GEOLOGY AND ORE DEPOSITS

Of The

CAMP BIRD MINE, OURAY COUNTY, COLORADO

by

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ABSTRACT

Geologic mapping in Imogene Basin two miles south of the portal of Camp Bird Mine No. 14 level shows a thick section of volcanic rocks composed of lithic tuff breccias of latite to rhyodacite and welded ash-flow tuffs of andesite to latite. Mine workings which are generally in the San Juan Formation, penetrate the volcanic rocks to the underlying Telluride Conglomerate and Cutler Formation.

Camp Bird vein trends east-west across the thesis area and is intersected by several northwest-trending veins and dikes. Some veins terminate at Camp Bird vein while others cut across this vein structure.

Detailed mapping (1:240) of Camp Bird vein shows that mineralization occurs as three distinct vein components: (1) an early quartz-sulfide component (2) quartz breccia component and (3) bull quartz vein filling. These components exhibit different structural relations that indicate the type of caldera activity that occurred during vein mineralization. Early mineralization occurs filling long continuous tension openings while later mineralization fills open, probable cymoid loop structures created by lateral movement along the vein structure.

Petrographic and geochemical analysis of wall rock samples collected adjacent to the Camp Bird vein show that alteration and trace metal dispersion related to vein mineralization
extend into the hanging wall and footwall to a depth of about 15 feet. Alteration includes addition, by replacement of quartz, sericite and calcite into the hanging wall. Trace metal dispersion associated with Camp Bird vein generally extends less than fifteen feet into the wall rock. It is most pronounced in the footwall. Progressing away from the vein, Cu, Pb, Zn and Ag show a rapid decrease to background levels while Mn shows a more erratic decrease.
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The purpose of this study was to place upon the occurrence and composition of the base metal sulfides and their relationship to the mother rocks in the Camp Bird vein. This investigation included the search for evidence of the presence or absence of copper and silver values in the sulfides occurring in the lower levels (7 level, 9 level, and 14 level). It was time to understand the origin of the quartz vein, the occurrence of the sulfuric and iron-rich silica, and the relationship of the mineralization with the Camp Bird vein. The study also included the study of the veins that occur in the Camp Bird vein between the 7 and 14 levels of the Camp Bird mine. Mapping was conducted on the spot on the western extension of the Camp Bird vein where three levels were evident. No mapping was completed. The area investigated was accordingly confined to that area, and it is hoped that a detailed study could be made of this particular portion of the mine.
INTRODUCTION

Purpose and Scope of Study

The purpose of this study is to investigate the occurrence and composition of the base metal mineral deposits in the Camp Bird vein. This investigation includes preparation of a map of the western portion of Camp Bird vein to show the relation of the ore shoots to vein structure and wall rock types.

Previous work concentrated on the occurrence of the gold ore and paid less attention to the sulfide mineralization in the lower levels (7 level, 9 level and 14 level) and its time and space relation to the gold-quartz breccia and bull quartz vein components.

Investigation of the wall rock bordering Camp Bird vein was conducted to determine the possible presence of alteration and geochemical patterns of dispersion.

This study is confined to fissure filling ore deposits that occur in the Camp Bird vein between the 7 and 14 levels of Camp Bird Mine. Mapping was confined to ore shoots on the western extension of the Camp Bird vein where three levels were available for mapping and correlation. The area investigated was accordingly confined so that a detailed study could be made of this particular portion of the mine.
Method of Study

Field work was conducted during June, July and August of 1973. The work consisted of underground and surface geologic mapping as well as sample collection for both underground and surface exposures.

Underground mapping was conducted on three levels, the 7 level, 9 level and 14 level, on the western extension of Camp Bird vein. Approximately 1000 feet of drift was mapped on each level at a scale of 1 inch = 20 feet. Cross-sections were drawn during the mapping at a scale of 1 inch = 10 feet to show detailed relations of the vein structure and wall rock lithologies and alterations.

Additional underground mapping was conducted in selected areas of 21 Level Orphan Vein replacement ore deposits and 3 level Camp Bird vein. These selected areas served to provide vertical comparison of the ore deposits ranging from the surface to the 21 level, a vertical distance of 4000 feet.

Wall rock samples were collected at five foot intervals along traverses perpendicular to Camp Bird vein into hanging wall and footwall. Sample traverses were taken on the 7 level, 9 level and 14 level for laboratory analysis of possible alteration and geochemical dispersion patterns.

Samples of the vein components were collected to identify mineralogy and characterize each separate vein episode. Samples of the sulfide mineralization were taken to determine the paragenetic sequence of sulfide minerals and gangue material.
Surface geologic mapping was conducted in Imogene Basin to correlate and compare Camp Bird vein with several northwest trending veins that cut across it. This mapping was done on aerial photographs enlarged to approximately 1 inch = 500 feet.

Whole rock samples were collected of each volcanic unit mapped on the surface to describe the volcanic history of the Imogene Basin area.

Thirteen thin sections consisted of wall rock from a sample traverse taken into the hanging wall and footwall of Camp Bird vein on the 7 level. Four thin sections consisted of gangue minerals from Camp Bird vein. The remaining thin sections were cut from rock samples of the volcanic rocks mapped on both the surface and underground.

Sixteen polished sections were made from sulfide ore from Camp Bird vein ore shoots on the 7, 9 and 14 levels.

Forty wall rock and seven vein samples were analyzed for trace metal content by means of atomic absorption spectrophotometry. The analyses were made on a Perkin-Elmer model 303 spectrophotometer for Cu, Pb, Zn, Ag, Cd and Mn.
Mining History and Previous Work

Mining activities first began in the western San Juan Mountains in the late 1870's. After the treaty with the Ute Indians in 1874 the region was opened to prospecting and most of the major lodes were discovered during the following ten years.

Rich lead-silver ore was produced until lower grade and lower metal prices forced abandonment of many of the mines. The district was developed primarily as a silver producer and no efforts were directed toward prospecting for gold. Veins of Imogene Basin were discovered in the 1880's. Mining activity was directed toward northwest-tending sulfide veins, and the sulfide vein in the footwall of the Camp Bird vein. Lower metal prices in the late 1880's made silver mining unprofitable and resulted in the curtailment of mining activity.

During its early history the rich gold-bearing quartz vein along the hanging wall of Camp Bird vein was discarded as waste. In 1896 Thomas Walsh discovered that this quartz contained high concentrations of gold. Subsequently Walsh gained financial control of Imogene Basin and began producing gold from Camp Bird vein at that time.

High grade gold ore was produced from that time up until approximately 1921. In 1916 the 11,000 foot long 14 level cross-cut, Camp Bird East and Camp Bird West drifts were completed. This additional development provided haulage for ore produced on the upper levels but the ore grade at the 14 level
was found to be substantially lower.

After 1921 mining activity was curtailed and limited gold ore was produced by lesors up until World War II. At that time production was shifted to production of base metals.

Upon acquiring the mine in 1968, Federal Resources Corp. sank a 700-foot vertical shaft to gain access to replacement ore bodies on the 21 level. Base metal ores are presently being produced from these replacement ore bodies as well as from Camp Bird vein West above 14 level.

Only limited geologic investigation has been conducted in Camp Bird Mine. Ransome (1901) recognized the compound structural nature of Camp Bird vein and first described the three major components and their spacial relations. Spurr (1925) discussed the age relations of these three major vein components. He decided that mineralization occurred in three sequential pulses: (1) galena-sphalerite-carbonate episode (2) gold-quartz episode and (3) barren quartz episode.

Moehlman (1936) also investigated the compound character of Camp Bird vein. He noted the affects of alteration and replacement associated with the vein development and also recognized two distinct stages in the wall rock alteration: (1) an early regional alteration and (2) a later alteration associated with the veins emplacement.

Burbank(1941) investigated the structural pattern of the region with respect to ore deposits and their relation to the time-space development of the Silverton caldera complex. Varnes (1941) describes epicycloidal fractures in the South Silverton
District and their possible relation to caldera development. He also compares those fractures in the south Silverton area to the Camp Bird vein.

Luedke and Burbank (1968) and Lipman and others (1973) have established some of the time space relations involved in the development of the volcanic centers of the San Juan Mountains. Burbank and Luedke (1969) discuss relations of the alteration to the regional structural tectonics and ore deposit development.
Location and Geographic Setting

Camp Bird Mine is located in the northwest corner of the San Juan Mountains (Figure 1). The San Juan Mountains are a lofty range covering nearly 8,000 square miles of southwestern Colorado. The range is characterized by high peaks with narrow drainage divides and deeply incised valleys.

Imogene Basin is situated on the divide between the Uncompahgre River drainage and the San Miguel River drainage. The basin is located approximately nine miles southwest of Ouray, Colorado at the head of Canyon and Imogene Creeks.

Access to Imogene Basin is by a well maintained gravel road for six miles up Canyon Creek to the Camp Bird millsite. A jeep road continues from the millsite to the basin and over Imogene Pass to Telluride.

Most places around the rim of Imogene Basin can be reached by foot but steep cliffs prevent access to some portions. Elevations in the area range from 9800 feet at the millsite and 14 level portal to over 13,300 feet on the rim of Imogene Basin.

The climate of the area is profoundly influenced by the extreme altitude. This creates a subarctic climate with spruce and fir trees growing on protected slopes. Timberline occurs between 11,000 and 12,000 feet.

The area receives moderate precipitation during the year consisting of heavy snowfall in winter (snow depths may attain 400 inches) and short high intensity thunder showers during
the summer months. The heavy snowfall and late spring melt allow for relatively short field season in the area. Severe electrical storms during July and August also hamper fieldwork.

Access to the underground workings of the Camp Bird Mine is provided by the 14 level tunnel. The portal is located at the Camp Bird millsite and the cross-cut trends approximately S 11° W and intersects Camp Bird vein 11,000 feet from the portal. At a distance of 8572 feet there is a vertical shaft down to the 21 level replacement ore deposits. The workings on the 21 level do not as yet extend to the Camp Bird vein. The replacement ore bodies occur along the Orphan and Walsh veins that trend NW-SE.

Where 14 level intersects Camp Bird vein, drifts have been driven along the vein for about 5000 feet east and 3000 feet west providing access to the ore shoots studied in this report. A 550 foot raise on the 14 level provides access to the 9 level and 7 level workings on the Camp Bird vein West.

Limited access is available to the upper workings of Camp Bird Mine. The 2 level cross-cut is almost totally inaccessible. The 3 level and Chicago cross-cuts provide access to limited portions of Camp Bird vein. Vein workings on the 3 level are accessible for only about 500 feet to the east and west of the intersection of the vein and cross-cut. The Chicago level workings provide access to a portion of the West Camp Bird vein.
Figure 1. Location map. Shows vein outcrop and No. 14 level mine workings. (after Burbank and Luedke, 1964)
Acknowledgments

The writer wishes to recognize the many people who have contributed to the preparation of this report.

Special thanks goes to Dr. R.M. Hutchinson, thesis committee chairman, for suggesting the thesis problem and for his supervision and assistance throughout the entire period of fieldwork and laboratory study.

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Appreciation is also expressed to Federal Resources Corp. for allowing access to the Camp Bird mine workings and permitting me to carry out this study.

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for providing financial assistance in the form of a teaching assistancehip in the Geology and Basic Engineering Departments.

My wife, Kathleen, and family also deserve special thanks for their help and continued encouragement during this program and for the sacrifices they have made.
Figure 2. View looking north across Imogene Basin. Potosi volcanic rocks are visible on Potosi Mountain in background and United States Mountain in middle distance. Silverton rocks outcrop in foreground and San Juan Formation in lower corner. The Pierson (P), Hidden Treasure (H), St. Paul (S), and Camp Bird (CB) are visible.
GEOLOGY

Regional Geology

Rocks outcropping in the Imogene Basin consist of Tertiary volcanics which can be divided into three stratigraphic units (Luedke and Burbank, 1968). These include an older unit composed of the San Juan Formation, a middle unit, the Silverton Group, and a younger unit, the Potosi Group. Quaternary rock glaciers and talus deposits also occur in Imogene Basin.

The San Juan Formation outcrops at the lower elevations in Imogene Basin forming a broad floor. North and east of the thesis area the San Juan Formation outcrops at elevations between 9600 feet and 12,000 feet on the slopes of Sneffles Creek, Canyon Creek and the Uncompahgre River Gorge. West of the area the San Juan Formation outcrops at intermediate elevations of 10,000 feet to 12,000 feet in Savage and Marshall Basins.

The San Juan Formation is about 2500 feet thick in the Camp Bird Mine and appears to thin to the north and west (Luedke and Burbank, 1968). It consists principally of tuff-breccias of rhyodacitic composition with ash-flow tuffs of quartz-latitic composition (Luedke and Burbank, 1963).

Above the San Juan Formation, four formations comprise the Silverton Group which outcrops in a cliff which surrounds
the east, south and west sides of Imogene Basin. The Picayune Formation and Eureka Tuff outcrop for about four miles along two high ridges that trend northeast and northwest of the thesis area.

The Burns Formation outcrops in the flatter upper portions of Imogene Basin and the upper portion of the cliffs on the southwest and southeast corners of the basin. The Burns Formation is about 600 feet thick in the thesis area but thins to zero thickness on the ridge to the northwest (Burbank and Luedke, 1964 and 1966). Two miles to the southeast, within the Silverton caldera, this formation exceeds a thickness of 1000 feet.

The Henson Formation, within the Silverton Group, outcrops as small discontinuous remnants within the thesis area. Other remnants are encountered along the rim of the Silverton caldera to the northeast and southwest of the area. Three miles to the southeast more than 1000 feet of Henson Formation outcrop on Red Mountain in the central part of the Silverton caldera (Burbank and Luedke, 1964).

The Potosi Group consists of the Gilpin Peak Formation and outcrops only at elevations exceeding 12,800 feet on the tops of scattered mountain peaks and along the divide between the San Miguel, Uncompahgre and Mineral Creek drainage basins. This divide forms an arcuate ridge trending northwest and southwest of Imogene Basin.

A system of aphanitic latitic to andesitic dikes trends
northwest across the area connecting the Silverton caldera rim with the Stony Mountain intrusive complex. The Stony mountain complex consists of a composite gabbro-granodiorite stock (Dings, 1941) located three miles northwest of Imogene Basin.

The 21-level workings of the Camp Bird Mine penetrate below the base of the San Juan Formation and into early and pre-Tertiary sedimentary rocks. The Telluride conglomerate and the Cutler Formation are the only sedimentary rocks encountered in Camp Bird Mine. These and older sedimentary rocks outcrop along Canyon Creek and the Uncompahgre River six miles to the northeast in the vicinity of the town of Ouray and along the San Miguel River four miles to the west at Telluride.

The sedimentary rocks that outcrop at Ouray (Figure 3) can be divided into two general sequences (Luedke and Burbank, 1968): (1) an older thin sequence of marine carbonates and clastics south of Ouray and (2) a younger thick sequence of clastic marine and continental sediments north of Ouray. These sedimentary rocks unconformably overlie Precambrian metamorphic rocks consisting of alternate layers of quartzite and slate cut by a diabase dike. The metamorphic rocks outcrop in the Uncompahgre gorge for a distance of about three miles south of Ouray.
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*FIGURE 3. Stratigraphic section of western San Juan Mountains. (after Luedke and Burbank, 1962 and Lipman and others, 1973)*
Regional Structure

The Silverton caldera, located three miles southeast of the thesis area, is the major structural feature of the region. It is situated at the probable intersection of two major structural lineaments in southwestern Colorado: the southwest extension of the northeast-trending Colorado Mineral Belt and the northwest-trending Uncompahgre Uplift (Luedke and Burbank, 1968).

Associated with the Silverton caldera is the Lake City caldera to the northeast along the general lineament trend. Lipman and others (1973) believe these calderas are superimposed upon two older calderas, the San Juan and Uncompahgre calderas.

A system of concentric ring fractures encloses both caldera centers. Ring fractures associated with the older San Juan and Uncompahgre calderas form an elongate ring around both centers. Those around the Silverton and Lake City calderas form a nearly circular or partially circular ring around these centers and within the bounds of the older set (Figure 4).

The thesis area is located about two miles northwest of the boundary fault system of the Silverton caldera. In this area, between the Silverton caldera and the Stony Mountain stock, there is a system of northwest radiating dikes and veins (Burbank and Luedke, 1964, 1966). The Camp Bird vein trends approximately east-west diagonally across this system.
Figure 4. Regional geology and structure of the western San Juan Mountains, after (Burbank and Luedke, 1969)
Geology of Camp Bird Area.

Surface geologic mapping was conducted in the area indicated on Figure 1. Rocks composing the San Juan Formation, the Silverton Group and the Potosi Group outcrop in Imogene Basin. A U.S. Geological Survey quadrangle map (Burbank and Luedke, 1964) is available that covers the Imogene Basin area at a scale of 1:24,000 (1 inch = 2000 feet). Mapping for this study (Plate IV) was conducted at a scale of 1:6000 (1 inch = 500 feet).

Recently, some question has arisen as to the correlation of the rocks included in the Silverton Group. Lipman and others (1973) using potassium-argon age determinations have been able to correlate formations within the Silverton Group with other formations found in the eastern San Juan Mountains. They feel that the Silverton and Potosi Group designation now used combines several unrelated volcanic units that can now be correlated with named formations elsewhere in the San Juan volcanic field. Formation names as mapped by Burbank and Luedke (1964) will be retained to promote consistency between this study and previous work.

No surface exposures of sedimentary rocks were mapped during this study. The sedimentary sequence occurs in the mine workings. Only the Cutler Formation and the Telluride conglomerate have been encountered on the 21 level of the Camp Bird Mine.
Description and Occurrence of Tertiary Volcanic Rocks

San Juan Formation- The San Juan Formation outcrops in the lower topographic portions of Imogene Basin. All major mine workings along Camp Bird vein are within this formation except for the Chicago level.

This formation extends downward nearly to the 21 level. About 250 feet of Telluride conglomerate occurs at and above the 21 level. The Cutler Formation occurs in the floor of the 21 level development workings. All mine workings included in this study are within the San Juan Formation which forms the wall rock adjacent to the Camp Bird vein on the 14 level.

Where mapped on the surface, 7, 9 and 14 levels, the San Juan Formation consists primarily of a lithic-crystal rhyodacite tuff breccia. Lithic fragments consisting of Uncompahgre quartzite pebbles, cobbles and boulders, dacite porphyry and andesite porphyry fragments compose as much as 75 percent of the rock. Most of the lithic fragments are angular lappilli and block sized material. Finer ash and individual crystal fragments are present in smaller quantity.

No stratification or flow structure is observed in hand specimen or in thin section, but the individual tuff breccia units exhibit a crude bedding when observed from a distance on surface exposures (Figure 5).

The San Juan Formation generally exhibits a strong regional propylitic alteration. This alteration is characterized by abundant calcite and chlorite with some epidote. The alteration was observed over large surface areas where outcrops of
the San Juan Formation occur.

**Picayune Formation** - The lowermost formation in the Silverton Group outcrops at the base of a prominent cliff that forms the rim of Imogene Basin. This formation appears to consist of a single unit approximately 80 feet in thickness.

Petrographic examination shows the rock to be a crystal vitric lithic andesite welded lapilli tuff. Ash and lapilli-sized lithic fragments are quartzite, dacite porphyry and andesite porphyry. Devitrified pumice lapilli comprise about 20 percent of the rock. Minor glass shards are present.

The rock exhibits a well-developed compaction structure delineated by highly compacted and densely welded pumice lapilli (Figure 7). Perlitic fractures and chalcedonic amygdules are also present.

This unit generally exhibits only moderate propylitic alteration. Sericitization occurs along with calcitization and hematization.

**Eureka Tuff** - The Eureka Formation occurs as a single tuff-breccia unit overlying the Picayune Formation. It outcrops along the cliffs forming the south rim of Imogene Basin and is only 40 feet in thickness.

The Eureka Tuff consists of crystal lithic latite tuff-breccia. Lithic fragments are quartzite, latite and dacite tuffs. The groundmass is a microcrystalline aggregate that may represent divitrification of glass.

This formation exhibits moderate to intense propylitiza-
tion and sericitization. Biotite phenocrysts have been altered to chlorite and magnetite, and the magnetite has been subsequently hematized.

**Burns Formation** - The Burns Formation outcrops in the higher portions of Imogene Basin. It forms the upper part of the cliff that rims the basin on the east and southwest. It also occurs in the flatter upper basins north of Chicago tunnel and south of the exposure of the Camp Bird vein. Where cut by the Camp Bird vein the Burns Formation is approximately 600 feet thick (Burbank and Luedke, 1964).

Petrographic examination of three thin sections collected throughout the formation indicate two distinctly different lithologies. One is a crystal lithic dacite tuff-breccia or lapilli tuff with lithic fragments consisting of quartzite and siltstone, and volcanic lithic fragments including dacite porphyry, andesite porphyry and dacite welded ash-flow tuff that exhibits well developed flow structure. Plagioclase and some biotite phenocrysts are set in a microcrystalline groundmass of devitrified glass. The other is a fine grained porphyritic-aphanitic hornblende andesite flow that consists of plagioclase, biotite and hornblende phenocrysts exhibiting sub-trachytic texture in an aphanitic groundmass.

The Burns Formation exhibits light to moderate propylitic alteration. Calcite is abundant with chlorite less abundant. Sericite and hematite are the most abundant alteration minerals.
Figure 5. View looking north from Imogene Basin shows crude bedding in San Juan Formation in cliffs at lower right corner of photograph.

Figure 6. Photomicrograph illustrating breccia texture of San Juan Formation. Plane polarized light. 50X.
**Henson Formation** - The upper formation of the Silverton Group occurs as isolated topographic remnants overlying the Burns Formation. These remnants have only limited areal extent and only two such remnants were observed in the area mapped.

The Henson Formation observed in Imogene Basin consists of a fine grained porphyritic-aphanitic biotite dacite flow breccia. Plagioclase and biotite phenocrysts occur in a microcrystalline groundmass.

The phenocrysts exhibit trachytic texture. The Henson Formation appears to contain some lithic fragments that possibly represent earlier volcanic flows incorporated into the flow.

**Gilpin Peak Formation** - The Gilpin Peak Formation, which is included in the Potosi Group, outcrops on the high ridge that forms the major drainage divide west of Imogene Basin. It also occurs as isolated remnants covering the tops of some of the higher peaks surrounding Imogene Basin. Burbank and Luedke (1964) mapped seven units within the Gilpin Peak Formation. Because of difficult accessibility and the marginal position of the Gilpin Peak to the thesis area, only the lowermost unit was observed during field mapping.

The Gilpin Peak consists of vitric-crystal-lithic latite ash-flow tuff. Lithic fragments are subordinate and are composed of dacite porphyry. Glass comprises 40 to 60 percent of the rock with shards more abundant than pumice. Plagioclase (andesine) and biotite phenocrysts occur in a devitrified
Figure 7. Photomicrograph of ash-flow tuff from Picayune Formation. Rock exhibits eutaxitic structure with pumice fragments compacted around phenocrysts. Crossed Nicols. 12X

Figure 8. Photomicrograph of tuff-breccia from Eureka Formation showing silicification (Q) of phenocrysts. Crossed Nicols. 50X
groundmass.

The unit observed is thought to represent a single ash-flow tuff cooling unit. Two thin sections, cut from samples taken near the base ($T_{pg1}$) and approximately 80 feet above the base ($T_{pg2}$) have nearly the same composition. The lower section contains coarser material and lithic fragments while the upper section contains finer material and few lithic fragments. The lower section shows no compaction, welding or flow structure. The upper section exhibits moderate welding, intense compaction and well developed flow structure. Compaction vesicles were observed in an outcrop between these two outcrops (Figure 13).

Thin section $T_{pg1}$ represents the lower unwelded zone of the ash flow and thin section $T_{pg2}$ represents the central densely welded zone. The compaction vesicles do not contain secondary mineralization and are believed to represent the transition zone from the lower unwelded zone to the upper densely welded zone.

Alteration of the Gilpin Peak is generally less intense than in the underlying units. The lower unwelded zone shows moderate calcitization and sericitization, while the upper densely welded zone shows only slight calcitization and sericitization. Biotite phenocrysts in both zones exhibit sericitization instead of the normally observed chloritization in the underlying units.
Figure 9. Photomicrograph of tuff-breccia from Burns Formation containing lithic fragments (LF) consisting of ash-flow tuff. Crossed Nicols. 12X

Figure 10. Photomicrograph of Henson Formation. Note intense silicification (Q) and calcitization (C) of phenocrysts; chloritization (Ch) of groundmass. Crossed Nicols. 50X
Quartz replaces the devitrified flattened pumice in the upper welded zone. These secondary quartz aggregates help to delineate the flattened pumice lapilli.

Moderate hematization was observed in the groundmass of the lower unwelded zone. Also, limonitization was observed adjacent to veins that cut through the Gilpin Peak Tuff. Figure 14 summarizes and compares the hydrothermal alteration of volcanic units mapped.

**St. Paul Dike** - The St. Paul dike was encountered while mapping underground along the ore shoots of Camp Bird vein. It did not outcrop in Imogene Basin in an accessible area but was encountered on the 7 level, 9 level and 14 level (Plates I, II, III). Where mapped the St. Paul dike varies in thickness from about ten feet on the 7 level to nearly 40 feet on the 9 level and intersects the Camp Bird vein with a trend of about N 30°W. Spurr (unpublished report) mapped the St. Paul vein in the western part of the No. 2 level workings that are now inaccessible but did not encounter the dike.

The St. Paul dike consists of microporphyritic to fine grained porphyritic-aphanitic hornblende latite porphyry. Later silicification makes it difficult to distinguish primary from secondary quartz. This rock may be quartz latite in composition.

The dike rock generally exhibits an intergranular to sub-pilotaxitic texture. Hornblende phenocrysts occur in a groundmass of plagioclase and orthoclase microlites with intergranular hornblende. Intense hydrothermal alteration makes positive
Figure 11. Photomicrograph of Gilpin Peak Tuff. Note disoriented phenocrysts that show no compaction. Calcitization (C) of phenocrysts is moderate. Crossed Nicols. 50X
Figure 12. Photomicrograph of Gilpin Peak Tuff. Central welded zone of ash-flow tuff shows devitrified glass (DG) compacted around phenocrysts. Rock exhibits only slight silicification (Q). Crossed Nicols. 6x
Figure 13. Photograph of eutaxitic fabric in lower portion of Gilpin Peak Tuff. Vesicles are tabular shaped cavities oriented nearly horizontal, without secondary filling.
## Alteration Minerals

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<th>Formation</th>
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**s** - strong - major constituent replacing more than two thirds of original mineral.

**m** - moderate - aggregate of both original and alteration mineral.

**w** - weak - original mineral still predominant.

**FIGURE 14.** Summary of relative intensity of hydrothermal alterations observed in volcanic rocks of Imogene Basin.
identification of original minerals difficult. Relict crystal form and alteration products suggest the above composition.

Alteration of this rocks consists of the decomposition and recrystallization of original constituents and also the addition of microveinlets and replacement minerals.

Hornblende phenocrysts have altered to microcrystalline aggregates of chlorite, epidote and calcite. Intergranular hornblende has also altered to chlorite with some epidote and calcite. Plagioclase microlites altered to microcrystalline aggregates of albite or sericite and epidote. Orthoclase microlites altered to sericite and are possibly replaced by quartz.

Microveinlets of quartz, calcite and epidote with pyrite may represent the introduction of material from the Camp Bird vein system. Their appearance is similar to microveinlets observed in samples taken from Camp Bird vein filling. Figure 15 is a photomicrograph of a microveinlet in the hornblende latite porphyry observed on the 7 level.

Variations were observed in the alteration of the St. Paul dike from 7 level down to 14 level. Chloritization was observed to be quite intense on the three levels studied. Epidotization, sericitization and calcitization varied between the levels but appear to indicate a general increase in intensity of alteration of the plagioclase and orthoclase microlites.

On the 14 level microlites show little alteration and appear as distinct fresh crystals. The microlites observed
from 9 level appear to be recrystallized to microcrystalline aggregates of albite but retaining the outline of the microlites. Samples observed from the 7 level show the microlites to be sericitized, epidotized and calcitized.

The variation in alteration observed between the levels seems to be caused by several factors. The most important factor is probably the distance from the Camp Bird vein that the dike was exposed for sampling, but it is believed that the physical character of Camp Bird vein may also be important. On the 14 level Camp Bird vein consists of a number of thin fractures from less than one inch to about two feet thick spaced through an area 70 feet wide. This may have dispersed ascending hydrothermal solutions and decreased the intensity of exposure to the St. Paul dike. On the 9 and 7 levels Camp Bird vein consists of a single fracture about five feet wide filled with vein material. The St. Paul dike on 9 and 7 levels received intense exposure to hydrothermal solutions ascending along the Camp Bird and being restricted to movement through a single fracture at the point of intersection with the St. Paul dike.

**Other Dikes** - Several dikes were encountered during the course of underground and surface mapping. The Pierson dike was mapped on the surface but was not encountered in the area mapped underground. Two dikes encountered underground, one on 7 level and one on 9 level, could not be located on the other levels.
Figure 15. Photomicrograph of calcite-epidote microveinlet shows mineral paragenesis to be quartz (Q), calcite (C), fluorite (F), and epidote (E). Crossed Nicols, 125X
The Pierson dike was mapped where it crosses the northern portion of the thesis area. The dike consists of a fine grained porphyritic-aphanitic biotite andesite porphyry. The aphanitic groundmass exhibits intergranular texture with plagioclase microlites enclosing hornblende. Phenocrysts of plagioclase and biotite make up about 10 percent of the rock.

Hornblende and biotite are chloritized and calcitized while the plagioclase is calcitized and sericitized. Quartz and pyrite are observed to be secondary additions to the rock.

A dike about 30 feet thick encountered intersecting the footwall of Camp Bird vein on the 9 level consists of holocrystalline, porphyritic-aphanitic rhyodacite porphyry, with phenocrysts of quartz, plagioclase, orthoclase and biotite.

Alteration of this rock consists of strong sericitization and calcitization but only slight chloritization.

Another dike about three feet thick encountered on the 7 level intersects the St. Paul vein. It was observed in the footwall of Camp Bird vein but could not be located in the hanging wall. This dike consists of holocrystalline porphyritic-aphanitic rhyodacite porphyry. Plagioclase, quartz, orthoclase and hornblende phenocrysts occur in a felsic groundmass.

Alteration of this rock consists of calcitization and sericitization of the plagioclase and orthoclase. Hornblende alters to chlorite and calcite, quartz and pyrite occur as microveinlets.
Description and Occurrence of Quaternary Deposits

Talus deposits - Numerous limited accumulations of talus occur at the base of many of the cliff-forming volcanic units that outcrop in Imogene Basin. Talus commonly accumulates at the base of Picayune Formation and the Gilpin Peak Formation. Rather extensive talus accumulations occur at the head of Rock Lake basin on the west side of the thesis area. The talus here covers a large area at the base of the cliff formed by the Gilpin Peak Formation (Potosi Group).

The talus is generally composed of angular blocks of the volcanic rocks ranging up to several feet in size. Some of the slopes have angles of repose greater than 40 degrees.

Rock glaciers - Two conspicuous rock glaciers occur in Imogene Basin. One is located at the south end of the basin and the other along the east side.

The rock glacier at the south end of Imogene Basin covers a portion of Camp Bird vein and extends down the valley as far as the No. 3 level portal. Material for this rock glacier was mostly derived from a cliff composed of the Burns Formation that overshadows the head of Imogene Basin. The rock glacier along the east side of Imogene Basin consists of two lobes derived from a cliff of the Burns Formation.

Structure

Imogene Basin and Camp Bird Mine are one-and-a-half miles northwest of the western rim of the Silverton caldera. The position of this area relative to the caldera has profoundly
Figure 16. View looking southwest across Imogene Basin at the prominent rock glacier at the head of the basin. The Camp Bird Vein outcrops at the base of the cliff in the lower left and upper right (CB). The 2 Level Portal is visible in the lower left corner.
influenced thickness of the volcanic units observed.

As noted previously there is a thick section of San Juan Formation in the area. This indicates that the area is near enough to the source to have received large amounts of volcanic material but far enough to not have been involved in the subsidence of the San Juan caldera (Lipman and others, 1973).

Thick sections of the Picayune Formation, Eureka tuff and Burns Formations occur within the rim of the Silverton caldera (Burbank and Luedke, 1964). It is believed that the thin units comprising these formations are ash-flows and tuff-breccias that represent the more siliceous fractions of the lavas erupted (Luedke and Burbank, 1963). These more siliceous lavas erupted with a more explosive force that ejected them out of the caldera and onto the surrounding rim.

The outcrops of Henson Formation that occur in the area may represent erosional remnants of similar explosive lavas that were ejected from the caldera and eroded prior to eruption of the Gilpin Peak Formation.

The Gilpin Peak Formation appears to represent ash-flow tuff eruptions. The ash-flow tuffs do not occur within the Silverton caldera block. They thicken away from the caldera rim in the area northwest of the caldera (Luedke and Burbank, 1968).

Associated with the Stony Mountain stock, located three miles northwest of the thesis area, is a system of narrow
dikes that are radial to the Silverton caldera and connect two centers (Figure 4). The dike system consists of two types of dikes. One type spirals away from the Stony Mountain center. The other type is radial to the caldera and has a N 45°W trend.

The Pierson dike occurring in Imogene Basin is part of this radial dike system and outcrops on the surface for three miles. The St. Paul dike does not appear to outcrop on the surface but is intersected only underground. Lateral surface extent of the St. Paul dike is therefore not known.

The Pierson dike on the surface and the St. Paul dike in the upper level mine workings dip 85° and 82° respectively to the northeast. On the 14 level, however, the St. Paul dike steepens and reverses dip to 85 degrees southwest. It is not known whether the St. Paul dike maintains this southwest dip at greater depth.

Burbank (1941) discusses the formation of these northwest-trending dikes. Fractures appear to have formed when intrusion of the Stony Mountain stock warped the area between these two centers. The warped crust then fractured into several long nearly evenly spaced blocks. Dikes were intruded along the margins of these blocks to yield the long continuous dikes observed in the area.

Two types of veins also occur in the area between the Silverton caldera and the Stony Mountain stock.

As with the dikes, these vein filled fractures consist
of a spiral set and radial set. The Camp Bird vein is the major vein representing the spiral fracture set. The numerous northwest-trending veins in Imogene Basin represent the radial fracture set.

The Camp Bird vein fracture developed after resurgence of the caldera and intrusion of the radial dikes. Subsidence of the Silverton caldera created a radial stress that induced shearing along a fracture that spiraled away from the caldera center (Burbank, 1941). This created the Camp Bird vein fracture which was reactivated and subsequently mineralized during several episodes (see discussion p. 71-73).

These epicycloidal fractures have developed elsewhere around the rim of the Silverton caldera. Varnes (1963) discusses similar veins in the South Silverton mining district. These spiral veins all originate at the ring fracture system outlining the Silverton caldera and spiral away from the caldera. All exhibit predominantly lateral movement. Figure 17 illustrates the stress field necessary for the development of epicycloidal veins.

The Camp Bird vein cuts the previously formed dikes but is subsequently cut by veins following the original northwest trend. It is believed that the northwest-trending veins formed when further distension of the zone between the Silverton caldera and Stony Mountain stock reactivated old fractures and created new fractures. Many of the northwest-trending veins follow previously intruded dikes with only minor dislocations.
FIGURE 17. Plan view of spiral fractures, radial fractures, cone fractures, and their relations to centers of radial stress.

The diagram represents ideal stresses about a circular center. Sr, radial stress; St, tangential stress; the curved lines which intersect the radial directions of principal stress, OR, at 45° are directions of maximum shearing stress. Form abc represents ideal spiral shear fracturing. Some fractures merge with cone fractures to yield form abd.

(after Burbank, 1941)
Most veins, however, are not associated with the earlier dikes. Some veins that outcrop on the surface may be associated with dikes at depth. This relation is exemplified by the St. Paul vein which outcrops on the surface with no attendant dike. At depth the St. Paul vein is associated with a dike though the vein shifts its relative position from hanging wall to footwall to center of the dike. Where these features intersect Camp Bird vein on the 7 level the St. Paul vein is dislocated from the St. Paul dike and occurs nearly 40 feet away from the hanging wall of the dike in the San Juan Formation.

The 7 level exposures of the Camp Bird vein, St. Paul dike and St. Paul vein demonstrate the age relations of these features. St. Paul dike is cut by Camp Bird vein which is subsequently cut by the St. Paul vein.

As demonstrated by the St. Paul vein, some of the northwest-trending veins cut the Camp Bird vein. However, others appear to terminate against the Camp Bird vein, do not cut through and cannot be located on the other side of the Camp Bird vein. This relation also indicates that the northwest-trending veins probably formed after the Camp Bird vein structure.
Summary of Geologic History

The geologic history of the Imogene Basin can be summarized as follows:

1. Deposition of a thick sequence of sedimentary rocks on Precambrian metamorphic rocks (Figure 3). This occurred from the Devonian period through the early Tertiary period. This episode also included several stages of structural activity, mountain building and erosion resulting in the thick accumulation of sedimentary rocks truncated by an angular unconformity and covered by the Telluride Conglomerate.

2. Eruption of pyroclastic rocks that constitute the San Juan Formation from a central vents. Eruptions started during the Oligocene epoch 30 to 35 million years ago (Lipman and others, 1973).

3. Subsidence of the Uncompahgre and San Juan calderas to form the San Juan depression, 28 million years ago (Figure 4).

4. Resurgence of the Uncompahgre and San Juan calderas and the eruption of the Silverton Group of volcanic rocks.

5. Subsidence of Silverton caldera, 27.5 million years ago, and Lake City caldera, 22 million years ago, (Lipman and others, 1973) and eruption of the Gilpin Peak ash-flow tuffs.

6. Resurgence of the Silverton caldera which in Imogene Basin was attended by intrusion of Stony Mountain Stock and radial dikes.
7. Subsidence of the Silverton caldera that created the spiral Camp Bird vein fracture.

8. Mineralization and alteration along fractures during both upsurge and collapse of the Silverton caldera.

9. Glaciation and topographic development during the Pleistocene epoch.

10. Formation of talus slopes and rock glaciers during the Holocene epoch since the cessation of glaciation.
ORE DEPOSITS

Mineralization

Mineralization of the Camp Bird vein is composed of at least four distinct vein components. Each component is characterised by a distinctive suite of minerals that occur in separate vein systems within the Camp Bird vein structure. The difference in composition of the vein components prevented the discovery of gold for nearly fifteen years after the discovery of the Camp Bird vein.

Ransome (1901) reported that Camp Bird vein consisted of three separate mineral components and that the gold ore was confined to one particular component. Spurr (1925) continued investigation of the vein components. He established age relations concerning the gold mineralization in the upper levels of the Camp Bird Mine.

Investigation of the west Camp Bird ore shoots has largely substantiated the findings of these earlier workers. However, some additional relations concerning the sulfide mineralization were observed that the earlier workers did not investigate.

Three major vein components were recognized during underground mapping. A fourth component was observed at isolated locations in the mine but was not found in the area of ore shoots of Camp Bird vein west.

The general mineralogy and character of the vein components remains consistent enough to allow identification on
all levels. One of the major mineralogic variations occurring with depth is the absence of gold in the vein component that produced gold ore in the upper levels of the mine.

**Quartz-Sulfide Component**

This component is the oldest of the three components mapped along the western ore shoots of Camp Bird Mine. It consists of intergrown coarse quartz grains with pyrite, galena, sphalerite and chalcopyrite. In some areas rhodonite was also observed as a gangue mineral.

This component contains from 10 percent to as much as 80 percent sulfide minerals. Generally however, this component appears to contain from 25 percent to 35 percent sulfide minerals.

Generally, galena and sphalerite are more abundant than pyrite and chalcopyrite. Pyrite is occasionally the predominant sulfide mineral. Variations in the relative proportion of sulfide minerals were not found to follow predictable patterns except pyrite was generally the predominant sulfide in low grade sections of the vein.

It was observed that the texture of the vein filling is directly proportional to the sulfide content. Higher sulfide content was found where the vein material exhibited a coarse texture. Conversely low grade sections of the vein exhibited a fine grained texture. Here again the major exception is coarse grained pyrite that occurs in low grade sections of the vein.
The quartz-sulfide vein component occurs in two ore shoots in the area mapped. The ore shoots extend from the 7 level down to the 14 level and vary considerably in lateral extent (Plate I, II, III). The westernmost of the two ore shoots varies in length from about 165 feet on the 7 level to nearly 300 feet on the 14 level. The other ore shoot varies in length from about 100 feet to 130 feet.

The ore shoots are highly irregular but generally appear to plunge to the southeast. Where correlation allowed estimation of the plunge, the western shoot plunges 56° S 40° E and the eastern ore shoot plunges 57° S 45° E.

Where mined along the ore shoots the quartz-sulfide vein component varies in width from 3 feet to about 10 feet. The quartz-sulfide can be mapped extensively outside the boundaries of the stope areas but is found to be quite narrow and often low grade. Only a few short sections along the vein were found not to exhibit a distinct quartz-sulfide vein.

Ransome (1901) and Spurr (1925) describe the quartz-sulfide vein as occurring along the footwall of the Camp Bird vein structure. At deeper levels however the quartz-sulfide component appears to occur along either wall. In some cases where cut by later quartz mineralization the quartz-sulfide component occurs along both the hanging wall and footwall of the Camp Bird vein structure.

Quartz-sulfide mineralization also occurs along a split that breaks into the footwall of the Camp Bird vein on the
14 level (Plate I). The extent of this split is not fully known but it does not occur on the upper levels.

Quartz-sulfide mineralization also occurs along the northwest-trending veins that intersect the Camp Bird vein. This mineralization appears identical to that occurring on the Camp Bird vein except that pyrite is more abundant and sphalerite is less abundant.

**Gold-Quartz Breccia**

This component derives its name from the No. 2 and No. 3 Levels of the Camp Bird Mine where it contained the high gold values. As mentioned previously, no gold values are associated with this component on the levels mapped which are 900 feet below the 3 Level on the Camp Bird structure (Plate VII).

This component consists of a quartz vein breccia composed of intergrown quartz grains surrounding breccia fragments of wall rock and quartz-sulfide vein material. Some sulfide minerals appear to have crystallized during deposition of the quartz but most appear as breccia fragments.

The quartz grains crystallized as elongate grains surrounding breccia fragments or lining the walls of tiny cavities. In thin section many rounded aggregates of quartz grains appear to have been cavities that were completely filled.

Megascopically many smaller vugs are observed lined with small clear quartz crystals, up to one quarter inch long. These small irregular vugs lined with clear crystals and the
Figure 18. Quartz-sulfide vein component. Note intergrown quartz and sulfide minerals w/ fractures in minerals filled with later sulfides. 
(Q) quartz, (sp) sphalerite, (cp) chalcopyrite, 
(g) galena, (py) pyrite

Figure 19. Bull quartz vein component showing cockscomb quartz in base and large quartz crystals.
angular breccia fragments are the most diagnostic features of this vein component.

Gold-quartz breccia occurs as vein filling from one to five feet thick. Within the Camp Bird vein structure it is observed cutting the earlier formed quartz-sulfide vein. The vein also occurs parallel to the quartz-sulfide vein along either the hanging wall or footwall. Veinlets of gold-quartz breccia six inches to one foot thick occur out in the hanging wall and footwall of the Camp Bird vein structure. These are generally more numerous in the hanging wall.

Gold-quartz breccia veins frequently occur associated with the quartz-sulfide ore shoots. These veins are generally narrow but quite continuous. Some thick but discontinuous veins of gold-quartz breccia occur on the 14 level where the Camp Bird structure makes a marked deflection and consists of a wide shattered zone.

Bull Quartz Component

The last vein component to be deposited within the Camp Bird vein structure consists of white crystalline quartz that exhibits a well developed cockscob structure. Generally this vein filling is barren containing no sulfide minerals or other gangue material. Breccia fragments of wall rock are rarely included.

The bull quartz vein component occurs as veins from a fraction of an inch to three feet in thickness. Frequently a vein one to three feet thickness occurs parallel to the Camp
Figure 20. Gold-quartz breccia vein component. Dark fragments are sulfide minerals, lighter fragments are wall rock.

Figure 21. Photomicrograph of rock fragment in gold-quartz breccia showing crude radial growth of quartz around fragments. Crossed Nicols 12X
Bird vein structure (Plates I, II, III). This vein cuts across both the quartz-sulfide type vein and the gold-quartz type vein and may be located on either the hanging wall, foot-wall or in between.

The bull quartz vein frequently contains large discontinuous tabular central cavities which are lined with large stubby quartz crystals up to one inch average diameter.

Large clusters of crystals occur with adjoining prism faces. The rhombohedron terminations of most of the crystals project into the cavity about the same distance. Individual crystals may be nearly one inch across the prism faces but crystals are rarely more than one and one half inches long. In contrast with the long, thin, clear crystals occurring in the gold-quartz breccia these crystals have a milky appearance.

Thin veinlets of bull quartz up to two inches thick and exhibiting a cockscomb structure occur with random orientation cutting the earlier vein components. Some veinlets cut earlier formed bull quartz veinlets. These thin veinlets also occur scattered for some distance into the hanging wall.

Besides the three vein filling components described, horses of wall rock are also observed within the Camp Bird vein structure. These horses occur separating the vein components at several locations. Figure 22 illustrates the structural relations of the vein components observed on the 7, 9 and 14 levels.
Alteration

Thirteen wall rock and four vein sample thin sections were studied to determine the alteration effect produced by the emplacement of the Camp Bird vein. The wall rock samples were collected on the 7 level along traverses oriented perpendicular to and into the hanging wall and footwall (Plate III). All wall rock samples were composed of San Juan Formation: lithic crystal rhyodacite tuff breccia. The vein samples examined were collected from the 7 level, 9 level and 14 level.

Four alteration products showed a distinct variation relative to the position of the Camp Bird vein. Four other alteration minerals showed a distinct association with the vein by their mere presence or absence.

Secondary quartz, chlorite, sericite and calcite show distinctive concentrations relative to the Camp Bird vein. Distribution of these minerals also appears to be affected by the order of alteration.

Figure 23 illustrates the distribution of alteration with respect to the Camp Bird vein. Generally, each alteration mineral shows its peak abundance where there are sharp decreases in the abundance of the other alteration minerals.

Small amounts of clay and pyrite occur close to the vein. Magnetite and hematite are observed only at considerable distance from the vein.

The presence of magnetite and hematite, absence of pyrite and clay minerals, and only moderate occurrences of secondary
quartz, chlorite, sericite and calcite that is noted about fifteen feet from the vein seem to indicate the greatest distance from the vein that hydrothermal solutions affected the wall rock. This pattern observed underground and the widespread area of alteration observed on the surface suggest that alteration occurred in two major phases (Reinking and Hilbelink, 1973): (1) a widespread propylitic alteration affecting great volumes of the volcanic rocks and (2) a localized quartz-sericite alteration associated with the mineralization of the veins.

Silicification is found to be the most abundant alteration adjacent to the Camp Bird vein. The quartz occurs as grains filling microveinlets near the vein wall and as aggregates filling pores at a distance from the vein walls. The amount of silicification decreases rapidly away from the vein. Silicification occurs in both the hanging wall and the footwall but appears to extend slightly farther into the hanging wall.

Chlorite alteration appears mainly in the footwall of Camp Bird vein. Alteration consists of chlorite replacing hornblende and quartz in the groundmass of the volcanic host. Chlorite occurring in the hanging wall appears to be a product of decomposition of biotite and possibly hornblende.

The greatest abundance of sericite observed occurred five feet into both the hanging wall and footwall. Sericite occurs replacing quartz, chlorite and the original plagio-
Figure 23. Distribution of alteration minerals.
clase. The peak observed at five feet is caused by the combination of two controlling factors. The solutions supplying sericite may have favored a high abundance near the vein. However, sericite replaced the original plagioclase more readily than the secondary quartz. The decrease in silicification away from the vein left a greater amount of plagioclase so that the most favorable location for sericitization occurred five feet from the vein.

Calcite appears to demonstrate relations similar to sericite. Calcite replaces the quartz, chlorite, sericite and the original plagioclase. It appears to most readily replace the plagioclase so that greatest abundance of calcite occurs away from the vein at a point where quartz and sericite replacement has decreased enough to leave abundant plagioclase that could be replaced by calcite.

The matrix of the volcanic breccia contains a cloudy appearing hematite that is thought to have formed when the volcanic rock cooled and therefore be primary in origin. The thin sections containing hematite also contain well developed magnetite grains. It is thought that the magnetite is also primary in origin. In the hanging wall of the Camp Bird vein both the hematite and magnetite disappear at the point where pyrite is first observed in the thin sections.

Only slight clay and epidote alteration was observed adjacent to the Camp Bird vein. Epidote was found to be quite abundant in the quartz-sulfide component of the vein filling
material. It is thought that this epidote (and calcite) represents subsequent replacement of the early deposited quartz by later solutions.
Figure 24. Photomicrograph of silicification in hanging wall of Camp Bird Vein on 7 level. Note calcite (C) replacing quartz (Q). Crossed Nicols, 50X

Figure 25. Photomicrograph showing calcite (C) and sericite (S) replacing large phenocrysts of plagioclase in footwall of Camp Bird Vein on 7 level. Crossed Nicols, 125X
Figure 26. Photomicrograph showing chlorite (Ch) microveinlet cutting silicification (Q) in footwall of Camp Bird Vein on 7 level. Plane polarized light, 125X
Figure 27. Photomicrograph illustrating paragenetic relations of calcite and pyrite. Calcite (C) fills crystal outline of original pyrite (py) in lower left corner. Crossed Nicols 125X
Figure 28. Photomicrograph of calcite (C) microveinlet cutting epidote (E) and sulfide microveinlet in quartz-sulfide vein component from 7 level indicating overlapping deposition of calcite and epidote. Crossed Nicols, 125x
Paragenesis of Mineralization-Alteration

Figure 29 summarizes the paragenetic sequence of mineralization-alteration associated with the quartz-sulfide vein filling. Evidence for previous mineralization was encountered in other parts of the mine but was absent from the area mapped. Later gold-quartz and bull quartz mineralization appear to have been less significant in the development of the alteration halo observed.

Polished sections of ore minerals indicate that fracture filling was the major mechanism of deposition of the sulfide minerals. Replacement textures were observed in the sulfide minerals but replacement appears to have only modified the grain to grain relationships and not have been an important mechanism of mineralization.

Later sulfide mineralization was separated from early pyrite mineralization by a sequence of fracturing. Another episode of fracturing followed sulfide mineralization but preceded alteration.

The paragenesis of the alteration minerals was observed in thin sections of wall rock adjacent to the Camp Bird vein. Replacement of original minerals appears to have been the dominant mechanism of emplacement of the alteration minerals. Replacement of earlier formed alteration minerals was also observed but was generally less effective than replacement of original minerals, especially plagioclase.

Correlation of the paragenetic sequences observed in
polished and thin sections was difficult due to the lack of identifiable features in both types of section. Because quartz has such a wide range of emplacement, it appears that chlorite and rhodonite offer the best correlation between the two types of sections. Though these minerals were difficult to identify in polished sections it is thought they were deposited after the sulfide minerals. Thin sections show both these minerals to appear before the sericite and other alteration minerals indicating that the major alteration phase occurred after deposition of the sulfide minerals.

Figure 29 also summarizes the time sequence of periods of fracturing and their relation to mineralization. The structural and paragenetic relations involved in the development and mineralization of the Camp Bird vein relative to the structural development of the Silverton caldera will be discussed in the following section.
FIGURE 29. Paragenetic diagram of mineralization-alteration and time position of vein faulting related to late stage caldera activity.

**xx** represents period of faulting
Structure

In a previous section the regional structural setting of the Camp Bird vein was discussed. This section will discuss the effect of this structural setting on the localization of ore deposits along the Camp Bird vein.

The radial stress caused by collapse of the Silverton caldera initiated lateral movement along the Camp Bird vein (Burbank, 1941). This lateral movement produced shearing along the vein so that deflections in the trend of the vein produced alternate zones of compression and tension.

Spurr (1925) recognized the importance of vein deflections in localizing the gold-quartz vein ore shoots. He noted that a deflection to a more northwest-southeast trend yielded thicker ore shoots than the general east-west trend of the Camp Bird vein. This relation is observed on the 14 level in the vicinity of the St. Paul dike where the northwest trend has yielded a wide vein zone with several veins of gold-quartz breccia and bull quartz (Plate I).

It should be noted, however, that only a thin quartz-sulfide vein occurs in this area. The thicker quartz-sulfide ore shoots occur along the Camp Bird vein where it exhibits a more westerly trend. This is demonstrated by both of the ore shoots mapped on the 7, 9 and 14 levels.

Extremely tight sections along the Camp Bird vein generally occur where the vein trends nearly east-west. However this relation does not exclude mineralization from occurring along
the east-west sections of the vein.

The quartz-sulfide mineralization appears to be profoundly affected by the presence of the St. Paul dike. Where the dike intersects the Camp Bird vein on the 7 level and 9 level the eastern ore shoot pinches from as thick as eight feet to a thin veinlet of quartz-sulfide that is difficult to trace through the area of intersection (Plate II and III). On the 7 level the eastern ore shoot again resumes its previous width some fifty feet east of the dike intersection. The 9 level drift does not extend east of the St. Paul dike.

Measurements of the attitude of the Camp Bird vein and the St. Paul dike on the 7 level and 9 level enable the plunge of the line of intersection to be calculated. On the 7 level the line of intersection plunges $59^\circ$ S $57^\circ$ E and on the 9 level it plunges $54^\circ$ S $43^\circ$ E. These attitudes compare closely with the attitude calculated for the boundaries of the ore shoots. The eastern and western ore shoots have plunges of $57^\circ$ S $45^\circ$ E and $56^\circ$ S $40^\circ$ E, respectively. These attitudes also indicate a close association between the occurrence of the ore shoots and the St. Paul dike. Although the ore vein pinches in the vicinity of the St. Paul dike, the similarity of the attitudes of these features suggests that the St. Paul dike exhibited some structural control on the development of the ore shoots along the Camp Bird vein.

The attitude of other intersections observed along the Camp Bird vein show similar correlation but generally do not agree as closely as values for the ore shoots and dike. The
attitude of most of the intersections is generally steeply in a southeast direction. This is in sharp contrast with the apparent attitude of the cymoid loop encountered on the 14 level which appears to plunge to the southwest (61° S 38° W).

The St. Paul dike exhibits some apparently paradoxical relations between the 7 level and 14 level. The dike reverses dip from 82° NE on the 7 level to 85° SW on the 14 level. In addition to the dip reversal it was observed that the sense of movement of the Camp Bird vein changes from apparent left-lateral to right-lateral movement with depth. The 7 level (Plate III) further exhibits a horse of aphanitic hornblende latite porphyry that appears to represent drag along the hanging wall of the Camp Bird vein. This horse extends nearly 60 feet farther west than the offset dike. A similar horst appears to occur along the hanging wall of the Camp Bird vein on the 9 level but exposures are poor and the extent of drag could not be determined.

These relations indicate multiple episodes of movement along the Camp Bird vein which reversed direction. Maximum displacement of the St. Paul dike may have been nearly 100 feet with subsequent reverse movement closing the offset to the presently observed 20 feet.

The attitude of the ore shoots and cymoid loop structures may suggest oblique movement during the development of the Camp Bird vein. No piercing points were identified that could be used to determine the net slip and the amount of oblique movement. Most of the movement appears to have been
horizontal.

In addition to the St. Paul and other dikes, several northwest-trending veins also intersect the Camp Bird vein. As discussed earlier, these veins either cut across or terminate at the Camp Bird vein.

The St. Paul vein generally is associated with the St. Paul dike but does become dislocated from the dike for short distances. On the 7 level (Plate III) the St. Paul vein was observed cutting the Camp Bird vein. The actual intersection could not be observed on either the 9 or 14 levels because mine workings are not accessible at the projected intersections.

Mineralization of the St. Paul vein consists of quartz-sulfide vein filling similar to that found along the Camp Bird vein. Quartz vein filling and calcite lined vugs also occur along the vein as younger episodes of mineralization. Gold-quartz breccia type mineralization found along the Camp Bird vein is not found along the St. Paul vein.

Lateral movement along the Camp Bird vein, that produced cymolid loop structures that localized deposition of the gold-quartz breccia are thought to have offset the early quartz-sulfide mineralization along the St. Paul vein. Subsequent movement and quartz mineralization along the St. Paul vein created the cross-cutting relations that are now observed.

A split occurs along the Camp Bird vein on the 14 level (Plate I and VI) between the two quartz-sulfide ore shoots. A fracture with quartz-sulfide mineralization rolls into the
footwall and follows a northwest trend.

This footwall vein structure consists of quartz-sulfide mineralization that forms a narrow (2-foot) vein filling except for two short (60-foot) ore shoots that widen to about four feet. The ore shoots occur where the split deflects to the northwest of its general trend. The split appears to have been active only during early stages of mineralization as no gold-quartz breccia or bull quartz occur along the split.

The structure is interpreted to be a footwall split away from the Camp Bird vein. The structure rolls away from the Camp Bird and is tangent to it at the point of intersection. It does not cut across or terminate at a sharp angle to the Camp Bird vein.

The split is not encountered above the 14 level along the 9 level workings. Dips measured along the split indicate that it dips away from the Camp Bird vein and if projected upward the split would intersect the Camp Bird vein below the 9 level.

The structural and paragenetic (Figure 29) relations indicate that fracturing and mineralization of the Camp Bird vein developed during successive resurgence and subsidence of the Silverton caldera.

Doming of the area appears to have created a set of tension fractures with a northwest trend, some of which were intruded to form andesite dike such as the St. Paul dike. Subsequent collapse of the caldera caused compression outward (Figure 17) which created the spiral form Camp Bird fracture.
The spiral form of the fracture is modified by short sections with a more northwesterly trend that had formed during the earlier period of fracturing. Both periods of fracturing occurred prior to mineralization of the Camp Bird vein.

After both sets of fractures formed, resurgence of the Silverton caldera again caused doming and tensional opening of the previously formed fractures, including the Camp Bird fracture. The tension openings were filled with the quartz-sulfide vein component.

Quartz-sulfide mineralization is wider along the more northwest trending portions of the Camp Bird Vein (Plate I) except where the major deflection occurs at the eastern end of the mapped area (3000 W). Here quartz-sulfide mineralization narrows eastward. It is thought that tensional separation was taken up by both the Camp Bird vein and the St. Paul vein, which occurs on the footwall of the St. Paul dike, leaving only a narrow zone of mineralization on both structures.

It is thought that the northwest-trending footwall split was mineralized during this period of resurgence.

Subsequent to sulfide mineralization subsidence of the caldera again created compression that caused lateral movement along the Camp Bird fracture. Right lateral movement opened deflections in the vein and caused shearing and brecciation that was mineralized to form the gold-quartz component. Movement was confined to the Camp Bird vein so that the thickest observed breccia component occurs where the vein trends most northwesterly.
During bull quartz mineralization resurgence and doming again caused tensional opening of fractures. Mineralization occurred along the northwest-trending fractures as well as the Camp Bird vein. Tensional openings were only partly filled leaving the large crystal lined cavities that are observed in this component.

Final post mineral collapse initiated compression that produced the gouge zones that are observed along the Camp Bird vein. Movement appears to have been reversed or rotational producing the relations observed on the 7 level (Plate III) where gouge along the hanging wall consists of rock from the St. Paul dike.
Geochemistry

Wall rock samples were collected for geochemical analysis from the 7, 9 and 14 levels. On the 7 and 9 levels samples were collected along traverses oriented perpendicular to the strike of the Camp Bird vein, into the hanging wall and footwall (Plates II and III). On the 14 level samples were collected from the cross-cut connecting the split with the main Camp Bird vein (Plate I). The sample interval was maintained at five feet along traverses.

Seven samples of the vein components were analyzed from several locations of all three levels along the Camp Bird vein. Samples listed in Figure 31 can be located on Plate I, II or III.

Mine samples were crushed and pulverized to -100 mesh. Half-gram samples of each were digested in hot nitric and perchloric acid and diluted to 15 ml total volume. Only 0.1 g sample was digested for vein rocks thought to contain high concentrations of trace elements.

The digested samples were analyzed on a Perkin-Elmer Model 303 atomic absorption spectrophotometer for the following elements: Cu, Pb, Zn, Cd, Ag and Mn. This instrument has a precision of at least 5 percent. The perchloric acid sample treatment is capable of extracting about 95 percent of the elements under discussion.

The results of the geochemical analyses of wall rock and vein component samples are tabulated in figures 30 and 31.
### Figure 30

**Results of Geochemical Analysis of Wall Rock Samples**

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FIGURE 31. Trace element content of vein components.

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bull Qtz - bull quartz component
gold-Qtz - gold quartz component
Qtz-sulfide - quartz-sulfide component
wall rock - horse within Camp Bird Vein structure
respectively.

Figures 32, 33 and 34 graphically represent the trace element distribution in the wall rocks adjacent to the Camp Bird vein. All six elements analyzed exhibit similar distribution patterns. Generally high concentrations of the trace elements near the vein wall drop rapidly away from the vein to lower concentrations that remain persistent to the greatest distance away from the vein.

The limited number of samples, 40, the high proportion of samples collected near the vein, and the local minor variations in geological conditions between the levels sampled made a statistical determination of the background values impossible. However, the distribution pattern of each element as seen on the diagrams shows that the concentrations fall off sharply away from the vein and level off to probable background values.

On the 7 level (Figure 32) penetration of this group of trace elements is farther into the footwall than the hanging wall. Cd, Pb and Zn show high concentrations five feet into the footwall. The Ag and Cu halo extends to the same width but without as great a contrast in concentrations as observed for Cd, Pb and Zn.

The distribution diagram for Mn does not fall off to persistent concentrations indicating that penetration of this element into the footwall is farther than the 20 feet that was sampled.
FIGURE 32. No. 7 level distribution of metal elements adjacent to Camp Bird Vein.
FIGURE 33. No. 9 Level distribution of metal elements adjacent to Camp Bird Vein.
FIGURE 34. No. 14 Level distribution of metal elements adjacent to Camp Bird Vein.
Ag and Cu penetrate only five feet into the hanging wall while Cd, Pb and Zn are persistently low to a distance of 37 feet from the vein. Mn can be followed for 25 feet from the vein.

Distribution of trace elements on the 9 level (Figure 33) is similar to that observed on the 7 level, but exhibits a slightly wider dispersion pattern. Cd, Pb and Zn appear to penetrate for a distance of ten feet into the footwall though there is an erratically low sample at five feet. The Ag and Cu halo extends only five feet.

The 9 level distribution diagram shows that Cd, Pb and Zn penetrate the hanging wall for five feet with much higher concentrations than observed on 7 level. Ag and Cu also penetrate five feet but show much lower concentrations than on 7 level. On 9 level anomalous concentrations of Mn penetrate both vein walls beyond the width of the sampling program.

The samples on 14 level were collected from between the main Camp Bird vein and the Camp Bird split. This zone is fractured and contains numerous thin quartz veinlets.

The distribution of trace elements on the 14 level (Figure 34) is characterized by generally higher concentrations of all the metals analyzed. The patterns have shapes similar to distribution on the 7 and 9 levels where high concentrations near the vein wall decrease about ten feet into the wall rock.

Higher concentrations of Ag, Cu and Zn were observed for
five feet from each of the bounding structures. Cu penetrates ten feet from the main Camp Bird vein but forms no halo adjacent to the Camp Bird split. Pb and Mn exhibit much higher concentrations on the 14 level than on the 7 and 9 levels but do not exhibit sharp increases near the structures.

Unlike those from 7 and 9 levels, the samples from between the two structures exhibit erratic data most of which are anomalous. This may indicate that this zone was probably subjected to mineralizing solutions from both structures. Metals could have been introduced to this zone along many thin fractures that localized trace mineralization without penetration into the rock adjacent to each minor fracture.

Analysis of seven samples of the various vein components (Figure 31) indicate that the elements analyzed were all associated with the quartz-sulfide stage of mineralization. Quartz-sulfide samples show high concentrations of all trace elements. The gold-quartz breccia component sample analyzed showed moderate concentrations of the trace elements which may have been derived from breccia fragments of quartz-sulfide vein component. Bull quartz analyzed from the later vein stage showed low concentrations of all the trace elements.

One vein sample taken from outside of the mapped area along the western part of the Camp Bird vein was analyzed. The sample consisted of a quartz-hematite vein that is clearly cut by a quartz-sulfide vein indicating that the quartz-hematite is an earlier stage of mineralization.
The quartz-hematite vein material contained low concentrations of Pb, Zn, Cd and Ag but a high concentration of Mn. This indicates that solutions with high concentrations of Mn were introduced prior to, as well as during quartz-sulfide mineralization. No quartz-hematite vein material was encountered within the area mapped.

Several features of the trace element distribution in the wall rock on all three mine levels can be summarized:

1. Penetration of trace elements extends only a short distance into wall rocks to a maximum of ten feet.

2. Penetration of trace elements is deepest into the footwall of the Camp Bird vein.

3. Zn, Pb and Cd exhibit the greatest contrast to apparent background values.

4. Mn appears to penetrate deepest into the wall rock although erratic concentrations and the limited sampling areas made interpretation of this element inconclusive.

The depth of penetration into the hanging wall and footwall appears to reflect the physical condition of the wall rock. The footwall had a greater porosity as shown by the deeper penetration of the mineralizing solutions. This is partly substantiated by the alteration study of the 7 level which exhibited a decrease of silicification and a greater abundance of chlorite in the footwall. This suggests less intense alteration with less attendant silicification.

Silicification could have controlled the penetration
of trace elements by sealing the wall rocks before the mineralizing solutions could penetrate. This affect is most evident in the hanging wall where silicification is greatest.

As indicated by the vein components analyzed, Mn appears to have been introduced earlier than the other trace elements. Mn exhibits the greatest penetration because it was being introduced either prior to or during silicification that subsequently sealed the wall rocks from exposure to solutions containing the metal elements.

Erratic concentrations that disrupt the distribution patterns, adjacent to the footwall on the 7 level and five feet into the footwall on the 9 level, may be due to either sampling error or variations in the metal distribution effected by local variations in the wall rock alteration. Too few sample traverses and samples were analyzed to determine the cause.
Summary of Factors Controlling Mineralization

During mineralization of the Camp Bird vein, several factors controlled the localization of the different vein components. Different factors were dominant during deposition of each vein component.

Among the most important factors controlling mineralization were:

1. Development of northwest-trending tension fractures during resurgence of Silverton caldera.

2. Development of Camp Bird "spiral" fracture during caldera subsidence prior to quartz-sulfide mineralization.

3. Reactivation of tension fractures during caldera resurgence attended by quartz-sulfide mineralization along:
   a. Camp Bird vein
   b. Camp Bird vein split
   c. northwest-trending veins.

4. Fracture filling by sulfide minerals was dominant mechanism for ore deposition. Coarse grained aggregates produce higher concentrations of the sulfide minerals.

5. Aphanitic dikes cut by the Camp Bird vein did not permit wide separation of the walls of the Camp Bird vein so that ore shoots are narrow in the vicinity of these dikes.

6. Prior silicification of wall rock prevented dispersion of metals into walls during quartz-sulfide mineralization.

7. Mineral paragenesis shows that alteration and replacement of wall rock minerals occurred after quartz-sulfide
mineralization.

8. Stresses radial to the Silverton caldera producing lateral movement on Camp Bird vein created alternate tension and compression zones. Gold-quartz mineralization occurs along these open cymoid loop structures.

9. Bull quartz mineralization occurs filling tension fractures that were reactivated subsequent to gold-quartz mineralization.

10. Only minor faulting with little displacement occurred along Camp Bird vein after mineralization.
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### APPENDIX I

**PERMANENT REFERENCE COLLECTION**

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