UNITED STATES GEOLOGICAL SURVEY

trace elements investigations report

TEI-311 (pt. 1)

# GEOLOGY OF THE COPPER KING MINE AREA, PRAIRIE DIVIDE, LARIMER COUNTY, COLORADO

By
Paul K. Sims and George Phair

This preliminary report is released without editorial and technical review for conformity with official standards and nomenclature, to make the information available to interested organizations and to stimulate the search for uranium deposits.

December 1952

DEPARTMENT OF THE INTERIOR
March 3, 1849



Prepared by the Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service, Oak Ridge, Tennessee

This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GEOLOGY AND MINERALOGY

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AEC, Oak Ridge, Tenn.,-W33654

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# GEOLOGY OF THE COPPER KING MINE AREA, PRAIRIE DIVIDE, LARIMER COUNTY, COLORADO

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## ABSTRACT

The Copper King mine, in Larimer County, Colo., in the northern part of the Front Range of Colorado, was operated for a short time prior to World War II for copper and zinc, but since 1949, when pitchblende was discovered on the mine dump, it has been worked for uranium.

The bedrock in the mine area consists predominantly of pre-Cambrian (Silver Plume) granite with minor migmatite and metasediments--biotite-quartz-plagioclase gneiss, biotite schist, quartzite, amphibolite, amphibole skarn, and biotite sköls. The metasediments occur as inclusions that trend northeast in the granite. This trend is essentially parallel to the prevailing foliation in the granite. At places the metasediments are crosscut sharply by the granite to form angular, partly discordant, steep-walled bodies in the granite. Faults, confined to a narrow zone that extends through the mine, cut both the pre-Cambrian rocks and the contained sulfide deposits. The Copper King fault, a breccia zone, contains a deposit of pitchblende; the other faults are believed to be later than the ore.

The two types of mineral deposits--massive sulfide and pitchblende deposits--in the mine area, are of widely different mineralogy, age, and origin. The massive sulfide deposits are small and consist of pyrite, sphalerite, chalcopyrite, pyrrhotite, and in places magnetite in amphibole skarn, mica sköls, and quartzite. The deposit at the Copper King mine has yielded small quantities of high-grade sphalerite ore. The massive sulfides

are pyrometasomatic deposits of pre-Cambrian age.

The pitchblende at the Copper King mine is principally in the Copper King vein, a tight, hard breccia zone that cuts through both granite and the massive sulfide deposit. A small part of the pitchblende is in small fractures near the vein and in boxwork pyrite adjacent to the vein; the post-ore faults, close to their intersection with the Copper King vein, contain some radioactive material, but elsewhere, so far as is known, they are barren. The pitchblende in the deposit forms a steeply plunging ore shoot that has a horizontal length of more than 50 feet and a vertical height of about 85 feet. The thickness of the ore shoot averages about 2 feet, but it ranges from a feather edge to about 4 feet. The hard pitchblende is intimately intergrown with siderite; other gangue minerals include pyrite, quartz, and finely comminuted fragments of the wall rocks. The vein was repeatedly reopened during mineral deposition as shown by several stages of brecciation and recementation by the vein matter. The pitchblende deposit probably formed at intermediate temperatures and depths and, according to the Pb/U ratio, is about 60 million years old--an early Tertiary age.

# INTRODUCTION

## Purpose and scope of the report

A black uranium mineral was discovered on the dump at the abandoned Copper King mine in 1949 by A. H. Brown and H. G. Ismert, and soon afterwards, the mine was dewatered and investigated by the U. S. Geological Survey (Granger and King, 1951). Phair identified the black uranium ore as pitchblende early in 1950. The source of the pitchblende was found to be a vein that had been worked on the 70-foot level during earlier mining operations. This vein was explored in 1950 and early 1951 by Cherokee Mines, and some pitchblende-bearing rock was mined. This work indicated that the deposit was of possible commercial interest, and accordingly a detailed study was undertaken by the Survey, on behalf of the Division of Raw Materials of the Atomic Energy Commission, in order to learn the character and extent of the deposit.

During September 1951, the present writers, assisted by J. W. Adams, mapped the geology of the mine workings and the surface. The mine was mapped on a scale of 5 feet equals 1 inch, using a base map made by a transit, tape, and brunton survey; the surface was mapped on a scale of 40 feet equals 1 inch by plane table and telescopic alidade. Subsequently, as mining progressed, the new development work was mapped by Sims. During the course of the mining, the Atomic Energy Commission sampled the pitchblende deposit to determine the grade. In September, the Commission started a diamond core drilling project at the Copper King mine that was completed in November.

This report, prepared principally to aid in the interpretation of the core drilling, presents the principal results of the field and preliminary laboratory work by the U. S. Geological Survey; it does not contain information obtained from the core drilling. A more comprehensive report that also will include the results of the laboratory studies of Phair is in preparation.

## Geography

The Copper King mine is on the Black Hawk No. 1 claim in sec. 8, T. 10 N., R. 72 W., 6th principal meridian, Larimer County, Colo., in the northern part of the Colorado Front Range (fig. 1). From Fort Collins it can be reached by following the road log below:

Road log from Fort Collins to Copper King mine

| | Miles |
|---|---|
| From Fort Collins proceed north along U. S. Highway 284 for a distance of | 23.3 |
| Turn left (west) on gravel road and proceed to road fork | 12.4 |
| At road fork take sharp left turn on road to Red Feather Lakes | |
| Proceed along this road to Copper King mine | 5.3 |

The mine is near the southwestern edge of Prairie Divide, a broad gently rolling mountain flat, at an altitude of about 8,000 feet. This flat is the result of a widespread pre-Wisconsin glaciation that has been named the Prairie Divide stage (Ray, 1940, p. 1856). The plain is mantled by weathered gravel that rests on deeply weathered till. At places, knobs and hills composed predominantly of granite protrude above the plain.

## Acknowledgments

The writers are indebted to Cherokee Mines, and particularly to T. H. Sackett, for full cooperation during the survey and for permission to use the production data; and to several members of the U. S. Geological Survey for assistance during the investigation. During the course of the study many of the economic problems were discussed with geologists and engineers of the Denver Exploration Branch of the Atomic Energy Commission.

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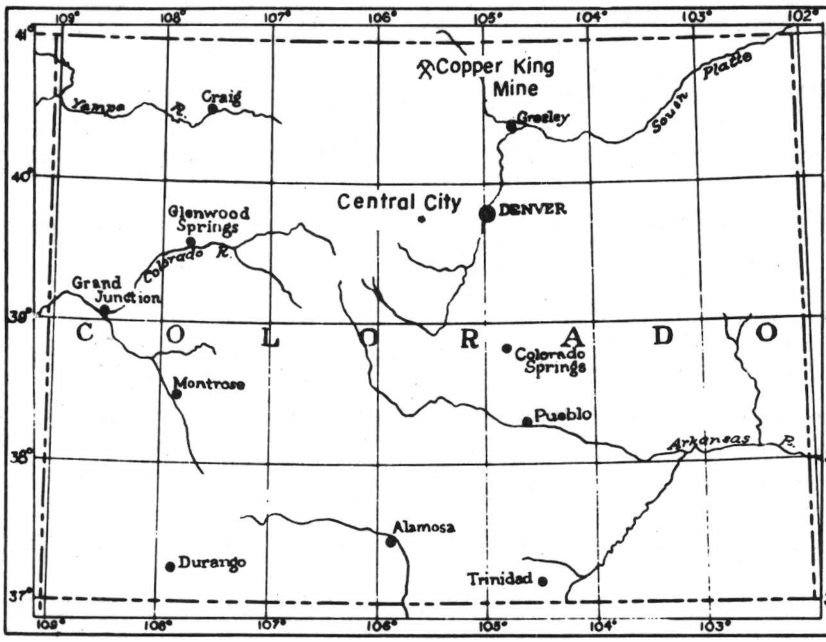


FIGURE 1.- INDEX MAP OF COLORADO SHOWING LOCATION OF COPPER KING MINE.

## HISTORY AND PRODUCTION

The Copper King mine and several nearby shafts (pl. 1) were opened during World War I in the search for copper and zinc ore. No ore is known to have been shipped, however, until 1920, when a carload of zinc ore was mined on the 70-foot level from a deposit of massive sulfides. This carload failed to pay the cost of milling, and the mine and prospect shafts were abandoned. In 1936, Richard Kyle of Idaho Springs, Colo., operated the Copper King mine briefly for zinc, but so far as known, no ore was shipped.

In the summer of 1949, A. H. Brown and H. G. Ismert examined the rock dump at the Copper King mine and found it to be highly radioactive. They filed claim on the mine on July 14, 1949, naming it the Black Hawk No. 1 claim (fig. 2). Shortly afterwards the mine workings--the shaft and the 70-foot level--were unwatered by the U. S. Geological Survey, and in 1950 and 1951 the operators extracted several tons of massive sulfide ore and some pitchblende-bearing rock from the 70-foot level and a 10-foot sump, located at the position of the present main shaft. Fifty-five tons of hand-sorted zinc ore that contained 18.2 percent zinc was shipped to Salt Lake City in 1951. The pitchblende-bearing rock recovered during the mining was stockpiled and in December 1951, 10,690 pounds that contained 0.71 percent $U_3O_8$ was shipped.

In 1951, Cherokee Mines, the mine operator, was granted a Defense Minerals Exploration Administration loan to sink a new, two-compartment shaft on the pitchblende deposit. This shaft, located 50 feet east of the old (West) shaft, at the position of the sump, was made by raising to the surface from the 70-foot level, and sinking below that level (fig. 3). During sinking,

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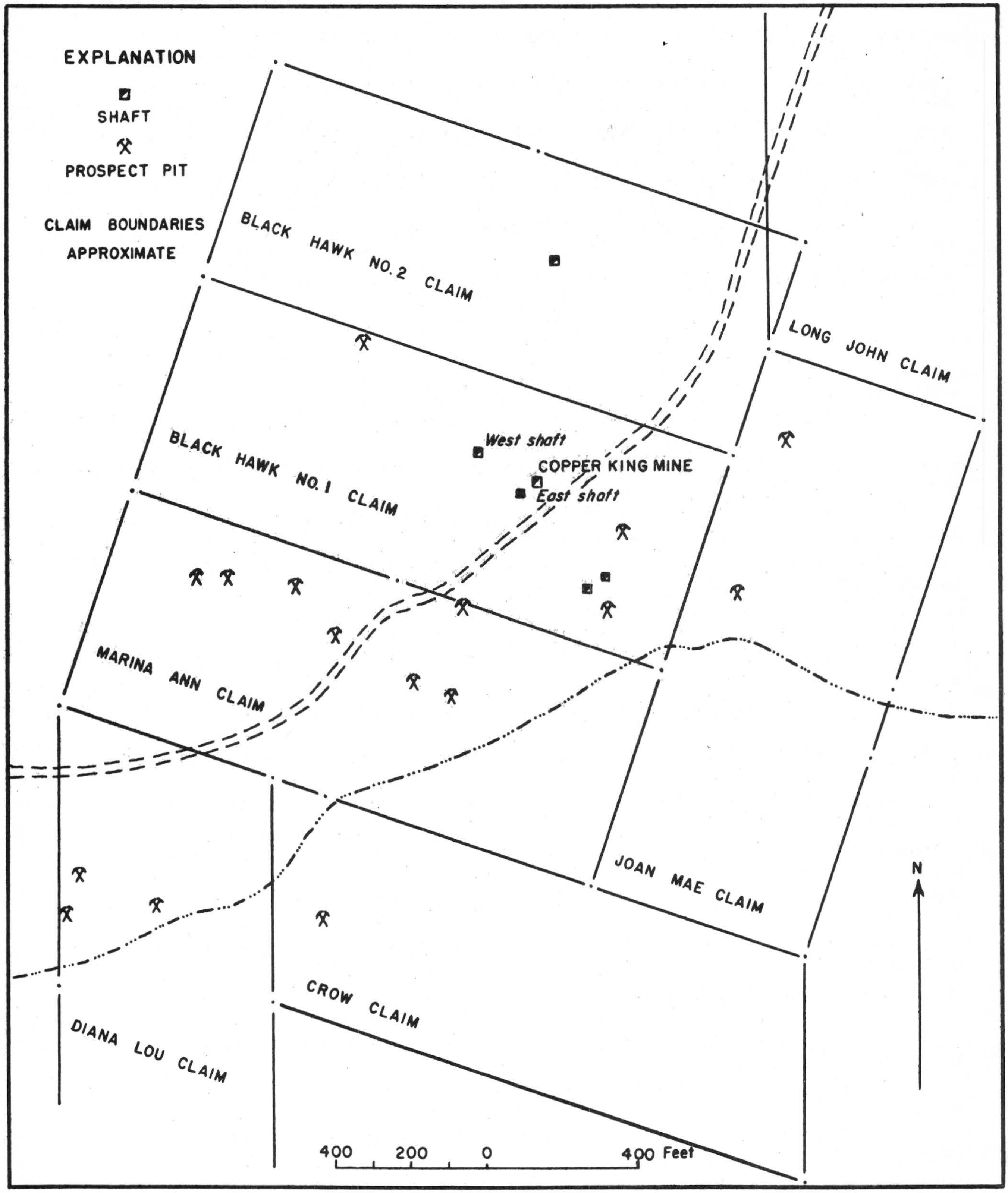


AFTER H.C. GRANGER AND R.U. KING
1951

FIGURE 2.-CLAIM MAP OF THE COPPER KING MINE AREA, LARIMER COUNTY, COLORADO.

stations were cut at the 110-foot and 160-foot levels. The shaft was completed to a depth of 169 feet in May 1952. In the summer of 1952, an inclined raise was driven from the 160-foot level to the bottom of the pitchblende ore shoot, and a sub-level was driven, east of the main shaft, along the approximate bottom of the ore shoot. The pitchblende ore that was extracted from the shaft, during sinking, and from the sublevel, was stockpiled until September, when 44 tons that averaged 0.48 percent $U_3O_8$ were shipped.

## MINE WORKINGS

The mine workings in November 1952 consist principally of two vertical shafts; three levels approximately 50 feet vertically apart with an aggregate of 180 feet of drifts; a sublevel, 53 feet long that is 15 feet vertically above the lowest lever; and a raise from the sublevel that connects with the 110-foot level (fig. 3). The principal manway and hoisting shaft is the main (East) shaft, a vertical two-compartment cribbed shaft, 169 feet deep. The West shaft is a vertical single compartment cribbed shaft, 64 feet deep, that bottoms on the 70-foot level. The 70-foot (first) level is a drift 118 feet long that connects with both shafts. Development work is in progress on the 110-foot (second) level and the drift extends 20 feet east from the station at the main shaft. The 160-foot (third) level has been little developed. An inclined raise, located 15 feet east of the main shaft, that contains a manway and an ore pass, connects with the sublevel, 15 feet vertically above the 160-foot level. The sublevel consists of a drift 52 feet long and a short crosscut; it connects with the main shaft.

In addition to the Copper King mine, there are 8 shallow shafts and prospect pits on the Black Hawk claim; these are designated by numbers on plate 1.

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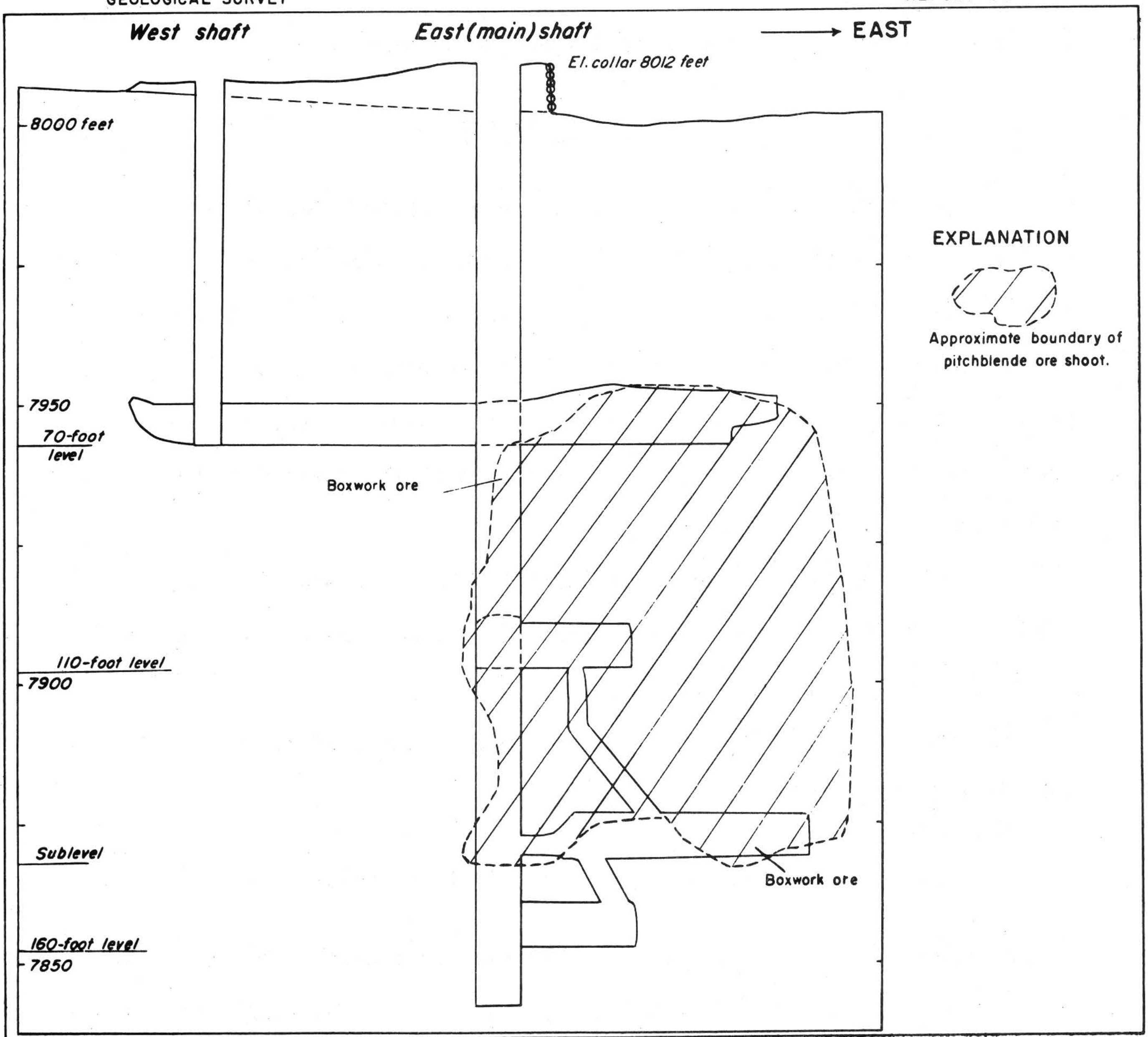


Geology and mine workings by P.K. Sims, November 1952

**FIGURE 3.-LONGITUDINAL PROJECTION OF MINE WORKINGS, COPPER KING MINE, SHOWING APPROXIMATE OUTLINE OF PITCHBLENDE ORE SHOOT.**

30 20 10 0 30 Feet

*Datum is assumed*

# ROCK UNITS

The rocks exposed in the mine area are pre-Cambrian in age and consist largely of granite with some migmatite and metasediments.

## Metasediments

The metasediments--biotite--quartz-plagioclase gneiss, biotite schist, quartzite, amphibolite, amphibole skarn, and biotite sköls--constitute 10 percent or less of the exposed rocks in the mapped area (pl. 1). They are the oldest rocks in the region and they occur as angular inclusions within the granite. Because of the sparse exposures, the complex structure, and the preponderance of the granite, the age sequence of the metasedimentary units is not known.

The amphibole skarn and related biotite sköls and quartzite are the host rocks for the massive sulfide deposits that have been mined in the Copper King mine and in prospect 3.

Rosiwal analyses of representative typical facies of the metasediments are given in table 1.

### Biotite-quartz-plagioclase gneiss

Biotite-quartz-plagioclase gneiss is exposed sporadically through the southern half of the mapped area (pl. 1), but because the rock weathers to flat, low surfaces the shape and extent of the individual bodies are poorly known. The largest exposure of biotite-quartz-plagioclase gneiss, 40 feet thick, is 150 feet southeast of the main shaft, and just west of prospect 4. This mass is separated from another body to the west by biotite granite. To the southeast, near shafts 1 and 2 and prospect 3, small isolated exposures of biotite-quartz-plagioclase gneiss and migmatite indicate the presence of a northeast-trending body of gneiss that at places is injected by granite. To the west of the Copper King shaft, 50 feet south of shaft 8 (pl. 1), a small exposure probably represents part of a larger body, which prior to the emplacement of the granite, connected with the gneiss now represented by migmatite, 130 feet west of the west shaft of the Copper King mine.

The biotite-quartz-plagioclase gneiss is a dark gray fine-grained, foliated rock that consists essentially of biotite, quartz, and plagioclase (table 1). Biotite, which constitutes 15 to 20 percent of the rock is strongly pleochroic and ranges from straw yellow to brownish green. The plagioclase ($An_{25}$) is poorly twinned and somewhat altered to sericite. Muscovite is an alteration product of biotite; magnetite, apatite, and zircon are sparse accessory minerals.

The gneiss has a conspicuous foliation that is the result of alternating lenses and streaks of felsic and mafic minerals. Megascopically visible magnetite grains commonly occupy the center of an "eye" or lenticle of quartz and plagioclase. The quartz and feldspar occur as polygonal grains; the biotite is subhedral and individual foliae are, for the most part, alined parallel to the mineral layering. Some biotite flakes are oriented at an angle of 30° to the dominant foliation.

## Biotite schist

A layer of biotite schist, 2 feet thick, crops out between biotite granite and biotite-quartz-plagioclase gneiss, 100 feet south-southeast of the main (East) shaft, but is not exposed elsewhere at the surface. The biotite schist is a black uniform rock that contains more than 90 percent biotite and less than 10 percent quartz. Abundant inclusions of zoned

Table 1.--Modal analyses of metasediments, Copper King mine area

| Mineral | A-31 | A-32 | C-4-2 | UG-9 | D-17-B |
|---|---|---|---|---|---|
| Quartz | 46 | 44 | | 85 | 16 |
| Microcline | tr. | | | | |
| Plagioclase | 33 | 40 | 49 | | |
| Biotite | 21 | 16 | 1 | 12 | 82 |
| Hornblende | | | 50 | | |
| Apatite | tr. | tr. | | tr. | 2 |
| Zircon | tr. | tr. | | | tr. |
| Muscovite | | | | | tr. |
| Magnetite | tr. | tr. | tr. | 3 | |
| Sphene (?) | | | | tr. | |
| Calcite (?) | | | | tr. | |
| Average grain diameter in mm | 0.2 | 0.24 | 0.20 | 0.75 | --- |

A-31 Biotite-quartz-plagioclase gneiss. Plagioclase is $An_{25}$. Texture is crystalloblastic. Biotite is pleochroic: straw yellow to dark brownish green. Plagioclase is partly sericitized. Rock has a conspicuous foliation and a later (weaker) foliation about 30° to the dominant direction.

A-32 Biotite-quartz-plagioclase gneiss with elliptical metacrysts of plagioclase

C-4-2 Amphibolite. Plagioclase is $An_{45}$. The biotite is an alteration product of hornblende.

UG-9 Biotitic quartzite. The quartz grains contain scattered, unoriented, subhedral crystals of biotite (phlogopite ?). Some biotite crosses the boundaries of quartz grains.

D-17-B Biotite schist. Biotite has two orientations, nearly at right angles. The older foliation is marked by finer-grained biotite and quartz seams; the later (weaker) foliation cuts across the older one. The biotite is pleochroic: straw yellow to greenish brown. It contains zircon with strong pleochroic haloes.

zircon (?), which have strong pleochroic haloes, occur in the biotite. Apatite, a sparse accessory mineral, and muscovite, an alteration product of the biotite, also are associated with the biotite. The quartz forms subrounded inclusions in the biotite.

Thin sections of the schist show that the biotite has 2 preferred orientations, at nearly right angles. The older, and dominant, schistosity is formed by sub-parallel biotite foliae and tabular to lenticular quartz grains; the later schistosity is marked by coarser foliae of biotite that are at a large angle to the dominant schistosity.

The biotite schist may be equivalent to the biotite sköls associated with the amphibole skarn in the mine workings.

## Quartzite

Dark gray to black fine-grained quartzite is interlayered with amphibole skarn on the south wall of the 70-foot level of the Copper King mine, immediately east of the main (East) shaft (pl. 2). The quartzite is predominantly a massive nearly equigranular heterogeneous rock that consists principally of quartz and about 10 percent of biotite; a part of the rock contains sparse to abundant magnetite. Another facies associated with the quartzite is a crudely layered rock containing layers of hornblende and quartz that alternate with layers of biotite and quartz. The quartz forms polygonal grains. The biotite ranges from colorless to pale brown and may be phlogopite. It forms scattered subhedral crystals and most plates have rounded terminations; the biotite crosses grain boundaries of quartz and appears younger than the quartz. Magnetite, pyrite, and sphene (?) are variable, but generally minor constituents of the rock. They embay and appear to replace the quartz.

## Amphibolite

A black fine-grained foliated gneiss that consists predominantly of hornblende and plagioclase of the composition of andesine is found on the dump of shaft 8 and locally in the Copper King mine (pl. 2), but does not crop out at the surface (pl. 1). The foliation is produced by sparse streaks and lenses of plagioclase and by the dimensional orientation of the hornblende and plagioclase. The rock has a granoblastic texture. Green hornblende constitutes 50 percent of the amphibolite (table 1); at places it is slightly altered to biotite. The plagioclase ($An_{45}$) is in part altered to sericite.

## Amphibole skarn

The rocks in the Copper King mine area that consist almost entirely of anthophyllite, cummingtonite, or actinolite, and which are related to the massive sulfide deposits, are mapped as amphibole skarn.

Skarn is an old Swedish mining term for aggregates of calcium, magnesium, iron silicates that characteristically are associated with certain deposits of iron ore and sulfides (Holmes, 1920, p. 211). The term skarn should be restricted to the silicate aggregates that have a demonstrable or inferred genetic relation with limestone or dolomite.

The amphibole rocks in the mapped area are similar to amphibole skarns that have been described from many localities in Fennoscandia, and because of their mineralogy, texture, structure, and spatial relation to the granite are believed to be altered carbonate rocks. Such an origin, however, can only be inferred as there are no known carbonate rocks in the mapped area. Crystalline limestones and skarn associated with tungsten deposits are present, however, a few miles south of Prairie Divide.

The skarn characteristically occurs as irregular, folded, pod-like bodies, a few feet in diameter, that have thin selvages, and locally inch-thin partings, of biotite sköls. On the 70-foot level, the skarn is interlayered with beds of quartzite, a foot or more thick.

The amphibole skarn, exposed in the Copper King mine, is gray to greenish gray massive and generally coarse-grained. The amphibole forms blades or needles that for the most part have a random or felted orientation. At places the blades are as much as 6 inches long; the average is half an inch.

The skarn is composed of 90 percent or more amphibole; biotite is the principal varietal mineral. The amphibole that constitutes the skarn varies from place to place in the mine. Also common are rocks consisting of nearly equal amounts by volume of fibrous anthophyllite and fine-grained "sugary" magnetite. Generally the skarn contains anthophyllite, but at many places it consists of cummingtonite. Actinolite skarn, so far as known, occurs only locally. Because of the difficulty of distinguishing the different amphiboles megascopically, the different varieties are mapped as amphibole skarn on plates 2 and 3.

The amphibole skarn is by far the principal host rock for the massive sulfide and magnetite deposits. Nearly all of the skarn contains some sulfides as scattered blebs and veinlets, and locally the sulfides are sufficiently abundant to constitute ore.

## Biotite sköls

Biotite, as thin selvages and partings, occurs in the amphibole skarn and sulfide ore. These selvages and partings are analogous to one type of sköl, or shell, that has been described by Fennoscandian geologists

(Eskola, 1914, pp. 226, 259). The most conspicuous skols form selvages as much as a foot thick around folded, pod-like bodies of skarn; others occur as wisps and contorted partings within the skarn and sulfide ore.

## Migmatite

At places migmatitized biotite-quartz-feldspar gneiss is closely associated with, and grades laterally into, biotite-quartz-feldspar gneiss. Because of the small volume of the migmatite it is mapped on plate 1 with biotite-quartz-plagioclase gneiss. The contacts of the migmatite with granite are sharp. The migmatized biotite-quartz-feldspar gneiss is a pink to gray generally fine-grained foliated rock of widely different appearance. A dark gray type of migmatite is biotite-quartz-feldspar gneiss that contains thin, discrete veinlets as much as half an inch thick, in part crenulated, of pink felsic material of the composition of alaskite; the felsic layers constitute only a small proportion of this rock. A much more common type, pink in color, is a streaked gneiss consisting predominantly of pink felsic material with streaks, wisps, and discontinuous layers of biotite; the mafics constitute a variable, but generally small proportion of this rock. The pink migmatite is easily distinguished megascopically from the biotite granite by its prominent compositional layering, its finer-grain size, and by an abundance of mafic minerals.

The migmatite differs in composition from biotite granite principally in containing more biotite, slightly less microcline, and slightly more plagioclase, as shown in table 2. The microcline is perthitic and it characteristically embays and locally surrounds quartz and plagioclase grains. The texture of the rock is mostly granoblastic.

Table 2.--Modal analyses of granites and migmatites, Copper King mine area

| Mineral | UG-1 | A-47 | C-4-1 | G-11 | D-2 | G-8 | C-1 | D-17-A |
|---|---|---|---|---|---|---|---|---|
| Quartz | 30 | 40 | 34 | 25 | 33 | 32 | 38 | 44 |
| Microcline* | 37 | 37 | 43 | 63 | 38 | 34 | 46 | 31 |
| Plagioclase | 27 | 22 | 20 | 12 | 25 | 24 | 9 | 14 |
| Biotite | 6 | 1 | 2.5 | tr. | 4 | 9.5 | 7 | 10.5 |
| Magnetite | | tr. | | tr. | tr. | tr. | tr. | tr. |
| Apatite | tr. | | | | | tr. | | tr. |
| Sericite | tr. | | tr. | tr. | | | | |
| Zircon (?) | | tr. | tr. | | | tr. | tr. | tr. |
| Muscovite | tr. | | 0.5 | | | 0.5 | tr. | 0.5 |
| Limonite | | | | | | | | tr. |
| Average grain diameter in mm | 1.0 | 0.4 | 1.0 | 0.6 | 0.7 | 0.2 | 0.25 | 0.3 |

* Most of the microcline is perthitic.

UG-1 Biotite granite. Plagioclase is $An_{22}$.

A-47 Alaskite. Plagioclase is $An_{30}$. The inner parts of plagioclase grains are altered to sericite. Most quartz shows strain shadows.

C-4-1 Alaskitic biotite granite. Most of plagioclase is sericitized; sericite more abundant in inner parts of crystals. Zircon has pleochroic haloes in biotite.

G-11 Alaskite, Plagioclase is $An_{30}$. Plagioclase is partly altered to sericite.

D-2 Alaskitic biotite granite. Plagioclase ($An_{32}$) is partly sericitized. Biotite partly altered to muscovite.

G-8 Migmatite. Plagioclase is $An_{25}$.

C-1 Migmatite. Microcline contains sparse sub-rounded quartz grains. The muscovite is an alteration product of biotite.

D-17-A Migmatite. Plagioclase is sericitized. Muscovite is alteration product of biotite.

The migmatite is believed to have formed by the introduction of granitic material, mostly perthitic microcline, into biotite-quartz-plagioclase gneiss, because it grades transitionally into the gneiss and it has essentially the same texture and structure as the gneiss. The dark migmatite that contains discrete, inch-thin layers of felsic material probably formed by the lit-par-lit injection of alaskite into biotite-quartz-plagioclase gneiss; the pink migmatite probably formed by an intimate permeation of granitic material into the same gneiss.

## Igneous rocks

Biotite granite and alaskite, and subordinate irregular bodies and dikes of granite pegmatite, are the only igneous rocks in the mapped area (pl. 1); they constitute about 90 percent of the bedrock. The granite is homogeneous; it contains small angular bodies of metasediments and migmatite. The contacts of the granite against the metasediments generally are conformable, but locally they cut sharply across the foliation of the inclusions.

The granite is pre-Cambrian in age and has been called Silver Plume granite by Lovering and Goddard (1950, pl. 1). Presumably the granite pegmatite is a late-stage differentiate of the granite. Lead-thorium age determinations on two monazites from the associated pegmatite yield very late pre-Cambrian ages consistent with a Silver Plume age (Phair, Shimamoto, and Sims, report in preparation).

Rosiwal analyses of representative facies of the granites are shown in table 2.

### Biotite granite and alaskite

The granite is typically a pink to buff uniform medium-grained, equigranular to slightly porphyritic, massive to poorly foliated rock that consists essentially of microcline, quartz, and plagioclase. Biotite is a variable constituent that ranges from a trace to as much as 6 percent; and accordingly the granite varies from alaskite through alaskitic biotite granite to biotite granite (table 2). A porphyritic texture is developed locally by feldspar crystals as much as an inch and a half long. A poor to fair foliation is produced by tabular feldspars.

Inclusions of biotite-quartz-plagioclase gneiss and migmatite are present locally in the granite. At places granite pegmatite and fine-grained aplitic alaskite dikes, generally less than a foot thick, occupy joints in the granite, but nowhere are they abundant.

The microcline constitutes 35 to 65 percent of the rock. It forms subhedral crystals and is somewhat perthitic. The albite blebs are chiefly rods and strings (Alling, 1938, pp. 142-147). A grated structure, typical of microcline, commonly is well developed; some grains also show Carlsbad twinning. At places the microcline contains sparse euhedral to subhedral crystals of plagioclase.

The plagioclase has the composition of oligoclase and constitutes 12 to 27 percent of the granite. It commonly forms subhedral crystals; it has good polysynthetic twinning and locally also Carlsbad twinning. Almost everywhere it is partly altered to sericite.

Quartz comprises 25 to 40 percent of the rock and forms irregular anastamosing grains that embay the earlier feldspars. In all specimens examined, it shows strain shadows and locally it is crackled and broken.

The biotite ranges from a trace in alaskite (G-11, table 2) to as much as 6 percent in biotite granite (UG-1). It is euhedral to subhedral and strongly pleochroic; it ranges from straw yellow to dark brownish green. At many places it is altered and dark green. Locally it contains small euhedral crystals of zircon (?) with pleochroic haloes.

Muscovite and sericite are common alteration products of biotite and are closely associated with the biotite. At many places muscovite forms rims around the biotite. The common accessory minerals are magnetite, apatite, and zircon (?). Limonite and hematite are local alteration products of the magnetite.

The essential minerals--quartz, microcline, and plagioclase--are intergrown in a manner similar to the mineral constituents of the volcanic rocks. The quartz is strained and locally broken; the feldspars, at places, are strained and fractured, indicating some cataclastic deformation after consolidation of the granite.

### Granite pegmatite

Sparse, small bodies of granite pegmatite are present in the granite and at the contacts between the granite and metasediments. At the surface the pegmatite forms small dikes, generally not more than a foot or two wide, along joints in the granite; underground it has been observed to occur as bodies in the granite as much as 4 feet wide that are both concordant and discordant. The contacts generally are transitional into granite.

The pegmatites are in part simple bodies that consist almost entirely of quartz and feldspar and in part are rich in biotite. The biotite forms plates as much as an inch long and a fourth of an inch thick that are oriented at random.

## STRUCTURE

### Foliation and lineation

The foliation in both the metasedimentary and igneous rocks exposed in the Copper King mine area (pl. 1) trends northeast and dips steeply to the northwest or southeast, except locally. The metasediments, which occur as inclusions of various sizes in the granite, trend northeast parallel to the foliation, but they are cross-cut sharply by the granite and for the most part form angular, discordant, blocky bodies in the granite. To judge from the dips in the metasediments, which generally are to the northwest, west of the mine and to the southeast, east of the mine, the metasediments are on the limbs of a northeast-trending, tightly folded, anticline whose axis is near the Copper King mine. This inferred structure, however, cannot be proved, and additional geologic mapping outside of this area is needed to substantiate or disprove it.

The foliation in the gneissic metasediments is the result of a fair to conspicuous compositional layering and the subparallel arrangement of the minerals; the foliation in the granite is the result of a poor to fair subparallel orientation of the tabular feldspar crystals. Both the quartz and feldspar in the granite show some mortar structure, indicative of post-consolidation cataclastic deformation. The schistosity in the biotite schist is, where observed, conformable to the foliation. Lineation, produced by elongate plates of biotite and hornblende and by mineral streaking, is conspicuous in the biotite-quartz-plagioclase gneiss, amphibolite, and the biotite schist; it is poorly developed in the granite, however, except locally, where elongate quartz and feldspar grains show a sub-parallel alinement. The lineation in all the rocks exposed at the surface is down dip, nearly normal to the strike of the foliation; the lineation in the metasediments in the mine workings plunges moderately steep to the northeast.

## Joints

Joints are a conspicuous feature of both the metasediments and granites, but they are most striking in the granites. The joints dip steeply, near the vertical, and they can be grouped according to their strike roughly into two sets--northeast- and northwest-trending joints. Most joints are barren, but a few contain discontinuous layers of pegmatite, or less commonly fine-grained alaskite, that are generally less than a foot thick.

Joints that trend about N. 80° W. and dip steeply were mapped at the surface at the approximate inferred position of the surface trace of the faults that have been intersected in the mine workings (pl. 1). Also a very conspicuous joint set produced by abundant closely spaced joints is present in the granite 200 feet east of the mine. These joints do not seem to be present elsewhere in the mapped area, and it is believed that they are essentially parallel to the eastward-trending faults that have been intersected in the mine, and probably are the result of the same forces.

## Faults

The faults of the mapped area are confined to a narrow, easterly-trending zone that extends through the Copper King mine. They do not crop out at the surface but are cut at numerous places in the mine workings. The faults cut the pre-Cambrian igneous and metamorphic rocks and the massive sulfide deposits; so far as known, they have small displacements. The Copper King fault, a breccia zone, contains the pitchblende deposit at the Copper King mine; the other faults are believed to be later than the ore.

The Copper King fault is marked by a breccia zone that is variable in structure. It has been traced for a horizontal distance of more than

50 feet and a vertical distance of about 85 feet (pls. 2 and 3). The fault is strong and persistent in the upper levels, where it cuts the massive sulfide deposit, but it is weak and discontinuous in the lower levels, where it cuts granite. On the 70-foot and 110-foot levels, and in the main shaft between these levels, the fault zone trends about N. 65° W., dips nearly vertical, and is as much as a foot thick. The breccia is tight and hard and it consists of finely comminuted, angular fragments of the wall rocks, a few mm or less in diameter, and vein minerals--siderite, pyrite, pitchblende, and minor quartz. On the 70-foot level, chlorite is locally abundant in the breccia zone. Where the fault cuts through pyrite and other less abundant sulfide minerals, the sulfides are sheared and finely granulated for as much as 6 inches on either side of the fracture. At places, the vein material is grooved, indicating some movement along the fault after deposition of the pitchblende.

The Copper King fault is intersected by fault "B" at the 110-foot level (pl. 2), and the probable continuation of the fault in granite below fault "B" is weak and discontinuous and is characterized by "horse-tailing". It consists of overlapping fractures, commonly less than 10 feet long, that are filled by 1-inch veins composed principally of siderite, and minor pitchblende. Breccias are absent. The principal fractures trend about east and dip nearly vertical, but there is considerable variation; subsidiary ("horse-tail") fractures, which possibly are tension openings and which are branches from the main fissures, trend on the average about N. 65° E. and generally dip nearly vertical (pl. 2). Both the main fractures and the subsidiary tension (?) openings, at places contain pitchblende.

Fault "B", a conspicuous fracture filled with abundant dark brown hydrous iron oxide, some porous, vuggy quartz, a green clay (?) mineral;

and gouge, is exposed on the 110-foot level (pl. 2) and in the main shaft (pl. 3). Where exposed, it trends about N. 80° E., dips 70° SE., and is 3 to 9 inches thick. It cuts, and apparently displaces, the Copper King vein at the 110-foot level (pl. 3); the intersection of the faults plunges moderately steep to the east. Fault "B", in turn, appears to be cut off by fault "A", and apparently terminates against it (pl. 3). Fault "B" is radioactive at places on the west wall of the shaft just above the 110-foot level, near its intersection with the Copper King vein, but the radioactivity is principally the result of uranium and its daughter products that were derived from the uranium in the Copper King vein.

Fault "A", the most conspicuous and continuous fault in the mine, has been intersected in the 70-foot level, in the main shaft, in the cross-cut on the sublevel, and in the 160-foot level (pls. 2 and 3). On the 70-foot level (pl. 2), the fault is a conspicuous fracture, exposed throughout the length of the drift in the back, that strikes N. 55° to 70° W. and dips on the average about 80° SW. (pl. 2). The fault dips 85° SW. in the shaft (pl. 3), but flattens to about 55° at the 160-foot level. Grooves and mullion structures that plunge 1° to 20° east can be seen on the walls of the fault at the 160-foot level. Fault "A" is a strong fracture, from less than a foot to 3 feet thick, that consists predominantly of soft, crumbly gouge. It is thickest and most conspicuous where it cuts granite. On the 70-foot level it contains abundant hydrous iron oxide, local inch-thin pyrite stringers, and discontinuous veins of dense, white quartz an inch or less thick; but these vein-forming minerals are absent, so far as known, in the lower part of the fault. A green clay (?) mineral is abundant in the fault at many places below the 110-foot level, where the fault cuts granite. The fault is locally radioactive at the elevation of the 110-foot level, but the radioactivity is principally the result of radium (?)

that occurs on fracture surfaces in the fault.

Several less prominent faults, branches and splits from the main openings, have been cut in the mine workings, and the most important of these are shown in plates 2 and 3.

## MINERAL DEPOSITS

Two types of mineral deposits of widely different character, age, and origin are present in the Copper King mine and the adjacent area--massive sulfide deposits of pre-Cambrian age and a pitchblende deposit of early Tertiary age. The massive sulfide deposits, composed of pyrite, sphalerite, chalcopyrite, pyrrhotite, and locally magnetite in amphibole skarn, mica sköls, and quartzite, occur in the Copper King mine and in two nearby prospect pits; they are not present in the granite. The only pitchblende deposit in the area, so far as known, is in the Copper King mine.

### Massive sulfide deposits

#### General character and structure

Massive sulfide deposits in amphibole skarn and associated rocks are present in the Copper King mine and in prospects 1 and 2, southeast of the mine (pl. 1). The deposit in the Copper King mine has been intersected on three levels and is moderately well known, but the deposits in shafts 1 and 2 have only been worked to shallow depths and are poorly known, and accordingly the description of the deposit is largely based on the Copper King mine.

The deposit in the Copper King mine is highly irregular and is enclosed by biotite granite (pls. 2 and 3). The external shape of the deposit is not fully known, but it appears to be a steep-walled body, both in cross (pl. 3) and longitudinal section, that extends below the lowest mine workings. The deposit is roughly tabular and generally conformable to the enclosing granite, except at its southwest end, where it is cross-cut sharply by the granite, as shown in plate 2. To judge from its intersections on the 70-foot and 110-foot levels, and in the sublevel, the contact with the granite at the southwest end of the deposit dips moderately steep to the east.

The internal structure of the deposit is complex and is not everywhere conformable to the margins of the inclusion. Because the ore has a conspicuous layering that is the result of the selective replacement of the original layered, folded host, the ore and the host form complex, tight folds that plunge moderately steep to steep northeast. The ore on the limbs of the folds dips moderately steeply but the ore in the axial regions of the folds is considerably flatter.

The deposit at the Copper King mine where intersected on the 70-foot level (pl. 2) and in the main shaft (pl. 3) is an elongate, roughly tabular body that has a stope length of more than 85 feet, a width of as much as 16 feet, and a breadth of approximately 40 feet. At places the deposit contains some generally small, irregular bodies of granite and pegmatite, which were intruded into the host before the formation of the sulfides. The inclusion is cut off at its southwest end by granite. The deposit, where intersected in the sublevel (pl. 2), has a stope length of 30 feet and a width of 8 feet or less.

The massive sulfide deposit in the Copper King mine does not everywhere contain sufficient quantities of sulfides to constitute ore, and accordingly the ore body is smaller than the deposit. The sulfides have nearly completely replaced some layers; other layers contain only scattered grains and veinlets of sulfides; others are nearly barren.

## Mineralogy

The massive sulfide ore within the deposit, insofar as possible, is distinguished on plates 2 and 3. On the 70-foot level, pyrite is the most abundant sulfide mineral; sparse sphalerite, chalcopyrite, and pyrrhotite occur at places with the pyrite. The pyrite-rich "ore" forms a steeply dipping layer, 2 to 3 feet thick, that is exposed at places along the north wall of the drift (pl. 2). Magnetite, without appreciable quantities of sulfides, forms a small body in quartzite that is exposed on the south wall of the drift, 10 feet east of the main shaft.

An ore body consisting principally of sphalerite lies immediately beneath the 70-foot level, and several tons of ore was mined from it in the main shaft. This body is a relatively flat-lying layer, about 6 feet thick, that plunges about 45° to the east. (See plate 3.) It is underlain by a layer of massive pyrite, about 12 feet thick, that contains only sparse amounts of sphalerite and chalcopyrite. The pyrite layer, in turn, is underlain by amphibole skarn that contains only sparse quantities of sulfides.

The deposit on the 110-foot level consists largely of massive pyrite and pyrrhotite, with sparse chalcopyrite and sphalerite, but little is known of the size and shape of the ore on this level.

Pyrite also is the most abundant sulfide in the ore in the sublevel, but a few layers of sphalerite-rich ore, a foot or less in thickness, that trend across the drift and dip 50°-60° eastward, were intersected about 20 to 25 feet east of the raise (pl. 2).

The principal host rock of the massive sulfides and the magnetite is amphibole skarn. The mica sköls are less important host rocks--for the most part the sulfides do not form massive bodies in the sköls, but instead they are sparsely disseminated through them or form thin, discontinuous seams more or less parallel to the mica foliae. The quartzite is the host for part of the magnetite on the 70-foot level.

Pyrite.--Pyrite is the most conspicuous and abundant constituent of the massive sulfide deposit and it occurs in varying amounts throughout the deposit. The pyrite is in part massive and homogeneous, but for the most part it forms boxwork or lacy "ore". The boxwork pyrite is of particular importance for it contains substantial quantities of sooty pitchblende at some places adjacent to pitchblende-bearing veins. The massive pyrite is brass-yellow and medium- to coarse-grained. It forms aggregates of poorly-developed crystals; crystal faces seldom are seen. The boxwork or lacy pyrite is pale yellowish-gray and is widespread throughout the deposit. It is highly variable in structure and texture. Much of it is characterized by highly irregular, delicate, lacy, branching and intersecting veinlets; associated with this type is pale yellowish-gray fine-grained slightly vuggy, massive pyrite. Another distinctive type, which locally contains sooty pitchblende, consists of pyrite veinlets, commonly half an inch or less thick, and spaced a fourth of an inch to an inch apart, that are oriented at approximate right angles. In the centers of many of the pyrite veinlets are thin films or veinlets of siderite. One or more additional sets of veinlets may occur as diagonals to the principal veinlet directions. The rock between the veinlets, in most specimens, is mica sköl; at places adjacent to pitchblende-bearing veins the interstices of the boxwork ore contains appreciable quantities of sooty pitchblende.

The origin of the box work and lacy types of pyrite is only partly known and additional studies are being carried on to determine the development of the structures and the pitchblende associated with it. The history of development of the boxwork-type ore probably was long and complex. It is believed that the pyrite that constitutes this ore is in part of pre-Cambrian age--related to the other massive sulfides--and in part of early Tertiary age--related to the period of pitchblende deposition. The early (pre-Cambrian) generation of pyrite occurs as irregular seams, brass-yellow in color, generally less than an inch thick, that are essentially parallel to the foliation of the host. The later generation of pyrite is pale yellowish-gray, and it forms veinlets that are approximately at right angles or diagonal to the foliation; thin films of siderite occupy the centers of nearly all of these veinlets. Presumably the original (pre-Cambrian) massive pyritic ore, which contained thin layers and discontinuous seams of biotite sköls, was fractured, and possibly jointed, during the early Tertiary (?). Subsequently, solutions related to the pitchblende-bearing fluids, at places permeated the rocks, and veinlets of pyrite, together with films of siderite, were formed along the fractures, principally as fracture fillings. Later, the sooty pitchblende was deposited as coatings on open spaces and vugs in the interstices of the boxwork pyrite.

Sphalerite.--Sphalerite, the most important ore mineral in the massive sulfide deposits, is dark brown and probably has the composition of marmatite. It occurs for the most part as massive, medium- to coarse-grained ore, relatively free from other sulfide minerals, that forms layers an inch or less to several feet in thickness. The layers commonly have sharp contacts against the adjacent pyrite and chalcopyrite layers, but at places they grade transitionally into mixed pyrite and sphalerite ore.

Chalcopyrite is nearly always associated with the sphalerite; it forms small blebs and seams in the sphalerite that are visible megascopically.

Polished specimens of this ore show chalcopyrite in tiny blebs scattered through the host, and small laths and trains, which in part are present along the octehedral planes in the inner parts of individual sphalerite grains. The larger grains of chalcopyrite, where in contact with sphalerite, embay and corrode the sphalerite.

Chalcopyrite.--Chalcopyrite has two principal modes of occurrence-- (1) distinct, massive, homogeneous layers and seams and (2) small, scattered blebs, laths, and veinlets in sphalerite. The layers of massive chalcopyrite are intercalated with layers of pyrite and sphalerite; the scattered blebs and veinlets are associated for the most part with sphalerite, and probably represent in part chalcopyrite exsolved from sphalerite and in part a replacement of sphalerite. A later age for some of the chalcopyrite is indicated by the embayment of the older minerals, principally sphalerite, and the inclusion of these minerals as isolated remnants in the chalcopyrite.

Pyrrhotite.--Pyrrhotite is generally a sparse constituent of the sulfide ore and it can be recognized by its bronze color. It is abundant only on the 110-foot level, where it forms small massive bodies and veinlets in the massive pyrite "ore"; elsewhere it occurs as small, sparse blebs in association with pyrite, sphalerite, and chalcopyrite. Polished sections show that the massive pyrrhotite is medium- to coarse-grained. The grains are subrounded and they form aggregates that embay and include the host.

Magnetite.--The magnetite is dark gray to black finely granular, or "sugary" and generally crumbly; nearly always it contains sparse to moderate amounts of bladed amphibole, mica, or quartz. The magnetite generally occurs in separate masses, away from the sulfides, and so far as known, it is abundant only on the 70-foot level of the Copper King mine, but it is present in much of the anthophyllite skarn throughout the mine. Polished sections show that the magnetite forms aggregates of sub-rounded to subhedral crystals that embay and corrode the host. At places, particularly in the quartzite, the magnetite is sparsely disseminated.

Paragenesis and age.--The paragenesis of the sulfide minerals in the deposit, so far as known, is as follows: pyrrhotite, pyrite, sphalerite, chalcopyrite, and pyrite. The magnetite has not been observed in contact with the sulfides, hence its place in the paragenetic sequence is not known; it is inferred, however, to be older than the pyrrhotite. The sulfides, with the exception of the last generation of pyrite, represent successive stages in a single period of pre-Cambrian ore deposition. The last generation of pyrite, because it is intergrown with siderite, which is known to be associated with the pitchblende-bearing fluids, is tentatively considered to be early Tertiary in age.

The massive sulfide and magnetite deposits are believed to be pre-Cambrian in age because of their close spatial relation to the pre-Cambrian (Silver Plume) granite, and their mineralogy and structure. The massive sulfide deposits show many similarities to other replacement types of sulfide deposits in the Front Range believed by Lovering and Goddard to be pre-Cambrian in age. The massive sulfide deposits at the Copper King mine are typical of the class of deposits that Lindgren (1933, pp. 35-49), Knopf (1933, pp. 537-539), and others have called pyrometasomatic. The ore presumably was deposited from late stage ore-bearing fluids derived by differentiation of the cooling magma that consolidated to form the biotite granite and alaskite. The ore minerals formed by replacement of the host. They selectively replaced the amphibole skarn, and to a lesser extent the biotite sköls and quartzite, which constituted part of a complexly folded inclusion of metasediments in the granite.

## Pitchblende deposits

### Form and structure

The pitchblende at the Copper King mine is principally in the Copper King vein, a tight, hard breccia zone, which has been previously described. A small part of it is in small fractures alongside of the vein and in box-work pyrite adjacent to the vein.

The Copper King vein is a tabular body of relatively small dimensions. It does not crop out at the surface, but it has been encountered underground on the 70-foot and 110-foot drifts, in the sublevel drift, and in the main shaft; and has been traced for a horizontal distance of more than 50 feet and a vertical distance of about 85 feet. In the upper part of the mine the vein is strong and persistent, but in the lower levels it is weak and discontinuous and characteristically "horse-tails".

The wall rocks of the vein are the massive sulfide deposit and related rocks and the granite. The vein generally is stronger, more continuous, and thicker in the sulfide deposit than in the granite. It characteristically branches and splits in the granite.

### Pitchblende ore shoot

The pitchblende in the Copper King vein forms a steeply plunging ore shoot that has a horizontal length of more than 50 feet and a height of about 85 feet (fig. 3). So far as known, the vein does not extend far beyond the limits of the ore shoot. The thickness of the ore shoot, because of the uranium in the walls of the vein, is dependent upon the grade of ore that is extracted, and accordingly, at present ore prices, will range up to 4 feet.

The western margin of the ore shoot has been essentially defined by the sinking of the main (East) shaft. In the shaft between the 70-foot level and the sublevel the vein is present generally on the east wall but it is absent on the west wall except near the 110-foot level and the sublevel. The upper boundary of the shoot is less well-defined, but mining on the 70-foot level indicates that the vein pinches to a feather edge in the back of the drift. The lower margin of the shoot has been delineated for the most part in the sublevel. This limit of the ore shoot is irregular in outline. The eastern margin of the shoot has not been definitely defined by mining, but to judge from the pinch in the ore on the 70-foot level, 35 feet east of the main shaft, and in the sublevel, 50 feet east of the shaft, it is inferred that these pinches are near the eastern limit of the shoot. This shoot boundary of the ore is inferred to be nearly vertical because of the sharply defined vertical boundary of the west edge, exposed in the shaft. It could be defined more precisely by extending the 110-foot drift a distance of 50 feet or more to the east.

The ore shoot is not everywhere sufficiently thick and high enough in grade to be minable, because the pitchblende within the shoot occurs in discontinuous seams, bunches, kidneys, and pods. The thickest and most continuous parts of the shoot are in the breccia zone, at and above the 110-foot level.

On the first level (pl. 2), along the north wall, 30 feet east of the main shaft, the vein is 2 inches thick and contains abundant pitchblende, 7 feet up on the wall, over an area of approximately 1 x 2 feet. A small patch of radioactive vein, about an inch thick, is present at floor level, 35 feet east of the main shaft. These masses are remnants of a larger seam, rich in pitchblende, that extended northwestward to within a few feet of the shaft, and which was mined out in 1949 and 1950, prior to this investigation.

In the main shaft (pl. 3) the Copper King vein is exposed nearly continuously on the east wall, except where faulted out, over a vertical distance of 65 feet. It extends from just below the 70-foot level, where the vein passes into the north wall, to the sublevel. The vein is not present on the west wall of the shaft, so far as known, except locally near the 110-foot level and just above the sublevel. A kidney of high-grade pitchblende ore, as much as 6 inches thick, was mined from the vein adjacent to soft gouge in faults "A" and "B" at the elevation of the 110-foot level, on the west wall; and a thin veinlet, that probably does not extend far into the west wall, was encountered at a depth of 28 feet below the 110-foot level.

It can be seen in the shaft that the Copper King vein is cut into two principal segments by fault "B", which intersects the vein at the elevation of the 110-foot level. The upper segment, exposed on the east wall from just below the 70-foot level to the intersection with fault "B", is a strong, nearly continuously radioactive vein in breccia. The vein is believed to extend upward to connect with the pitchblende-bearing vein that was largely mined out from the 70-foot level, and accordingly this segment of the vein has a vertical height at the position of the shaft of about 45 feet. The thickness of this segment ranges from about 1 to 12 inches; the average is about 3 inches. Because of the presence of some uranium in fractures in the walls of the vein and in boxwork pyrite, the mining thickness of this segment of the vein probably averages slightly more than 2 feet.

The lower segment of the Copper King vein, exposed in the shaft between the 110-foot level and the sublevel, is weak and discontinuous and is characterized by "horse-tailing". This segment of the vein is poorly defined and it consists of several overlapping short branching veinlets, generally less than an inch thick. The height of this segment in the shaft is about 30 feet (pl. 3); the thickness is highly variable and is dependent upon the number of overlapping and branching veinlets, their thickness, and their uranium content. Samples taken by the Atomic Energy Commission on the east wall of the shaft (Ken Baker, oral communication) indicate that at places in the shaft this segment has a minable width of 3 feet or more.

In the sublevel, which is at the approximate bottom of the ore shoot (fig. 3), the discontinuity and horse-tailing that characterizes the lower segment of the vein, can be well seen (pl. 2). The primary vein structure is represented by thin, discontinuous veinlets that trend about east. Subsidiary fractures, probably tension openings, that branch from the main vein system trend about N. 65° E. on the average, but there is considerable variation. Both the primary veinlets and the veinlets that "horse-tail" from this set, for the most part contain siderite, and at places, pitchblende. At this elevation the pitchblende seams along the veinlets generally are less than 10 feet long.

Boxwork pyrite that contains considerable quantities of high-grade pitchblende was mined on the sublevel from the ground 25 to 30 feet east of the raise. Most of this ore occurred in a layer, generally 1 to 2 feet thick, 25 feet east of the shaft, that trended across the strike of the northeast-trending vein. Other layers of boxwork pyrite that are somewhat thinner were mined further to the east. Most of this type of ore was extracted from the back; it extended upward for 2 to 5 feet or more. The pitchblende within the boxwork pyrite was between the pitchblende-bearing veins, or within about 2 feet of a radioactive seam.

The vein is not present at the elevation of the 160-foot level, so far as known; this level is thought to be below the bottom of the ore shoot. Fracture surfaces in biotite-quartz plagioclase gneiss exposed in the west wall of the shaft at this level, however, are at places slightly radioactive.

## Character of the vein

The Copper King vein is a variable structure that at most places is composed of finely comminuted fragments of the wall rocks and material introduced by the vein-forming solutions. The character of the vein is to a large extent determined by the character of the wall rocks. The vein, where it cuts massive sulfide deposits and the related amphibole skarn is hard and compact and consists of angular fragments and shreds of sulfides and amphibole skarn and variable amounts of minerals introduced by the ore-bearing solutions--siderite, pyrite, quartz, and pitchblende. Limonite is a local alteration product of siderite. Vugs, where present, are small and widely spaced. The walls of the vein typically are frozen. The wall rock adjacent to the vein appears fresh and unaltered, except locally.

The fracture was repeatedly reopened during mineral deposition, as shown by several stages of brecciation and recementation by the vein matter. Quartz is probably the earliest vein mineral; it was deposited after the development of the microbreccia. Following the deposition of the quartz--pyrite, siderite, and pitchblende were deposited. Subsequent brecciation shattered the earlier minerals, and another generation of siderite, which veined the early minerals, was deposited. At places, during a much later time, oxidation, probably by supergene processes, altered the siderite to hydrous iron oxide. Further studies of the paragenesis and occurrence of the vein minerals are in progress and will be presented in a later report.

The hard pitchblende in the vein is always intimately intergrown with siderite. It occurs as shreds and angular blocks, generally less than a mm in diameter, that form ice-cake structures in siderite; as veinlets, a mm or less thick that cut the older minerals; and as colloform coatings on fracture walls, vugs, and breccia fragments. It commonly coats brecciated pyrite and chalcopyrite but rarely, if at all, coats the broken fragments of sphalerite.

## Boxwork pyrite ore

Boxwork pyrite, described previously, which contains important quantities of sooty pitchblende, has been encountered at 3 places in the Copper King mine. Substantial amounts of this type of ore were mined from the shaft, just below the 70-foot level; a small pocket, only slightly radioactive, was found on the north wall of the drift, opposite the shaft, on the 110-foot level; and several tons was mined from the sublevel, 35 to 45 feet east of the main shaft. With the exception of the boxwork pyrite on the 110-foot level, all of these occurrences are adjacent to or within 2 to 3 feet of a pitchblende-bearing vein.

The pitchblende in the boxwork pyrite is soft and sooty. It occurs in the openings between the pyrite veinlets, commonly as coatings on open spaces and vugs. At places the quantity of pitchblende in the boxwork "ore" increases toward openings that contain thin coatings of pitchblende. Studies of the boxwork-type of ore are in progress and it is hoped that these studies will provide data on the origin of the sooty pitchblende.

## Age and origin

$Pb^{206}/U^{238}$ and $Pb^{207}/U^{235}$ age determinations upon two samples of hard pitchblende from the Copper King vein, not from the boxwork, gave ages by the two methods ranging from 55 to 76 million years after suitable common lead corrections. This range is similar to that obtained for four samples from the Central City district when similarly corrected, and shows that the uranium mineralization in both areas was contemporaneous within those limits. The details of these determinations will be presented in a paper now in preparation by Phair, Shimamoto, and Sims.

The source of the pitchblende-bearing solutions is not known. By analogy with the Central City district (Phair, 1952), however, it can be inferred that the ore-bearing solutions were derived from a magma of early Tertiary age. The nearest exposed Tertiary igneous rocks, so far as known, are in the Manhattan mining district, about 10 miles southwest of the Copper King mine (Lovering and Goddard, 1950, plate 1).

## SUGGESTIONS FOR PROSPECTING

The search for additional pitchblende resources in the Copper King mine and the adjacent area should consist of further exploration along the Copper King vein and its lateral and vertical projection and radiometric and geologic reconnaissance of the surrounding area. The pitchblende ore shoot in the Copper King mine is essentially coincident with the extent of the Copper King vein; only locally does the vein extend beyond the limits of the ore shoot and it is improbable that much ore will be found outside of the ore shoot, shown in figure 2, except perhaps to the east. It is recommended, therefore, that drifting along the vein be carried further to the east on the 70-foot and 110-foot levels and on the sublevel. The drifting should be continued until the vein entirely pinches out; a non-radioactive zone along the vein does not necessarily indicate the edge of an ore shoot. Core drilling by the Atomic Energy Commission has indicated the presence of some radioactive vein matter to the east of the mine workings, along the approximate projection of the Copper King vein (Ray Derzay, oral communication).

A radiometric and geologic reconnaissance of the region between Prairie Divide and Manhattan, 10 miles to the southwest, might disclose new pitchblende deposits. It should be kept in mind, however, that the radioactive vein at the Copper King mine did not crop out at the surface; also, the vein could not be detected at the surface by ground geiger counters and scintillation instruments. During the reconnaissance, if radioactive localities are detected, attention should be directed to the Tertiary intrusive rocks that are exposed at places in the Manhattan area, to determine if certain of the intrusives are spatially, and perhaps genetically, related to the uranium.

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