Beryllium Deposits of the Mount Antero Region, Chaffee County, Colorado

By JOHN W. ADAMS

A CONTRIBUTION TO ECONOMIC GEOLOGY

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By JOHN W. ADAMS

ABSTRACT

Pegmatite and quartz veins that contain beryllium minerals occur in Tertiary granite in the vicinity of Mount Antero and White Mountain, Chaffee County, Colo. The pegmatites, which generally do not exceed a few feet in maximum dimension, are found throughout a main granite stock, in outlying granite masses, and in greisenized granite. Miarolitic pegmatites, from which fine specimens of aquamarine, phenakite, and bertrandite have been obtained, appear to be confined to the granite forming the upper part of the main stock.

A beryl-bearing quartz vein, once mined for molybdenite, occurs in quartz monzonite at the California mine southwest of Mount Antero. 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 material collected from the mine dump. The vein at the California mine is 1½ to 3 feet thick where exposed, is nearly vertical, strikes N. 72°–75° E., and is thought to extend for at least 1,000 feet along the strike to the northeast.

Beryl-bearing quartz veins similar to this vein are of world-wide distribution. They contain molybdenum, tin, tungsten, and bismuth and are believed to be transitional between pegmatites and hydrothermal veins. The beryl from some tungsten-bearing deposits has a high index of refraction (ω) compared to beryl from tin- and molybdenum-bearing veins.

INTRODUCTION

Mount Antero and White Mountain, in Chaffee County, Colo., have been known for many years as a source of crystals of the beryllium minerals beryl, phenakite, and bertrandite. Their occurrence in small pegmatites of the area was described by Switzer (1939). Beryl is found also in a quartz vein that was once mined for molybdenite (Worcester, 1919, pp. 34–38; Landes, 1934). It is known as the California vein and was studied in detail to determine the possibilities for commercial development.

Mount Antero and White Mountain are prominent peaks of the Sawatch Range of central Colorado, on the west side of the Arkansas River valley about 15 miles northwest of Salida and 100 miles south-

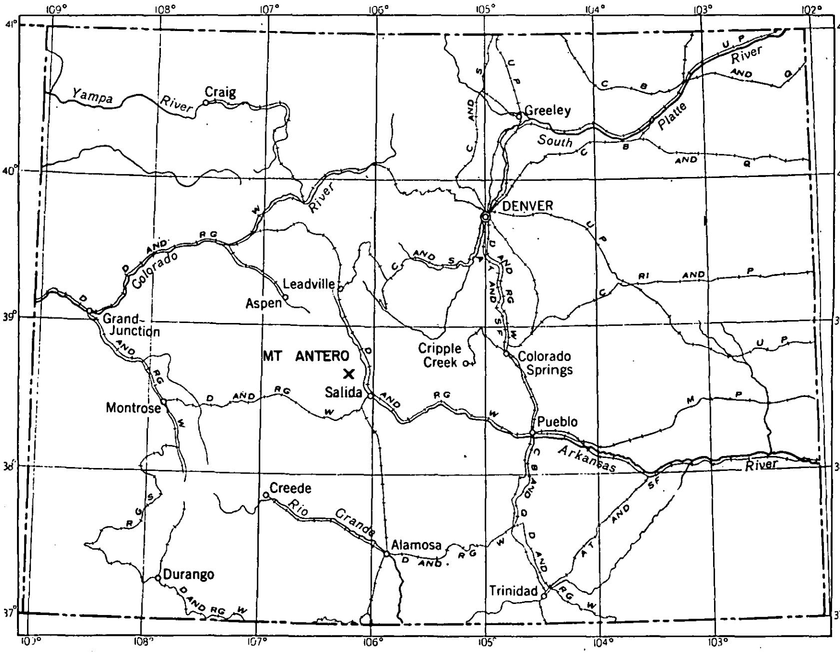

FIGURE 26.—Index map of Colorado showing location of Mount Antero area.

west of Denver (fig. 26). Mount Antero has an altitude of 14,245 feet and is a few hundred feet higher than White Mountain, 1¼ miles to the south. The beryllium deposits are in the immediate vicinity of these peaks (fig. 27). The area, which is above timberline, consists of steep talus-covered slopes, boulder fields, and broad grassy flats. Access to the region 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 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 Browns Creek, or Browns Creek trails. The Baldwin Gulch trail, shown in figure 27, starts about a mile west of New Alpine on the Chalk Creek road (State Highway 162) and offers an approach from the north. The other trails start from the Arkansas River valley and enter the mountains from the east. The Little Browns Creek route is most generally used to approach Mount Antero and White Mountain. Although the trails and connecting roads are shown on the San Isabel National Forest Map of the U. S. Forest Service, local inquiry regarding the trails is advisable. Aerial photographs are available, and partial topographic coverage is afforded by the Garfield quadrangle sheet (scale, 1 : 62,500). (See fig. 27.)

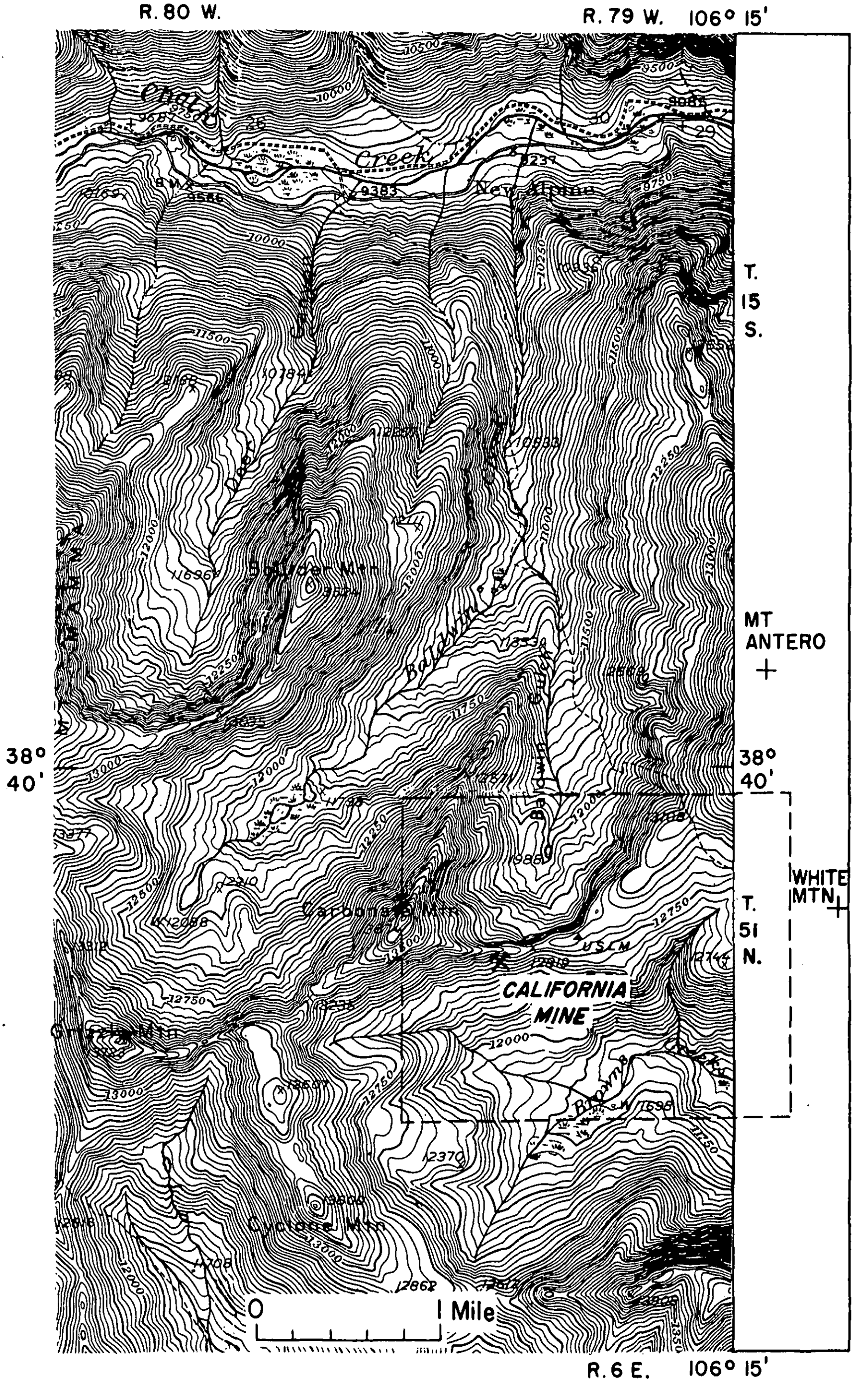

FIGURE 27.—Part of the Garfield quadrangle, Colorado and contiguous unmapped area, showing location of the California mine and approximate positions of Mount Antero and White Mountain. Area within dashed lines shows approximate location of figure 28.

The writer, assisted in the field by A. F. Trites, Jr., made a brief reconnaissance examination of the beryllium deposits of the Mount Antero region between June 24 and July 1, 1948, as part of the beryllium investigations being conducted by the U. S. Geological Survey on the behalf of the Atomic Energy Commission. In the summer of 1951, M. C. Dings, C. S. Robinson, and M. R. Brock completed a geologic map of part of the Mount Antero region as part of their mapping of the Garfield quadrangle, a cooperative project of the U. S. Geological Survey and the State of Colorado. This map was available to the writer during the final stage of manuscript preparation. The area was revisited for one day in September 1951 by the writer, C. S. Robinson, and G. R. Scott of the Geological Survey.

GENERAL GEOLOGY

The rocks of the Mount Antero region are granite, andesite, Princeton quartz monzonite, and Pomeroy quartz monzonite all of which are parts of a large intrusive complex known as the Princeton batholith. These rocks were first named and described by R. D. Crawford (1913), and are believed by him to be probably of Tertiary age. He concluded that Pomeroy quartz monzonite is older than Princeton quartz monzonite and that both rocks were intruded by the granite. Crawford was unable to establish definitely the relative age of the andesite, but considered it to be the youngest rock. This is now questionable, inasmuch as beryl-bearing quartz veins, presumably derived from the granite, occur in an andesite body (C. S. Robinson, personal communication) on the ridge between Baldwin Gulch and Browns Gulch.

Most of the beryllium-bearing pegmatites and veins, except the California vein, are in the main granite stock that is several miles in extent, and underlies a large part of Mount Antero and White Mountain. A much smaller body of the same granite crops out about three-fourths of a mile west of the main stock and is separated from it by andesite and Crawford's Pomeroy quartz monzonite. The California vein, in the vicinity of the mine workings, is in Pomeroy quartz monzonite, but probably extends into granite and possibly andesite.

BERYLLIUM DEPOSITS OF THE MOUNT ANTERO REGION

PEGMATITES

The pegmatites of the Mount Antero region are described by Switzer (1939, p. 793) as being "uniformly small in size, seldom exceeding three feet in width and extending laterally for only a few feet." Where the pegmatites could be completely excavated, they were found to be "roughly disk-shaped or cylindrical bodies of limited extent in all directions." On the basis of mineralogy Switzer classified them as follows:

1. Beryl pegmatites: Beryl-smoky quartz.
2. Phenakite pegmatites: Phenakite-colorless quartz. Phenakite-smoky quartz.
3. Beryl-phenakite-bertrandite pegmatites: Beryl-phenakite-bertrandite. Beryl-phenakite-bertrandite-fluorite.
4. Topaz pegmatites.

Pegmatites containing large miarolitic cavities occur near the top of the granitic stock. Almost all the pegmatites seen by the writer, however, were little more than relatively coarse-grained schlieren a few inches wide and at most a few feet long that grade imperceptibly into the enclosing granite. These pegmatites rarely contain the well-developed miarolitic cavities in which gem minerals occur and except for small crystal-lined voids less than an inch across are composed entirely of interlocked anhedral to subhedral grains. This schlieren type of pegmatite commonly so rich in beryl as to be almost monomineralic, is widely, though sparsely, distributed throughout a vertical range of at least 2,500 feet in the granite of the main stock. This type is present also in the smaller body of granite and greisen to the west.

The pegmatites characterized by large miarolitic cavities, which may be as much as 4 feet in diameter, are found in granite on the higher slopes of Mount Antero and White Mountain. This granite most probably formed the upper few hundred feet of the stock. Switzer (1939, p. 800) says that all the pegmatites and quartz veins which he studied were in a zone 500 feet thick. The upper limit of this zone is probably the top of the stock, which is only a short distance below the summit of Mount Antero, as shown by an essentially horizontal contact of granite with overlying Princeton quartz monzonite at an altitude of about 14,000 feet (C. S. Robinson, personal communication).

Pegmatites from any part of the stock may contain small voids, thus the miarolitic pegmatite zone must be defined as a zone in which the cavity development is most pronounced. Undoubtedly the size of the cavities increases in general with elevation, but the size of any individual cavity is probably the result of local pressure conditions, the volume of material, and the concentration of volatiles.

The mineralogy of the miarolitic pegmatites and the more common schlieren type is fundamentally the same. The dominant minerals of both types are smoky quartz, perthitic microcline, albite, beryl, muscovite, and fluorite. Accessory minerals include phenakite, topaz, garnet, apatite, bertrandite, calcite, biotite, magnetite, limonite, and sulfur. Some of the rarer minerals, such as topaz, may locally become dominant in an individual pegmatite. Bertrandite is probably restricted to pegmatites of the miarolitic type, as it is apparently the product of reaction of late-stage fluids or gases on beryl exposed in

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open cavities. A description and analysis of cyrtolite from Mount Antero has been given by Genth and Penfield (1892, p. 387), but no subsequent discoveries of the mineral have been reported. Limonite forms pseudomorphs after pyrite crystals, and the sulfur probably is derived also from pyrite (Montgomery, 1938, p. 368). A black, strongly radioactive mineral that occurs sparsely in the pegmatites is probably brannerite. No lithium minerals have been identified from the pegmatites.

VEINS

Quartz veins containing beryllium minerals are present in the Mount Antero area. They differ from the pegmatites in that they are much richer in quartz, contain little or no feldspars, and appear to be more nearly continuous.

Two such veins in the granite of the southwest face of Mount Antero were described by Switzer (1939, pp. 797–800) as (1) a muscovite-quartz vein containing phenakite, and (2) a phenakite-quartz-fluorite vein. A third vein, containing beryl and molybdenite lies outside the main granite stock and has been previously described by Landes (1934, pp. 697–702). It is discussed in this paper under "The beryllium-bearing vein at the California mine." (See page 101.)

In general the mineralogy of the veins is quite similar to that of the pegmatites with the notable exceptions of perthitic microcline, which has not been found in the veins, and of molybdenite, hübnerite and the sanadine variety of orthoclase which have not been noted in the pegmatites. Quartz, fluorite, muscovite, beryl, phenakite, albite, pyrite, and probably brannerite occur in both types of deposits and suggest that a close relationship, if not a complete gradational sequence, exists between the pegmatites and the veins. Switzer (1939, p. 801) believes that the veins in the granite represent the lower-temperature or late-stage mineralization phase of the pegmatites, a phase which followed the crystallization of beryl and microcline. As phenakite was the only beryllium mineral found in the veins in the granite, and as it followed beryl in the paragenetic sequence of the pegmatite minerals, Switzer concluded that phenakite was stable at a lower temperature than beryl and might be present under conditions unfavorable for beryl crystallization.

The relationship between phenakite and beryl, while apparently applicable to the deposits in the main granite stock of Mount Antero and White Mountain, does not always exist. This fact is shown by the beryl-bearing vein at the California mine, and by the world-wide occurrence of beryl in quartz veins—further discussed under "Beryl-bearing quartz veins of other areas." (See page 114). It is more probable that the formation of phenakite instead of beryl is a result of differences in the chemical environment, not lower-temperature conditions.

GREISEN AND GRANITE

Two areas of greisenized granite were sampled for possible beryllium content. The first of these areas is about a mile northeast of the California mine and consists of a large boulder field of greisen (fig. 28, locality B). The greisen has a coarse, granular texture and contains small vugs lined with quartz crystals which generally range from 1 to 2 millimeters in length. Microscopically, the rock consists almost entirely of interlocking quartz grains with some interstitial fine-grained muscovite or sericite and scattered flakes of molybdenite. Chip samples taken from a number of representative specimens of greisen showed only a trace of beryllium by spectrographic analysis (Saratoga Laboratories, Inc.).

The second area of greisen (fig. 28, locality C) was found in the small mass of granite west of the main granite stock. A sample of this greisen, collected by C. S. Robinson contained 0.0008 percent BeO (spectrographic analysis by U. S. Geological Survey).

During the writer's examination of the Mount Antero region several small chip samples were collected from the granite on the north slope of White Mountain. These samples were believed to be representative of the granite and contained no megascopic beryl. A composite of these samples contained 0.018 percent BeO (spectrographic analysis by Saratoga Laboratories, Inc.). Because of the high percentage of BeO in this sample, additional samples of granite were collected by C. S. Robinson and M. R. Brock from 12 widely separated exposures of the main stock and outlying masses. The highest BeO content found in these additional samples was 0.0016 percent; and all were consistently much lower than the original composite sample (spectrographic analysis, U. S. Geological Survey). Although beryl-bearing pegmatities are relatively abundant on White Mountain, it is doubtful that the granite from this part of the main stock actually contains more BeO than the small quantities found in the 12 samples from other exposures. Until verified by check samples, the anomalous BeO content of the White Mountain samples should be questioned, and it is probable that neither the granite nor greisen contains appreciable amounts of beryllium.

THE BERYLLIUM-BEARING VEIN AT THE CALIFORNIA MINE

LOCATION AND HISTORY

The California mine is about 2 miles southwest of the crest of Mount Antero, on the south slope of the divide between the basins of Browns Creek and Baldwin Gulch (figs. 27, 28), at an altitude of approximately 12,500 feet.

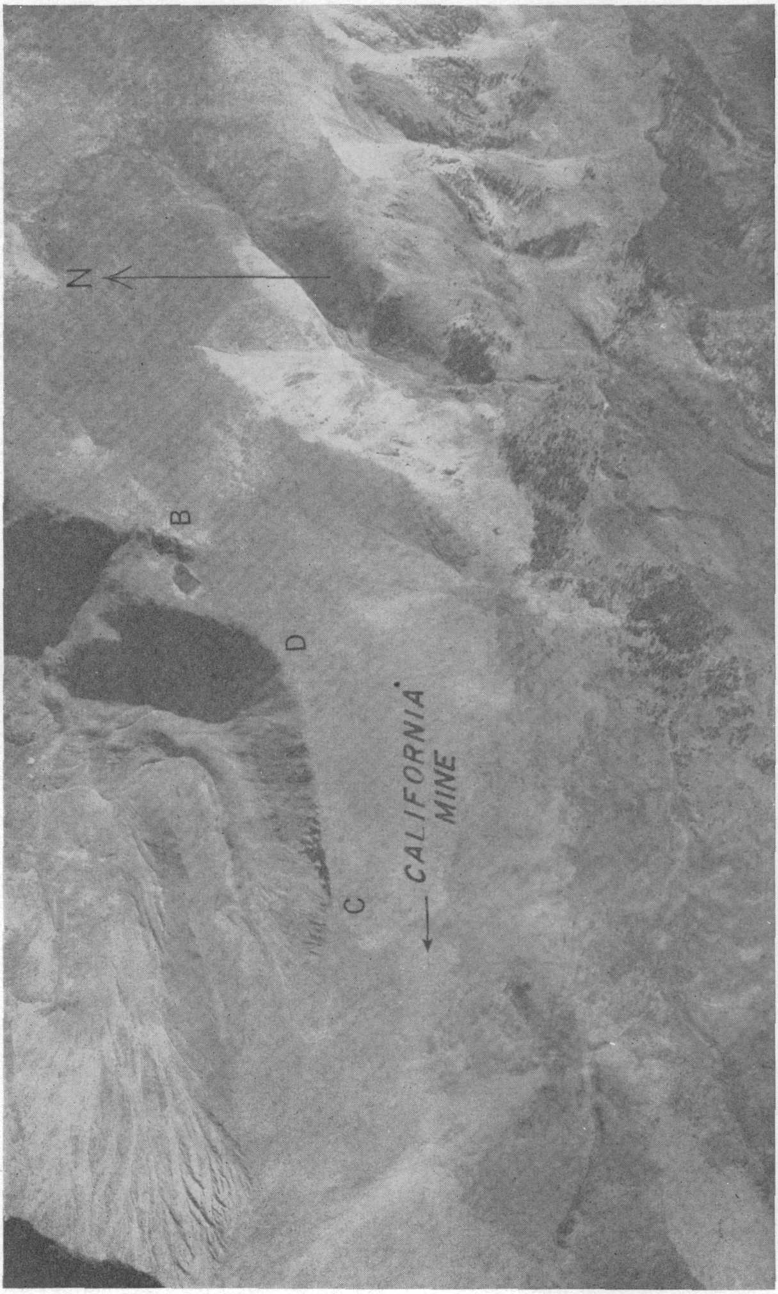

FIGURE 28.—Aerial photograph of area surrounding the California mine, showing localities B, C, and D. Approximate scale, 1 inch = ¼ mile.

Although some earlier work had been done, most of the development of the mine was done during World War I by the Molybdenum Mines Co., of Denver. No production is recorded, 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 19,925, is claimed by Mr. G. G. Furman, Farmington, N. Mex.

WORKINGS

Worcester (1919, p. 35) described the workings as follows:

> 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 underground workings are now inaccessible, but as recently as 1938 the lower adit and part of the main drift were open but in a dangerous condition (Over, Edwin, personal communication). 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.

POMEROY QUARTZ MONZONITE OF CRAWFORD

The country rock in the vicinity of the mine, identified by Crawford (1913, p. 279) as the Pomeroy quartz monzonite, is part of a large stock, as shown on his geologic map of the Monarch and Tomichi mining districts. The California mine is about half a mile north of the area shown on this map.

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.

Wall-rock alteration apparently is related to the intensity of vein mineralization. Where the vein is essentially barren of molybdenite and beryl the quartz monzonite is unaltered except for an inch or less of siliceous material along the contact. The rich beryl and molybdenite vein-filling on the dump, however, is associated with a sericite-quartz rock that probably represents altered country rock adjacent to the highly mineralized parts of the vein. This type of rock is also present locally in walls of the open-cut where it was probably adjacent to the ore. The sericite-quartz rock contains abundant molybdenite and molds of cubic pyrite crystals.

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 (1919, p. 36), 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.

The observations obtained by the writer from the present limited outcrop indicate a strike of N. 75° E.

The length of the vein is problematical. Outcrops are rare along the steep hillside (fig. 29) where grassy patches alternate with wide talus areas. A large block projecting through the talus about 1,000

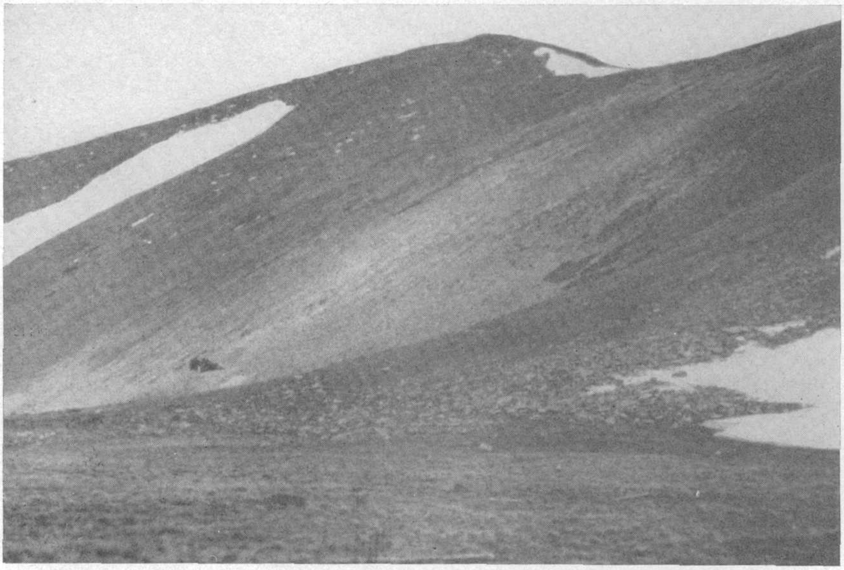

FIGURE 29.—South slope of Carbonate Mountain, looking northwest. The California mine in the left foreground; portal of lower adit is just behind building.

feet east-northeast of the mine may be an outcrop of the vein. This exposure consists of a quartz vein about 1 foot wide that contains about 2 percent beryl but no visible molybdenite. Limonitic material is interstitial to crystals of beryl and quartz. The block may not be in place, but is probably part of the California vein.

Numerous fragments of coarsely crystallized vein quartz and oxidized pyritic wall rock were found in a prospect pit (fig. 28, locality D) in andesite near the crest of the ridge and about half a mile northeast of the California mine. A single specimen of beryl and a few small crystals of hübnerite were found in the quartz at this locality. Reexamination of the pit in September 1951 failed to disclose additional beryl, but a beryl-bearing quartz vein in andesite was seen in a small excavation a few hundred feet southwest of the pit. This vein was about 1 foot wide and had a selvage zone of small blue beryl crystals. While there is little supporting evidence, these findings may represent the easternmost extension of the California vein. The vein could not be traced 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 beryl-bearing quartz at several points to the northeast is, however, encouraging.

MINERALOGY

The mineralogy of the California vein has been discussed previously by Landes (1934, pp. 697–702). He reports that the following minerals are present: quartz, beryl, molybdenite, molybdite, mica (muscovite and sericite), and tourmaline. Three additional vein minerals were collected by the 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 (1919, p. 36) are as much as 12 inches in length. It ranges in color from clear and colorless to dark smoky, but generally it 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, 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 apparently falls into the following three types which reflect 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. The beryl generally tends to be in columnar aggregates; individual crystals are poorly formed.

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

(3) Beryl that formed as isolated crystals in vugs is comparatively rare. These crystals rarely exceed an inch in length, but they are commonly of gem quality. Simple combinations of prism and pinacoid forms predominate, but some of the crystals have first and second order pyramids as well. The crystals may be light bluish green, pale straw yellow, or colorless. Several of the crystals collected are markedly zoned. They are bluish in color for most of their length, but near their terminal end they are almost colorless (fig. 30). 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 (fig. 30). In the crystal shown in figure 30 (collected by Edwin Over, 1938), the almost colorless terminal end appears dark in the photograph in contrast to the bluish cloudy part. This is the result of the scattering of light by clouds of bubbles in the colored part of the crystal and the almost complete transmission of light through the clear terminal end. The molybdenite inclusion consists of a cluster of several brilliant crystal plates.

The manner of occurrence of these isolated crystals is shown by a large fragment of vein quartz found on the dump. The specimen contains a vug lined with milky quartz crystals from which projects a transparent straw-yellow beryl crystal about 7 millimeters long. Small muscovite crystals are implanted on the quartz lining the vug and grow against the lower part of the beryl crystal. 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.

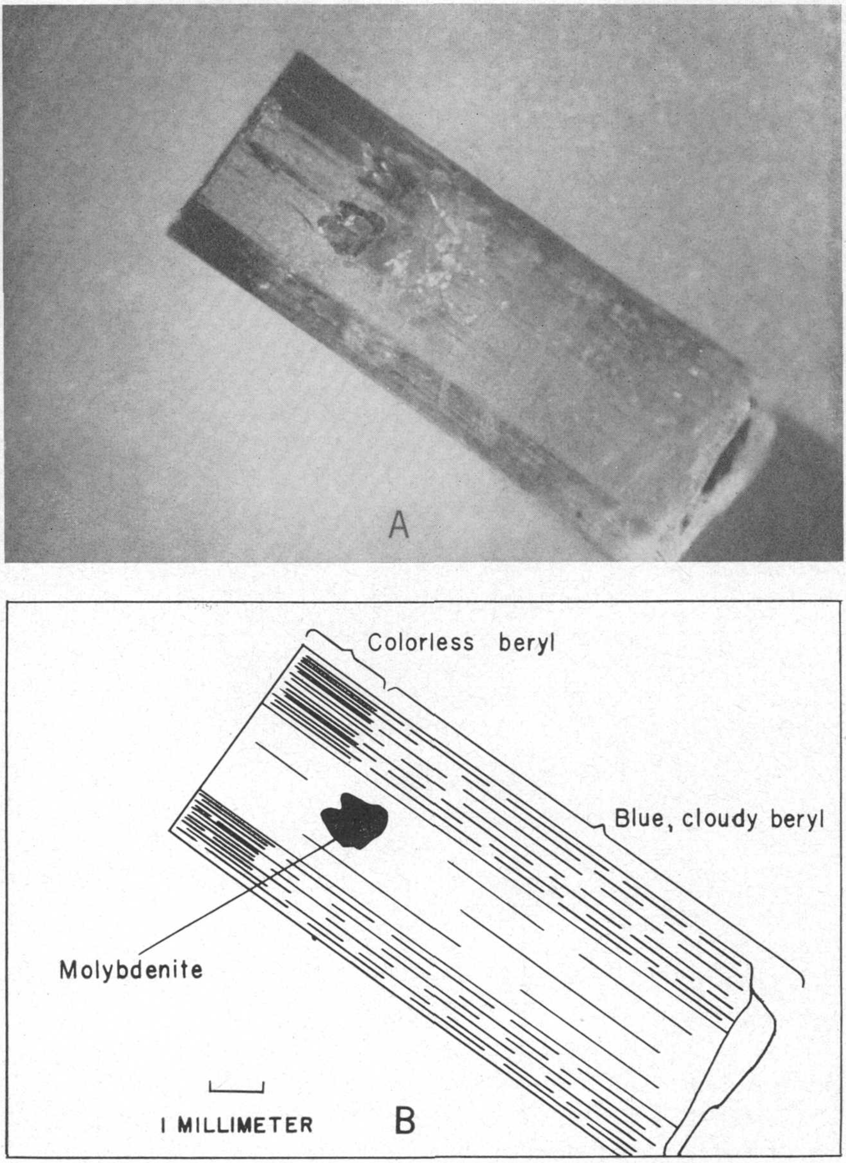

FIGURE 30.—Molybdenite in beryl, California mine. *A*, Zoned beryl crystal enclosing molybdenite. *B*, Sketch of crystal to show zoning and position of molybdenite inclusion.

The beryl varies considerably in color and appearance, but only slight differences in the index of refraction 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 the values approach the higher figure. The lower indices were obtained from almost colorless crystals (table 1). From an unpublished curve prepared by W. T. Schaller of the U. S. Geological Survey, the average index of refraction of the beryl would indicate that it contains approximately 13.5 percent BeO. Further mention (p. 117) will be made of the index of refraction of beryl from quartz veins inasmuch as a relationship appears to exist between this property and the metals present in the veins.

TABLE 1.—*Indices of refraction of beryl from several localities*

Locality	Type of deposit	Associated metallic minerals	Types of beryl	(Nω) Index of refraction
Tungsten Queen mine, Benson quadrangle, Ariz.	Quartz vein	Scheelite	Minute blue crystals	1.591
Pine Crow claim, Marietta district, Mineral County, Nev.	do	Wolframite	Blue crystals and masses	1.588
Victorio Mountains, Luna County, N. Mex.	do	Hübnerite, scheelite.	Pale yellow-brown	1.573
Do	do	do	do	1.574
Lakeview mine, Pershing County, Nev.	Contact metamorphic (?).	Scheelite	Colorless prismatic	1.590
Little Tungsten mine, Oreana, Nev.	do	do	Pale emerald-green, prismatic.	1.587
Irish Creek, Va	Quartz vein	Cassiterite, minor wolframite, bismuto-plagionite.	Minute greenish crystals	1.577
Cowboy tin mine, Hill City, S. Dak.[1]	do	Cassiterite	Light-green crystals	1.569
Mohawk tin mine, Hill City, S. Dak.[1]	do	do	White crystals	1.568
Do.[1]	do	do	White anhedral	1.570
California vein, Chaffee County, Colo.	do	Molybdenite	Colorless, prismatic enclosing MoS_2.	1.572
Do	do	do	Colorless prismatic	1.572
Do	do	do	Light-blue, columnar	1.575
Do	do	do	Blue-green glassy	1.575
Locality D, possible extension California vein.	do	Rare hübnerite	Light yellow-brown prismatic.	1.574

[1] Data, including indices, from Page, L. R., and others, 1953, Pegmatite investigations, 1942–45, Black Hills, S. Dak.: U. S. Geol. Survey Prof. Paper 247. [In press].

Spectrographic analyses (table 2), made in the laboratory of the 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 in the beryl from both the vein and the pegmatites. Blue beryl from both localities contained approximately 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; material can be found on the dump, however, that is representative of the molybdenite-rich parts of the vein seen by Worcester when the mine was in operation. He has described these rich parts as follows: (Worcester, P. G., 1919, p. 36).

TABLE 2.—*Spectrographic analyses of minor elements* [1] *in beryl from Chaffee County, Colo.*

[Analyses by Janet D. Fletcher, U. S. Geological Survey]

Material	Specimen no.	Locality	Index of refraction N_ω	Percent											
				Mn	Ti	Ga	Sc	MgO	CaO	Fe_2O_3	Li	Na	K	Cs	Cr
Blue gem beryl	AB-1	White Mountain	1.576	0.003	0.001	0.002	0.006	<.1	<.1	0.3–0.6	0.03	0.1	0.02	0.2	--------
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-14	California mine	1.575	.006	.003	.003	.02	<.1	<.1	.3–.6	.03	.1	.02	.2	--------

[1] 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.

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 of 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 to 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 (1919, 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 millimeters 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 consists 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 by the 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 (1919, p. 36) noted considerably more pyrite in the mineralized wall 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 (1920, p. 912), and Landes (1934, p. 698) reports finding "a few very small fragments of black tourmaline."

Minute fibrous lemon-yellow crystals of molybdite form powdery films or felty aggregates and are 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 (1919, p. 36) has noted that although molybdite is more abundant in 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 (1911, pp. 84–92) as part of an investigation which found the mineral to be 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 about 5 millimeters in length. The exterior of the crystal has a brownish-yellow coating resulting from alteration, but freshly broken surfaces are black and have a submetallic luster. Quantitative spectrographic analyses and X-ray powder patterns made by the Geological Survey laboratory show the mineral to be brannerite, essentially an oxide of titanium and uranium. The brannerite is metamict, being isotropic and giving an X-ray powder pattern only after ignition. This species has previously been reported from only one locality (Hess and Wells, 1920, pp. 225–237, 779–780), a gold placer in Custer County, Idaho.

PARAGENESIS

The limited information obtained from surface exposures and dump material makes it difficult to reconstruct the history of the vein. Some conclusions involving the individual minerals can be drawn, however, 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. Locally, accessory minerals are either 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 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 about the same time as molybdenite but probably was of shorter duration.

(6) Pyrite probably formed about the same time as molybdenite largely from the reaction of sulfide-rich solutions on the iron-bearing minerals in the wall rocks.

(7) The formation of vugs began early in the history of the vein by channelways being progressively sealed off leaving voids in which solutions of varying composition were trapped. The solution present in any particular void is believed to represent a fraction of the vein fluids passing through the channelway just prior to entrapment, and the minerals deposited on the walls of this void will be those representative of that particular stage of mineralization. For example a vug such as described on page 106 probably enclosed fluids of the period when molybdenite deposition began. The vug contained the early minerals, quartz, and beryl, a minor amount of muscovite, and some molybdenite as indicated by secondary molybdite. The clear transparent beryl of the vug suggests growth in an undisturbed environment.

(8) Late vugs or open fissures have the same mineral assemblage, with abundant molybdenite coating all other minerals. The beryl is "opaque" or cloudy.

(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-buff 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 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*	*Inclusions tested*
Beryl	250–255	8
Fluorite	265–272	7

The depth at which the California vein formed is not known, but according to Ingerson (1947, p. 383) the pressure correction to be added would be only about 65° C assuming a depth of 10 kilometers. Applying this correction would bring the temperature of the beryl crystallization to about 315° C, or close to the lower limit of the hypothermal range as defined by Lindgren (1933, p. 212). 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 the period of maximum molybdenite deposition.

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 generally so small and so widely scattered that they are valueless except as a source of gems and specimen material.

On the basis of the analysis of a composite of chip samples collected from White Mountain, it was first thought that the granite might 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 (spectrographic analysis by Saratoga Laboratories, Inc.). The fragments making up the sample were taken at some distance from pegmatites and showed no megascopic beryl. The results of additional samples taken in 1951, however, tend to disprove this and indicate the beryllium content of the granite of the main stock and outlying masses to be insignificant.

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 (fig. 28, 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 is apparently barren. A channel sample taken across an outcrop contained 0.016 percent beryllium oxide (spectographic analysis by Saratoga Laboratories, Inc.), the equivalent of a little over 0.1 percent beryl; the vein as exposed may average less.

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 than cannot be predicted with the limited geologic information now available.

Undoubtedly much could be learned about the vein by reopening the underground workings. To do this, at least a ton of slide rock would have to be removed from the portal before even 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 yield good structural information, but the presumably spotty distribution of the valuable minerals in a narrow vein would make sampling by this method unreliable.

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 metallic elements are not uncommon in granite pegmatites but, unlike beryllium, they are rarely sufficiently abundant to be of economic interest.

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

Wolframite veins in the Torrington district, New South Wales (Runner and Hartman, 1918, p. 32) contain 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 (1945, pp. 1–17) quartz veins with margins of plagioclase or muscovite contain molybdenite with minor amounts of pyrite, and less commonly, native bismuth, bismuthinite, chalcopyrite, and columbite. Norman (1945, p. 15) 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 (1947, p. 31) state:

Practically the only minerals in the tungsten 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., (Hobbs, 1944, p. 254) where it is 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, Virginia (Koschman, Glass, and Vhay, 1942) beryl is found in the tin lodes as minute 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 ($5PbS.4Bi_2S_3$).

Reid (1919, p. 70) mentions beryl at the S and M Syndicate mine in Tasmania. 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 (1943, pp. 129–157). The usual association is with tin and tungsten, 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 Sherlovoi Gore (Schorl Mount), (Sinegub, 1943; Fersman, 1940, pp. 120–122) in the Agin 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 topaz, and fluorite.
2. Smoky quartz, in places in well formed crystals.
3. Ferberite (wolframite?), basobismutite (Frondel, 1943, p. 531), topaz, and other 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, potassium and lithium micas, potash feldspar, tourmaline, kaolinite, and siderite (?).

Holser[1] reports a quartz vein in the Victorio Mountains, Luna 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 millimeters in diameter and 5 centimeters in length. The vein is in dolomitic limestone.

At Winslow, Maine (Hess, 1905, p. 163) beryl occurs in quartz veins in schist, associated with cassiterite, lepidolite, fluorite, and arsenopyrite.

Beryl is present in several of the tin-bearing quartz veins of Hill City district, Pennington County, S. Dak. (Page and others, 1953). These deposits contain "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, 1933, pp. 513–517; Hewett, 1937, pp. 803–804; Weissenborn, 1948, pp. 648–649).

In the several beryl-bearing veins described above, copper commonly is present in small amounts, but lead and zinc are uncommon 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 (1934, p. 702) concludes:

> 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 (Landes, 1937, p. 559) devoted to the relationship between pegmatites 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.

[1] Holser, W. T., 1952, Beryl and helvite in the Victorio Mountains, New Mexico: U. S. Geol. Survey Trace Elements Inv. Rept. 166. [Unpublished.]

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 seems apparent 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 metalliferous 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.

INDEX OF REFRACTION OF BERYL FROM NONPEGMATITE DEPOSITS

The study of beryl from the California mine and from some of the localities discussed in the preceding section indicates that the index of refraction (ω) of beryl from the various deposits varies within the same range as the beryl from granite pegmatites (Page, L. R., and others, 1953). 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. The increase of the index of refraction of pegmatite beryl is accompanied by a decrease in the BeO content through the substitution of certain alkalies, notably Cs_2O, Li_2O, and Na_2O for BeO.

Although beryl from only 9 localities was studied by the writer, it is believed that the data (table 1) indicate that the beryl in veins containing molybdenum or tin has a low or intermediate index compared to beryl associated with tungsten. The anomalous occurrence of low-index beryl in the tungsten vein at the Victoria Mountains, New Mexico, (table 1) indicates that the relationship needs to be qualified, and it is not known to the writer whether the index variations of beryl from nonpegmatitic deposits are accompanied by the same compositional changes found in pegmatite beryl.

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