GEOLOGY AND ORE DEPOSITS OF THE WHITEPINE AREA, TOMICHI MINING DISTRICT, GUNNISON COUNTY, COLORADO

by

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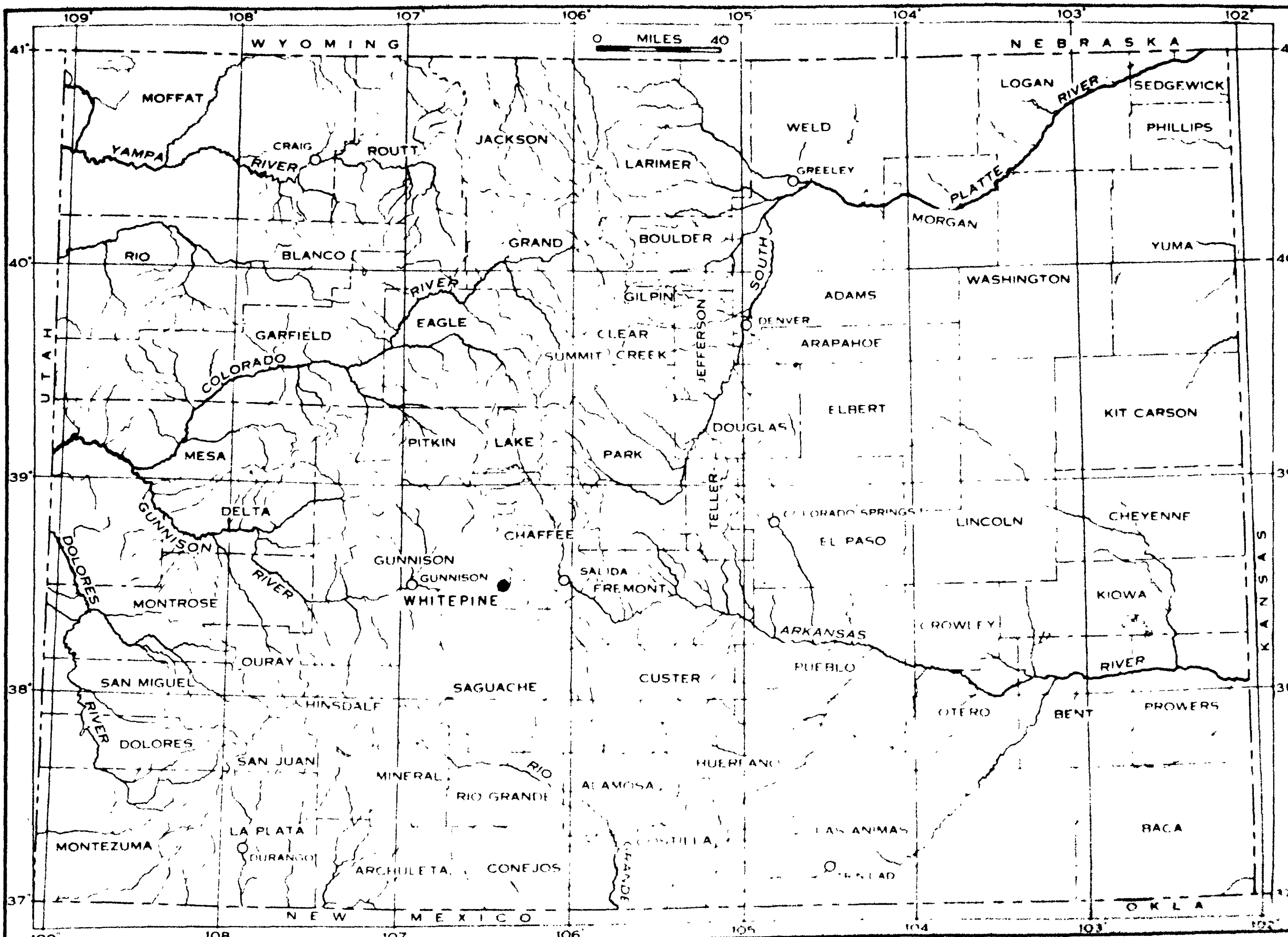


FIGURE I

INDEX MAP OF COLORADO SHOWING LOCATION OF WHITEPINE AREA, TOMICHI MINING DISTRICT

ABSTRACT

The Tomichi mining district is on the western slope of the Continental Divide near the southern end of the Sawatch Range in southeastern Gunnison County, Colorado. The most productive part of the Tomichi district was the Whitepine area. It is estimated that since the discovery of ore in 1879 the area has produced approximately $7,000,000, principally in lead and zinc, with lesser amounts of silver, copper, and gold.

Geologically, the Whitepine area is a faulted syncline of Paleozoic rocks that was intruded by Tertiary igneous rocks. The oldest rock of the area is the Silver Plume granite of pre-Cambrian age. Deposited upon this successively were the Sawatch quartzite (Late Cambrian), Manitou dolomite (Early Ordovician), Harding quartzite (Middle Ordovician), Fremont dolomite (Late Ordovician), Chaffee formation (Late Devonian), Leadville limestone (Late Mississippian), and Beldon shale (Late Pennsylvanian); a total thickness of about 1,450 feet.

During the Laramide Revolution, the sedimentary rocks were folded into a broad northward-plunging syncline, faulted, and intruded by a series of igneous rocks. The igneous rocks, in order of relative age from oldest to youngest, are: a rhyolite stock, the Princeton quartz monzonite batholith, quartz monzonite or quartz latite porphyry dikes, and rhyolite or pitchstone porphyry dikes.

The ore deposits of the Whitepine area may be classified into replacement deposits, vein deposits, and contact metamorphic deposits. The replacement deposits may be further subdivided into deposits along faults and bedded deposits. Of the types of deposits, the most productive have been the replacement deposits along faults. The major replacement deposits along faults are those of the Akron, Morning Star,

and Victor mines. The ore deposits of these mines are in the foot wall of the Star fault; in the Akron mine in the Manitou dolomite and in the Morning Star and Victor mines in the Leadville limestone. The chief bedded replacement deposits are those of the Erie, North Star, and Tenderfoot mines. In the Erie mine the ore deposits are in the Leadville limestone at, or just below, its contact with the Belden shale. In the North Star and Tenderfoot mines the ore bodies are in the Manitou dolomite along the crest of an anticline and the trough of a syncline, respectively. The vein deposits occur in the Silver Plume granite, Princeton quartz monzonite, and Paleozoic sedimentary rocks. The only vein of commercial importance was that of the Spar Copper mine, which is in the Silver Plume granite. Contact metamorphic minerals are found chiefly in the top of the Leadville limestone in the vicinity of the Erie mine, and in the limestone of the Belden shale. Magnetite is the only ore mineral and it was produced only from the Iron King mine.

The replacement deposits consist, in general, of sphalerite, galena, pyrite, and chalcopyrite in a gangue of silicified limestone or dolomite, quartz, and calcite. The veins, for the most part, consist of pyrite and quartz with only minor amounts of galena, sphalerite, and chalcopyrite. In both types of deposits gold is believed to be associated with the pyrite and sphalerite, and silver with the galena. Oxidized ore was the chief product of the early mining. This ore consists of calamine, cerussite, smithsonite, or anglesite, or a combination of these minerals, in a gangue of siliceous limonite or silicified limestone or dolomite. Oxidation did not extend, in most cases, for more than 150 feet below the surface.

The ore deposits are believed to be genetically related to the Princeton quartz monzonite batholith. Ore-bearing solutions derived from the cooling of magma are believed to have migrated upwards along the pre-existing faults replacing favorable zones in the sedimentary rocks, or depositing quartz and ore minerals in open fissures in the igneous rocks.

INTRODUCTION

Location and accessibility. The Whitepine area comprises about 2 square miles near the southern end of the Tomichi mining district in the Sawatch Range in Gunnison County, Colorado. The Tomichi mining district has no definite limits but is approximately that area of the Sawatch Range drained by the headwaters of Tomichi Creek. The Sawatch Range, one of the principal ranges of the Colorado Rocky Mountains, extends from about the latitude of Salida, Colorado, at the south to that of Gilman, Colorado, on the north (Fig. 1).

The only inhabited town within the area is the town of Whitepine, which, for the most part, is owned by the Callahan Zinc-Lead Company and maintained by them for use of their employees. A few buildings remain of the old town of North Star near the center of the mapped area.

A gravel road from Whitepine, maintained by the County, goes south for about seven miles where it joins State Highway 328. This State Highway extends south seven more miles and joins U. S. Highway 50, about one mile east of Sargents, Colorado. At the junction of the Whitepine road with State Highway 328 is another gravel road, from the east, maintained during the summer months by the United States Forest Service, that goes over old Monarch

Pass, near the south end of the Sawatch Range, and joins U. S. Highway 50 about one mile below, or east, of what is now called Monarch Pass (formerly called Agate Pass). U. S. Highway 50 is the main road between Salida and Gunnison, Colorado. Whitepine, via State Highway 328 and U. S. Highway 50, is about 45 miles from Salida and 47 miles from Gunnison. The nearest standard gauge railroad station is at Salida on the main line of the Denver and Rio Grande Western Railroad between Pueblo, Colorado, and Salt Lake City, Utah.

Topography and drainage. The topography is typical of that of glaciated mountain areas. The altitudes range from about 9,700 feet along the Tomichi Creek Valley to about 11,500 feet at the top of Lake Hill. The area lies on the western slope of the Continental Divide about one mile west of the crest. As the result of glaciation, the valley floors are relatively broad and choked with debris deposited by the glaciers. The valley walls are steep but the crests of the ridges and tops of the hills which, except for Lake Hill, were overridden by the glaciers, are relatively smooth and rounded.

Drainage of the area is by Tomichi Creek, a tributary of the Gunnison River. Other than Tomichi Creek, there are only two permanent streams in the area; Galena Creek, which cuts across the center of the area, and Spring Creek, which forms the southern boundary of the area.

Climate and vegetation. The climate of the area is typical of the mountainous districts of Colorado. During the summers the days are temperate but frost may occur at night. Thunder showers during the days are common. Snow starts falling in September and falls at intervals until May, the heaviest snows usually coming at the first of the year. The snow begins to melt in May and by July is gone, except locally in the heavy timber on the north slopes.

Most of the area is heavily timbered, particularly the north slopes, by second and even third growths. Only locally, as on the long ridge north of Lake Hill and on the western slope of Lake Hill, is there any open ground. Most of the trees are evergreens, chiefly lodgepole pine and Englemann spruce. Aspens are locally abundant and occur in dense groves, as along Galena Creek in vicinity of the old town of North Star. Willows and alders grow along the stream valleys.

Field work and acknowledgments. The field work upon which this report is based was done between June and September of 1949. All the surface mapping and most of the underground mapping were done at this time. Additional underground mapping, primarily in keeping the mine maps up to date, was done in 1950 to 1952. In 1949 the author was assisted by D. H. Whitebread who is responsible for the topography.

This work was part of a project of mapping the geology of the Garfield 15-minute quadrangle, which extends from latitude 38° 30' to 38° 45' and longitude 106° 15' to 106° 30'. This work was done by the United States Geological Survey in cooperation with the Colorado Geological Survey Board and the Colorado State Metal Mining Fund. The project was under the supervision of McClelland G. Dings of the United States Geological Survey who contributed considerable time and advice, both in the field and the laboratory, towards the completion of this work. A report on the geology and ore deposits of the Garfield quadrangle, incorporating part of the work on the Whitepine area, by M. G. Dings and C. S. Robinson ~~has been~~ prepared ~~for publication by the United States Geological Survey as a Professional Paper.~~

The author also wishes to acknowledge the help of the staff and employees of the Callahan Zinc-Lead Company, in particular, J. E. Dunn, John Botelho, and K. K. Hood, who furnished the bases for most of the mine maps, made available the report by P. J. Shenon and R. P. Full (1946), and gave permission for publication of the mine and production data.

Previous work. The most significant work in this area prior to the present investigation was that of R. D. Crawford's on the Monarch and Tomichi districts, which was published in 1913 as Bulletin 4 of the Colorado Geological Survey. The only other specific geologic report published containing information on this area was that of Harder (1909) who describes the iron-ore deposits. P. J. Shenon and R. P. Full (1946) after a brief visit and examination of the area submitted a private report as consultants to the Callahan Zinc-Lead Company. Their report was particularly useful in that it gave maps and descriptions of much of the mine workings inaccessible to the author.

At the end of this report is a list of the references used in preparing this report. This includes all the principal publications that relate directly to the geology of the Whitepine area, plus some that deal with the geologic features of the surrounding area.

GENERAL GEOLOGY

The Whitepine area of the Tomichi mining district is essentially the west limb of a northward-plunging syncline that has been faulted and intruded by igneous rocks. The oldest formation in the area is the Silver Plume granite of pre-Cambrian age. The Sawatch quartzite, of Cambrian age, was deposited on the Silver Plume granite, and following this were deposited in succession the Manitou dolomite, Harding quartzite, and Fremont dolomite of Ordovician age, the Chaffee formation of Devonian age, the Leadville limestone of Mississippian age, and the Belden shale of Pennsylvanian age.

At some period during either late Cretaceous, but more likely early Tertiary time, the area was intruded by a rhyolite, folded into a syncline and faulted. Two major thrust faults, the Morning Glim and Star faults, cut the west limb of the syncline, the only part of the syncline preserved from erosion. Following the faulting, the area was intruded by the Princeton quartz monzonite and a series of quartz monzonite or quartz latite, and rhyolite and pitchstone porphyry dikes.

Following a period of uplift and erosion (or several such periods) the area was exposed and glaciated. The glaciers smoothed the topography and deposited morainal material in and along the sides of the stream valleys; some of this material has been reworked by streams during recent times.

PRE-CAMBRIAN ROCKS

The central core of the Sawatch Range is chiefly composed of rocks of pre-Cambrian age (Dings and Robinson, in preparation; Burbank, et al, 1935). These include metamorphic equivalents of sedimentary and igneous rocks and parts of two large granitic batholiths, the Pikes Peak and Silver Plume batholiths. Of these, only the Silver Plume granite is exposed in the Whitepine area.

Silver Plume Granite

The Silver Plume granite crops out on the west side of West Point Hill, east of the Star fault on the west flank of Lake Hill, and east of the Morning Glim fault along the eastern edge of the mapped area (pl. 1). The exposures are, in general, poor. The rock weathers easily, and the slopes underlain by the granite are usually covered by a heavy growth of trees. The mapping of the contacts of this granite with the other formations is based primarily on float.

Underground, the Silver Plume granite is exposed on the Akron, 150, and 250 levels of the Akron mine (pls. 4, 6). Part of the workings of the North Star (pl. 11), Tenderfoot (pl. 12), Morning Star (pl. 13), Victor (pl. 14), Spar Copper (Fig. 3), and West Point mines are in this granite.

The granite, where fresh, is typically a light gray, medium-grained porphyritic rock; weathered surfaces are reddish-brown or dark gray. The phynocrysts, which make up about 50 percent of the rock, are tabular feldspar crystals from 5 to 15 mm. long, which commonly show a parallel to subparallel arrangement. The groundmass consists of feldspar, quartz, and biotite.

In thin section, the feldspars are seen to consist of orthoclase, microcline, microperthite, and oligoclase. The potash feldspars usually exceeds in amount the plagioclase feldspar, but the two are almost equal; in some localities the plagioclase exceeds the potash feldspar. Of the phenocryst, the amount of potash feldspar greatly exceeds that of plagioclase. Biotite was the only primary ferromagnesian mineral noted. Accessory minerals are sphene, zircon, apatite, and iron oxides, probably magnetite and ilmenite.

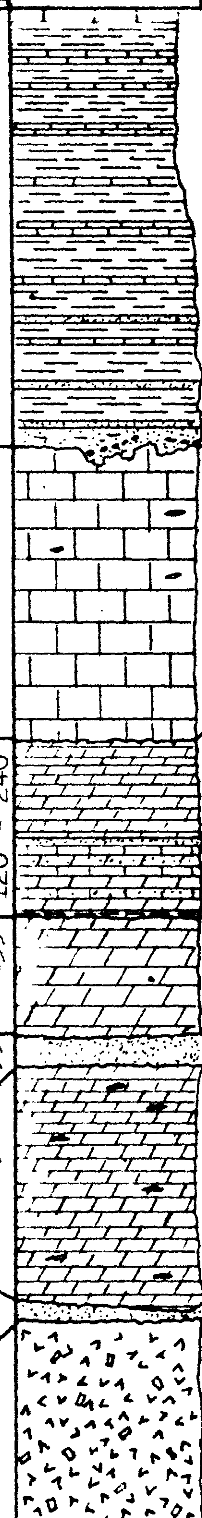
All specimens examined showed some alteration. The plagioclase feldspar has been altered in part to sericite, hydromica, and possibly other clay minerals, the biotite to chlorite, and the iron oxides to hematite and limonite. In the Akron mine, the Silver Plume granite on the hanging wall of the Star fault has been altered almost beyond recognition. The rock consists of a dark-gray clay with only a few partially altered grains of feldspar and grains of quartz.

In the Tomichi district this formation should properly be termed a quartz monzonite. The name Silver Plume granite, however, has been used throughout Colorado and is so firmly fixed in the geologic literature that it is not practical to change it.

Crawford (1913, p. 49) referred to this granite as the "porphyritic granite" and in his study of the Monarch and Tomichi districts did not map it separately from what he termed the "coarse biotite granite." Stark and Barnes (1935, pl. 1) mapped the "porphyritic granite" of Crawford of this area as the Pikes Peak granite. Dings and Robinson (in preparation) in their study of the geology of the Garfield quadrangle mapped Crawford's "coarse grained granite" and "porphyritic granite" separately. They correlated the "coarse grahed granite" with the Pikes Peak granite and tentatively correlated the "porphyritic granite" with the Silver Plume granite.

The Silver Plume granite, as defined by Ball (1906, p. 371-389), is widely recognized in other parts of Colorado (Burbank, and others, 1935). Stark and Barnes (1935, pl. 1) show an area of Silver Plume granite in the vicinity of Twin Lakes about 30 miles north of the Tomichi district, which is nearest known exposure of Silver Plume granite to the Tomichi district. Dings and Robinson (in preparation) at the time of writing of their report hesitated to make a definite correlation. The author, however, believes that the physical appearance, mineral composition, and age of the granite in the Garfield quadrangle are essentially the same as the known Silver Plume granite and that the correlation is valid.

The age of the Silver Plume granite is assumed to be pre-Cambrian. Evidence for this age in the Tomichi district is that the Sawatch quartzite of Late Cambrian age has been deposited on an eroded surface of the granite. In the Monarch district, on the east side of the Continental Divide east of the Tomichi district, Dings and Robinson (in preparation) found that Crawford's "porphyritic granite" clearly cuts the Pikes Peak granite, which adds evidence for the pre-Cambrian age of this, the Silver Plume granite, and for correlating this granite with the known Silver Plume, as this is the relationship noted at other exposures in Colorado.



System	Series	Formation and member	Thickness, in feet	Columnar section	Description
PENNSYLVANIAN	UPPER PENNSYLVANIAN	Belden shale	500+		Basal part, conglomeratic quartzite, quartzite, and argillite or shale, grading into interbedded shales and dark-gray limestone. Upper part, dark carbonaceous shale and gray limestones.
MISSISSIPPIAN	LOWER MISSISSIPPIAN	Leadville limestone	200 - 400		Light- to dark-gray limestone to dolomite marble. Depositional limestone marble breccia near base. Gray chert nodules in upper two-thirds.
DEVONIAN	UPPER DEVONIAN	Chaffee formation: Dyer dolomite member	115± (Chaffee formation 120 - 240)		White to dark-gray dolomite to limestone marble.
		Chaffee formation: Parting quartzite member	85±		Light- to dark-gray limestone to dolomite marble, and limy sandstone or quartzite.
ORDOVICIAN	UPPER ORDOVICIAN	Fremont dolomite	99 - 135		White to light-gray, medium- to coarse-grained, dolomite or dolomitic limestone marble.
	MIDDLE ORDOVICIAN	Harding quartzite	30 - 33		Gray, brown, or pinkish-white, medium-grained, well sorted quartzite.
	LOWER ORDOVICIAN	Manitou dolomite	235 - 250		White, gray, and dark-gray dolomite, dolomitic limestone, and limestone marble. Locally gray chert nodules.
CAMBRIAN	UPPER CAMBRIAN	Sawatch quartzite	0 - 20		White, gray, or brown medium-grained quartzite.
PRE-CAMBRIAN		Silver Plume granite			Light-gray, medium-grained porphyritic granite with phenocrysts of potash feldspar.

Figure 2. General section of the sedimentary rocks of the Whitepine area, Tomichi mining district.

PALEOZOIC SEDIMENTARY ROCKS

In the Whitepine area, sedimentary rocks of Paleozoic age form a broad syncline that has been down faulted and so preserved from erosion. The sedimentary rocks range in age from Cambrian to Pennsylvanian and include the Sawatch quartzite (Upper Cambrian), Manitou dolomite (Lower Ordovician), Harding quartzite (Middle Ordovician), Fremont dolomite (Upper Ordovician), Chaffee formation (Upper Devonian), Leadville limestone (Mississippian) and the Belden shale (Pennsylvanian), a total section of about 1,450 feet.

All the carbonate rocks, except the limestones of the Belden shale, have been recrystallized to marble and locally altered by hydrothermal solutions or contact metamorphism. The correlation of these rocks with rocks elsewhere in Colorado is based primarily on their composition and stratigraphic position rather than fossil evidence.

A generalized stratigraphic section of the sedimentary rocks of this area is given in Figure 2.

Sawatch quartzite

The Sawatch quartzite, of Late Cambrian age, crops out in two belts, one east of the Star fault near the base of Lake Hill and one across the west end of West Point Hill, that extend from the southern limit to about the center of the mapped area (pl. 1). It overlies unconformably a fairly even surface of Silver Plume granite and is overlain unconformably by the Manitou dolomite.

The Sawatch quartzite is poorly exposed at the surface and the mapping is based primarily on float. The best exposure is in the road-cut about 100 feet south of the North Star shaft (pl. 1). Underground, this formation is well exposed on the Akron level of the Akron mine about 280 feet east of the May raise (pl. 4).

The thickness of the Sawatch quartzite ranges from 0 to about 20 feet. Just north of Spring Creek, on the south side of West Point Hill, the Sawatch quartzite is absent and the Manitou dolomite rests directly on the Silver Plume granite. The quartzite may also be absent on the north slope of West Point Hill as Crawford (1913, p. 299) reports that in the West Point mine the ore occurred at the contact of limestone and granite; exposures in this area are rare. The thickest section measured is about 600 feet northwest of the Breadwinner shaft where the formation is 20 feet thick. On the northwest side of West Point Hill the Sawatch is about 12 feet thick and on the Akron level, Akron mine, east of the May raise, 14 feet thick. At other places in this mine it is only four feet, or less, in thickness. The irregularity in the thickness of the Sawatch quartzite is accounted for by its deposition on a slightly irregular surface and by erosion prior to the deposition of the Manitou dolomite.

The Sawatch quartzite is, in general, a white, medium-grained, dense quartzite. The color is chiefly white although it may be gray or brown, or even pink on weathered surfaces due to the presence of hematite. The quartzite throughout most of its thickness is well sorted, with rounded grains ranging from 0.5 to 2 mm/ in diameter. Near the base of the formation, however, there may be present a coarse, sometimes arkosic, quartzite or conglomeratic quartzite. This basal member is discontinuous, lensing out within a few feet, and ranges in thickness from half a foot, or less, to two feet. The lenses consist mostly of well rounded white quartz pebbles (rarely exceeding an inch in diameter), locally some feldspar and mica grains, and a few small pebbles of granite in a quartzite matrix. The basal member is best exposed in the road cut about 100 feet south of the North Star shaft.

The Sawatch quartzite was named by Eldridge (1894, p. 6) for its persistent occurrence along the flanks of the Sawatch Range. Later geologists have expanded this name to include all the formations of Cambrian age in central Colorado, not just the basal quartzite. Johnson (1944, p. 310-314), in his study of the stratigraphy of the Sawatch Range, divided the Sawatch into four members: lower quartzite member, glauconitic sandstone member, upper quartzite member, and Peerless shale member. The Sawatch quartzite of the Tomichi district is correlated on the basis of stratigraphic position and lithology with the lower quartzite member of Johnson.

No fossils were found nor have any been reported from the lower quartzite member. Fossils from the upper, or Peerless shale member, in the Sawatch and Mosquito Ranges--east of the Sawatch Range--indicate, according to Johnson (1944, p. 314), that the age of this formation is Middle to Late Cambrian. It is generally accepted as being of Late Cambrian age.

Manitou Dolomite

The Manitou dolomite, of Early Ordovician age, crops out along two belts; one east of the Star fault along the west flank of Lake Hill and one west of the Star fault on the west and north sides of West Point Hill (pl. 1). These belts extend from the southern limit to about the center of the mapped area. The Manitou dolomite throughout most of the area unconformably overlies the Sawatch quartzite but locally, as north of Spring Creek and probably on the north side of West Point Hill, it rests directly on the Silver Plume granite. It is overlain unconformably by the Harding quartzite.

The exposures, in general, are poor, although locally certain members form low cliffs. The Manitou dolomite is exposed underground on most of the levels of the Akron (pls. 4, 6, 7), the Tenderfoot (pl. 12), and North Star (pl. 13) mines--it is the chief host-rock for the ore bodies in these mines.

The lower limestone members of the Tomichi limestone below the quartzite, as described by Crawford (1913, p. 56-61) are equivalent to the Manitou dolomite of this report.

The thickness of the Manitou dolomite ranges from 150 feet on West Point Hill to 335 feet in the Akron tunnel. These thicknesses, however, are believed to have been modified by faulting and folding. A typical section measured on the west slope of Lake Hill was about 240 feet thick. This agrees with a section measured by Dings (Dings and Robinson) along the South Arkansas River east of the town of Garfield on the east side of the Continental Divide in the Monarch district as 240 feet, and with sections measured by Crawford (1913, p. 57), who reported thicknesses of 290, 260, and 235 feet in the Monarch district and stated that: "In the Tomichi district the limestone below the quartzite has a thickness about equal to that of the same limestone east of Garfield." (260 feet). The section measured as 150 feet on West Point Hill was near the two east-trending faults at the crest of the hill (pl. 1). It is believed that part of the Manitou dolomite at this locality was cut out by faulting. The section exposed on the Akron level of the Akron mine, east of the Star fault, is 335 feet thick. There has been considerable faulting and folding in this section and, undoubtedly, there has been a repetition of beds.

The thickness of the Manitou dolomite as measured by Johnson (1944, p. 318) in the Sawatch Range, ranges from 20 feet at Gilman, Colorado, near the north end of the Range, to 375 feet in the Aspen mining district, on the west-central flank of the Range. Johnson (1944, p. 318-319) attributes this range in thickness in part to variation in the amount deposited and in part of erosion after the deposition of the Manitou dolomite and prior to deposition of the Harding sandstone (Harding quartzite of this report). He believes that post-Manitou erosion was the more important cause for the range in thickness. There is no evidence in the Tomichi district for such a period of erosion; the contact between the Manitou dolomite and Harding quartzite where observed was apparently conformable. Studies by Dings and Robinson (in preparation) in adjacent areas, however, indicate that Johnson's conclusions are probably correct.

The Manitou dolomite in the Tomichi district has been metamorphosed to a marble. At no exposures, either at the surface or underground, could the original character and composition of this formation be observed. The degree of metamorphism, in part probably dependent on the original composition of the rock, varies along the strike and dip. In general, however, the formation is dolomite, dolomitic limestone, and limestone marble and, except for in the vicinity of the ore deposits where there has been considerable hydrothermal alteration, the composition is believed to have been only slightly affected, if at all, by the metamorphism. Studies made of this formation in nearby areas (Dings and Robinson, in preparation) have shown that the formation is essentially composed of dolomite and dolomitic limestone.

The exposures of the Manitou dolomite at the surface in the Tomichi district are poor. The best section exposed is on the west slope of Lake Hill and the following detailed section was measured there.

Section of Manitou Dolomite on the West Flank of Lake Hill

		Feet
Harding quartzite		
Unconformity		
Manitou dolomite		
14.	Dolomite marble, white thin-bedded (1-12 inches)	21.5
13.	Dolomite marble, alternating white and gray bands, thin-bedded (1-12 inches), coarse-grained (5-15 mm)	17
12.	Covered. Float indicates dolomite marble, white to gray, medium-grained (1-5 mm)	21
11.	Dolomite marble, pinkish-gray, medium-grained. Contains 1-inch nodules of gray chert	6
10.	Covered. Float indicates dolomite marble, gray, medium-grained	10
9.	Partly covered. Dolomite marble, gray, medium-grained	15
8.	Chert, gray, band 1 to 12 inches thick, averages 6 inches	0.5
7.	Dolomite marble, gray, medium-grained, 1-inch nodules of gray chert near center of section	11
6.	Partly covered, dolomite marble, gray, medium-grained	40
5.	Dolomitic limestone marble, pinkish-gray, medium-grained	1
4.	Partly covered, dolomite marble, gray, medium-grained	20
3.	Dolomitic limestone marble, pinkish-gray, medium-grained	1
2.	Covered. Float indicates dolomite and dolomitic limestone marble, gray and white	67

		Feet
1.	Dolomite marble, dark bluish-gray, fine- to medium-grained	8.5
	Total Manitou dolomite	239.5

Unconformity

Sawatch quartzite

In the Akron mine, the Manitou dolomite is exposed in all the accessible workings but at most exposures has been so highly altered that the beds cannot be distinguished. The upper 89 feet of this formation, however, is well exposed on the Akron level east of the Star fault and is not too highly altered. Here the formation is white to black dolomite, dolomitic limestone and limestone marble in beds 0.5 to 15 feet thick with bands of black chert nodules that are up to 1 foot thick and 2 feet long.

The black and gray chert nodules are not apparently restricted to any definite bed or beds in this formation. They occur in any of the beds in the formation in zones that are discontinuous along both strike and dip. They may be used to distinguish the Manitou dolomite from the Fremont dolomite, which lies above the Harding quartzite. No chert was observed in the Fremont dolomite in the Tomichi district.

The Manitou dolomite of this report is equivalent to the Manitou limestone as named by Cross (1894). The type section is exposed at Manitou Springs and Manitou Park, Colorado. The lithologic name was changed from limestone to dolomite by Johnson (1944, p. 316) as this formation is primarily a dolomite, not only at its type section, but throughout central Colorado.

The age of the Manitou dolomite has been determined by fossils as Lower Ordovician. No fossils were found in the Tomichi district--the recrystallization of the dolomite would probably have destroyed any fossils, if present--but Crawford (1913, p. 60) found poorly preserved specimens of Dalmanella, probably D. testudinaria, about 60 feet above the vase and Orthoceras (species unknown) about 80 feet above the base in the Monarch district on the east side of the Continental Divide. Worcester (Crawford and Worcester, 1916, p. 56) reported Dalmanella cf. testudinaria (Dalmen)?, Dalmenella hambergensis Walcott, Reticularia sp. (?), and Lingula sp. (?) from the lower part of the Yule limestone (Manitou dolomite of present usage) on Fossil Ridge in the Gold Brick district, which is about 12 miles west of the Tomichi district. Johnson (1944, p. 319-320) reported cystoid plates and columnals, Manorthis hamborgensis (Walcott), cross sections of low spiral gastropods, and brachiopod fragments suggesting Dalmanella from the same locality.

Although no fossils were found in the Manitou dolomite in the Tomichi district, its stratigraphic position and lithology make its identification positive.

Harding Quartzite

The Harding quartzite, of Middle Ordovician age, crops out in an almost continuous band through the middle of the mapped area from the southern limit to where the Princeton quartz monzonite has intruded the Paleozoic sedimentary rocks north of Galena Creek (pl. 1), and in another band that extends across West Point Hill from Spring Creek almost to Galena Creek. The exposures, except on the north side of West Point Hill, are in general good. It is more resistant to erosion than is the Manitou dolomite, on which it rests unconformably, and the Fremont dolomite, which unconformably overlies it, and, therefore, often forms a low ridge. This formation, because of its composition and resistance to erosion, is a useful marker in the section between the Sawatch quartzite and Belden shale, which is composed mostly of limestones and dolomites. The Harding quartzite is exposed underground on the Akron level of the Akron mine east of the Star fault (pl. 4).

This formation is locally known as the "parting quartzite" and should not be confused with the Parting quartzite of the Chaffee formation, which crops out in this area. Crawford (1913, p. 56-61) included this formation in his Tomichi limestone.

The Harding quartzite is remarkably uniform in thickness in the Tomichi district. On West Point Hill the thickness is 31 feet, 400 feet northwest of the Breadwinner mine on Lake Hill it is 30 feet, and on the Akron level of the Akron mine 33 feet. The work of Dings and Robinson (in preparation), however, shows that this formation thins from a maximum of 38 feet in the Monarch district --across the Continental Divide to the east of the Tomichi district --to 10 feet in the Tincup district on the west flank of the Sawatch Range--about 12 miles northwest of the Tomichi district. Johnson (1944, p. 321) reports that this formation is missing from the Paleozoic section of the Sawatch Range north of the south end of Taylor Park, which is just north of the Tincup district.

The Harding quartzite is typically a medium-grained quartzite. On weathered surfaces it may be brown or pink with small patches of yellow-brown hydrated iron oxide. Fresh surfaces are gray or dull white. The grains range from 0.25 to 5 mm. in diameter. The typical Harding consists of 75 percent of grains from 0.25 to 0.5 mm. in diameter with 25 percent of the grains about 1 mm. in diameter. This good sorting and the grain size is characteristic of the formation. Locally small lenses, 0.5 to 2 inches thick, may be coarse grained with grains up to 5 mm. in diameter. The grains are typically cemented with silica but locally, especially near the middle of the formation, there may be some beds of fine-grained calcareous cemented sandstone.

The best exposure of the Harding quartzite is on the Akron level of the Akron mine (pl. 4) east of the Star fault, where the following section was measured:

Section of the Harding Quartzite in the Akron Mine

		Feet
Fremont dolomite.		
Unconformity.		
Harding quartzite		
3.	Quartzite, white and brownish white, with two distinct grain sizes (0.25-0.5mm., 75 percent; 1 mm., 25 percent). Beds one-half to two feet in thickness	11.5
2.	Quartzite, white with iron stained patches, fine to medium grained. Beds ½ to 1-½ feet in thickness	16
1	Quartzite, white, vitreous, medium grained. Beds not distinguishable	6
	Total Harding quartzite	33
Unconformity.		
Manitou dolomite.		

The Harding quartzite was named the Harding sandstone by Walcott (1892, p. 154-167) for its exposure in the Harding quarry near Canyon City, Colorado. Kirk (1930, p. 456-465) established the age of the Harding as Middle Ordovician and correlated the quartzite of Crawford's (1913, p. 56-59) Tomichi limestone of this area, as well as other exposures in Colorado, with the Harding sandstone at Canyon City. Tweto (1949, p. 149-235) in the Pando area, Colorado, modified the name to Harding quartzite; the name used in this report.

No fossils were found, nor have any been reported, in the Harding quartzite in the Tomichi district. Fossil fish remains, however, have been found at many localities throughout Colorado. (Walcott, 1892; Kirk, 1930; Johnson, 1944; Dings and Robinson).

Fremont Dolomite

The Fremont dolomite, of Late Ordovician age, crops out along the west side of Lake Hill from the southern limit of the mapped area to north of Galena Creek, and from Spring Creek across West Point Hill almost to Galena Creek. This formation rests unconformably on the Harding quartzite and is unconformably overlain by the Chaffee formation. The exposures at the surface are, in general, good, especially west of the Breadwinner mine on Lake Hill, on West Point Hill, and the ridge northeast of the North Star-Divident shaft. Underground, the formation is exposed on the Akron level of the Akron mine east of the Star fault (pl. 4) and in the lower Morning

Star tunnel (pl. 13). Crawford (1913, p. 56-59) included this formation in his Tomichi limestone.

The thickness of the Fremont dolomite ranges from 99 feet east of the Breadwinner shaft on Lake Hill to 135 feet on West Point Hill. On the Akron level of the Akron mine (pl. 4) east of the Star fault this formation is 117 feet thick. The variation in thickness, often within short distances, is typical of this formation. Dings and Robinson (in preparation) found that within the Garfield quadrangle it ranged in thickness from 15 to 135 feet. Johnson (1944, p. 323) reports that the formation is absent in the Sawatch Range north of the head of the Taylor River, which is about 40 miles northwest of Whitepine.

The differences in thickness are attributed (Johnson, 1944, p. 323; Dings and Robinson) to erosion during the Silurian and Devonian periods rather than to differences in original deposition. Evidence for this is the consistent lithology throughout the Sawatch Range--there is no evidence of a shore facies as it thins to the north--and a slight angular discordance, which may be observed locally, between the Fremont dolomite and the overlying Chaffee formation.

The Fremont dolomite in the Tomichi district has been recrystallized to a marble. On fresh surfaces the formation ranges in color from light-gray to white--white being the most common. Weathered surfaces are locally iron stained. In composition, it is a dolomite or dolomitic limestone. The grain size of the marble ranges from medium to coarse, with the coarse grains being the most abundant. The average grains are about 3 mm. in diameter, with a maximum of about 10 mm. The metamorphism has destroyed any evidence of bedding, if there ever was any. The best exposure is on the Akron level of the Akron mine and the following section was measured there:

Section of the Fremont Dolomite in the Akron Mine

	Feet
Chaffee formation.	
Unconformity.	
Fremont dolomite:	
2. Dolomite marble, white, massive, medium to coarse-grained	31
1. Dolomite marble, white, massive, medium to coarse-grained, small patches of hydrous iron oxide	86
Total Fremont Dolomite	117
Unconformity.	
Harding quartzite.	

The Fremont limestone was named by Walcott, (1892, p. 154-167) for its typical exposures in Fremont County, Colorado. The name, Fremont dolomite, is used in this report because this formation in the Tomichi district consists mostly of dolomite, as it does throughout the Garfield quadrangle (Dings and Robinson) and Sawatch Range (Johnson, 1944, p. 322-324). The fact that this formation is essentially a dolomite throughout such a large area is believed to prove that this formation was deposited as a dolomite and that the MgO content is not the result of metamorphism or alteration by hydrothermal solutions related to the ore deposits.

No fossils were found, nor have any been reported, from the Fremont dolomite in the Tomichi district. Crawford (1913, p. 60) in the Monarch district (east of Whitepine on the east side of the Continental Divide) reported Receptaculites oweni, Halysites catenulates, and small cup corals in the Fremont dolomite (upper Tomichi limestone of his report). Dings (Dings and Robinson) found Halysites gracilis and streptelasma sp. from the same locality. Crawford and Worcester (1916, p. 56) in the Gold Brick district (about 12 miles west of Whitepine) found Halysites catenulates, Receptaculites oweni, Platystrophia sp., Heliolites sp. (probably a calapoecia) from unit 3 of the second lower fossiliferous member of the Yule limestone, an equivalent of the Fremont dolomite. Kirk (1930, p. 457) and Johnson (1944, p. 324) established the age and correlation of the Fremont dolomite in the Tomichi district with that of other areas in Colorado.

Chaffee Formation

The Chaffee formation, of Late Devonian age, is poorly exposed in the Tomichi district, except east of the Star fault on the Akron level of the Akron mine (pl. 4). It crops out in two bands; (1) extending from the southern edge of the mapped area around the west side of Lake Hill to north of Galena Creek, and (2) across West Point Hill. The contact of the Chaffee formation with the Fremont dolomite, on which it rests unconformably, may be located, even in covered areas, on the basis of float with considerable accuracy because of the difference in lithology of the two formations. The contact with the Leadville limestone, which unconformably overlies the Chaffee formation, however, is very difficult to pick even under the best conditions--the lithology of the upper Chaffee and the lower Leadville are very similar. The Chaffee formation consists of two members; the lower member the Parting quartzite and the upper the Dyer dolomite, which are difficult to distinguish in the Tomichi district. Crawford (1913, p. 61-66) in mapping this district included the Chaffee formation and Leadville limestone in his Ouray limestone.

The thickness of this formation in the Tomichi district was measured at three localities; on West Point Hill where it was about 240 feet thick, on Lake Hill where it was about 120 feet thick, and on the Akron level of the Akron mine east of the Star fault where it was about 200 feet thick. Only in the Akron mine could the two members be distinguished and here the Parting quartzite was 84 feet thick and the Dyer dolomite 116 feet thick. Johnson (1944, p. 324-331) reports that in the Sawatch Range the Parting quartzite ranges in thickness from 40 to 100 feet (averaging about 60 feet) and the Dyer dolomite from 70 to 200 feet. Dings and Robinson (in preparation) observed a range in thickness from 0 to 300 feet, the thickest section (300 feet) was in the Monarch district east of the Continental Divide. It was noted that at all places where the two members could be distinguished, the Dyer dolomite was the thicker. This range in thickness is attributed in part to variation in the amount of deposited sediments--the Parting quartzite member is believed to be a near shore facies of the Devonian sea (Johnson 1944, p. 328) --and in part to a period of erosion between the deposition of the Dyer dolomite member and the Leadville limestone.

The Chaffee formation has, in detail, the most varied lithology of any of the lower Paleozoic formations. In general, it consists chiefly of dolomitic limestone with subordinate beds of dolomite, limestone, shaly limestone, limy shale, dolomitic or limy sandstone, and quartzite. The lithology varies within short distances; individual beds are lenticular and the lithologic types intergrade. The carbonate beds at most places in the Tomichi district have been metamorphosed to marble. The individual beds are red, green, brown, black, gray, or white in fresh exposures but a characteristic feature of this formation is the light brown or yellowish-brown color of most of the weathered exposures.

The Parting quartzite member is best exposed on West Point Hill and on the Akron level of the Akron mine. The basal unit of this member consists of reddish-gray, greenish-gray or dark-gray, thin bedded (less than 1 to 4 in.) shaly limestone 8 to 15 feet thick. This unit is very characteristic and makes an excellent horizon marker for separating the Chaffee formation from the underlying Fremont dolomite. This unit is termed the "Fairview" shale by miners in the Tincup (Hill, 1909, p. 35-36) and Gold Brick (Crawford and Worcester, 1916, p. 55) districts. The beds above this basal member vary greatly in lithology and thickness throughout the district but consist chiefly of dolomite, dolomitic limestone, or limestone containing interbedded lenses of sandstones and quartzite. The sandstones are dolomitic and limy sandstones that intergrade with sandy dolomite and sandy limestones. Individual beds range from less than one inch to 20 feet thick. The sandstones beds and especially the quartzites, are in general thinner than the dolomite or limestone beds, with a maximum thickness of about 10 feet. The top of the Parting member is placed at the top of the highest discernable sandstone or quartzite bed in the Chaffee formation.

The Dyer dolomite member is not well exposed anywhere at the surface. Only in the Akron mine could a section be studied in detail. In general, this member consists of black, gray, and white limy dolomite, and dolomitic limestone, with a few dark shale partings and rare sandstone and chert lenses. The beds range in thickness from less than one inch to 20 feet, averaging about 10 feet. Included in the Dyer dolomite member are all the beds above the uppermost sandstone or quartzite bed and below the Leadville limestone.

The contact between the Dyer dolomite and the Leadville limestone is very difficult to pick, especially at the surface. At this contact, where exposed in the Tomichi district, is a thin bed of dolomitic sandstone or sandy dolomite in the base of the Leadville limestone.

The following section, measured on the Akron level of the Akron mine, was the best exposure of the Chaffee formation in the Tomichi district.

Section of the Chaffee Formation in the Akron Mine

		Feet
Leadville limestone.		
Unconformity.		
Chaffee formation.		
18.	Dyer dolomite member Limy dolomite marble, white, medium-grained	7
17.	Limy dolomite marble, black, fine-grained	20
16.	Limy dolomite marble, white, medium- to coarse-grained, massive	26
15.	Dolomite marble, white. At top, two ½ to 2 inch seams of gray chert 1 to 2 inches apart, 1 to 2 inch chert seam at base	2
14.	Limy dolomite marble, white, locally iron-stained, medium- to fine-grained	15
13.	Limestone marble, gray, fine-grained, partly silicified with some disseminated pyrite	1
12.	Dolomitic limestone marble, white to gray, medium- to coarse- grained, beds 2 to 6 feet thick	21
11.	Limestone or dolomitic limestone marble, white, silicified, with disseminated grains of pyrite, chalcopyrite, and galene	1
10.	Limy dolomite and dolomitic limestone marble, white to gray, fine- to coarse-grained, beds 4 to 12 feet thick. At base 2 to 4 inch bed of black sandy dolomite marble, iron-stained	23
	Total Dyer dolomite member	116

	Feet
Parting quartzie member.	
9. Dolomitic and limy sandstone, white, fine-grained and finely laminated cross-bedding. Beds 2 to 8 feet thick	19
8. Dolomitic limestone marble, brown to black, some disseminated pyrite	2
7. Dolomitic limestone and limy dolomite marble, white, buff, and gray, fine- to medium-grained, beds 2 to 5 feet thick	9
6. Dolomite marble, black, buff, and white, fine-grained	12
5. Dolomitic limestone marble, black to gray, fine-grained	9
4. Dolomite marble, white with black streaks, fine-grained. Black streaks limestone marble	7
3. Dolomitic limestone marble, black, fine-grained	2
2. Limestone marble, slightly dolomitic, black to brown, fine-grained, beds less than 1 to 5 inches thick	15
1. Shaly limestone marble, greenish-gray, white, and brown, fine-grained, beds less than 1 to 4 inches thick	9
Total Parting quartzite member	84
Total Chaffee formation	200

Unconformity.

Fremont dolomite.

The Chaffee formation was named by Kirk (1931, p. 222-240). In his study of the Devonian rocks of Colorado he noted that many names had been used for the beds of Devonian age and that they had been included with formations of other ages. He proposed that the Devonian beds, as typically exposed in Chaffee County, and extending from Glenwood Springs and the Crested Buttes quadrangle on the west to Salida on the east and from the Alma district to the north to the Kerber Pass district on the south, be termed the Chaffee formation. The Tomichi district lies within this area. The correlation of the Chaffee formation of the Tomichi district with the type section south of Salida could only be made on the bases of lithology and stratigraphic position; metamorphism of the carbonate rocks to marble destroyed and paleontological evidence, if present.

Although no fossils were found in the Chaffee formation in the Tomichi district, fossils found by Dings (Dings and Robinson) and by others (Crawford, 1913, p. 62; Kirk, 1931, p. 222-240; Johnson, 1944, p. 328-330) have established the age as Late Devonian. Dings found the following fossils (identified by P. E. Cloud, U. S. Geological Survey) in the Garfield quadrangle:

> Pelmatozoan joints, fragmentary starfish, echinoderm fragments, trepostomatous bryozoan, bryozoan fragments, _Camarotoechia_ cf. _C. contracta_ (Hall), _Paurorhyncha endlichi_ (Meek), _Paurorhyncha_?, _Cyrtospirifer_ cf. _C. animasensis_ (Girty), _Cyrtospirifer_ sp., unidentified spiriferoid brachiopod,

fragments of unidentified brachiopods, Athyris sp., Schuchertella?, Productella?, Schizophoria?, coiled cephalopod.

Leadville Limestone

The Leadville limestone, of Mississippian age, crops out in a broad belt extending from the southern edge of the mapped area across the west side of Lake Hill to north of Galena Creek. Only a small remnant crops out west of the Star fault on West Point Hill and to the north for about 1,500 feet. The exposures, in general, are fair; locally some beds form low cliffs. The lower contact of this formation is difficult to locate; the lithology of the Leadville limestone and the Chaffee formation, which unconformably underlies it, are very similar. The contact of the Leadville limestone and the overlying Belden formation is very irregular and comparatively easy to locate because of the difference in lithology of the two formations --the lower beds of the Belden formation are conglomerates, quartzites, or argillites. Crawford (1913, p. 61-66) included the Leadville limestone in his Ouray limestone.

The Leadville limestone is second only to the Manitou dolomite as the most important stratigraphic zone for ore deposits. Production from the Erie mine, Eureka-Nest Egg, and David H. mines has come from this formation.

The thickness of the Leadville limestone changes rapidly along the strike and dip and ranges from about 200 feet to about 400 feet. At no place in the Tomichi district is a complete section well exposed. West of the Star fault all but about the lower 150 feet has been eliminated by faulting. The only section measured is on the west side of Lake Hill, which totaled about 342 feet.

The abrupt change in thickness of the Leadville limestone is typical of the formation throughout the Sawatch Range. Dings and Robinson (in preparation) found that within the Garfield quadrangle the thickness was 200 to 300 feet at most places but that it ranged from 0 to 400 feet. Johnson (1944, p. 336) in his study of the stratigraphy of the Sawatch Range measured sections that ranged in thickness from 35 to 515 feet in thickness.

The range in thickness is undoubtedly due primarily to erosion prior to the deposition of the Belden formation. In the Erie mine (pl. 10), where ore was mined from the Leadville limestone at or near the contact with the Belden formation, the contact is very irregular in detail and resembles present day erosion surfaces on limestone. Dings and Robinson (in preparation) found that north of Middle Quartz Creek in the Garfield quadrangle a pre-Belden stream had eroded a channel through the Leadville limestone.

The Leadville limestone consists essentially of limestone and dolomite with some beds gradational in composition between these two extremes, and a few shaly and rare sandy beds. All the carbonate beds have been metamorphosed to marble. The base of the Leadville limestone at most places in the Sawatch Range is characterized by sandy limestone (Johnson, 1944, p. 332; Dings and Robinson). In the Tomichi district, however, the basal beds are shaly rather than sandy. Overlying the basal shaly beds are massive beds of limestone and dolomite, the lower 50 feet of which may contain one or more layers of depositional breccia. The depositional breccia usually consists of limestone marble fragments of from less than 1 to 5 inches in diameter cemented by limestone marble. If the pebbles are light colored, the cement will be dark, and vice versa. The lower third of the formation is predominantly limestone marble and the upper two-thirds dolomite marble; lenses of chert are fairly common in the upper two-thirds.

The lower 185 feet of this formation is well exposed on the Akron level of the Akron mine east of the Star fault. Here the basal unit consists of two feet of thin-bedded (beds 1 to 5 inches thick) black, fine-grained argillaceous limestone marble. Above this is about 63 feet of black, gray, and white, thin-bedded, limestone marble with several, less than one to 2 inch, shale seams and a few thin beds of dolomitic limestone and limy dolomite marble. The remaining section (142 feet) is mostly black, white, and gray, medium- to coarse-grained, massive, thick-bedded dolomite marble with some limy dolomite marble. Near the top of this section are thin lenses of black chert nodules.

The following section, measured on the west side of Lake Hill, was the best exposure of the complete section of the Leadville limestone in the Tomichi district.

Section of the Leadville Limestone Measured on the West Side of Lake Hill

		Feet
Belden ~~Formation~~ Shale		
Unconformity.		
Leadville limestone.		
9.	Dolomite marble, gray, fine-grained	3.5
8.	Covered	79.9
7.	Dolomite marble, black, coarse-grained fossiliferous (Brachiopods, horn corals, sponges; poorly preserved)	57.5
6.	Dolomite marble, black and white bands 1 to 6 inches thick, chert nodules 1 to 4 inches thick in white bands, coarse-grained	70.6
5.	Covered	25.0
4.	Limestone marble, gray and white, medium-grained, thin-bedded	19.4
3.	Limestone marble, slightly dolomitic, dark gray, medium-grained, thin-bedded	24.7
2.	Limestone marble breccia, white pebbles (1 to 2 inches in diamter) in gray cement	1
1.	Covered	60
	Total Leadville limestone	341.6
Unconformity.		
Chaffee formation.		

Near the top of the Leadville limestone, solution cavities have developed. These are well exposed near the west end of the most westerly drift and near the south end of the main drift on the number 4 level of the Erie mine (pl. 10).

The name Leadville limestone was applied to the Mississippian and Devonian limestone and dolomites by Eldridge (1894, p. 6) in the Anthracite-Crested Butte area, by Spurr (1898, p. 22) in the Aspen district, by Emmons (1898, p. 6) in the Ten Mile district, and by Worcester (Crawford and Worcester, 1916, p. 59) in the Gold Brick district. Crawford (1913, p. 61) included the present Chaffee and Leadville formations in his Ouray limestone for the Monarch and Tomichi districts. Kirk (1931, p. 239) recommended that the name Leadville limestone be restricted to the Mississippian limestones and proposed the name Chaffee formation for the Devonian beds. This usage has been followed by most workers in this area since Kirk's proposal.

The recrystallization of the Leadville limestone in the Tomichi district has destroyed most of the evidence of fossil remains, which are so common in the Leadville limestone of most areas. Only on the west side of Lake Hill were any fossils fonnd, and these were poorly preserved. The following fossils, collected on Lake Hill, were identified by J. S. Williams and Helen Duncan of the U. S. Geological Survey: Caninia sp. indef., Zaphrentoid corals, and Syringopora surcularia (Girty). In addition, the following fossils were collected by Dings (Dings and Robinson) in the study of the Garfield quadrangle (identification by Williams and Duncan): Syringopora acoleata (Girty), Spirifer centranatus (Winchell), Spirifer sp. indef., and Composita sp. The lithology, stratigraphic position, and paleontologic evidence make the correlation of Leadville limestone of the Tomichi district with that of other areas definite.

Belden Shale

The Belden shale, of Pennsylvanian age, is exposed in a broad band extending from the southeastern limit of the mapped area across Lake Hill and along the eastern side of the area, almost to the northern end. A complete section of the Belden shale is not exposed in the Tomichi district; it is cut off on the east by the Morning Glim fault, along which the pre-Cambrian Silver Plume granite has been thrust over the Belden shale. In general, this formation is poorly exposed. Only the lower part, that above its contact with the Leadville limestone on Lake Hill, is well exposed.

Crawford (1913, p. 67-70) named these beds in the Tomichi district the Garfield formation. This report will follow the terminology of Dings and Robinson who adopted the names proposed by Tweto (1949) for the Pennsylvanian-Permian (?) sedimentary rocks exposed in the Pando area, Colorado.

The replacement deposits in the Spar Copper mine are the only ore deposits in the Belden shale of the Tomichi district.

The thickness of the Belden shale could not be determined in the Tomichi district as the formation is cut off on the east by the Morning Glim fault. The thickest section in this district is on Lake Hill and is calculated as about 550 feet. Probably this figure is considerably in error because of drag folding along the Morning Glim fault, which could not be observed as most of the area is covered. Dings and Robinson (in preparation) found the maximum thickness of the Belden in the Garfield quadrangle to be about 1,100 feet. They observed that the Belden at most places could be divided into three distinct units: a lower unit of dark shale or argillite and quartzite, 200 to 500 feet thick; a middle unit of limestone and shale, 400 to 700 feet thick; and a upper unit about 200 feet thick containing more quartzite than the other units. The Belden shale of the Tomichi district probably includes the lower unit and possibly part of the middle unit.

The Belden shale in the Tomichi district is typically composed of dark shale or argillite, dark limestone, and quartzite, with a few beds of limy shale, shaly limestone, conglomeratic quartzite, and conglomerate. At the base is usually 5 to 85 feet of quartzite and conglomeratic quartzite with lenses of quartzite. Locally, however, shale or argillite rest directly on the Leadville limestone. The quartzites are fine- to coarse-grained and are composed mostly of quartz grains but in some lenses unaltered angular grains of feldspar and mica are common. In the conglomeratic quartzites and the conglomerates, the pebbles are usually composed of white quartz. The quartzite and conglomeratic beds are discontinuous along both their strike and dip. Individual beds range from a few inches to about 10 feet thick. Interbedded with these quartzites and becoming more abundant higher in the sections are beds of shale or argillite, which probably make up about 60 percent of the exposed section. The shale is typically black, carbonaceous, and ranges from a fissile shale to a hard argillite. The argillite is most abundant in the lower part of the section on Lake Hill and in the vicinity of the Erie mine. Shale, rather than argillite, is common north of Galena Creek. The shale beds are commonly 1 to 10 feet thick but the range in thickness is from an inch or less to 60 feet. The limestone beds interfinger with the shales or argillite. They are usually black or dark gray (weathering to a light gray), fine-grained and locally fossiliferous. Individual limestone beds range from 1 to 30 feet in thickness, but the average is probably less than 5 feet. Except for north of Galena Creek, the limestone beds of the Belden formation have not been recrystallized to marble. Thin beds gradational in composition between the shales or argillites, quartzites, and limestones occur locally within the section. The following section, measured on the west side of Lake Hill, gives the lithology of the lower part of the Belden shale.

Lower Part of the Belden Shale Measured on Lake Hill

		Feet
Belden shale.		
7.	Limestone, dark grey	?
6.	Argillite, black, very dense and hard, thin-banded (less than 1 inch to 4 inch bands)	60.5
5.	Rhyolite dike----------- 20 feet wide	
4.	Argillite, black, very dense and hard	42.2
3.	Quartzite, pink and white, lenticular, medium- to coarse-grain, less than 1 to 5 foot beds. Pink beds contain fresh feldspar and mica	20.3
2.	Quartzite, white, coarse-grained, locally conglomeratic quartzite and conglomerate lenses	16.1
1.	Conglomeratic quartzite, white poorly sorted, locally arkosic. Lenticular beds less than 1 to 10 feet thick	26.2
	Total measured section of Belden shale	165.3
Unconformity.		
Leadville limestone.		

Fossils were found in limestone beds of the Belden shale near the top of Lake Hill but, in general, in a poor state of preservation. Better specimens were found elsewhere in the Belden shale of the Garfield quadrangle and were submitted to Mackenzie Gordon, Jr., of the Geological Survey for identification. The following fossils establish the age and correlation of the Belden shale in the Garfield quadrangle: *Conularia* sp., *Polypora* sp. indef., *Orbiculoidea* sp., *Spirifer* sp., possibly *S. occidentalis* (Girty), *Crurithyris* sp. indef., *Chronetes (Lissochonetes) geinitzianus* (Waagen), *Productus (Dictyoclostus) coloradoensis* (Girty), *Productus (Juresania) nebrascensis* (Owen)?, *Marginifera ingrata* (Girty), *Nuculopsis*? sp., *Leptodesma*? sp., *Schizodus* sp., *Aviculopecten* sp., *Volsella*? sp. *Pleurophorus*? sp., *Aclisina*? sp., *Pseudorthocoras*? sp.

TERTIARY INTRUSIVE ROCKS

Igneous rocks, probably of Tertiary age, have intruded the pre-Cambrian granite and Paleozoic sedimentary rocks of the Whitepine area. The rocks range in composition from quartz monzonite to granite and in texture from medium-grained to glassy-porphyritic. They include, in order of relative age, a small rhyolite plug, the Princeton quartz monzonite batholith, dikes of quartz monzonite and quartz latite porphyry, and rhyolite and pitchstone porphyry.

Rhyolite

A small intrusive of rhyolite, the oldest of the Tertiary intrusives, lies west of the Star fault under Porcupine Ridge and the valley of Galena Creek (pl. 1). The glacial deposits on Porcupine Ridge and along Galena Creek make it impossible to determine the aerial limits of this intrusive. Pieces of the rhyolite have been found on the dumps of prospect pits on Porcupine Ridge about 550 feet west of the Star fault and on the basis of poor float, the rhyolite is believed to extend for about 100 feet south of Galena Creek to about 500 feet northwest of Porcupine Ridge.

The rhyolite is best exposed in the Akron mine (pls. 4, 5, 6, 7). The Akron tunnel intersects the contact of the Princeton quartz monzonite and the rhyolite about 1,760 feet east of the portal, and then crosscuts about 1,600 feet of rhyolite. The rhyolite is also exposed at the south end of the Akron level (pl. 4), at the north end of the Akron-Morning Star development drift (pl. 7), and on the 150 and 250 levels of the Akron mine (pl. 6).

Crawford (1913, pl. 4), to whom the underground workings were not accessible, and Shenon and Full (1946) mistakenly--probably because of the poor exposures and extensive alteration--mapped this formation as the Tomichi limestone (Manitou dolomite, Harding quartzite, and Fremont dolomite of this report).

At the contact of the Princeton quartz monzonite and rhyolite in the Akron tunnel, it is impossible to determine which of the formations intruded the other from the alternating bands of rhyolite and Princeton. About 200 feet to the east, however, a small dike of Princeton quartz monzonite, with inclusions of rhyolite, cuts the rhyolite, and the rhyolite is therefore the older. Near the intersection of the Akron tunnel with the Akron level (pl. 5) the rhyolite is in contact with the Manitou dolomite. The relationship between those two formations is not entirely clear here; a 2 to 3 foot shear zone occurs along the contact. At the other places in the Akron mine, however, where the contact between the rhyolite and Manitou are exposed, as on the Akron, 150, and 250 levels, dikes of rhyolite cross-cut the bedding of the Manitou dolomite.

The contact between the rhyolite and the Manitou dolomite is often difficult to recognize because of the intense alteration of both formations in the vicinity of the ore bodies. For this reason, the contact at most places is shown on the maps as an approximate contact. The author found that the best way to distinguish the two formations in underground mapping was to observe how they break on blasting; the Manitou dolomite tends to break in tabular pieces and the rhyolite in prismatic pieces. The location of this contact is of considerable importance in mining. What is termed the "foot wall ore body" occurs in the Manitou dolomite along or near its contact with the rhyolite.

The rhyolite has been highly altered and as altered, is a white to gray, very fine grained to aphanitic rock. Megascopically the rocks appear to be composed of grains of quartz in a matrix of clay. Locally, highly altered phenocryst of biotite and feldspar up to 2 mm in diameter and 1 mm cubes of pyrite may be observed. On weathered surfaces, the rocks appear to be an iron stained quartzite.

Microscopically the rock is seen to vary considerably in its composition as a result of the varying amounts of alteration. The typical specimen consists of about 90 percent quartz grains of from less than 0.1 mm to 0.3 mm in diameter. The quartz grains are angular to rounded and most show secondary growth. Locally the grains form clusters up to 5 mm in diameter, which megascopically look like rounded phenocrysts of quartz. The quartz grains are in a matrix of sericite grains that on the average are less than 0.1 mm in diameter. Larger grains of sericite, up to 1 mm in diameter, occur sparsely distributed throughout most specimens. Biotite phenocryst, up to 2 mm in diameter, were observed in some sections. The biotite ranges from dark-green and pleochroic biotite to an almost clear "bleached" biotite. Some of the biotite is altered to chlorite. The origin of the clear mica is indicated by the euhedral outline of the original biotite. The clear mica has a lower birefringence than the sericite of the groundmass, and it is assumed to be a hydromica. The euhedral outline of tabular feldspar phenocrysts are found in some sections. The feldspar has been so highly altered that it is impossible to determine its original composition.

In nearly all specimens, small cubes of pyrite are present, and in some, chalcopyrite. In some specimens, in particular those taken from near the rhyolite-Manitou dolomite contact, small calcite veins (less than 1 to 3 mm. wide) cut the rhyolite. No accessory minerals that might be expected in a rhyolite were observed.

At several exposures along the Akron tunnel and in the Akron mine, the rhyolite is banded. This banding is so well developed that it has been mistaken for bedding in what was thought to be a "quartzite" (Shenon and Full, 1946). The bands range in thickness from less than an inch to 4 inches. Microscopic examination of these bands shows that the banding is the result of there being locally a difference in the amount of silicification. Near the center of each band is a small veinlet of quartz, and the wall rock on either side of these veinlets has been silicified outward with decreasing intensity. Where the bands of silicification from two parallel veins meet, the silicification has been the least, and along this line of weakness a small fracture has been developed. The combination of silicification and subsequent fracturing gives the appearance of bedding.

This formation has been so highly altered that it is impossible to determine its original composition. The rock is termed a rhyolite because in mapping it has been shown to be an intrusive rock and the residual biotite and feldspar phenocryst would indicate that the rock was probably originally a rhyolite. The Akron mine workings were not accessible to Crawford (1913, pl. 4) and in mapping the surface, he saw probably only the exposure west of the Star fault on Porcupine Ridge. Without the underground exposures it was logical from this exposure to think this formation was the quartzite of his Tomichi limestone (Harding quartzite).

Shenon and Full (1946) recognized this formation in the Akron tunnel and in their report termed it the "Akron formation." They thought that the age was pre-Princeton quartz monzonite but admitted that their brief examination of the area did not determine the origin of the formation, or the part, if any, it played in localizing the ore. They did send Professor G. E. Goodspeed of the University of Washington 3 selected specimens, from which he made and examined six thin sections. His conclusions, as stated by Shenon and Full, were:

> . . . that two were fine-grained quartzites and that the third was a rhyolite type rock, now almost entirely replaced with fine-grained quartz.

M. G. Dings (Dings and Robinson) submitted six specimens collected from the Akron tunnel to Clarence S. Ross of the U. S. Geological Survey, who made a brief petrographic study of the specimens and the following report:

The sections numbered 3, 4, 7, and 8 are highly metamorphosed quartzites, tending to confirm the conclusion of Professor Goodspeed. The other two, Nos. 5 and 6 are approximately 50 percent quartz and 50 percent sodic plagioclase. There is the presence of a few plagioclase phenocrysts which suggest derivation from a rhyolitic rock. If it were not for these, one would probably conclude that all were of similar origin, and represent extreme metamorphism of sedimentary materials of somewhat varying composition. However pseudophenocrysts might result from the extreme metamorphism here represented. On the other hand extreme silicification and metamorphism might produce the entire series from an igneous rock.

Although the composition of the original rock is not definitely known, microscopic study indicates that the rock has been subject to at least three periods of hydrothermal alteration, and possibly some metamorphism. The present rock, which on the average consists of about 90 percent quartz grains, must have been formed by the silicification of the original rock. The cataclastic texture--angular to rounded quartz grains--would indicate that the rock had been subject to considerable pressure and the secondary growths of quartz around the quartz grains would indicate recrystallization as possibly a result of metamorphism.

The sericitization followed the first stage of silicification. As seen in thin-sections, sericite grains have replaced some of the quartz grains. Locally, a later period of silicification controlled by many small fractures replaced the sericite with decreasing intensity the greater the distance from the fracture. This period of silicification was accompanied by the introduction of pyrite and chalcopyrite, and is believed to be related to the formation of the ore deposits. The small veinlets of calcite that cut the rhyolite near its contact with the dolomite on the east, cut the silicification related to the fractures. These probably were developed by hydrothermal solutions that passed through the Manitou dolomite and then into the rhyolite; also probably related to the formation of the ore deposits in the dolomite.

Dikes of rhyolite cut the Ordovician Manitou dolomite and it is therefore younger than this formation. The rhyolite is cut by the Star fault and the fault has been intruded by the Princeton quartz monzonite; the rhyolite is then older than the fault and older than the Princeton quartz monzonite, which in turn has been cut by all other intrusives of the Tomichi district. The rhyolite is then the oldest of the intrusives, and is believed to be of Tertiary age as explained under the sections on the origin and the age of intrusive rocks.

Princeton Quartz Monzonite

The Princeton quartz monzonite of the Whitepine area is part of a large batholith that lies to the north and east of the area. In this area, it extends from south of Spring Creek across the west slope of West Point Hill to Galena Creek, where it is covered with glacial debris. Samples of it may be found in the prospect pits on Porcupine Ridge to the north of Galena Creek and it undoubtedly underlies the glacial cover on this ridge. It crops out again along a small westward-trending valley and along the east side of Tomichi Creek Valley at the north end of the mapped area (pl. 1). A small plug of what is believed to be Princeton quartz monzonite crops out just west of the Star fault on West Point Hill. Underground it is exposed in the Akron tunnel (pl. 5). The Princeton quartz monzonite is not well exposed in this area. Much of the area is forested and the Princeton quartz monzonite has been mapped on the basis of float. Its contacts with other formations were not observed at the surface. Only its contact with the rhyolite is well exposed in the Akron tunnel.

The Princeton quartz monzonite and Princeton batholith were named by Crawford (1913, p. 78) for Mt. Princeton, which is on the east side of the Sawatch Range, as the bulk of this mountain is composed of this formation. The Princeton batholith is one of the largest bodies of Tertiary intrusive rocks in Colorado (Burbank, et al, 1935). It is a small batholith with a maximum diameter of about 20 miles. A most notable discussion of the Princeton batholith, its distribution, its age, and petrographic relationship to other Tertiary intrusive of central Colorado is given by Crawford in, "A Contribution to the Igneous Geology of Central Colorado," Am. Jour. Sci., 5th ser., v. 7, pp. 365-388.

The Princeton quartz monzonite in the mapped area is typically a gray, bluish-gray, or, but rarely, white, medium- to coarse-grained equigranular rock. Locally it may be porphyritic. Weathering does not ordinarily appreciably change its color, but in several places, especially in the south end of the district, highly weathered parts are difficult to distinguish from the pre-Cambrian Silver Plume granite.

In hand specimen the minerals that may be recognized are: white orthoclase (sometimes pink), gray to bluish-gray plagioclase feldspar, glassy quartz, fresh shiny black biotite plates (many of which are euhedral), dull green hornblende, and typical of the Princeton, cinnamon-brown euhedral crystals of sphene.

Studies of thin-sections show that this formation, where unaffected by the intruded rocks, is surprisingly uniform in composition and grain size. The typical thin-sections show that the rock is a hypautomorphic granular rock consisting essentially of plagioclase feldspar, orthoclase, quartz, biotite, and hornblende, with accessory minerals of sphene and black iron-oxides, probably both magnetite and ilmenite.

The plagioclase feldspar is usually more abundant than orthoclase. It occurs as subhedral to anhedral grains of less than 1 to 6 mm. in length. It shows polysynthetic twinning, zoning, and a few grains enclose grains of biotite and hornblende. In composition, it is mostly labradorite but there is some andesine; the composition ranges from Ab_{40} An_{60} to Ab_{30} An_{70}.

The orthoclase occurs as anhedral grains with slightly "dusty" surfaces due to alteration, and it poikilitically encloses all other minerals except quartz. The grains range from less than 1 to 4 mm. in diameter. A few grains may show micrographic intergrowths of quartz.

The quartz occurs in anhedral grains of from less than 1 to 3 mm. in diameter. It is usually clear, rarely containing a few inclusions or gas bubbles.

In the Whitepine area, the biotite in the Princeton quartz monzonite is in excess of hornblende. It occurs as euhedral to anhedral grains of from less than 1 to 3 mm. in diameter. It is usually black and strongly pleochroic although a few grains may be bleached or altered to chlorite and magnetite around their edges.

The hornblende occurs in anhedral grains that appear crushed, and it ranges from less than 1 to 6 mm. in length. It is dark green to black and strongly pleochroic; the edges of some grains may be altered to chlorite and magnetite.

The accessory minerals include sphene in euhedral crystals of less than 1 mm. in length, and opaque iron oxides(probably magnetite and ilmenite).

The apparent order of crystallization was accessory minerals (except for some magnetite derived from the alteration of the ferro-magnesian minerals), hornblende, biotite, plagioclase, orthoclase, and quartz.

The following table lists two chemical analyses and two mineral analyses of typical specimens of Princeton quartz monzonite. Only the second mineral analysis is of a sample from the area covered by this report. This sample came from the Akron tunnel.

Chemical and Mineral Analyses of Princeton Quartz Monzonite

	Chemical Analyses		Mineral composition of Taylor Mt. quartz monzonite (Rosiwal method by R. D. Crawford, 1913, p. 145)	
	Gulch south of Williams Pass 1/	Taylor Mt. 2/		
SiO_2	65.37	67.64	Quartz	18.8
Al_2O_3	17.04	14.75	Orthoclase	25.8
Fe_2O_3	2.30	0.81	Plagioclase	42.5
FeO	2.16	1.95	Hornblende	2.9
MgO	0.63	0.94	Biotite	8.2
CaO	3.37	3.98	Iron ore	1.2
Na_2O	3.76	3.40	Titanite	0.6
K_2O	4.20	4.06		100.0
H_2O-	0.06	0.13	Mineral composition of Princeton quartz monzonite from Akron tunnel (Rosiwal method by C.S. Robinson)	
H_2O+	0.34	0.19		
TiO_2	0.48	1.36	Quartz	21.1
ZrO_2	-----	trace	Orthoclase	29.0
P_2O_5	0.21	0.20	Plagioclase	31.8
Cl	----	0.08	Hornblende	3.4

1/ Mt. Princeton quartz monzonite, Gulch south of Williams Pass Quartz Creek district, Colorado. Leonard Shapiro, U.S. Geol. Survey, analyst. Na_2O and K_2O determined with flame photometer by S.M. Berthold, U.S. Geol. Survey.

2/ Mt. Princeton quartz monzonite, Taylor Mountain, Monarch district, Colorado. From Crawford (1913, p.144). R.M. Butters, analyst.

Chemical and Mineral Analyses of Princeton Quartz Monzonite (cont.)

	Chemical Analyses		Mineral composition of Princeton quartz monzonite from Akron tunnel (Rosiwal method by C. S. Robinson)	
	Gulch south of Williams Pass	Taylor Mt.		
MnO	0.08	0.27	Biotite	12.5
CO_2	0.08	----	Iron-oxides	1.6
BaO	0.16	----	Sphene (Titanite)	0.6
	100.24	99.76		100.0

Distributed throughout the Princeton quartz monzonite are dark colored, ellipsoidal bodies that range from 1 to 12 inches in diameter. They are fine-grained to aphanitic and porphyritic; the phenocrysts are plagioclase. These bodies consist chiefly of plagioclase feldspar, biotite, and hornblende. The mafic minerals constitute about a third of the rock. A few crystals of orthoclase and quartz may be recognized in most specimens and the accessory minerals are sphene and iron-oxides. They grade into the surrounding Princeton quartz monzonite through border zones less than 10 mm. wide.

These dark bodies are believed to be basic segregations of the Princeton magma. Dings and Robinson (in preparation) found that these bodies were of rather uniform composition and size and that they were evenly distributed throughout the Princeton batholith. Also no rock types similar to these bodies were observed in mapping the Garfield quadrangle. If these bodies were inclusions, they would be expected to have a wider range in size and be more abundant near the borders.

On West Point Hill, just west of the rhyolite porphyry dike that intruded the Star fault, is a small intrusive that is believed to be Princeton quartz monzonite. It is a medium-grained, hypautomorphic, porphyritic rock with phenocrysts of orthoclase feldspar up to 15 mm. in length. Other minerals recognizable in hand-specimens are plagioclase, quartz, biotite, and pyrite. A study of thin-sections shows that the plagioclase feldspar has been highly altered, and the variety cannot be accurately determined, and that biotite and hornblende have been altered to chlorite magnetite, and a "bleached mica," probably a hydromica. There has been secondary silicification accompanied by pyritization--the pyrite is most abundant in the ferromagnesian minerals.

A mineral analysis of a sample of this rock was made and is given below with that of a typical sample of Princeton quartz monzonite.

	Mineral composition of intrusive on West Point Hill, west of Star fault. (Rosiwal method by C. S. Robinson)	Mineral composition of Princeton quartz monzonite from Akron tunnel. (Rosiwal method by C. S. Robinson)
Quartz	26.7	21.1
Orthoclase	36.2	29.0
Plagioclase	31.5	31.8
Biotite and hornblende	2.2	15.9
Iron-oxides	1.5	1.6
Pyrite	1.6	-----
Sphene (less than)	0.3	0.6
	100. 0	100.0

It will be noted that the two samples have essentially the same composition but in comparison with the typical Princeton quartz monzonite, this altered rock has more orthoclase than plagioclase, a higher percentage of quartz, and a lower percentage of ferro-magnesian minerals. This, in part, may be due to misindentification of the minerals as a result of their alteration. The composition, however, is more nearly that of the Princeton quartz monzonite than any other rock in the area and it is, therefore, correlated with the Princeton quartz monzonite.

At no place within the mapped area was the contact of the Princeton quartz monzonite with another rock exposed, except for the contact of the Princeton and the rhyolite intrusive in the Akron tunnel. In prospect pits in the Princeton near its contact, however, it was noted that there was considerable variation in both the texture and mineral composition.

Along the north side of Spring Creek near the contact of the Princeton quartz monzonite with the Silver Plume granite and the Manitou dolomite, the Princeton quartz monzonite is a dark to light gray aphanitic porphyritic rock. The phenocrysts consist of subhedral to anhedral orthoclase, up to 10 mm/ long; plagioclase (labradorite) subhedral, zoned and twinned up to 4 mm/ long; and subhedral biotite up to 2 mm/ in diameter. Anhedral quartz, euhedral sphene and magnetite, and pyrite may be recognized in some hand specimens. The groundmass, about 60 per cent of the rock, consists mostly of lath-shaped feldspar crystals with some biotite, hornblende, augite, apatite, and epidote (probably an alteration product) in grains of less than 1 mm. in diameter with some interstitial quartz.

South of Spring Creek near the contact of the Princeton quartz monzonite and Silver Plume granite, the Princeton resembles the aplite dikes of Princeton that were found elsewhere in the Sawatch Range (Dings and Robinson, in preparation). The rock is a grayish-white to yellowish-white aphanitic rock. The only minerals recognizable in hand specimen are quartz, sphene, magnetite and pyrite in anhedral grains of about 0.5 mm/ in diameter. A microscopic study showed that the groundmass consists of lath-shaped untwinned feldspar crystals less than 0.1 mm/ long. The feldspar, although altered in part to clay minerals and sericite, is apparently orthoclase.

The exposures in this area are poor and it may be that this rock is an aplite dike along the contact of the Princeton quartz monzonite, or it may be a border facies of the Princeton. No aplite dikes were noted in the Princeton in the Whitepine area but to the north of this area, they are very common along the borders, but not necessarily at the contacts, of the Princeton batholith (Dings and Robinson, in preparation).

Only one dike of Princeton quartz monzonite was noted in the Whitepine area. This dike is cut by the Akron tunnel about 2,010 feet east of the portal. The dike, although not typical of the Princeton quartz monzonite, mineralogically resembles more closely the Princeton than it does any of the dike rocks in the area. The rock is light-gray, fine-grained hypautomorphic and porphyritic. The phenocrysts, about 10 percent of the rock, consist of subhedral plagioclase (labradorite) feldspar up to 5 mm. long, subhedral biotite up to 3 mm. long, and a rare anhedral orthoclase or quartz phenocryst of 1 to 3 mm. in diameter. The groundmass is rather uniform in grain size averaging about 1 mm. It consists of subhedral zoned and twinned plagioclase (labradorite); anhedral orthoclase (about equal in amount to the plagioclase); subhedral biotite; and quartz. Accessory minerals include: sphene, iron-oxides (magnetite and ilmenite), and pyrite. Most of the minerals, except the accessory minerals and quartz, have been partly replaced by silica and altered to clay minerals. Along the borders of this dike are small, less than 1 to 3 inch, inclusions of rhyolite.

The age of the Princeton batholith is indicated on the geologic map of Colorado as Eocene (Burbank, et al, 1935). Crawford (1913, p. 75) refers to the Princeton batholith as "post-carboniferous" but states that is is probably "post-Cretaceous." In the Whitepine area, the youngest rock intruded by the Princeton quartz monzonite is the Belden shale of Pennsylvania age, and so it could only be proven to be post-Carboniferous in age. The relative age as determined in this area is: It is younger than the Belden shale and the rhyolite intrusive, and, as it cuts the Star and Morning Glim faults, is younger than the major period of faulting. It was intruded by rhyolite porphyry and quartz monzonite (or quartz latite) porphyry dikes, and is cut by many quartz-pyrite veins, and is, therefore, older than these.

Dikes

The dikes of the Whitepine area have been classified into two general groups: quartz monzonite and quartz latite porphyry dikes, and rhyolite and pitchstone porphyry dikes. The most common dikes are the quartz latite porphyry and rhyolite porphyry dikes.

The dikes are the youngest of the rocks of the area. They have intruded the pre-Cambrian Silver Plume granite, the Paleozoic sedimentary rocks, and the Princeton quartz monzonite. The quartz monzonite and quartz latite porphyry dikes have been arbitrarily assigned as older than the rhyolite and pitchstone porphyry dikes, on the assumption that the more basic dikes would be intruded first.

It is believed that the intrusion of the dikes was controlled by pre-existing faults.

Quartz Monzonite Porphyry and Quartz Latite Porphyry Dikes

Four dikes of quartz monzonite or quartz latite porphyry crop out in the mapped area (pl. 1). In addition, two dikes of this composition are exposed underground in the Akron tunnel (pl. 5). These dikes cut the Silver Plume granite, the Belden shale, and the Princeton quartz monzonite.

The largest of these dikes extends from near the southeastern limit of the mapped area (pl. 1) northeastward to the north slope of Lake Hill, where it rather abruptly turns westward and then northwestward. Mapping in adjacent areas (Crawford, pl. V, 1913; Dings and Robinson, pl. 1, in preparation) has shown that this dike crops out for about a mile south of the Whitepine area. The dike is well exposed where it crosses the top of Lake Hill, but on the north slope of Lake Hill and the northwestward extension of the dike towards the Eureka-Nest Egg group of mines, it was mapped primarily on the basis of float. To the north of this large dike, and probably connected with it at depth, is a small quartz latite porphyry dike about 300 feet long that trends northeasterly.

Crawford (1913, pl. V) mapped the large dike as a monzonite porphyry or quartz monzonite porphyry, but from the exposures in the Whitepine area, it would be better classified as a latite or quartz latite porphyry, as most of the dike has an aphanitic rather than a fine-grained groundmass.

The dike ranges in width from about 2 feet at its northern end to about 50 feet at the top of Lake Hill. The contacts were not well enough exposed to measure the dip accurately, but from its relation with the topography, it apparently dips from steeply east to vertical.

The texture and composition of the dike vary along and across the dike. The typical rock from near the center of the dike consists of a dark gray to gray-green aphanitic porphyritic rock. The phenocrysts, which make up about 40 percent by volume of the rock, consist of euhedral to subhedral plagioclase feldspar grains up to 10 mm. long, euhedral to subhedral potash feldspar up to 8 mm. long, subhedral biotite up to 2 mm. in diameter, subhedral hornblende up to 4 mm. long, and rare quartz grains up to 4 mm. in diameter.

In thin sections the potash feldspar was identified as orthoclase, some showing simple Carlsbad twinning. The plagioclase is oligoclase, and possibly some andesine, it is zoned and shows polysynthetic twinning. The plagioclase is usually in excess of orthoclase. All of the phenocrysts are partially crushed and corroded along their boundaries. Most of the minerals show some degree of alteration along fractures; particularly the biotite and hornblende.

The groundmass is almost equigranular and, depending upon the sample, the grains range in size from less than 0.1 to 1 mm. The grains are mostly feldspar and about equally divided between plagioclase and orthoclase. Quartz fills the interstices between the feldspar grains and, depending upon the specimen, ranges from less than 5 to about 20 percent. There is no apparent systematic variation in the amount of quartz, but rather there are local concentrations of quartz. By far, most of the dike contains less than 5 percent quartz and the dike would be properly classified as a latite porphyry.

The only accessory minerals noted in this dike were iron-oxides (magnetite and/or ilmenite) and pyrite.

The texture of the dike is much finer grained near its borders and the phenocrysts become less abundant. Samples from the contact show a glassy groundmass--glass comprising as much as 30 percent of the groundmass in some samples--and phenocrysts only of zoned plagioclase feldspar.

Near the top of Lake Hill at the center of the dike the average grain size of the groundmass would be about 1 mm. and the rock could be properly classed a monzonite rather than a latite. The minerals in the groundmass for most of the dikes, however, cannot be recognized in hand specimen and the dike as a whole should be classified as a latite, or a quartz latite porphyry.

The second largest dike of this group extends across the northern end of the mapped area. The southern end of it is at the northeastern limit of the mapped area about 500 feet southeast of the portal of the Morning Glim tunnel (pl. 1). It extends northwestward and westward to the small plug of Princeton quartz monzonite just east of Tomichi Creek.

In general, the exposures of this dike are poor. About 500 feet of this dike near its western end is covered by glacial moraine. The width and attitude of the dike are not known. The only good exposure of the dike is where the road to the Parole tunnel crosses the dike. Here the dike is about 25 feet wide and dips vertically to steeply west. The mapping is based on float and exposures in prospect pits.

Crawford (1913, pl. V) mapped this dike as a rhyolite or rhyolite porphyry dike, which it resembles megascopically because of alteration. Microscopic studies, however, show a high percentage of plagioclase feldspar, which would make the dike a quartz latite porphyry.

All samples of this dike showed considerable alteration and it was difficult to determine what the original minerals were. The typical hand specimen is a grayish-white, aphanitic to glassy, porphyritic rock, with the phenocrysts about 10 percent of the rock. The most abundant phenocrysts are of quartz, in euhedral to anhedral grains up to 8 mm. in diameter. The feldspar phenocrysts are about equally divided between potash and plagioclase feldspar. They range from 2 to 15 mm. in length with an average length of about 5 mm. A few biotite phenocrysts, up to 5 mm. in diameter, are present. Pyrite could be identified in all hand specimens.

In thin sections it was noted that all the minerals are fractured, partly replaced by quartz, and, except for quartz, partly altered. The potash feldspar phenocrysts tentatively identified in thin section as sanidine, but this identification was not positive as all crystals were partly altered. The plagioclase feldspar phenocrysts are apparently oligoclase with possibly some albite. All show zoning and most polysynthetic twinning. The biotite phenocrysts are almost completely colorless, and show very little pleochroism in thin section.

The groundmass is microcrystalline and consists of lathed shaped crystals imbayed by quartz, and with quartz filling interstices. The ratio of untwinned laths to polysynthetic twinned laths is about 3 to 2, and this is assumed to be the ratio of potash to plagioclase feldspar. Quartz comprises about 30 percent of the groundmass. The only accessory minerals identified were magnetite, and/or ilmenite, and pyrite.

The dike is apparently rather uniform in texture, composition, and alteration throughout its length, although exposures are so poor that the samples examined might not be representative of the whole dike.

In the vicinity of this dike are several ore bodies and the alteration is believed to be the result of the hydrothermal solutions that formed the ore deposits (see p. 128).

On the northwest slope of Porcupine Ridge, about 2,500 feet northeast of the town of Whitepine, are two caved prospect adits that, as indicated by the material on their dumps, were driven along the contact of a quartz latite porphyry dike and the Princeton quartz monzonite. The dike was completely covered by glacial material and was mapped entirely on the basis of the two adits. As a result, the width and attitude of this dike are not known.

This dike consists of a light-gray, aphanitic, porphyritic rock. The most abundant phenocrysts are of plagioclase feldspar; euhedral to subhedral grains up to 10 mm. long. Orthoclase phenocrysts are less abundant, subhedral, and up to 12 mm. long. Phenocrysts of biotite and quartz are relatively rare and range in diameter from 2 to 5 mm., the biotite is euhedral to subhedral, and the quartz anhedral.

In thin section the plagioclase phenocrysts were identified as labradorite with a few of oligoclase. All are zoned and show polysynthetic twinning. Around each crystal is a reaction rim of about 0.1 mm/ in width. The orthoclase phenocrysts also show reaction rims and a few show simple Carlsbad twins. The biotite phenocrysts are partly altered to chlorite and all are broken and bent. The quartz phenocrysts show a reaction rim with the groundmass.

The groundmass is microcrystalline and shows lath-shaped crystals of plagioclase and orthoclase feldspar and subhedral grains of biotite with the interstices filled with quartz. The accessory minerals are: magnetite and/or ilmenite, and pyrite.

In the Akron tunnel, about 1,220 and 1,480 feet east of the portal, are two quartz latite porphyry dikes. These are the only dikes of this composition exposed in the accessible underground workings of the Whitepine area.

These dikes range in width from 5 to 10 feet and they dip vertically or steeply northwest.

The dikes are composed of a dark gray-green aphanitic porphyritic rock with phenocrysts of plagioclase and potash feldspar, biotite, quartz, and epidote. The plagioclase phenocrysts are euhedral to subhedral and up to 10 mm. long. The potash feldspars are subhedral and up to 5 mm. long; the biotite is euhedral to anhedral and up to 3 mm. in diameter, the quartz is subhedral and up to 4 mm. in diameter; and the epidote is in granular and radiating fibrous masses up to 8 mm. in diameter.

In thin sections, the plagioclase feldspar phenocrysts were identified as labradorite. They are zoned, show polysynthetic twinning, and have reaction rims with the groundmass. The potash feldspar was identified as orthoclase. Some of the orthoclase crystals are surrounded by reaction rims. The epidote replaces biotite and plagioclase and is an alteration product of these two minerals. Accessory minerals include sphene, magnetite and/or ilmenite, and pyrite.

The groundmass is extremely fine grained, so fine grained that it was impossible to identify the constituent minerals. Apparently most of the groundmass is microlites with a little interstitial quartz and some isotropic material, probably glass.

The composition of all the quartz monzonite and quartz latite porphyry dikes is, except for later alteration, essentially the same. It is therefore assumed that they all were derived from the same parent magma, and are all of the same age.

Rhyolite Porphyry and Pitchstone Porphyry Dikes

Dikes of rhyolite porphyry and pitchstone porphyry are restricted to that part of the mapped area that is south of Galena Creek. They occur along and in the footwall of the Star fault, on the west slope of West Point Hill, and on the western and northern slopes of Lake Hill (pl. 1). Underground, dikes of this composition are exposed in the workings of the Akron mine (pls. 4, 6), Akron-Morning Star development drift (pl. 7), Morning Star mine (pl. 13), Tenderfoot mine (pl. 12), and the Victor mine (pl. 14). The dikes have intruded the Manitou dolomite, Fremont dolomite, Chaffee formation, Leadville limestone, Belden shale, and the Princeton quartz monzonite.

The dikes of this group are of particular interest as the ore bodies of the Akron, Morning Star, and Victor mines occur in the footwall of the Star fault where the fault zone has been intruded by rhyolite or pitchstone porphyry dikes.

All the dikes along the Star fault and adjacent to the fault in the footwall have the same textural and mineralogical characteristics and, therefore, will be discussed together.

As mapped, there are two separate dikes that intruded the Star fault. The southernmost dike was mapped, except locally where covered by mine dumps, from about 300 feet south of the portal of the Victor tunnel, to about 700 feet north of the Morning Star shaft (pl. 1). The northern 300 feet may not be continuous; the mapping is based on very poor float and a few pieces of pitchstone porphyry on the dump of the prospect shaft at the north end of the dike. The northernmost dike along the Star fault, starts in the footwall of the Star fault about 900 feet south of the portal of the Tenderfoot tunnel and about 200 feet west of the fault. It could be followed continuously to about opposite the portal of the Tenderfoot tunnel. North of this point, if present at the surface, it has been obscured by slope-wash and mine dumps. It was mapped, or shown on the surface map, on the basis of subsurface information and the presence of rhyolite porphyry in the dumps of workings along the fault.

The two dikes along the fault, and those in the footwall just west of the fault, are believed to be connected at depth. They all have the same textural and mineralogical characteristics and, as may be seen on the subsurfaces maps (plates 4, 6, 7, 12, 13, 14), the dikes along the fault have many branches.

The dikes range in width from less than 1 foot to as much as 95 feet (pls. 4, 13). In general, the dip of the dikes along the Star fault follows that of the fault, ranging from 40 to 80 degrees east. Locally, however, they may be vertical or dip steeply west.

The pitchstone porphyry and the rhyolite porphyry are just different textural varieties of the same chemical composition. The pitchstone occurs locally along the borders of the rhyolite dikes and the small dikes may be entirely pitchstone porphyry.

The typical rhyolite porphyry consists of a light- to dark-gray aphanitic porphyritic rock with phenocrysts of potash feldspar, plagioclase feldspar, biotite, and rarely quartz. In thin section, the potash feldspar phenocrysts were identified as sanidine with possibly some orthoclase. The sanidine is euhedral to subhedral and the crystals range from less than 0.1 to 5 mm. in length. A majority show simple Carlsbad twinning and some show zoning and reaction rims. As inclusions in the sanidine are grains of plagioclase, biotite, sphene, and apatite. Sanidine and/or orthoclase make up about 70 percent of the phenocrysts.

Biotite, which makes up about 15 percent of the phenocrysts, occurs as euhedral to anhedral crystals that range from less than 0.1 mm. to 4 mm. and average about 1 mm. in diameter. They have reaction rims with the groundmass and inclusions of magnetite (or ilmenite), sphene, and apatite. The plagioclase feldspar, about 10 percent of the phenocrysts, is oligoclase. It occurs in euhedral to subhedral grains of from less than 0.1 mm. to 3 mm. long. The crystals show polysynthetic twinning, zoning, reaction rims with the groundmass, and inclusions of biotite, sphene, apatite, and magnetite or ilmenite. Quartz phenocryst, on the average, are rare, usually less than 3 percent of the phenocrysts, but locally may be very abundant. The quartz is subhedral to anhedral, corroded, and with inclusions of sphene, apatite, and magnetite or ilmenite. They range in diameter from less than 0.1 mm. to as much as 5 mm. with an average of about 1 mm.

The groundmass is extremely microcrystalline to glassy. All samples showed some glass and in the average sample, glass constituted about 30 percent of the groundmass.

The pitchstone porphyry occurs locally along the contacts of the rhyolite porphyry dikes and makes up the entire mass of some of the smaller dikes. It does not occur along the contacts of all the rhyolite porphyry dikes; in fact, to find pitchstone porphyry at the contact is the exception. The masses of pitchstone range from 6 inches to 3 feet in thickness and are as much as 100 feet in length. These masses of pitchstone porphyry grade into the typical rhyolite porphyry.

The typical pitchstone porphyry is a dark gray-green to almost black, glassy rock. In hand specimen phenocrysts of feldspar, biotite, and a few grains of magnetite and pyrite may be recognized. In thin section, sanidine and possibly some orthoclase were identified. The sanidine crystals are euhedral to subhedral, from less than 1 mm/ to 4 mm/ long, many show simple Carlsbad twins, most are zoned, and the centers of many of the zoned crystals are corroded. The plagioclase feldspar phenocrysts are oligoclase. They are subhedral, from less than 1 to 3 mm/ long, polysynthetic twinned, and zoned. The biotite crystals are euhedral to anhedral and range from less than 1 mm/ to 4 mm/ in diameter. Quartz phenocrysts are rare. They are euhedral to anhedral, range from less than 1 to 2 mm/ in diameter, and many are embayed, showing reabsorption by the groundmass. Accessory minerals, in general less than 1 mm/ in diameter, include euhedral sphene, magnetite and/or ilmenite, pyrite, and apatite.

Most of the groundmass is isotropic but locally there are knots or bands of microcrystalline material composed of lath-shaped crystals and quartz.

The rhyolite porphyry and pitchstone porphyry dikes in the footwall of the Star fault are locally altered. This is particularly true where the dikes are along the Star fault and in the footwall adjacent to ore bodies. At all exposures, the dikes show some degree of alteration. It ranges from that in which only the phenocrysts are slightly altered to clay minerals to that in which the phenocrysts and groundmass are just a mass of clay and in which no minerals may be recognized.

On the western and northern slopes of Lake Hill is the largest rhyolite porphyry dike in the Whitepine area. It extends from the southern edge of the mapped area northward along the west side of Lake Hill to the north slope of Lake Hill where it abruptly turns southwest for about 1,100 feet and then abruptly turns north again (pl. 1). A small dike about 600 feet north of this large dike is believed to be connected with it at depth. These dikes range in width from less than 1 foot to 30 feet, and average about 20 feet wide. In general, the dikes are vertical or dip steeply east. Locally, however, they may dip steeply west.

To the northwest of these two dikes is another rhyolite porphyry dike about 500 feet long that trends northeast and dips steeply southeast.

These dikes differ slightly in mineral composition, principally by abundance of quartz phenocrysts, from those along and in the footwall of the Star fault.

The typical hand specimen is a dark grayish-white to grayish-green aphanitic porphyritic rock with conspicuous phenocrysts of quartz and feldspar. The quartz phenocryst, the most abundant phenocrysts, range from about 1 to 5 mm/ in diameter, are euhedral to anhedral, and are corroded. The feldspar phenocrysts are euhedral to subhedral and are from less than 1 to 6 mm/ long. Also recognizable in hand specimen are a few phenocrysts of biotite, up to 3 mm. in diameter, and oxidized cubes of pyrite, up to 4 mm.

in diameter.

In thin section, it may be seen that the quartz phenocrysts are cracked and have many liquid inclusions. They are embayed by the groundmass and around each is a reaction rim. The feldspar phenocrysts are both potash and plagioclase feldspar. The potash feldspar phenocrystsare sanidine, and show zonal structure and have a reaction rim around them. The plagioclase feldspars, labradorite and oligoclase, are polysynthetic twinned and have a reaction rim around them. The biotite phenocrysts are bent and broken and nearly completely altered to chlorite. Accessory minerals include magnetite and/or ilmenite and pyrite.

The groundmass consists of microcrystalline lath-shaped crystals, with parallel extinction, with interstices filled with quartz. In most specimens, some glass is present.

All specimens examined showed some degree of alteration. All the feldspars show dusty surfaces and some are completely altered to clay. Most of the biotite is chloritized, and there has been some secondary silicification. Most of the pyrite grains are oxidized but, as all samples came from the surface, this may be the result of weathering.

The dikes are much finer grained near their contacts and locally pitchstone may be present. This is particularly true of the two small dikes north of the large dike. The pitchstone porphyry has essentially the same composition as the rhyolite porphyry; at least, the phenocrysts are the same. The only apparent difference is the groundmass, which consists mostly of glass.

Two rhyolite porphyry dikes of slightly different mineral composition occur in the Whitepine area. Both are in the Princeton quartz monzonite; one on the south slope and one on the west slope of West Point Hill. Crawford (1913, pl. V) mapped one of these --the one on the west slope of West Point Hill--as a latite dike but on the basis of the specimens examined by the author, this dike is probably a rhyolite porphyry.

These two dikes have essentially the same composition. In hand specimen they are light to dark grayish-white aphanitic porphyritic rocks with phenocryst of feldspar, quartz, and biotite.

In thin section, most of the feldspar phenocrysts were identified as sanidine. These are euhedral to subhedral, less than 1 to 2 mm. long. Some show simple Carlsbad twins, reaction rims, and a few are zoned. Plagioclase feldspar phenocrysts are rare. They were identified as oligoclase, and they show polysynthetic twinning, and reaction rims. Quartz phenocrysts are more abundant than the plagioclase but less abundant than sanidine. The quartz is subhedral to anhedral and in grains of less than 1 mm. The biotite phenocrysts, in subhedral crystals up to 2 mm. in diamter, are bent and broken. Accessory minerals include magnetite and/or ilmenite, sphene, and small (less than 1 mm.) cubes of pyrite.

The groundmass is micro-crystalline and so fine-grained that no minerals could be identified. Apparently it consists of feldspar microlites with interstitial quartz.

The rhyolite and pitchstone porphyry dikes are considered to be the youngest of the igneous rocks of the area. They can only be proven to be younger than the Princeton quartz monzonite. They are arbitrarily assigned as younger than the quartz monzonite porphyry and quartz latite porphyry dikes on the assumption that the more basic dikes would be intruded first.

Origin and Age of Tertiary Intrusive Rocks

The Whitepine area is too small an area to be considered alone in determining the origin and age of the intrusive rocks. Crawford (1924), in a study of the igneous geology of central Colorado, and Dings and Robinson (in preparation), in their study of the Garfield quadrangle, Colorado, have postulated certain ideas as to the origin and age of the igneous rocks of central Colorado, which includes those of the Whitepine area. A brief summary of their ideas, and the evidence for them, follows:

Crawford (1924) noted the similarity in age and composition between the various quartz monzonite bodies in central Colorado that occur in a belt about 50 miles long extending from the Monarch and Tomichi districts, Chaffee and Gunnison Counties, on the south to the Montazuma district, Summit County, on the north. He postulated that these quartz monzonites are apophyses of a large quartz monzonite batholith that underlies this region. In support of this idea he showed that other intrusives, ranging in composition from quartz diorite to granite, had the same relative age to the quartz monzonites and to the structures in the various districts. It was therefore logical to assume that the intrusives belonged to the same petrographic province and were of the same ultimate origin, that is, the magma of the underlying batholith.

Dings and Robinson (in preparation) mapped in the Garfield quadrangle nine distinctive intrusive rock types, not including dikes. These, when arranged in order of relative age, fall into three groups; in each group the rocks range from an older rock of intermediate or basic composition to a younger rock of granite, rhyolite, or quartz monzonite. The names of these rock types, and their composition are, in order of age from oldest to youngest: (1) Quartz diorite porphyry; (2) Tincup quartz monzonite porphyry; (3) Rhyolite (of Whitepine area); (4) Quartz diorite; (5) Gneissic quartz monzonite; (6) Mt. Pomeroy quartz monzonite; (7) Andesite; (8) Princeton quartz monzonite (in Whitepine area); and (9) Mt. Antero granite.

Assuming, as Crawford postulated, that the parent magma for all these rocks was that of an underlying batholith, then it is necessary to explain the three series. Dings and Robinson propose that part of the magma of the underlying batholith was separated from it, probably as a result of early tectonic movement, and that differentiation took place in one or more magma reservoirs independent of the main batholith, and so gave rise to the three series. If it is assumed that there were three magma reservoirs, then it is proposed that they were probably separated from magma of the underlying batholith at succeeding times, in order of relative ages of the three groups. As possible evidence for this, it was noted that some of the intrusives were emplaced both before-- as the rhyolite of the Whitepine area--and after two major periods of faulting, and that the Princeton quartz monzonite (the largest of the intrusives) followed the most intense period of faulting--the period of faulting during which the Star and Morning Glim faults of the Whitepine area were formed.

If it is assumed that there was but one magma reservoir, then it can be postulated that the three series were formed by differentiation and that part of the partially crystallized magma was removed, or allowed to escape during periods of tectonic movement. In such a reservoir, differentiation by crystal settling, as proposed by Bowen (1928), and later filter pressing, as proposed by Harker (1909, p. 323), could have occurred several times, and so given rise to the three series.

The dikes of the Whitepine area are similar in composition, texture, and age to other dikes found distributed throughout the Garfield quadrangle. All are, as far as could be determined, younger than the Princeton quartz monzonite. Because of their uniform characteristics and their wide distribution they are assumed to be related to the magma that formed the Princeton batholith.

As previously mentioned (p. 62), the dikes of quartz monzonite or quartz latite porphyry are assumed to be older than those of rhyolite or pitchstone porphyry. This assumption is based entirely on their composition. In normal differentiation of a magma (Bowen, 1928), the more basic constituents separate first, which might have furnished the magma for the quartz monzonite and quartz latite porphyries, and the more acidic constituents later, which might have furnished material for the rhyolite and pitchstone porphyry dikes.

The geologic age of the intrusive rocks could not be determined in the Whitepine area, nor from evidence in the surrounding area. The Princeton quartz monzonite intruded the Belden shale of Pennsylvanian age and so can only be proven to be of post-Pennsylvanian age. The rocks, however, are undoubtedly of Tertiary age because of their similarity to other rocks of proven Tertiary age (Emmons, 1894; Cross and Larsen, 1935; Burbank et al, 1935; Vanderwilt, 1937, pl. 1).

Dings and Robinson (in preparation) tentatively assigned the ages from Paleocene to Oligocene to the Tertiary intrusives of the Garfield Quadrangle. This age designation was based on the fact that considerable time was required for the emplacement of the intrusives as shown by the fact that some preceded and others followed major periods of tectonic movement and, if the assumption that the three series of rocks were derived by differentiation is accepted, then time must be allowed for differentiation to take place.

To the north of Whitepine about 5 miles at the head of Tomichi Creek, are two types of extrusive rhyolitic breccias. These were assigned to the Miocene by Dings and Robinson because, as pointed out be Crawford (1913, p. 75-76), they were erupted after erosion had removed much of the probable thick cover of the intrusive rocks, and because the Miocene epoch elsewhere in Colorado (Cross and Larsen, 1935, p. 50-54) was characterized by extensive flows and volcanic breccias. This evidence then would indicate that the youngest of the intrusive rocks was possibly Oligocene.

QUATERNARY DEPOSITS

The Quaternary deposits of the Whitepine area are glacial and fluvial deposits. The fluvial material is thin and is principally reworked glacial material. No effort was made to map the fluvial material separately from the glacial material.

Glacial material, primarily ground moraine, occurs in the valley of Tomichi and Galena Creeks and high on Porcupine ridge. The morainal material is thickest in Tomichi Creek valley. The maximum thickness is not known but bull-dozing in the Tomichi Creek valley indicates that at least 20 feet of material is present. The material thins on the sides of the valleys and on Porcupine ridge is estimated to be, on the average, about 2 feet thick, locally completely thinning out. In mapping, preference was given to the bedrock rather than the surficial geology, where the nature of the bedrock could be determined with a fair degree of accuracy. For this reason, several local patches of morainal or fluvial material were not shown on the geologic map (plate 1).

The glacier that was responsible for these deposits headed about five miles north of Whitepine, at the headwaters of Tomichi Creek, and terminated about two and a half miles southwest of Whitepine. The glacier is believed to have buried all the area at altitudes of less than 11,000 feet, which includes all the area except the top of Lake Hill.

The morainal material consists of unsorted rock fragments ranging from boulders several feet in diameter to the finest rock flour. Locally, especially along the present stream channels this material has been reworked, and the finer material removed.

In the Tomichi district there is evidence of only one period of glaciation. Dings and Robinson (in preparation), Crawford (1913, p. 34) and Behre (1933) have found evidence in adjacent areas indicating that there were at least two periods of glaciation. The one in evidence in the Tomichi district is believed to represent the latest or Wisconsin stage of glaciation.

STRUCTURE

The Whitepine area is the western limb of a northward-plunging syncline that subsequent to the folding, was faulted. Small folds are superimposed on the syncline and some of the smaller folds are drag folds related to the period of faulting. Bedding-plane faults developed during folding but most of the faults are related to the major period of faulting that followed the folding, and that formed the Morning Glim and Star faults. The faults served as channels for the Tertiary intrusives and for the ore-bearing solutions. There was some minor faulting following the intrusion of the igneous rocks and the formation of the ore deposits.

Folds

The sedimentary rocks of the Whitepine area form the west limb of a gently northward-plunging syncline, the axis of which was east of the Whitepine area and, since folding, has been obliterated by the Morning Glim fault. Minor folds were developed on this limb of the syncline at the time it was formed and some, in particular where the beds are overturned, as the result of the later major period of faulting. In general, the beds dip from 15 to 50 degrees east and the change in dips are gradual (pl. 1).

In the North Star and Tenderfoot mines (pls. 11, 12) are exposed a minor anticline and complimentary syncline. Ore was deposited along the base of the Manitou dolomite. The maps of these mines (pls. 11, 12) show that the dips of the limbs of the folds range from 15 to 60 degrees and that the folds plunge northeastward from about 30 to 50 degrees. It could not be determined whether these folds were the result of the period of folding that formed the Whitepine syncline or were the result of drag during the major period of faulting that formed the Star fault, just to the east of the folds.

Locally along the Star and Morning Glim faults, the beds dip steeply east and at several points are overturned. The best example of the overturning of the beds as a result of the faulting may be seen on the ridge about 700 feet east of the Erie tunnel. Within this 700 feet the beds change in dip from 30 degrees east to 80 degrees east, and then 80 degrees west. As the Morning Glim fault is just east of this ridge, it is probable that the overturning was the result of faulting.

Faults

In the Whitepine area are two major faults: the Morning Glim and Star faults, and numerous associated minor faults. The Morning Glim and Star faults have been the chief structural control for the emplacement of intrusives and the formation of ore deposits.

Morning Glim fault. The Morning Glim fault extends from the southeastern to the northern end of the mapped area. Dings and Robinson (in preparation, pl. 1) and Crawford (1913, pl. II) show that this fault extends southeast of the Whitepine area about three-fourths of a mile, where both the foot and hanging walls are pre-Cambrian granite and the fault can be traced no farther. At its north end the fault has been cut off by the Princeton quartz monzonite.

Dings and Robinson (in preparation) believe that the Morning Glim fault is just an extension of the Tincup fault, having been cut off from the Tincup fault by the intrusion of the Princeton batholith. About 8½ miles of Princeton quartz monzonite separate the southern end of the Tincup fault from the northern end of the Morning Glim fault. The Tincup fault, named for the town of Tincup, Colorado, was first described by Stark (1934, p. 1004-1007).

At no place within the Whitepine area was the fault exposed and so the exact attitude and the character of the fault zone, or surface, could not be determined. The fault zone is commonly marked at the surface by a zone of silicified and iron-stained country rock, in places as much as 200 feet wide. At its southeastern end Dings and Robinson (in preparation) report that the fault dips 55°N.E. In the Whitepine area the fault has an average N. 30°W. trend and from the relation of the trend to the topography dips apparently steeply northeast. Locally, however, as where the fault crosses Galena Creek, it dips steeply west.

The displacement along this fault cannot be determined as there is no stratigraphic horizon east of the fault. The vertical displacement is equal to at least the total thickness of the Paleozoic section west of the fault (about 1,450 feet) as the pre-Cambrian granite has been thrust over this section. If it is assumed that the base of the Sawatch quartzite was at least as high as the Continental Divide (altitude about 12,250 feet) east of the Whitepine area the vertical displacement was at least 3,500 feet. Dings and Robinson (in preparation) determined that the minimum throw on the Tincup fault was at least 3,200 feet and the dip slip was about 10,500 feet. They believe that these figures are much too low.

Star fault. The Star fault extends from Spring Creek on the south, northward across West Point Hill past the old town of North Star to the top of Porcupine Ridge. At the south end it is cut off by a tongue of Princeton quartz monzonite whose eastern contact would about follow the projection of the fault. South of Spring Creek is a shear zone in the Silver Plume granite that is probably a continuation of the Star fault, but, as both sides of the fault are Silver Plume granite and this country is heavily timbered, no displacement could be determined. The north end of the fault on Porcupine Ridge is covered by glacial moraine but it is believed that the Princeton quartz monzonite cuts off this end of the fault only a few hundred feet north of where it was last observed.

Crawford (1913, pl. V) mapped the Star fault as swinging east of the North Star mine and ending in the "Garfield formation" (Belden shale of this report) south of Galena Creek. The underground workings of the Akron, North Star and Erie mines were not accessible to Crawford so this mistake is understandable.

The Star fault is not well exposed at the surface and much of the fault, or fault zone, has been intruded by rhyolite and pitchstone porphyry dikes. Underground the fault is exposed by the workings of the Akron, Morning Star, Victor and Tenderfoot mines. From the maps of these mines, plates 3, 4, 5, 6, 7, 12, 13, and 14, it may be seen that in general this fault strikes from north to northwesterly and dips from 30° to 80° E. Locally, however, the fault may strike northeasterly and it may dip steeply west.

The fault zone ranges in width from a few inches to as much as 110 feet. On the Akron level of the Akron mine (pl. 4) the Akron tunnel cuts the fault zone, which here consists of about 110 feet of breccia and gouge containing about 90 feet of altered rhyolite porphyry. At the south end of the Akron level the fault is about a 40-foot zone of breccia of Manitou dolomite in clay gouge. On the 250 level of the Akron mine (pl. 6) the fault is believed to be represented by a 2 to 6 inch gouge seam. Near the south end of the fault in the lower Morning Star tunnel (pl. 13) the fault zone is about 110 feet wide. The western 100 feet of this zone has been filled by a rhyolite porphyry dike. The eastern 10 feet consists of brecciated, silicified, and locally mineralized limestone and dolomite marble in a clay gouge.

At no place, either at the surface or underground, could the displacement along the Star fault be determined. At the north end of the fault on the surface and in the Akron mine the Manitou dolomite was thrust over the rhyolite intrusive. South of Galena Creek, at the surface, and in the Akron mine (pl. 4) just north and south of the Akron tunnel, Manitou dolomite on the hanging wall is in contact with Manitou dolomite on the foot wall. No stratigraphic horizon could be identified on either side of the fault so the displacement could not be measured, but the maximum vertical displacement could not be more than 240 feet; the approximate thickness of the Manitou dolomite. Near the south end of the fault, on West Point Hill, the pre-Cambrian Silver Plume granite has been thrust over the Mississippian Leadville limestone, a minimum vertical displacement of about 700 feet. If the Sawatch quartzite on the hanging wall of the fault and the fault are projected to their intersection (pl. 1, section B-B'), the vertical displacement of the fault at this point would be about 1,200 feet. The vertical displacement south of this point would be even greater.

The Star fault, prior to the intrusion of the Princeton batholith, probably joined the Morning Glim fault and was a branch of this fault formed at the same time.

Other faults. Throughout the Whitepine area are many small faults, most of which were too small to show on the surface map but many of which are shown on the maps of the underground workings.

On West Point Hill, near its western end, are two faults that have displaced the Silver Plume granite, Sawatch quartzite, Manitou dolomite, Harding quartzite and part of the Fremont dolomite. The two faults are about 180 feet apart and strike a little north of west. The dip could not be determined but, from the relation of the faults to the topography, must be about vertical. The east ends of these faults do not reach the contact of the Fremont dolomite and Chaffee formation so it must be assumed that the faults die out or join short of this contact. The west end of faults could not be followed for any distance into the Silver Plume granite.

The components of movement along these faults could not be accurately determined. Along the northern fault, the Sawatch quartzite has been displaced about 100 feet and the Harding quartzite about 170 feet west. Along the southern fault, the Sawatch quartzite has been displaced about 80 feet and the Harding quartzite about 110 feet west.

Part of this apparent horizontal displacement is due to the dip of the beds, which is apparently greater in the block between the two faults. South of the faults, the Manitou dolomite dips 65° E. and the outcrop width is about 110 feet. North of the faults the dip was not determined but the outcrop width of the Manitou dolomite is about 190 feet; between the two faults the outcrop width is about 90 feet. The dip of the Manitou dolomite between the faults must then be greater than that on either side.

From the apparent horizontal displacement, and the widths of the outcrops, it is apparent that the displacement along the northern fault must have been greater than that along the southern fault.

Throughout the mines are numerous minor faults (pls. 4, 5, 6, 7, 10, 11, 12, and 13). Most of these faults parallel in both strike and dip the major faults. In general they strike northerly and dip from 50 to 90° east or west. They are from 1 inch to 2 feet wide and contain gouge and breccia, and are locally mineralized. In the Princeton quartz monzonite the minor faults are commonly filled with quartz and the walls silicified. The minor faults in the sedimentary rocks are usually barren, unless near an ore body. The mineralized ones may contain galena, sphalerite, pyrite and chalcopyrite. The displacement along these minor faults could not be measured, but is believed to be small.

Bedding plane faults are found throughout the area, both at the surface and underground. They range from 1 to 3 feet in width and are usually filled with gouge and breccia. Locally, as in the North Star (pl. 11) and Tenderfoot (pl. 12) mines they may be mineralized. As with the other minor faults, the displacement along these faults could not be determined and is believed to be small.

Structural Control of Emplacement of Intrusive Rocks

The intrusion of igneous rocks in the Whitepine area, and surrounding areas, was, in part, controlled by pre-intrusive faults. The most obvious proof of this are the rhyolite and pitchstone porphyry dikes that have intruded the Star fault.

No structural control for the intrusion of the rhyolite could be determined. Possibly there was none as this intrusive preceded the major period of folding and faulting. The emplacement of the next oldest intrusive, however, the Princeton quartz monzonite, was locally controlled by pre-existing faults. North of Spring Creek the east contact of a tongue of Princeton quartz monzonite approximately follows the southward projection of the Star fault. As previously mentioned (p. 84), northwest of the Whitepine area about 3½ miles [of] the Tincup-Morning Glim fault has been obliterated by the Princeton batholith. This fault, which has a large displacement and along which bordering rocks were probably shattered over a considerable distance, was an easy conduit for the magma that formed the Princeton batholith.

Beside the obvious example of the rhyolite and pitchstone porphyry dikes that intruded the Star fault, it is believed that the emplacement of the other dikes of the Whitepine area was controlled by pre-existing faults. The dikes in the footwall of the Star fault, adjacent to the fault, essentially parallel the fault and were probably intruded along minor faults formed at the time the Star fault was formed.

On Lake Hill are two dikes, one of rhyolite and pitchstone porphyry and the other of quartz monzonite and quartz latite porphyry, that probably intruded along faults of small displacement related to the Star and Morning Glim faults. The shape of the rhyolite porphyry is particularly suggestive that the dike intruded along faults. The dike trends northerly across the west side of Lake Hill and then abruptly turns southwesterly for about 1,000 feet and then just as abruptly turns northerly again. This dike resembles one that might have intruded along a fault parallel to the Morning Glim and Star faults until it came to a gash fault, which it then followed until it came to another fault parallel to the Morning Glim and Star faults. The quartz monzonite dike on Lake Hill at its south end does not parallel one of the major faults. The north end, however, turns abruptly and parallels the Morning Glim fault.

The emplacement of the quartz latite dike at the north end of the area was probably controlled by faults related to the Morning Glim fault. This dike at its south end trends northwesterly and, just after it crosses the Morning Glim fault, abruptly turns parallel to this fault. Within 800 feet it again turns abruptly northwesterly. The shape of this dike would indicate that at either end it was intruded along gash faults and in the center along a minor fault parallel to the Morning Glim fault.

SUMMARY OF THE AGES OF FOLDING, FAULTING, AND INTRUSIVE ACTIVITY

There were three major periods of intrusive activity and two periods of deformation in the Whitepine area.

The oldest intrusive rock is the rhyolite west of the Star fault and this intrusive is older than the major period of faulting as it is cut by the Star fault (pl. 1). Whether this rock was intruded prior to or accompanied the folding could not be determined but, because it is so highly fractured it must have been subjected to considerable stress, so is believed to have been emplaced prior to the folding.

Folding preceded the period of major faulting as the syncline of the Whitepine area is cut by the Morning Glim and Star faults. Undoubtedly some minor faults, such as the bedding-plane faults, were formed during folding.

The major period of faulting followed the period of folding. During this period the Morning Glim and Star faults were formed and probably most of the minor faults. Some minor drag folding and possibly the overturning of some of the beds were the result of the formation of the major faults.

The Princeton batholith was intruded following the major period of faulting and its emplacement was in part controlled by the pre-existing faults. As the batholith cooled and contracted, small fractures probably developed in the cooled outer shell. This probably was the origin for some of the small fractures observed in the Princeton quartz monzonite.

After the Princeton batholith was at least partly cooled, dikes of latite composition and probably shortly after, dikes of rhyolite composition were intruded along pre-existing faults.

Subsequent to the intrusion of the dikes and the formation of the ore bodies, there was some minor faulting, much of it repeated movement along pre-existing faults. In the Akron and Morning Star mines (pls. 4, 6, 7, and 13) gouge and breccia were observed along the contacts of the rhyolite porphyry dikes. One fault was observed on the 75 level of the Akron mine (pl. 6) that offset the contact of a rhyolite dike. Numerous small faults offset the contacts of the ore bodies, the best example of which may be seen at the number 4 level of the Erie mine (pl. 10) about 720 feet south of the portal.

The geologic age of these periods of intrusion, folding and faulting could not be determined. They were undoubtedly associated with the Laramide Revolution, which is believed to have started in late Cretaceous time and extended well into the Tertiary period. As discussed nder the origin and age of intrusive rocks (p. 80), the intrusives are believed to have been emplaced between the Paleocene and Oligocene epochs and as the major periods of folding and faulting were preceded and followed by intrusive activity, they would fall within the same time period.

METAMORPHISM

The metamorphism of the rocks of the Whitepine area is the result of the intrusion of the Princeton quartz monzonite batholith. At several places around this batholith the sedimentary rocks within half a mile, and sometimes as much as one and a half miles, have been recrystallized and in many, particularly the limestones and dolomites, typical contact metamorphic minerals as garnet, diopside, tremolite, epidote, etc., have developed. The Whitepine area is just one of several areas of sedimentary rocks that show the effects of contact metamorphism.

For convenience, the discussion of the metamorphism will be divided into four parts: the physical changes, a description of the metamorphic minerals and their occurrence, origin of the metamorphic minerals, and metamorphic differentiation.

Physical Changes

The principal effect of the metamorphism in the Whitepine area has been the recrystallization of the limestones and dolomites to marbles. To lesser extent, the quartzites have been recrystallized and the shales altered to argillite. The marbles range from fine- to coarse-grained; medium- to coarse-grained varieties being the most abundant. The quartzites are extremely hard and it was noted in thin sections that there has been secondary growths of quartz around the quartz grains. The shales range from only slightly baked shale to dense argillites.

The recrystallization of the carbonate rocks was, in part, controlled by their structural and stratigraphic positions. South of Porcupine Ridge all the carbonate rocks except the limestones of the Beldon shale have been recrystallized; the limestones of the Belden shale show little or no effects of metamorphism. North of Porcupine Ridge, however, all the carbonate rocks, including the limestones of the Belden shale, have been recrystallized. The reason for this is believed to be that south of Porcupine Ridge the basal units of the Belden shale are quartzites and shales that acted as a thermal blanket protecting the overlying limestones from the heat of the Princeton batholith, which is to the west--the opposite direction to the dip of the beds--and probably at depth. To the north of Porcupine Ridge the basal quartzites and shales are very thin or absent, and the Princeton quartz monzonite has directly intruded the limestones of the Belden shale.

The different stratigraphic units do not all show the same degree of recrystallization, nor is the recrystallization the same within a single stratigraphic unit. In general, the Fremont dolomite and the Leadville limestone are coarser grained than are the Manitou dolomite and the Chaffee formation. It has been impossible to explain this, possibly because the original composition of the formations could not be determined. Harker's contention (1939, p. 77) that dolomite marble is usually finer grained than limestone marble does not seem to hold here. There is as much variation in grain size within each of the carbonate units as there is between units. This could not be the result of differences in original composition as, in general, carbonate rock of a single unit have a uniform composition over large areas. The variation in grain size must be the result of differences in thermal conditions, the factors controlling which cannot be observed now, either because they are buried, or have been removed by erosion.

Metamorphic Minerals and Their Occurrence

Minerals that developed as the result of the contact metamorphism are common throughout the Whitepine area. They are most abundant in the carbonate rocks, particularly along certain zones, as the top of the Leadville limestone and just west of the Star fault. The following is a list of the metamorphic minerals, their composition, and a brief description of them and their occurrence.

Diopside $(CaMg(SiO_3)_2$[3/] Diopside is common in the marbles and in the basal quartzites of the Belden formation. It usually occurs as isolated, fine grains. On West Point Hill, however, northwest of the Victor mine is a large mass of diopside in the Leadville limestone. This mass ranges from 2 to 6 feet thick and is about 20 feet long. The diopside is gray to grayish-green and fine-grained. The mass is veined by coarsely crystalline calcite and serpentine. Admixed with the diopside are small books of phlogopite about one quarter inch in diameter. Northeast of the West Point tunnel, about 600 feet, on the dumps of two prospect adits, and in the float on the hill above these adits, diopside,

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3/ Chemical composition of metamorphic minerals from: Dana, E.S., and Ford, W. E., 1932, A Textbook of Mineralogy: Fourth edition, John Wiley & Sons, New York, N.Y.

similar to that northwest of the Victor mine, is associated with phlogopite, muscovite, orthoclase, and quartz in the Manitou dolomite. In the Erie mine the ore minerals are in a diopside-epidote-garnet rock formed from the Leadville limestone. The diopside and epidote at this mine are very fine-grained and form a dense dark green to greenish-gray rock that encloses coarse grained masses of garnet, magnetite, sphalerite, galena, pyrite, and chalcopyrite.

Epidote ($H\ Ca_2(Al,\ Fe)_3\ Si_3O_{13}$). Small yellowish-green and green grains of epidote are found locally throughout the area but it is most common at the top of the Leadville limestone and in the basal quartzites of the Belden shale in the Erie mine and Congress tunnel. Here it is associated with diopside and garnet in a dense, fine-grained, dark-green to greenish-gray rock.

Garnet, variety andradite ($3CaO.Fe_2O_3.3SiO_2$). Garnet occurs with diopside, epidote, magnetite, and the ore minerals in the Erie mine and with serpentine, tremolite, and magnetite in the Iron King mine. In the Erie mine it is in the Leadville limestone and basal quartzite of the Belden shale. At the Iron King mine, in the limestones of the Belden shale. The andradite is dark brownish-red to dark brown, coarse-grained, and massive. The masses of andradite range from less than 1 inch to 10 inches in diameter.

Magnetite ($FeO.Fe_2O_3$). Magnetite is associated with diopside, epidote, garnet and the ore minerals in the Erie mine and Congress tunnel, and with serpentine and tremolite in the Iron King mine, and in prospects north and south of the Iron King mine along the Morning Glim fault. It is in the Leadville limestone and the quartzites of the Belden shale at the Erie mine and Congress tunnel, and in the limestones of the Belden shale of the Iron King mine. It is black, coarse-grained and massive. Masses of magnetite several feet in diameter were reported (Crawford, 1913, p. 305) to have been mined in the Iron King mine.

Muscovite ($(H,K) AlSiO_4$). Muscovite is found associated with diopside, phlogopite, orthoclase, and quartz on the dumps of two small prospect adits in the Manitou dolomite about 600 feet northeast of the West Point tunnel. The workings, as judged from the dumps, of these adits were not extensive enough to have reached the pre-Cambrian granite. The muscovite is grayish-white and coarse-grained. The "books" range from less than ½-inch to 3 inches in diameter. They are imbedded with the orthoclase and quartz in what is apparently a highly altered limestone marble.

Orthoclase ($KAlSi_3O_8$). Orthoclase occurs with diopside, phlogopite, muscovite, and quartz in the Manitou dolomite on the dumps of two prospect pits about 600 feet northeast of the West Point tunnel. The orthoclase is pink and coarsely crystalline with the crystals ranging from less than 1 to 4 inches in length. The crystals are imbedded in quartz and limestone marble.

Phlogopite ($H_2KMg_3Al(SiO_2)_3$). Phlogopite associated with diopside and serpentine is found in the Leadville limestone northwest of the Victor mine and in the Manitou dolomite, northeast of the West Point tunnel, where it is associated with diopside, muscovite, orthoclase, and quartz. The phlogopite is pale greenish-white and in small euhedral to subhedral books that range from 1 to 4 mm. in diameter. It also was found in altered Silver Plume granite on the dump of the West Point tunnel.

Serpentine ($H_4Mg_3Si_2O_9$). Serpentine marble is found throughout the area as streaks or bands in the limestone and dolomite marbles. The percentage of serpentine varies considerably in these marbles. Large masses of serpentine, several feet in diameter, are associated with the magnetite deposits along the Morning Glim fault and particularly in the Iron King mine.

Tremolite ($Ca_2Mg_5(OH)_2(Si_4O_{11})_2$). Tremolite in streaks and bands is common in the entire area. Some tremolite will be found on nearly any of the dumps of the prospect pits in the carbonate rocks. In the vicinity of the David H. mine, tremolite in pale yellowish- to greenish-white, long-bladed, radiating crystal aggragates are common in the Leadville limestone. In the vicinity of the Iron King mine the tremolite is associated with serpentine and magnetite. Here it is fine-grained and massive.

Origin of the Metamorphic Minerals

The metamorphic minerals in the sedimentary rocks are believed to have been formed by reaction between solutions derived from the Princeton batholith and the country rock. Although the origin of these minerals is discussed separately from that of the ore minerals (p. 137), it is believed that the formation of the metamorphic minerals and the ore minerals were just different steps in a continuous process--that is, the metamorphic minerals were formed first from solutions derived from the Princeton batholith and that with time the composition of these solutions changed and at a later time deposited the ore minerals. The formation of metamorphic minerals under these conditions is commonly termed metasomatism.

Metasomatism was defined by Lindgren (1933, p. 91) as: "The process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate." As so broadly defined, metasomatism in metamorphism could apply to the reactions that take place in a closed system where the chemical constituents of a rock adjust to the change in temperature and pressure conditions to form new minerals in equilibrium under these conditions, or to the reactions between the minerals of the rock and solutions, either gaseous or liquid, that emanate from an intrusive body. In general, modern usage (Turner, 1948, p. 109-114) has restricted metasomatism to the reactions between the minerals in a rock and introduced solutions.

Following the intrusion of an igneous body and during the later stages of its crystallization, solutions of high temperatures and pressures are driven off into the surrounding rocks. These solutions contain some of the chemical constituents of the igneous body and are often enriched in constituents that the igneous mass is poor in (Turner, 1948, p. 110). These solutions are generally believed to be liquids (hydrothermal metasomatism) but under conditions of high temperature and low pressure might be gaseous (pneumatolytic metasomatism). These solutions will penetrate the country rock surrounding the igneous body--where available, following lines of least resistance as faults, joints, bedding planes, etc.--and the active constituents of the solutions will react with the minerals of the country rock forming what have become known as "skarn" or typical "contact metamorphic minerals."

Some of the contact metamorphic minerals in the Whitepine area could have formed (and some undoubtedly did) by the reactinn between minerals already present in the rock as a result of an increase in temperature and pressure without the addition of material by solutions. Such minerals, as diopside, tremolite, epidote, and serpentine, could have formed by the reaction between the limestone and dolomite with impurities as silica, alumina, and iron, which would be present in the sedimentary rocks, with only the expulsion of carbon dioxide. These minerals, however, are most abundant along structures that would have given access to solutions and in most cases are associated with such minerals as phlogopite, garnet, and magnetite, which could only have been formed by the addition of materials by solutions, and are therefore believed to have been formed, for the most part, by hydrothermal or pneumatolytic metasomatism.

The principal areas in which metasomatism has taken place are around the Erie mine, the Iron King mine, northwest of the Victor mine, and the area around the two prospect pits about 600 feet northeast of the West Point tunnel.

Around the Erie mine, the upper part of the Leadville limestone, for as much as 40 feet below its contact with the Belden shale, has been changed to a diopside-epidote-garnet rock that contains masses of magnetite. The diopside and epidote could have been formed by the reaction of the limestone and dolomite with impurities that are normally present in such a rock. The garnet and magnetite, however, contain a high percentage of iron, which could only have been introduced. Garnet, the variety grossularite ($3CaO.Al_2O_3.3SiO_2$), is common in metamorphosed limestones but the variety andradite ($3CaO.Fe_2O_3.3SiO_2$), which is found in the Whitepine area, is less common, principally because of the presence of iron, which is not ordinarily present in limestones. It is believed that the iron to form andradite was derived from the solutions.

Studies of thin and polished sections from the Erie mine, indicate that the diopside and epidote formed first, followed by the formation of andradite, and that the magnetite formed last. This sequence would indicate that solutions with time became richer in iron.

In the area of the Iron King mine, and along the Morning Glim fault north and south of this mine, are masses of magnetite in a gangue consisting principally of tremolite. The tremolite could have formed from constituents present in the limestones of the Belden shale. The magnetite could only have been formed by hydrothermal or pneumatolytic metasomatism.

The area northwest of the Victor mine, where the Leadville limestone has been altered to a diopside-phlogopite rock, the diopside could have formed from the constituents present in the Leadville limestone but the phlogopite, which contains potassium and aluminum in addition to silica and magnesium, was probably formed from solutions.

This is also true for the area northeast of the West Point tunnel where the Manitou dolomite has been altered to diopside and phlogopite. In addition, however, there is also some orthoclase and muscovite, which are very rich in potassium, and coarsely crystalline quartz.

From this discussion it is apparent that the solution with formed metamorphic minerals were different in two separate areas. East of the Star fault in the Erie and Iron King mines the minerals formed were rich in iron and silicon with possibly a small amount of aluminum added. West of the Star fault the minerals formed are rich in potassium, aluminum and silicon. The difference in composition of the minerals is not probably the result of differences in the country rock but probably due to difference in the composition of the solutions. Although all the solutions are believed to have been derived from the magma of the Princeton batholith, solutions of different composition could be accounted for by their having different sources within the magma, being derived from the magma at different stages in its crystallization, or by the difference in the composition of the rock through which the solutions passed before the minerals were formed.

Metamorphic Differentiation

One of the effects of metamorphism of the carbonate rocks has been the separation of the limestone and dolomite in dolomitic limestones or limy dolomites by metamorphic differentiation. In carbonate rocks the chemical composition of a single bed is usually constant over large areas. The carbonate rocks of the Whitepine area now are not consistent in their composition within short distance along their strike and dip; the composition may range from pure calcite to pure dolomite. This is believed to be the result of metamorphic differentiation.

As an example, at the top of the Manitou dolomite west of the Breadwinner mine, coarsely crystalline dolomite veins (less than 1 to 2 inches thick) cut, parallel to the bedding, an almost pure medium grained limestone marble. It is believed that the original rock was a dolomitic limestone and that during recrystallization to a marble, the dolomite separated into the veins. This is an exceptional case. In most cases the dolomite has separated into lenticular or rounded bodies (similar to concretions) or into wavy bands that are not, ordinarily, parallel to the bedding.

ORE DEPOSITS

Most of the ore production of the Tomichi mining district has been obtained from the Whitepine area. The principal metals produced, in order of their value, are lead, zinc, silver, gold, copper, and iron. The ore has been obtained from three types of deposits; replacement deposits in sedimentary rocks along faults and bedded replacement deposits, vein deposits, and contact metamorphic deposits. Of these, the replacement deposits along faults have accounted for most of the production.

The ore deposits are believed to be genetically related to the Princeton batholith and their formation to have been controlled by the structure and stratigraphy.

HISTORY AND PRODUCTION

The Tomichi mining district was one of the early mining districts developed on the western slope of the Continental Divide in Colorado. According to Crawford (1913, p. 284) ore was first discovered in this district in 1879 and in that same year the North Star, Nest Egg, Denver City, David H., and probably Eureka claims were staked (pl. 2). Between 1879 and 1883 most of the other important claims were located.

Very little information is available on the history or production of the district prior to 1901, when the Federal Government first started to compile records. Most of the early production came from the oxidized zone and high values per ton of ore were returned.

From the reports of the Director of the Mint (Burchard, 1882, 1883, 1884; Kimball, 1887, 1888; Leech, 1890, 1892); and from Henderson (1926) the greatest period of activity in the Tomichi district was during the period from 1883 to 1893. The total of the recorded production was only about $1,000,000 but it is believed that the actual production was at least twice this. During this period the major producing mines were the North Star, Eureka-Nest Egg, Denver City, May, Mazeppa, Morning Glim, and Victor.

Between 1893, when the price of silver dropped, and 1900, few of the mines operated; one mine would open for a year or so, only to close, and then another mine open. In 1900 the Director of the Mint (Roberts, 1900) reports that the "Whitepine district" produced 22,000 tons of sulfide ore.

The Akron Mining Company was formed in 1901 by the consolidation of the North Star, May, and Mazeppa mines, and in this year the company started what is now known as the Akron tunnel. This tunnel was completed to its intersection with the North Star-Dividend shaft in 1903. This company also constructed the first mill in the district in 1905. Since the consolidation of these mines and the completion of the Akron tunnel, this group has been the most productive in the Tomichi district.

From 1901 to 1937 the production from this district was small. There was a slight increase in production during World War I but that fell off in the 1920's. The mines that did produce during this period were the Akron, Morning Star, Erie, Eureka-Nest Egg and Spar Copper.

The Callahan Zinc-Lead Company acquired control of the Akron and Erie mines in 1937. They modernized the mines and their equipment and in 1943 started production. By 1947 production was great enough for them to build an 80-ton flotation mill. In 1951 they acquired control of most of the mines in the Whitepine area, including the Morning Star and Victor mines.

The following table gives the production of the Tomichi mining district from 1901 to 1950. This includes some production of mines outside the Whitepine area, but this is believed not to amount to more than one percent of the total production of the district. In addition, a small amount of iron ore is reported (Crawford, 1913, p. 305) to have been produced from the Iron King mine.

Production of the Tomichi Mining District,
in Recovered Metals, 1901-1950 4/

Year	Dry Tons Crude Ore	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1901	1,626	76	17,713	684	1,800	
1902	374	5	14,191	----	184,041	
1903	193	9	2,218	----	997	
1904	21	15	672	----	2,902	
1905	700	52	7,000	----	210,000	
1906	189	0	3,209	----	66,055	37,508
1907	299	10	8,893	13,690	88,057	68,645
1908	408	5	12,151	5,485	154,000	147,000
1909	76	2	17,363	48,324	19,512	------
1910	463	10	8,960	3,181	171,773	176,315
1911	809	12	139,121	3,766	281,157	508,569
1912	416	5	8,996	6,079	132,064	225,752
1913	196	5	3,758	3,985	39,917	57,690
1914	677	9	10,917	79	27,226	358,250
1916	3,689	22	14,268	12,393	283,496	222,375
1917	4,876	71	25,199	84,946	554,595	633,035
1918	1,011	3	6,973	215	286,901	346,157
1919	1,731	3	3,361	858	93,933	149,592
1920	5,782	2	12,258	0	56,090	106,840
1921	48	0	860	0	42,302	0
1923	7,682	39	19,481	1,788	1,684,635	3,611,222
1924	9,928	109	60,766	1,462	3,882,458	4,637,934
1925	4,618	67	34,957	7,800	1,295,466	1,434,203
1926	2,895	136	23,533	11,886	918,006	932,049
1927	1,591	23	14,974	4,757	621,491	537,274
1928	1,427	20	10,207	2,641	514,013	725,983
1929	429	7	3,438	725	141,864	182,235
1930	108	1	293	28	33,740	51,520
1931	118	1	1,608	611	81,155	0
1933	302	4	4,577	1,018	170,585	67,098
1934	79	0	1,064	391	34,150	41,794
1935	72	159	1,141	157	40,008	1,879
1937	18	2	467	252	3,436	1,354
1939	20	0	451	0	0	0
1940	14	0	362	1,103	4,043	0

4/ Compiled from records of A.J. Martin, Statistics Branch, Economics Division, U.S. Bureau of Mines. No recorded production for years not listed. Published with permission of the owners.

Production of the Tomichi Mining District,
in Recovered Metals, 1901-1950 4/
(continued)

Year	Dry Tons Crude Ore	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1941	92	2	805	0	34,386	45,791
1942	380	3	1,865	1,379	105,521	144,981
1943	3,941	87	44,156	20,680	597,870	916,479
1944	5,768	67	21,408	43,794	794,270	1,151,837
1945	6,176	51	22,896	24,035	782,659	1,033,388
1946	4,220	28	14,266	47,746	730,251	1,071,976
1947	10,235	75	63,892	55,900	3,121,264	4,191,471
1948	18,158	89	85,312	31,468	4,016,293	5,153,785
1949	14,676	67	60,578	39,073	2,737,872	3,755,978
1950	12,342	--	72,836	-------	1,578,650	2,426,660
Totals	128,873	1,373	744,443	482,380	1,746,077,542	34,790,959

4/ Compiled from records of A. J. Martin, Statistics Branch, Economics Division, U.S. Bureau of Mines. No recorded production for years not listed. Published with permission of the owners.

TYPES OF DEPOSITS

The ore deposits in the Whitepine area of the Tomichi district are of three types: (1) replacement deposits in the sedimentary rocks, (2) vein deposits in sedimentary rocks, the Princeton quartz monzonite, and the Silver Plume granite, and (3) contact metamorphic deposits. Of these types the most important, on the basis of ore produced, are the replacement deposits.

Replacement Deposits

The replacement deposits are chiefly in the limestone and dolomite marbles of the Manitou dolomite and Leadville limestone, but small deposits occur in the Chaffee formation and the Belden shale. The deposits occur in these formations either as bedded deposits or as deposits along pre-mineral faults. The deposits occur in these formations either as bedded deposits or as deposits along pre-mineral faults. The deposits along the pre-mineral faults have been the most productive.

In the footwall of the Star fault are the ore deposits of the Akron, Morning Star, and Victor mines. In the footwall of the Morning Glim fault are the ore deposits of the Spar Copper mine. In the Akron mine, the ore deposits occur in a wedge of Manitou dolomite in the footwall of the Star fault and east of the contact between the Manitou dolomite and the rhyolite intrusive. The ore bodies of the Morning Star and Victor mines occur in slivers of Leadville limestone between the hanging wall of the Star fault and the rhyolite dike that intruded the fault, and in the Leadville limestone in the footwall below the rhyolite dike. In the Spar Copper mine, the ore bodies are in limestone beds of the Belden shale in the footwall of the Morning Glim fault. In all of these mines, the ore bodies are elongated parallel to the faults and, in general, follow the faults in strike and dip.

In the David H. mine, and in numerous small prospects throughout the area, are small replacement deposits in limestone and dolomite marbles along steeply dipping fractures. In the Isabel mine, the ore bodies, rather than being in the footwall of the Star fault, are apparently in the Manitou dolomite in the hanging wall of the fault.

The replacement deposits along faults range from small lenses or pods, measured in inches, to large bodies, as one in the Akron mine that was mined for a pitch length of 300 feet, a breadth of about 150 feet, and an average thickness of 8 feet.

The ore deposits are not necessarily in contact with the faults but may be separated by a few inches of gouge or country rock, or by several feet of country rock.

The only important bedded replacement deposits are those of the Erie and Eureka-Nest Egg mines. In these mines, the ore bodies are at or near the top of the Leadville limestone. Bedded deposits also occur in the Manitou dolomite along the crest of an anticline in the North Star mine, in the Manitou dolomite in the trough of a syncline in the Tenderfoot mine, and at the base of the Chaffee formation in the Breadwinner and Denver City mines.

The bedded deposits range from small lenses or irregularly shaped masses with maximum dimensions of a few inches to the main ore shoot of the Erie mine, which was mined for a pitch length of about 250 feet, a breadth of 40 to 200 feet, and an average width of 6 feet.

The mineralogy of the replacement deposits, whether bedded or deposits along faults, is essentially the same, with only minor variations in detail. The chief sulfide minerals are galena, sphalerite, pyrite, and chalcopyrite. In addition, minor amounts of stephanite, tetrahedrite, and tennantite have been found. The pyrite and sphalerite are probably gold bearing and the galena contains silver.

The sulfide minerals form fine- to coarse-grained masses, pods, or lenses, or they may occur as discrete grains disseminated in the country rock. The galena is usually medium- to coarse-grained and occurs as almost pure masses, or intergrown with sphalerite, with disseminated grains of pyrite and chalcopyrite. The sphalerite is yellowish-brown to dark black and, most commonly, medium-grained. It occurs intergrown with galena in irregularly shaped masses, with disseminated grains of pyrite and chalcopyrite, and in bands intergrown with galena or pyrite. The pyrite occurs as cubes, pyritohedrons, or irregular grains; in general in smaller grains than the other sulfides. It may be disseminated in the masses of galena and sphalerite, in bands intergrown with sphalerite, in separate masses, which may form an irregular border to the ore bodies, or disseminated in the country rock. Chalcopyrite is not nearly as abundant as the other sulfide minerals. It is usually fine- to medium-grained, and occurs as disseminated grains in the masses of galena and sphalerite and in the bands of sphalerite and pyrite. It is rarely found disseminated in the country rock.

The chief gangue minerals of the replacement deposits are marbleized limestone and dolomite, silicified limestone and dolomite, and minor amounts of quartz and calcite. Barite occurs as a gangue mineral in the replacement deposits of the Spar Copper mine. In the Erie and Eureka-Nest Egg mines, earlier formed contact-metamorphic minerals--magnetite, garnet, diopside and epidote--comprise most of the gangue.

Vein Deposits

The vein deposits are of only minor importance. Only from one, the Spar Copper, has there been any recorded production. The veins occur in the sedimentary rocks, the Princeton quartz monzonite, and the Silver Plume granite.

The veins in the sedimentary rocks are found in association with the replacement deposits. They are best exposed in the Akron and Erie mines (pls. 4, 6, 10). In the country rock surrounding the replacement deposits are numerous small fractures, some of which have been mineralized. These veins are rarely more than a few inches wide. The sulfide minerals are galena, sphalerite, pyrite, and chalcopyrite. Of these, galena, and pyrite are the most common. The sulfide minerals are usually fine- to medium-grained. The chief gangue minerals of these veins in the sedimentary rock are fine to coarse-grained quartz and calcite.

No ore has been produced from the veins in the Princeton quartz monzonite in the Whitepine area. In other parts of Tomichi district, however, and in the Chalk Creek district about 10 miles to the northeast, veins in the Princeton quartz monzonite have been major producers. These veins are best exposed in the Whitepine area in the Akron tunnel (pl. 5).

In general, they consist of sheared and altered zones, from less than 1 to 4 feet wide, that are cut by quartz-pyrite stringers of less than 1 to 6 inches wide. Quartz is the most abundant mineral. In the quartz are fine, disseminated grains of pyrite, which may also be disseminated in the bordering sheared and altered zone. Grains of chalcopyrite and galena may be found in some of the veins.

In the hanging wall of the Morning Glim fault are several veins in the Silver Plume granite. These veins are believed to be filled fissures that formed as the result of movement along the Morning Glim fault.

Most of the veins, as determined from the dumps of prospect pits or adits, are similar to the veins in the Princeton quartz monzonite. The most important of these veins is the Spar Copper vein, which produced some ore. This vein is not exposed at the surface, but its trend may be followed for about 300 feet by a series of caved prospect pits and shafts. According to Crawford (1913, p. 304) this vein, as exposed in the Parole tunnel, is about 3½ feet wide and includes ore about 1 foot wide, and has been followed for about 500 feet. The vein matter on the dump shows veinlets of banded quartz and pyrite in altered granite, with minor fine- to coarse-grained galena, sphalerite, tetrahedrite, chalcopyrite, and calcite occurring as narrow bands or lining small vugs in the banded quartz; Crawford (1913, p. 304) found a little enargite and also reported native copper. Gold and silver are present in the vein, as shown by the production records, but their mineral form is not known.

The feldspar and ferromagnesium minerals of the granite, within or along the vein, have been altered to yellow clay. Where veinlets of quartz and pyrite cut the altered granite, the granite on either side is silicified and pyritized for 1 to 10 inches.

Contact Metamorphic Deposits

As previously discussed (p. 94), the sedimentary rocks have been metamorphosed as a result of the intrusion of the Princeton batholith. Locally, as along the contact of the Leadville limestone and the Belden shale and along the north end of the Morning Glim fault, contact metamorphic minerals were formed. These minerals include garnet, epidote, diopside, tremolite, magnetite, etc. Magnetite is the only one of these minerals of economic importance and at only one place, the Iron King mine, was there a deposit large enough to be considered worth mining.

The Iron King mine was not accessible to the author but Harder (1909, p. 194-198) gives a description of the deposit, from which the following information, in part, is taken: The ore bodies occur as replacement deposits of the limestone of the Belden shale in the foot wall of the Morning Glim fault. They parallel this fault, and range in thickness from 5 to 40 feet. The ore is compact magnetite with specks of limonite, chlorite, quartz, and calcite disseminated in it. The rock adjacent to the ore bodies contain typical contact metamorphic minerals as epidote, chlorite, diopside, and garnet.

The contact metamorphic deposits, although classified separately, are believed to have been formed during the same period as the other deposits, but at an earlier stage. They might, except for their mineralogy, be classified with the replacement deposits.

MINERALOGY OF THE ORES

The following section is an alphabetical list of the ore and gangue minerals that are found in the Whitepine area, with a note as to their occurrence.

Anglesite ($PbSO_4$). Anglesite is reported (Crawford, 1913, p. 289) to have been one of the chief products of Eureka-Nest Egg mine. Specimens may be found on the dumps of this mine as narrow white bands surrounding grains of galena. It also probably constituted part of the oxidized ore produced from other mines.

Azurite ($2CuCO_3 \cdot Cu(OH)$). Small quantities of azurite were found in the ore of the Spar Copper mine and from several prospect pits on Porcupine Ridge. It also occurs as a stain, or thin coating, on some of the rocks on the dumps of most of the mines. It is probably derived from the oxidation of the small amount of chalcopyrite that occurs in the ore bodies.

Barite ($BaSo_4$). Coarsely crystalline masses of barite were found as gangue in the replacement ore of the Spar Copper mine. A small amount is associated with the ore of the Erie mine and was found on the dump of a small prospect adit in the Silver Plume granite in the hanging wall of the Morning Glim fault, northeast of the Parole tunnel.

Calamine ($H_2Zn_2SiO_5$). Calamine usually occurs as fine, white to yellowish-white, radiating crystals that line small vugs. It was probably a common mineral in the ores from the oxidized zone. Specimens of it may be found on the dumps of the North Star, Denver City, Breadwinner, and David H. mines, and numerous small prospects.

Calcite ($CaCO_3$). Calcite, in addition to being the chief constituent of the limestone and dolomite of the area, occurs in medium- to coarse-grained masses as gangue in the replacement deposits.

Cerussite ($PbCO_3$). This was, with silver, the chief ore mineral of the oxidized zone. Greyish-white or yellowish-white granular to earthy masses occur on the old dumps of North Star, David H, Breadwinner, Denver City, Erie, and Eureka-Nest Egg mines, and numerous small prospects.

Chalcocite (Cu_2S). A small amount of black sooty chalcocite was found associated with secondary copper minerals on the dumps of several small prospect pits near the top of Porcupine Ridge, north of the town of North Star.

Chalcopyrite ($CuFeS_2$). Chalcopyrite is found in all the primary ore deposits of the area. It is most abundant in the ore from the Erie mine and from the Spar Copper vein. It usually occurs as small (1 to 5 mm) grains disseminated in masses of galena and sphalerite and, but rarely, is the quartz gangue of the veins.

Chrysocolla ($CuSiO_3 \cdot 2H_2O$). Small amounts of chrysocolla are associated with other secondary copper minerals on the dumps of the Morning Glim and Erie tunnels, the Victor shaft, and several prospects on Porcupine Ridge. It is greenish white to greenish blue and forms thin opal-like seams.

Copper (Cu). Small blebs of native copper were found in association with secondary copper minerals on the dumps of three prospect pits near the top of Porcupine Ridge north of the town of North Star. It was reported to Crawford (1913, p. 304) that copper was found in the Morning Glim tunnel.

Cuprite (Cu_2O). Cuprite is found as small dull red, finely granular to earth masses associated with secondary copper minerals on the dumps of three prospect pits near the top of Porcupine Ridge north of the town of North Star.

Enargite ($3Cu_2S \cdot As_2S_5$). Crawford (1913, p. 287) reported finding enargite associated with pyrite in a specimen of ore from the Morning Star tunnel (Spar Copper mine).

Galena (PbS). Galena is the chief ore mineral of the district and with sphalerite constitutes the ore. It commonly occurs as medium- to coarse-grains intergrown, and showing mutual contacts, with sphalerite. Locally, it may be in disseminated grains, particularly in the carbonate rocks adjacent to the replacement deposits. An ore specimen from the dump of the Morning Glim tunnel carried galena in tetrahedrons pseudomorphic after tetrahedrite. The galena is believed to contain the silver values found in the ore.

Gold (Au). No native gold, or gold minerals were seen in the area. Gold, however, is one of the products of the smelting of the ore and is believed to occur in the pyrite, and possibly the sphalerite and chalcopyrite. Free gold is reported to have been produced from the oxidized zone of the ore deposits.

Hematite (Fe_2O_3). Hematite is found associated with the magnetite deposits, particularly around the Iron King mine, and along the Morning Glim fault. A small mass of specular hematite was found associated with phlogopite in altered Silver Plume granite on the dump of the West Point tunnel.

Limonite ($2Fe_2O_3 \cdot 3H_2O$). Limonite is the chief gangue mineral in the oxidized zone of the ore deposits. It is also found associated with the magnetite ores along the Morning Glim faults. Cubes of limonite $\frac{1}{2}$ to 2 inches across, pseudomorphic after pyrite may be found on the dump of a prospect pit about 450 feet northeast of the Mazeppa shaft.

Magnetite ($FeO \cdot Fe_2O_3$). Massive, glossy-black magnetite ore was produced from the Iron King mine. Several other small deposits of magnetite may be found along the north end of the Morning Glim fault. Magnetite is one of the gangue minerals of the lead-zinc ore of the Erie mine.

Malachite ($CuCO_3 \cdot Cu(OH_2)$). Malachite is found as thin coatings or stain on some of the rocks on most of the dumps of the district. It is also associated with other secondary copper minerals on the dumps of the prospect pits on Porcupine Ridge.

Psilomelane (Colloidal MnO, with impurities). Psilomelane was found as a black earthy material associated with limonite on the dumps of three small prospect adits in the Manitou dolomite about 500 feet southwest of the Breadwinner mine.

Pyrite (FeS_2). Pyrite is common in all the ore deposits or any of the areas that have been altered by hydrothermal solutions. It occurs as medium- to coarse-grained cubes and pyritohedrons in the ore deposits, and as fine-grained cubes and pyritohedrons in the wall rock. The pyrite probably carries some of the gold values.

Quartz (SiO_2). Quartz is the principal gangue mineral of the veins in the Princeton quartz monzonite and Silver Plume granite.

In the veins, are two varieties: the older, gray and very fine-grained, and the younger, white and medium- to coarse-grained. Only a small amount of medium-grained quartz is found as gangue in the replacement deposits and in the veins in the sedimentary rocks.

Silver (Ag). Silver is produced from the smelting of the ores from the district, principally from the lead concentrates. No silver, or silver minerals, were found and it is assumed that the silver occurs in the galena.

Smithsonite ($ZnCO_3$). Greyish- and brownish-white smithsonite as crystalline incrustations is found in association with other oxidized ore minerals, particularly cerussite and calamine, on the dumps of many of the old mines and prospects. Good specimens may be found on the dumps of the North Star, Breadwinner, Denver City, and David H mines.

Sphalerite (ZnS). Sphalerite with galena constitutes the ore of the district. It occurs as fine- to coarse-grains either in single grains or irregular shaped masses intergrown with the galena or in bands intergrown with pyrite. It ranges in color from yellowish-brown to almost black. The black variety, or marmatite, is the most common. The sphalerite probably contains some of the gold values.

Stephanite ($5Ag_2S \cdot Sb_2S_3$). Crawford (1913, p. 290) reported stephanite of good quality as being found in the David H mine.

Tetrahedrite ($3Cu_2S \cdot Sb_2S_3$). Specimens of tetrahedrite were found in association with sphalerite, galena, pyrite, and chalcopyrite on the dump of the Morning Glim tunnel. It occurs as black tetrahedrons about one-eigth inch in diameter lining small vugs. Crawford (1913, p. 287) reports that tetrahedrite and tennantite ($3CuS \cdot As_2S_3$) were also found at the David H and Victor mines.

PARAGENESIS OF THE ORES

The sequence of deposition of the primary minerals, as determined from a study of hand specimens and polished sections, is apparently the same for the replacement deposits and the veins. The differences noted under the descriptions of each of the mines are the result principally of the presence of a rare ore or gangue mineral that was found only in that one mine. It is believed, as discussed under the origin of the deposits, that the ore-bearing solutions had one source, the magma of the Princeton batholith, and that all the ore deposits of the Whitepine area were formed at essentially the same time. The following discussion is a summary of the paragenetic relationships noted in all the ore deposits.

The formation of the contact metamorphic minerals preceded the deposition of the sulfide minerals. Of the contact metamorphic minerals, magnetite is the youngest. Accompanying the formation of the contact metamorphic minerals, there was some silicification of the country rock. It is possible that the continuation of the deposition of the silica after the formation of the contact metamorphic minerals resulted in the deposition of the quartz of the sulfide deposits. The early quartz of the vein deposits is a very fine-grained grayish-white to dark-gray quartz, as is also the quartz that resulted from the silicification of the country rock, and is believed to be the first mineral formed of the replacement and vein deposits.

The first sulfide mineral deposited was pyrite--grains of pyrite have been partly replaced by the other sulfide minerals. The pyrite apparently accompanied the early quartz deposition as it is found disseminated in the fine grain quartz, and wherever the wall rock is silicified, disseminated in the silicified wall rock.

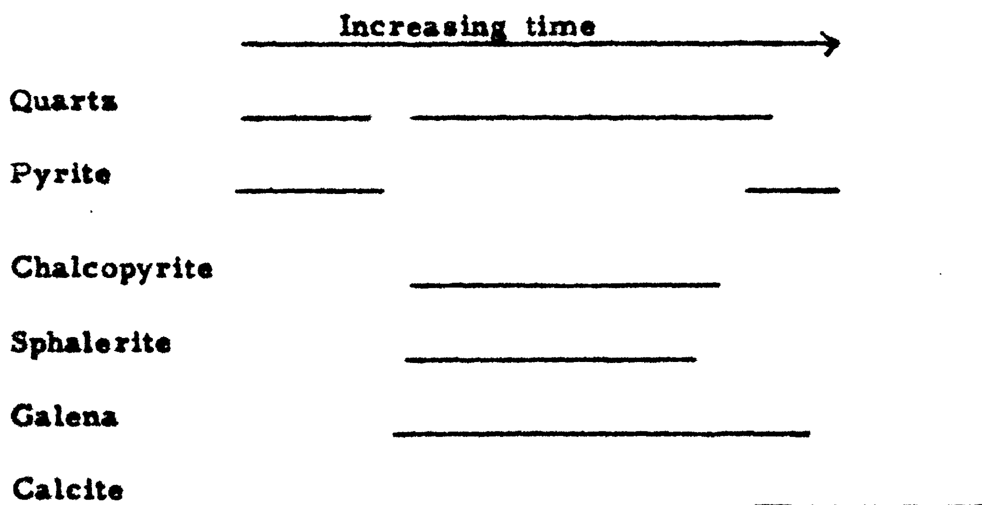
The deposition of pyrite was followed by the deposition of sphalerite, galena, and chalcopyrite. A study of the polished sections shows sphalerite cut or replaced by chalcopyrite and galena; chalcopyrite by sphalerite and galena; and galena by sphalerite. This indicates that chalcopyrite, sphalerite and galena were deposited almost simultaneously, and that possibly a slight variation in conditions locally caused one or the other to be deposited first. In most of the polished sections examined, galena replaced sphalerite and chalcopyrite in more cases than these two minerals replaced galena. This might indicate that the deposition of galena continued for a short time after the deposition of the other two minerals had stopped.

Accompanying the deposition of the base-metal sulfides and, particularly in the replacement deposits, following their deposition, was deposited a medium- to coarse-grained, white quartz. In the Spar Copper vein, this quartz was accompanied by the deposition of a small amount of pyrite.

Calcite and dolomite seams or crystals cut the sulfides and quartz and were the last minerals deposited.

The following diagram is a graphic representation of the sequence of deposition in this area.

Sequence of Deposition of the Principal Sulfide and Gangue Minerals of the Whitepine Area, Tomichi Mining District



In the Spar Copper mine two minerals, tetrahedrite and barite, were found that were not found in any of the other deposits. In this mine tetrahedrite accompanied the deposition of the chalcopyrite and the deposition of both these sulfides preceded the deposition of the sphalerite and galena. The deposition of the barite preceded that of any of the sulfides, including pyrite, and possibly preceded the deposition of the early quartz.

OXIDATION OF THE ORE DEPOSITS

Most of the early production, particularly that before 1884, was from the oxidized zone of the ore deposits. This type of ore, which usually carried high values in gold and silver per ton, has been mined out and the only evidence of its character are a few pieces of the ore that may be found on the dumps of the smaller mines and prospects.

The oxidized ore of the replacement deposits is typically a yellowish- to reddish-brown siliceous limonite or soft porous limonitic carbonate rock. The chief ore minerals are cerussite, residual patches or grains of galena, and free gold. These ore minerals are usually associated with minor amounts of other oxidized ore minerals, some of which may locally be of some economic importance. These include smithsonite, calamine, anglesite, cuprite, malachite, azurite, chrysocolla, chalcocite, and native copper. The chief gangue minerals are limonite and quartz but locally calcite, dolomite, or silicified limestone may be abundant.

Typical sample of the oxidized ore may be found on the dumps of the Eureka-Nest Egg and the Breadwinner mine. The Eureka-Nest Egg ore consists of grains of galena, averaging about one-fourth inch in diameter, coated with a very thin band of anglesite that in turn is coated by a thin band of cerussite in a limonitic, vuggy quartz. Cerussite also occurs as fine white crystals lining small vugs. At the Breadwinner mine, crystals of calamine, cerussite, and smithsonite line long thin vugs between bands of limonitic quartz that cut limestone marble containing small grains of galena.

An unusual assemblage of oxidized copper minerals was found on the dumps of three prospect pits on Porcupine Ridge near the contact of the Chaffee formation and Leadville limestone about 550 feet northwest of the Congress tunnel. Here were found specimens of native copper, cuprite, chalcocite, azurite, and malachite.

The oxidized ore of the veins consists of siliceous limonite that may contain a few residual grains of pyrite. The veins are so small and poorly exposed, particularly on the surface, that very little could be determined about their oxidized ore.

The magnetite of the Iron King mine, the only contact metamorphic deposit of the area, was undoubtedly oxidized to limonite at the surface. Crawford (1913, p. 287) reports that two tons of cuprite were produced from near the Iron King mine; this was probably an oxidized ore.

There is no evidence of a zone of secondary enrichment in any of the ore deposits of this area. Possibly there were such zones but they were mined early and the old workings are no longer accessible. Possibly the chalcocite found on Porcupine Ridge was the result of secondary enrichment.

The only enrichment of the ore deposits as the result of oxidation was residual enrichment. From the production records it is apparent that the chief values in the early days of mining were in silver and lead. The sphalerite, pyrite, and chalcopyrite, being more soluble than the argentiferous galena or its oxidation products, lead carbonate and sulfate, were removed and thereby increasing the percentage of lead and silver. Probably some free gold was liberated by the solution of the pyrite and chalcopyrite.

The ore deposits were apparently not oxidized, to any extent, for more than 100 or 150 feet from the surface. Crawford (1913, p. 294) reports that in the Morning Star mine oxidized ore was mined to a depth of 100 feet and that sulfide ore was encountered in the Victor mine at 75 feet in depth. In the Erie mine on the number 3 level some of the ore is partially oxidized. The number 3 level is about 184 feet below the surface at this point. In the Akron mine, partially oxidized ore was found at the south end of the 350 level at a point about 150 feet below the surface.

HYDROTHERMAL ALTERATION

The country rock associated with the ore deposits has been altered, presumably by the hydrothermal solutions related to the deposition of ore. Three general types of alteration were noted: silicification, pyritization, and clay alteration. The silicification and pyritization of the country rock occurred at the same time, and, for convenience of discussion, will be considered together. Unfortunately, it was not possible in most cases to determine the mineral composition of the clay that resulted from the alteration of the country rock and, therefore, this type of alteration may include several types of alteration as defined by such authorities as Lovering (1949), Sales and Meyer (1948), and Schwartz (1939). In general, however, this, or these, types of alteration result in a loss of silica as compared to the original composition of the rock, and are in contrast to the silicification, an addition of silica. In general, the igneous rocks show all three types of alteration and the sedimentary rocks only silicification and pyritization.

The chief types of wall rock alteration that are associated with the ore deposition are silicification and pyritization, which are believed to have been simultaneous. These types of alteration may most clearly be seen along the veins in the igneous rock.

Specimens from the dump of the Morning Glim tunnel, which worked the Spar Copper vein in the Silver Plume granite, and the veins in the Princeton quartz monzonite, as exposed in the Akron tunnel, show veins of quartz that cut altered country rock. The feldspar and ferromagnesian minerals of the country rock for some distance on either side of the veins have been altered to a white or yellowish clay. Immediately adjacent to the veins the country rock has been silicified and pyritized with decreasing intensity the greater the distance from the vein. This silicification consists of a very fine-grained gray to dark-gray quartz. Associated with the quartz and extending beyond the silicification are small, generally less than 1 mm cubes of pyrite. The deposition of this type of quartz with its associated pyrite preceded the deposition of the base metal sulfides and a later deposition of quartz, which is white and medium- to coarse-grained.

The silicification and pyritization of the sedimentary rocks associated with the ore deposits is similar to that found along the veins in the igneous rocks but its control and extent are not as clear.

In the Akron mine the wedge of Manitou dolomite that lies between the rhyolite porphyry dike along the Star fault and the rhyolite intrusive to the west has been highly silicified, so highly silicified in fact that it is often difficult to distinguish it from the altered rhyolite (pls. 4, 6, 7). Here, as in the veins, the silicification and pyritization consists of a dark-gray, very fine-grained quartz with small cubes of pyrite. The quartz associated with the base metal sulfides is a medium- to coarse-grained quartz and was deposited later than the silicification and pyritization.

In the Erie mine the ore zones have also been silicified and pyritized and this alteration resembles that of the Akron mine and the veins. In this mine it may be seen that the silicification and pyritization has not only affected the country rock but also locally cuts the contact metamorphic minerals, as garnet, diopside and epidote.

The rhyolite intrusive west of the Star fault has been highly altered, principally by silicification. As compared to the silicification of the other igneous rocks and the sedimentary rocks, this rock has been subjected to two periods of silicification separated by a period of sericitization. The original rock, which was believed to have been a rhyolite (see p. 47), was first apparently highly silicified and most of original minerals completely replaced by silica. The rock was then subject to considerable brecciation and ground to grains of from 0.1 to 0.3 mm in diameter. These grains occur in a matrix of sericite grains that are not broken so apparently formed after brecciation of the silicified rock. Also many of the grains of quartz are partly replaced by sericite. Following the sericitization the rock was sheared and numerous small fractures developed. Quartz has been deposited along these fractures and the wall of the fractures silicified with decreasing intensity the greater the distance from the fracture. This silicification was accompanied by pyritization as small cubes of pyrite are found in the quartz, in the fractures, and in the silicified walls of the fractures. This later stage of silicification and pyritization probably is the same as that found in the veins in the other igneous rocks and in the sedimentary rocks.

A small body of altered Princeton quartz monzonite crops out on West Point Hill just west of the Star fault. The plagioclase feldspar has been altered almost beyond recognition to minerals of high birefringence, possibly propylite and/or sericite, and the ferromagnesian minerals, biotite and hornblende, to chlorite, magnetite, and bleached mica, probably hydromica. Following this type, or types, of alteration, there was some secondary silicification and pyritization. The pyrite is most common in the biotite and hornblende, which might indicate that the altering hydrothermal solutions furnished only the sulfur and that the iron for the pyrite was derived from ferromagnesian minerals.

As previously noted, the rock on either side of the veins in the Silver Plume granite and Princeton quartz monzonite have been altered to a white or yellowish-white clay. The width of this alteration is apparently directly proportional to the width of the vein. The intensity of the alteration decreases with the distance from the vein and grades into the unaltered country rock. That is, all the minerals except quartz and some accessory minerals at margin of the vein have been altered to clay, a little farther, the plagioclase feldspar and ferromagnesian minerals are all altered but the potash feldspars are relatively fresh, still farther only the ferromagneisan minerals are altered and these principally to chlorite and hydromica.

In the Akron mine the rhyolite and pitchstone porphyry dikes have locally been highly altered, particularly where these dikes form the hanging wall for an ore body. No silicification was noted in these dikes, only clay alteration. These dikes, which normally have a dense, very fine-grained or aphanitic porphyritic texture, have been altered to a dark-gray to bluish-gray clay. The phenocrysts, principally ferromagnesian minerals, feldspar, and rarely quartz, except for the quartz have been altered beyond recognition.

In the Akron and Morning Star mines (pls. 5, 6, 13) the Silver Plume granite in the hanging wall of the Star fault has been highly brecciated and altered. This rock has been completely altered to a grayish-white or yellowish-white clay and the only mineral of the original rock that can be recognized is the quartz. There is no apparent silicification of this rock although the dolomite and limestone in fault contact with the granite has been silicified.

Most of the dikes of the area show some degree of clay alteration, particularly near their contacts. In most , except those adjacent to ore bodies, the alteration consists of a chloritization, and locally epidotization of the ferromagnesian minerals and the development of dusty surfaces on the feldspar crystals.

The origin of the hydrothermal solutions that formed the contact metamorphic minerals, the wall rock alteration, and the ore deposits is discussed in more detail under the origin of the ore deposits. This brief study of the wall rock alteration in association with the ore deposits shows, however, that between the period when the contact metamorphic minerals were formed and the period of deposition of the base metal sulfides, there was a period when the principal effect of the hydrothermal solutions was the alteration of the country rocks along those structures that controlled the migration of the hydrothermal solution; the same structures, in part, that controlled the formation of the contact metamorphic minerals and the ore deposits.

The sequence of alteration for all the igneous rocks was the same--that is, alteration to clay minerals followed by silicification and pyritization. For the sedimentary rocks there was no apparent period of clay alteration that preceded the silicification and pyritization. This could be explained by the fact that the effect of the clay alteration was principally a loss of silica and the sedimentary rocks being chiefly limestones and dolomites contained little, if any, silica.

The observed facts related to the wall rock alteration would appear to support a hypothesis proposed by Harrison Schmitt (1954, p. 879-889). That is, that the silicification and accompanying pyritization related to hypogene ore deposits, both normal vein and porphyry copper deposits, is the result of local reactions rather than the addition of silica derived by the solutions from their source. Schmitt points out that originally a vein is an open fracture or breccia zone and that the walls are sheared with decreasing intensity the greater the distance from the center of the fracture. This relatively open zone is the area in which the silica is deposited while the zone beyond this is leached of silica. This is certainly the case in the igneous rocks in the Whitepine area. He believes that the iron for the pyrite is also derived locally from the alteration of the ferromagnesian minerals and that the hydrothermal solutions furnish only sulfur, possibly in the form of H_2S.

The silicification of the sedimentary rocks of the Whitepine area can be explained by the same reasoning. The most highly silicified sedimentary rock in the area is the wedge of Manitou dolomite in the footwall of the Star fault in the Akron mine. In the hanging wall of the Star fault is the Silver Plume granite, which has been altered to clay, and along the Star fault is a rhyolite or pitchstone porphyry dike that locally has also been altered to clay. It seems possible that the silica for the silicification of the Manitou dolomite could have been obtained by the hydrothermal solutions from the clay alteration of the Silver Plume granite and the rhyolite or pitchstone porphyry dikes. These same relationships also exist on the lower tunnel level of the Morning Star mine.

STRUCTURAL AND STRATIGRAPHIC CONTROL OF THE ORE DEPOSITS

The migration of the solutions that formed the ore deposits was controlled in the Whitepine area by pre-mineral faults and folds or the presence of a relatively impervious bed above a pervious one, or a combination of these factors. Of these structure and stratigraphic controls, the most important were the large pre-mineral faults.

In the foot wall of the Star fault are the ore bodies of the Akron, Morning Star, and Victor mines. Along this fault, for most of its length, the Silver Plume granite was thrust from the east over the Paleozoic sedimentary rocks. Later, but prior to the deposition of the ore, the fault zone was intruded by rhyolite and pitchstone porphyry dikes. The sedimentary rocks in the foot wall are principally limestone or dolomite marbles that were intensely sheared as the result of the movement, and probably the intrusion of the dikes, along the Star fault zone. Ore solutions, migrating upward from depth along this fault zone were channeled into this sheared rock by the relatively impervious granite in the hanging wall of the fault, the dikes along the fault and, in the case of the Akron mine, by the rhyolite intrusive to the west of the fault. The result of the movement along this fault was to furnish almost ideal conditions for ore deposition by making channel for the migration of ore solutions and restricting the solution to a rock chemically favorable for replacement.

Along the Morning Glim fault essentially the same conditions exist but, for some reason, no sulfide ore deposits have been found. The only mine along this fault is the Iron King, from which magnetite was produced. Possibly the reason no major ore deposits have been found along this fault is that the formation at the surface in the foot wall of the fault is the Belden shale, which consists of interbedded and lenticular beds of shale, limestone and sandstone, that would not fracture as easily or tend to leave open fractures as did the massive limestones and dolomites of the Manitou dolomite and Leadville limestone in the foot wall of the Star fault. Possibly at depth where the Manitou and Leadville formation are in contact with fault, there are major ore deposits.

The ore bodies of the North Star and Tenderfoot mines occur along, or near, the crest of a northward-plunging anticline and syncline respectively. Unfortunately, neither of these mines was accessible to the author so the details as to the structural control were not available. Probably the ore deposits were formed at the crests of these folds because of fracturing at the time of folding. Fractures commonly form at the crests of folds and, in this case, the fractures may have furnished channels for the upward migration of the ore solutions. In the North Star mine the solutions apparently migrated along the fractures at the contact of the Manitou dolomite with the underlying Sawatch quartzite, and replaced the more soluble limestone and dolomite marbles of the Manitou dolomite. In the Tenderfoot mine, the main ore body is about 130 feet stratigraphically above the base of the Manitou dolomite (Shenon and Full, 1946), and there was probably some stratigraphic as well as structural control to the ore deposition.

The main ore deposits that show stratigraphic control are those of the Erie mine. The control was also in part structural. The ore bodies of this mine occur at the top, or just below the top, of the Leadville limestone. The basal beds of the Belden shale in this area are dense quartzites and argillites, which were deposited on an uneven erosion surface on the Leadville limestone. The formations in this area dip 30 - 45°E. Apparently the ore solutions at some point at depth reached the contact of the Belden shale and Leadville limestone--possibly at the intersection of this contact with the Morning Glim fault. These solutions then migrated up the dip of the beds being prevented from going directly upward by the impervious nature of the quartzites and argillites of the basal Belden shale. The ore solutions reacted with the more soluble Leadville limestone to form the main ore deposits.

The Breadwinner and Denver City mines apparently developed small ore deposits at the base of the Chaffee formation. The basal unit of the Chaffee formation consists of 8 to 15 feet of very thin-bedded shaly limestone or limestone marble. Both the Breadwinner and Denver City were inaccessible so the details as to the occurrence of the ore could not be determined, and it is not known whether it was the composition of the beds or faulting that controlled the deposition of the ore. Where this unit could be observed, however, it was noted that there were many small bedding-plane faults. Such faults developed probably as the result of folding and they would develop in such a thin-bedded unit rather than in the more massive Parting quartzite member of the Chaffee formation above, or the very massive Fremont dolomite below this unit. Such bedding-plane faults could act as channels for the migration of ore solutions.

Although certain deposits are restricted to certain stratigraphic zones, faulting, or the structure, was probably the primary control in localizing the formation of the ore deposits.

ORIGIN OF THE ORE DEPOSITS

The ore deposits of the Whitepine area are believed to be genetically related to the Princeton quartz monzonite batholith. This idea was first proposed by Crawford (1913, p. 223-225, 295-296) for the origin of the ores of both the Monarch and Tomichi districts. Later, after regional studies (Crawford, 1924, p. 384-388), he postulated that the Princeton batholith had a greater areal extent than is indicated by its surface exposures and that it was probable that the ores of many of the mining districts of central

Colorado were related to this batholith. Dings and Robinson (in preparation) in their study of the Garfield quadrangle agreed with this idea of Crawford's for the replacement deposits and "pyritic-quartz" veins but found other types of deposits that they believed were related to intrusives younger than the Princeton quartz monzonite.

The geologic facts observed in the Whitepine area support Crawford's hypothesis. Of the intrusive rocks of the area only the Princeton quartz monzonite is large enough to have formed the widespread metamorphism and the contact metamorphic deposits. The replacement and vein deposits have the same mineralogical composition and are assumed to have had the same source. They are younger than the Princeton quartz monzonite because the veins cut this body. They are also believed to be younger than the dikes because the dikes are altered and the alteration is believed to have preceded the ore deposition (see p. 128). In addition, Shenon and Full (1946) report sulfide ore in a rhyolite porphyry dike on the 100 level of the Akron mine (pl. 6). Again, their volume and widespread distribution (particularly outside the area) can only be accounted for by their having been derived from a large igneous body; the volume and areal extent of the dikes and other intrusives are too small to have supplied the volume of solution necessary to form the deposits, and there is no other large intrusive within several miles of this area.

A distinction has been made throughout this report between the contact metamorphic deposits, the replacement deposits, and the vein deposits. These terms imply, possibly because of the general acceptance of the classification of ore deposits by Lindgren (1933, p. 203-213), different conditions of formation of the deposits. The contact metamorphic deposits, or as Lindgren terms them "pyrometasomatic," which consist of magnetite with associated garnet, diopside, etc., were formed by replacement of the sedimentary rocks. Lindgren (1933, p. 212) states that this type of deposit is formed at, "Temperatures probably 500° --800° C. $\pm$ " with, "pressure, very high." The lead-zinc replacement deposits and the vein deposits would be classified by Lindgren (1933, p. 212) as mesothermal deposits, the only difference between them being that the replacement deposits were formed by the ore solutions dissolving the country rock and simultaneously depositing the ore, and in the veins just depositing the ore in previously existing openings. The temperature for the formation of these being 200° - 300° C. and the pressure high. This would indicate that the physical conditions, as well as the chemical composition of the ore solutions derived from the Princeton batholith, changed between the time the contact metamorphic deposits were formed and replacement and vein deposits were formed. It is proposed that in the Whitepine area that the formation of the ore deposits, both the contact metamorphic as well as the vein and replacement deposits, was a continuous process and that the change in composition of the ore solutions and physical conditions of deposition were primarily a function of time.

The sequence of events as related to the ore deposits in this area was the formation of the contact metamorphic deposits, the clay alteration of the country rock, the silicification and pyritization of the country rock, and the replacement (or deposition in openings) of the country rock by base-metal sulfides. This sequence would indicate that the early solutions were rich in iron, which, because of the amount of iron, could only have been derived from the crystallization of Princeton magma. The iron solution contained some silica but this could have been obtained by solutions in their upward migration through the already solidified Princeton, or from the Silver Plume granite and other rocks as might be indicated by the clay alteration. With time, the silica content of the solutions increased with the resulting silicification of the country rock and the percentage of iron decreased. Also, the solutions became richer in sulfur, possibly as H_2S, which precipitated what iron was present as pyrite.

Between the preceding stage and the stage of precipitation of the base-metal sulfides, if Lindgren's temperature ranges are accepted, the solutions had to drop in temperature by 300° to 500°C. and either the composition of the solution had to radically change, primarily by the addition of lead, zinc, and copper, and a loss of silica, or the composition of the solutions did not radically change, but that the change in temperature and/or a change in pH resulted in the precipitation of the base metals. Regardless of which change took place, it is believed that the change was gradual and over a considerable period of time.

The precipitation of the base-metal sulfides was essentially the last stage in the formation of the ore deposits. The only minerals formed following the precipitation of the sulfides was a small amount of calcite and dolomite in the veins and replacement deposits. This was probably just the precipitation of these minerals that the ore solutions had dissolved in precipitating the sulfides.

MINES AND PROSPECTS

In the following section is given, in alphabetical order, a detailed description of the mines and prospects of the Whitepine area. The locations of these mines is shown on plate 1, the geologic map of the area. Each mine description has been made as complete as possible, with a minimum of references to the preceding part of this report. This procedure was followed in order that a reader, only interested in one mine, would not have to read the whole report to obtain the essential geologic facts. This has necessitated a certain amount of repetition.

Except for parts of the Akron, Erie, and Morning Star mines, all the workings of the mines and prospects were inaccessible. The descriptions for these are based on surface mapping and the examination of dumps, old reports and maps in the files of the Callahan Zinc-Lead Co., a private report to the Callahan Zinc-Lead Co. by P. J. Shenon and R. P. Full (1946), and published descriptions, as those of Crawford (1913). The production data since 1901 was furnished by A. J. Martin of the Economics Division, Statistics Branch, U. S. Bureau of Mines, Denver, Colorado, who compiled this information for Dings and Robinson (in preparation). Permission has been obtained from the mine owners for publication of the mine maps and production figures included in this report.

Akron

The Akron mine, the largest mine in the Tomichi district, is a composite of several older mines. The main workings are along the Star fault south of the old town of North Star and access to these workings is through the Akron tunnel, the portal of which is about 800 feet south of Whitepine and 300 feet east of road along Tomichi Creek (pl. 1). The portal of the Akron tunnel, and the surface installations, may be reached by a road that joins the road along Tomichi Creek about 1000 feet south of Whitepine.

The mine is owned by the Callahan Zinc-Lead Company, who control most of the claims in the Whitepine area (pl. 2). Near the portal of the Akron tunnel this company maintains their offices and operate in conjunction with the mine a machine shop, a sawmill, and a 80-ton differential flotation mill.

History and production. In 1901 the North Star, Tenderfoot, May, Mazeppa, and W. and A. (Woodworth and Allen) mines were incorporated under the Akron Mining Company, and in that year the Akron tunnel was started to get underneath these mine workings. The tunnel was completed to its intersection with the North Star-Dividend shaft in 1903. From 1903 to 1907 the Akron Mining Company produced ore from the North Star, May, and Mazeppa shafts, and from the Akron tunnel. In 1907 the mine was closed down and was not operated again until 1916 when the mine was reopened and a 60-ton mill built. Very little information is available on the operation of the mine from 1915 to 1937, when the Callahan Zinc-Lead Co. acquired control, and it is believed that the mine was only operated intermittently by leasers. In 1937 and 1938 the Callahan Zinc-Lead Co. reopened the Akron tunnel, but did not mine any ore. The mine was subleased in 1941 and a small amount of ore produced. In 1942 the Callahan Zinc-Lead Co. started operating the mine again and have operated it to the present (1952).

The following table gives the recorded production of the mine from 1901 to 1950. This production came from ore shoots of the North Star, May, Mazeppa, and W. and A. mines. The production for 1924, 1942, and since 1947 includes production of the Erie mine, and possibly others.

Production of the Akron Mine, in Recovered Metal, 1901-1950 5/

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

*Akron, Erie, and other ore combined.

5/ Compiled by A. J. Martin, Statistics Branch, Economics Division, U.S. Bureau of Mines, Denver, Colorado. No production for years not listed. Published by permission of the owners.

The average grade of the ore from 1925 to 1950, as calculated by the Callahan Zinc-Lead Co., was 6.04 ounces of silver per ton, 11.43 percent lead, and 14.96 percent zinc.

Development. The principal workings of the Akron mine consist of about 16,500 feet drifts and cross-cuts, which is more than the total of all the other known workings in the Whitepine area.

The principal means of access to the mine workings is through the Akron tunnel, but as escape man-ways, for ventilation, and for getting power cables into the mine, the Mazeppa shaft and a raise from the 350 level to the Tenderfoot tunnel are kept open.

For convenience of discussion, the working of the mine may be divided into three groups (pl. 3): (1) the Akron tunnel and the Akron level, (2) the Akron-Morning Star development drift, and (3) the main workings above the Akron level.

The Akron tunnel extends from just above Tomichi Creek (altitude of portal 9,720 ft.) eastward for about 3,400 feet where it connects with the Akron level (pls. 3, 4, and 5). This tunnel is the main haulage way for the Akron mine.

The main workings of the Akron level, consisting of about 1000 feet of drift, are south of the tunnel. In addition, about 500 feet of drifts extend north of the intersection of the tunnel with the Akron level. The most westerly of these drifts was driven in order to mine the Mazeppa ore shoot, the rest were exploration work along the Star fault. In 1952 the company was sinking a winze in the most westerly drift north of the tunnel, on what is hoped is the downward extension of the Maseppa ore shoot.

A long exploration drift at the Akron level extends about 2,100 feet east of the Star fault. This drift, a continuation of the Akron tunnel, was driven to intersect the North Star-Dividend shaft and to explore the contact between the Sawatch quartzite and the Manitou dolomite (pl. 5). About 1,100 feet of exploration drift were driven north and south--mostly south--of the main drift to the North Star-Dividend shaft. The main drift was extended eastward from the foot of the North Star-Dividend shaft with the intended purpose of intersecting the ore shoots of the Erie mine at depth, but was never completed.

The Akron-Morning Star development drift was started in 1950 to explore the ground under the Morning Star and Victor mines (pl. 3 and 7). This drift starts from the south end of the Akron level and extends southward for about 1,300 feet and then turns east for about 350 feet and then north for about 250 feet, with a 100-foot cross-cut to the east. At a point about 900 feet south of the Akron level, a drift about 400 feet long was driven east from the main Akron-Morning Star development drift to intersect the Star fault. In 1952 the company started a raise from near the south end of this drift with the intended purpose of intersecting the old workings of the Morning Star mine.

Most of the mining has been done from the levels west of the Star fault and above the Akron level (pls. 3 and 6). Above the Akron level are five main levels, designated as the 75, 100, 150, 250, and 350, which have about 6,000 feet of drifts and crosscuts. In addition, between these main levels are several small sub-levels (now caved). The levels are interconnected by a series of raises: the main raises being the May raise (pl. 3) and the raise near the south end of the Akron level that extends from this level to the 250 level. These upper levels were originally connected with the old workings of the May and Mazeppa shafts (pls. 9 and 10), which are now caved.

Geology. The maps of this mine, plates 4 to 9, are based on surveys by the Callahan Zinc-Lead Co. The geology of all of the accessible workings was mapped by the author from 1949 to 1952. The author was assisted in 1949, when most of the mapping was done, by Donald H. Whitebread. The geology of some of the inaccessible workings, and in some heavily timbered areas, was modified from maps of the Callahan Zinc-Lead Co. by P. J. Shenon and R. P. Full (1946).

All the formations in the district, with the exceptions of the Belden shale and glacial deposits, are exposed in the Akron mine.

The Silver Plume granite is exposed in the hanging wall of the Star fault on the Akron level (pl. 4), the Akron-Morning Star development drift (pl. 7), and the 250 level (pl. 6). At each exposure the rock was shattered and altered and the drifts were heavily timbered so the exposures were poor. All the minerals in the rock, except for quartz, were altered beyond recognition. The identification of this rock was based on the quartz and the position of this rock.

The Manitou dolomite--the host rock for the main ore bodies of the Akron mine--is exposed on all levels of the mine and on both the hanging and foot walls of the Star fault. On the foot wall of the fault the Manitou dolomite is shattered, altered, and locally mineralized. Although at most places the beds are difficult to distinguish, in general they strike northerly and dip 30 to 80° E. On the hanging wall of the fault this formation is recrystallized but not highly shattered or altered except adjacent to the fault and along the ore zone near the North-Star Divident shaft. The formation has been folded but not highly faulted east of the Star fault.

The Harding quartzite, Fremont dolomite, Chaffee formation, and Leadville limestone are only exposed in the long exploration drift east of the Star fault on the Akron level (pl. 4). No ore bodies have been found in these formations.

The rhyolite--termed the Akron formation by Shenon and Full (1946)--is exposed on the foot wall of the Star fault in the Akron tunnel (pl. 5), the Akron level (pl. 4), the Akron-Morning development drift (pl. 7), and the 75, 100, 150, and 250 levels (pl. 6). The main body of the rhyolite is west of the principal mine workings and is cut by the Akron tunnel (pl. 5). On the various levels of the Akron mine it may be seen that this formation intruded the Manitou dolomite and forms the foot wall for the western ore zone. The alteration (as previously discussed p. 50) is so intense that it is difficult to distinguish this formation from the altered Manitou dolomite. The contact with Manitou dolomite may only be mapped approximately because of the alteration and the numerous small stringers of rhyolite that irregularly intruded the Manitou.

The Princeton quartz monzonite is not exposed in the main working of this mine. It is only exposed, about 1,800 feet of it, in the Akron tunnel, and this is the best exposure of the formation in the district. Here it is a gray, medium-grained, equigranular rock consisting of about equal proportions of orthoclase and plagioclase (andesine-labradorite) feldspar, quartz, biotite, and hornblende, with accessory minerals of sphene and magnetite.

Two quartz latite porphyry dikes cut the Princeton quartz monzonite in the Akron tunnel; one about 1,220 feet and the other about 1,480 feet east of the portal. The dikes are composed of a gray-green, aphanitic, porphyritic rock, with phenocrysts of quartz, orthoclase, plagioclase (labradorite), biotite, and epidote. The groundmass is microgranular and no minerals could be identified. The plagioclase feldspar are the most abundant phenocrysts. The epidote is alteration product of the biotite. Accessory minerals are titanite, magnetite or ilmenite, and pyrite (probably secondary).

A rhyolite porphyry dike, younger than the rhyolite body and the Princeton quartz monzonite, is exposed in the main workings of the mine (pl. 4, 6). This dike, and branches of it, intruded the Star fault zone and locally the foot and hanging walls of the fault. It is not everywhere present along the fault, locally at some levels it was not intruded but may be along the fault directly above or below this level. As an example, on the 150 level (pl. 6), near its north end, the dike divides into two branches. The western branch does not extend through to the 250 level but terminates in a blunt end about half-way between the levels. The dike ranges in thickness from a few inches to as much as 90 feet. In general, it dips 30° to 80° E. Locally, however, it may dip steeply west. It forms the hanging wall for several of the main ore bodies of the mine.

The rhyolite dike is typically a white, aphanitic porphyritic rock with phenocrysts of sanadine, plagioclase feldspar (oligoclase), and biotite; phenocrysts of quartz are rare. The groundmass is microcrystaline with a varying amount of glass. Accessory minerals are sphene, magnetite, and apatite. The dike at its contact with the country rock is finer grained than the main mass of the dike. Locally, pitchstone porphyry formed at the contact (pl. 4). These zones of pitchstone range from 6 inches to 3 feet thick and grade into the typical rhyolite porphyry.

All exposures of the dike show some alteration, chiefly sericitization of the feldspar and alteration of biotite to chlorite, and possibly hydromica. Locally along the foot wall of the dike, and particularly where an ore body is in the Manitou dolomite west of the dike, the dike is highly altered. The phenocrysts, except for a rare quartz grain, and the groundmass may be completely altered to a dark gray clay in which no minerals could be identified.

The chief structure in the mine is the Star fault. The fault is cut by workings on the Akron level (pl. 4), the Akron-Morning Star development drift (pl. 7), and the 150 and 250 levels (pl. 6). On the Akron level, on the eastward continuation of the Akron tunnel, the fault is a 110-foot breccia and gouge zone containing 90 feet of altered rhyolite porphyry. At the south end of the Akron level, the fault is about a 40-foot zone of breccia of Manitou dolomite (in part mineralized) in a clay gouge. The Star fault zone at the south end of the Akron-Morning Star development drift is 35 feet wide and completely filled with rhyolite porphyry. In contrast to these exposures, is an exposure in the easterly drift at the north end of the 250 level (pl. 6) where the fault is a 2 to 6-inch gouge seam.

The displacement along the Star fault could not be measured in the mine, or at the surface. At the north end of the fault, at the surface, the Manitou dolomite has been thrust westward over the rhyolite. On Lake Hill, Silver Plume granite has been thrust over Leadville limestone, a minimum displacement of 700 feet but the actual displacement is believed to be much greater (pl. 91).

The fault strikes northward and dips, in general, from 30 to 80° E. Locally, however, it may dip steeply west.

The country rock on either side of the Star fault is cut by many smaller faults; most of them essentially parallel to the Star fault. Most of these were probably formed at the same time as the Star fault. There has been some faulting, however, since the intrusion of the rhyolite porphyry and the deposition of the ore. At the west contact of the rhyolite porphyry dike is from 2 to 24 inches of gouge at most exposures, which could only have developed by repeated movement along the contact after the intrusion of the dike. Several small faults offset the ore bodies or the contact of the rhyolite porphyry, most of them too small to show at the scale of mapping. One good example of such a fault may be seen on the 75 level (pl. 6).

The sedimentary rocks were folded prior to the formation of the Star fault. The sedimentary rocks to the west of the Star fault are so highly shattered and altered that no details as to the folding could be worked out. To the east of the Star fault, on the Akron level (pl. 4), are the downward continuation of the northward plunging syncline and anticline that controlled the deposition of ore in the Tenderfoot and North Star mines. Very little ore was found along these structures in the Akron mine.

Ore bodies. The ore bodies in the Akron mine are in a wedge of Manitou dolomite west of the Star fault and east of the rhyolite. This wedge of Manitou dolomite ranges in width from about 20 feet, as at the north end of the Akron level (pl. 4), to about 80 feet, as near the south end of the 150 and 250 levels (pl. 6). The principal ore bodies are along two zones in this wedge; one along and just west of contact of the Manitou dolomite and the rhyolite porphyry dike that intruded the Star fault--known as the "hanging wall ore zone"--, and the other just east of the contact of the Manitou dolomite and the rhyolite intrusive--known as the "foot wall ore zone." At the north end of the 150 and 250 levels, the two zones grade into each other.

The ore bodies in the zone just west of the Star fault were the first mined; these were the ore deposits of the May, Mazeppa, and W and A mines. The ore occurs in lenticular bodies elongated parallel to the Star fault. The eastern contacts of the ore bodies are from a few inches to a few feet from the contact of the Manitou dolomite and the rhyolite porphyry dike. The ore bodies are never in direct contact with the dike, being always separated from the dike by at least a few inches of gouge. These contacts of the ore bodies with the country rock are sharp.

Plate 8, a stope map of the hanging wall ore zone, shows the extent of the ore deposits along this zone. The map gives the erroneous impression that there was only one ore body, which is not true. As may be seen on the maps of the 150 and 250 levels, plate 6, the ore of these levels was in two distinct bodies, which when projected into the vertical plane for plate 8, gives the erroneous impression.

The ore bodies range in pitch length from 50 to 300 feet, in breadth from 10 to 150 feet, and width from 2 to 25 feet. Their dip is, in general, parallel to the Star fault and ranges from 40 to 80° E.

The ore bodies of the foot wall ore zone are at or within a few inches of the contact of the Manitou dolomite and the rhyolite. They are not as well defined as those in the hanging wall zone in that their contacts are "assay contacts." That is, the country rock has been mineralized over a considerable distance and the ore bodies are only that part of mineralized country rock that may be mined at a profit. The western contacts of the ore bodies are more sharply defined than the eastern, as no ore has been found in the rhyolite and most of the Manitou dolomite has been highly mineralized at its contact with the rhyolite. Locally faulting has occurred along the contact and few inches of gouge has developed that separates the ore bodies in the Manitou dolomite from the rhyolite.

Plate 9, a stope map of the foot wall ore zone, shows the extent of mining as of 1952. At this time a considerable amount of ore was still to be mined. Most of the ground above the 150 level to the sub-level above the 250 level, except for the southern third, was ore. The ore deposits as mined range in pitch length from 50 to 300 feet, in breadth from 10 to 150 feet, and in width from 3 to 75 feet. The dip of the ore bodies approximately parallels the dip of the east contact of the rhyolite, which ranges from vertical to 50° E.

In addition to the two ore zones, there are many small mineralized fissures throughout the mine. Most of these are in the wedge of Manitou dolomite west of the Star fault. They also occur in the Manitou dolomite in the Akron-Morning Star development drift (pl. 7), and in the Manitou dolomite, Chaffee formation, and Leadville limestone on the Akron level east of the Star fault (pl. 4). The ore deposits of the North Star mine interesected by the workings on the Akron level are described with those of the North Star mine.

Mineralogy. Most of the ore mined has been composed of primary sulfides. The early mining through the May, Mazeppa, and W and A shafts was, undoubtedly, oxidized ore.

Very little is known of the character of the oxidized ore except for a few specimens found on the dumps of the old shafts. The character of this type of ore from this area is briefly described with the descriptions of the May, Mazeppa, and W and A mines. In the recent workings of the Akron mine, some oxidized ore was encountered at the south end of the 350 level (pl. 6) about 150 feet below the surface.

The oxidized ore on the 350 level of Akron mine consisted of 2 to 4 feet of iron-stained Manitou dolomite cut by 1 to 12 inch bands of siliceous limonite and calcite containing cerussite and residual grains of galena, and 1 to 6 inch bands of unaltered galena and sphalerite.

The ore in the hanging wall ore zone and the foot wall ore zone are very different in physical appearance and in grade. The mineralogy is the same. The ore in the hanging wall ore zone is composed of large masses of fine- to coarse-grained sphalerite and galena with small disseminated grains of pyrite and chalcopyrite and very little intermixed gangue. Much of this ore averages better than 30 percent combined lead and zinc, the ratio of zinc to lead being about 4 to 3 with about 6 oz. of silver per ton. The ore in the foot wall ore zone is composed of 1 to 6 inch bands of sulfides in a gangue of clay and silicified Manitou dolomite, with disseminated sulfides. The individual bands of sulfides consist of layers of nearly pure galena with some sphalerite alternating with layers of sphalerite mixed with pyrite and chalcopyrite. The width and spacing of the sulfide bands determine the mineable limits to the ore. The average grade of the ore mined from the foot wall ore zone is between 10 and 15 percent combined lead and zinc with a ratio of zinc to lead of about 2 to 1 and with about 7 ounces of silver per ton.

The sphalerite is the ferriferous variety marmatite as indicated by its dark brown to black ("black-jack") color. It is massive, occurring in anhedral grains of from less than 1 to 20 mm in diameter intergrown with grains of galena. The galena is massive, cleavable, and in anhedral grains of 1 to 20 mm in diameter. (A few cubes of galena as much as 2 inches across were seen in small vugs in the country rock.) The pyrite is fine- to medium-grained (less than 1 to 10 mm in diameter), in euhedral to subhedral cubes, and the grains are usually cut by many microscopic fractures. The pyrite is disseminated in the ore and gangue minerals and in the wall rock. Locally, particularly in and near the foot wall ore body are veins of almost pure, fine- to medium-grained pyrite. The chalcopyrite is medium-grained (1 to 10 mm in diameter), anhedral, and, as compared to the other minerals, rare. No silver minerals were seen in the ore, or in polished sections of the ore, nor have any silver minerals been reported from the Akron mine. As the silver that is produced is refined from the lead concentrates, it is assumed that silver occurs in the galena.

Although there is a difference in the physical appearance and mode of occurrence of the ore from the two ore zones, there is no apparent difference in the paragenesis. Pyrite, accompanied by silicification, was the first mineral deposited. The pyrite has been replaced by sphalerite and galena along small fractures in the pyrite and along grain boundaries. The sphalerite and galena form mutual boundaries and were apparently deposited simultaneously. In some polished sections it appears that the galena replaced the sphalerite more than the sphalerite replaced galena. Possibly, the deposition of galena continued after the deposition of sphalerite had stopped. The sequence of the deposition of the chalcopyrite in the ore of this mine cannot be determined; chalcopyrite is rare. Specimens from other mines, however, indicate that the chalcopyrite was deposited simultaneously with the sphalerite and galena.

The principal gangue of the ore is altered Manitou dolomite, a white to dark gray clay-like substance (plastic) resembling fault gouge, and fine- to coarse-grained quartz and calcite. The Manitou dolomite has been highly silicified. The silicification apparently preceded the ore deposition and was accompanied by the introduction of disseminated pyrite. The fine-grained quartz is intermixed with the ore minerals and, in some cases, has replaced the ore, indicating that the deposition of silica continued after the ore minerals started to be deposited. The fine- to coarse-grained calcite occurs as irregular masses in the ore and in the small mineralized shears. It forms a mosaic pattern with the ore minerals but also fills small cracks in these minerals, which would indicate that some of it was deposited with the ore minerals and that its deposition continued after the deposition of the ore minerals had stopped.

The character of the clay-like material in the ore is not known; no minerals could be identified. Some of it resembles gouge in that it occurs in thin stringers of less than 1 to 2 inches wide. It could possibly be gouge that developed along faults that were later used as channel-ways for the ore solutions, the ore solutions replacing the country rock but not the gouge. Another possibility is that it may be residual argillaceous material not replaced by the ore that replaced the carbonate minerals of the Manitou dolomite.

Structural control. The principal structural control for the deposition of the ore deposits was the Star fault. This fault, and the related faults in the Manitou dolomite in the foot wall of the fault, were the major channels for the ore-bearing solutions rising from depth. The Star fault was intruded by the rhyolite porphyry dike and this, and the impervious nature of the fault gouge and breccia, probably deflected the solutions into the many small faults in the Manitou dolomite. As would be expected, the more highly fractured zones in the Manitou dolomite are next to the Star fault and along the contact of the Manitou dolomite and the rhyolite intrusive. These correspond to the "hanging wall" and the "foot wall" ore zones.

The ore bodies have an apparent northward plunge. This could be accounted for by the fact that the main mass of the Princeton batholith, the probable origin of the ore solutions, lies to the north. The ore solutions, rising from some depth in the batholith, would be expected to migrate south and upward from the batholith.

Breadwinner

The Breadwinner mine is on the northwest slope of Lake Hill, about 2,000 feet N. 60°W. from the top of this hill (pl. 1). It was controlled in 1952 by the Callahan Zinc-Lead Co., who hold it under lease and option from the Hayden Mining Company of Colorado Springs, Colorado.

No production has been reported from this mine and the size of the dump indicates that the workings were not extensive. The mine was worked through a shallow shaft that was sunk along the contact of the Fremont dolomite and the Chaffee formation. From the material on the dump, it is judged that most of the workings were in the basal shaly limestone--locally known as the "Fairview shale" --of the Chaffee formation. Some of this shaly limestone on the dump of the shaft contains the oxidized ore minerals calamine, cerussite, and smithsonite, and the primary ore mineral galena, in a gangue of banded sugary quartz and limonite. A sample of this material, as reported by Crawford (1913, p. 302), assayed 37.70 percent zinc. There is no surface evidence of mineralization in the vicinity of this mine.

Congress Tunnel

The Congress tunnel was driven into Porcupine Ridge from a point about 100 feet north of the Galena Creek road and about 1,500 feet northeast of the town of North Star. The portal may be reached by a trail from the Galena Creek road. The tunnel is on the Comstock Jr. patented claim, controlled in 1952 by the Callahan Zinc-Lead Co.

No production has been recorded for this mine. In 1952 the tunnel was caved about 50 feet in from the portal and, judging from the size of the dump, the workings are not extensive.

The tunnel was apparently driven along the contact of the Leadville limestone and the Belden shale. The dump consists of quartzites and argillites typical of the Belden shale, and of limestone marble and dolomitic limestone marble similar to the Leadville limestone. The ore minerals occur in a dark green, fine-grained, epidote-diopside-garnet rock that is believed to have originally been a limestone or dolomite. The ore seen on the dump is similar to that of the Erie mine (p. 174) and consists of aggregates of intergrown sphalerite, galena, and pyrite, and minor disseminated chalcopyrite.

David H.

The David H. mine is about 1,400 feet northwest of the top of Lake Hill (pl. 1). It may be reached by a poor road that goes past the Eureka-Nest Egg and Erie mines and joins the road along Galena Creek about 1,500 feet northeast of the town of North Star. In 1952, the mine was held by the Callahan Zinc-Lead Company under a lease and option from the Hayden Mining Company of Colorado Springs, Colorado.

Very little information is available on the history or production of the mine. The following table gives the production of the mine from 1901 to 1950.

Production of the David H. Mine, 1901-1950 6/

Year	Crude Ore (Dry Tons)	Gold (Ounces)	Silver (Ounces)	Lead (Pounds)
1901	108		4,997	
1902	374	5	14,191	184,041
1903	30		1,116	750
Totals	512	5	20,304	184,791

6/ Compiled by A. J. Martin, Statistics Branch, Economic Division, U.S. Bureau of Mines, Denver, Colorado. No production for years not listed. Published with permission of the owners.

The mine was worked through three shafts, all of which are now caved. No information is available as to the depth of the shafts or the extent of the underground workings. The most easterly of the three shafts has the largest dump and may have reached a depth of about 100 feet. The other two probably did not exceed 50 feet in depth.

The shafts were sunk in dolomite marble of the Leadville limestone. The marble here is a grayish-white or dark-gray, coarsely crystalline dolomite. Locally the marble contains clusters of radiating, fibrous, grayish-white crystals of tremolite.

The ore is oxidized lead-zinc-silver ore and occurs in small pockets along steeply dipping, northerly striking fractures. Ore minerals, identified from material on the dumps, include galena, cerussite, calamine, and smithsonite. In addition, Crawford (1913, p. 302) reported tetrahedrite and stephanite. The ore minerals occur in a gangue of dolomite marble, in banded sugary-quartz, or siliceous limonite. Good specimens of cerussite and calamine were found lining small vugs in the banded quartz.

Denver City

The Denver City patented claim is near the east end of West Point Hill (pl. 1, 2). In 1952 it was controlled by the Callahan Zinc-Lead Company. Very little is known about the history of the mine, and apparently no ore has been produced for many years. The mine was reopened in 1934 but no production was reported. The available production figures on this mine, obtained from reports of the Director of the Mint (Kimball, 1887, 1888; Leech, 1890) is given below.

Production of the Denver City Mine, 1888, 1889, 1890

Year	Gold	Silver	Copper	Lead	Total
1888	$ 40.00	$1,939.35		$352.00	$2,331.35
1899	322.00	565.00	$ 105.57		992.57
1890	80.00	155.00	1,680.00		1,915.00
Totals	$442.00	$2,659.35	$1,785.57	$352.00	$5,238.92

The mine was worked through an inclined shaft (bearing N. 71°E. at 55 degrees inclination) about 350 feet south of West Point Hill, and a tunnel (bearing about S. 9°E.) about 1,000 feet north of West Point Hill. The shaft was caved in 1950, but the size of the dump would indicate that the shaft reached a depth in excess of 100 feet. The tunnel was also caved in 1950, and it is assumed from the size of the dump that the tunnel did not intersect the shaft.

The shaft was sunk at, or just below, the contact of the Fremont dolomite with the basal shaly limestone (locally known as the "Fairview shale") of the Chaffee formation. Most of the material on the dump is white, massive dolomite marble of the Fremont dolomite. The tunnel, judging from the material on the dump, was started in the Manitou dolomite and cut through the Harding quartzite into the Fremont dolomite. There is no material on the dump that would indicate that the tunnel reached the contact of the Fremont dolomite and the Chaffee formation, which is apparently the ore zone in this mine.

The oxidized ore minerals calamine, cerussite, smithsonite, and malachite were found on the dump of the shaft in the shaly limestone of the basal Chaffee formation. Information available to Crawford (1913, p. 299) was that most of the ore produced was hoisted through the shaft and was obtained from a continuous but patchy ore shoot. A small amount of calamine and malachite were found in Fremont dolomite on the dump of the tunnel. The ore minerals occur in a gangue of banded, iron-stained, sugary-grained quartz and siliceous limonite. Good crystals of cerussite were found lining vugs in the banded quartz.

Erie Mine

The Erie mine is about 1,200 feet northeast of the town of North Star on the south side of Galena Creek. It may be reached by a truck road that joins the Galena Creek road about 1,500 feet northeast of the town. The mine was controlled in 1952 by the Callahan Zinc-Lead Company.

The Erie claim according to Crawford (1913, p. 284) was located in 1882. The only production record prior to 1901 was in 1891 when Crawford (1913, p. 303) reports that the mine produced ore valued at $16,399. From 1901 to 1943 the mine was operated intermittently and all the work was done through the Erie shaft. In 1943 the Callahan Zinc-Lead Company acquired control of the mine and extended the Silver Trowel tunnel, now called the Erie tunnel, about 400 feet to its intersection with number 4 level of the Erie shaft. Since 1944 all the mining has been done through this tunnel.

The following table gives the recorded production of the Erie mine from 1901 to 1947. Included is some production of the Eureka-Nest Egg, May, Mazeppa, North Star, and Spar Copper mines. In 1942 and since 1947 the production of the Erie mine has been included with that of the Akron mine.

Production of the Erie Mine in Recovered Metals, 1901-1947 7/

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

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

The grade of the ore shipped in 1944 is reported by Shenon and Full (1946) to have been 0.0125 ounces of gold and 2.01 ounces of silver per ton, 7.56 percent lead, and 10.48 percent zinc.

The mine was first worked through the Erie shaft, which was caved in 1949. According to Shenon and Full (1946), the shaft is vertical for 90 feet and then inclined to the east for 230 feet. Old maps in the files of the Callahan Zinc-Lead Company show that six levels extend laterally from the shaft (pl. 3). Of these, only the Erie tunnel, or number 4 level, and the number 3 level were accessible in 1949. The total workings consist of about 4,000 feet of drifts and cross-cuts (pl. 3). Plate 10 is a geologic map of the number 3 and 4 levels.

The mine workings, for the most part, are in the Leadville limestone just below the contact of the Leadville limestone and Belden shale. The Leadville limestone, away from the ore zones, consists of medium- to coarse-grained limestone marble and dolomitic limestone marble. Along the ore zones the Leadville limestone has been altered to a green, dense, fine-grained, diopside-epidote-garnet rock that contains masses of magnetite and some tremolite. This rock grades into the unaltered marble through a distance of 2 to 4 feet.

The Belden shale was deposited on an irregular erosion surface on the Leadville limestone. This formation forms the hanging wall for the ore and only the basal units are exposed in the

Erie mine. These consist of interfingering beds of conglomeratic quartzite, quartzite, and argillite, that prior to the contact metamorphism were conglomeratic sandstone, sandstone, and shale. A few metamorphic minerals, as diopside, garnet, epidote, and magnetite, may be found in these basal units of the Belden shale.

The Erie mine is in the west limb of the Whitepine syncline about half-way between the Morning Glim and Star faults (pl. 1). The formations strike northerly and dip 25 to 50 degrees east. The country rock and ore deposits are cut by numerous northwesterly to northeasterly striking faults that dip steeply east or west, the easterly dipping faults being the more common. The displacement, if any, along these faults is small. At the south end of the number 4 level is a fault zone about 70 feet wide. In this zone are blocks of quartzite, up to 4 feet in diameter, cemented with coarsely crystalline calcite. This fault zone could not be found on the surface, and the displacement could not be determined.

The most extensive mineralized zone is in the Leadville limestone along the contact of the overlying Belden shale. This mineralized zone, as exposed in the mine, is about 600 feet long and averages about 8 feet wide (pl. 10). A second mineralized zone, 2 to 6 feet wide, 10 to 30 feet southwest of the zone along the contact, or 5 to 30 feet lower stratigraphically, occurs in the northwestern end of the mine. This second zone apparently pinches out at about the shaft--at least, it has not been found southeast of the shaft. Both mineralized zones approximately parallel the bedding of the Leadville limestone in both strike and dip. These zones, which consist of a mineralized diopside-epidote-garnet rock, are mineralized wherever they are exposed in the mine, but only locally was the mineralization extensive enough to form ore. The contacts of the ore with the diopside-epidote-garnet rock are gradational over 2 to 4 feet. It is notable that no ore bodies have been found in the country rock that has not been metamorphosed to a diopside-epidote-garnet rock. Ore minerals do occur, however, along small fractures in the marble--as along the south drift, southeast of the most southerly raise--and as disseminated grains in the quartzites and argillites of the Belden shale.

The ore minerals are primary sulfides and their oxidation products. The only oxidized ore in the mine was seen on the number 3 level near the Erie shaft and near the portal of the Erie tunnel. This material consists of siliceous limonite with a few grains of galena. On the dump of the Erie shaft, and the dumps of the prospect pits in this vicinity, pieces of oxidized ore may be found that consist of a vuggy iron-stained quartz with anglesite and cerussite surrounding grains of galena and lining the vugs in the quartz.

The primary sulfide minerals in the Erie mine are sphalerite, galena, pyrite, and chalcopyrite. The sphalerite is a dark-red to black variety that occurs in fine-grained, irregularly shaped masses intergrown with the galena. The galena is fine- to coarse-grained and occurs as irregular masses up to 4 inches in diameter. In polished sections, it was noted that the contacts of the galena and sphalerite are the mutual type. Pyrite and chalcopyrite occur as disseminated fine grains in the country rock and as fine to coarse grains in the galena and sphalerite.

The ore minerals occur in a yellowish-green, fine-grained, very dense, locally silicified rock composed essentially of a mixture of diopside and epidote. Garnet (andradite) and magnetite are commonly associated with the ore minerals and locally there is some tremolite. Small amounts of ore minerals are found in the quartzites of Belden shale associated with a sugary quartz gangue.

The paragenesis of the ore and gangue minerals is very clear. In most hand specimens of the ore the relative ages of the minerals can be determined, and a study of polished sections has substantiated what was seen in the hand specimens. The epidote-diopside-garnet rock was formed first, and this rock was first replaced by magnetite. Pyrite is the earliest of the sulfide minerals. In polished sections it may be seen that some cubes of pyrite are partly replaced by sphalerite or galena along crystallographic planes. The sphalerite, galena, and chalcopyrite show mutual contacts and were apparently deposited simultaneously following the deposition of the pyrite.

The ore occurs in shoots that plunge northward. The largest shoot was stoped from at least the number 3 level, a few feet northwest of the shaft, to the number 6 level, a pitch length of about 250 feet. This stope ranges in length from 40 to 200 feet and averages about 6 feet in width. Other smaller shoots, to the north and south of the main shoot, were stoped on both mineralized zones. Most of these range from 20 to 80 feet in stope length, 5 feet in width, and were stoped for a pitch length of 50 to 100 feet (pl. 10).

The controlling factor in the deposition of the ore was the contact of the Belden shale and Leadville limestone. Ore solutions rising from below reached this contact and then migrated up dip along it, depositing ore in the Leadville limestone.

Eureka-Nest Egg Mine

The Eureka-Nest Egg mine is on the north slope of Lake Hill at an average altitude of 10,700 feet. It may be reached by a poor road that passes the Erie shaft and tunnel and joins the Galena Creek road about 1,500 feet northeast of the town of North Star.

The Eureka-Nest Egg mine was one of the earliest mines in the Tomichi district. Crawford (1913, p. 284) reports that in 1879 the first ore was discovered in the district, and in that year the Nest Egg and probably the Eureka claims were located. Kirchoff (1886, p. 255) states that in 1885 the Eureka-Nest Egg was the most prominent mine in the Whitepine district. The reports of the Directors of the Mint give the following production of this mine for the years 1887, 1888, 1890 (Kimball, 1887, 1888; Leech, 1890).

Production of Eureka-Nest Egg Mine for 1887, 1888, and 1890

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

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

Production of Eureka-Nest Egg Mine, 1901-1950 8/

Year	Crude Ore (Dry tons)	Gold (Ounces)	Silver (Ounces)	Copper (Pounds)	Lead (Pounds)	Zinc (Pounds)
1917	35	1	198	24	10,548	
1918	11		61		4,080	
1924	9,762	107	58,546		3,806,380	4,613,051
1933	108	2	1,833		87,146	
Total	9,916	110	60,638	24	3,908,154	4,613,051

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

8/ Compiled by A. J. Martin, Statistics Branch, Economic Division, U.S. Bureau of Mines, Denver, Colorado. No production for years not listed. Published with permission of the owners.

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

On the dumps oxidized ore minerals, cerussite and anglesite, are found associated with galena in vuggy, iron-stained, quartz gangue. Galena crystals averaging about one-fourth inch in diameter are coated with a very thin band of anglesite that in turn is coated with a band of cerussite. Cerussite also occurs as fine white crystals lining small vugs. Galena, sphalerite, chalcopyrite, and pyrite, accompanied by epidote and garnet, are found in irregular shaped masses in fine-grained quartzite and in partially silicified dolomitic limestone marble. Most of the ore, as in the Erie mine (p. 174), is believed to have been produced from the upper Leadville limestone at or near its contact with the Belden shale, and very little from the quartzites of the Belden shale.

Iron King

The Iron King mine is on the east side of Tomichi Creek valley, at an altitude of 10,500 feet, about 4,000 feet northeast of Whitepine. A road to the mine branches to the east from the Tomichi Creek road about 3,800 feet northeast of Whitepine.

The mine was owned in 1950 by the Callahan Zinc-Lead Company. Very little information is available on the history or production of the mine. Crawford (1913, p. 305) reports that sometime prior to 1910 several tons of magnetite and two tons of rich copper ore were shipped from the mine.

No information is available on the workings of the mine. Access to the mine was apparently through an adit but in 1950 the hillside around the portal of the mine had slumped so that neither the exact position of the portal nor the bearing of the adit could be determined. From the dump, it is estimated that workings did not exceed 100 feet.

The country rock is altered limestone marble with interbedded shale and quartzite of the Belden shale. Much of the limestone marble, particularly adjacent to the ore, has been altered to serpentine and tremolite marble, the shales to argillite, and probably the quartzites silicified.

In addition to the Belden shale, in the vicinity of the mine there is Silver Plume granite, a quartz latite porphyry dike, and

Princeton quartz monzonite. The Silver Plume granite is about 50 feet to the northeast of the mine on the hanging wall of the Morning Glim fault. To the southwest about 150 feet is a quartz latite porphyry dike that shows considerable alteration. The Princeton quartz monzonite has intruded the Belden shale and cut off the Morning Glim fault about 600 feet northwest of the mine.

The structure in the vicinity of the mine was difficult to determine because the bedrock is covered with slope wash and vegetation. Apparently the Belden shale dips steeply northeast, but it has been so highly fractured that an accurate dip could not be determined. The mapping of the Morning Glim fault was based on float and the attitude could not be determined. It apparently strikes northwesterly and dips steeply east.

In 1950 the ore bodies of the mine could not be seen. Crawford (1913, p. 305) reports that in 1910 the mine showed a face of magnetite about 30 feet high. In 1906 Harder (1909, p. 194-198) visited the mine and the following description is taken from his report (p. 196, 197).

> The principal deposits vary in thickness from 5 to 40 feet, and extend along the contact (Morning Glim fault of this report) for a distance of several hundred yards. Beyond in either direction is merely a local staining and a few small veins. Ore occurs also in small bodies where the rhyolite (quartz latite porphyry of this report) has intruded the sediments away from the granite contact (Morning Glim fault), especially where the sediments are limestones, and a few deposits are found in the limestone away from the intrusive masses. The deposits along the granite contact (Morning Glim fault) and in

association with the rhyolite (quartz latite porphyry) consist largely of magnetite, but those entirely within the limestone, at some distance from the igneous rocks, are composed of dark-brown porous limonite.

The ore associated with the igneous rocks is mainly a glossy, black, compact magnetite with seams and specks of limonite. Locally this ore grades into blue, fine-grained magnetite with chlorite, quartz, and calcite disseminated through it, similar to some of the Taylor Peak ore. In the Iron King cut, masses of serpentine and quartzite are interlayered with the magnetite. Large masses of brown ocherous material, which probably represent partial replacements of the limestone-shale formation, occur between the sediments and the ore bodies. This partly replaced border varies in thickness and degree of alteration; in some places it consists merely of stained quartzite, but elsewhere it is soft and friable and contains numerous veins of magnetite, limonite, chlorite, and kaolin. Here and there masses of partly replaced sandstone and shale occur as lenses surrounded by ore or as bands between adjacent ore deposits. The sediments near the ore deposits are heavily impregnated with contact minerals, among which the most conspicuous are epidote, chlorite, amphibole, pyroxene, garnet, pyrite, and magnetite.

Isabel

The Isabel mine is about 800 feet north of the town of North Star on the south side of Porcupine Ridge at an altitude of about 10,250 feet. In 1952 the mine was held by the Callahan Zinc-Lead Company under a lease and option from the Hayden Mining Company of Colorado Springs, Colorado.

No records are available on the production of this mine, nor is there any information as to the extent of the underground workings. The mine was worked through an adit, caved in 1950, that was driven N. 90°W. into Porcupine Ridge. Judging from the size of the dump, the workings did not exceed 100 feet.

The adit was driven along the Star fault and the material on the dump indicates that most of the workings were in the Manitou dolomite. In this area, the Manitou dolomite, consisting of limestone and dolomite marble, in the hanging wall of the Star fault has been thrust from the east over the rhyolite in the foot wall of the fault--the fault is believed to dip steeply eastward. The rhyolite is highly altered and fractured and megascopically resembles a quartzite. (Its identification is based upon the study of thin sections and underground mapping in the Akron mine.)

Crawford (1913, p. 307) reports that the mine opened a small body of ore above the "Parting quartzite" (Harding quartzite of this report), and that the ore was chiefly lead carbonate with some galena. Crawford, unfortunately, did not have access to the

Akron tunnel and so did not recognize the rhyolite; he mapped this intrusive as the "Parting quartzite." Interpreting Crawford's description of the occurrence of the ore in the light of the present mapping, it is believed that the ore probably came from the Manitou dolomite in the hanging wall of the Star fault above the rhyolite in the foot wall.

Maid of Erin-Silver Pick

The Maid of Erin-Silver Pick mine is on the western end of West Point Hill about 900 feet west of the road from the town of North Star to the Victor mine. In 1950 the Maid of Erin and Silver Pick patented claims were owned by the Hayden Mining Company of Colorado Springs, Colorado.

The only recorded production from the mine was reported[9] in 1916 to be 55 tons of crude ore that yielded 1 ounce of gold and 1,240 ounces of silver per ton, 277 pounds of copper, and 11,049 pounds of lead.

The mine was worked through a shaft, which was caved when visited in 1949. From the size of the dump, it is estimated that the workings did not exceed 100 feet.

The mine is in a small fault block separated from the adjacent formation by two eastward trending faults (pl. 1). The shaft was sunk at the contact of the Harding quartzite and Fremont dolomite but, from the material on the dump, it is believed that the shaft went through the Harding quartzite and into the Manitou dolomite. The Fremont dolomite in this area is a coarsely crystalline, white dolomite marble; the Harding quartzite is a

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9/ Records compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colorado. Published with permission of the owners.

medium-grained, well sorted, yellowish-brown to white quartzite; and the Manitou dolomite is medium-grained, grayish-white to gray, dolomite or limestone marble.

No information is available as to which formation the ore occurred in, or as to what the ore minerals were; no ore minerals were found on the dump. It is probable, however, that the ore occurred in the Manitou dolomite at or near its contact with the Harding quartzite and that the ore minerals were oxidized lead, zinc, and copper minerals.

May, Mazeppa, and W. and A. Mines

The May, Mazeppa, and W. and A. shafts were incorporated into one mine, the Akron mine, shortly after their discovery. The shafts are 300 to 600 feet southeast of the old town of North Star (pl. 1). The mines were owned in 1950 by the Callahan Zinc-Lead Company.

Very little information is available on the history and production of the mines. Shenon and Full (1946) report that the May shaft was the first of the three shafts started. The following table gives the only production figures available on the mines.

Production of the May, Mazeppa, and W. and A. Mines, 1888, 1890, and 1891 10/

Year	Gold	Silver	Lead	Totals
1888	$300	$11,636	$ 2,640	$14,576
1890		129,792	218,339	348,131
1891		305,200	274,915	580,115
Totals	$300	$446,355	$495,894	$942,822

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

According to Shenon and Full (1946), the mines closed in 1907, and very little if any work was done from 1907 to 1937 when the Callahan Zinc-Lead Company acquired control. Any production of the mines from 1903 to 1950 would have been included with that of the Akron mine.

The workings of the mines were caved when visited in 1950, except for the Mazeppa shaft. The following information was obtained from a report prepared for the Callahan Zinc-Lead Company by P. J. Shenon and R. P. Full (1946). The May shaft extends from the surface to the 400 level of the Akron mine (pl. 8). The Mazeppa shaft extends from the surface to a sublevel about 20 feet above the 400 level. This shaft is maintained as an escape manway for the Akron mine and a conduit for power cables to the mine. The W. and A. (Woodworth and Allen) shaft, which was caved, extends from the surface to the 400 level. The 400 level includes about 600 feet of workings, and at its south end is the May raise, which connects it with the main workings of the Akron mine. The ground above the 400 level is believed to have been stoped from the May shaft to the W. and A. shaft.

The country rock is white and gray dolomitic limestone marble of the Manitou dolomite and a rhyolite porphyry dike. The subsurface geology is not known as the workings were caved or timbered, and there are no geologic maps available. The shafts were started in the hanging wall of the Star fault, which has locally been intruded by a rhyolite porphyry dike. The dike and fault dip east. Shenon (1946) reports that the ore was produced from west of the rhyolite dike, that is, from the foot wall of the fault. The ore occurs in the Manitou dolomite. No specimens of the ore occur on the dumps but it is assumed that the ore of this mine is essentially the same as that of the Akron mine (p. 148). The Akron mine further developed the ore body of the May, Mazeppa and W. and A. mines.

Morning Star

The Morning Star mine is 500 to 1,000 feet northwest of the saddle between West Point Hill and Lake Hill at an altitude of about 10,500 feet (pl. 1). The lower tunnel, the only part of the workings accessible in 1952, is reached by a road that goes south from the Galena Creek road at the old town of North Star. The mine was controlled in 1952 by the Callahan Zinc-Lead Company under a lease and option from the Hayden Mining Company of Colorado Springs, Colorado.

Production was first reported in 1907, and the mine was operated intermittently from then to 1935. There are no earlier records on the mine. In 1951 the lower tunnel was reopened and some of the workings rehabilitated (pl. 13). The following table gives the production from 1901 to 1950.

Production of Morning Star Mine, in Recovered Metal, 1901-50 11/

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

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

The mine was originally accessible through an inclined shaft and two tunnels (pl. 1, 3). The shaft extends from the surface, altitude about 10,600 feet, to about half-way between the upper and lower tunnels. The upper tunnel, N. 55°W. 250 feet from the shaft, extends into the hill for about 600 feet. About 230 feet in from the portal is a short drift to the south that connects the lower tunnel with the shaft. Another drift about 320 feet from the portal goes north from the tunnel for about 120 feet. The lower tunnel, N. 35°W. 650 feet from the shaft, goes into the hill for about 720 feet where it divides into two drifts. The total workings on this level are about 2,500 feet. Below the lower tunnel level, and connected with it by two winzes, is a lower level with about 1,250 feet of drifts and crosscuts.

A long development drift has been driven from the Akron level of the Akron mine to beneath the workings of the Morning Star mine (pl. 7). It is planned that a raise will be driven from this development drift to the winze level below the lower tunnel level. This work is being done to drain the lowest level of this mine and to explore for the continuation of the Morning Star ore shoot.

The workings of the Morning Star mine are in the Silver Plume granite, Fremont dolomite, Chaffee formation, Leadville limestone, and rhyolite or pitchstone porphyry dikes. The Silver Plume granite occurs east of the Star fault in the hanging wall of the fault. Where exposed on the lower tunnel level, it has been highly brecciated and altered; it consists of a grayish-white clay with grains of quartz, and a few indistinct and altered grains of feldspar and biotite.

The Fremont dolomite and Chaffee formation occur only on the lower tunnel level. About the upper 50 feet of the Fremont dolomite is cut by the lower tunnel, and it consists of massive, coarse-grained, white dolomite marble. The Chaffee formation consists of medium- to coarse-grained, gray, brown, or black, dolomite and limestone marble. The two members of this formation, the Parting quartzite and Dyer dolomite, could not be distinguished in this mine. The basal unit, locally known as the "Fairview shale," is well exposed about 115 feet from the portal and consists of shaly limestone, or limestone marble.

The upper tunnel was started in the Leadville limestone but the tunnel is now caved back to a pitchstone porphyry dike that cuts across the tunnel. Although this tunnel was caved and the Leadville limestone could not be observed underground, it may be seen from surface exposures that the Leadville limestone in this area consists of medium- to fine-grained, grayish-white to black dolomite and limestone marble.

Several rhyolite or pitchstone porphyry dikes are cut by the working of this mine; the most important of which is the dike intruded along the Star fault. All the other dikes are believed to be just branches of this dike. The dikes in general strike northerly and dip from 45 to 60°E. Locally, they may dip west. The rhyolite and pitchstone porphyry dikes are just different textural varieties of the same rock. The pitchstone porphyry is found locally along the borders of the rhyolite porphyry dikes and, as near the portal of the upper tunnel, a small dike may be composed entirely of pitchstone porphyry.

The typical rhyolite porphyry consists of a light- to dark-gray aphanitic porphyritic rock with phenocrysts of sanidine (possibly some orthoclase), oligoclase, biotite, and rarely quartz. The typical pitchstone porphyry is a dark-green to almost black glassy rock with phenocrysts of sanidine (possibly some orthoclase), oligoclase, biotite, and rarely quartz. The contacts of the pitchstone porphyry with the rhyolite porphyry are gradational through 4 to 12 inches.

The major structure of the mine is the Star fault. Along this fault the Silver Plume granite has been thrust from the east over the Paleozoic sedimentary rocks to the west. The fault strikes northerly and dips from 40 to 60 degrees east. The vertical displacement along this fault is a minimum of about 700 feet but it is believed that the actual displacement is at least twice this (see p. 87). The fault zone has been intruded by a rhyolite porphyry dike and, if it is assumed that the width of the dike represents the width of the fault zone, the zone ranges in width from about 20 feet to 160 feet.

Throughout the mine are several small faults. Some of these faults, as at the base of the Chaffee formation, are bedding-plane faults. Others essentially parallel the Star fault in strike and dip and are believed to be related to this fault. These small fault zones consist of from 1 inch to 4 feet of gouge and breccia.

The folding in this mine is difficult to determine because of poor exposures at the surface, the intrusion of the dikes, and metamorphism. Apparently, however, the sedimentary rocks strike northerly and dip from 30 to 60 degrees east.

According to Crawford (1913, p. 300) the ore occurs in limestone blocks in fault contact with the granite east of the rhyolite dike, and in limestone west of the dike. He reports seeing sulfide ore bodies 1 to 6 feet wide west of the dike and one ore body east of the dike 6 feet wide and extending upwards for 100 feet, with a dip of 47° east.

The only mineralization seen during the present investigation was in a zone of highly brecciated and silicified limestone or dolomite marble, about 15 feet in width, at the east end of the most northerly drift on the lower tunnel level.

Only a small amount of ore was seen in the mine and on the dumps. The ore in the lower tunnel is apparently partly oxidized as it consists of small grains of galena in a siliceous iron-stained gangue. It was reported to Crawford (1913, p. 301) that lead carbonate extended about 100 feet down from the surface and that a body of oxidized ore 1 to 5 feet thick extended upward 50 feet from the upper tunnel level.

Only primary sulfide ore was found on the dumps. It consists of small (less than 1 inch) patches of galena with disseminated fine-grained galena and yellow sphalerite in a white or gray dolomitic limestone marble. Associated with the galena and sphalerite are small amounts of fine-grained pyrite and chalcopyrite. Crawford (1913, p. 301) reports that an ore sample taken from near the bottom of the shaft, which is about half-way between the upper and lower tunnel levels, assayed 0.14 ounces of gold and 19.10 ounces of silver per ton, 22.7 percent lead, and 45.0 percent zinc.

The paragenesis of the ore minerals in this mine is the same as that of the other mines of the district. That is, pyrite was deposited first followed by the simultaneous deposition of sphalerite, galena, and chalcopyrite.

Unfortunately, very little of the mine was accessible and none of the ore shoots could be examined. Apparently the major control of the ore deposition was the Star fault and the rhyolite porphyry dike along the fault. The hanging wall of the fault and the rhyolite porphyry dike being less susceptible to replacement and less fractured, probably channeled the ore solutions through the blocks of limestone or dolomite between the dike and the hanging wall of the fault, and below the dike in the foot wall of the fault. From the alignment of the workings of the mine, the ore shoots apparently plunge steeply north, the direction of the main body of the Princeton quartz monzonite.

North Star

The North Star mine is about 1,200 feet south of the town of North Star at an altitude of about 10,400 feet (pl. 1). The mine may be reached by a poor road that joins the road along Galena Creek about 700 feet east of the town of North Star. The mine was owned in 1952 by the Callahan Zinc-Lead Company.

The North Star mine was one of the first mines of the Tomichi district. According to Crawford (1913, p. 284) the North Star claim was located in 1879. Ore is reported to have been shipped from the mine in 1881 and 1882 (Burchard, 1882, p. 464) and in 1883 it is reported (Burchard, 1883, p. 308) that seven shafts were in operation and that the ore averaged 140 ounces of silver per ton and 50 percent lead. For 1884 Burchard (1884, p. 217) reports that this mine was producing 4 to 6 carloads of ore per week. There is no production recorded from 1885 to 1900 but in 1900 Roberts (1900) reports the mine produced about 10,000 tons of ore. In 1901 the Akron Mining Company was formed from the North Star, May, Mazeppa, and W. and A. mines, and the Akron tunnel was started. This tunnel was completed to its intersection with the North Star-Dividend shaft in 1903. Since 1901 any production from this mine was combined with that of the other mines of the Akron Mining Company and listed under the Akron mine.

The two main shafts of the North Star mine are the North Star and North Star-Dividend shaft. Neither of these shafts, nor any of the workings of this mine, were accessible in 1950. No information was available on the North Star shaft but plate 3, a composite map of the mine workings of the district, shows that there were five levels off the North Star-Dividend shaft with a total of about 1,200 feet of drifts and cross-cuts. Plate 11 is a geologic map of the North Star-Dividend shaft levels developed from the Akron level of the Akron mine. There are five main levels above the Akron level and two below with a total of about 1,400 feet of drifts and cross-cuts. These maps were modified from similar maps prepared for the Callahan Zinc-Lead Company by P. J. Shenon and R. P. Full (1946).

The country rock, as determined from aerial mapping and the mine dumps, is Sawatch quartzite and Manitou dolomite. The Sawatch quartzite is a brownish-white to white, medium-grained, dense quartzite. The Manitou dolomite consists of grayish-white to dark-gray limestone and dolomite marble.

As none of the workings was accessible to the author, the following description of the occurrence of the ore is quoted from the report by P. J. Shenon and R. P. Full (1946) prepared for the Callahan Zinc-Lead Company. 12/

12/ Quoted by permission of the Callahan Zinc-Lead Company.

The North Star ore is found along the nose of a pitching anticline as irregular replacement bodies in the Tomichi limestone (Manitou dolomite of this report), and along cross-cutting fractures not far above the Sawatch quartzite. The writers mapped three mineralized beds and several cross-cutting fractures whereas Michael Clapp (former manager of the mine) reports four ore bearing horizons. The most persistent and regularly mineralized horizon is immediately above the Sawatch quartzite. None of the stopes were long; for the most part, less than 50 feet, and the thickness was generally less than three feet. The only North Star stope seen by the writers was less than three feet wide.

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

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

Oxidized and primary sulfide ore minerals are found on the dumps of the shafts. Cerussite, calamine, and smithsonite occur in a soft white dolomitic gangue, locally limonitic. Fine- to coarse-grained galena and pyrite are found in the dolomitic limestone country rock and in coarsely crystalline calcite veins.

Fine-grained sphalerite is associated with the galena and there is a small amount of chalcopyrite associated with the pyrite. Most of the rocks on the dumps are iron-stained, and small amounts of azurite, malachite, and chrysocolla are found as stain on some of the rocks.

The structural control to the ore deposition in this mine was undoubtedly the plunging anticline. As would be expected, the rocks at the crest of the anticline were fractured, and probably more so than on the limbs. The ore solutions migrated up the crest of the anticline along these fractures replacing the Manitou dolomite.

Spar Copper

The Spar Copper mine includes the Morning Glim, Ensign, and Parole tunnels, which were driven at different levels to intersect the same vein. They are at altitudes of from 10,400 to 10,600 feet on the east slope of the Tomichi Creek valley, about three-fourths of a mile northeast of Whitepine (pl. 1). The Morning Glim tunnel may be reached by a poor road that joins the Galena Creek road about 2,000 feet northeast of the town of North Star. The Parole tunnel may be reached by a road that joins the Tomichi Creek road about 3,800 feet northeast of Whitepine. Trails connect the Morning Glim with the Ensign tunnel and Parole tunnel. The mine property includes the Morning Glim and Spar patented claims that in 1950 were owned by C. A. Tutt of Colorado Springs, Colorado, and the Jersey, Snowden, Ensign, Iron Duke, and Bob Lee patented claims owned by the Callahan Zinc-Lead Company.

The production records are incomplete and partly contradictory. Leech (1890, p. 134) reported the mine produced silver valued at $698 and lead valued at $428 in 1890. The following table gives the production of the mine from 1901 to 1950 as reported to the U. S. Bureau of Mines. Some production from this mine has been included with that of the Erie, Eureka-Nest Egg, May, Mazeppa, and North Star mines.

Production of the Spar Copper Mine, in Recovered Metal, 1901-1950 13/

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

Shenon and Full (1946) report that according to Mr. Dyrenforth, a former operator of the mine, the mine produced a total of about 4,800 tons of ore. Of this, according to Dyrenforth, 2,300 tons was oxidized copper-silver ore, assaying 7 percent copper and 5 ounces of silver per ton, produced from the Morning Glim tunnel; and 2,500 tons averaging 20 percent lead, 30 percent zinc, 10 ounces of silver, and 0.04 ounce of gold per ton, came from the

13/ Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colorado. No production for years not listed. Published by permission of the owners.

Parole tunnel. According to Shenon and Full (1946) J. E. Dick shipped 320 tons of ore from the mine in 1925-26, which averaged 0.4 percent copper, 12 percent lead, 22 percent zinc, 10 ounces of silver, and 0.047 ounce of gold per ton. The production as reported by Shenon and Full was not credited by the U. S. Bureau of Mines to the Spar Copper mine, and probably was included by the operators with shipments from other mines.

All the tunnels were caved in 1950, and the following discussion is based on earlier reports. The Morning Glim, Ensign, and Parole tunnels are successively lower levels driven to work the Spar Copper vein (fig. 3). Crawford (1913, p. 303) states that the Morning Glim tunnel is about 1,200 feet long, and that the Parole tunnel, after cutting the Morning Glim fault, continues along the Spar Copper vein for about 500 feet. Shenon and Full (1946) report that the Ensign tunnel is about 365 feet long.

The mine workings are on both sides of the Morning Glim fault. This fault strikes northerly and dips steeply east with Silver Plume granite on the east having been thrust over the Belden shale on the west--a vertical displacement of at least 1,400 feet. The ore of the Spar Copper mine was produced from two localities, a vein in the granite east of the Morning Glim fault, and a replacement deposit in the limestone marbles of the Belden shale west of the fault.

The vein is not exposed at the surface, but its trend may be followed for about 300 feet by a series of caved prospect pits and

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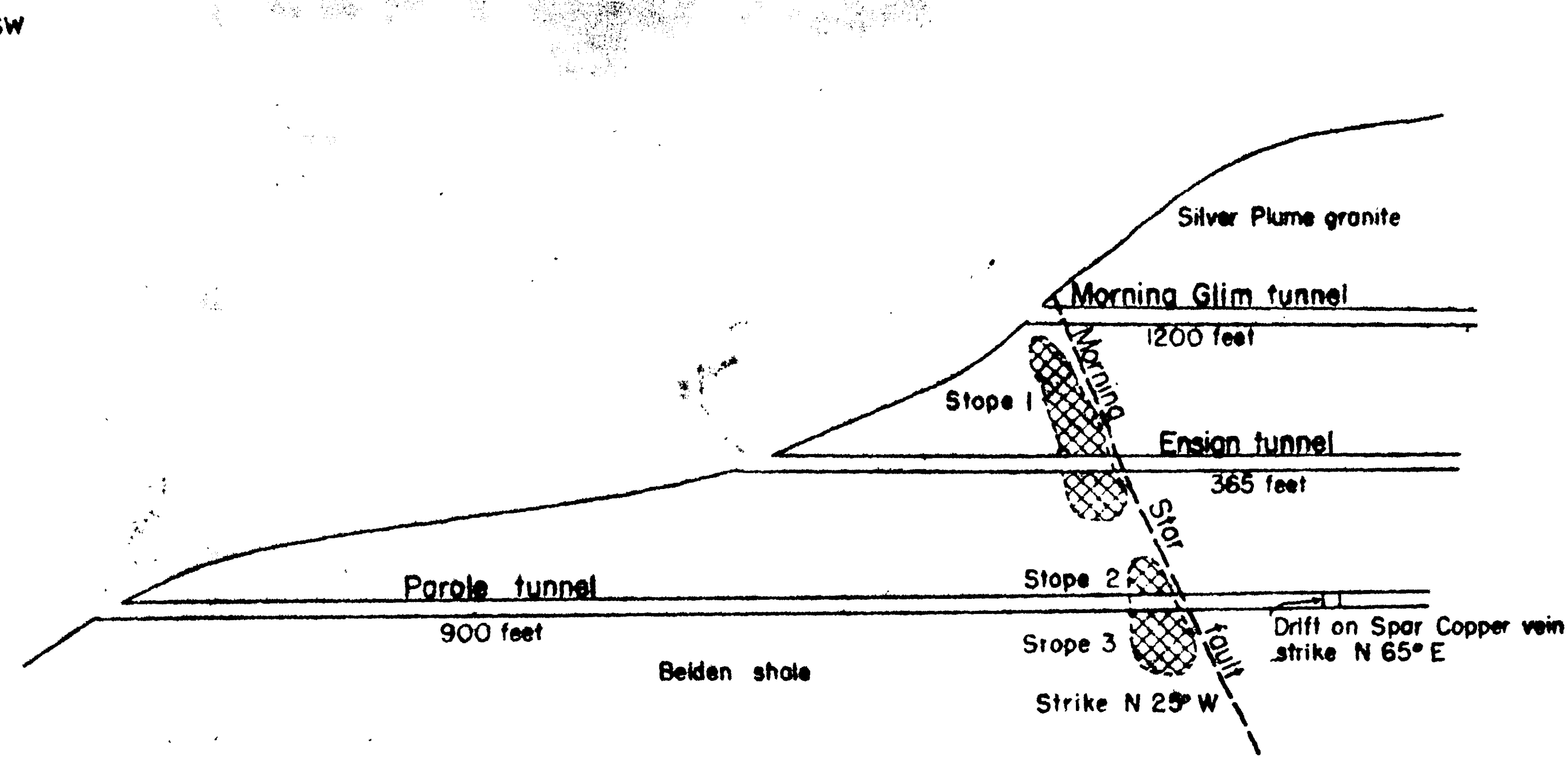


FIGURE 3 SKETCH OF THE SPAR COPPER MINE
(Not to scale)

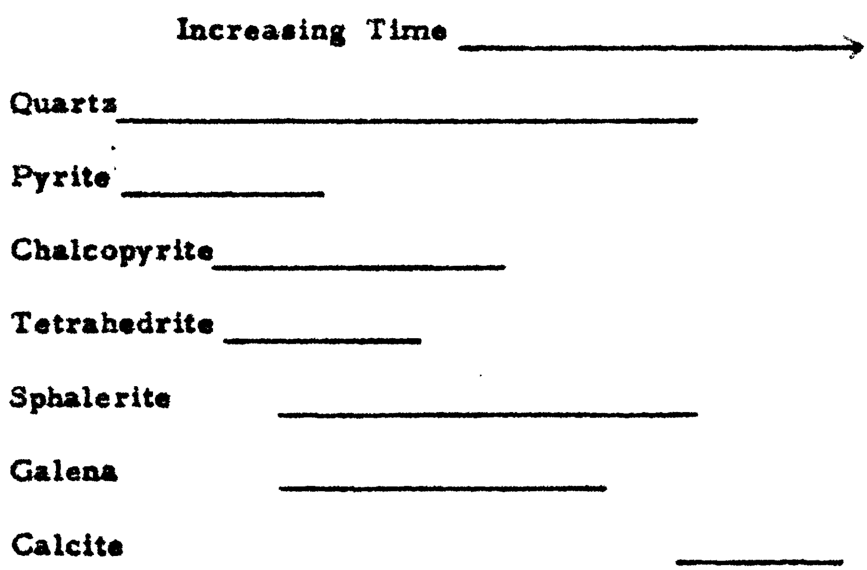
This map is preliminary and has not been edited or reviewed for conformity

Copied from sketch by

shafts. The granite on either side of the vein is a light-gray, medium-grained, porphyritic rock consisting of phenocrysts of feldspar, quartz, and biotite. According to Crawford (1913, p. 304) the vein, as exposed in the Parole tunnel, is about 3½ feet wide, and includes ore about one foot wide. The ore occurs in lenticular bodies on either side of the vein or in small stringers in the vein. The vein has been followed in the Parole tunnel for about 500 feet. Vein matter on the dumps shows veinlets of banded quartz and pyrite, with minor galena, sphalerite, tetrahedrite, chalcopyrite, and calcite occurring as narrow bands, or lining small vugs in the banded quartz, in the altered granite. The galena is coarse- to fine-grained and may or may not have small grains of sphalerite intermixed with it. Chalcopyrite and tetrahedrite occur lining small vugs or as fine grains intermixed with the other metallic minerals. Crawford (1913, p. 304) found a little enargite and also reported native copper. The feldspars and ferromagnesian minerals of the granite, within and along the vein, have been altered to yellow clay. Where veinlets of quartz and pyrite cut the altered granite, the rock on either side is silicified and pyritized for 1 to 10 inches from the veinlet. Gold and silver are present in most of the ore, as shown by the production records, but their mineral form is not known.

The paragenesis of the ore and gangue minerals of the vein, as determined from a study of polished sections, is shown in the following diagram.

Sequence of Deposition of Minerals
of the Spar Copper Vein



Quartz and pyrite were deposited first and the deposition of quartz apparently continued throughout the time of ore deposition. The early quartz, and that which was accompanied by the deposition of pyrite, is a very fine-grained dark-gray quartz. The later quartz, that which accompanied the deposition of the copper, lead, and zinc minerals, is white medium-grained, and commonly, as are the metallic minerals, is banded and lines small vugs. The chalcopyrite and tetrahedrite were apparently deposited simultaneously. Galena forms mutual contacts with sphalerite and replaces pyrite, chalcopyrite and tetrahedrite. It, in turn, is replaced by chalcopyrite. Pseudomorphs of galena after tetrahedrite occur in some vugs. Calcite, a minor gangue mineral as compared with quartz, occurs as small crystals lining vugs and was apparently the last mineral deposited.

The Parole tunnel, judging from the dump, was the principal means of access to the ore bodies in the Belden shale west of the Morning Glim fault. The Belden shale in the vicinity of the mine is composed of limestone marble with interbedded shale and quartzite. Samples of the ore from the dump of the Parole tunnel contain pyrite, chalcopyrite, galena, and sphalerite with gangue minerals of quartz, calcite, and barite in grayish-white to dark blusih-gray limestone marble. The ore and gangue minerals, with the exception of barite, are fine-grained and occur as disseminated grains in the marble, in aggregates of fine grains 0.1 to 1 inch in diameter, or in small (less than 1 inch) veins. The barite occurs as coarse grains (0.5 to 1 inch in diameter) disseminated in the limestone marble or in coarsely crystalline masses up to several inches in diameter.

The paragenesis of the ore and gangue minerals in the replacement bodies was, with the exception of barite and calcite, apparently the same as in the Spar Copper vein. Barite apparently preceded the deposition of all other minerals and calcite, rather than following the deposition of the other minerals, accompanied the deposition of all other minerals.

Malachite and azurite were the only oxidized ore minerals found. These occurred as stain on some of the rock on the dumps and were probably derived from the oxidation of chalcopyrite and tetrahedrite. Dyrenforth reported to Shenon and Full (1946), however, that 2,300 tons of oxidized ore was shipped from the Morning Glim tunnel.

As none of the mine was accessible, the details as to the shapes of the ore shoots or their alignment could not be determined. The Spar Copper vein is probably a filled fissure related to the formation of the Morning Glim fault. The Morning Glim fault was also probably the major structural control for the emplacement of the ore bodies in the Belden shale, furnishing a channel way for the ore-bearing solutions.

Tenderfoot Tunnel

The portal of the Tenderfoot tunnel is about 700 feet south of the Town of North Star at an altitude of 10,200 feet (pl. 1). A poor road goes west from the portal of the mine about 300 feet and joins the road from the town of North Star to the Morning Star mine. The mine was owned in 1952 by the Callahan Zinc-Lead Company.

Very little information is available on the history or production. The Tenderfoot ore body was discovered while driving the Tenderfoot tunnel to its intersection with the North Star-Dividend shaft. L. B. Stitzer reported to Shenon and Full (1946) that the mine produced a large quantity of high grade ore. This production was included with that recorded for the Akron mine.

The Tenderfoot tunnel was driven about 800 feet to intersect the North Star-Divident shaft. Several small drifts, totaling about 580 feet, were driven from both sides of the tunnel. In 1950 the tunnel was caved about 270 feet from the portal. Plate 12, a geologic map of the mine, was modified from one prepared for the Callahan Zinc-Lead Company by P. J. Shenon and R. P. Full (1946).

The tunnel starts in the Manitou dolomite, which here is a grayish-white and dark-gray limestone marble and dolomitic limestone marble. About 250 feet south of the portal it cuts the

Star fault, which brings the Silver Plume granite in contact with the Manitou dolomite. A rhyolite porphyry dike intruded along the fault zone. The west contact of the dike was mapped by Shenon and Full (1946) in a drift south of the tunnel as dipping 75° E., presumably the same as the dip of the Star fault. East of the dike is the Silver Plume granite, followed by northeastward dipping Sawatch quartzite, and Manitou dolomite. The Sawatch quartzite and Manitou dolomite are folded into a syncline plunging to the northeast. According to Shenon and Full (1946), most of the ore was produced from a pipelike ore body just west of the trough of the syncline. The ore was in the Manitou dolomite about 130 feet stratigraphically above the Sawatch quartzite. Shenon and Full (1946) report that this ore body was stoped upward for at least 40 feet, and for a length of from 10 to 20 feet. In addition, a small amount of ore was mined from along a steeply dipping fracture about 60 feet southeast of the main ore body, and from the base of the Manitou dolomite along a bedding-plane fault at the contact of the Manitou dolomite and Sawatch quartzite. There are no records available on the mineral content of the ore, and no ore specimens were observed on the dump. Presumably the ore was mined for lead and zinc.

Victor

The Victor mine is on the south side of West Point Hill, at an altitude of about 10,600 feet, and is 600 feet south of the Morning Star shaft. The mine is reached by a poor road which passes the Morning Star and North Star mines, and joins the Galena Creek road about 700 feet east of the old town of North Star (pl. 1). In 1952 the mine was controlled by the Callahan Zinc-Lead Company under a lease and option from the Hayden Mining Company of Colorado Springs, Colorado.

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

Production of the Victor Mine, in Recovered Metal, 1901-1950 14/

Year	Crude Ore (Dry Tons)	Gold (Ounces)	Silver (Ounces)	Copper (Pounds)	Lead (Pounds)	Zinc (Pounds)
1906	100		1,800		40,000	37,508
1909	74	2	4,640	48,324	17,425	
1916	41		285	84	3,983	10,998
1917	47	1	458	474	4,082	11,000
1919	221		2,175	309	75,764	149,592
1920	251				55,344	106,840
1923	475	5	6,889	1,642	262,485	24,168
1924	166	2	2,220	1,462	76,048	24,883
Totals	1,375	10	18,467	52,295	535,161	364,989

The mine workings were caved when visited in 1950. Old maps obtained by the Callahan Zinc-Lead Company show that the mine was worked by three inclined shafts and a tunnel (pl. 14). The Victor shaft, about 300 feet in length, bears about due east and is inclined 45 degrees. Along the shaft at 40 to 50 foot intervals are six levels with a total of 300 feet of workings. No maps were available of the Victor tunnel, but according to

14/ Compiled by A. J. Martin, Statistics Branch, Economics Division, U. S. Bureau of Mines, Denver, Colorado. No production for years not listed. Published by permission of the owners.

Crawford (1913, p. 300), the tunnel was driven 200 to 300 feet prior to 1911.

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

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

> The largest ore body hitherto discovered in the mine extended from the surface to a depth of 182 feet and was just west of the porphyry dike that may be seen in the Morning Star mine. The longest drift on ore has a length of 300 feet. The greatest thickness of the ore body was eight feet. The ore was chiefly silver-bearing lead carbonate and averaged $62.00 a ton in value. A few years ago a tunnel, which was driven 200 or 300 feet, cut a body of sulphide ore about 75 feet below the surface on the east side of the porphyry dike--that is, between the porphyry and the granite. This ore was in or near the Star fault. Of the four carloads shipped from the tunnel the best ran 93 ounces silver per ton, 26 percent lead, and 6 percent copper.

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

The ore deposition in this mine, as in the Morning Star mine, was controlled by the Star fault, and the rhyolite porphyry dike intruded along the fault. Ore solutions rising along the fault were channeled by the fault and dike into the fractured limestone both above and below the dike.

West Point

The West Point mine is on the north slope of West Point Hill, at an altitude of about 10,200 feet, just west of the lower Morning Star tunnel (pl. 1). It may be reached by a trail from the lower Morning Star tunnel. In 1952, the mine was owned by the Callahan Zinc-Lead Company.

Very little information is available on the history, production, or workings of the mine. Crawford (1913, p. 299) reports that several tons of ore were removed when the adit was being driven and that in 1912 the owners reported shipping a carload of silver-lead carbonate ore. As shown on the plan map of the district, plate 3, the workings, which were caved when visited in 1950, consist of a tunnel about 1,100 feet long and a raise 900 feet from the portal. Crawford (1913, p. 299) states that the tunnel was driven in granite for about 300 feet and then in limestone for 200 feet, but detailed mapping in the vicinity of the mine has shown that the adit was started in Manitou dolomite and intersected a shear zone about 300 feet from the portal. (The shear zone may be followed on the surface by a series of caved prospect pits and shafts.) The adit is then believed to have followed the shear zone to its intersection with the granite.

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

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

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