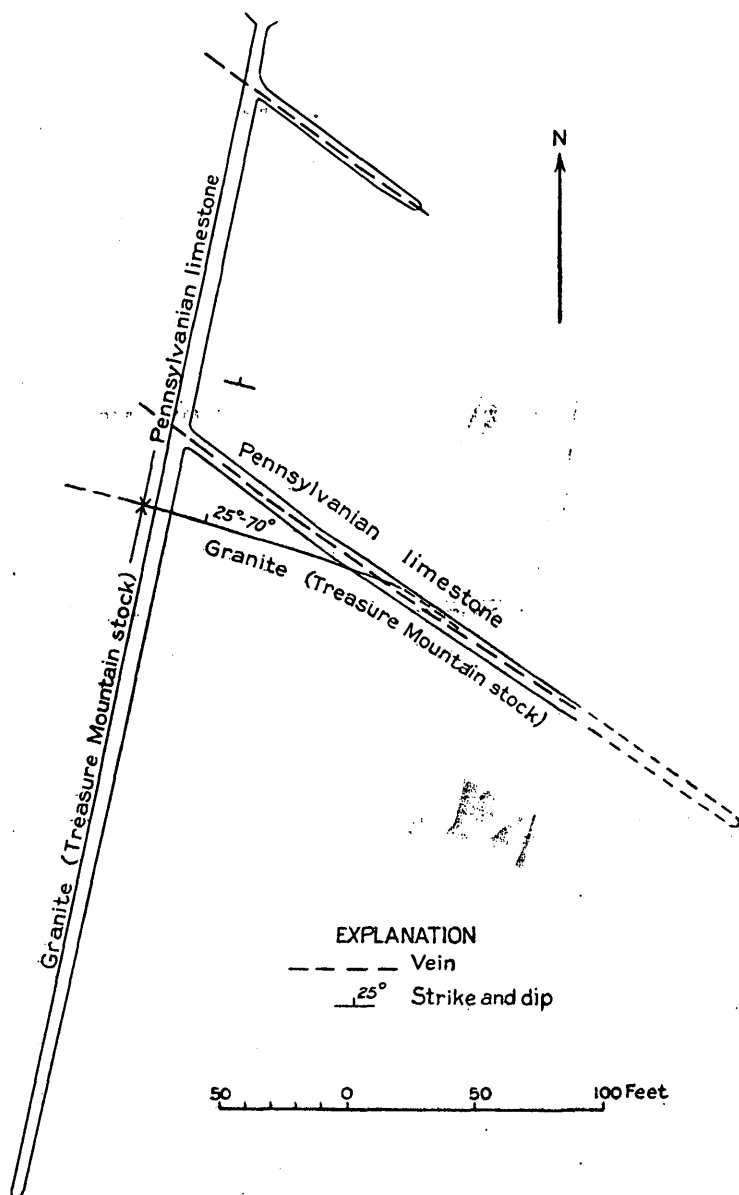
FIGURE 16.—Bear Mountain tunnel.

district of sulphide mineralization in the Mississippian (Leadville) limestone.

Lead Bullet.—The Lead Bullet prospect is at an altitude of 12,050 feet on the north slope of Treasure Mountain, a few hundred feet below the crest of the divide between Treasure and Whitehouse Mountains. It can be reached from either Yule Creek or the Crystal River over precipitous trails that climb 3,000 feet in less than 2 miles. At this altitude snow gathers as early as September and remains until June or July. After the snow has melted, which is usually in late summer, water can be obtained only from a small stream several hundred feet below.

In addition to the workings at the location given, there is a lower group of prospects formerly known as the Jack Wacker claims, about 3,000 feet to the southwest and a few hundred feet lower, on the opposite side of the divide. The upper workings consist of a tunnel, which was inaccessible, and the lower workings include numerous pits, open cuts, and a caved tunnel. A small tonnage is reported to have been shipped from the open pits and cuts in the early days. No shipments have been made from either workings in recent years.

From the distribution of the workings it seems that mineralization was confined to the Parting member or other formations near it, at the base of the Devonian. Spongy and vuggy masses of quartz, with quartz crystals lining the openings, replace one of the calcareous beds of the Parting member where it crosses the divide and afford further evidence of mineralization at this horizon. The tunnel on the north slope or upper workings is in the upper part of the Manitou (Ordovician) dolomite at the portal and is run southwest. Quartz masses on the dump resemble those found on the divide in the Parting member, but whether the tunnel intersected this member is not certain. The lower workings are in the Parting member, and the pits, open cuts, and tunnels have been confined to it. Veins are not evident, and it is probable that mineralization followed the stratification; accordingly this deposit is classed as a bedded deposit.

Sulphides were found only on the dump of the upper workings and consisted of galena and pyrite with a gangue of fluorite and quartz. A high silver content is claimed for the ore, but an assay of selected galena gave only 11 ounces of silver to the ton. This relatively small amount of silver is in accord with the usual finding in the area—namely, that galena does not necessarily make highly argentiferous ore. At the lower workings the rocks are iron-stained, and all the sulphides that may have been present are leached out. The presence of quartz and fluorite gangue indicates that the mineralization at the lower and upper places was essentially the same.

A high silver content, if present, probably occurs only in the oxidized parts of the mineralized bed and represents an enrichment of the metal. The proof of high silver, its associations, and the

form of the metal are important in determining the possibilities of the prospect.

Skyline.—The Skyline mine is three-quarters of a mile northwest of the Lead Bullet and 400 feet lower, at an altitude of 11,650 feet; it can be reached by the same trails.

A few tons of almost pure coarsely crystalline galena ore is reported to have been shipped. Silver has not been quantitatively important, although a small amount is present. The development consists of an irregular opening 5 to 20 feet across that follows down the mineralized zone for a distance of about 40 feet.

Mineralization occurred in the lower part of the Mississippian (Leadville) limestone along a zone or band of dolomite marble. Several similar layers of dolomite, except that they lack sulphides, are interbedded with the white calcite marble in the lower part of the Mississippian. There is evidence of some mineralization at the same horizon to the southwest, on the opposite side of the divide. These are the only places in the area in which evidence of sulphide mineralization was recognized in the Mississippian (Leadville) limestone.

The ore, consisting of massive coarsely crystalline galena, occurs in irregular masses almost devoid of gangue and other sulphides. The form of the ore body is not clear, but evidence of a vein is lacking, and the body seems to be a massive replacement deposit. The sedimentary formations dip to the southwest, and the stope, of irregular form, pitches in the same direction but at a steeper angle. As a result the stope, which is about 40 feet long, ends at a horizon 15 or 20 feet stratigraphically below the zone in which it starts and in which mineralization appears to have been strongest. The extent, if any, of mineralization down the dip has therefore not been determined, but it is clearly limited along the strike of the bed, which is well exposed in the cliff.

Yule Creek.—The somewhat isolated Yule Creek deposit is about a mile southeast of the quarry of the Yule Colorado Marble Co. No ore is known to have been shipped from this prospect. It has been developed by a shaft, which was not accessible, and a tunnel 230 feet long in the relative positions shown in figure 17.

The ore occurs in the lower part, or Parting member, of the Devonian Chaffee formation and consists of dark-brown to black sphalerite with some pyrite and a small amount of calcite gangue. Galena and chalcopyrite were not observed. The tunnel, apparently planned to intersect a zone exposed in the shaft, crosscuts the beds and then follows a stratum for almost 50 feet to the point where ore is first encountered. The first indication of mineralization is a gouge 1 to 2 inches thick along a bedding surface. The gouge continues for several feet until it abruptly gives way to a 6-inch layer of massive

sphalerite, which increases in thickness to 12 inches within the next 9 feet along the strike. The 12-inch vein continues 18 feet and is then cut off by a vertical fault that trends N. 78° E. From the fault to the face of the tunnel the rocks are barren. The fault caused very little fracturing of the rock and was not evident on the surface. The amount and direction of movement on it could not be determined from the scant development.

The form of the deposit as exposed in the tunnel is clearly tabular parallel to the bedding. The bed along which the sphalerite was deposited projects to the surface 10 or 15 feet east of the shaft, and it should have been found at a depth of about 15 or 20 feet in the shaft, which is claimed to be 40 feet deep and bottomed in mineralized rock. The relations suggest the possibility that the bed encountered in the shaft may not be at the same horizon as the one in the tunnel.

EXPLANATION
——— Fault
— — — Vein
⊥ Strike and dip
▣ Shaft

50   0   50 Feet
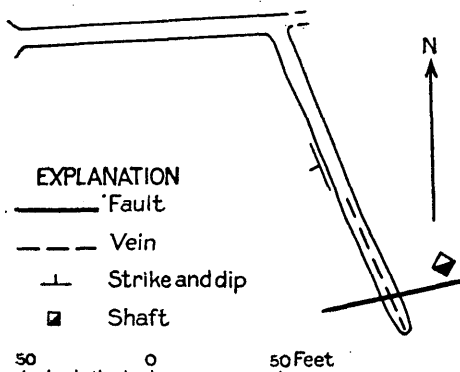
FIGURE 17.—Zinc prospect on Yule Creek about a mile southeast of the Yule Colorado marble quarry.

The body of sphalerite exposed in the tunnel is too small to be of commercial value, but its possible continuation south of the fault should be considered. The displacement that cut off the ore cannot be large, as it did not offset the formations enough to be noticeable on the surface. Drifting both east and west should locate the faulted ore if ore is present. Crosscutting to the east to determine the possible extent of ore reported in the bottom of of the shaft should also be considered.

This deposit is of interest because it is virtually isolated and well outside of the main mineralized belt. Some pyrite and a very little galena were noted on the northwest end of the knoll a little over 1,000 feet to the northeast. Apart from this the closest mineral deposits are the Skyline and Lead Bullet prospects, about 2 miles to the north, both of which are themselves outside the main mineralized zone.

CRYSTAL MOUNTAIN TUNNEL

The portal of the Crystal Mountain tunnel is southeast of Crystal at an altitude of a little less than 9,500 feet, on the stream that drains Bear Basin. The tunnel was driven in an easterly direction to intersect the downward extension of the veins, including the Harris-Farley group, that crop out on the east slope and on the north end of Crystal Mountain. There is no record that veins of economic

importance were intersected. The tunnel, which is now inaccessible, is shown in figure 18.

The tunnel is in the Hermosa beds (?), with its portal about 150 feet vertically below the limestone conglomerate that in mapping was considered the top of the formation. Whether or not any
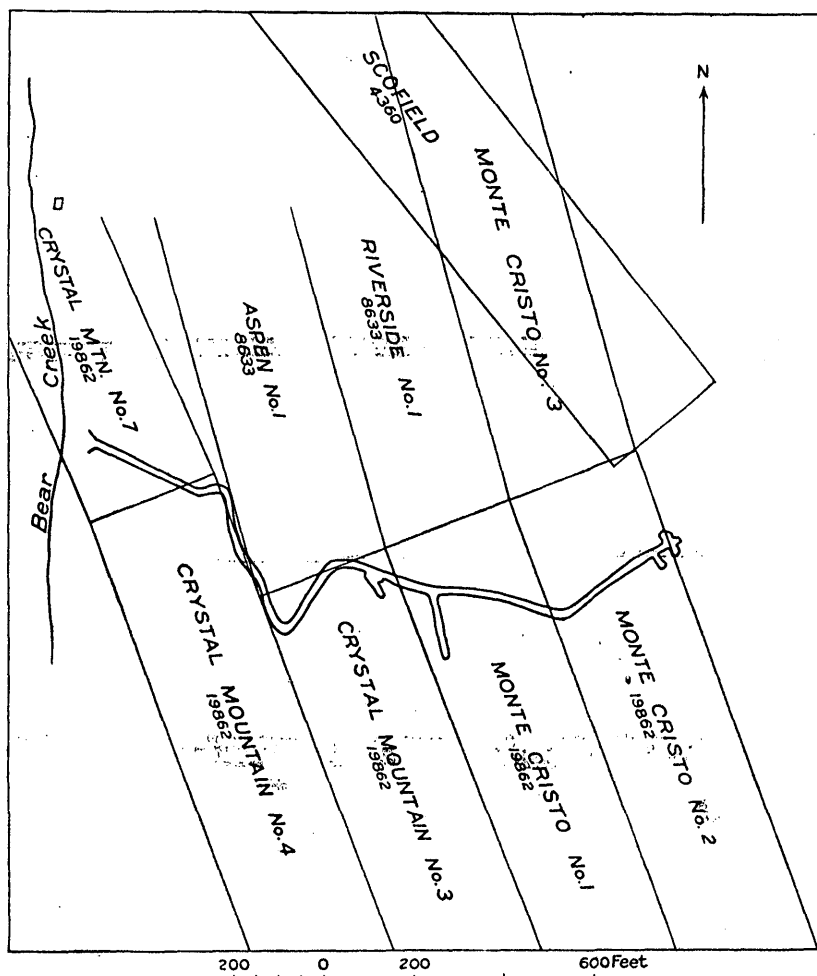
FIGURE 18.—Crystal Mountain tunnel.

Maroon grits were intersected by the tunnel could not be determined. On the mine map from which figure 18 was taken each short branch from the main tunnel was marked as "drift on vein", and from this it is inferred that mineralization occurred at these places.

HARRIS-FARLEY AND HIGH TIDE VEIN GROUP

Several veins crop out on the northeast slope of Crystal Mountain. They trend northwestward, crossing the north end of the mountain above an altitude of 11,000 feet. Some of the veins are visible in the precipitous cliffs from the valley below. A little ore is said to have been shipped from these veins, but no regular production was made. Of the numerous workings on these veins the Harris-Farley tunnel, which is about 600 feet long, and the High Tide shaft and tunnel seem to be the most extensive.

The veins occur along faults and are typical in their character and habit of those common to the area. Their strikes are northwest, and they are vertical or dip steeply northeastward. Several of those shown could not have been recognized except for the presence on Crystal Mountain of the Morrison (Jurassic) formation, which served as a horizon marker and permitted recognition of offsets. It is very unlikely that all the fissures are shown on the geologic map, and, moreover, it is almost certain that fissures extend farther along the strike than is shown. However, their branching character and the known lack of persistence of individual fractures make it unsafe to project them far beyond their outcrops. Some hold to the view that the Harris-Farley vein and the High Tide vein are continuous; although this is possible, it is far from being demonstrated, but there can be no doubt that they are related. Efforts have also been made to trace these veins across the valley of the Crystal River to Sheep Mountain, but without success. It is unlikely that individual fractures are continuous across this interval, but the zone of faults and veins as a whole is continuous, as is shown by the fissure veins that cross the crest of Sheep Mountain.

In the Harris-Farley tunnel the quartz vein is 15 to 30 feet wide; it shows pyrite and a small amount of the economic sulphides. The vein is reported to carry 1 to 2 ounces of silver to the ton and only small amounts of copper, zinc, and lead. At the High Tide the workings were not accessible. Surface outcrops are oxidized and show a relatively large amount of chrysocolla with the amorphous black oxide of copper. On the dumps sphalerite, galena, and chalcopyrite in a gangue of quartz and fluorite are common though not particularly abundant.

SOUTHERN PART OF THE AREA

NORTH POLE MINE

The North Pole mine is at an altitude of 12,150 feet in North Pole Basin, between Crystal and Galena Mountains. In spite of its difficultly accessible location some ore was shipped. The shipments, of which there is a partial record,[78] included both oxide and sulphide

---

[78] Nelson, W. P., Denver, Colo., private file.

ores. The oxide ore was treated by the Hoffman Smelting & Reduction Co., at Marble, in 1898 and 1899. This ore averaged about 12 percent of copper, the only metal mentioned, and yielded the shipper $4,049.79 after deduction of the smelting charge of $7 a ton. From 1902 to 1906 some sulphide ores were shipped, but although the composition of the ore is given, the amount of ore represented is not indicated. The shipments are listed in detail below, and they are of interest because they represent an ore that is relatively high in copper as compared with other deposits in the area. Furthermore, a good silver content goes with the copper, which is not the rule in most of the other prospects.

Shipments of ore from North Pole mine

Date	Buyer	Gold (ounce per ton)	Silver (ounces per ton)	Copper (percent)	Remarks
Dec. 10, 1902	U. S. Smelting Co		3.36	13.50	Oxide.
Do	do		13.90	11.30	Sulphide.
Sept. 10, 1903	Boston & Colorado		13.70	14.30	Sulphide, 2.5 percent.
Do	do		13.70	14.30	Sulphide lead.
Sept. 19, 1905	Grand Junction Smelting Co.		6.60	3.87	Mixed.
Do	do		7.50	4.39	
Oct. 12, 1905	do		4.96	4.66	
Dec. 7, 1905	do		7.20	4.60	
Dec. 18, 1905	do	0.02	6.40	5.30	
Dec. 24, 1905	do	.01	5.35	5.60	
Dec. 27, 1905	do	.01	4.41	4.30	
Jan. 4, 1906	do	.02	5.15	5.50	SiO₂, 33.7 percent.
Do	do	.02	5.65	5.75	{SiO₂, 30.6 percent. CaO, 11.6 percent.
Jan. 8, 1906	do		6.20	6.00	
Do	do	.015	5.80	5.80	
Jan. 10, 1906	do		4.34	5.30	
Jan. 11, 1906	do		5.50	4.60	{SiO₂, 33.6 percent. CaO, 12.9 percent. Fe, 17.9 percent.
Do	do	.02	4.80	5.20	
Jan. 10, 1906	do		5.43	5.35	{SiO₂, 37.5 percent. CaO, 15.2 percent. Fe, 16.8 percent.

The workings are not extensive. They consist of two upper tunnels, the Shakespeare and the North Pole (see fig. 19), and a lower crosscut tunnel. The Shakespeare tunnel is caved. The lower crosscut tunnel was planned to intersect the ore of the North Pole tunnel at depth. It crosscuts several hundred feet of Hermosa (?) beds but does not reach its objective. Hermosa (?) quartzite, recrystallized limestone, and shale altered to hornfels form the country rock. The beds strike N. 15°–20° W. and dip 25°–30° NE. In 20 to 30 feet in the North Pole tunnel (see fig. 19) the strike is N. 10° E., but this appears to be local, as it is not reflected on the surface where outcrops are good. The change of strike is suggestive of a fault or a sharp local flexure, which would also account for the fracturing.

The mineral deposit seems to have been formed by replacement along a limy bed. The distribution of minerals as observed in the

North Pole tunnel is shown in figure 19. Descriptions indicate that the plan of the Shakespeare tunnel, to the southwest, approximately parallels that of the North Pole, and it may be along the same stratum at a slightly lower level. The bedding is not evident in the North Pole tunnel where ore is present, but in the short southwest crosscut and just inside of the portal it is well defined and is approximately parallel to the main tunnel. Underground the trend of the banded quartz is north to northwest, and if it continues in this direction the last 30 to 40 feet of the tunnel is east of the mineralized zone.

The usual sulphides, sphalerite, chalcopyrite, galena, and pyrite, are present. However, the percentage of copper shown by the ore shipped is relatively high as compared with the average throughout the area. In addition to quartz and fluorite, which are common, hedenbergite is a characteristic gangue mineral and is relatively abundant. It is banded with quartz and usually occurs along the top and bottom of the ore as exposed in the tunnel. Brown resinous garnet is also abundant nearby, but whether it constitutes a vein mineral is not certain. Hedenbergite is common with garnet that formed during the period of metamorphism induced by the Treasure Mountain stock of granite. The presence of hedenbergite, a contact-metamorphic mineral, in the North Pole ore that also contains sulphides is interpreted to mean that this deposit shows the transition from the period of metamorphism to the period of vein formation. The relatively high copper content of the ore tends to support this tentative conclusion.

EXPLANATION

xxxxx Ore in limy bed

_25° Strike and dip

100   0   200 Feet

FIGURE 19.—North Pole tunnel.

GALENA MOUNTAIN

Galena Mountain forms a ridge between Schofield Park and North Pole Basin. Numerous veins, most of which have been prospected, are to be found on this ridge and southward to Rock Creek. Mexican Cut and the Blue Jay, Rockett, Homestake, and Brooklyn tunnels, described separately, lie in this small area, which represents the south-central part of the mineralized fault zone. Special mention is made of this area as a whole because of the large number of faults that are shown. The detail given on the geologic map (pl. 1) was possible because a separate topographic base on a scale of 1 to 12,000 was available. The area was mapped and described separately in a preliminary report.[79] The character of the topography and the presence of good horizon markers made many of the otherwise obscure faults recognizable.

None of the veins have made any regular production of ore, though it is said that small shipments were made from several prospects. The veins are all essentially the same, consisting largely of quartz with much pyrite and small amounts of sphalerite, chalcopyrite, galena, and locally tetrahedrite (gray copper). Fluorite is almost invariably present, and calcite is widely distributed in small amounts. In the low saddle south of Galena Lake barite, not common elsewhere, is abundant. Specularite is common and most abundant in those quartz veins along the larger faults that are more or less continuous. An abundance of specularite, barite, quartz, or pyrite does not indicate the amount of economic sulphides that may be present.

Mexican Cut.—On the east slope of Galena Mountain a mineralized stratum over 1,000 feet in length is exposed in the cliff of a glacial cirque. This locality is generally referred to as Mexican Cut, which is also the name of the patented claim showing the best sulphide outcrop. There is no record of shipment of ore from Mexican Cut, and the developments consist of several shallow cuts.

Mineralization occurred along the limestone 40 to 60 feet above the base of the Morrison formation. The strike of the beds is roughly parallel to the trend of the bluff, and the dip is easterly. The limestone has been largely replaced for several hundred feet along the outcrop by metamorphic silicates. Within this zone silicification and deposition of quartz with small amounts of sphalerite and galena and some chalcopyrite occurred. In one cut a deposit of massive sulphide almost 3 feet across and several feet long has been exposed, but its extent has not been determined. The rocks show the usual amount of fracturing, but fissure veins are lacking,

[79] Vanderwilt, J. W., Preliminary geologic notes on Galena Mountain, a part of Snowmass Mountain area, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 1, pp. 5–18, 1932.

and the relations suggest a bedded deposit. The cliff along which the mineralized limestone crops out is approximately parallel to the fault system of the area, and the mineralization could have been related to a fracture now largely removed by erosion. Future prospecting should be directed along the limestone formation, as the hornfels both above and below is not mineralized.

Blue Jay tunnel.—The Blue Jay tunnel is east of Galena Mountain and a few hundred feet below the mineralized limestone of Mexican Cut. It is a straight drift about 300 feet long on a fissure vein that strikes N. 70° W. and dips vertically. The vein changes along its strike from a barren knife-edge fracture to quartz averaging less than 2 inches in width with local lenses 24 inches wide. The wider part of the vein is of slight extent along the drift and apparently also vertically, as two raises in the widest part, about 50 feet from the face of the tunnel, were not continued far. These raises were not accessible. Chalcopyrite, much pyrite, and some sphalerite occur in the quartz, which also contains a little specularite. The quantity of ore is too small to be of commercial value, but the vein is of interest because it represents a mineralized fissure with a strike that is 40°–50° farther west of north than the strike of the main fault zone.

Rockett tunnel.—The Rockett tunnel is about 1,500 feet east of Galena Lake on Galena Mountain, at an altitude of 11,700 feet. This prospect represents mineralization on a branch fissure of a larger fracture, the Whopper fault. At the tunnel portal, near the base of the Dakota (?) quartzite, there is a displacement along the vein of 5 to 10 feet. To the north the fissure cannot be traced across the hornfels of the Morrison (Jurassic) shale. To the south the displacement increases as the larger fault is approached, and it is in line with a fracture that branches from the Whopper fault. Obviously, in considering the possible continuity of a particular fissure vein, it is important to determine its relation not only to rock formations but also to fractures nearby.

The vein is typical of those common in the Dakota (?) quartzite. It is 12 inches to 2 feet wide and consists largely of quartz with much pyrite, a little sphalerite, chalcopyrite, galena, and some fluorite. It has little commercial promise.

Homestake tunnel.—The Homestake tunnel is on the glacial bench that lies above and southwest of Schofield Park. It is almost due north of the Brooklyn tunnel and has been driven south in the Whopper fault. It extends for about 300 feet in the massive quartz vein, which is fully 20 feet wide along the fault. Pyrite is relatively abundant, and sphalerite, chalcopyrite, and galena are present only in small amounts.

Brooklyn tunnel.—The Brooklyn tunnel is on the southeast slope of Galena Mountain. It was intended to intersect several veins that crop out higher up the slope, in the Mancos shale immediately above the Dakota (?) quartzite. The plan of the tunnel and fractures encountered are shown in figure 20. No ore was shipped.

The tunnel crosses the Whopper fault and passes from Mancos shale into Dakota (?) quartzite about 150 feet in from the portal. The fault is marked by a vein of calcite 2 feet wide and considerable massive quartz with pyrite, specularite, and small amounts of sphalerite, galena, and chalcopyrite. About 250 or 300 feet in from the portal the tunnel crosses a second fault and passes from the quartzite into hornfels of the Morrison, in which it continues to the face. The fractures in the hornfels are small and, as is characteristic of this rock, show relatively little mineralization. It is somewhat doubtful whether the tunnel reaches its objective. The veins exposed on the surface would have to extend across the entire thick-

EXPLANATION
—————— Fault
— — — Vein
_75° Strike and dip

100   0   100   200 Feet
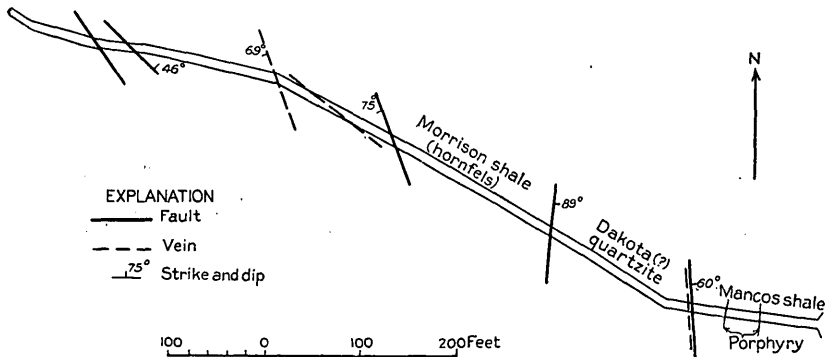
FIGURE 20.—Brooklyn tunnel.

ness of the Dakota (?) quartzite and a considerable thickness of Morrison formation before reaching the tunnel level. Veins of this type may extend some distance in the Dakota (?) quartzite, but they would not ordinarily continue far below the quartzite; generally the veins pinch out on passing into hornfels.

SCHOFIELD PARK

The canyon of the Crystal River southeast of Crystal is narrow and steep-walled for 5 miles and then widens into an open valley called Schofield Park. The park is less than a mile north of Schofield Pass and is accessible from Crested Butte by car. A town called Schofield, marked in 1933 by a few dilapidated cabins, was located here and served the surrounding territory.

The floor of the valley is Dakota (?) quartzite on the east and Morrison on the west. Only small amounts of sulphides, chiefly

pyrite, are present. The veins characterized by these sulphides are chiefly in Dakota (?) quartzite, and iron-stained outcrops are common, but prospecting in the park has not developed any commercial deposits. The veins strike and dip parallel to the trend of the main fault zone.

Whopper lode.—The Whopper lode is on the north side of the Crystal River Canyon almost 3 miles above Crystal and about half a mile below Schofield Park. It is at an altitude of 10,300 feet, a few hundred feet vertically above the trail that follows along the stream. The property has been developed by a shallow shaft and two tunnels, one about 20 feet vertically above the other. The upper tunnel is 80 feet and the lower one 60 feet long on the vein. A small stope, which, however, was inaccessible, is at the end of the upper tunnel. Frazer[80] examined the prospect in 1881, and at that time, according to his description, the upper tunnel was 66 feet long and a lower tunnel 37 feet long. A shaft 30 feet deep is also mentioned in his report. Little recent development work has been done, although an effort has been made to sort ore on the dump for shipment. The amount of ore shipped cannot have been large.

Mineralization occurred along a fault with a northwest strike and steep easterly dip which has been traced for more than 4 miles to the southeast and which has been named the Whopper fault, after this deposit. The base of the Dakota (?) quartzite is about 6 feet above the upper tunnel on the east side of the fault and is nearly 50 feet higher on the west side of the fault. The fault continues to the northwest, and a few small pits, each showing some sulphides, are located along its course. The vein was prospected to the south. Owing to poor exposures its continuity is not certain to the northwest beyond the limestone of Niobrara age in the Mancos shale. In the Dakota (?) quartzite the vein is 2 to 4 feet wide, with an average of a little over 2.5 feet. In all probability the vein, if it follows the habit of other veins in quartzite in the area, is less well developed in the Mancos and Morrison shales than it is in the Dakota (?) quartzite.

Sphalerite, galena, chalcopyrite, and tetrahedrite (gray copper) constitute the economic sulphides, and pyrite, quartz, and some fluorite the gangue minerals. The mineralogy of the vein is therefore in keeping with that of the veins at other prospects in the area. About one-third of the vein is estimated to be ore that carries well above the average proportion of economic sulphides

---

[80] Frazer, Persifor, Jr., The Whopper lode, Gunnison County, Colo.: Am. Inst. Min. Eng. Trans., vol. 9, pp. 249–258, 1881.

to gangue in most of the veins. Prommel [81] examined the property and obtained the following assays from channel samples of the vein:

Assays of samples from Whopper lode

	Width of vein (feet)	Gold (ounce per ton)	Silver (ounces per ton)	Copper (percent)	Zinc (percent)	Lead (percent)
Number of assay:						
1	2.7	0.10	39.30	0.73	7.45	3.47
2	2.5	Trace	1.70	1.35	No assay	No assay
3	3.2	No assay	2.70	1.45	12.97	7.84
4	2.4	do	.44	.42	2.82	.45
5	2.0	Trace	2.40	1.56	No assay	No assay
6	3.5	No assay	4.20	1.35	11.60	4.70
7	2.1	do	2.40	.42	4.50	7.50
8	4.3	do	6.30	2.29	4.05	4.70
9	3.0	do	18.00	.52	6.20	2.35
10	3.7	do	3.70	.94	8.80	2.35
11	2.6	do	2.50	1.25	4.62	2.02
12	3.4	do	3.20	1.14	.67	7.62
13	2.3	do	7.30	1.14	3.38	6.16
14 [1]		0.02	6.50	4.26	9.80	27.99
15 [2]	3.5	No assay	1.20	.42	1.25	1.46
16 [1]		0.06	9.85	2.60	24.80	15.90
17 [1]		0.02	10.20	1.77	6.20	42.78
18 [1]		0.32	59.30	.73	7.45	2.02

[1] Sorted ore.
[2] Ore from vein in a digging about 250 feet south by east of the tunnels but presumably the same vein.

These assays of the Whopper lode probably give the relative proportions of the important metals in ore that may be expected in other quartz veins in the area, but of course the volume of the ore is not indicated. Sorting, as shown by samples 14, 16, 17, and 18, would obviously be practicable. Samples 16, 17, and 18 are of particular interest as they represent selective sorting of zinc (16), lead (17), and silver (18). Separation of zinc from lead was only moderately successful, but the selection of lead and silver was quite satisfactory. Silver was selected on the basis of amount of tetrahedrite observed, and the result obtained proved that here at least galena was not very argentiferous.

With a favorable price of metals the Whopper lode may be an exception among the quartz veins in the area, which as a group offer little promise of containing commercial ore bodies. The assays given represent the vein as opened horizontally and vertically for about 100 feet. The geologic conditions are simple, so that further prospecting or development can be planned efficiently and at a minimum cost. Intersections of the Whopper fault with known favorable beds, such as the limestone of Niobrara age in the Mancos shale and the limestone about 60 feet above the base of the Morrison formation, are worthy of consideration. Such intersections are as a rule not well exposed and consequently have not been explored. Shallow pits or trenches are generally sufficient to determine whether

[81] Prommel, H. W. C. (consulting geologist and mining engineer, Denver, Colo.), private report, October 1929.

mineralization has occurred and, if so, whether it appears to be of economic importance.

John Baroni tunnel.—The John Baroni tunnel is on the east side of Schofield Park in the Mancos shale. On the dump is a few tons of high-grade lead-zinc ore. The tunnel is about 300 feet long, as shown in figure 21. It intersects a small part of the Mancos shale below the limestone of Niobrara age. A dike of the type of the Lincoln porphyry is also intersected and appears to have been an important objective for prospecting, but the porphyry does not show mineralization. Sulphides are confined to veins, the largest of which is well defined, is 2 to 12 inches wide, and is crossed obliquely by the tunnel. (See fig. 21.)

The sulphides locally are massive and consist largely of resinous sphalerite, galena, pyrite, and small amounts of chalcopyrite. The gangue comprises quartz, calcite, and a little fluorite. A part of the

FIGURE 21.—John Baroni tunnel.
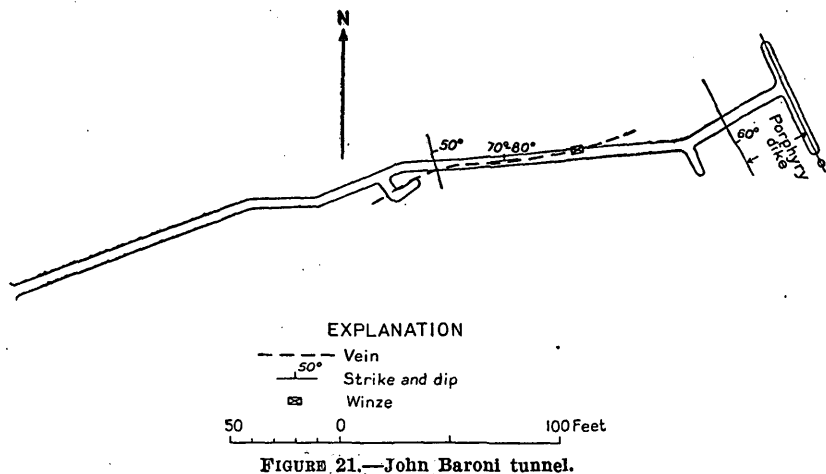
vein contains high-grade zinc-lead ore, but because of its narrowness the prospect is not very encouraging. However, the possible extension of the vein into the limestone member of the Mancos is worthy of consideration, especially as it would cost relatively little to prospect this zone.

Hercules-Ajax mine.—The Hercules-Ajax mine is on the east tributary of Rock Creek about 1,000 feet east of Schofield Park proper. Some ore is said to have been treated in the mill formerly located at the lower end of Schofield Park. The workings (see fig. 22) include on the south side of the stream a short tunnel along the vein and on the opposite side of the stream a shaft 90 feet deep with a drift 40 feet long along the vein 60 feet below the surface. In 1929 and 1930 a new tunnel was driven on the north side of the stream to intersect the vein, but the extension proved the vein to be only a few inches wide and to consist largely of pyrite.

The mineralization followed a well-defined fissure vein that strikes N. 55° E. and dips 70° NE. The fissure is a fault that is paralleled by two other faults a few hundred feet upstream, east of the mine.
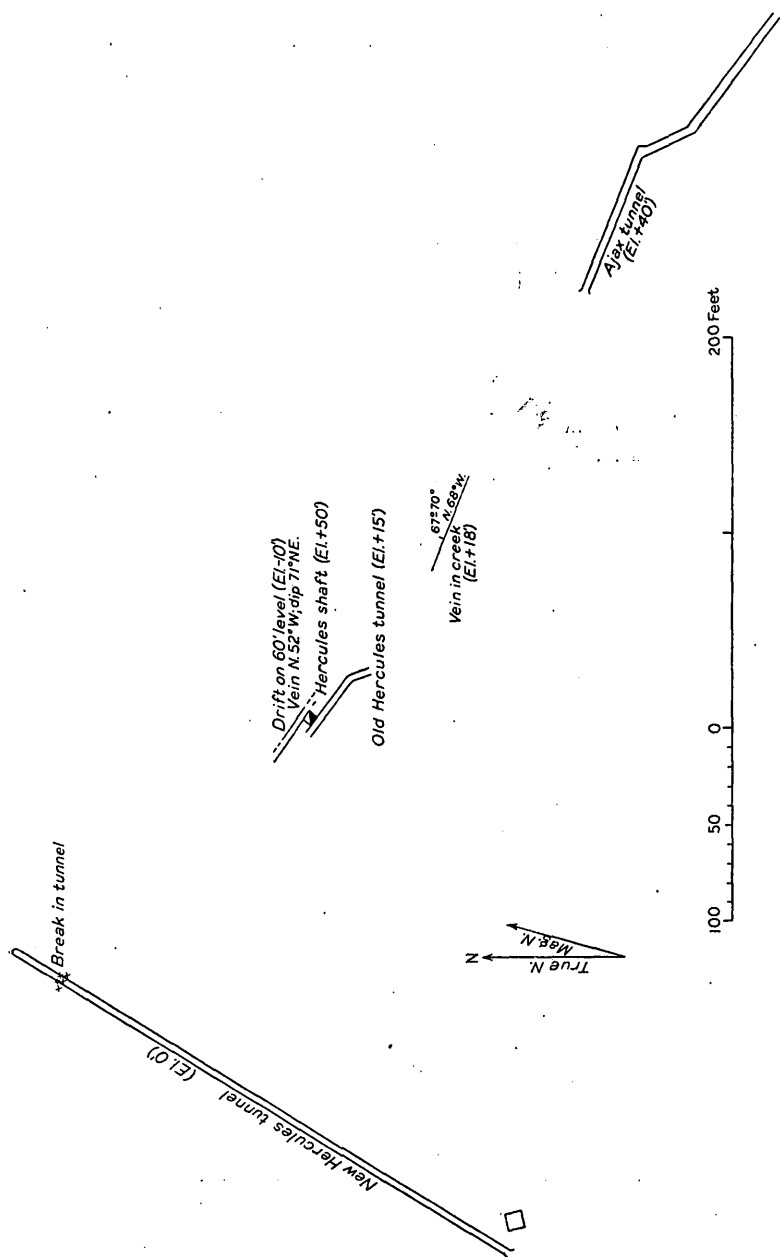
FIGURE 22.—Hercules-Ajax mine.

The hanging wall or east side of each fault moved up 15 to 20 feet with respect to the west side.

The vein is very well developed and exposed in the channel of the stream, where it consists of a band of massive quartz with pyrite 6 to 24 inches wide. Both here and underground, however, the economic sulphides are confined to a band less than 6 inches wide in the massive quartz, which carries no valuable metals.

The sulphides observed are sphalerite, galena, chalcopyrite, pyrite, and a few grains of tetrahedrite (gray copper) scattered in a gangue of quartz and calcite with some fluorite. The pockety character of the vein does not offer much inducement for further prospecting except possibly to examine its intersection to the south with the limestone of Niobrara age on the surface. Outcrops of this limestone in the area are poor and discontinuous so that only its general course and attitude could be mapped, and the contact as shown on the geologic map (pl. 1), therefore, cannot be relied upon to include details of structure.

TREASURY MOUNTAIN

Eureka mine.—The Eureka mine is a few hundred feet below and southwest of the peak of Treasury Mountain, at an altitude of about 13,200 feet. It can be reached from Marble by a trail in the valley of Yule Creek and also from Crested Butte by a trail up Slate Creek. The distance from Marble is 12 miles and from Crested Butte 18 miles. Little is known regarding the total production of this mine. However, in the early days it apparently attracted more attention than any other prospect in the area, as may be judged from the following quotations:[82]

Eureka on Treasury Mountain * * * put in shape for production; * * * ore of two grades, the first runs 65 to 110 ounces silver and 8 to 12 percent copper; the second runs 22 ounces silver and 24 percent lead. * * * The Eureka * * * has produced more than any other mine in the Elk Mountains. Several carloads of various grades of ore were shipped to Boston & Colorado Works, which averaged about $300.00 in gold, silver, and copper. The galena and antimonial silver ores were shipped to Kansas City and assayed 25 ounces silver and 60 percent lead.

Recent attempts to work the property have failed, owing chiefly to prohibitive costs of transportation to and from the railroad.

Essentially nothing is known about the extent of developments. The Eureka mine as it is locally known refers specifically to the tunnel near the old bunkhouse and ore bin. This tunnel, however, is full of ice the year around. About 500 feet below are several open cuts and a 50-foot tunnel along a bed. A short distance northwest of the mine and a few hundred feet east of the divide are additional old workings, all inaccessible. To judge from the character of the ore on the dumps, the shipments of 1883 referred to by Burchard may represent an accumulation from several prospects rather than from one ore body.

---

[82] Burchard, H. C., Report of the Director of the Mint, 1883, pp. 240, 308–328, 1884.

Mineralization occurred in the upper part of highly metamorphosed Hermosa (?) strata only a few hundred feet below the Jurassic, all but a few hundred feet of the Maroon beds being cut out at the angular unconformity at the base of the Jurassic beds. Several small and very irregular quartz veins are present, but well-defined fissures are lacking. The small veins cut across the bedding and apparently were not considered of economic importance, as they have not been prospected. Development in several places has been clearly directed parallel to the beds along two or three horizons, which show mineralization at their outcrops. It seems, therefore, that the form is that of bedded deposits. Unfortunately the size and extent of any one ore body could not be determined.

Dark-brown sphalerite, chalcopyrite, and galena with a gangue of quartz and fluorite are common, though in varying proportions, on all the dumps. Hearsay reports claim very rich tetrahedrite (gray copper) ore. The antimonial silver referred to in 1883 by Burchard supports such claims, but none was found by me. Hedenbergite is present, and chalcopyrite is common on the dumps. These two minerals are characteristic of the North Pole mine, and their presence suggests a similarity in the mineralization of the two localities.

Head of Yule Creek.—At the head of Yule Creek are two interesting prospects. One is about three-quarters of a mile west of the Yule Creek-Slate River pass, at an altitude of about 11,500 feet, on the south side of the valley. The other is about half a mile farther west and 100 feet lower.

The first prospect referred to shows an exposure 2 to 6 feet thick and 20 feet long of massive sulphides in a shallow open cut. It is marked by an abundance of limonite stains at the surface, which helps to distinguish it from several other small and less important prospects nearby. The mineralized zone is about 30 feet above the base of the Jurassic. Pyrite and sphalerite with some galena and chalcopyrite constitute the sulphides. A definite vein could not be recognized, although there is some evidence of a small fault that strikes N. 70° E. and dips 60° NW., or approximately parallel to the surface. The maximum displacement cannot be more than a few feet and may represent a mere surface slip rather than a fault. The exposure suggests replacement of undetermined extent along a bed.

The second prospect is in the Parting member of the Chaffee formation (Devonian). Here there are several small pits and tunnels, of which the largest is a tunnel about 15 feet long in or just above the basal quartzite bed of the Parting member. The tunnel follows a small fault that strikes N. 75° W. and dips 75° N., along which the north side moved up about 5 feet. The fissure contains irregular masses of pyrite with fluorite and quartz, as well as small local

segregated bodies of sphalerite and chalcopyrite. Quartzite and hornfels, which compose the country rock, are stained brown and black for about 20 feet on each side of the fissure. In the dolomite above the Parting member the fissure is barren at the outcrop, and it could not be traced far below the tunnel. A few hundred feet to the west and at the same horizon are similar fault fissures that also show mineralization; none, however, show any mineralization at the surface either above or below the Parting member. Little ore is exposed at the outcrops, and the prospecting done is too scant to show whether ore occurs farther in on the vein. These prospects show encouraging amounts of sulphides, but further development can scarcely be justified because of the unfavorable location with respect to transportation facilities.

PARADISE PASS AND VICINITY

Paradise Pass is a saddle between a tributary of Rock Creek and the Slate River south of the limits of the area mapped. At the pass and to the north there has been some mineralization, but no ore seems to have been produced from this locality. Several dumps that mark the position of caved shafts or tunnels are all that remain as evidence of prospecting in the area.

Mancos shale and diorite which has been intruded into the shale compose the country rock. Both contain veins of sulphides. The shales are indurated and contain much disseminated pyrite. Baldy and Cinnamon Mountains, rising to the east and west of Paradise Pass, are made up of shale that is superficially coated with limonite, a reddish-brown oxidation product of the pyrite, and from a distance they appear red. Individual specimens do not appear highly stained, so the strongly colored appearance of the two mountains is doubtless due to the uniform distribution of limonite over a relatively large area. The limonite stain is not related to sulphide mineralization of the veins. Metamorphism of the shale and the development of pyrite are like the metamorphism of Morrison shales around Treasure Mountain.

The fault zone so prominent on Galena Mountain trends toward this area, and although the displacements of the faults decrease materially in the Mancos shale south of Rock Creek, there can be little doubt that fracturing continued at least as far as Paradise Pass. The character of mineralization is like that in Rock Creek and on Galena Mountain, to the north, but the veins appear more irregular and seem to have even less continuity. The predominant trend of the veins is approximately north, or in line with the trend of the main fault zone of Treasure Mountain. Only small amounts of the economic sulphides were found on the old dumps, and early prospectors apparently found little to encourage their efforts.

The Bennet tunnel is a prospect at an altitude of 12,300 feet just northeast of Mount Belleview and east of Schofield Pass. The most direct trail to it branches from the road a few miles north of Gothic. Gothic is 5 miles south of Schofield Pass, in the valley of the East River, and is outside the limits of the area mapped. The chief value of the ore is in silver, of which a few thousand dollars' worth is said to have been produced. A tunnel about 250 feet long on a vein represents the only important development work done. Several small pits nearby do not show mineralization.

The country rock is felsitic porphyry and Mancos shale, locally altered to hornfels. A vein extends N. 50°–55° E. with essentially a vertical dip from the shale into the porphyry and crosses the contact nearly at right angles. As far as could be determined mineralization was confined to this vein. The fissure that marks the course of the vein on the surface is a conspicuous feature in the bluffs of porphyry only a few hundred feet above the line of the tunnel. From this fissure on the surface it is evident that the vein is narrow, though the character of the vein is not well exposed. In the tunnel the vein is continuous, though not more than 6 inches in average width, and consists largely of calcite with spots and small lenticular masses of galena lining the vugs that are present locally. The silver, however, is not associated with the galena. It occurs along both walls of the vein in streaks, less than 1 inch wide, of black earthy mineral containing nodules of tetrahedrite (gray copper) stained green with malachite. Material selected from these streaks is reported to assay several hundred ounces of silver to the ton. Qualitative tests of the tetrahedrite gave a very copious precipitate of silver chloride. In view of the high cost of transportation and mining, due to the unfavorable location of the prospect, it is doubtful whether such a narrow vein of silver-bearing tetrahedrite can be mined at a profit with ordinary prices of the metal.

Plate 1 shows that this prospect is more or less outside of the main mineralized zone. It is no closer to this mineralized zone than it is to a mineralized area to the southeast, on White Rock Mountain.

MOLYBDENITE PROSPECTS

The occurrences of molybdenite in the area are too scant to be of economic importance. They do not show any direct relation to the other sulphides.

Molybdenite is reported near Paradise Pass and on Yule Creek by Worcester.[83] The molybdenite near Paradise Pass, supposedly oc-

---

[83] Worcester, P. G., Molybdenum deposits of Colorado: Colorado Geol. Survey Bull. 14, pp. 66–67, 1919.

curring in a quartz vein, was not seen by Worcester, nor could it be located by me. Molybdenite was found in two places on Yule Creek about a mile west of the extreme head of the valley. One deposit is on the north side of the valley at an altitude of 11,700 feet, or about 800 feet above the stream. Here two quartz veins in the pre-Cambrian gneiss contain molybdenite in scattered flakes, which are confined to a few streaks only one-half to 1 inch in width. A few thin plates of molybdenite an inch across were found, but the average is less than one-third this size. The veins strike N. 35° E. and dip 75° NE., parallel to the banding of the gneiss. Although prospected by only one or two shallow pits, the surface exposures are excellent, and the slight extent of the veins is evident.

The second occurrence of molybdenite is on the opposite side of the valley near the gneiss-granite contact, at an altitude of about 10,900 feet, 50 to 100 feet above the stream. A few scattered flakes of molybdenite were found in the Treasure Mountain granite in a pegmatitic stringer less than a quarter of an inch wide and within a few inches of the contact. There was no indication of alteration of any part of the granite, either in hand specimen or in thin section, and the molybdenite had the aspect of a primary mineral. In the gneiss a few hundred feet south of this occurrence a little molybdenite was found in massive quartz of what appeared to be an irregular vein, the strike and dip of which were not evident. Outcrops of the gneiss are not continuous, but the surrounding scattered exposures of it indicate that the amount of molybdenite is small.

MARBLE DEPOSITS

YULE COLORADO MARBLE

SUMMARY

The recrystallized limestones and dolomites on Treasure Mountain include a great variety of marbles, only one of which—the Leadville limestone, of Mississippian age—has been productive. Serpentine marble of the Ordovician (Manitou dolomite) has small commercial possibilities: test blocks of it have been quarried at the head of Yule Creek, but it is not sufficiently distinctive to compete under existing circumstances with serpentine or verde antique marbles now on the market. The Devonian and Pennsylvanian marbles are too thin-bedded to be of commercial interest, and their more attractive colors and textures are not uniformly developed. The marble produced in the district has come entirely from one quarry on Yule Creek about 3 miles from Marble. It is known to the building industries both as Colorado Yule and Yule Colorado marble. This quarry was opened by the Colorado Yule Marble Co. and operated continuously from 1908 to 1916, when the company failed. Thereafter the property underwent several changes in ownership, but little quarrying was

done until 1928, when the Yule Colorado Marble Co. was organized as a subsidiary of the Vermont Marble Co. to operate the quarry. Since 1928 a moderate quantity of marble has been marketed each year.

The Yule Colorado marble is white, medium-grained, and generally banded with pale-brownish streaks which in places contain angular fragments of chert. These features are the basis for the following commercial classification: (a) "Statuary", which closely resembles the Pentelic marble of Greece; (b) "second statuary", in which markings are inconspicuous; (c) "golden vein", in which the brownish streaks are conspicuous; (d) "crystal grade" (discontinued in 1936), in which chert fragments as well as brown and less commonly dark-gray streaks are present in a groundmass that may be either gray or white. The original company subdivided the streaked or "veined" marble into "golden vein", with brown streaks, and "Colorado cloud", with dark-gray streaks. As the brown streaks represent oxidation of minute pyrite grains that are present in the dark gray, these two varieties grade into each other. The statuary grade commands the highest price, and the crystal grade the lowest. The difference expresses both relative attractiveness and costs of quarrying and selection; each grade is considered equally durable as a building stone. It is said that the marble of statuary grade is available in larger dimensions in this quarry than in any other quarry in the United States. "Golden vein" and "second statuary" grades are represented on plates 21, 22, and 23. The local reserves of commercial marble are very large, and the capacity of the present quarry equipment has exceeded the market demands for many years.

A mill for finishing marble is located at Marble, and both finished and unfinished marble are shipped to many parts of the United States, but more to the Pacific coast than to the East. The location of the quarry prevents extensive use of the marble in the principal markets, which are in the East and are more readily supplied with marble for most purposes from the Appalachian States.

HISTORY AND DEVELOPMENT

Exposures of marble are conspicuous both on Yule Creek and on the Crystal River (called Rock Creek in old reports) between Marble and Crystal, and these exposures were probably noted by the earliest explorers to enter the area. The first reference in the literature to the marble deposits in the area was made in 1882 [84] in "Mineral Resources of the United States", which in succeeding years recorded bits of information concerning development of the district. In the report for 1885, for example, we are told that "a bed of remarkable fine marble was opened up during this year on one

---

[84] Geol. Survey Mineral Resources, 1882, p. 454. 1883.

branch of Rock Creek." This statement apparently referred to exposures of marble at the head of Yule Creek. We are further told that the representative of the Union Pacific Railroad who examined the deposits reported that all tests "proved in the highest degree satisfactory." The statement continued by saying that although marble was found in abundance it was not considered practicable to develop the deposits because of difficulty of access. Unfavorable location has continued to be the most severe handicap to the development and operation of quarries.

The first approach of a railroad came with development of coal at Crested Butte. Eventually the railroad was built to Pittsburg, on the Slate River only 6 miles south of the head of Yule Creek. By 1895 [85] a railroad grade was actually built to the head of the creek. Up to this time the deposit of marble at the head of Yule Creek seems to have been considered the best, if not the only one of importance in the area. However, just as the coal industry brought one railroad to Pittsburg on the south, so coal in Coal Basin brought another to Redstone, which is on the Crystal River about 12 miles north of Marble (in early days called Marble City). This railroad was later extended to Marble.

The marble is exposed along the lower part of Yule Creek and in the valley of the Crystal River 3 to 4 miles from Marble. The marble is of the same character in both places, but the outcrops on Yule Creek are the more prominent and have been more extensively developed. At the head of Yule Creek, 11 miles from Marble, the altitude is about 12,000 feet and convenient power is not available, whereas on lower Yule Creek the deposits are at an altitude of about 9,000 feet, and water power is available from both the Crystal River and Yule Creek.

The first record of production is in Mineral Resources for 1896,[86] which states, "At the present time (March 1897) Colorado is engaged in producing marble for a public building in Denver, * * * but it is doubtful if any considerable amount was taken out in 1896." Authentic records show an output in 1897 valued at $99,600, and in 1899 at $10,766. After 1899 no output was recorded until 1908,[87] when a quantity estimated at 30,000 cubic feet and valued at $55,400 was sold.[88] About this time the stock of the Colorado Yule Marble Co. was widely advertised for sale, and an immense sum was spent while development was in progress. During 1909 Colorado, through the activities of the Colorado Yule Marble Co., rose from tenth to fourth in rank among the States as a producer of marble. It

[85] Underhill, G. W., Colorado marble: Stone, vol. 11, pp. 1–5, 1895.

[86] Geol. Survey 18th Ann. Rept., pt. 5 (continued), pp. 978–979, 1897.

[87] Geol. Survey Mineral Resources, 1908, pt. 2, p. 561, 1909.

[88] These and other figures of output have been supplied by Miss A. T. Coons, of the Bureau of Mines, and are published by permission of the Vermont Marble Co., the present owner.

retained this rank until 1916, when the company, unable to liquidate the large debt incurred during development and confronted with a decreased demand for marble incident to the World War, went into the hands of receivers. During the period 1908–17 the company shipped 1,142,500 cubic feet of rough and finished marble, valued at $5,422,100. The annual average value increased steadily from $1.85 a cubic foot in 1908 to $6.63 a cubic foot in 1914, when finished marble was shipped to Washington, D. C., for the Lincoln Memorial. Thereafter the average value declined, and shipments ceased in 1917.

The property remained idle during 1918, and in 1919, according to newspaper reports, it was sold at sheriff's sale to a junk dealer; but it was purchased in the same year by persons who, reluctant to see the equipment scrapped, organized as the Yule Marble Co. of Colorado. It was not until 1922, however, that this company resumed operation of the mill and sold 2,800 cubic feet, valued at $12,000, from old stock stored at Marble. In 1923 the quarry was taken over by the Carrara Yule Marble Co., which quarried some stone marble but was succeeded in the same year by the Colorado Consolidated Yule Marble Co. In 1924 the property was evidently leased to the Tennessee-Colorado Marble Co. and was operated by the Gray Knox Marble Co., of Knoxville, Tenn. During 1923 and 1924 sales amounted to 99,383 cubic feet, valued at $572,862, and the average value per cubic foot of different shipments ranged from $1.95, presumably for rough stock, to $8.63 for the more expensively finished stock. The Colorado Consolidated Yule Marble Co. retained ownership and sold considerable marble until late in 1928, when the property was sold to the Yule Colorado Marble Co., in which the Vermont Marble Co., of Proctor, Vt., held a half interest. In 1929 the Vermont Marble Co. became sole owner, although the Yule Colorado Marble Co. continued as a subsidiary. Sales of rough and finished marble for exterior and interior building and for monumental work have been made in every succeeding year up to the present (1936). The sales since the reopening of the property in 1922 have amounted to 232,553 cubic feet, valued at $1,107,577, and the average value of rough and finished marble has been $4.76 a cubic foot, practically the same as that for the earlier period.

Other companies that attempted to develop marble quarries in the district never attained production. One, the Strauss quarry interests, constructed a long inclined track but developed no sound marble. The Colorado White Marble Co. drove a tunnel on the west flank of Whitehouse Mountain about a mile north of the main quarry, crosscutting Pennsylvanian beds to intersect the marble. The tunnel did not reach its objective, but two diamond-drill holes from the

face of the tunnel are said to have entered a promising grade of marble.

The fundamental factor in the vicissitudes of the marble industry on Yule Creek can be found in the location of the deposit, although the early management of the initial company may have been a contributing factor; according to reports, money was spent too lavishly during the development stage. Owing to location the cost of production in the Yule Creek district and the cost of transportation to most of the larger markets were greater than in the eastern districts. Counteracting features, however, were the high quality and attractiveness of the better grades of the marble. The Yule Colorado marble has been regarded by the trade as one of the best of the "white marbles", and rough specimens of the statuary grade are practically identical with the famous Pentelic marble of Greece. No other domestic quarry, it seems, can furnish such large blocks of pure white or statuary marble, and it was for this reason that this marble was selected for the Tomb of the Unknown Soldier in Arlington National Cemetery.

PUBLISHED AND UNPUBLISHED REPORTS

Although the marble deposits of the district attracted considerable attention, even at early dates, only two short descriptions have been published,[89] other than the generalized statistical statements in Mineral Resources and occasional notes in trade journals. Lakes, in his earlier description, emphasizes the great variety in color of marble at the head of Yule Creek in a stratigraphic section 750 feet thick, which evidently included Ordovician, Devonian, and Mississippian formations. In his later article, after the quarry in lower Yule Creek had been opened, he described the marble as 200 feet thick, with 40 percent of pure-white statuary marble and the rest clouded, dove-colored, and green serpentine varieties.

An unpublished report by George P. Merrill, based on an examination for the Colorado Yule Marble Co. in August 1914, has also been available. Merrill briefly considered the geology of the marble formation, including a serpentine marble, evidently in the Ordovician beds of upper Yule Creek. Unfortunately all the illustrations, including the measured section, were missing from his report. Chemical and physical tests from Merrill's report are quoted on pages 160, 161.

DISTRIBUTION

In extent and distribution the marble is coextensive with the Mississippian (Leadville) limestone. (See pl. 1.) This formation is cut out on Yule Creek by the angular unconformity at the base

---

[89] Lakes, Arthur, Colorado marble: Stone, no. 3, pp. 213–222, 1895; Some remarkably fine marble quarries of Colorado: Min. World, vol. 32, pp. 609–611, 1910.

of the Jurassic and is cut out on the Crystal River by the intrusive granite mass of Treasure Mountain.

Although the entire formation as exposed is recrystallized to marble, only a minor part of it is marketable. The exposures that extend from the head of Yule Creek to Bear Basin are too unfavorably located with respect to transportation to be profitably developed under present market conditions. Much unavailable marble also occurs in the band of conspicuous outcrops on the dip slope across the west flank of Treasure Mountain. These outcrops are so much fractured and iron-stained from surface weathering as to discourage development. The Strauss quarry is in the lower part of this dip slope. Below the dip slope, where the Mississippian passes under the cover of Hermosa (?), marble of marketable quality may be expected. On the Crystal River south of Twin Bridges the marble lies favorably for development and appears relatively free from defects. Both of these localities are as close to the town of Marble as the quarry on Yule Creek and are at no higher altitude.

PRINCIPAL FEATURES OF THE MARBLE FORMATION

The Mississippian limestone in the district is characterized by its massive structure and by the prominent bluffs or cliffs in which it is exposed. On and around Treasure Mountain recrystallization of the limestone into medium-grained white marble has accentuated the massive character of the formation. Massive marble cliffs over 150 feet high are common. In detail the formation shows certain variations, the most conspicuous of which are the gray, buff, and white dolomite interbedded with marble in its lower part (see pl. 3, A) and the presence of stringers of chert and irregular masses of dolomite in marketable marble in its upper 60 to 100 feet.

In the old Strauss quarry a single bed of chert 2 feet thick is exposed. In the Yule Colorado marble quarry chert stringers are usually less than an inch thick but are sufficiently numerous to constitute a problem in quarrying. The chert does not occur in continuous layers of appreciable length but forms closely or moderately spaced angular fragments (pl. 19, A) commonly as much as 4 inches in length and an inch or less in thickness. Rows of these fragments may extend for several feet and apparently represent lenticular layers of chert that were fractured and stretched apart during regional folding and the later arching and recrystallization of the marble over the granite stock of Treasure Mountain. The major dimensions of the chert fragments are parallel and in line with the direction of stretching, which is interpreted as evidence that stretching has been parallel to the original bedding planes. This conclusion is further supported by the fact that the stringers of chert lie in the plane of cleavage or grain of the marble.

In addition to the dolomite beds in the lower part of the Mississippian there are light-gray to buff masses of dolomite and of diopside-quartz aggregates in the upper part. These masses are referred to by the operators as "lime." Although the dolomite and diopside-quartz aggregates occur in the same part of the quarry, they do not appear to have formed at the same time.

They have been seen only in the quarry, as they are very inconspicuous on weathered surfaces and are easily overlooked. The dolomite masses are irregular in form, and those of diopside and quartz are more lenticular. Both are in zones generally parallel to the chert stringers and the direction of cleavage. They are detrimental because they are comparatively hard and brittle, are much fractured, and have an unattractive gray color. The true character of the dolomite is only poorly shown on natural surfaces but is clearly defined in several large sawed blocks that have been set aside at the mill as waste. Some of these are shown in plate 20, A, which illustrates the irregular form of these bodies of dolomite and the character of the accompanying fractures. The fractures may be open or they may be tight seams, as in plate 20, A, but they are invariably transverse to the bedding. Rhombohedral crystals of calcite line many of the open fractures and fill some of them. A few quartz crystals are also present in some of the fractures. Finer-grained calcite replaces the dolomite walls along these fractures. The replaced parts may be either irregular or more uniform. In the specimen shown on plate 20, A, the fractures themselves are not sharply defined but are marked by the white streaks, two of which are relatively wide and clearly shown and one of which is very thin and extends from the point of the hammer. The dolomite is finer-grained than the calcite. This difference is readily recognizable by the unaided eye, as well as under the microscope. Even in those places where the dolomite grades to calcite and the grain appears to be coarser than the average, the dolomite proves to be finer-grained than the surrounding calcite. This change from dolomite to calcite appears to be as gradual under the microscope as it does in plate 20, A.

The features described and illustrated on plate 20, A, are interpreted to mean that calcite has replaced dolomite. As the dolomite is fine-grained and gray, it is regarded as a dolomitic zone in the limestone, which was present before recrystallization of the limestone was completed. The fractures suggest tension, and they have probably resulted from the stretching of the beds indicated by the fractured bands of chert. In dolomitic rocks such fractures could be preserved, whereas in the limestone or marble they would be obliterated during recrystallization of the calcite. The fractures cannot be traced beyond the limits of the dolomite. However, in places veinlets of coarse calcite that fill these fractures can be traced

for several inches beyond the boundary of dolomite into the white marble before they merge into the surrounding calcite.

The diopside and quartz are concentrated in fairly well defined lenticular masses. They resemble the dolomite only in their gray color. Instead of having irregular and gradational boundaries like the dolomite, the diopside-quartz lenses have rather uniform out-lines and well-defined boundaries. Furthermore, they are free of the fractures so characteristic of the dolomite. They are also much less common than the dolomite masses—in fact, they were found in only one place in the quarry. Some of the lenses seen in cut blocks of marble were 3 to 5 feet long and 2 to 12 inches thick. One end of a large lens and the parallel sides of a smaller one are shown in plate 20, B. The diopside and quartz are intergrown with calcite, and all three minerals occur throughout the lenticular bodies, but the first two are more concentrated along the margins than in the central part, where calcite predominates. In places the central parts of the lenses consist mainly of white marble, but a small amount of diopside is invariably present. A secondary, hydro-thermal origin of the diopside and quartz is suggested by local occurrences of dark-brown sphalerite or zinc blende along the border of the areas. The largest amount of sphalerite seen is shown in plate 20, B. More commonly it is present only in small isolated grains, some of which are not associated with diopside or quartz. The diopside-quartz bodies are avoided as much in quarrying as the dolomite and chert.

The massive marble possesses a well-developed grain or schistose structure and also contains pale-brown to dark-gray streaks or "veins." The grain and streaks are parallel to the stringers of chert. Many of the brown streaks are so faint as to be virtually invisible on fresh fractured surfaces, but on polished surfaces they show as "veins" of soft and delicate shades. (See pls. 21, 22.) Marble of this character is classed as "golden vein" and is the principal product of the quarry.

The grain of the marble, even when well developed, is incon-spicuous in small specimens but is readily discernible by the rela-tive ease with which the marble fractures along one plane as com-pared with other directions. Thin sections under the microscope show that the length of the calcite grains is usually at least twice their width. The grain is an expression of schistosity, and marble fractures easily along it, whereas fracturing is more difficult in planes parallel to the dip and perpendicular to the strike of the marble formation and is most difficult in planes normal to both strike and dip.

COMPOSITION

The Yule Colorado marble is predominantly calcite. The dolomite, chert, diopside, quartz, and sphalerite already referred to constitute only a very small part of the marble as a whole. In addition to these minerals a very small amount of fuchsite, green chromiferous mica, is present. This mineral is described in Merrill's report. It occurs in small irregular seams in one place in the quarry. In thin section the mineral exhibits a bright-green color without any apparent crystal structure.

Acid tests and microscopic examination show that the marble consists of remarkably pure calcite over relatively large areas. This fact is also shown by the following chemical analyses taken from Merrill's report:

Chemical analyses of Yule Colorado marble

[Made under direction of A. W. Smith, Case School of Applied Science, Cleveland, Ohio, Oct. 22, 1907]

	Streak	Clear
Calcium carbonate ($CaCO_3$)	98.84	99.50
Magnesium carbonate ($MgCO_3$)	.25	.19
Iron carbonate ($FeCO_3$)	.02	.03
Manganese carbonate ($MnCO_3$)	.03	.02
Silica (SiO_2)	.27	.05
Alumina (Al_2O_3)	.05	.03
Iron oxide (Fe_2O_3)	.28	Trace
Manganese oxide (MnO_2)	.06	None
Calcium sulphate ($CaSO_4$)	.08	.09
Undetermined	.12	.09
	100.00	100.00
Specific gravity	2.711	--------

The "streak" represents the markings in the "golden vein" marble. Its analysis shows that the color is due chiefly to iron oxide.

The important detrimental impurities, chert, dolomite, and the diopside quartz aggregates, were practically absent in the two samples analyzed, as is shown by the trivial quantities of silica and magnesium carbonate. The amounts of sphalerite, galena, and chalcopyrite throughout the deposit are too small to be important. Brown and red iron-stained marbles are common in places near the contact with the overlying Pennsylvanian (Hermosa? formation).

PHYSICAL PROPERTIES

Merrill's report[90] includes the physical tests given below, but does not indicate the parts of the formation from which the test pieces were taken.

---

[90] Merrill, G. P., A report on the Colorado Yule marble properties, 1914. [Manuscript report to Lincoln Memorial Commission.]

A. IRREGULAR MASS OF DOLOMITE (GRAY) IN WHITE CALCITE MARBLE.

Note the gradational boundaries.   The white streaks nearly perpendicular to the hammer handle extend along small fractures.
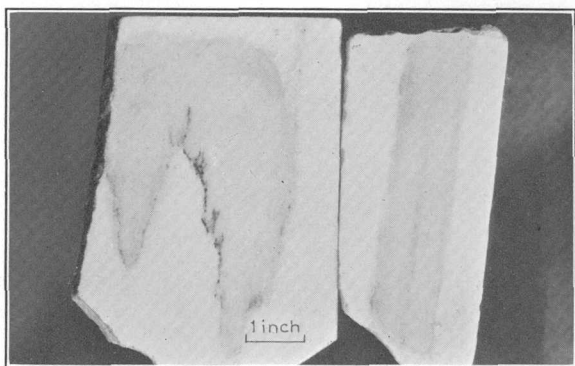
B. CROSS SECTION OF PARTS OF A LENS OF DIOPSIDE AND QUARTZ.

Piece at right is end of lens that was about 4 feet long.   Black is sphalerite.   Piece at left shows parallelism of sides.   (See pl. 12, *B.*)
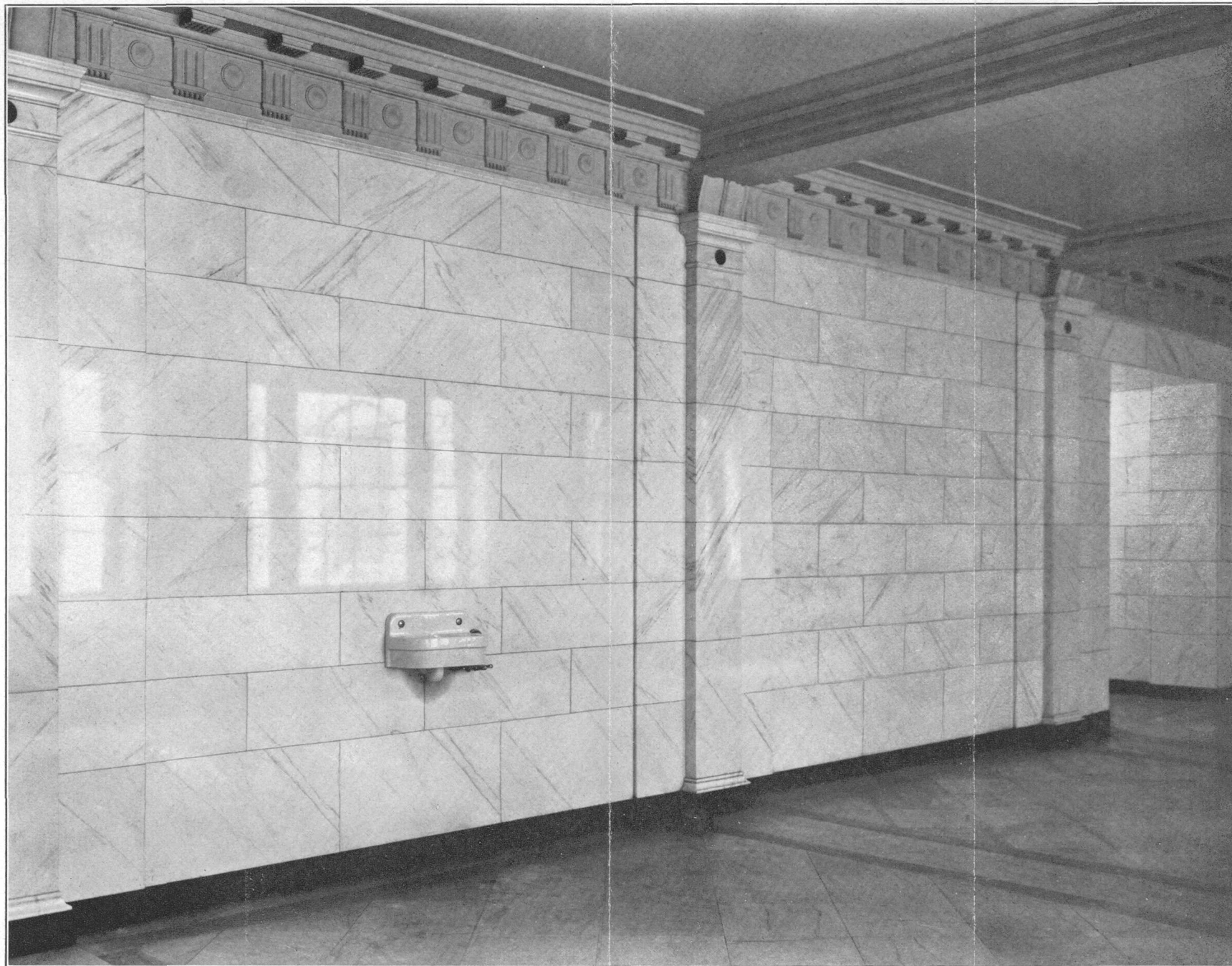
"YULE GOLDEN VEIN" ASHLAR, WITH "BELGIAN BLACK" BASE.
Providence County Courthouse, Providence, R. I.   Courtesy of the Vermont Marble Co.

"YULE GOLDEN VEIN" FLUTED PILASTERS AND FRIEZE COURSE, WITH "LOREDO CHIARO" PANELS AND "BELGIAN BLACK" BASE.

Field Building, Chicago, Ill.   Courtesy of the Vermont Marble Co.

Results of absorption tests on 3-inch cubes

[Test 14234, Bureau of Standards, Washington, D. C., Nov. 3, 1913]

Cube no.	Dry weight (grams)	Absorption after immersion for 48 hours [1] (gram)	Ratio [2]
1	1,295.99	0.79	0.00061
2	1,308.00	.84	.00064
3	1.258.56	.96	.00076

[1] The very low absorption values of these specimens were rendered slightly uncertain by the rough faces of the cubes. The foregoing results have been corrected as far as possible for error due to this cause.
[2] As usually stated in test records the figures in this column would be given as 0.061 percent, etc.

Compression tests

[By Milo S. Ketchum, C. E., Dean, University of Colorado]

Sample no.	Height (inches)	Cross section (inches)	Area (square inches)	Load (pounds)	
				Total	Per square inch
1	1.95	2.02×1.97	3.98	38,660	9,710
2	2.02	1.98×1.96	3.88	37,450	9,630
3	1.97	1.98×1.98	3.92	40,990	10,450
4	1.98	1.98×2.00	3.96	43,520	10,990
Average					10,195

Cross-breaking tests

[By Milo S. Ketchum, C. E., Dean, University of Colorado]

Sample no.	Length (inches)	Breadth (inches)	Depth (inches)	Load (pounds)	Modulus
1	6	2.01	2.00	890	1.000
2	6	2.01	1.98	900	1.060
3	6	2.00	2.01	870	.970
4	6	2.00	2.01	950	1.100
Average					1.030

Other data supplied by the National Bureau of Standards [91] are as follows:

Replying to your inquiry of May 20 in regard to physical tests on Colorado Yule marble, we wish to advise that certain results were obtained on samples of this marble submitted for consideration in connection with the Lincoln Memorial, as follows:

> Modulus of rupture, average of four tests, 1,200 pounds per square inch.
> Compressive strength, average of twelve tests, 7,600 pounds per square inch.
> Absorption, average of eight tests, 0.10 percent.

The modulus of rupture values were obtained on strips about 12 inches long, 2 inches wide, and ⅞ inch thick, while the compressive strength and absorption values were obtained on blocks 2 by 2 by ⅞ inch. The compressive strength was determined by testing the blocks flatwise—that is, by applying the loads to

[91] Letter to G. F. Loughlin, Geol. Survey, dated May 26, 1936.

the 2- by 2-inch faces. Absorption tests were also made on three polished 2-inch cubes submitted in addition to the above samples, and the average result was 0.13 percent.

When the memorial was being constructed some question came up in regard to the veining matter, and eight 9-inch cubes were submitted for compression tests. These were tested perpendicular and parallel to the direction of the veining, and the average compressive strength obtained was 9,800 pounds per square inch. The minimum value was 8,600 pounds per square inch and the maximum 10,800. The compressive strengths obtained on the large cubes were surprisingly high compared with those obtained by testing smaller pieces flat-wise, since one would expect higher strength for the latter shape.

Comparison with tests made at the Bureau of Standards [92] on 50 commercial domestic marbles shows that the ratio of absorption of the Yule Colorado marble, as recorded on page 161 (top), ranks with the lowest recorded, whereas the 0.10 percent recorded on page 161 (bottom) is near the average, and the 0.13 percent is exceeded in 10 marbles. It is striking that the highest percentage should have been obtained with polished cubes, which one would expect to be less absorptive than unpolished samples, and the high percentage apparently represents pores, minute fractures, or other flaws too small to be detected when the cubes were prepared. It may be that the polished cubes represent the "east-side" marble, which is more permeable than the rest. The compressive and transverse breaking strengths, without allowance for differences in the apparatus used, are comparable with those of the weaker marbles, which include some of the most extensively used white or nearly white, well-crystallized marbles. The difference in strength between the large cubes and the smaller, flat samples also implies that the small samples were of originally less sound material or, because of their small size, were rendered less sound during preparation.

The texture of the commercial grades appears uniform as a whole, but there are exceptions of practical significance; for example, a small amount of relatively coarse-grained marble is present on the east side of the quarry 150 to 200 feet down in the pit and seems to be confined to this position. This variety is classed as "east-side" or "soft" marble not suitable for exterior use, except in protected places, as after a few years of exposure to weathering it begins to crumble and its polished surfaces lose their smoothness. Stratigraphically this horizon is 100 feet or more below the top of the formation and, locally at least, may mark the lower limit of commercial marble. Further work will be necessary to determine whether the "soft" stone represents a stratum of considerable extent, or whether it is a purely local feature and the result of obscure deformation that has rendered it comparatively porous and weak.

---

[92] Kessler, D. W., Physical and chemical tests on the commercial marbles of the United States: Bur. Standards Tech. Paper 123, pp. 34–50, 1919.

The research department of the Vermont Marble Co. has recently given considerable attention to the influence of texture on the workability and durability of its marbles and finds that the degree of interlocking of grains and the width of spaces between grains are very influential factors in these respects. The degree of interlocking is conveniently expressed by a coefficient of irregularity which is based on the aggregate length of grain contact in a given representative area divided by the cube root of the number of grains in that area. Marbles with a coefficient of less than 8 are relatively incoherent and therefore subject to dissolution. Their porosity as well as their cohesive strength is likely to be affected adversely by different kinds of tool work. The soft or "east-side" marble cited above has a coefficient of only 7.05, whereas the coefficients of the more satisfactory marbles in the deposit range from 8.35 to 10. Similarly the ratio of absorption of the "east-side" marble ranges from 0.20 to 0.30, whereas that of the other marbles ranges from 0.10 to 0.13.[93]

COMMERCIAL OUTLOOK

The cost of producing marble on Yule Creek is high compared with that in the marble districts of Georgia, Tennessee, and Vermont, owing to the high altitude, high relief, and especially the severe winter seasons; furthermore, the large quarries of white or nearly white marble in Vermont, Georgia, and Alabama have a distinct advantage as regards the largest markets, which are in the East, and those in Alaska furnish competition for markets in the Pacific coast and adjacent States. The Yule Colorado marble is advantageously situated with respect to the region between the Mississippi River and the longitude of Salt Lake City, in which, however, markets are comparatively small and widely scattered. Where competitive costs are subordinated to special features, such as large blocks of statuary stock, the Yule Colorado marble may reach more distant markets, but the demand for such special stock is obviously small and intermittent.

QUARRIES AND PROSPECTS

STRAUSS QUARRY

Many shallow pits have been dug by early prospectors on the outcrops of marble. The most extensive prospect, locally known as the Strauss quarry, is on the southwest slope of Treasure Mountain, where the Mississippian limestone, which contains the marble, forms an extensive dip slope and provides many exposures of white marble. The quarry is about 3 miles from Marble and 1,000 feet above Yule Creek, was served by a standard-gage railroad, and used electric power developed from water of Yule Creek. Several test pits were

---

[93] Information supplied by G. W. Bain, Vermont Marble Co.

made, none of which developed sound stone. Evidently the operators expected to find good marble a short distance below the surface, not realizing the necessity of following the dip of the formation. The test pits did not get below the fractures and stains produced by surface weathering. Good marble can be expected only where the marble dips under the overlying Pennsylvanian beds and is protected from weathering.

YULE COLORADO MARBLE QUARRY

"Yule Colorado marble" is the trade name for the product of the Yule Colorado Marble Co., which was organized in 1928 and was operating the quarry in 1935 as a subsidiary of the Vermont Marble Co. From 1908 to 1916 the marble was universally known to the trade as the "Colorado Yule marble." Less commonly the term "Yule marble" was used. The new name, "Yule Colorado marble", however, has been used in this report as a general name for all the marble in the Mississippian limestone of the area. Owing to the very uniform character of the marble, this description of the Yule Colorado marble quarry, with the exception of local and minor variations, is generally applicable to any part of the Colorado Yule marble.

The quarry is on Yule Creek 3½ miles from Marble, at an altitude of about 9,500 feet, and the finishing plant is at Marble. A standard-gage electric railroad along the west and south side of Yule Creek connects the quarry with the mill and the steam railroad at Marble. The mill, trolley line, and quarry are operated by electric power developed at the company's plant about a mile west of the marble on the Crystal River. Water used to develop electricity is derived from the Crystal River and Lost Trail and Yule Creeks.

The quarry openings are a little more than 200 feet vertically above the trolley track, to which the marble blocks are lowered with a cable hoist.

NATURE AND SIZE OF THE OUTCROP

On the southwest side of Yule Creek the white marble forms a continuous cliff 75 to 150 feet high and more than 4,000 feet long. To the southeast, or upstream from the quarry, the marble terminates under the angular unconformity at the base of the Jurassic (Morrison) formation; to the northwest it crosses Yule Creek and forms dip slopes that extend to the crest of Treasure Mountain. Yule Creek approximately follows the strike of the formations, and the marble thus exposed rises to the southeast with the gradient of the stream. The quarry is in the lower or downstream end of this cliff of marble (pl. 24).

The quarry has four openings or tunnels, nos. 1-4, which enter the marble cliff and cross the deposit to the hanging wall, and workings

from them are continuous. A fifth, called no. 5 prospect, lies a little southeast of the others. Blocks are removed by the south entrance, to no. 4, and the men enter through no. 3. No. 1, north of no. 3, has been closed and houses the transformer station. Nos. 2 and 3 were the source of marble before 1927 but were abandoned because blocks of adequate size free from dolomite could not be economically quarried in no. 2 and too much of the marble in no. 3 was unsound. No. 2 is now a water hole. No. 4, which lies between no. 3 on the north and no. 2 on the south, has been the source of all the marble quarried since 1927. Its floor had a horizontal extent of 200 feet across the strike of the marble in 1936, according to Bain.[94]

STRUCTURAL FEATURES

Strike and dip.—The attitude of the marble is obscured by the almost complete obliteration of bedding. Unfortunately the quarry openings do not reveal clearly the true strike and dip. In the Devonian dolomite below and the Pennsylvanian shales above, a strike of N. 30° W. was recorded with a dip of 45°–50° W. However, chert bands presumably parallel to bedding in the quarry strike N. 5°–10° E. and dip about 45° W. In the no. 5 prospect tunnel only a few hundred feet south of the quarry (see pl. 24) the chert bands strike N. 24° W. and dip 65° SW. In the quarry the grain of the marble is parallel to the chert bands, which in turn are believed to be parallel to the original bedding.

Thickness.—The entire Mississippian formation at the quarry is 239 feet thick, but less than half of this thickness is pure calcite marble. About 100 feet of the lower part contains interbedded dolomite marble similar to that shown in plate 3, *A*, and therefore is not marketable because of its lack of uniformity both in color and in texture. It forms the footwall of the quarry. The upper 20 to 40 feet, below the overlying Pennsylvanian (Hermosa?) beds, although calcite marble, generally shows a few streaks of gray or red that make it unsalable. It forms the hanging wall of the quarry. There remains a thickness of 100 to 125 feet of white marble from which the salable stone is obtained. The best marble, in the recently active part of the quarry, has been obtained 50 to 75 feet below the top of the formation. The distribution of the best marble and the relation of the chert bands, fractures, veins, and grain to the bedding present a complex problem in quarrying. This problem has been given careful study by the Vermont Marble Co., as is shown in the paragraphs below, submitted by G. W. Bain, the company's geologist, who studied the quarry in 1936. These paragraphs confirm my observations at the quarry and also give the results of special laboratory investigations and mill practice.

---

[94] Bain, G. W., written communication.

Because of its variation in quality the deposit is divided into three parallel parts or members—the "east-side", the "bench" or central part, and the "west-side." The width of each member varies along both strike and dip, but the aggregate thickness is remarkably constant.

The "east-side" marble lies between the footwall and the first siliceous dolomite bed (the "east lime") within the marble horizon. It is 87 feet thick in no. 4 opening and contains some fossil corals (*Syringopora* and *Zaphrentis*) and a few brachiopods. It is dominantly light-colored and free from veining but is locally dark blue gray along bands adjacent to the footwall and the overlying dolomite bed. It contains about 2,000 grains to a square centimeter, and the grains are separated from one another by spaces 0.000007 centimeter wide. These spaces allow the marble to absorb from 0.2 to 0.3 percent of water by weight. The grains do not interlock tightly and their coefficient of irregularity (see p. 163) is 7.05. The "east-side" marble is very flexible and is considered "soft" by the quarry and mill operators. Its texture shows a much lower degree of alinement of crystal grains than that of the "west-side" marble.

The low coefficient of irregularity of the "east-side" marble indicates a low degree of bonding which is not affected by simple fabrication processes such as sand rubbing but is materially weakened by shaping in planers and turning in lathes. This feature also renders the marble unsatisfactory for steps and other forms that are subject to abrasion and other kinds of wear and lowers its resistance to weathering. The marble, however, has rendered good service as ashlar and slabs, whose surfaces are plane, sand-rubbed, or hone-finished, and it is also satisfactory for monument bases that are not subject to appreciable infiltration of water; but "east-side" stock is not recommended or sold by the company for monument dies.

The "bench" or middle member of the deposit lies between the two dolomite or "lime" zones, the upper of which becomes locally a zone of chert nodules. The horizontal width of the "bench" marble is 40 feet. The "bench" marble itself is white and clear, but some inconspicuous golden veining is present within the bench member. Thin cherty layers are almost completely absent, but layers of dolomite or "lime" occur at intervals of 2 to 8 feet both along and across the strike. Because of this close spacing it is difficult to obtain marble blocks more than 4 feet thick. These dolomite layers, originally continuous, have been pulled apart into lenslike or kidney-shaped masses by the flowage that produced the marked parallel arrangement of grains in the calcite marble. Most of the dolomite masses are gray. Many were white originally but have become gray after exposure. Both varieties are brittle and have many cross fractures called "cutters" that end abruptly at the contacts between dolomite and calcite marble.

The "bench" marble contains from 2,000 to 3,000 grains to the square centimeter, with interspaces only 0.000003 centimeter wide. It absorbs from 0.10 to 0.13 percent of water by weight. Its grains are thoroughly interlocked, and their coefficient of irregularity is 8.35 or more. The marble is very rigid and elastic. Permanent distortion is negligible when applied stress is held within the limits of practical use. In contrast to the "east-side" marble, no slippage along grain boundaries has been detected.

The high coefficient of irregularity of grains in the "bench" marble indicates a high degree of bonding and permits a greater variety of treatment. The marble can be carved, worked on a carborundum machine, and fabricated by most processes without raising the absorption ratio of golden vein stock above

0.13 percent and that of statuary stock above 0.15 percent. It is therefore adapted to almost any use and is restricted only as regards color and available sizes of blocks.

The "west-side" marble member is the choice part of the deposit. It lies between the cherty upper dolomite zone and the cherty layers adjacent to the hanging-wall conglomerate. Its thickness varies slightly from an average of 75 feet. It contains zones of light, golden-vein, and white statuary marble separated by thin cherty beds and rows of nodular chert. These zones rarely attain 10 feet in horizontal width, and blocks more than 8 feet in their smallest dimension and free from chert are difficult to obtain. Large masses of dolomite or "lime", however, are absent. The marble itself is extremely white and clear, and its grains have a distinctly linear pattern.

The "west-side" marble contains from 2,000 to 3,000 grains to the square centimeter. The grains are slightly smaller and irregular adjacent to golden-vein and chert bands than elsewhere. Tests show an extremely low ratio of absorption. Twenty different cubes of statuary grade absorbed less than 0.12 percent of water by weight, and cubes of golden-vein grade absorbed 0.10 percent or less. Spaces between grains in the golden-vein parts average 0.0000025 centimeter in width and those in the statuary parts average 0.000003. The coefficient of irregularity is over 10 in the golden-vein parts and over 9 in the statuary parts. The marble is extremely rigid, and in its modulus of elasticity it ranks with the marbles of highest grade. The linear arrangement of the crystal grains is very distinct, and 10 percent of their vertical axes fall within 1 percent of the area of a projection sphere.

The high degree of irregularity of grains in the "west-side" marble adapts it to the greatest variety of uses. Because of its greater thickness and its uniform markings and quality the sizes of its blocks are not so restricted as those of the "bench" marble. The extreme degree of linear crystal arrangement renders the "west-side" marble unusually translucent, and it is one of the company's chief sources of "lumar"—marble in thin slabs lighted from behind.

Fractures.—Two sets of fractures are recognized, and both are important in quarrying the marble. A third set is confined to marble within 10 or 15 feet of the surface and therefore of no great consequence. The first two sets are classed as "main headers" and "dry seams" by quarrymen. The main headers are readily visible in the quarry and are comparatively continuous. They strike about N. 65° E., dip 80° S., and lie from 30 to 50 feet apart. The dry seams are inconspicuous and not continuous. They strike N. 55° W. and dip 65°–75° NE. They occur in steplike (en échelon) zones that are more irregularly spaced but closer together than the main headers and not easily seen. They are, therefore, a constant obstacle to quarrying. Not infrequently a large block of marble channeled and broken loose at considerable expense will split into two pieces along a dry seam. It even happens that these flaws do not show up until after a block has been cut into slabs in the mill.

The features described are represented in figure 23, a diagrammatic representation of conditions observed in opening 3, but the zones of dry seams are inadequately represented, so as to avoid overcrowding the diagram. It is, of course, desirable to quarry rectangular blocks. Furthermore, for "golden vein" marble, it is necessary that the blocks

be oriented properly with bedding. With the sets of fracture nearly at right angles to each other and at an angle to the bedding, such rectangular blocks are difficult to obtain. To obtain the largest blocks the marble is quarried with the bedding in places where the fractures are least pronounced; but near the larger fractures or main headers the cuts are made at different angles, depending on the prevalence of the smaller fractures or dry seams, chert bands, masses
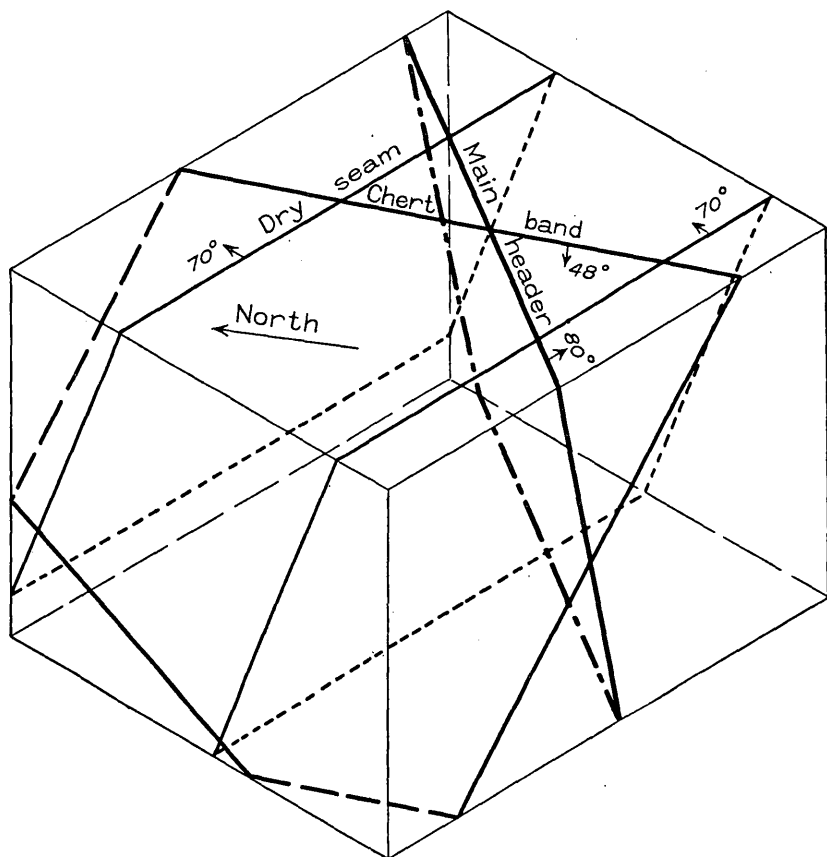
FIGURE 23.—Block diagram showing relation of the joint systems, chert bands, and dolomitic bodies found in the quarry. "Grain" or schistosity is parallel to chert bands.

of dolomite, and diopside-quartz lenses. Quarrying with or across the bedding is also governed by the grade of stock to be produced, as shown on pages 170, 171.

In spite of these difficulties the quarry can produce large blocks of essentially pure-white marble. Dimensions noted by Merrill ranged from 6 to 23 feet in length, 3.3 to 8 feet in width, and 2 to 4.7 feet in thickness.

"YULE VEINED STATUARY" (SECOND STATUARY) WALK AND TRIM, WITH ITALIAN "BLACK AND GOLD" BASE.
Fidelity Building, Los Angeles, Calif.   Courtesy of the Vermont Marble Co.
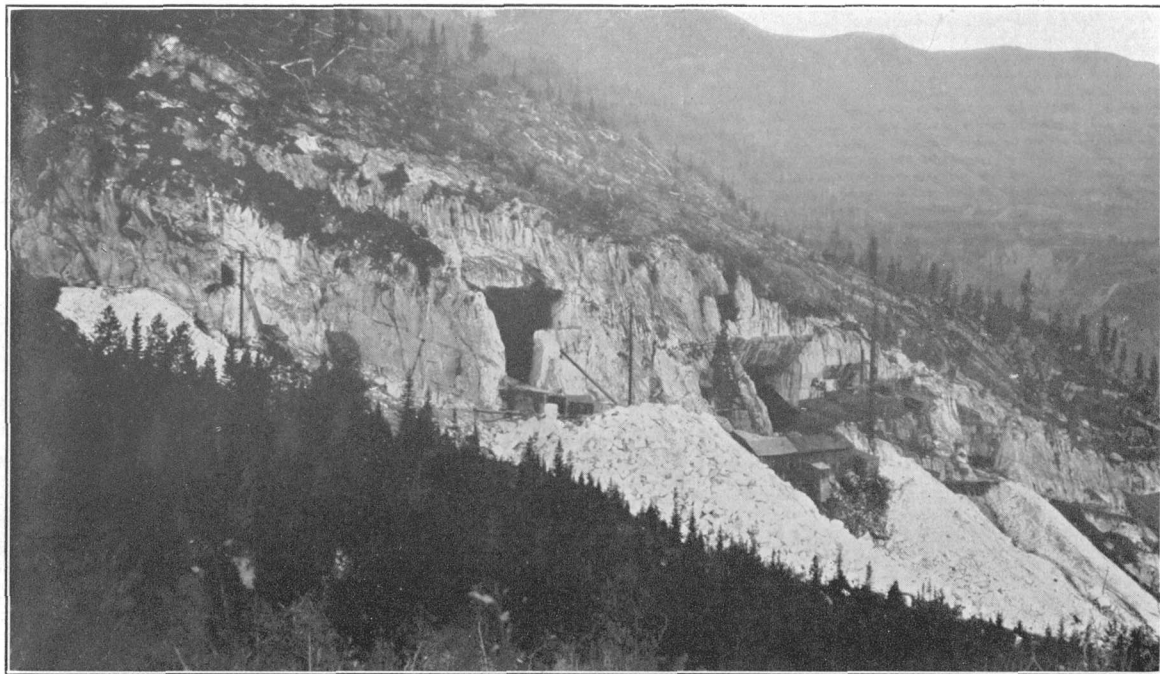
CLIFF OF WHITE MARBLE SHOWING POSITION OF YULE COLORADO MARBLE QUARRY.

The white dump at the left is from a prospect.

BLOCK FOR TOMB OF THE UNKNOWN SOLDIER

The largest block quarried, that for the Tomb of the Unknown Soldier in Arlington National Cemetery, Va., measured 14.0 by 7.4 by 6.0 feet and in the rough weighed 56 tons. The method of quarrying and shipping this block, as described in a written communication by H. S. Hobart, who was then in charge of the quarry, and in a published article,[95] is summarized as follows:

To obtain a block of desired quality for the die of the monument required more than a year. It was first necessary to quarry a mass that weighed more than 100 tons. A wire saw was then installed in the quarry to cut it approximately to the size required and to reduce its weight to an amount that could be safely handled with the equipment available and also to detect any defects. The block thus reduced weighed 56 tons. It was hoisted from the quarry by a specially reinforced derrick shipped from Vermont for the purpose. Before hoisting, the block was allowed to hang in the ropes for about 15 minutes to test their strength. The straight lift from the floor to the top or quarry bank was about 100 feet. Upon reaching the top the block was swung about 90° and landed on a "home-made" car which had two low wheels in front and none in back, the rear end dropping to assist in braking the load. It was then moved for about 200 feet along a track that had approximately a 20° grade and a 20° curve where it passed out of the quarry opening. As the block was much too heavy for the 800-foot cableway from the quarry to the trolley line, it was necessary to build a track 600 feet long up the slope to connect with the 200-foot track leading from the quarry. As the trolley line to Marble had a minimum grade of 4 percent and grades of 10, 12, and even 17 percent at certain places, a regular block car could not be used, especially as the block had to be moved in January, when it would have been too cold to brake so heavy a load. The temporary track, therefore, was connected with the trolley track and the "home-made" car made the trip of 3½ miles to Marble in 2 days. Two electric locomotives, one before and one behind the car, did the hauling. As the concentrated load on the "home-made" car could not cross the bridge over the Crystal River safely, a regular railroad flat car on which the block was to be shipped was pushed across the bridge, the trolley track disconnected and raised to the top of the flat car, and the marble block hauled onto the flat car with tackle blocks. The block was then shipped to West Rutland, Vt., for sawing, thence to Proctor, Vt., for cutting, and finally to Arlington Cemetery, Va., for erection and carving.

GRADES OF MARBLE

In outcrop the marble is of very uniform appearance. Cut and polished surfaces, however, show combinations of clear massive white stone, delicate brown streaks locally termed "veins", and chert fragments. Irrespective of strength and durability, therefore, there are differences of attractiveness which, although largely a matter of personal preference, are sufficiently marked to affect the market price. These differences together with adaptability for different uses form

---

[95] A block of marble for the Unknown Soldier's tomb: Through the Ages, vol. 9, no. 3, pp. 24–28, 1931.

the basis for grading. The marble is grouped by the company [96] into the four grades cited below. A fifth grade, called "crystal", was marketed until 1936, when its sale was discontinued.

1. *Statuary marble.*—The most valuable grade. Essentially pure white, with less than 0.1 percent of golden or other veining. Its grain size and the color of its surfaces are as nearly uniform throughout as can be selected by experienced graders.

2. *Veined or second statuary marble.*—Similar to grade 1 but may have as much as 0.5 percent of veining or clouding. (See pl. 23.) The texture is usually very uniform, and markings are so spaced as to be inconspicuous. Usually only marble graders can distinguish between statuary and veined statuary.

3. *Golden-vein marble.*—White with pronounced veining. The veins are delicate brown to yellowish streaks that average less than a quarter of an inch in thickness and extend more or less regularly across even large slabs. Slight variation in grain size adjacent to the veins may be evident but is essentially a microscopic feature. The presence of a few gray streaks and minute quantities of chert may be tolerated. This grade, represented in plates 21 and 22, is the dominant product of the quarry.

4. *Bottom-base stock.*—Similar to the golden-vein marble but with small irregularities in marking that give one face of a block a different appearance from the others. This face may be used as the bottom in a monument, pillar drum, or similar block, so that it appears identical with the golden-vein marble; but this restriction in its use reduces it below the regular golden-vein grade.

5. *Crystal grade.*—The crystal grade, discarded in 1936, was similar to the golden-vein and statuary grades but contained an appreciable quantity of chert, mostly in thin streaks. The gray color commonly associated with the chert is also conspicuous. The discarding of this grade resulted from the company's country-wide study of buildings containing Yule Colorado marble, which showed that the chert aged to a dark-gray color and that the cherty marble did not have as satisfactory an appearance as the other grades. Much of the marble in the Lincoln Memorial, which evidently represents quarry-run material, is of the "crystal" grade. Several blocks in this memorial and in the Denver post office contain fractures or "dry seams" and reflect the difficulty that the original operators had in obtaining marble absolutely free from flaws from no. 3 opening.

The foregoing grades include marble for all uses, with due regard to the surfaces that are to be exposed. A slab for the wall of a building, for example, may qualify as of statuary grade although it was sawed from a block that as a whole would have to be classed in a different grade. Slabs or blocks selected from bottom-base stock may pass for either statuary or golden-vein grade, so long as any disqualifying markings are confined to concealed surfaces.

Veining or marking, though irregular, is commonly subparallel to the bedding. Most of the statuary marble is sawed parallel to the bedding, but most of the golden-vein marble is quarried and sawed in a vertical plane to give a diagonal pattern, and stock thus ob-

---

[96] Information furnished by H. S. Hobart and G. W. Bain, of the Vermont Marble Co.

tained is called "diagonal golden vein." Some blocks are sawed in a horizontal plane or parallel to the quarry floor to produce an irregular, interfingering pattern, and stock from them is called "top-of-the-quarry golden-vein." Golden-vein stock sawed parallel to the bedding is also furnished but is not popular.

Antiquing or aging.—The marble eventually acquires a light creamy tone or "patina", which is much sought by sculptors. The time required for this tone to develop on "west-side" and "bench" stock is influenced by the kind of finish given. With the rough-sand finish, which is used on all building stock unless otherwise specified, the creamy tone becomes evident in about 15 years unless its development is artificially hastened; with the fine-sand finish and honed surfaces more than 20 years is required for the same degree of tone to appear. The statuary grades show the creamy tone somewhat sooner than the golden-vein grade. Polished slabs of "west-side" marble have lain beside the railroad at Marble for 20 years without any change in color or dulling of the surface.

RESERVES OF MARBLE

The depth to which the marble can be expected has not been determined, but along the outcrop from the crest of Treasure Mountain down to Yule Creek through a vertical distance of about 2,000 feet no distinct difference in the degree of marbleization has been noted. The extent down the dip, therefore, is probably greater than the depth to which quarrying is commercially feasible.

The pits from which the marble has been quarried are only about 200 feet deep and still about 50 feet above the level of the track. By crosscutting from the track level to the marble an additional depth equal to that quarried will be made available. The three pits in their combined length expose fully 600 feet of the bed along the strike. Marble of uniform character is present throughout this distance and probably continues an equal distance to the south, where the bed has not been developed. On this basis, which is believed to be conservative, the marble reserve of this quarry is three times greater in volume than that already quarried.

REPRESENTATIVE BUILDINGS CONTAINING YULE COLORADO MARBLE

The buildings listed below illustrate the different interior and exterior uses of Yule Colorado marble:

Representative buildings containing Yule Colorado marble

Locality	Building	Use	Date of erection
Pacific coast region:			
California:			
Compton_____	Angelus Abbey Mausoleum_____	Interior___	
Huntington Park___	Huntington Memorial_____		
Long Beach_____	Long Beach Auditorium_____	Interior___	
Los Angeles_____	Bankers Building_____	___do_____	
	Calvary Mausoleum_____	___do_____	
	Chamber of Commerce_____	___do_____	
	Charles A. Lindbergh Jr. High School_____	___do_____	
	Examiner Building_____	___do_____	
	Fidelity Building & Loan Assoc_____	___do_____	
	Kaufmann Memorial_____	Exterior___	
	Los Angeles Theater_____	Interior___	
	Merchants National Life Building_____	_____	1915.
	Merritt Building_____	Interior and exterior.	
	Pan American Building_____	___do_____	
	Senator Frank Flint Memorial_____	Exterior___	
	Sun Realty Building_____	Interior___	
	Sunnyside Mausoleum_____	___do_____	
Pasadena_____	Kellow Mausoleum_____	Exterior___	
Sacramento_____	St. Mary's Mausoleum_____	Interior___	
San Diego_____	Catholic Mausoleum_____	___do_____	
	Greenwood Mausoleum_____	___do_____	
San Francisco_____	Benbough Mausoleum_____	___do_____	
	Crocker First National Bank_____	___do_____	
	Cypress Lawn Mausoleum_____	___do_____	
	Municipal Building_____	___do_____	
	Palmieri Mausoleum_____	Exterior___	
	Santa Fe Building_____	_____	
	Thorne Memorial_____	_____	
	West Coast Life Building_____	Exterior___	1916.
Santa Monica_____	Community Mausoleum_____	Interior___	
Oregon:			
Portland_____	First National Bank_____	Exterior___	
	First National Bank connecting building_____	_____	1916.
	Bedell Building_____	Interior___	1922.
Washington:			
Seattle_____	New Infirmary Building, University of Washington_	___do_____	
Spokane_____	Zukor Store Building_____	Exterior___	1935.
Tacoma_____	Pacific Savings & Loan Building (remodeled with marble facing).	___do_____	1931.
Rocky Mountain region:			
Colorado:			
Canon City_____	Post office_____	Interior___	
Denver_____	Capitol Life Insurance Building_____	Exterior___	1923.
	Colorado National Bank_____	___do_____	1914.
	Customs Building_____	Interior and exterior.	1931, 1936
	Empire Building_____	___do_____	1905.
	Federal Reserve Building_____	Exterior___	1925.
	City and County Building_____	Interior___	1929.
	Union Station_____	___do_____	1914.
	Post office building_____	Exterior___	1914.
West-central region:			
Iowa:			
Sioux City_____	Graceland Chapel_____	_____	
Kansas:			
Wichita_____	Post office_____	Interior___	1932.
Nebraska:			
Omaha_____	Forest Lawn Chapel_____	___do_____	
East-central region:			
Illinois:			
Chicago_____	Michael Reese Hospital_____	___do_____	
	New Field Building_____	___do_____	
	Rosehill Mausoleum_____	___do_____	
Ohio:			
Cleveland_____	Cuyahoga County Courthouse_____	___do_____	
	Knollwood Mausoleum_____	___do_____	

Representative buildings containing Yule Colorado marble—Continued

Locality	Building	Use	Date of erection
Middle Atlantic region:			
District of Columbia:			
Washington_____	Lincoln Memorial_____	_____	1915.
Pennsylvania:			
Philadelphia_____	Byberry Hospital_____	Interior___	
New York:			
New York_____	Fidelity Bond & Mortgage Co_____	___do_____	
	Goelet Building (entrance)_____	Exterior___	
	Municipal Building_____	Interior___	
Virginia:			
Arlington Cemetery_	Tomb of Unknown Soldier_____	_____	
New England:			
New Hampshire:			
Manchester_____	Elliott Memorial_____	_____	
Rhode Island:			
Providence_____	Providence County Courthouse_____	Interior___	

OTHER MARBLE DEPOSITS

Each sedimentary formation has formed a particular kind of marble, depending on its composition, and a great variety is therefore present in the area. These varieties are mentioned in the early descriptions of the marble, and, although the Mississippian limestone alone has been quarried, the other varieties present in Ordovician, Devonian, and Pennsylvanian formations are still referred to occasionally as of possible commercial value. For this reason the properties pertaining to marketability of the marble of each formation are briefly given below. Detailed metamorphic effects are described elsewhere in this report.

ORDOVICIAN

The Ordovician contains serpentine marble (Manitou dolomite) and white marble (Fremont limestone). The white marble of the Fremont is a single massive bed 30 to 40 feet thick. It is a medium-grained rock very similar lithologically to the Yule Colorado marble. No attempts have been made to quarry this bed, for although apparently of good quality it is not as thick a bed as the white marble of the Mississippian limestone and it is less favorably located.

Bedding planes are very prominent in the serpentine marble and commonly limit the thickness of quarry blocks to about 2 feet, although a few are 4 feet thick. The marble contains countless irregular and wavy stringers of gray or green to yellow serpentine parallel to the bedding. (See pl. 11, *A*.) Commonly a gradation from greenish yellow through green to black occurs in an individual band. The calcite groundmass is white to gray and provides an attractive contrast to the colors of the serpentine.

A small amount of serpentine marble was quarried at the head of Yule Creek, but so far as is known not any was marketed. More favorable locations of similar serpentine marble are opposite or southeast of the quarry of the Yule Colorado Marble Co. on Yule

Creek and a short distance south of Twin Bridges on the Crystal River. Should the quality of this rock ever warrant the expense of prospecting, the beds could be tested at each place with the use of diamond drills.

DEVONIAN

Dolomite of the Devonian recrystallized to a fine-grained marble of light buff to gray. The bedding planes are well developed and spaced less than 2 feet apart. In many places white diopside is present. The diopside as a rule is evident only on weathered surfaces and may be so small in amount that it can be detected only by very careful examination under the microscope, or by dissolving out the calcite with acid. Both the color and relative thinness render this bed unmarketable.

PENNSYLVANIAN

Much marble occurs in the Pennsylvanian Hermosa (?) formation, but as a rule it is gray and unattractive. Most of the beds are thin as well as impure and interbedded with either sandstone or shale. Locally specimens of black marble are available, and these have attracted some attention. However, the black marble is too slight in extent and too irregular in occurrence to be of commercial value.

One bed of limestone in the Hermosa (?) formation resembles the white marble of the Mississippian as seen from a distance. Conspicuous exposures of this bed are to be seen on the slope of Crystal Mountain both in North Pole Basin and Bear Basin, on the northwest face of Treasury Mountain in the extreme head of Bear Basin, and on the east and north slope of Whitehouse Mountain. On the slope of Crystal Mountain the color of the white marble, which is a recrystallized limestone conglomerate (pl. 4, A), is not uniform and is unattractive. In the second locality referred to, the marble is 20 to 30 feet thick, and it appears white from a distance, but at close range it has a decided yellow cast due to the presence of much serpentine. The color is uniform and rather attractive, but the bed occurs only on the east side of Bear Basin, where it is virtually inaccessible. The Pennsylvanian marble on Whitehouse Mountain is of considerable thickness but is too thin-bedded to be of commercial value; in addition its color is not a uniform white but is shaded with strong tints of buff and gray. It is a recrystallized magnesian or dolomitic limestone, and the irregular distribution of the dolomite accounts for the lack of uniformity in color. No effort has been made to develop any of the Pennsylvanian marble.

PATENTED CLAIMS

The following table lists the patented claims shown on the map (pl. 1, oversheet) in numerical and alphabetic order and gives the patent numbers.

Index of claims shown on map (pl. 1) in numerical order

No. on map	Name of claim	Patent no.	No. on map	Name of claim	Patent no.
1	Schofield Placer	8260	80	Victoria	8601
2	Stonington Town Site		83	City of Rome	8601
3	Marble City Placer	7741 Am	84	Charlotte	8601
4	Williams No. 1	6360A	85	Royal Arch	8601
5	Williams No. 2	6360A	86	Minnie Friend	10060
6	M. S	6166B	87	Grand Ella	10060
7	Banner Placer	7602	88	Sweepstakes	6645
8	Banner M..S	6250B	89	Dora	6645
9	Evans	6410	90	Wedge	10060
10	Keystone No. 2	5361A	93	Condon	6645
11	Wooden Eagle M. S	6361B	94	Nellie R	6645
12	Lakelet M. S	6360B	95	Ida B	6645
13	Guilford	6361A	96	Lillian	6645
14	Lacy Placer	8260	97	Lottie	6645
15	Virginia	12206	98	Howard	6645
16	Greensboro Placer	12204	99	White World	6645
17	Valley	3388	100	Red Plume	6645
18	H. E. S. No. 318 (H. G. Haxby)		101	Sally K	6645
19	Queen Placer	7738	103	Lead Chief	6939
20	City of Glasgow	3387	104	Eagle	5587
21	Lady Gay	3521	105	Bonanza King	6463
23	Overland No. 2	7955	106	Giblets	6645
24	Georgia	6238	107	Serpentine Marble Placer	20117
25	Tennessee	6238	108	Extension	13293
26	Monitor Placer	8543	109	Extension No. 1	13293
27	Vermont Placer	8543	113	May	8487
28	Marble Placer	8543	114	Silver Purse	6675
29	Prince of Wales	6250A	115	Orphan Boy	6769
30	The Black Marble Placer	12228	116	Silver Nugget	6676
33	R. H. K.	6166A Am	117	Lizzie G. No. 2	6408
34	Yule Placer	3618	118	Stanley No. 2	7318
35	Star	6674	119	Stanley No. 1	7318
36	Banner	6339A	120	Silvery Crop	6471
37	Eagle	6339A	123	Spar	6471
38	Falcon	6339A	124	Brooklyn	6471
39	Flag	6339A	125	Silver Crown	6471
40	Curbstone	6339A	126	Ben Hur	6471
43	Flag M. S	6339B	127	Crystal River	6471
44	Corwen Placer	17727	128	Catalpa	7027
45	Blue Marble	4411	129	Handy	6471
46	White Marble	4411	130	King Solomon	6471
47	London	4411	133	May Flower No. 2	6471
48	New Discovery	4411	134	May Flower	6471
49	Yule	4530	135	Rascal Marble Placer	19244
50	Prince Arthur	4530	138	Silver King	8064
53	Italian	4530	139	Tennessee	6471
54	Empress	4530	140	Silver Tip	8064
55	Emperor	4530	143	Lyons	6471
56	Dolomite	4530	144	Sorrel Broncho	6471
57	Hogback	4474	145	Blue River	6471
58	Vermont	4474	146	Lucky Star	6471
59	White Lime	5113	147	Copper King	6866
60	Turbine	6339A	148	Leviathan	4127
61	Fraction	4474	149	General Stone	6787
62	Lake	8601	150	Watcoga	6329
63	Islet Placer	8680	151	Black Eagle	6329
64	Kline Placer	8680	152	Hawley	15073
65	Raspberry	4474	153	Black Bird	6329
66	Belleview	4474	154	Little Anna	6329
67	Hoosier	4474	155	Little Doris	15073
68	Oriole	6431	156	Silver Tip No. 2	8064
69	Oriental	6431	157	Island Belle	6833
70	Occidental	4474	158	McVey Placer	15072
71	Slate	4474	159	J. T. Johnston	7655
72	Oxford	8601	160	Pat Moore	7655
73	Hood Placer	8601, 19217	163	Daisy	7655
74	White Cloud	8601	164	McKee	15073
75	Albatross	8601	165	Legacy	7655
76	Fine Marble Placer	16451	166	Black Queen	5783
77	Pilot Knob	8601	167	Mountain Chief	3458
78	Marble Herd	8601	168	General Geo. A. Stone No. 2	4043
79	White Castle	8601	169	New York City	6807

Index of claims shown on map (pl. 1) in numerical order—Continued

No. on map	Name of claim	Patent no.	No. on map	Name of claim	Patent no.
170	Geo. A. Duncan No. 1	4044	270	Bear Mountain No. 6	13621
173	Excelsior No. 1	4302	273	Bear Mountain No. 24	13621
174	Small Hopes	6654	274	Bear Mountain No. 23	13621
175	Mountain Lion	3637	275	Bear Mountain No. 22	13621
176	Goodenough	18880	276	Bear Mountain No. 21	13621
177	Kershaw	8641A	277	Bear Mountain No. 20	13621
178	Cleopatra	4187A	278	Bear Mountain No. 19	13621
179	Gothic Belle	3872	279	Bear Mountain No. 18	13621
180	Undine	8641	283	Bear Mountain No. 26	13621
183	Undine No. 2	8641	284	Bear Mountain No. 25	13621
184	Mammoth	4186A	285	Bear Mountain No. 17	13621
185	Monarch	18290	286	Bear Mountain No. 16	13621
186	Big Indian	4068	287	Bear Mountain No. 15	13621
187	Scottish Chief	3864	288	Crystal Mountain No. 2	19862
188	Dalton	4189	289	Crystal Mountain No. 4	19862
189	Truckie	4188	290	Crystal Mountain No. 3	19862
190	Climax	7739	293	Monte Cristo No. 1	19862
193	Margaret D. Placer	15242	294	Monte Cristo No. 2	19862
194	Bruin	4066	295	Harris and Farley	777
195	Silver Bell	4067	296	Schofield	4360
196	Homestake No. 2	3772	297	Riverside No. 1	8633
197	Milwaukee	2922	298	Aspen No. 1	8633
198	Rocky Point	16595	299	Crystal Mountain No. 7	19862
199	Homestake	2857	300	Aspen	8633
200	City Detroit	8641	303	Riverside	8633
202	Banker's Daughter	8627	304	Bear Mountain No. 13	13621
203	Belle of Mexico	5593	305	Bear Mountain No. 14	13621
204	Evening Star	3456	306	Bear Mountain No. 7	13621
205	J. A. Garfield	18806	307	Bear Mountain No. 8	13621
206	Fargo	5538	308	Bear Mountain No. 9	13621
207	Saturday Night	7655	309	Bear Mountain No. 10	13621
208	Dynamite	7655	310	Bear Mountain No. 11	13621
209	San Diego	3793	311	Bear Mountain No. 14.5	13621
210	M. S.	4187B	313	City	7849
211	M. S.	4186B	314	Wanderer	7849
213	Lucky Boy	2858	315	Protection	7085
214	Stonewall	6123	316	Home	7085
215	Sweet Home	3457	317	M. S.	5309B
216	Diadema	12166	318	Lost Horse M. S.	6239B
217	Mora Carmody	3793	319	O. S. B	8581
218	Silver Temple	7117	320	Inez No. 4	11450
219	Look Out	16596	321	Inez No. 3	11450
220	Ute Chief	3000	322	Inez No. 2	11450
223	Lake Superior	3001	323	Crystal M. S.	5708B
224	Romance	3635	324	Gray Copper	5309A
225	Brittle Silver	3636	325	Inez No. 1	11450
226	Bald Eagle	3545	326	Havelock No. 1	18606
227	Frank Howard	3199	327	Havelock	18606
228	America	7863	328	Copper King No. 13	18606
229	Iron Clad	7863	329	Copper King No. 11	18606
230	Black Hawk	7863	330	Copper King No. 12	18606
233	Spar	7863	333	Copper King No. 9	18606
234	Atlanta	7863	334	Copper King No. 8	18606
235	Michigan	6239A	335	Copper King No. 10	18606
236	Lost Horse	6239A	336	Lead Chief	2548
237	Carlyle	2671	337	20th Century No. 2	18606
238	Clarke No. 3	3136	338	20th Century No. 1	18606
239	Clarke No. 2	3198	339	Copper King No. 7	18606
240	Inez No. 13	11450	340	Copper King	18606
243	Inez No. 12	11450	341	20th Century No. 3	18606
244	Inez No. 11	11450	343	Copper King No. 4	18606
245	Inez No. 10	11450	344	Copper King No. 3	18606
246	Inez No. 9	11450	345	Copper King No. 2	18606
247	Inez No. 8	11450	346	Copper King No. 5	18606
248	Inez No. 7	11450	347	Copper King No. 6	18606
249	Inez No. 6	11450	348	Winchester	18606
250	Inez No. 5	11450	349	Winchester No 1	18606
253	Pointer	11450	350	Winchester No. 2	18606
254	Midland	5315	353	El Negocio	15329
255	International	12098	354	Irene	4183
256	Bullion Queen	12098	355	Eaton	2957
257	Crystal City No. 3	8581	356	Denver City	9929
258	Crystal City	8581	357	Mammoth Cave	9929
259	Crystal City No. 2	8581	358	Daisy	10280
260	Tiger	8581	359	Agatha	10280
263	Cashier	12808	360	Buckeye Boy	7950
264	Old Solitary		361	Buckeye No. 1	7950
265	Bear Mountain No. 1	13621	362	McPike	18707
266	Bear Mountain No. 2	13621	363	King Solomon	13442
267	Bear Mountain No. 3	13621	364	El Dorado	3717 Am
268	Bear Mountain No. 4	13621	365	Smuggler	7950
269	Bear Mountain No. 5	13621	366	Daisy No. 2	10280

Index of claims shown on map (pl. 1) in numerical order—Continued

No. on map	Name of claim	Patent no.	No. on map	Name of claim	Patent no.
367	Power	19655	468	Shakespeare No. 2	16164
368	Mary Newcomb M. S	5946B	469	Shakespeare No. 1	16164
369	Lead King M. S	11587B	470	Clipper	4857
370	Mary Newcomb	5946A	473	North Pole No. 7	16164
373	Ben Butler No. 4	5707	474	North Pole No. 8	16164
374	Lead King	11587A	475	North Pole No. 9	16164
375	F. G. Richardson	5710A	476	North Pole No. 10	16164
376	Laura	2547	477	North Pole No. 11	16164
378	Meadow Mountain No. 3	18679	478	North Pole No. 14	16164
379	Meadow Mountain No. 2	18679	479	North Pole No. 15	16164
380	Meadow Mountain No. 1	18679	480	North Pole No. 12	16164
383	Graham	16366	483	North Pole No. 13	16164
384	F. G. Richardson M. S	5710B	484	Puritan No. 9	20325
385	Prospect	4160	485	Mammoth No. 3	3617
386	Belleview	5709	486	Puritan No. 10	20325
387	John M. Maxwell	5708A	487	Puritan No. 11	20325
388	Extension	9929	488	Greenback	3441
389	Burt	12588	489	Mammoth No. 1	3616
390	Belle of the West	3773	490	Puritan No. 8	20325
391	New York	16366	493	Puritan No. 7	20325
393	Belle of Titusville M. S	9697	494	Iron	2815
394	Hudson	4222	495	Sara Bernhardt	4443
395	Cheney	3734	496	Ira Way	2907
396	Belle of Titusville	3428	497	Golden Rule	4429
397	Cavern	2816	498	Puritan No. 5	20235
398	Black Diamond No. 1	12828	499	Oriental	20235
399	Billy Bryan No. 2	12828	500	Mexican	4412
400	Black Diamond No. 2	12828	503	Blue Jay	20235
403	Billy Bryan No. 1	12828	504	New York	1416
404	Whopper	2938	505	Grasshopper	20235
405	Teller	2937	506	Ajax	20384
406	Kanawha	2927	507	Climax	20384
407	Providence	4858	508	Lookout	20384
408	Mocking Bird	7211	509	Lookout No. 3	20428
409	Dewey	17909	510	Lookout No. 5	20428
410	Dewey No. 2	17909	512	Yelm	7106
413	Limited	17909	513	Mountain Quail	4032
414	Bon Ton	2856	514	Lookout No. 4	20428
415	High Tide	779	515	Lookout No. 2	20384
416	Carbonate	6595	516	Tyro	20384
417	Crystal Mountain	778	517	Zacatacus	20427
418	International	2868	520	Dixie Queen No. 2	20428
419	Equinox	7630	522	Jenny Lynd	3566
420	Crystal	3433	523	Dixie Queen	20384
421	Noon Tide	3432	524	Shetland	4037
423	Old Hamilton	5615	525	Standard	6867
424	Crystal Mountain No. 6	19862	526	Soladad	5652
425	Crystal Mountain No. 5	19862	527	Centeral	6867
426	Crystal Mountain No. 1	19862	528	King of the West	20427
427	Justice	7232	529	Anna	7082
428	Mountain Quail	4113	530	Osceola	20427
430	Ida M	5088	532	Echo	7622
433	South Star	5088	533	Duke of Wellington	20427
434	Minnesota	5088	534	Grand View	3475
435	Crown	7892	535	New Discovery	20427
436	Crown No. 2	7892	536	Indicator	11416
437	Crown No. 3	7892	537	Toledo	5525
438	Crown Extension	7892	538	May Flower	20384
440	Silent Star	12826	539	Cameron	3863
441	Ella C	17946	540	Chesapeake	5068
442	Ella	4182	543	Emma	20427
443	Lone Star	3824	544	Log Cabin	20427
444	Miller M. S	1370	545	Setz No. 5	20427
445	M. S	1367B	546	Four X	20427
446	Dan Harris M. S	1369	547	Cora	4838
447	Utah	1368	548	Rocket	20384
448	Cottage Home No. 2	12972	549	Mancos	20384
449	Nevada	1367A	550	Homestake	20384
450	Lula	3293	551	Hiawatha	20384
451	Schofield Townsite		553	Setz No. 3	20427
453	May Flower	4197	554	Setz No. 4	20427
454	Alice	4196	555	Setz No. 2	20384
455	Columbine No. 2	16753	556	Setz	20384
456	Columbine No. 1	16753	557	Puritan No. 4	20235
457	Niagara	4911	558	Puritan No. 1	20325
458	Pitkin	2906	559	Puritan No. 13	20325
459	Greenback	5481	560	Puritan No. 3	20235
460	New Discovery	5482	562	Millsite	20324
461	Commonwealth Placer	17347	563	Puritan No. 2	20235
463	Shakespeare No. 7	16164	564	Galena Park No. 1	19300
464	Shakespeare No. 6	16164	565	Out West Placer	1309
465	Shakespeare No. 5	16164	566	Cleveland	15183
466	Shakespeare No. 4	16164	567	Hercules	14154
467	Shakespeare No. 3	16164	568	Ajax	14154

Alphabetic index of claims shown on map (pl. 1)

Name of claim	Patent no.	No. on map	Name of claim	Patent no.	No. on map
Agatha	10280	359	C larke No. 2	3198	239
Ajax	20384	506	Clarke No. 3	3136	238
Ajax	14154	568	Cleopatra	4187A	178
Albatross	8601	75	Cleveland	15183	566
Alice	4196	454	Climax	20384	506
America	7863	234	Climax	7739	190
Anna	7082	529	Clipper	4857	470
Aspen	8633	300	Columbine No. 1	16753	456
Aspen No. 1	8633	298	Columbine No. 2	16753	445
Atlanta	7863	234	Commonwealth placer	17347	461
Bald Eagle	3545	226	Condon	6645	93
Banker's Daughter	8627	202	Copper King	6866	147
Banner	6399A	36	Copper King No. 2	18606	345
Banner M. S.	6250B	8	Copper King No. 3	18606	344
Banner Placer	7602	7	Copper King No. 4	18606	343
Bear Mountain No. 1	13621	265	Copper King No. 5	18606	346
Bear Mountain No. 2	13621	266	Copper King No. 6	18606	347
Bear Mountain No. 3	13621	267	Copper King No. 7	18606	339
Bear Mountain No. 4	13621	268	Copper King No. 8	18606	334
Bear Mountain No. 5	13621	269	Copper King No. 9	18606	333
Bear Mountain No. 6	13621	270	Copper King No. 10	18606	335
Bear Mountain No. 7	13621	306	Copper King No. 11	18606	329
Bear Mountain No. 8	13621	307	Copper King No. 12	18606	330
Bear Mountain No. 9	13621	308	Copper King No. 13	18606	328
Bear Mountain No. 10	13621	309	Cora	4838	547
Bear Mountain No. 11	13621	310	Corwen Placer	17727	44
Bear Mountain No. 13	13621	304	Cottage Home No. 2	12972	448
Bear Mountain No. 14	13621	305	Crown	7892	435
Bear Mountain No. 14.5	13621	311	Crown No. 2	7892	436
Bear Mountain No. 15	13621	287	Crown No. 3	7892	437
Bear Mountain No. 16	13621	286	Crown Extension	7892	438
Bear Mountain No. 17	13621	285	Crystal	3433	420
Bear Mountain No. 18	13621	279	Crystal Mountain	778	417
Bear Mountain No. 19	13621	278	Crystal Mountain No. 1	19862	426
Bear Mountain No. 20	13621	277	Crystal Mountain No. 2	19862	288
Bear Mountain No. 21	13621	276	Crystal Mountain No. 3	19862	290
Bear Mountain No. 22	13621	275	Crystal Mountain No. 4	19862	289
Bear Mountain No. 23	13621	274	Crystal Mountain No. 5	19862	425
Bear Mountain No. 24	13621	273	Crystal Mountain No. 6	19862	424
Bear Mountain No. 25	13621	284	Crystal City	8581	258
Bear Mountain No. 26	13621	283	Crystal City No. 2	8581	259
Belle of Mexico	5593	203	Crystal City No. 3	8581	257
Belle of the West	3773	390	Crystal M. S.	5708B	323
Belle of Titusville M. S.	9697	393	Crystal River	6471	127
Belle of Titusville	3428	396	Curbstone	6339A	40
Belleview	5709	386	Daisy	10280	358
Belleview	4474	66	Daisy	7655	163
Ben Butler No. 4	5707	373	Daisy No. 2	10280	366
Ben Hur	6471	126	Dalton	4189	188
Big Indian	4068	186	Dan Harris M. S.	1369	446
Billy Bryan No. 1	12828	403	Denver City	9929	356
Billy Bryan No. 2	12828	399	Dewey	17909	409
Black Bird	6329	153	Dewey No. 2	17909	410
Black Diamond No. 1	12828	398	Diadema	12166	216
Black Diamond No. 2	6329	400	Dixie Queen	20384	523
Black Eagle	6329	151	Dixie Queen No. 2	20428	520
Black Hawk	7863	230	Dolomite	4530	56
Black Marble Placer	12228	30	Dora	6645	89
Black Queen	5783	166	Duke of Wellington	20427	533
Blue Jay	20235	503	Dynamite	7655	208
Blue Marble	4411	45	Eagle	6339A	37
Bonanza King	6463	105	Eagle	5587	104
Bon Ton	2836	414	Eaton	2957	355
Brittle Silver	3636	225	Echo	7222	532
Brooklyn	6471	124	El Dorado	3117 Am	364
Bruin	4066	194	Ella	4182	442
Buckeye Boy	7950	360	Ella C	17946	441
Buckeye No. 1	7950	361	El Negocio	15329	353
Bullion Queen	12098	256	Emma	20427	543
Burt	12588	389	Emperor	4530	55
Cameron	3863	539	Empress	4530	54
Carbonate	6595	416	Equinox	7630	419
Carlyle	2671	237	Evans	6410	9
Cashier	8581	263	Evening Star	3456	204
Catalpa	7027	128	Excelsior No. 1	4302	173
Cavern	2816	397	Extension	9929	388
Centeral	6867	527	Extension	13293	108
Charlotte	8601	84	Extension No. 1	13293	109
Cheney	3734	395	Falcon	6339A	38
Chesapeake	5068	540	Fargo	5538	206
City	7849	313	F. G. Richardson	5710A	375
City Detroit	8641	200	F. G. Richardson M. S.	5710B	384
City of Glasgow	3387	20	Fine Marble Placer	8601	76
City of Rome	8601	83	Flag	6339A	39

Alphabetic index of claims shown on map (pl. 1)—Continued

Alphabetic index of claims shown on map (pl. 1)—Continued

Name of claim	Patent no.	No. on map	Name of claim	Patent no.	No. on map
North Pole No. 9	16164	475	Shakespeare No. 4	16164	466
North Pole No. 10	16164	476	Shakespeare No. 5	16164	465
North Pole No. 11	16164	477	Shakespeare No 6	16164	464
North Pole No. 12	16164	480	Shakespeare No. 7	16164	463
North Pole No. 13	16164	483	Silent Star	12826	440
North Pole No. 14	16164	478	Silver Bell	4067	195
North Pole No. 15	16164	479	Silver Crop	6471	120
Occidental	4474	70	Silver Crown	6471	125
Old Hamilton	5615	423	Silver King	8064	138
Old Solitary	12808	264	Silver Nugget	6676	116
Oriental	20235	499	Silver Purse	6675	114
Oriental	6431	69	Silver Tip	8064	140
Oriole	6431	68	Silver Tip No. 2	8064	156
Orphan Boy	6769	115	Silver Temple	7117	218
O. S. B	8581	319	Slate	4474	71
Osceola	20427	530	Small Hopes	6654	174
Out West Placer	1309	565	Smuggler	7950	365
Overland No. 2	7955	23	Soladad	5652	526
Oxford	8601	72	Sorrell Broncho	6471	144
Pat Moore	7655	160	South Star	5088	433
Pilot Knob	8601	77	Spar	6471	123
Pitkin	2906	458	Standard	6867	525
Pointer	11450	253	Stanley No. 1	7318	119
Power	19655	367	Stanley No. 2	7318	118
Prince Arthur	4530	50	Star	6674	35
Prince of Wales	6250A	29	Stonewall	6123	214
Prospect	4160	385	Stonington Town Site		2
Protection	7085	315	Sweepstakes	6645	88
Providence	4858	407	Sweet Home	3457	215
Puritan No. 1	20325	558	Teller	2937	405
Puritan No. 2	20235	563	Tennessee	6238	25
Puritan No. 3	20235	560	Tennessee	6471	139
Puritan No. 4	20235	557	Tiger	8581	260
Puritan No. 5	20235	498	Toledo	5525	537
Puritan No. 7	20325	493	Truckie	4188	189
Puritan No. 8	20325	490	Turbine	6339A	60
Puritan No. 9	20325	484	20th Century No. 1	18606	338
Puritan No. 10	20325	486	20th Century No. 2	18606	337
Puritan No. 11	20325	487	20th Century No. 3	18606	341
Puritan No. 13	20325	559	Tyro	20384	516
Queen Placer	7738	19	Undine	8641	180
Rascal Marble Placer	19244	135	Undine No. 2	8641	183
Raspberry	4474	65	Utah	1368	447
Red Plume	6645	100	Ute Chief	3000	220
R. H. K	6166A Am	33	Valley	3388	17
Riverside	8633	303	Vermont	4474	58
Rocket	20384	548	Vermont Placer	8543	27
Rocky Point	16595	198	Victoria	8601	80
Romance	3635	224	Virginia	12206	15
Royal Arch	8601	85	Wanderer	7849	314
Sally K	6645	101	Watcoga	6329	150
San Diego	3793	209	Wedge	10060	90
Saturday Night	7655	207	White Castle	8601	79
Sara Bernhardt	4443	495	White Cloud	8601	74
Schofield Townsite		451	White Lime	5113	59
Schofield	4360	296	White Marble	4411	46
Schofield Placer	8260	1	White World	6645	99
Scottish Chief	3864	187	Whopper	2938	404
Serpentine Marble Place	20117	107	Williams No. 1	6360A	4
Setz	20384	556	Williams No. 2	6360A	5
Setz No. 2	20384	555	Winchester	18606	348
Setz No. 3	20427	553	Winchester No. 1	18606	349
Setz No. 4	20427	554	Winchester No. 2	18606	350
Setz No. 5	20427	545	Wooden Eagle M. S	6361B	11
Shetland	4037	524	Yelm	7106	512
Shakespeare No. 1	16164	469	Yule	4530	49
Shakespeare No. 2	16164	468	Yule Placer	3618	34
Shakespeare No. 3	16164	467	Zacatacus	20427	517

INDEX