(200)
T672

UNCLASSIFIED

This document consists of
46 pages, Series A
CATEGORY III
(Beryllium)

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

BERYLLIUM DEPOSITS OF THE MOUNT ANTERO REGION, CHAFFEE COUNTY, COLORADO.

By John W. Adams

May 1951

Trace Elements Investigations Report 126

Pub. as USGS Bull. 982-D.

USGS - TEI Report 126

The distribution (Series A) of this report is as follows:

3 copies . . . . . AEC, Washington (J. C. Johnson)

8 copies . . . . . AEC, New York (P. L. Merritt)

1 copy . . . . AEC, Denver, Colo. (C. C. Towle, Jr.)

1 copy . . . . AEC, Spokane, Wash. (E. E. Thurlow)

1 copy . . . . AEC, Grand Junction, Colo. (T. W. Oster)

10 copies . . . . USGS, Washington (Mineral Deposits Branch)

1 copy . . . . USGS, Washington (Geochemistry and Petrology Branch)

1 copy . . . . USGS, Washington (Geophysics Branch)

1 copy . . . . USGS, Washington (Alaskan Branch)

1 copy . . . . USGS, Washington (V. E. McKelvey)

2 copies . . . . . USGS, Denver, Colo. (L. R. Page)

1 copy . . . . USGS, Denver, Colo. (J. Fred Smith, Jr.)

1 copy . . . . USGS, Grand Junction, Colo. (R. P. Fischer)

1 copy . . . . USGS, Spokane, Wash. (A. E. Weissenborn)

1 copy . . . . USGS, Plant City, Fla. (J. B. Cathcart)

4 copies . . . . . USGS, Washington (TEPCO)
(Including master copy)

CONTENTS

ILLUSTRATIONS

TABLES

BERYLLIUM DEPOSITS OF THE MOUNT ANTERO REGION, CHAFFEE COUNTY, COLORADO

By John W. Adams

ABSTRACT

Pegmatites, commonly containing beryllium minerals, occur in a granite stock in the vicinity of Mount Antero and White Mountain, Chaffee County, Colo. These pegmatites have been known for many years as a source of fine specimens of aquamarine, phenakite, and bertrandite, but do not appear to be of sufficient size to be of interest as a commercial source of beryllium.

At the California mine, southwest of Mount Antero, a quartz vein containing molybdenite and beryl occurs in a quartz-monzonite stock. The mine was operated on a small scale during World War I. The surface cuts were caved and the mine workings were inaccessible in June 1948. The vein, where exposed, is $1\frac{1}{2}$ to 3 feet thick, nearly vertical, and strikes N. 72°-75° E. Mineralogical study shows that some of the beryl was formed during the deposition of molybdenite. Brannerite, an oxide of titanium and uranium, was identified in the material collected. Early reports and material seen on the dump indicate that rich molybdenite ore was accompanied by considerable beryl, but no accurate appraisal of the beryl reserves can be made without reopening the mine workings and trenching on the surface. It is estimated, however, that about 60 tons of beryl is present in 1,000 feet of vein. This reserve is based on a possible beryl content of 0.5 percent.

Most of the beryl is too small to be recovered by hand cobbing.

Beryl has been reported in quartz veins containing molybdenum, tin, tungsten, or bismuth in many localities throughout the world. The mineral assemblages of these deposits contain species common to pegmatites and polymetallic quartz veins.

The refractive index of beryl from several tungsten deposits was found to be higher than that of beryl associated with tin or molybdenum, and to correspond to that of alkali-rich beryl from the inner zones of lithium-bearing pegmatites.

INTRODUCTION

A brief reconnaissance examination of the beryllium deposits of the Mount Antero region, Chaffee County, Colo., was made June 24 to July 1, 1948, as part of the beryllium investigations being conducted by the U. S. Geological Survey for the Atomic Energy Commission. The purpose of this examination was to investigate the area as a commercial source of beryl and to ascertain whether or not a more detailed study of the deposits should be undertaken. The writer was assisted in the field by A. F. Trites, Jr.

Mount Antero and White Mountain have been known for many years as a source of fine crystals of the beryllium minerals beryl, phenakite, and bertrandite. Their occurrence in small pegmatites of the area has been described by Switzer. _/ Beryl is found also in a quartz

---

_/ Switzer, G., Granite pegmatites of the Mt. Antero region, Colorado: Am. Mineralogist, vol. 24, pp. 791-809, 1939.

vein that at one time was mined for molybdenite.[/] This vein, the

[/] Worcester, P. G., Molybdenite deposits of Colorado: Colorado Geol. Survey Bull. 14, pp. 34-38, 1919.

[/] Landes, K. K., The beryl-molybdenite deposit of Chaffee County, Colorado: Econ. Geology, vol. 29, pp. 697-702, 1934.

California, was considered of special interest by the writer and was studied in detail.

Mount Antero and White Mountain are prominent peaks of the Sawatch Range of central Colorado and are situated along the west side of the Arkansas Valley about 15 miles northwest of Salida and about 100 miles southwest of Denver (fig. 1). Mount Antero has an altitude of 14,245

Figure 1. Index map of Colorado showing location of Mt. Antero area.

feet and is a few hundred feet higher than White Mountain which is about 1¼ miles to the south. The beryllium deposits are in the immediate vicinity of these peaks (fig. 2). The area is above timberline,

Figure 2. Portion of the Garfield quadrangle, Colorado, and contiguous unmapped area, showing location of the California mine and approximate positions of the summits of Mt. Antero and White Mountain. Area within dashed lines is shown on Plate 1.

and the terrain consists of steep talus-covered slopes, boulder fields, and broad grassy flats. Access is limited to the summer months, and even then the weather around the peaks is apt to be severe and unpredictable. Violent electrical storms, often accompanied by hail, are common, and snow and high winds may be expected at any time. The

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 126

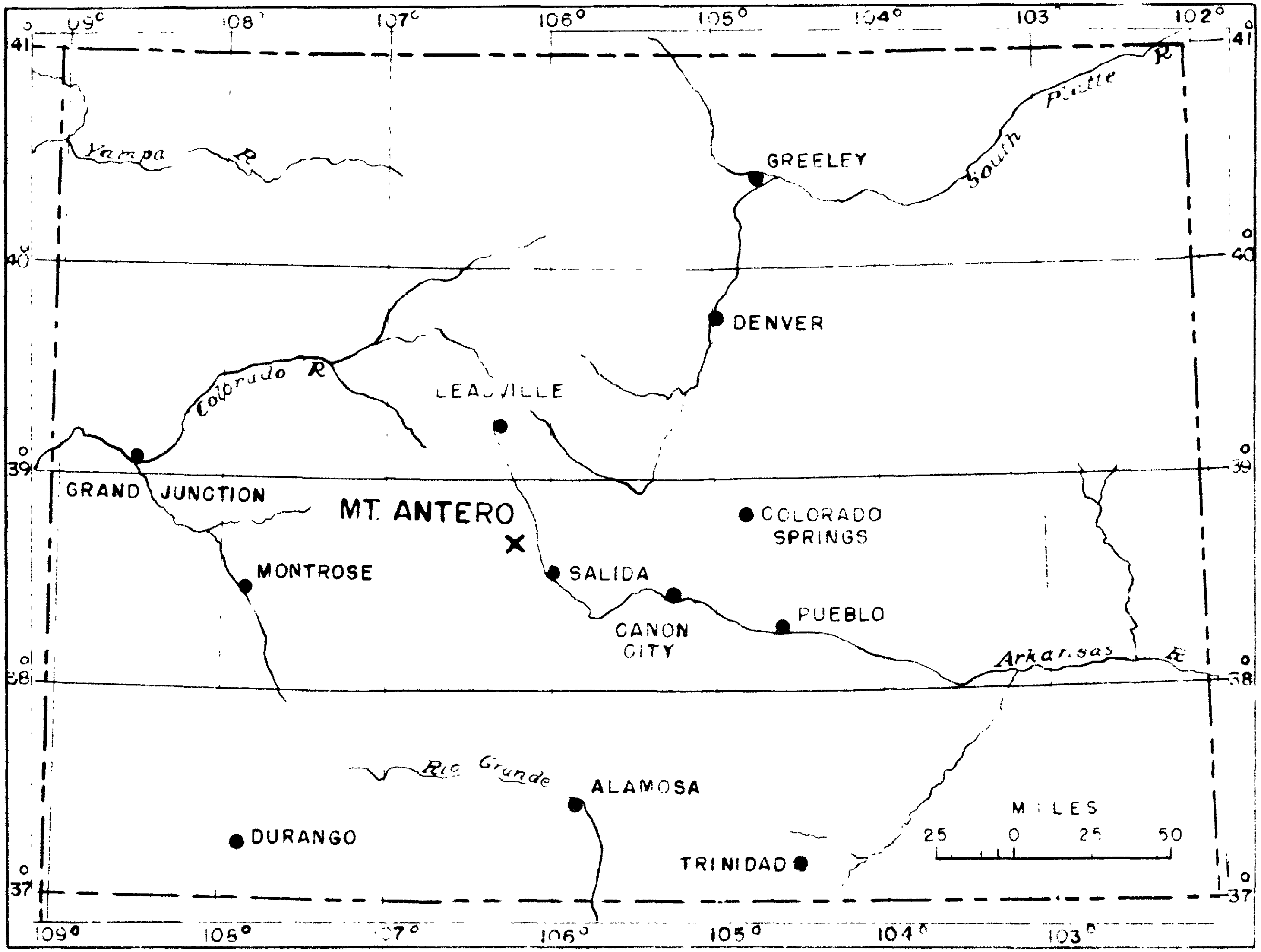


FIGURE [illegible] —INDEX MAP OF COLORADO SHOWING LOCATION OF MT ANTERO AREA

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 126

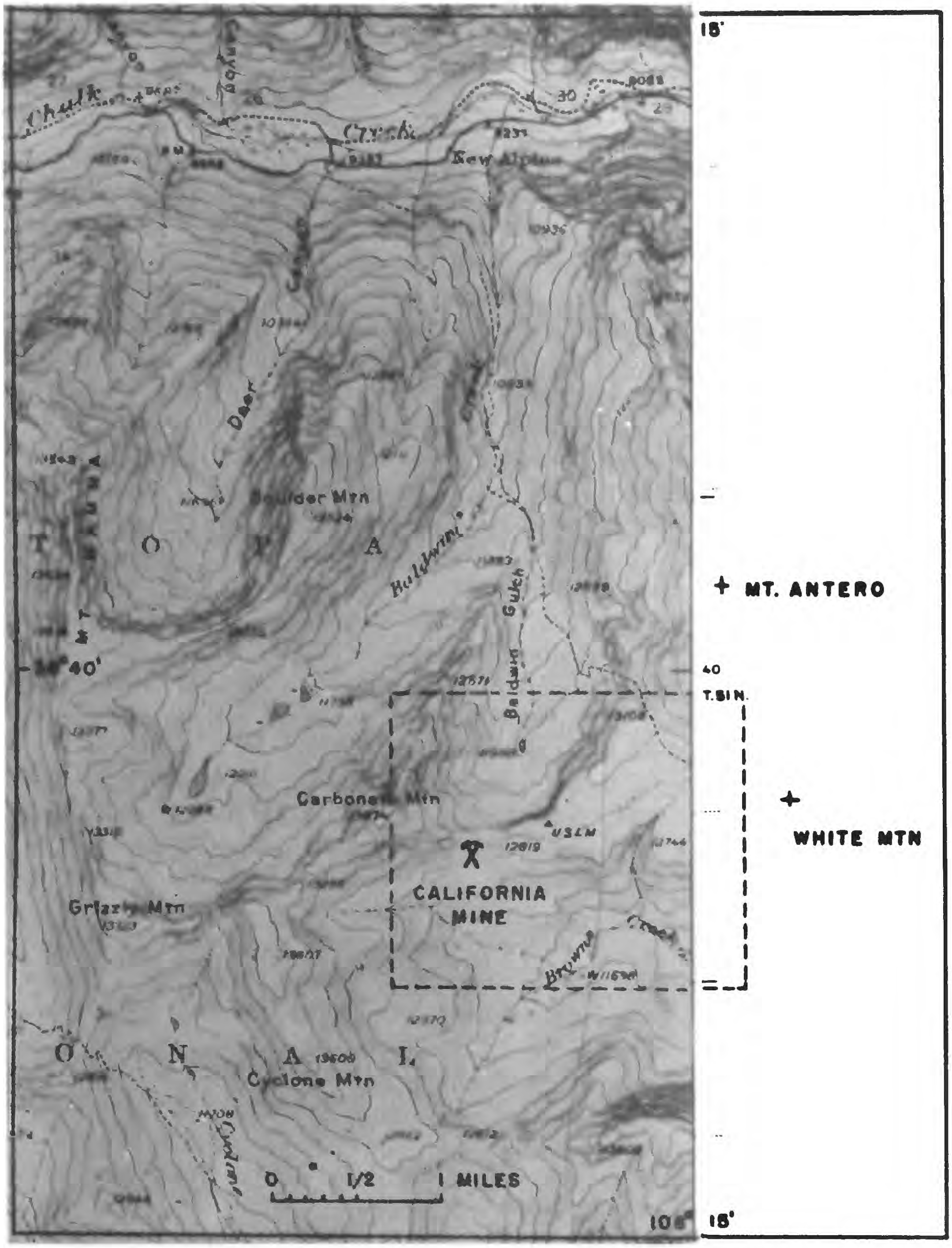


Fig. 2.-- Part of the Garfield quadrangle, Colorado, and contiguous unmapped area, showing location of the California mine and approximate positions of the summits of Mount Antero and White Mountain. Area within dashed lines is shown on Plate 1.

weather conditions, the altitude, and the generally steep and hazardous terrain make work in the area physically difficult.

The area may be reached by the Baldwin Gulch, Little Brown's Creek, or Brown's Creek trails. The Baldwin Gulch trail, shown in figure 2, starts about a mile west of New Alpine on the Chalk Creek road (State Highway 162) and offers an approach to the area from the north. The other trails start from the Arkansas Valley and enter the mountains from the east. The Little Brown's Creek route is that most generally used to approach Mount Antero and White Mountain. Local inquiry regarding the trails is advisable, although the trails and connecting roads are shown on the San Isabel National Forest map of the U. S. Forest Service. Aerial photographs of the area are available. Partial topographic coverage is afforded by the Garfield quadrangle, Colorado (scale 1:62,500). (See fig. 2.)

GENERAL GEOLOGY

The beryl deposits studied are in intrusive rocks related to the Princeton batholith. Most of the beryllium-bearing pegmatites and veins, except for the California vein, are in a granite stock several miles in extent, which makes up a large part of Mount Antero and White Mountain. The California vein is in a body of Pomeroy quartz-monzonite. These rocks have been described by R. D. Crawford, _/ who believes that

_/ Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi district, Colorado: Colorado Geol. Survey Bull. 4, 1913.

they are post-Carboniferous and probably Tertiary in age, and that the quartz monzonite represents an earlier intrusion than the granite.

BERYLLIUM IN THE ROCKS OF THE MOUNT ANTERO AREA

Pegmatites

The date of the discovery of the Mount Antero deposits is not known to the writer, but in 1887 a short paper by R. G. Cross _/ de-

_/ Cross, R. G., Notes on aquamarine from Mt. Antero: Am. Jour. Sci., 3d ser., pp. 161-162, 1887.

scribes some aquamarine and phenakite crystals found there a few years previously by N. A. Wanamaker. Later, some fine crystals of bertrandite were discovered. The morphology of the phenakite and bertrandite from this locality was described by S. L. Penfield _/ and in a later

_/ Penfield, S. L., Phenakite from Colorado: Am. Jour. Sci., 3d ser., vol. 33, pp. 131-134, 1887; Bertrandite from Mt. Antero: Am. Jour. Sci., 3d ser., vol. 36, pp. 52-55, 1888.

paper _/ he discussed the pronounced etching of some of the aquamarine

_/ Penfield, S. L., Some observations on the beryllium minerals from Mt. Antero: Am. Jour. Sci., 3d ser., vol. 40, pp. 488-491, 1890.

crystals and suggested that the beryllium of the bertrandite was obtained at the expense of beryl. Sterrett _/ described the locale and

_/ Sterrett, D. B., Precious stones: Mineral Resources U. S., 1908, pt. 2, pp. 809-811, 1909.

occurrence of the gem minerals of Mount Antero and stated that "These gems would doubtless be mined regularly if the locality were more accessible."

As the locality became more widely known, it attracted many mineral collectors. No further effort was made to study the deposits until interesting accounts of the gem-bearing pegmatites, and of the difficulties met in working them, were written by Edwin Over _/ and

---

_/ Over, Edwin, Jr., Mineral localities of Colorado: Rocks and Minerals, vol. 3, pp. 110-111, 1928; Further exploration on Mt. Antero: Rocks and Minerals, vol. 10, pp. 27-29, 1935.

Arthur Montgomery. _/ A later detailed study of the mineralogy and

---

_/ Montgomery, Arthur, Storm over Antero: Rocks and Minerals, vol. 13, pp. 355-369, 1938.

---

genesis of the deposits was made by Switzer. _/ On the basis of min-

---

_/ Switzer, G., op. cit.

---

eralogy he grouped these deposits into two major types, pegmatites and quartz veins, and on the same basis he further divided both types as follows:

A) Pegmatites:

1) Beryl pegmatites.
   a) Beryl-smoky quartz.

2) Phenakite pegmatites.
   a) Phenakite-colorless quartz.
   b) Phenakite-smoky quartz.

3) Beryl-phenakite-bertrandite pegmatites.
   a) Beryl-phenakite-bertrandite.
   b) Beryl-phenakite-bertrandite-fluorite.

4) Topaz pegmatites.

B) Veins:

1) Muscovite-quartz vein (containing phenakite).

2) Phenakite-quartz-fluorite vein.

3) Beryl-quartz-molybdenite vein.

The pegmatites, according to Switzer, are "uniformly small in size, seldom exceeding three feet in width and extending laterally for only a few feet." Where it was possible completely to excavate the pegmatites, they were found to be "roughly disc shaped or cylindrical bodies of limited extent in all directions."

The phenakite-bearing veins appear to be more continuous than the beryl-bearing pegmatites, and are believed by Switzer to have formed at a lower temperature. Of the three vein types, only the "beryl-quartz-molybdenite" vein was seen by the present writer. It lies outside of the granite stock and will be discussed further under "The beryllium-bearing vein at the California mine."

The minerals of the pegmatites and veins in the granite have been described in the several papers to which reference is made. These minerals include quartz, perthite, albite, muscovite, beryl, fluorite, phenakite, topaz, bertrandite, apatite, ilmenorutile, columbite (?), monazite, cyrtolite, limonite, and sulfur. The limonite occurs as pseudomorphs of pyrite crystals, and the sulfur probably is also derived from pyrite. _/

_/ Montgomery, Arthur, op. cit., p. 368.

Many of the deposits appear to be unusually rich in beryllium minerals and to contain fluorine as fluorite or more rarely as topaz. Apatite and monazite are the only phosphates reported, and both are rare. A description and analysis of the cyrtolite are given by Genth and Penfield. _/ No tourmaline or lithia minerals have been identified.

_/ Genth, F. A., and Penfield, S. L., Contributions to mineralogy, No. 54: Am. Jour. Sci., 3d ser., vol. 44, p. 387, 1892.

During the writer's visit only a few pegmatites were seen. These were little more than veinlets or schlieren a few inches wide and a few feet long. The dominant mineral in these is either plagioclase (albite) or light-smoky quartz; small books of muscovite are abundant, and microcline and fluorite are very common. Most of the pegmatites contain bright blue beryl. Fragments of quartz crystals and, more rarely, bits of aquamarine in shallow pits in the slide rock show where miarolitic cavities had been uncovered by mineral collectors, but the pegmatites themselves had been either mined out or buried in the debris and appear to have extended but little beyond the workings. Examination of outcrops, slide rock, and stream and morainal debris indicates that the beryllium-bearing pegmatites constitute only a minute amount of the granitic terrain. None of the pegmatites seen or reported have been of sufficient size to be of economic interest other than as a source of gems or specimen material. The remarkable finds of gem minerals from these pegmatites usually have been the result of long arduous search of large areas of talus for the source of pegmatite float.

Switzer _/ has observed that the miarolitic pegmatites are re-

_/ Switzer, G., op. cit., p. 800.

stricted to a zone, presumably flat lying, about 500 feet thick. Because the vertical range of the exposed granite is more than 3,000 feet and the miarolitic pegmatites commonly are found near the summits of Mount Antero and White Mountain, it would appear that these pegmatites are localized in the upper part of the stock as it is now exposed. The small veinlets or schlieren that do not contain miarolitic cavities, but do contain beryl, apparently are not subject to this limitation and are widely, though sparsely, distributed in the granite.

Greisen

Two areas of greisen were sampled for possible beryllium content. The first of these areas is located about a mile northeast of the California mine and consists of a large boulder field (pl. 1, locality B) of greisen that appears to be nearly in place. Chip samples taken from

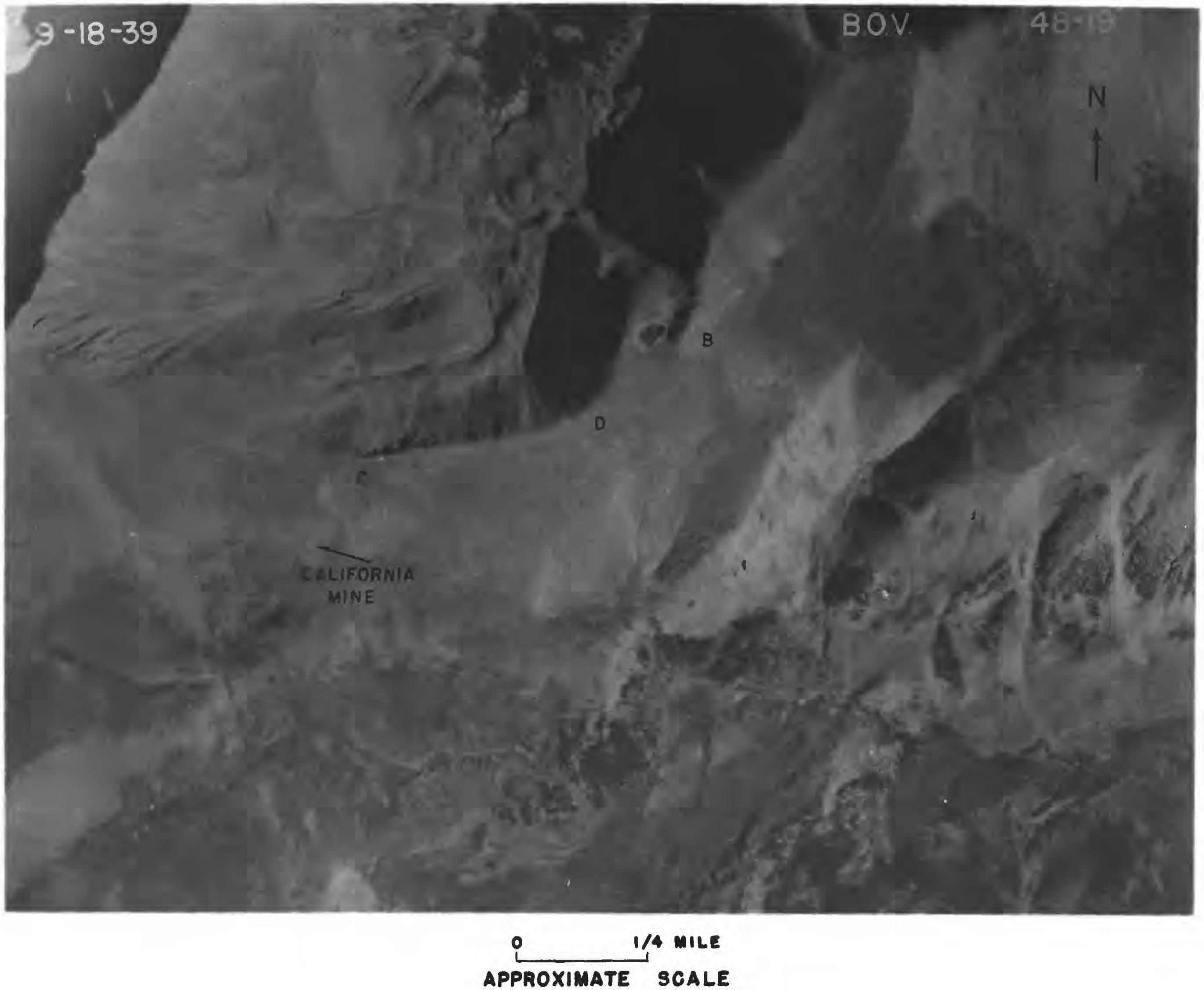


PLATE 1.— AERIAL PHOTOGRAPH OF AREA SURROUNDING THE CALIFORNIA MINE.

a number of representative specimens of the greisen were analyzed spectrographically and showed only a trace of beryllium. The greisen has a coarse sugary texture and contains small vugs lined with quartz crystals generally 1 or 2 mm in length. Microscopically, the rock is seen to consist almost entirely of interlocking quartz grains with some interstitial fine-grained muscovite or sericite and scattered flakes of molybdenite.

The second locality that was sampled is a small prospect pit (pl. 1, locality C) on the south side of the crest line of the ridge and about 900 feet north-northeast of the California mine. The excavation is made in a greisen similar in appearance to that described above, but in part more coarse grained. The coarser material contains from 5 to 10 percent topaz and scattered flakes of molybdenite; both minerals are in close association with minute muscovite blades. Spectrographic analysis _/

_/ Analysis by Saratoga Laboratories, Inc.

of dump material showed 0.015 percent beryllium oxide. No beryllium minerals were noted in the hand specimens or thin sections.

Although the distribution and extent of the greisen were not studied during the writer's visit, it is possible that they may occupy large areas of the quartz monzonite and undoubtedly are worthy of further study as a possible source of beryllium, molybdenum, and tin.

The beryllium-bearing vein at the California mine

Location and history

The California mine is about 2 miles southwest of Mount Antero, on the south slope of the divide between the basins of Brown's Creek and Baldwin Gulch (fig. 2 and pl. 1), at an altitude of approximately 12,500 feet.

Although there had been some earlier work, most of the development of the mine was done during World War I by the Molybdenum Mines Company of Denver. There is no recorded production, but when the property was visited by P. G. Worcester in 1917, small lots of hand-cobbed ore were being shipped to Denver for experimental treatment. At that time the company held four claims, the California, California No. 2, Nevada, and Nevada No. 2. The mine has not been operated since 1918. Ownership of the property, known as the California Group, Patent 19925, is claimed by Mr. G. G. Furman of Farmington, N. Mex.

Workings

Worcester [/] described the workings as follows:

[/] Worcester, P. G., op. cit., p. 35.

"All the development work, with the exception of some shallow surface cuts and location shafts, has been done on the California claim. In the summer of 1917 the workings consisted of: an open cut with a 50-foot drift on the vein; an inclined shaft 50 feet deep, near the open cut, but apparently not on the vein; a cross-cut tunnel, that was started 50 feet vertically below the open cut and was run 98 feet to the vein; and drifts from this tunnel, one 30 feet westerly on the vein and another 126 feet to the east. Small stopes, only 2 or 3 feet above the normal roof of the tunnel, have been run for 75 feet on the east drift. Mr. W. B. Lowry reported in June 1918, that since July 1917 the drift has been continued on to the east 15 feet to a fault, and 130 feet beyond, where the vein was recovered."

All the underground workings now are inaccessible, but as recently as 1938 the lower adit and at least part of the main drift were open but in a dangerous condition. _/ The portal of the adit now is buried under slide rock, but the rails leading from it into the sorting shed still can be seen. The inclined shaft and upper adit have been completely obscured by caving and by the slumping of the walls of the open cut. There are no usable buildings at the mine.

_/ Over, Edwin, oral communication.

Pomeroy quartz monzonite

The country rock in the vicinity of the mine has been identified by Crawford _/ as the Pomeroy quartz monzonite, a large stock, part of which is shown on his geologic map of the Monarch and Tomichi mining districts. The California mine is about half a mile north of the mapped area.

_/ Crawford, R. D., op. cit., p. 279.

In the vicinity of the mine the rock has a light-gray groundmass of plagioclase, orthoclase, and quartz, with numerous irregular dark aggregates of finely intergrown biotite, chlorite, and magnetite. Phenocrysts of purplish-gray plagioclase are present in some places. The rock has been somewhat altered and mineralized along the margins of the California vein; locally the altered material is sericite-quartz rock that contains molybdenite and pyrite for several inches outward from the vein. The wall rock that is adjacent to the parts of the vein containing little or no molybdenite or beryl is unaltered and unmineralized to within an inch or less of the contact.

The California vein

The part of the California vein that was mined is a quartz vein containing molybdenite, beryl, muscovite, molybdite, and minor amounts of other minerals. Worcester, _/ who saw the vein exposed in the workings, describes it as follows:

> "The vein varies from 18 inches to 3 feet in width. Its average dip is 80° N. 18° W., but it straightens up in many places to almost 90°. It seems to be a strong vein. It holds its course well and according to Mr. W. W. Rogers, superintendent at the mine, it has been followed by float on the surface for a mile or more. Work done since the writer's visit to the property in 1917 shows that at a distance of 141 feet from the cross-cut the vein is faulted, and that the east side is displaced 30 feet to the north."

These observations indicate a strike of N. 72° E., which approximates a strike of N. 75° E., obtained from the present limited outcrop

---

_/ Worcester, P. G., op. cit., p. 36.

by the writer.

The extent of the vein is problematical. The terrain along its general trend is a steep hillside (pl. 2) with alternate grassy patches and wide talus areas; outcrops are rare. What may be an outcrop of the vein was seen in a large block projecting from talus about 1,000 feet east-northeast of the mine. It consists of a quartz vein about a foot wide that contains about 2 percent beryl but no visible molybdenite. Limonitic material is interstitial to crystals of beryl and quartz. The exposure may not be in place, but is probably part of the California vein.

The easternmost extension of the California vein is probably at a prospect pit (pl. 1, locality D) near the crest of the ridge and about half a mile northeast of the mine. Although no rock in place is exposed in this pit, numerous fragments of vein quartz and oxidized pyritic wall rock were found. The quartz, which is white and in part coarsely crystallized, contains some hübnerite. A single specimen of beryl, embedded in quartz, was found at this locality. White quartz float is common along the crest of the ridge and on both sides of the divide, and probably the ridge is traversed by a number of veins. No vein float was found southwest of the mine.

To project the California vein with certainty beyond the known limits of the workings cannot be justified from the surface indications seen during the brief examination by the writer. The occurrence of a beryl-bearing quartz vein at the two points to the northeast is, however, encouraging, and for the purpose of estimating reserves, the

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 126

Plate 2.-- South slope of Carbonate Mountain, looking northwest. The California mine in the left foreground; portal of lower adit is just behind building.

vein is assumed to continue in that direction for 1,000 feet.

Mineralogy

The mineralogy of the California vein has been discussed previously by Landes. _/ He reports that the following minerals are present:

_/ Landes, K. K., op. cit.

quartz, beryl, molybdenite, molybdite, mica (sericite), and tourmaline. Three additional vein minerals were collected by the present writer from the dump above the portal of the lower adit; these are fluorite, rutile, and brannerite.

Quartz is the most abundant mineral, and although generally massive, some of it occurs in well-formed crystals that, according to Worcester _/

_/ Worcester, P. G., op. cit., p. 36.

are as much as 12 inches in length. It ranges from clear and colorless to dark smoky but usually is milky white. The surface exposures of the vein near the mine are almost entirely quartz.

The beryl in the vein is variable in form, transparency, and color. Although the color differences may be ascribed to slight compositional variations, the other two factors, form and transparency, are probably closely related to constantly changing physical conditions during the period of beryl growth. From a study of the material collected, the beryl appears to fall into the following three types which reflect three different growth environments:

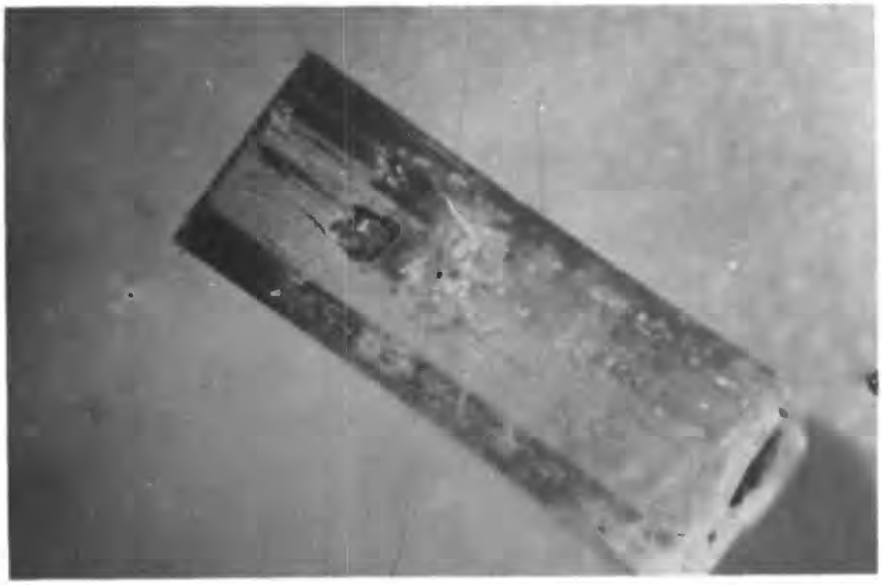
1) The greater part of the beryl occurs as crystals embedded in quartz. These crystals, which undoubtedly were the first to form, are generally less than 2 inches in length and rarely exceed one-half inch in diameter. The color ranges from pale green or blue to almost white. Clear and glassy areas are rare, and the crystals generally are fractured. Individual crystals are poorly formed and tend to develop columnar aggregates.

2) Less abundant are the crystals that formed vuggy intergrowths with quartz. These crystals apparently were formed on the walls of open channels, near the end of the deposition of beryl and quartz when there was less mutual interference and possibly a slower growth rate. Some individual crystals have excellent crystal form; but these, although commonly more transparent than the embedded crystals, are rarely of gem quality.

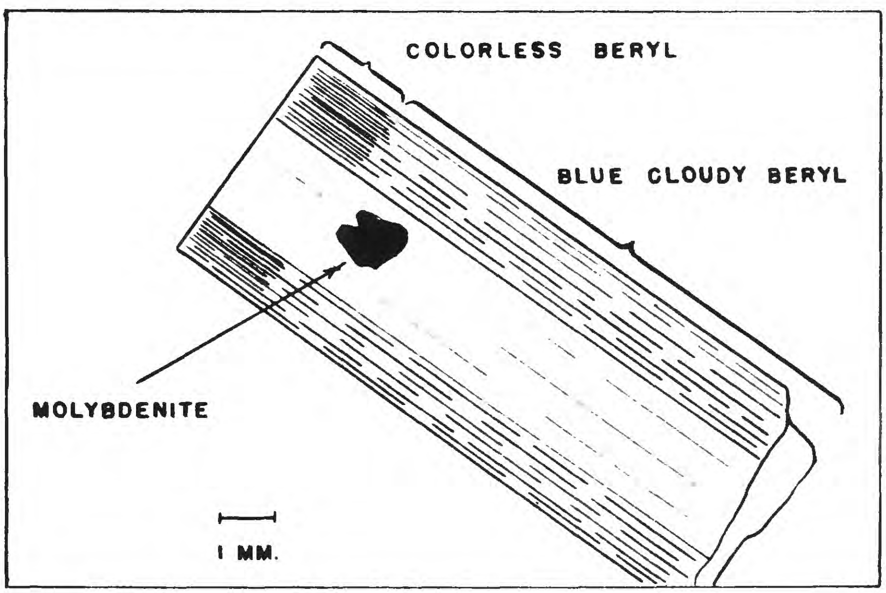
3) Comparatively rare is the beryl that formed as isolated crystals in vugs. Such crystals rarely exceed an inch in length, but they are commonly of gem quality. Simple combinations of prism and pinacoid predominate, but some of the crystals have first and second order pyramids. The crystals may be light bluish green, pale straw yellow, or colorless. Several of the crystals collected are markedly zoned; for the most part bluish, they are almost colorless near their terminal end (pl. 3). The colorless parts are more transparent than the bluish parts, owing to the presence of fewer minute fluid cavities. Some crystals have fine flakes of mica coating one or more prism faces, and both mica and molybdenite may be enclosed in the beryl (pl. 3).

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACE ELEMENTS INVESTIGATIONS
REPORT 126



A. Zoned beryl crystal enclosing molybdenite.



B. Sketch of crystal to show zoning and position of molybdenite inclusion.

Plate 3.-- Molybdenite in beryl, California mine.

In the crystal _/ shown in plate 3, the almost colorless terminal end

_/ Collected by Edwin Over, Jr., 1938.

of the crystal appears dark in contrast to the bluish cloudy part as a result of the scattering of the light by clouds of bubbles in the lower part of the crystal and the almost complete transmission of the light through the clear terminal end. The molybdenite inclusion consists of a cluster of several brilliant crystal plates completely enclosed in the beryl.

Another specimen illustrating the occurrence of isolated crystals growing in vugs was found on the dump. It consists of a straw-yellow beryl crystal about 7 mm long attached to walls of the vug, which is lined with milky quartz crystals apparently in continuity with massive quartz. Muscovite crystals coat the quartz and grow against the lower part of the beryl. A little molybdite, presumably derived from molybdenite, is interspersed with the mica. The order in which the three types of beryl have been described does not imply a strict genetic sequence, although probably the more abundant beryl of the first type was of early origin. It is possible that conditions prevailed that permitted the simultaneous development of all three types at different points in the vein.

The beryl varies considerably in color and appearance, but only slight differences in refractive index can be noted, and from this it may be assumed that differences in composition are slight. Observed values for the slow ray range from 1.572 to 1.575, and almost all of the values approach the higher figure. The lowest index was obtained from almost colorless crystals (table 1). _/ From an unpublished curve

_/ Table 1.—Refractive indices of beryl.

prepared by W. T. Schaller of the U. S. Geological Survey, the average refractive index of the beryl would indicate that it contains approximately 13.5 percent BeO.

Spectrographic analyses (table 2), _/ made in the laboratory of

_/ Table 2.—Spectrographic analyses of minor elements in beryl from Chaffee County, Colorado.

the U. S. Geological Survey, of beryl from the California mine and from White Mountain indicate that there is a close similarity in the type and amounts of the minor constituents present in the beryl from the vein and the pegmatites. Blue beryl from both localities contained the same percentage of the alkali elements (Na, K, Li, and Cs). This similarity in composition, suggesting a common origin, is further shown by the almost identical values for the omega index of refraction (close to 1.575) that is given by the California mine beryl and both gem and common blue beryl from the pegmatites in the granite.

Molybdenite occurs sparsely in small veinlets in the massive quartz outcrop of the vein; however, material can be found on the dump representative of the molybdenite-rich parts of the vein that were seen by Worcester when the mine was in operation and which he has described as follows: _/

Table 1.—Refractive indices of beryl from several localities

Locality	Type of deposit	Associated metallic minerals	Types of beryl	(Nw) Index of refraction
Tungsten Queen mine, Benson quadrangle, Arizona.	Quartz vein	Scheelite	Minute blue crystals	1.591
Pine Crow claim, Marietta district, Mineral County, Nevada.	Quartz vein	Wolframite	Blue crystals and masses	1.588
Victorio Mts., Luna County, New Mexico.	Quartz vein	Hübnerite, scheelite	Pale yellow brown	1.573
Victorio Mts., Luna County, New Mexico.	Quartz vein	Hübnerite, scheelite	Pale yellow brown	1.574
Lakeview mine, Pershing County, Nevada.	Contact metamorphic (?)	Scheelite	Colorless prismatic	1.590
Little Tungsten mine, Oreana, Nevada.	Contact metamorphic (?)	Scheelite	Pale emerald green, prismatic	1.587
Irish Creek, Virginia.	Quartz vein	Cassiterite, minor wolframite, bismuto-plagionite	Minute greenish crystals	1.577
Cowboy Tin mine, Hill City, S.D._/	Quartz vein	Cassiterite	Light green crystals	1.569
Mohawk Tin mine, Hill City, S.D._/	Quartz vein	Cassiterite	White crystals	1.568
Mohawk Tin mine, Hill City, S.D._/	Quartz vein	Cassiterite	White anhedral	1.570
California vein, Chaffee County, Colorado.	Quartz vein	Molybdenite	Colorless, prismatic enclosing MoS_2	1.572
California vein, Chaffee County, Colorado.	Quartz vein	Molybdenite	Colorless, prismatic	1.572
California vein, Chaffee County, Colorado.	Quartz vein	Molybdenite	Light blue, columnar	1.575
California vein, Chaffee County, Colorado.	Quartz vein	Molybdenite	Blue green, glassy	1.575
Locality D, possible extension California vein	Quartz vein	Rare hübnerite	Light yellow-brown prismatic	1.574

_/ Data, including indices, from Page, L. R., et al, Pegmatite investigations, 1942-45, Black Hills, S. Dak.: U. S. Geol. Survey Prof. Paper (in preparation).

Table 2.—Spectrographic analyses _/ of minor elements in beryl from Chaffee County, Colorado

Material	Specimen Number	Locality	Refractive index (Nw)	Mn	Ti	Ga	Sc	MgO	CaO	Fe_2O_3	Li	Na	K	Cs	Cr
Blue gem beryl	AB-1	White Mt.	1.576	.003	.001	.002	.006	<.1	<.1	.3-.6	.03	.1	.02	.2	-
Pale-yellow gem beryl	CB-12	California mine	1.575	.003	.003	.001	.004	<.1	<.1	.3-.6	.03	.09	.02	.09	0.0002
Blue beryl	CB-1[illegible]	California mine	1.575	.006	.003	.003	.02	<.1	<.1	.3-.6	.03	.1	.02	.2	—

Looked for but not found: Ba, Sr, Zr, V, Ni, Co, Cu, Y, La, Cb, Pb, Ag, P, As, Sb, Ge, Tl, Cd, Zn, Ta, Mo, Sn, B, Rb

_/ Analyses by U. S. Geological Survey, July 25, 1950

_/ Worcester, P. G., op. cit., p. 36.

"Molybdenite is found everywhere that the vein has been opened. The richest ore is near the walls, but there are rich streaks and vugs scattered all through the vein. In these rich streaks, and along the walls, chunks of solid molybdenite from 1 to 2 inches thick, and from 6 inches to 2 feet in length, are of common occurrence. The molybdenite is entirely crystalline, the flakes being as a rule, one-eighth to one-half an inch in diameter. The intimate association of pure white quartz crystals, some of which are 12 inches long, with opaque or clear beryl (aquamarine) crystals, and molybdenite is an interesting phase of the occurrence of this ore. Much of the richest ore is found with beautiful specimens of beryl. In many places pockets are found between masses of beryl and quartz crystals from which it is possible to dig out with a candlestick 20 or 30 pounds of practically pure molybdenite and molybdite. While the vein as a whole is strong, there are rich and lean streaks all through it."

The molybdenite, in the specimens collected by the writer, is concentrated along surfaces that presumably represent the walls of open channelways or vugs. Away from such surfaces, it is in isolated flakes that in many places project into small voids between beryl and quartz crystals. Because the molybdenite commonly is partly embedded in beryl or quartz and may be completely enclosed in transparent beryl, it is reasonable to assume that the molybdenite formed in part contemporaneously with beryl and quartz. The occurrence of the large masses of molybdenite interstitial to beryl and quartz crystals as described by Worcester _/

_/ Worcester, P. G., op. cit., p. 36.

indicate, however, that these masses were deposited after beryl and quartz.

Muscovite is relatively abundant in the vein as scattered flakes, scales, and crystals, none of which are more than 3 mm in maximum dimension.

Like molybdenite, with which it is associated in places, muscovite coats the walls of vugs and may be on, or enclosed in, crystals of beryl. Specimens of altered and mineralized wall rock on the dump consist largely of fine-grained sericitic mica. The crystallization of muscovite probably began and ended during the early stage of molybdenite formation.

A single broken crystal of a black submetallic mineral, found on the dump, was identified as impure rutile by X-ray and other tests made in the U. S. Geological Survey laboratory. The crystal was embedded in milky quartz associated with beryl and molybdenite.

Several fragments of colorless to dark-purple fluorite were found on the dump and in minute crystals and grains in altered wall rock.

Worcester _/ noted considerably more pyrite in the mineralized wall

---

_/ Worcester, P. G., op. cit., p. 36.

---

rock than in the vein; however, no pyrite was seen in any of the vein material collected in this investigation, and probably the mineral was not a common constituent of the vein where mined. Chalcopyrite was reported by Hess, _/ and Landes _/ reports finding "a few very small fragments of

---

_/ Hess, F. L., Molybdenum: Mineral Resources U. S., 1917, pt. 1, p. 912, 1920.

_/ Landes, K. K., op. cit., p. 698.

---

black tourmaline."

Molybdite occurs as minute fibrous lemon-yellow crystals forming powdery films or felty aggregates and is almost everywhere in close association with molybdenite. Molybdite commonly fills the voids between other minerals and occurs with jarosite in pyrite molds in altered wall rock. Worcester _/ has noted that although molybdite is more abundant in

_/ Worcester, P. G., op. cit., p. 36.

the upper workings, it is found in considerable quantities in the main tunnel level. Molybdite from the California mine was studied and analyzed by Schaller _/ as part of an investigation which established that the

_/ Schaller, W. T., Mineralogical notes, ser. 1: U. S. Geol. Survey Bull. 490, pp. 84-92, 1911.

mineral is hydrated ferric molybdate ($Fe_2O_3.3MoO_3.\ 7\frac{1}{2}H_2O$), rather than molybdenum trioxide as was previously believed.

An incomplete crystal of a radioactive mineral was found on the dump above the portal of the lower adit. The crystal, showing only what appear to be prism faces, is roughly square in cross-section and is about 5 mm in length. Freshly broken surfaces are black and have a submetallic luster. The exterior of the crystal is brownish yellow from alteration. It is isotropic, and quantitative spectrographic analyses and X-ray powder patterns made in the laboratory of the U. S. Geological Survey indicate that the mineral probably is brannerite, a species that in published literature has previously been reported _/ from only one locality, a gold

_/ Hess, Frank L., and Wells, Roger C., Brannerite, a new uranium mineral: Franklin Inst. Jour., vol. 189, no. 2, pp. 225-237; no. 6, pp. 779-780, 1920.

placer in Custer County, Idaho. Brannerite is essentially an oxide of titanium and uranium.

Paragenesis

The limited information that could be obtained from surface exposures and dump material makes it hazardous to reconstruct the history of the vein; however, some conclusions involving the individual minerals can be made, together with generalizations regarding the deposit.

1) Quartz makes up the bulk of the vein and appears to have been deposited almost continuously throughout the period of vein formation. Accessory minerals are locally abundant or sparse. Feldspars appear to be absent.

2) Beryl is concentrated along the outer edges of the vein, where most of it is embedded in quartz. The deposition of beryl probably began at the same time as that of quartz, but terminated earlier.

3) A minor amount of beryl forms a vuggy intergrowth with quartz. This beryl is thought to be generally of later formation than the beryl that is completely enclosed in quartz. The quartz in the vuggy intergrowths is commonly smoky or colorless in contrast to the more abundant milky quartz.

4) Molybdenite is partly embedded in the quartz and beryl of the vuggy intergrowths, and it projects into voids between the crystals. Molybdenite deposition may have begun early in the period of vein development but most of the molybdenite formed later

along open fissures resulting from incomplete filling of vein space by quartz and beryl.

5) The deposition of muscovite began at about the same time as molybdenite but probably was of shorter duration.

6) Pyrite probably formed at about the same time as molybdenite and largely by the action of sulfide-rich solutions on the iron minerals of the wall rocks.

7) The formation of vugs appears to have begun early in the history of the vein. Vugs that developed soon after molybdenite started to form contain crystals of quartz, muscovite, molybdenite, and beryl. The molybdenite is sparse. The beryl is clear and glassy and some of it encloses molybdenite.

8) Late vugs or open fissures have the same mineral assemblage, with abundant molybdenite coating all other minerals. The beryl is "opaque" or cloudy from its growth in a disturbed environment.

9) A change in the nature of the solutions sometime after molybdenite deposition resulted in corrosion of the vein. This action probably was very limited as most of the fissures had been sealed off. Both beryl and quartz were attacked, leaving molybdenite flakes standing out in relief from the etched surface.

10) Oxidation of the pyrite and molybdenite followed corrosion of the vein. Pyrite has been oxidized to a much greater extent than molybdenite and has left numerous cubic molds in the wall rock that are now filled wholly or partly with light bluff powdery jarosite and

yellow needles of molybdite.

Temperature of formation

Tests were made to determine the temperature of crystallization of beryl and fluorite from the California vein. These tests, based on the temperature of disappearance of the vapor phase of fluid inclusions, were made by Earl Ingerson of the U. S. Geological Survey.

Determinations were made on two specimens, a crystal of glassy straw-yellow beryl and a cleavage fragment of very pale purple fluorite, both showing several fluid inclusions. The results, uncorrected for pressure, are given below:

Mineral	Temp. range °C	Remarks
Beryl	250 - 255	Eight inclusions tested
Fluorite	265 - 272	Seven inclusions tested

The depth at which the California vein formed is not known, but according to Ingerson _/ the pressure correction to be added would be only

_/ Ingerson, Earl, Liquid inclusions in geologic thermometry: Am. Mineralogist, vol. 32, p. 383, 1947.

about 65° assuming a depth of 10 kilometers. Applying this correction would bring the temperature of the beryl crystallization to about 315°, or close to the lower limit of the hypothermal range as defined by Lindgren._/

_/ Lindgren, W. S., Mineral deposits: p. 212, 4th ed., 1933.

The particular beryl crystal tested was of the late-stage type that developed in vugs, hence its temperature of crystallization probably was somewhat lower than that at which vein deposition began but is higher than the temperature range existing during maximum molybdenite mineralization.

Beryllium resources

In the brief reconnaissance of the granitic area of Mount Antero and White Mountain nothing was seen that could be considered a commercial deposit of beryllium minerals. The pegmatites, although unusually rich in beryl, are of such small size and so widely scattered as to make them valueless except as a source of gems and specimen material.

The granite may contain appreciable beryllium. A composite sample of small granite fragments collected from several exposures on the north slope of White Mountain had a BeO content of 0.018 percent. _/ The fragments making up the sample were taken at some distance from pegmatites and showed no megascopic beryl.

_/ Spectrographic analysis by Saratoga Laboratories, Inc.

Little information could be obtained regarding the possible beryl resources of the California vein. As previously stated, there is reason to believe that the vein continues for 1,000 feet to the northeast, and possibly the mineralized vein material exposed in the prospect pit (pl. 1, locality D) represents the extension of the vein more than a half mile from the mine.

Examination of the dump of the California mine suggests that as much as 10 percent beryl may have been present in molybdenite-rich parts of the vein. As exposed on the surface in the vicinity of the mine workings, the vein shows little beryl or molybdenite and in part appears to be barren. A channel sample taken across an outcrop contained 0.016 percent beryllium oxide, _/ the equivalent of a little over 0.1 percent beryl; the vein as exposed may average less.

_/ Spectrographic analysis by Saratoga Laboratories, Inc.

Assuming the vein extension for 1,000 feet beyond the working with a maximum stoping height of 50 feet at the mine and 150 feet at the northeast limit, and using a vein width of 1.5 feet, a value is obtained of 150,000 cubic feet of vein material. Using a factor of 12.5 cubic feet per ton, this gives 12,000 tons of rock. If we can assume that higher-grade ore will bring up the lean or barren portions of the vein so that the average will be 0.5 percent beryl, the block of ground described should contain 60 tons of beryl. This estimate may be erroneous, but a more thorough evaluation of the reserves would require extensive exploration that does not seem justified on the basis of the reconnaissance examination.

Although most of the beryl is readily recognizable, the general size of the crystals is too small for efficient hand sorting. From Worcester's observations it would be expected that any beryl-rich parts of the vein that might be developed also would contain considerable molybdenite, and for the economic exploitation of the vein it would be almost imperative to utilize some method of milling that would recover both minerals efficiently. Any successful operation of the deposit certainly would depend on the extension or recurrence of rich ore, factors that cannot be predicted with the limited geologic information now available.

Undoubtedly much could be learned about the vein by reopening the underground workings. There is no way of estimating the amount of work this would require, except that at least a ton of slide rock would have to be removed from the portal before the condition of the adit could be determined.

Surface sampling has been limited to a few small outcrops. Additional exposures could be obtained only by much difficult trenching through slide rock that may be as much as 10 feet in depth.

Exploration by core-drilling probably would afford good structural information, but the presumably spotty distribution of the valuable minerals in a narrow vein would make sampling by this method unreliable. The mine is most difficult of access, and any heavy machinery or equipment would have to be transported by pack animals about 7 miles. No attempt to prospect or develop the deposit should be planned without full consideration of the difficult conditions that its location imposes.

BERYLLIUM-BEARING QUARTZ VEINS OF OTHER AREAS

Beryl has been reported from several metalliferous veins throughout the world, and probably this mineral is present, but has been overlooked, in many other deposits. These occurrences of beryl are all in quartz veins that in many places contain tungsten, tin, molybdenum, or bismuth in economic quantities. These elements are not uncommon in granite pegmatites but, unlike beryllium, they are rarely sufficiently abundant in the pegmatites to be economically interesting.

The mineralogy of several of the reported vein occurrences is given for comparative purposes:

Wolframite veins in the Torrington district, New South Wales, _/ con-

_/ Runner, J. J., and Hartmann, M. L., The occurrence, chemistry, metallurgy, and uses of tungsten: South Dakota School of Mines, Bull. 12, p. 32, 1918.

tain beryl associated with native bismuth, molybdenite, chalcopyrite, arsenopyrite, cassiterite, ilmenite, monazite, fluorite, topaz, smaltite, and lithia mica.

At the La Corne molybdenite deposit, Quebec, described by Norman, _/

_/ Norman, G. W. H., Molybdenite deposits and pegmatites in the Preissac-LaCorne area, Abitibi County, Quebec: Econ. Geology, vol. 40, pp. 1-17, 1945.

quartz veins with margins of plagioclase or muscovite contain molybdenite with minor amounts of pyrite and, more rarely, native bismuth, bismuthinite, chalcopyrite, and columbite. Norman states that "conspicuous amounts of tourmaline and beryl are present in some veins, and a little scheelite occurs rarely."

In describing the mineralogy at the San Antonio mine in Argentina, Smith and Gonzales _/ state: "Practically the only minerals in the tungsten

_/ Smith, W. C., and Gonzales, E. M., Tungsten investigations in the Republic of Argentina, 1942-1943: U. S. Geol. Survey Bull. 954-A, p. 31, 1947.

veins are wolframite and quartz. The presence of sparse grains of sulphides is suggested by spots of secondary copper and arsenic (?) minerals, but no sulphides were seen. A few crystals of beryl were found in one vein."

Beryl occurs in the tungsten veins at Boreana, Ariz., _/ where it is

_/ Hobbs, S. W., Tungsten deposits in the Boreana district and the Aquarius Range, Mohave County, Arizona: U. S. Geol. Survey Bull. 940-I, p. 254, 1944.

associated with wolframite, scheelite, and chalcopyrite in a quartz gangue. Other minerals in the tungsten veins are fluorite, pyrite, arsenopyrite, molybdenite, a little calcite, and small stringers of microcline.

At Irish Creek, Va. _/ beryl is found in the tin lodes as minute

_/ Koschmann, A. H., Glass, J. J., and Vhay, J. S., Tin deposits of Irish Creek, Virginia: U. S. Geol. Survey Bull. 936-K, 1942.

crystals that are most abundant at the edges of the quartz veins, but also are scattered throughout the bordering greisen. The veins contain cassiterite, muscovite, fluorite, phenakite, carbonates, minor wolframite, and sparse sulfides including bismutoplagionite ($5PbS \cdot 4Bi_2S_3$).

Reid _/ mentions beryl at the S and M Syndicate mine in Tasmania.

_/ Reid, A. McIntosh, The mining fields of Moina, Mt. Claude, and Lorinna: Tasmanian Geol. Survey Bull. 29, p. 70, 1919.

The major economic minerals of the vein are wolframite, cassiterite, bismutite, and bismuthinite, and the subordinate minerals are native bismuth, molybdenite, scheelite, gold, chalcopyrite, pyrite, arsenopyrite, galena, monazite, and limonite. The gangue is largely quartz, with lesser amounts of fluorite, topaz, pinite, and beryl. The other minerals noted were calcite, satin spar and laumontite.

Occurrences of beryl in quartz veins in Kazakhstan S. S. R., are described briefly by Sinegub./ The usual association is with tin and tung-

---

_/ Sinegub, E. S., Berill: Nematallicheskiye iskopayemye SSSR, MOSCOW-LENINGRAD, vol. 2, pp. 129-157, 1943.

---

sten, but two veins in granite near the Karagaila River contained beryl, molybdenite, and bismuthinite. Sinegub states:

"In the first vein, in addition to beryl, which occurs along its entire length, there are also large druses of molybdenite and bismuth glance; in the second, besides beryl, bismuth glance occurs chiefly. There is some muscovite in the structure of the vein. Tourmaline is entirely absent. The beryl is distributed in the veins more or less evenly; it also occurs in the form of schliers segregations in the granite together with schliers of amazon stone."

In the vicinity of Shorlovoy Gora (Schorl Mt.), _/ in the Agin

---

_/ Sinegub, E. S., op. cit.

_/ Fersman, A. E., Pegmatites, vol. 1, Granite pegmatites, pp. 120-122, 1940.

Buryat Mongolian National District of Eastern Siberia, beryl occurs in veins cutting a granite laccolith. The veins generally are symmetrically zoned as follows:

1) Greisen layer along walls; contains quartz, green mica, topaz, and fluorite.

2) Smoky quartz, in places in well formed crystals.

3) Ferberite (wolframite?), basobismutite _/, topaz, and other

---

_/ Shown to be identical with bismutite (Bi_2CO_5).
Frondel, Clifford, The oxides and carbonates of bismuth: Am. Mineralogist, vol. 28, p. 531, 1943.

---

minerals.

4) A central core of greenish-blue beryl.

In addition to the minerals mentioned above, Fersman states that the following occur in the veins: Native bismuth, gold, molybdenite, cassiterite, arsenopyrite, pyrite, chalcopyrite, sphalerite, bismuthinite, scheelite, molybdite, torbernite, monazite, scorodite, malachite, goethite and hematite, biotite, K and Li micas, potash feldspar, tourmaline, kaolinite, and siderite (?).

Holser _/ reports a quartz vein in the Victorio Mountains, Luna

_/ Holser, W. T., Beryl and helvite in the Victorio Mountains, New Mexico: U. S. Geological Survey report in preparation.

County, N. Mex., that contains beryl, hübnerite, and scheelite. The beryl occurs irregularly in a hanging-wall quartz-mica selvage, as crystals up to 5 mm in diameter and 5 cm in length. The vein is in dolomitic limestone.

At Winslow, Maine, _/ beryl occurs in quartz veins in schist, associ-

_/ Hess, Frank L., and Graton, L. D., The occurrence and distribution of tin: U. S. Geol. Survey Bull. 260, p. 163, 1905.

ated with cassiterite, lepidolite, fluorite, and arsenopyrite.

Beryl is present in several of the tin-bearing quartz veins of the Hill City district, Pennington County, S. Dak. _/ These deposits contain

_/ Page, L. R., et al., Pegmatite investigations, 1942-1945, Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper (in preparation).

"primarily milky-white vein quartz, clots and streaks of fine-grained muscovite, and clots or masses of white beryl." Attempts have been made to mine these veins for cassiterite.

The writer has been unable to find any reported occurrence of beryl in base-metal deposits, although beryllium is known to occur in a few such deposits as a constituent of other minerals, notably helvite. _/

_/ Burbank, W. S., The manganese minerals of the Sunnyside veins, Eureka Gulch, Colorado: Am. Mineralogist, vol. 18, pp. 513-527, 1933.

Hewett, D. F., Helvite from the Butte District, Montana: Am. Mineralogist, vol. 22, no. 6, pp. 803-804, 1937.

Weissenborn, A. E., A new occurrence of helvite: Am. Mineralogist, vol. 33, pp. 648-649, 1948.

In the several beryl-bearing veins described above, copper commonly is present in small amounts, but lead and zinc are rare or absent. Conversely, topaz, cassiterite, tourmaline, monazite, and wolframite, generally considered to be high-temperature minerals, may be present in conspicuous amounts.

In his description of the California vein, Landes _/ concludes:

_/ Landes, K. K., op. cit., p. 702.

"The relationship between beryl and pegmatites is so close that one is justified in assuming that beryl-containing deposits have been formed by pegmatitic solutions. The quartz-molybdenite-beryl vein of Chaffee County, Colorado, which occurs in a region of granite and pegmatite intrusion, is thought to have been deposited by hydrothermal solutions escaping from a deeper solidifying pegmatite. If these conclusions are correct, quartz veins containing beryl may be looked upon as a link connecting pegmatites with normal quartz veins."

In a later paper _/ devoted to the relationship between pegmatites

_/ Landes, K. K., Pegmatites and hydrothermal veins: Am. Mineralogist, vol. 22, p. 559, 1937.

and hydrothermal veins, Landes states:

> "Granitic magmas produce pegmatites and these, in turn, produce hydrothermal solutions which may precipitate ores of tin, tungsten, and molybdenum both in the pegmatite and in veins in the country rock adjacent to and for indefinite distances above the pegmatite."

The writer is in agreement with Landes' statement that the presence of beryl appears to link the quartz veins and the pegmatites, but he cannot wholly subscribe to a pegmatitic origin for all these veins. From the mineralogy of the examples cited above, it would appear that some of the deposits, for example, the La Corne, Quebec, molybdenite veins, closely resemble pegmatites; but others, like the Tasmanian occurrence, are richer in heavy metals, contain little or no feldspar, and may be considered to have a closer kinship to hydrothermal veins. It would seem reasonable to assume an essentially continuous sequence of deposits having a common magmatic source and ranging from pegmatites through the high-temperature quartz veins to the normal heavy-metal veins. In the transition from pegmatite to metal vein, conditions highly favorable for beryl development may change to those in which beryl cannot form and in which any remaining beryllium must be precipitated as some other compound.

REFRACTIVE INDEX OF BERYL FROM QUARTZ VEINS

During the investigation of the granitic pegmatites of the Black Hills, S. Dak., it was noted _/ that the refractive indices of beryl

---

_/ Page, L. R., et al., op. cit.

from individual pegmatites and from various parts of a single deposit may show considerable variation. The index usually recorded is that of the slow ray (omega), which varied from about 1.566 to 1.592. Beryl from simple pegmatites or from outer zones of complex ones generally has an index between 1.57 and 1.58. Indices higher than 1.58 characterize beryl from inner zones or late fracture fillings of lithia-bearing pegmatites. There is a direct relationship between the refractive index and the percentage of contained BeO, and a curve can be drawn so that the approximate BeO content can be determined directly from the refractive index. An unpublished curve prepared by W. T. Schaller of the U. S. Geological Survey shows that beryl containing the theoretical 14 percent BeO will have the slow ray index close to 1.566, whereas beryl with only 10 percent BeO has an index of about 1.600. The deficiency in BeO below the theoretical 14 percent is made up by the substitution of various alkalies, notably Cs_2O, Li_2O, and Na_2O. Both Cs_2O and Li_2O generally are most abundant in the same inner zones of pegmatites in which beryl of higher index is found.

Indices of beryl, from quartz veins and other deposits, which have recently been determined by the writer, show that beryl associated with tungsten minerals also may have an index close to 1.59, comparable to high-alkali beryl from lithia pegmatites. Beryl of low index (less than 1.58) may be expected from veins in which tin or molybdenum is dominant. Material from only a few deposits was available for study, and further work may show the need to qualify the interpretation, as suggested by the occurrence of relatively low-index beryl in the tungsten-bearing vein of the Victorio Mountains, N. Mex. (table 1).

Until beryl crystals from non-pegmatitic occurrences are analyzed for minor elements and BeO, it will be impossible to state whether their index variations are related to the same alkali substitution that takes place in pegmatite beryl.