ARIZONA-I

the Mineralogical Record
Volume Eleven, Number Three
May–June 1980 $3

WULFENITE — RED CLOUD MINE (ED OVER SPECIMEN)

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Articles

Departments

publisher
John S. White
Smithsonian Institution

editor
Wendell E. Wilson

associate editors
written content:
Paul E. Desautels
Smithsonian Institution
Pete J. Dunn
Smithsonian Institution
Peter G. Embrey
British Museum
(Natural History)
Richard C. Erd
U.S. Geological Survey
Richard V. Gaines
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photomicrography
Julius Weber
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circulation manager
Mary Lynn White

designed by
Wendell E. Wilson
Mineralogical Record

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COVER: WULFENITE from the Red Cloud mine (see p. 141). This crystal, 5 cm across and nearly 1 cm thick, was part of the famous 1938 discovery of Ed Over. Richard Bideaux specimen; Wendell Wilson photo.

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notes from the EDITOR

ARIZONA ISSUE!

Arizona: the name conjures up many images. Desert vistas and saguaro cactus, the Tucson Show, John Wayne movies, *Arizona Highways* magazine, and the countless famous and obscure mineral localities which are the heritage of Arizona's arid climate and wealth of metalliferous deposits. For many reasons collectors typically have a soft spot in their heart for Arizona. To many who have lived there (e.g. your editor) or were born and raised there (e.g. your circulation manager) the quest to return permanently is an undying one (finally achieved in our case). For all these reasons and more, it is with great pleasure that we present to you this first special issue on Arizona . . . *Arizona-I.* The second such issue, *Arizona-II,* follows directly as the July-August issue, and a third, devoted largely to Bisbee, is in the works.

We have attempted to cover in these issues as many famous or deservedly famous localities as possible, as well as Arizona's two leading mineral museums and other related items. In many cases, the mineralogy of these localities is comprehensively dealt with here for the first time in the literature.

Special thanks for the extra funds used to produce these issues must go to Randolph Rothschild, our long-time donor, to the many people who donated specimens at our auction, and to our anonymous donor from Georgia.

As with the Tsumeb and Colorado issues, we expect these special issues on Arizona to become classics in their own way (at least that has been our goal), and so we are enclosing a special order form by which dealers and subscribers may order extra copies at the wholesale price. Orders will be accepted for the pair *(Arizona-I* and *Arizona-II)* only, and if you check the "reserve *Arizona-III*" box we will reserve for you an identical number of copies of *Arizona-III* when it comes out.

ARIZONA IN THE BACK ISSUES

The first decade of the *Mineralogical Record* saw the publication of many articles and items on Arizona which should not be forgotten. This seems like the ideal place in which to give a recap for future reference. Herewith an annotated list, in chronological order (**volume,** *number* and page in parentheses; in some cases a descriptive paraphrase is given in place of the title):

Multiple Japan-law quartz twins from the Yankee Boy mine (1, *1,* 33), by Richard A. Bideaux. Three specimens described, each of which consist of two quartz crystals Japan-law twinned to a third, making a sort of trilling.

Tilasite from Bisbee (1, *2,* 68), by Sidney A. Williams. The third occurrence worldwide described from an outcrop near the White Tail Deer mine in the Bisbee district.

Wickenburgite (1, *2,* 80), by Sidney A. Williams. Abstract of the first description of this new species, found at several prospects near Wickenburg, Arizona (including the Potter-Cramer prospect, best known).

Hemihedrite (1, *2,* 80), by Sidney A. Williams and John W. Anthony. Abstract of the first description of this new species, found at the Florence mine, Pinal County, and the Pack Rat claim near Wickenburg.

Cornetite from Saginaw Hill (1, *3,* 117), by BaSaw Khin. The fifth ocurrence worldwide described from a locality about 7 miles southwest of Tucson.

Kinoite (1, *3,* 125), by John W. Anthony and Robert B. Langhon. Abstract of the first description of this new species, found in drill core from the Santa Rita Mountains, Pima County, and later found rather abundantly in the Christmas mine, Gila County.

Bideauxite (2, *1,* 29), by Sidney A. Williams. Abstract of the first description of this new species, found on only two specimens from the Mammoth-St. Anthony mine, Tiger.

Tucson Show 1971 (2, *2,* 53), by John S. White. A discussion of what was new in minerals at the show.

Chalcoalumite from Bisbee (2, *3,* 126), by Sidney A. Williams and BaSaw Khin. A description of fine crystals found in the Sacramento pit.

Multiple Japan-law quartz twins—addendum (2, *4,* 185), by Richard A. Bideaux. A brief update on his previous article on the subject in which are described multiple Japan-law twins consisting of up to six individuals.

Minerals of the Grandview Mine (2, *5,* 214), by Wayne C. Leicht. A comprehensive article on the Grand Canyon locality famous for its beautiful blue specimens of cyanotrichite.

Classic locality: the Apache mine (2, *6,* 252), by Wendell E. Wilson. A comprehensive article on one of Arizona's famous vanadinite localities.

Tucson Show 1972 (3, *2,* 65), by John S. White. A discussion of what was new in minerals at the show.

Arizona mineral museums (3, *3,* 114), by Paul E. Desautels. In Paul's column, *The Museum Record,* he discusses the University of Arizona collection and the Arizona Mineral Museum in Phoenix.

Arizona wulfenite localities (3, *4,* 148), by Richard A. Bideaux. In Dick's column, *The Collector,* he discusses wulfenite localities worldwide, including the most important ones in Arizona. The discussion continued in the following issue (**3,** *5,* 198).

79 mine, minerals and paragenesis (3, *6,* 247), by Stanley B. Keith. A comprehensive article on one of Arizona's famous localities for wulfenite, aurichalcite and other species. This and the following article marked the first use of color photography in the *Record.*

Folio: the 79 mine (3, *6,* 265), by Wendell E. Wilson. A companion article to the preceding one by Keith, centering mostly on color photography of the important species.

Arizona azurite localities (4, *1,* 4), by Richard A. Bideaux. In his column, *The Collector,* Dick discusses famous azurite localities worldwide, including a number in Arizona.

Apache revisited (4, *2,* 78), by Wendell E. Wilson. A short note in the *What's New in Minerals?* column describing the current (deteriorating) status of the Apache mine.

Minerals of the Rowley mine (5, *1,* 10), by Wendell E. Wilson and Douglas K. Miller. A comprehensive article on one of Arizona's famous wulfenite localities, accompanied by color photography.

Tucson Show 1974 (5, *2,* 76), by John S. White. A discussion of what was new in minerals at the show.

Connellite from Bisbee (5, *3,* 106), by Richard A. Bideaux. In his column, *The Collector,* Dick traces the discovery and identification of Copper Queen mine connellite (misidentified as footeite in 1891).

Arizona aragonite (5, *5,* 222), by John S. White and Trudy Houser. In the *Q/A column* a find of aragonite from near Ash Fork is discussed because a local woman named Winnie decided to rename the mineral after herself and sell it. The attempt is made to discredit the illegitimate name. A photo of the aragonite appears in a subsequent issue (6, *1,* 39) to assist collectors.

Copper from the Ray mine (5, *5*, 233), by Wendell E. Wilson. A description of new, large crystals of copper to 5 inches long from the Ray mine.

Graemite, a new Bisbee mineral (6, *1*, 32), by Sidney A. Williams and Phillip Matter III. Full first description of the new mineral graemite, from the Cole shaft at Bisbee.

Ray coppers again (6, *1*, 40), by William Panczner. A follow-up note to the previous one by Wilson, in which *twisted* copper crystals are described.

Descloizite from the C. and B. Vanadium mine (6, *3*, 109), by Thomas J. Trebisky. Brief description of descloizite, plus mention of others, from a locality in the Dripping Springs Mountains.

Tucson Show 1975 (6, *3*, 141), by William Moller. A discussion of events and mineral news at the show.

Tucson Show 1975 (6, *4*, 162), by William B. Sanborn. Another description of the Tucson Show in general, aimed at people who have never attended one.

Ed Over at the Red Cloud mine (6, *4*, 176), by Terry Szenics. The story of one man's discovery, which has remained the most famous one, at the Red Cloud mine.

Recent work at the 79 mine (7, *2*, 55), by Wendell E. Wilson and John S. White. A short description of recent commercial collecting.

Recent work at the Christmas mine (7, *2*, 56), by Wendell E. Wilson and John S. White. A short description of a find of rosasite.

Four Peaks amethyst deposit (7, *2*, 72), by Jack Lowell and Ted Rybicki. A short description of the locality and the types of quartz found there.

Tucson Show 1976 (7, *3*, 129), by Wendell E. Wilson. A discussion of what was new in minerals at the show, including a discovery of fine azurite crystals at the New Cornelia mine in Ajo.

Petrified Forest National Park (7, *4*, 158), by Peter J. Modreski. A description of preservation efforts at this petrified wood locality near Holbrook.

Chrysocolla pseudomorphs from Ray (8, *1*, 58), by Wendell E. Wilson. A short description of a discovery of pseudomorphous crystals of chrysocolla to 3 inches.

The Mineralogy of Arizona (8, *5*, 415). A review of the new book by John W. Anthony, Sydney A. Williams and Richard A. Bideaux.

Luethite (9, *1*, 40), by Sidney A. Williams. Abstract of the first description of this new species, found at a small prospect in Santa Cruz County.

Tucson Show 1978 (9, *3*, 192), by Wendell E. Wilson. A discussion of what was new in minerals at the show, including Grey Horse mine vanadinite.

Chalcanthite from the Helvetia district (9, *4*, 252), by George Robinson. Naturally formed chalcanthite from a mine about 40 miles south of Tucson.

Cuprite from the Copper Queen mine, Bisbee (9, *4*, 259), by Pete J. Dunn. Scanning electron microscope photos.

Arizona literature (10, *1*, 14), by Arthur E. Smith and Donald R. Cook. A short bibliography of important references to minerals of the state.

Hematite from near Quartzsite (10, *1*, 35), by Wendell E. Wilson. A description of a recent discovery of exceptional hematite crystals with quartz from the Veta Grande claim near Quartzsite.

Khinite (10, *1*, 51), by Sydney A. Williams. Abstract of the first description of this new species, found at the Old Guard mine, Tombstone.

Parakhinite (10, *1*, 51), by Sidney A. Williams. Abstract of the first description of this new species, found at the Emerald mine near Tombstone.

Dugganite (10, *1*, 51), by Sidney A. Williams. Abstract of the first description of this new species, found at the Old Guard mine, Emerald mine, and Joe shaft near Tombstone.

Tucson Show 1979 (10, *3*, 187), by Wendell E. Wilson. A discussion of what was new in minerals at the show, including a superb 2.5-inch hematite crystal from Quartzsite, Arizona.

ANNUAL LIST OF DONORS to the *MINERALOGICAL RECORD*

Presented here is a listing of everyone (I hope) who donated to the auction this year or made cash donations to the *Mineralogical Record* during the last 12 months or so, except a few who wished to remain anonymous. Of the more than 150 lots donated to the auction, we ended up with control cards for all but three of them (lots 130, 139 and 147); consequently we don't know who donated these. If you were missed, not listed here, or did not get a letter of acknowledgment (usable for tax purposes) please write to me and I will rectify the matter.

I know all the readers of the *Record* will join with me in saying thanks to these generous people who help to keep our magazine going year after year.

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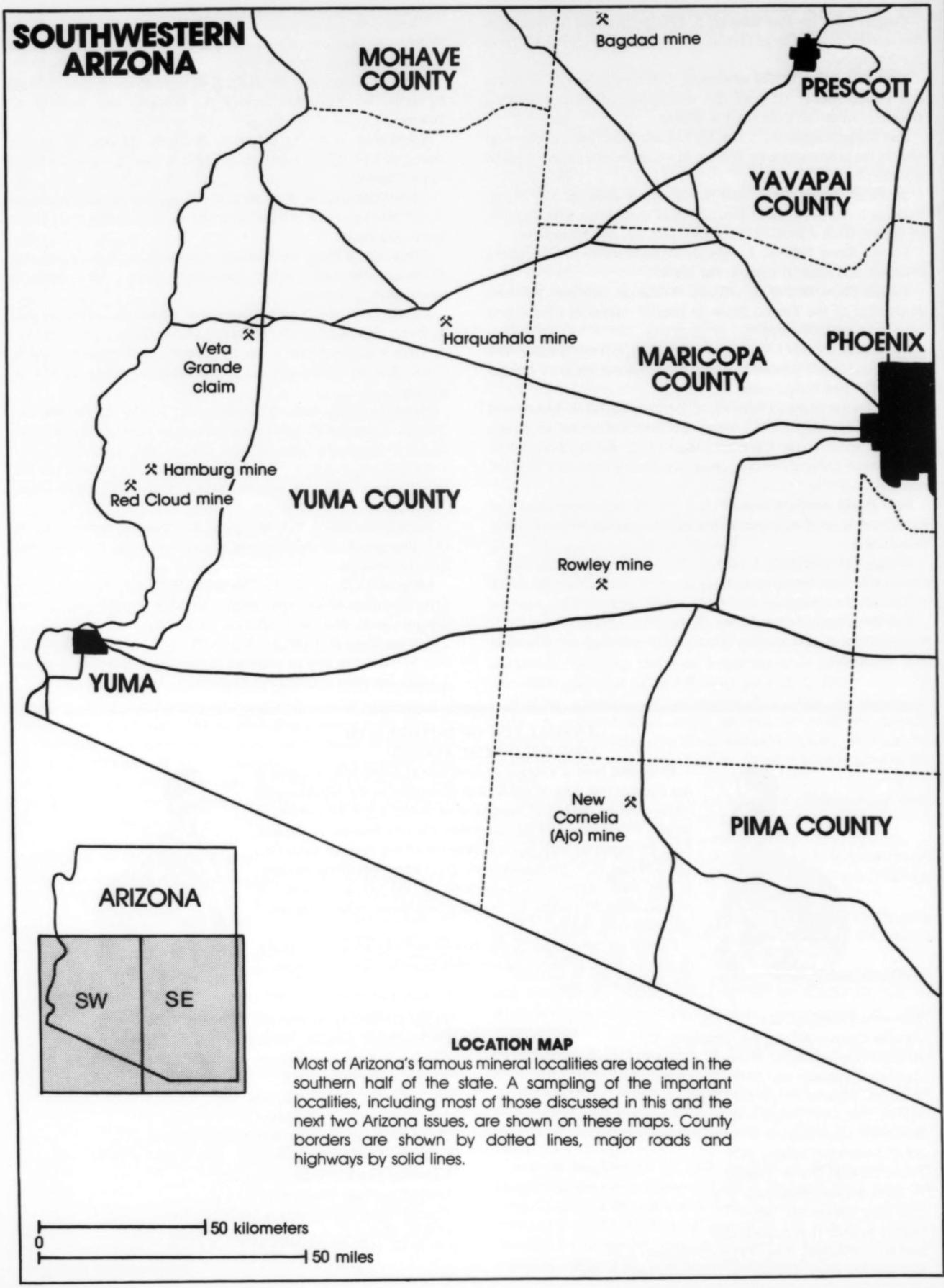
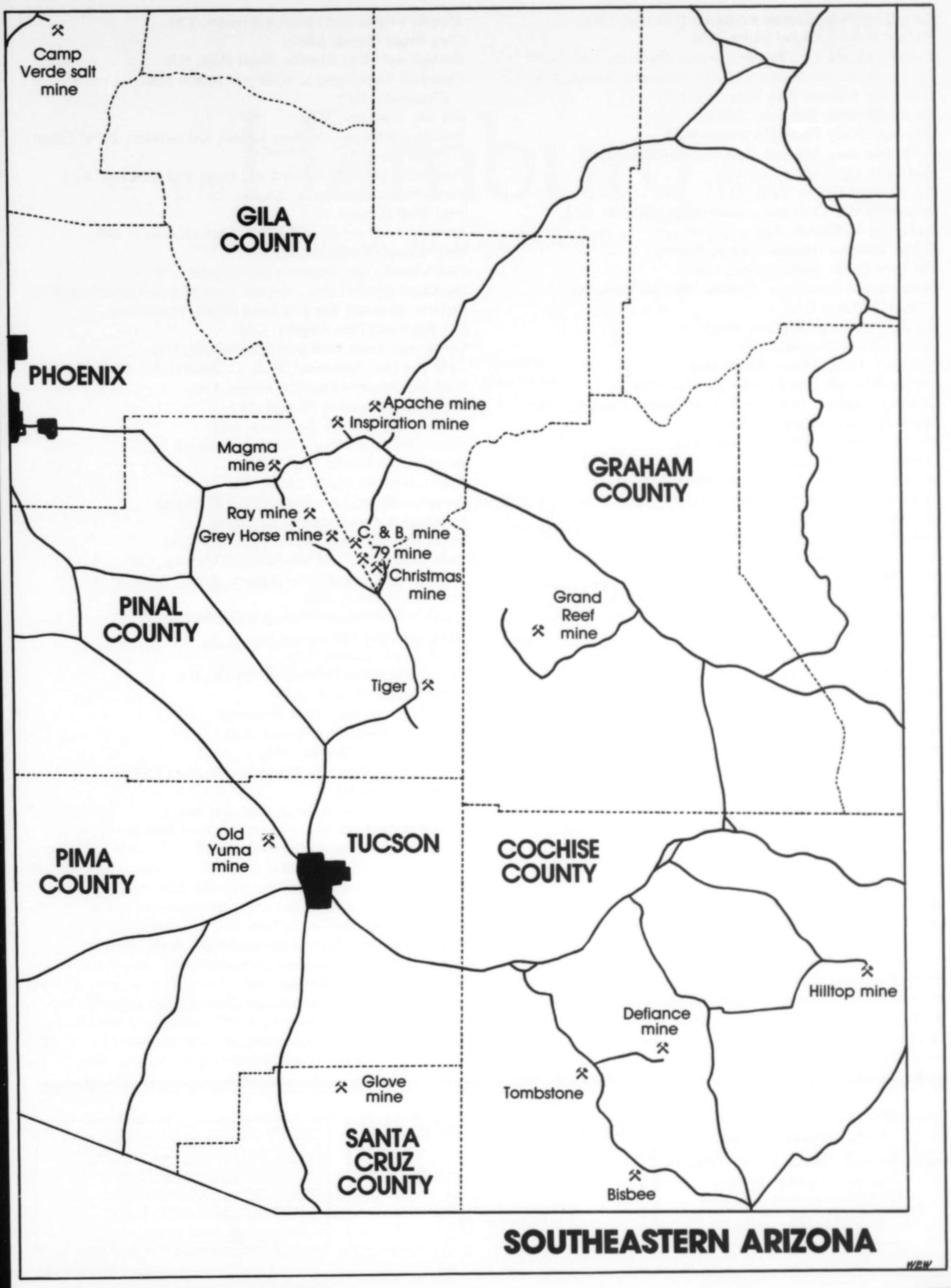
(continued on page 134)



LOCATION MAP

Most of Arizona's famous mineral localities are located in the southern half of the state. A sampling of the important localities, including most of those discussed in this and the next two Arizona issues, are shown on these maps. County borders are shown by dotted lines, major roads and highways by solid lines.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the Hamburg mine and vicinity, yuma county, arizona

by
David M. Shannon
1727 West Drake Circle
Mesa, Arizona 85202

Brilliant, transparent crystals of vanadinite with an unsurpassed, deep red color have been found since the late 1800's at the Hamburg mine, Yuma County, Arizona. Although sometimes overshadowed by the nearby Red Cloud mine, this old Dana locality still produces some of Arizona's finest vanadinite in crystals from micromount size to more than a centimeter.

LOCATION

The Hamburg mine is located about 1 mile northeast of the Red Cloud mine in the Trigo Mountains, Yuma County, Arizona (T4S R23W, Sec 1 center). The area is included on the U.S.G.S. 7½-minute quadrangle *Picacho, Arizona/California.* About 30 meters north of the Hamburg mine is the Princess mine. Because of their close proximity, the true identity of these two mines has caused collectors much confusion. Further similarities between the two mines include identical geology, workings of similar extent, and the occurrence of at least micromount vanadinite.

The dirt access road is usually passable by virtually any vehicle as far as the Red Cloud mine. The jeep trail extending the remaining 1 mile to the Hamburg mine ranges from difficult, even for four-wheel drive, to a two-hour road-building adventure.

HISTORY

The Hamburg mine, as with most of the mines in the Silver district of Yuma County, was first located in the 1860's as a silver lode deposit. During 1880 and 1881, William P. Blake and others sank an 18-meter shaft inclined at an angle of about 45° (Wilson, 1933). At the base of the incline a horizontal drift was run for about 12 meters, exiting on the eastern base of the hill. So far as is known, no ore was ever mined from the Hamburg mine and it has lain idle since these early prospecting days except for the periodic visits of mineral collectors.

GEOLOGY AND TOPOGRAPHY

The elevation of the Hamburg mine is only 277 meters (900 feet) above sea level, but this low height should not be construed as gentle terrain. The Trigo Mountains reach an elevation of over 900 meters (3000 feet) and are extremely rugged for their height, consisting of a series of sawtooth ridges and steep-sided canyons. Most of the rock surfaces are black with desert varnish and pitted with small cavities.

The Hamburg mine, and the adjacent Princess mine, consist of veins of brecciated, silicified andesite emplaced along a fault in Precambrian schist, granite and Tertiary volcanic rocks (Wilson, 1933). A clearly defined hanging wall of polished slickensides extends the entire length of the incline and forms the roof of the mine workings. This fault, though offset by another, unmineralized fault, appears to be the same fault on which is situated the Red Cloud mine.

Vanadinite occurs in brecciated andesite and quartz seams, and is apparently restricted to a small stope at about the 12-meter (40-foot) level. The zone is bordered above and below by iron-stained andesite.

CLIMATE

Temperatures in this remote area of the low desert are almost continuously above 100°F from late May through September, and it is not unusual for the temperature to reach 125°F. There is no

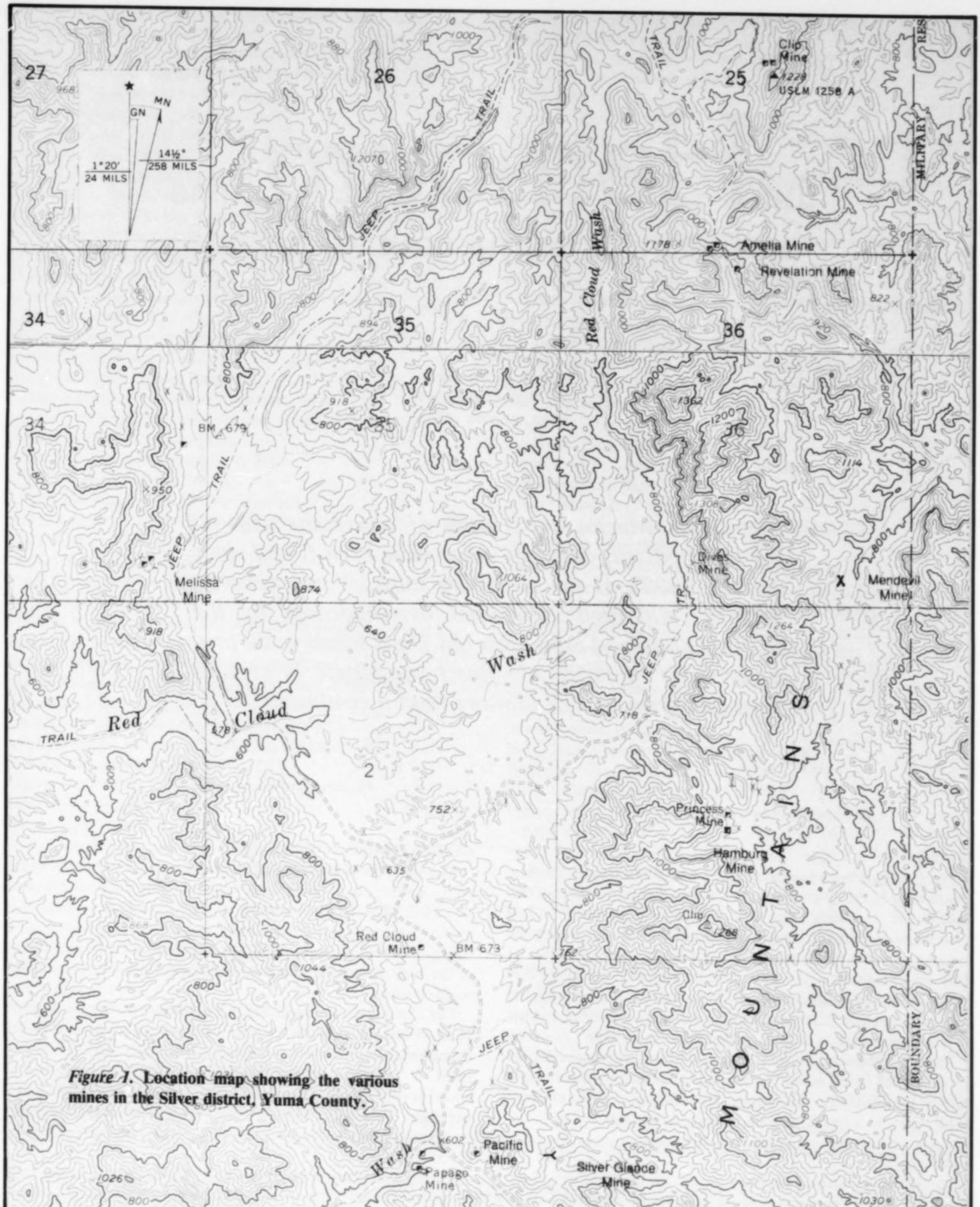

Figure 1. **Location map showing the various mines in the Silver district, Yuma County.**

Figure 2. **Rough terrain surrounding the Hamburg mine (center). Photo by the author.**

Figure 3. **Entrance to the Hamburg mine. Note the fault contact which forms the hanging wall of the mine. The Princess mine is just over the first rise. Photo by the author.**

water and little shade; trips to this area during the summer months are strongly discouraged. The winter weather is generally pleasant, with temperatures of 70° to 80° during the daytime and 40° to 50° at night.

MINERALS

Vanadinite $Pb_5(VO_4)Cl$

Although other minerals may be found at the Hamburg mine, vanadinite is the mineral of primary interest. The crystals line fractured quartz and calcite seams; the size of the cavities ranges from a few mm to 7 or 8 cm. Fragments of gray quartz matrix covered on

Figure 4. **A drawing of vanadinite from "Yuma County, Arizona," probably the Hamburg mine, published by V. R. von Zepharovich in 1889 (in *Lotos*) and later republished by Dana (1904).**

Figure 5. **Two gemmy crystals of vanadinite on matrix from the Hamburg mine; the left crystal is 2.5 mm. Collection of the author.**

Figure 6. **Vanadinite crystals from the Hamburg mine, with typical proportions and cavernous terminations. The large crystal is 6 mm. Collection of the author.**

all sides by vanadinite crystals are found within these seams. The size of the crystals ranges from a few tenths of a mm to 1.5 cm or more. Crystals as large as 2 or 3 mm commonly have flat, pinacoidal terminations and brilliantly smooth, lustrous faces. The larger crystals tend to exhibit hopper growth, some being no more than a hexagonal skeleton. Typically the color is a vibrant red like the color of an automobile taillight lens. Rarely the color grades into orange-red and lemon-yellow. The combination of bright red, hexagonal prisms, often 2 or 3 times longer than wide, commonly with hopper terminations, on gray matrix is characteristic of Hamburg mine specimens. On the largest crystals the prism faces also show hopper growth.

Wulfenite $PbMoO_4$

Orange-red crystals of wulfenite to 1.5 cm in size and similar to Red Cloud mine specimens have been found just above the vanadinite area.

Mimetite $Pb_5(AsO_4)_3Cl$

Microscopic yellow tufts of mimetite crystals occur in association with wulfenite just above the vanadinite zone.

Anglesite $PbSO_4$ and **Cerussite** $PbCO_3$

Anglesite and cerussite are found sparingly as pods completely replacing galena.

Lead oxides

Traces of lead oxides, probably minium (red), litharge (red) and massicot (yellow) are found intermixed in the altered galena pods.

Other minerals

Galena, smithsonite, argentite (acanthite) and cerargyrite were reported by early writers (Emmons, 1885, Wilson, 1933). Quartz (some amethystine), barite, hematite, fluorite, calcite and aragonite also occur as gangue minerals.

DISCUSSION

Many references list "deep red, brilliant crystals of vanadinite from the Red Cloud mine" (e.g. Palache, 1944, Anthony, *et al.*, 1977, Ford, 1949). A review of the original reference cited for this occurrence (Silliman, 1881) indicates that the statement was taken out of context and probably refers instead to the Hamburg mine. Silliman was referring in general to the Silver district rather than specifically to the Red Cloud mine. In his words:

> *Vanadinite occurs in three mines, near together, the "Hamburg," the "Princess," and the "Red Cloud." The crystals of vanadinite are extremely beautiful, alike for brilliancy of color, luster, and perfection of form. . . . The Hamburg Mine has fur-*

Figure 7. **A group of fine vanadinite crystals from the Hamburg mine, some with cavernous prism faces. The large crystal is 6 mm. Collection of the author.**

> *nished the most numerous and on the whole, the best specimens of vanadinite. . . . The vanadinite (at the Red Cloud mine) is smaller and grouped in more confused masses than at the Hamburg Mine.*

It is the author's experience that collectors attempting to obtain a good specimen of "deep red, brilliant crystals of vanadinite" from the Red Cloud mine will be disappointed with the best that mine can furnish. Vanadinite crystals found at the Red Cloud mine rarely exceed ½ mm in size and are orange-red, similar in color to the Red Cloud wulfenite. The various authors of this century who have cited the Red Cloud mine as the origin of fine vanadinite probably meant to refer to the Silver district in general, but mentioned the Red Cloud mine because of its fame for producing the world's most desirable wulfenite specimens.

MELISSA AND ROMALDO PACHECOS MINES

A discussion of the area would be incomplete without mentioning the Melissa mine, which has attained minor fame for its small (usually under 5 mm), red, bipyramidal crystals of wulfenite. These are collected with relative ease, although few collectors bother to try, with the more tantalizing promise of Red Cloud mine wulfenite nearby. Actually many superb red wulfenite crystals have been found at the several mines along the mineralized fault, but those which resemble Red Cloud mine specimens are usually labeled as Red Cloud because the locality name is more famous.

Who was Romaldo Pachecos and where was his mine? These questions have plagued Arizona mineral buffs for decades. A few old claim papers bearing Romaldo's name have been found (Eugene Schlepp, personal communication), but the location data are far too sketchy to pinpoint the prospect, other than to say it was in the Silver district. What makes the problem interesting is the number of superb vanadinite specimens extant which are labeled

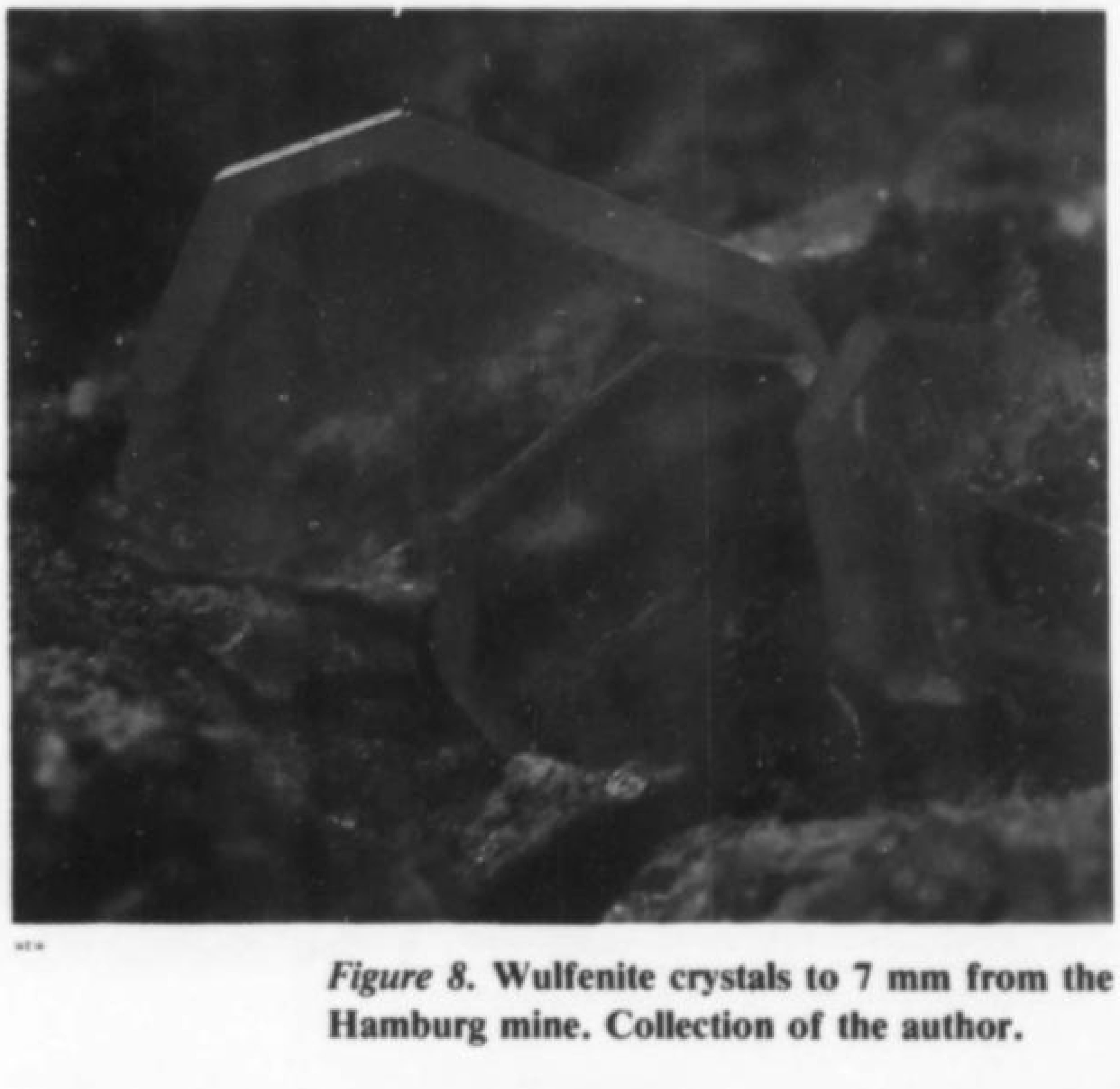

Figure 8. **Wulfenite crystals to 7 mm from the Hamburg mine. Collection of the author.**

Figure 9. **A multiple crystal of fine red vanadinite from the Romaldo Pachecos mine, donated to the Smithsonian Institution by W. F. Hillebrand in 1894. The crystal is 1.5 cm across.**

"Romaldo Pachecos mine, Silver district, Yuma County, Arizona," particularly two in the Smithsonian Institution. Catalog and label data indicate that the specimens were transferred to the Smithsonian from the U.S. Geological Survey collection by the mineralogist W. F. Hillebrand in 1894, but Hillebrand (who most likely collected them personally) gave no further location data either. Some people feel the Hamburg mine and the Pachecos mine are one and the same; others disagree, and place the Pachecos mine somewhere over near the Black Rock mine, perhaps as just a cut instead of a shaft or adit. Chances are we will never know for certain.

ACKNOWLEDGMENTS

The author is indebted to Wendell E. Wilson for help in the preparation of this article and the accompanying photos, and particularly for his research on the Romaldo Pachecos mine.

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famous mineral localities:

the RED CLOUD mine

yuma county, arizona

by
Gary M. Edson
U.S. Geological Survey
Denver Federal Center
Denver, Colorado 80225

The story of the Red Cloud mine began over 100 years ago in one of the oldest mining districts in Arizona. Since that time the mine has regularly produced specimens of red wulfenite which, in form, color, luster and esthetics, are universally acknowledged as the finest in the world. The locality is still producing such specimens.

LOCATION

The Red Cloud mine is in the southern part of the Trigo Mountains, 80 km by road north of the city of Yuma, in Yuma County, Arizona (Fig. 5). The U.S. Geological Survey 7½-minute topographic map of the Picacho quadrangle shows the location of the mine (Sec 2, T4S, R23W).

HISTORY

The history of the Red Cloud mine can be divided into two general periods: before 1890, when the mine was a financial success; and since 1890, when most of the activity was promotion and exploration.

The first prospectors began working claims in the area in the

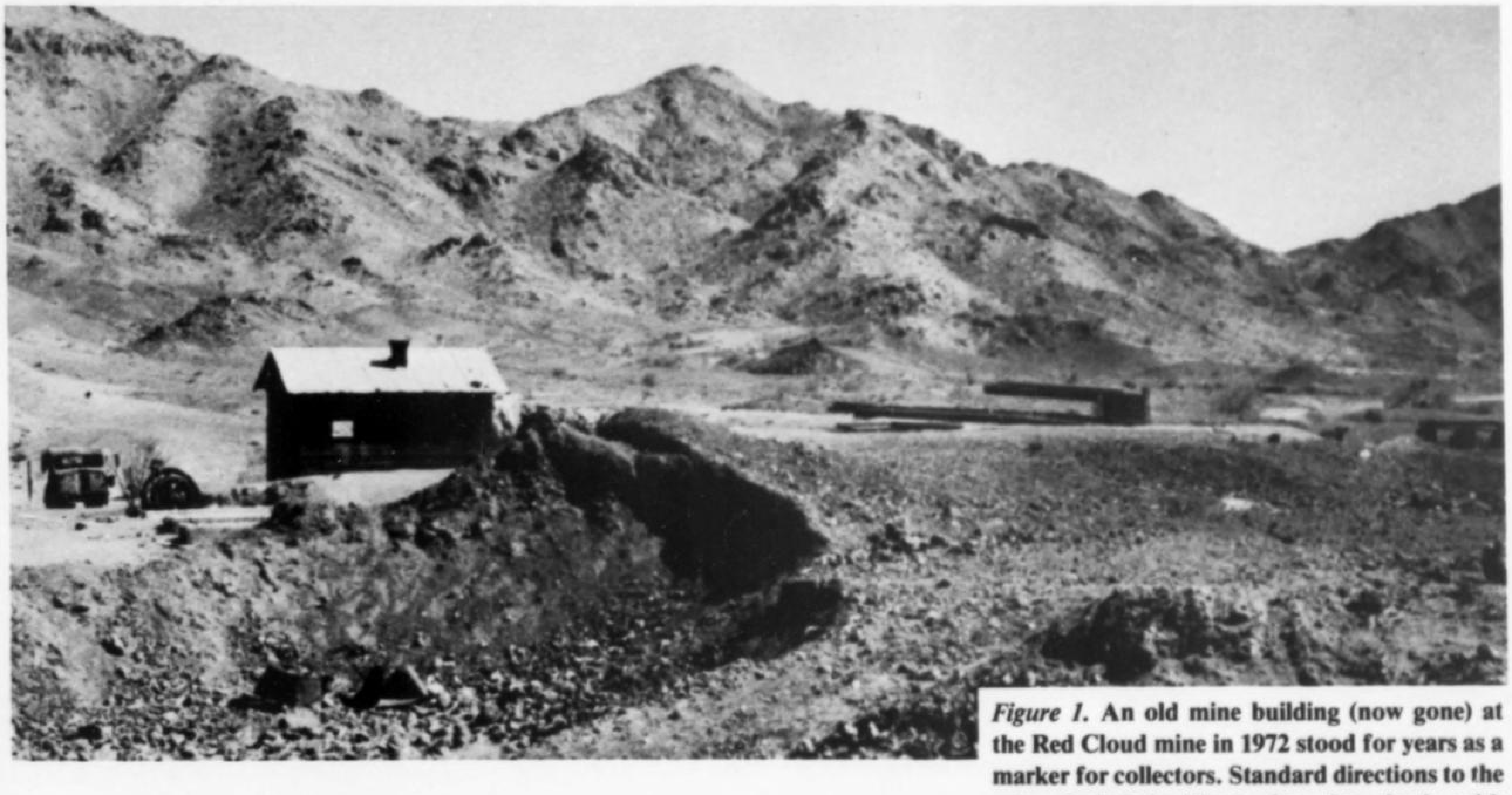

Figure 1. **An old mine building (now gone) at the Red Cloud mine in 1972 stood for years as a marker for collectors. Standard directions to the mine included, "look for the shack with 'WULFENITE IS LOVE' written on the side." In the distance, across Yuma Wash, are part of the Trigo Mountains.**

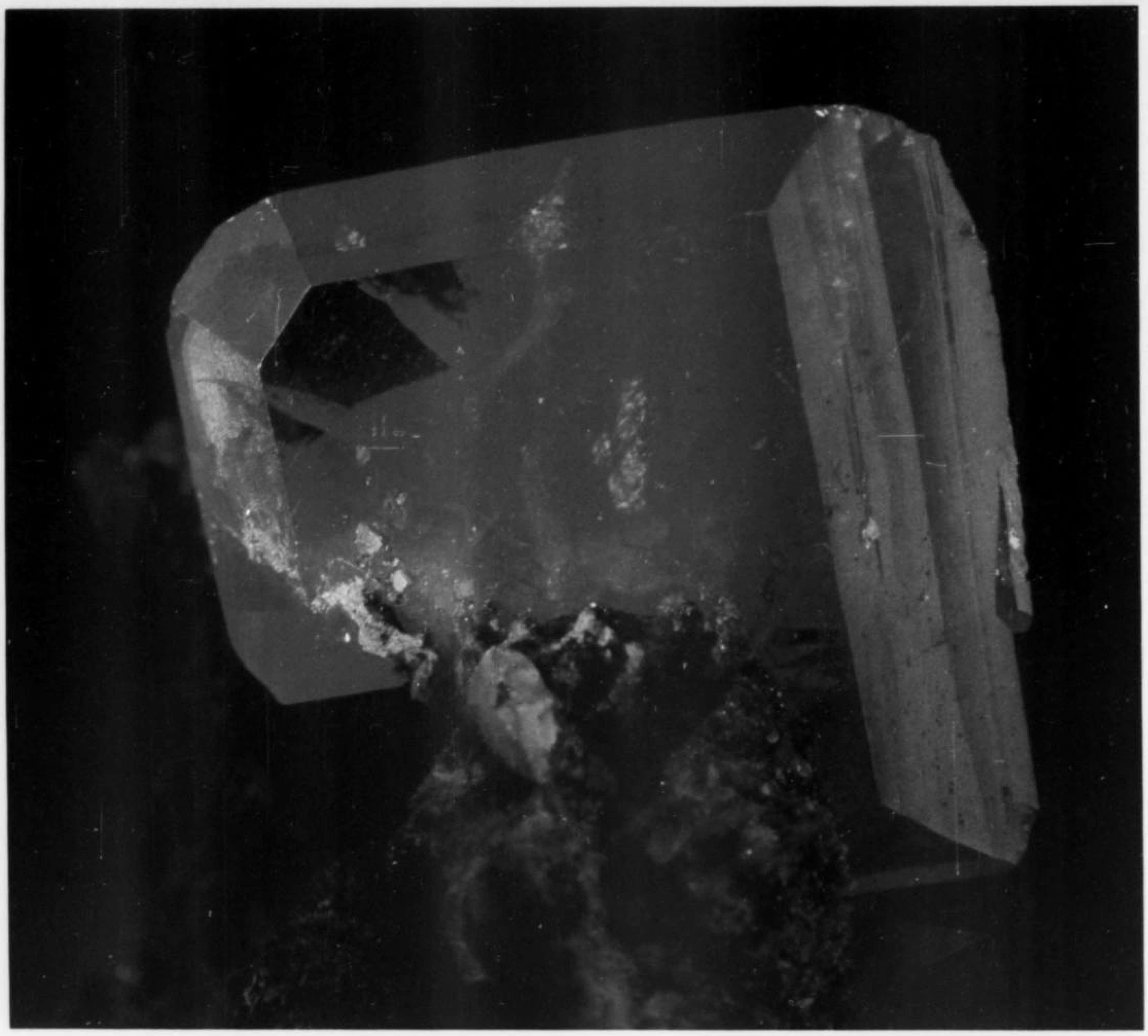

Figure 2. **A fine crystal of wulfenite 2 cm across, on matrix. Smithsonian specimen.**

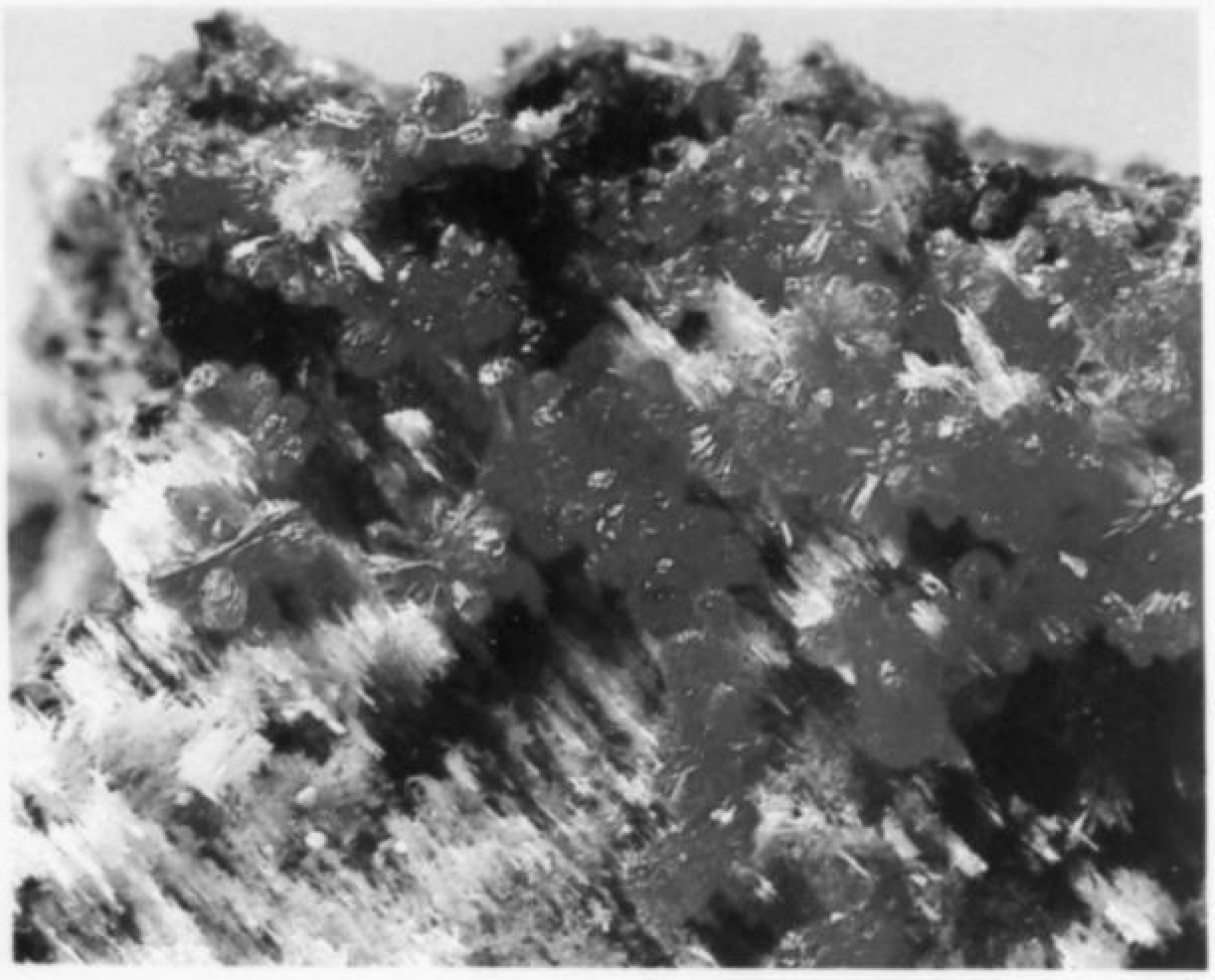

Figure 3. **Red mimetite from the Red Cloud mine; the group is about 3 cm across, and was found in a long channel lined with such specimens but devoid of wulfenite. Grant Richards specimen.**

1860's and the Silver mining district came into being in the 1870's. Until about 1880 the Red Cloud mine, named after the nearby Red Cloud trail used by early Spanish explorers, consisted only of a small open cut. Silver-lead worth more than $30,000 was taken from the outcrop (Hamilton, 1884), and freighted by wagon down the Red Cloud wash to Norton's Landing on the Colorado River, for shipment by boat to the Selby smelter (Keith, 1978). The present upper workings, including the inclined shaft, wide stopes, and passageways joining them, were made by the Red Cloud Mining Company of New York in about 1880 (Hamilton, 1881). Production in silver and lead until 1890 was not recorded, but a consulting mining engineer, Elgin Bryce Holt (1942), believed that it may have been over $1 million. Keith (1978) estimates a total closer to $500,000 (21,000 tons of ore at 18 oz. of silver/ton).

From 1890 to 1917 the Red Cloud lay idle, owing to depressed silver prices. It was then bought by a syndicate, headed by Holt, which leased the property to a succession of operators. One of these lessees was the Primos Chemical Company, which drove a 102-m crosscut into the hanging wall on the 500 level for diamond drilling to intersect the vein at greater depth. A disagreement arose between the owners and the Primos people, which resulted in abandonment of the project (Holt, 1942).

In 1941 Penn Metals Inc., of Pennsylvania, operated a small flotation plant on dump material. However, this undertaking was not a financial success, so they hired Holt to make an evaluation and submit a report. The development program he outlined in-

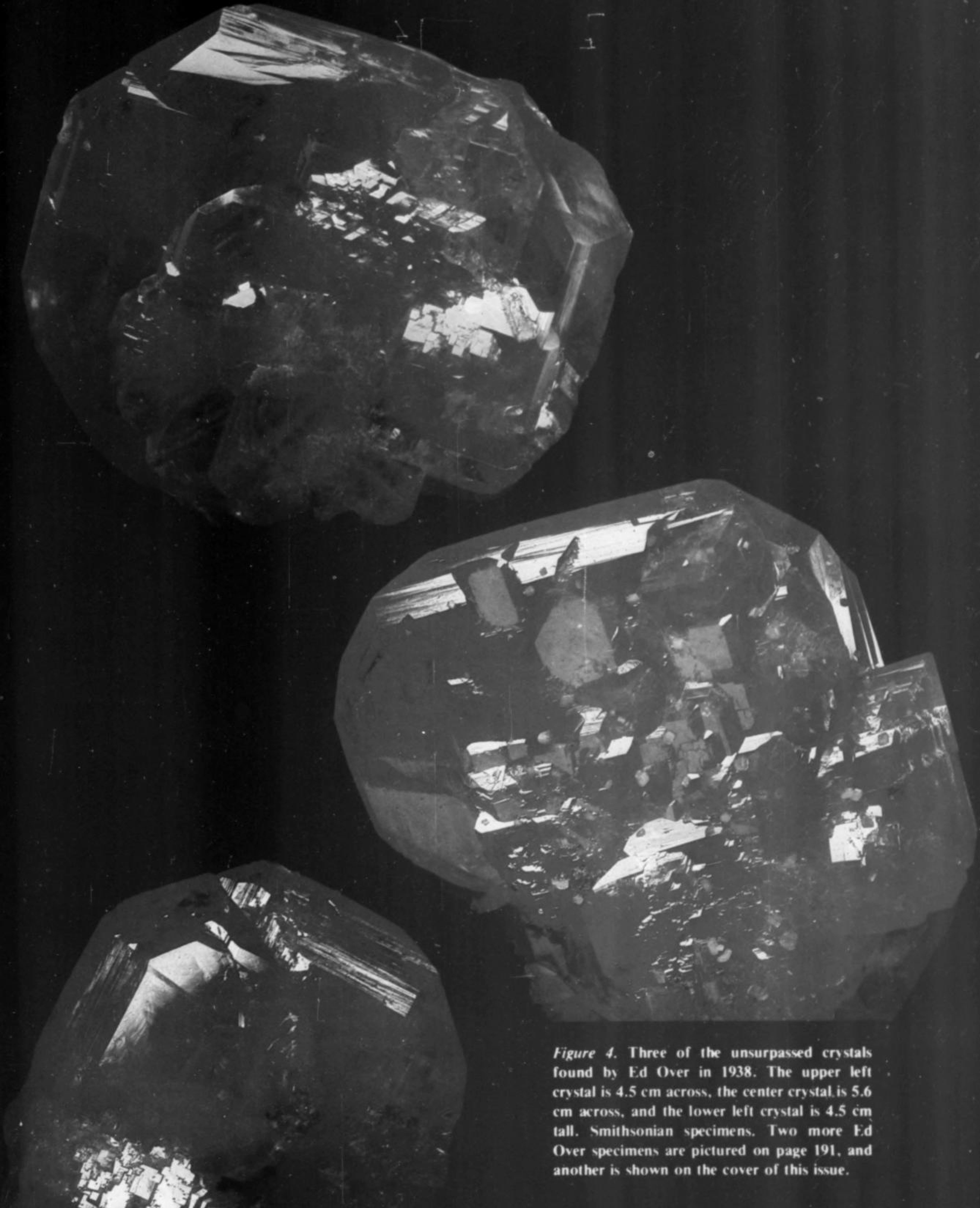

Figure 4. Three of the unsurpassed crystals found by Ed Over in 1938. The upper left crystal is 4.5 cm across, the center crystal is 5.6 cm across, and the lower left crystal is 4.5 cm tall. Smithsonian specimens. Two more Ed Over specimens are pictured on page 191, and another is shown on the cover of this issue.

Figure 5. **Location of the Red Cloud mine.**

volved a redesigned and enlarged mill, including flotation and cyanide processing, together with an ambitious exploration program (Holt, 1942). Penn Metals did not adopt his recommendations, and the Red Cloud mine has been mostly idle since then. Although many people have collected mineral specimens there in recent years, the mine is on a patented claim and is therefore private property.

THE MINE WORKINGS

Except for the crosscut on the 500 level, all of the mine workings are on an incline which follows the dip of the vein (Fig. 8). The depth of various levels is measured (in feet) on this incline. The part of the mine developed prior to 1890 includes workings down to the 270 level: the inclined shaft, which varies in plunge from about 25° to 40°, the stopes on either side of it, and the small, irregular passageways that join them at various points (Fig. 6). Drifting followed lines of least resistance and local concentrations of high-grade ore, and so these workings are very irregular.

The north and south stopes show the locations of the two main ore shoots on the vein (Fig. 6). The north stope opens at its back into a drift at about the 50 level, and at its bottom connects with the 270 level. The south stope formerly opened directly to the surface and appears to have been developed through drifts off of another inclined shaft, but this access is now blocked by debris. There are also stopes and a short inclined shaft below the 270 level that appear to belong to the early workings.

The newer part of the mine includes a 61-m vertical shaft that intersects the 270 level drift, the inclined shaft that leads down to the 500 level, and the drifting and crosscutting below the 270 level off this inclined shaft.

GEOLOGY

The rocks of the Silver mining district consist of a basal complex of highly metamorphosed Mesozoic schists and intrusive granitic rocks of Tertiary or Cretaceous age. The most recent materials are Tertiary volcanic flows, tuffs, and breccias, which unconformably overlie the older units. These volcanics are the dominant rock type in the Trigo Mountains.

The *Arizona Mining Journal* published a geologic description in 1925 (Thompson, 1925). The granitic rock was identified as monzonite, and the Tertiary formations were described as a series of volcanic breccia, agglomerate, tuff, and lava flows, all of andesitic composition. Overlying these flows are rhyolitic tuff and sandstone, together with thinly bedded limestone. Capping all of this is

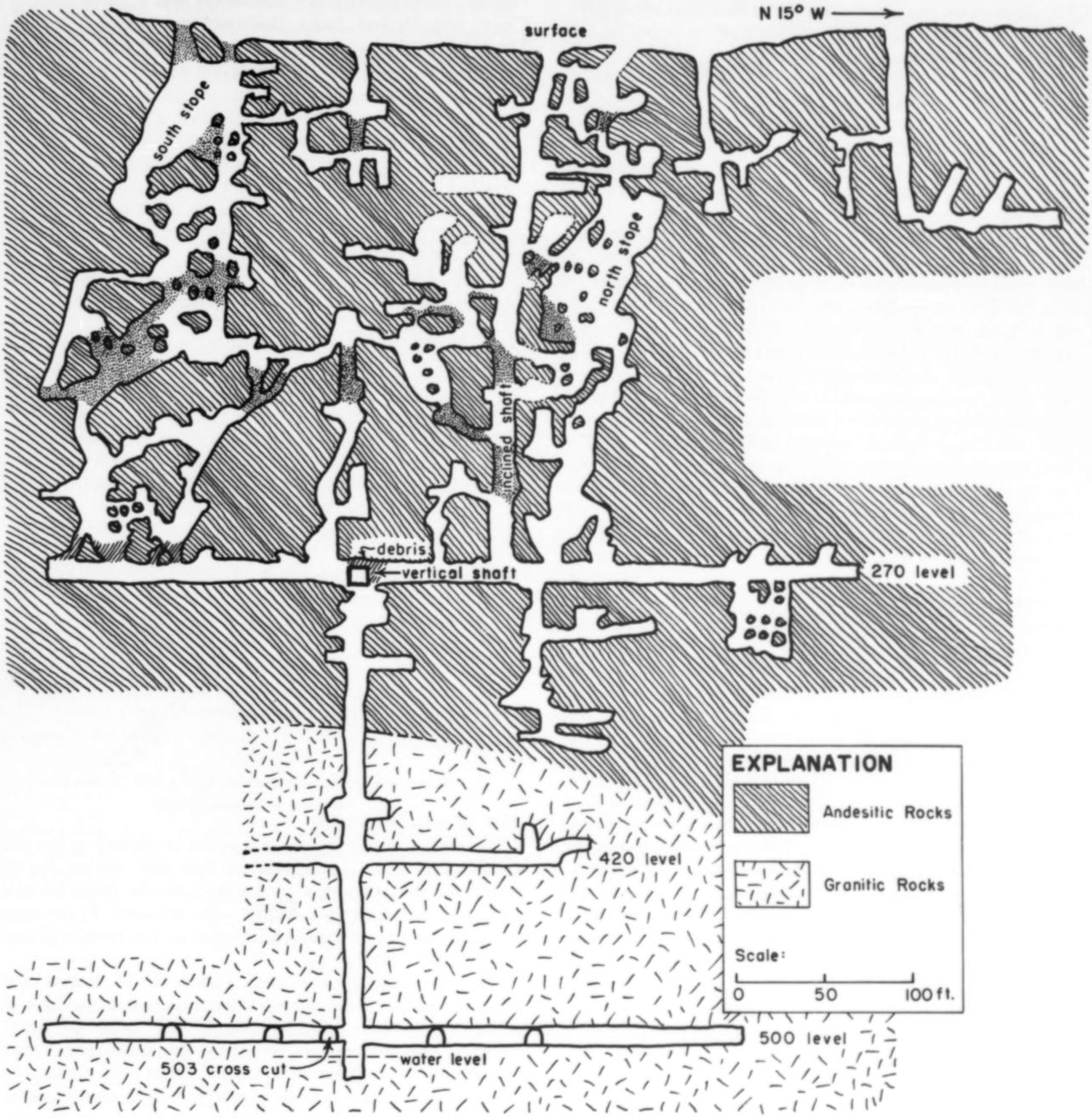

Figure 6. **A section along the plane of the vein showing workings in the Red Cloud mine. The map is modified after one drawn by B. McDougall in 1918 and published in Wilson (1933), after updating the workings to that time. Stipled areas are among those now blocked by debris. Dashed lines indicate relatively new excavations by collectors. Current operations are removing some of the debris blocking various areas. (Recent data from David Shannon, personal communication.)**

a vast outpouring of lava that covers the northern part of the mining district. In the southern part of the area erosion has stripped away the upper volcanic and sedimentary sequence, leaving volcanic plugs and dike-like lines of intrusions which are exposed as towering sawtooth ridges.

Examination of the granitic rocks immediately west of the Red Cloud mine shows apparent monzonite to quartz monzonite composition with occasional irregular areas of biotite-hornblende quartz diorite.

Mineral deposition was controlled by a system of faults which acted as channelways for the original solutions which deposited the sulfides. The two major structures in the southern end of the district are the Red Cloud and McNeal faults. They both strike northward, but in a V-shaped configuration, intersecting just south of the Red Cloud mine. The western fault, the Red Cloud, dips to

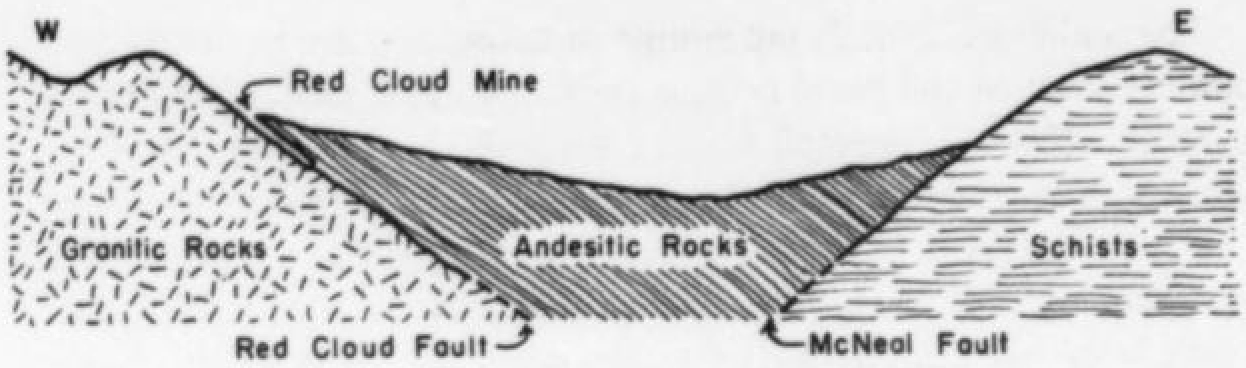

Figure 7. **Vertical section view showing the Red Cloud and McNeal faults (redrawn from Thompson, 1925).**

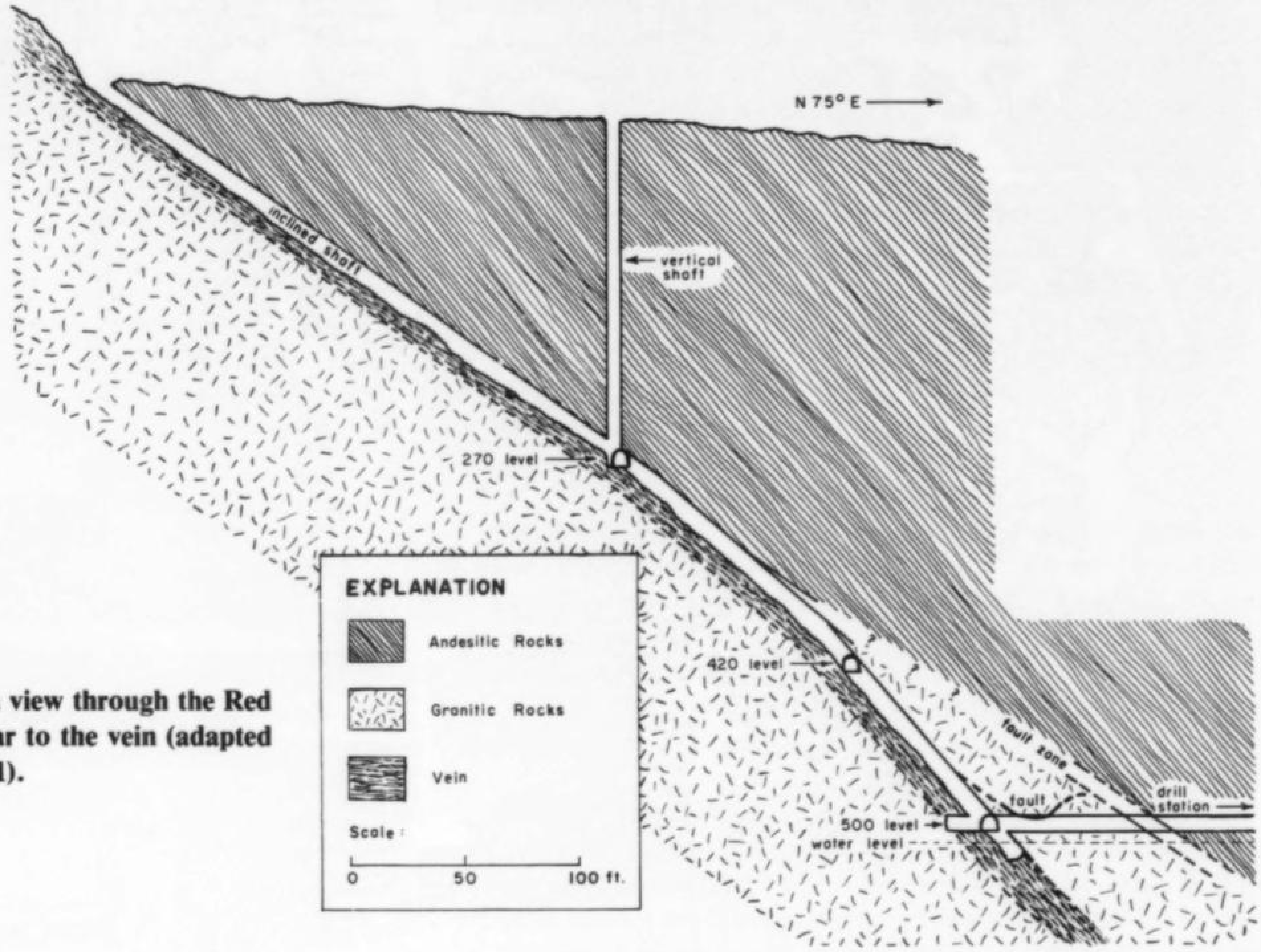

Figure 8. **Vertical section view through the Red Cloud mine perpendicular to the vein (adapted from Wilson, *et al.*, 1951).**

the east, and the eastern fault, the McNeal, dips to the west, enclosing a wedge of Tertiary lavas (Fig. 7). These fault zones are contacts between the young volcanics and the older schists and granites. Vein mineralization occurred on both faults, but it was most intense at the south end of the Red Cloud fault (Thompson, 1925). Slickensides on the fault in the Red Cloud mine indicate probable dip-slip movement.

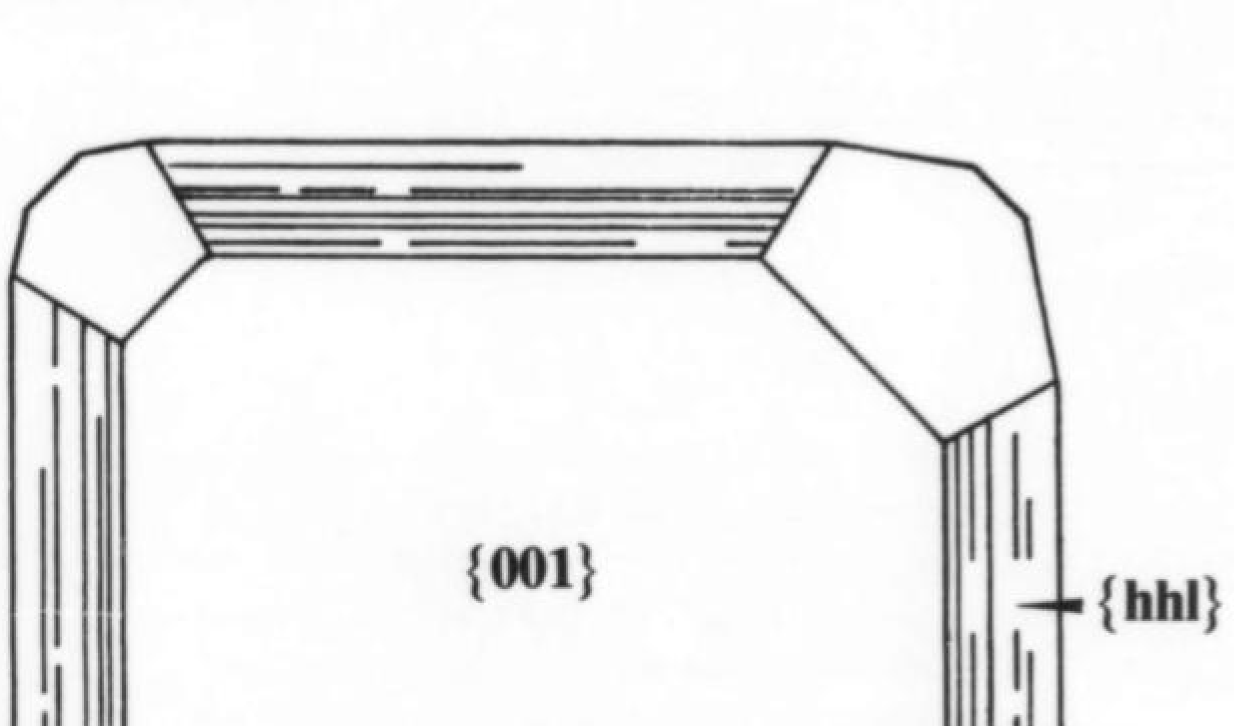

Figure 9. **A typical crystal of Red Cloud mine wulfenite, showing forms.**

THE RED CLOUD VEIN

The original sulfide deposit is regarded as Tertiary in age and epithermal in type. The near surface fault zone was invaded by fluids from the same volcanism that produced the flows, but at a somewhat later time, and sulfides were deposited. It has been theorized that postore faulting transported some sulfides to greater depth (Wilson, 1951).

Many high-angle fractures, dipping about 60° W., intersect the vein on a common strike. These fracture zones contain remnants of galena and well-crystallized wulfenite and other secondary minerals. The fractures are interpreted as tension gashes that formed because of movement on the Red Cloud fault. Apparently this movement occurred as a series of slips, with motion preceding both the sulfide emplacement and the secondary, oxide-zone mineral formation. The fractures enhanced permeability for mineralizing fluids.

The vein was described by Wilson (1933) as being composed of quartz, calcite (much of it manganiferous), and fluorite, which form vuggy masses, together with gouge and brecciated wallrock. Limonite, hematite, and wad line the cavities and openings, as well as cerussite, smithsonite ("turkey fat"), vanadinite, wulfenite, and very minor malachite. Nodules of argentiferous galena occur, partly altered to black anglesite and yellowish cerussite. Chlorargyrite was the main silver ore mineral and is present in small disseminated masses among the oxidized minerals. In addition to the minerals listed by Wilson, willemite, mimetite, minium (R. A. Bideaux, personal communication, 1973), stetefeldtite, and plattnerite can be found.

The vein is a layered structure, and has been described as consisting of both a hanging wall and a footwall vein. The mine workings are in the upper vein, and the height of the stopes show it to be 1.2 to 3.7 m in thickness. This vein is where the high-grade silver values were found. The footwall vein has never been adequately explored and is still intact. It is probably 2.4 to 3.7 m in thickness with lower metal values and more calcite, by volume, than the hanging wall vein (Holt, 1942). Somewhat below the 270 level the andesite hanging wall gives way to granitic rocks, and so both walls are of the same composition. From here to the 500 level the vein steepens, and contains a smaller proportion of ore minerals. The oxidized zone extends very deep; apparently completely unoxidized sulfide minerals were never located by diamond drilling (Holt, 1942).

MINERALS

The minerals of greatest interest to collectors are wulfenite and cerussite. In addition, vanadinite, mimetite, and willemite are found in the mine, but usually as micromount material. Following are descriptions of the well-crystallized and less common minerals.

Wulfenite $PbMoO_4$

Wulfenite crystals occur in a broad size range, from mirocrystals to individuals 5 or 6 cm on a side. The color and habit are remarkably consistent throughout the mine. Whereas most wulfenite is pale yellow, Red Cloud specimens are brilliant red to red-orange. An obvious question is, what causes this color?

Emission spectrographic semiquantitative analysis reveals 30 parts per million (ppm) chromium in a sample of Red Cloud wulfenite. Electron probe microanalysis showed 130 ppm chromium (Hildebrand, *et al.,* 1973). The red-orange color of Red Cloud wulfenite is explained by analogy with pure lead chromate, the mineral crocoite; in the wulfenite, chromium substitutes for molybdenum, producing chromate complex ions. The chromate ion is highly absorptive, and so even low concentrations can have a strong coloring effect. A semiquantitative analysis of Red Cloud wulfenite is presented in Table 1.

Table 1. Red Cloud mine wulfenite trace element semiquantitative analysis*

Si		0.028
As	ND	0.05
Mg		0.0052
Fe		0.0028
W		0.20
Ca		0.0031
Cr		0.0030
Sr	ND	0.001
V	ND	0.002
Other elements		nil

*In percent. ND = not detected at indicated concentration. Spectrographic analysis by Pacific Spectrochemical Laboratory, Inc., Los Angeles, Calif.

Considerable amphibole and biotite, both altering to chlorite, are seen in a thin section of a quartz diorite phase of the granitic rocks west of the vein. Samples of this rock produce strong emission spectral lines for chromium, which is probably associated with the mafic minerals. Chromium ions may have been carried into the Red Cloud vein from the adjacent quartz diorite by ground water.

Very few Red Cloud wulfenite crystals are transparent throughout; they commonly contain cloudy internal regions and wisps of lighter orange material. The large basal pedion faces are composed of several areas, separated by irregular boundaries, which are not quite parallel. That is, each "crystal" is actually composed of several crystals that are imperfectly aligned with respect to one another. This type of mosaic growth is common in large crystals of all species.

The wulfenite crystals are simple in habit, and are bounded by a combination of the basal pedion {001} and first and second order pyramids (Fig. 9). A small single crystal was oriented by the Weissenberg X-ray method, and the dominant pyramid was shown to be of the first order. Angular measurements were then taken on a Stoe two-circle reflecting goniometer. All faces produced several signals because of the imperfect crystal growth. The small second order pyramid was shown to be {013} on the basis of a consistent ϱ angle of 36°. The first order pyramid, {hhl}, is irregular and is composed of steps and curved areas, producing a whole family of goniometrical reflections varying from 42° to 28° in ϱ angle. These results imply that at least three or four forms are involved in this pyramid area. Measurement on 35 of these areas from 10 crystals showed strong, consistent signals at a ϱ angle of about 42° (the high and low values were 43°42' and 40°12', respectively, and the average was 41°47', with a standard deviation of 59'). Using the axial ratio from *Dana's System* (Palache, *et al.,* 1951), this corresponds to a {227} form, with a calculated angle of 42°5'. This form is not listed in *Dana's System* nor in any other reference work or journal consulted. This may be the first time it has been reported. Given the mosaic growth imperfections of the crystals, it was impossible to identify the other first order pyramidal forms. Interestingly, Williams (1966) states that wulfenite crystals associated with willemite are perhaps the most aberrant in forms, and he cites {229}, among others, as being characteristic of wulfenite in this association.

Because wulfenite is in the tetragonal pyramidal class, there is no symmetry plane perpendicular to the *c* axis ([001]), and the dipyramidal appearance of Red Cloud, and other, crystals is due to twinning on the basal pedion (Palache, *et al.,* 1951).

Some very small Red Cloud wulfenite crystals consist of only the first order pyramid, resulting in an octahedral-like habit. Most medium-sized crystals, from 2 mm to 10 mm, are composed of the pedion and first order pyramid and have a rectangular shape when viewed down [001]. Larger crystals tend also to develop the second order pyramid which bevels the corners to form eight-sided plates. These are the famous Red Cloud "stop signs."

Cerussite $PbCO_3$

Cerussite at the Red Cloud mine has been reported in crystals as much as 4 cm in length, many of them being arrow-shaped twins (Galbraith, 1970). As an example, a V-twin (Fig. 10) consists of two crystals of about equal size elongated on [001] and twinned on {hk0}; consequently, the V is quite thick from front to back along [001]. The specimen is euhedral with lustrous faces and is about 28 mm along [001] and 23 mm along [h00] of each member. Cerussite is found as microcrystals and small reticulated masses on the 270 level, and apprently the larger crystals have come from deeper in the mine.

Vanadinite $Pb_5(VO_4)_3Cl$

Some question exists as to the quality and size of vanadinite specimens produced from the Red Cloud mine. According to *Dana's System* (Palache, *et al.,* 1951), this mineral occurs as "magnificent specimens" there, and reference is made to an 1881 article in the *American Journal of Science.* The article (Silliman, 1881) lists the Hamburg, Princess, and Red Cloud mines as locations for vanadinite. The largest crystals came from the Hamburg (see Shannon, this issue, p. 135), and they were usually less than 1 mm in length. The smaller Red Cloud crystals were of a rich orange-red color. So it would seem, then as now, that Red Cloud vanadinite usually occurs as microcrystals. These are much elongated on the *c* axis, being six to eight diameters long, and consisting of a prism and pinacoid with some pyramidal development. The cross section always seems to be hexagonal; that is, no 12-sided crystals composed of first and second order prisms have been observed. The faces are bright and lustrous, and the crystals are often transparent. In addition, larger hexagonal prisms of

Figure 10. **A twinned crystal of colorless cerussite about 2 cm tall from the Bideaux collection. Photo by Stanley Keith.**

vanadinite, up to 4 mm long, are infrequently collected. These are opaque, orange-red in color, and approximately equant in proportion.

Mimetite $Pb_5(AsO_4)_3Cl$

Other prismatic microcrystals can be found associated with wulfenite. These are less than 1 mm in length, yellow to orange in color, opaque, nonlustrous, and have pointed or irregular terminations. They occur as isolated individuals and in clusters. Some of the clusters have a sheaf-like appearance, the crystals splaying out stilbite fashion. X-ray powder pattens are of the vanadinite-pyromorphite-mimetite type, but most closely resemble mimetite in the doubling and tripling of some lines. This, coupled with the general appearance of the crystals, suggests that the mineral is mimetite.

Willemite Zn_2SiO_4

X-ray powder patterns verified the existence of willemite, which occurs in two generations of growth. First-generation material consists of minute clear to milky-white to dark-gray hexagonal prisms as much as 1 mm in length. These are terminated by a basal pinacoid, have lustrous faces, and are up to two diameters long. Second-generation material occurs as mats of acicular fibers which are white, perhaps up to 1 or 2 mm in length, and are densely intergrown. Red Cloud willemite fluoresces greenish yellow under shortwave ultraviolet illumination.

Stetefeldtite $Ag_2Sb_2(O,OH)_7$(?)

A yellow powder or crust is sometimes found with wulfenite, and its powder pattern matches that for stetefeldtite, according to the Joint Committee on Powder Diffraction Standards (JCPDS) Powder File card 8-12. The formula given is $Ag_ySb_{2-x}(O,OH,O_2O)_{6-7}$, where x is approximately 0.5 and the value of y is between 1 and 2. Fleischer (1975) gives $Ag_2Sb_2(O,OH)_7$(?). Thus, there is uncertainty at least about the composition of the material. *Dana's System* (Palache, *et al.*, 1944) lists this as an ill-defined material and suggests that it may be a mixture of other oxides.

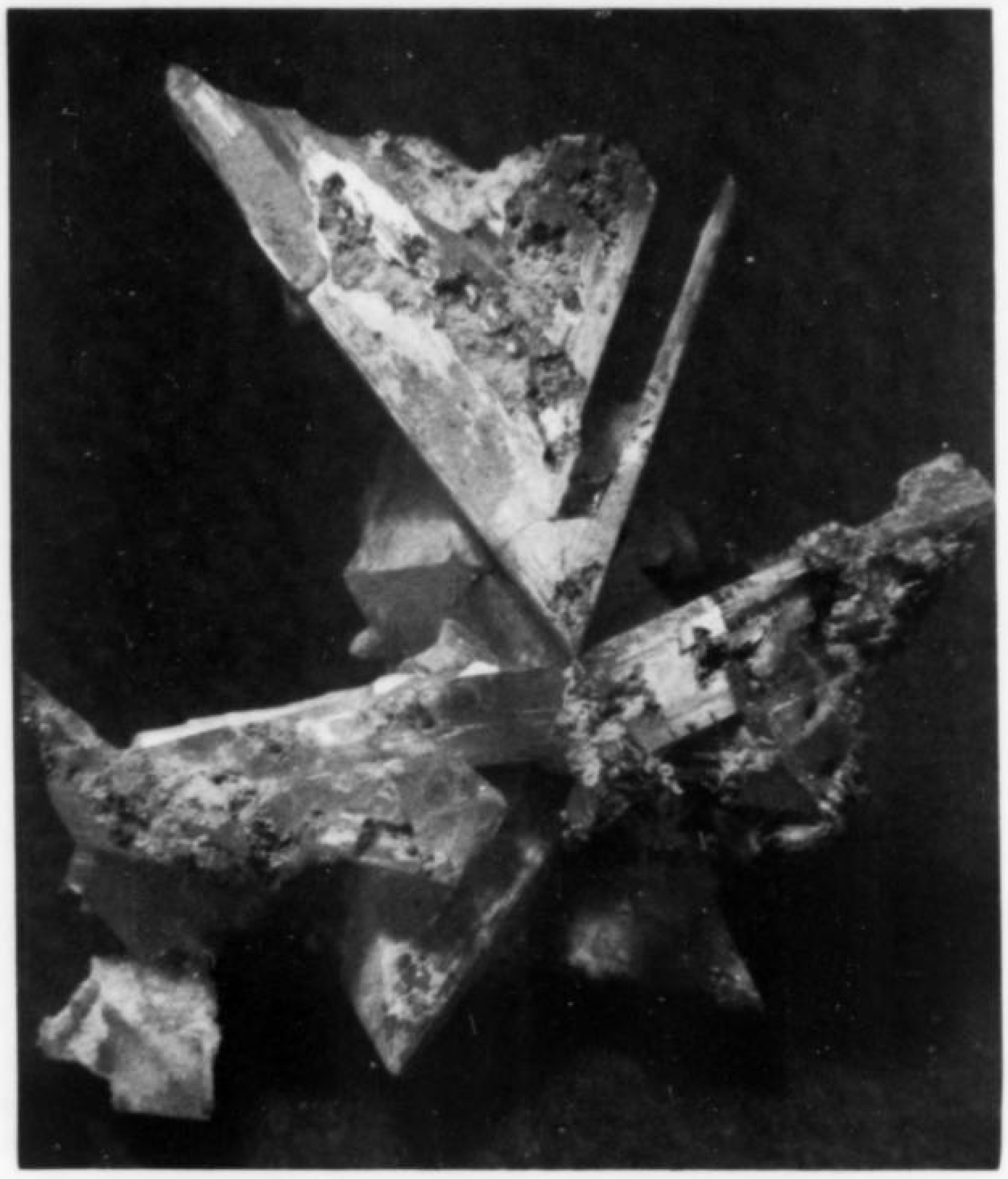

Figure 11. **Cerussite twins measuring 3.2 cm from the Red Cloud mine. Specimen and photo: Grant Richards.**

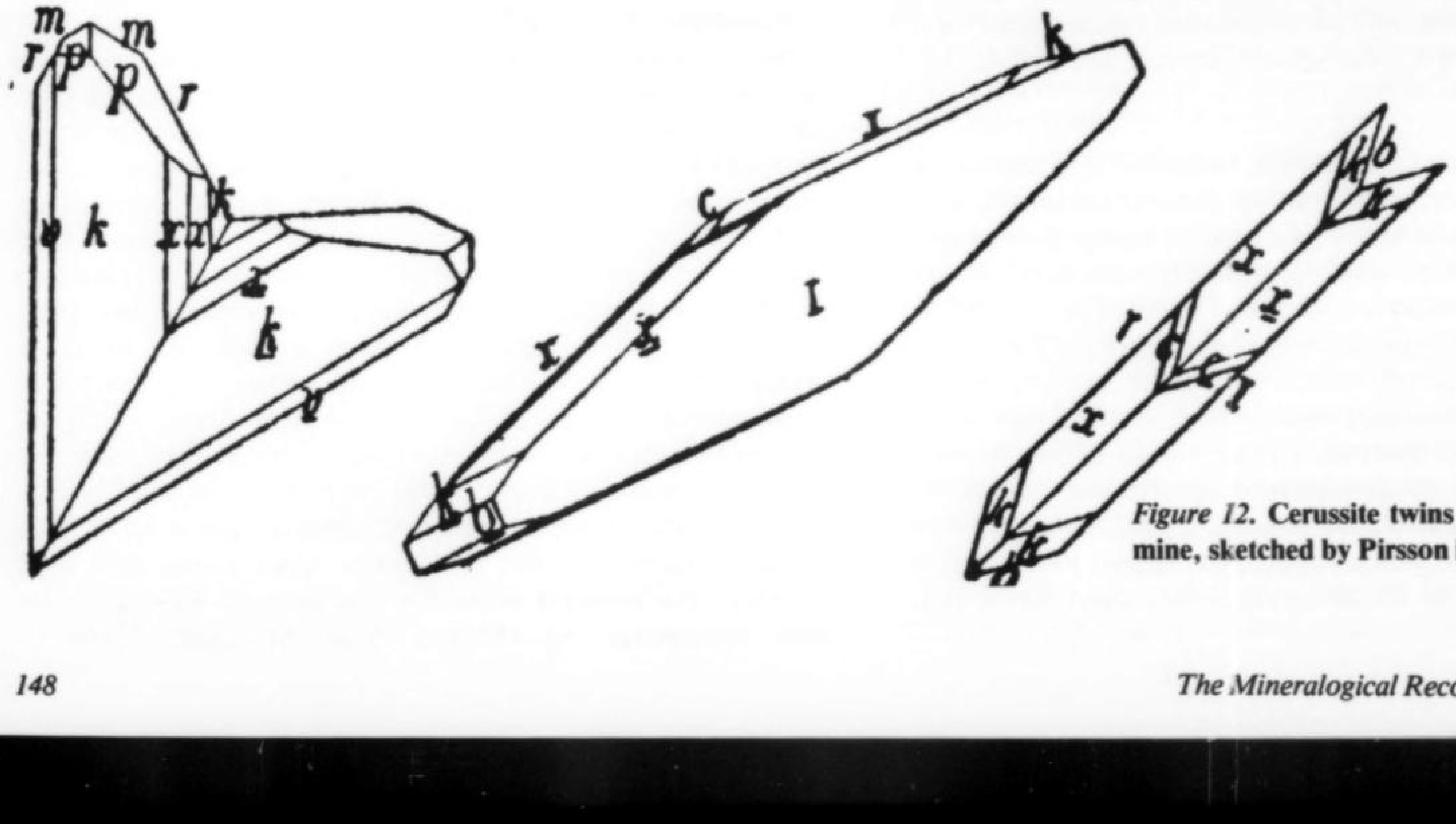

Figure 12. **Cerussite twins from the Red Cloud mine, sketched by Pirsson in 1881 (Dana, 1904).**

Plattnerite PbO_2

Minute black needles of plattnerite, requiring high magnification for resolution, have been found on vanadinite. This material was collected from the south stopes.

Galena PbS

Massive pods and veins of galena were always the objective of commercial mining at the Red Cloud mine because the galena is argentiferous, containing as much as 500 ounces of silver per ton (recent analyses on numerous pods by Clarkson Laboratory, San Diego; data courtesy of David Shannon). These are found throughout the mine (though most have been removed from the upper levels), and some collecting specialists feel that pockets of the best wulfenite crystals occur near these galena pods.

Other minerals

Aragonite is found as delicate, late forming flos-ferri in some vugs especially above the 100-foot level. Barite is a common gangue mineral in the Red Cloud vein and occurs rarely as microscopic crystals. Rhombohedral calcite crystals, usually manganiferous, are not uncommon in sizes up to 2 cm. Fluorite occurs in exceptionally nice micro specimens, as colorless to pale purple cubes, some highly modified. Gypsum is not uncommon; one 45-cm vug on the 150-foot level was found completely filled with granular gypsum. Fine, clear crystals of hemimorphite to a few mm are also fairly common. Anthony *et al.* (1977) list massicot as coming from the Red Cloud mine. Quartz, sometimes amethystine, has been found as well, occasionally with micro red wulfenite crystals perched on micro amethyst crystals to form superb micromounts.

PARAGENESIS AND GEOCHEMISTRY OF THE VEIN

The original Tertiary mineralization of the Red Cloud vein apparently produced mainly calcite, quartz, fluorite, sulfide minerals, and manganese minerals deposited in a reducing environment. Erosion eventually exposed the vein to surface oxidizing conditions, and these primary minerals, especially the sulfides, were altered to the secondary oxides, carbonates, and others typical of an oxidized zone.

The important economic primary sulfides were galena and acanthite. Altogether this material is often called "argentiferous galena," because the acanthite occurs disseminated in the galena (Wilson, 1933). There is no pyrite to be found now, but the extensive limonite and hematite in the gossan suggest its original abundance. The oxidation of pyrite is often crucial in explaining the oxidation of the other sulfides in a deposit, and this process was probably important in the Red Cloud vein. In the zone of aeration (the section between the surface and the water table), ground water contains dissolved carbon dioxide, and a weak solution of carbonic acid is formed which reacts with pyrite to form ferric oxides and hydroxides and sulfuric acid. The iron compounds limonite (largely goethite) and hematite are insoluble and so precipitate to form gossan. This leaves the sulfate and hydrogen ions in solution as a strong acid that acts as a potent solvent for other primary minerals.

As oxidation sets ions free from their original mineral associations, they react with one another and with the wallrock to form new minerals that are stable in this acidic, oxidizing environment. These secondary minerals of the Red Cloud vein are calcite, quartz, manganese oxides, limonite, hematite, smithsonite, anglesite, cerussite, willemite, wulfenite, vanadinite, and mimetite, among others.

Considerations of Eh-pH stability fields for the secondary minerals, together with their paragenesis, give a means for interpreting the geochemical history of an oxidized deposit. This can be an involved exercise, but in essence it consists of taking the stability fields for the various minerals in the order of their formation as an indication of the changing environment in the vein over the span of time involved.

Based on examination of Red Cloud specimens collected, a paragenesis was inferred (Fig. 14). Chlorargyrite could not be correlated with the other minerals, because it was not recognized in the mine. Cerussite could only be established as being later than the wad on which it was found; it was not seen associated with willemite, wulfenite, vanadinite, or mimetite. Wulfenite was observed growing on the more coarsely crystalline generation of willemite, and acicular mats of willemite were often found on wulfenite. Vanadinite and mimetite could not be differentiated with respect to time, but both were found on the two generations of willemite and on wulfenite. Plattnerite occurs on vanadinite as perhaps the last mineral to form.

This paragenesis could not be related completely to Eh-pH diagrams because free energy data are not available for willemite, wulfenite, vanadinite, and mimetite, and therefore their stability fields cannot be established except by indirect means. However, Eh-pH diagrams do exist which include hematite, certain manganese oxides, chlorargyrite, anglesite, and cerussite (Garrels and Christ, 1965; Schmitt, 1962). Further, according to Williams (1966), a wulfenite-willemite association implies moderately high Eh and pH. I conclude that the vein environment was rather strongly acidic and oxidizing, at least through the wulfenite-producing stage.

Figure 13. **Colorless hemimorphite crystal groups to a few mm in size, on matrix, from the Red Cloud mine. David Shannon specimen.**

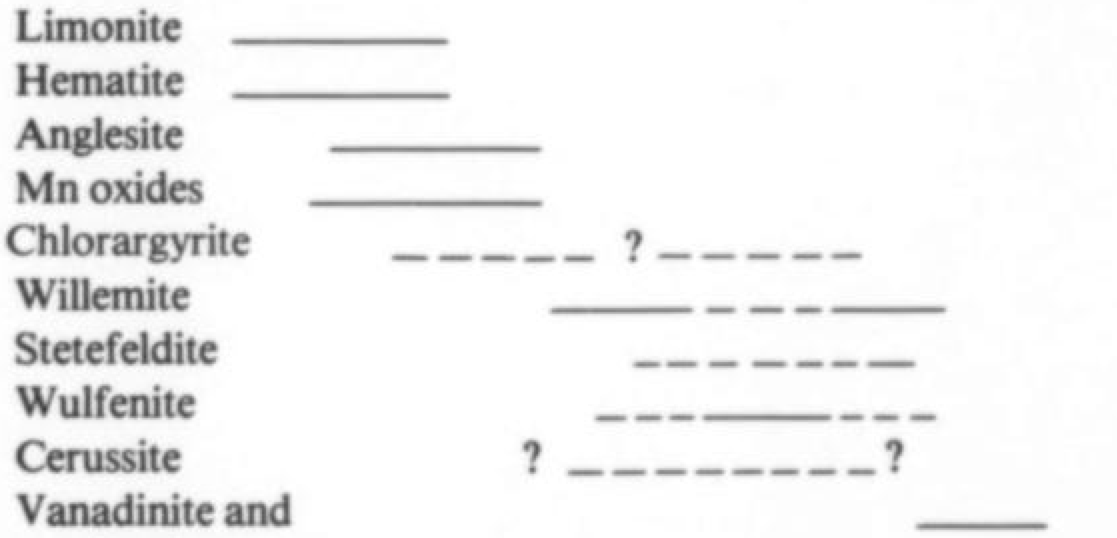

Figure 14. **Observed paragenesis of some oxide zone minerals at the Red Cloud mine. Cerussite established only as later than manganese oxide matrix.**

The suite of primary minerals can account for all ions needed to produce the secondary minerals except for the molybdate, arsenate, and vanadate needed for wulfenite, mimetite, and vanadinite. Also antimony needed for stetefeldtite is of unknown origin. Titley and Anthony (1961) concluded that molybdenum need not be indigenous but can be transported to the site of deposition as a soluble molybdate ion. They inferred that this is probably true for most oxidized veins where wulfenite is found and molybdenite is not found among the primary minerals. Geochemical data suggest very low concentrations of molybdenum, arsenic, and vanadium in typical, unmineralized granitic rocks and andesites, and if these ions are derived from the country rock, their concentrations must be greatly enhanced. Enrichment in molybdenum occurred as disseminated molybdenite mineralization in the porphyry copper deposits of the southwestern United States, where wulfenite is also typically found in oxidized veins. However, such a porphyry copper deposit in the Silver mining district has yet to be discovered.

Figure 15. **Crystals of pale amethyst (the largest about 2.5 cm) from the Red Cloud mine. Robert E. Reynolds specimen; photo by Grant Richards.**

If significant concentrations of this metal ion or of arsenic and vanadium cannot be found in rocks near the Red Cloud vein, then these must have been original constituents of the primary mineralization. Such primary minerals, however, have not been found at depth.

COLLECTING HISTORY*

Wulfenite from the Red Cloud mine apparently first began finding its way to mineral dealers such as A. E. Foote and Henry Ward during the 1880's operations by the Red Cloud Mining Company. Many fine pieces with old labels can be found in museums today. During these first underground operations, the miners used candles for illumination and cowhide bags for hauling ore to the surface. Artifacts such as these are still occasionally found in the rubble and backfill, amidst the hand-hewn pine and cottonwood timbers. Two candleholders were very recently found still stuck in a timber when a zone was emptied of backfill. These earliest workings, chiseled and blasted out by primitive means, are easily recognized by their irregular and sometimes cramped meanderings, as opposed to later, more systematic stoping and drifting at lower levels. And these old workings, mostly above the 150-foot level, have produced the most specimens.

Areas of the mine extending down to the 500 level were opened around 1925 and have produced very little wulfenite, although the little which has been found there is superb. The lower workings have been relatively inaccessible in recent years due to dust, debris and insufficient oxygen to support collectors.

The greatest discovery at the Red Cloud mine was made by the now-legendary Ed Over during his first and last trip there in 1938. In a letter to Arthur Montgomery, Over even mentioned meeting a man "who shipped wulfenites to Ward's and Foote's about 1910." Over's letters to Montgomery provide a fascinating record of the discovery, as detailed by Szenics (1975). His letter of February 14 covers the exciting discovery itself. Some excerpts:

"On the 9th I tried another brecciated seam that has pocketed three times . . . each pocket has been bigger and better. I can't compare this stuff with anything I've seen before. . . . But I will say that these single crystals, clusters and groups are the finest wulfenites I've ever seen . . . the pocket bottoms are covered with loose crystals . . . I think this seam is one in a million. Am shipping 8 boxes, 6½ are from this place. P.S. Note large rose-shaped cluster of crystals especially."

Over's main cavity was about 8 inches wide. The floor of the cavity was carpeted with soft, pulverulent manganese oxides, and the wulfenite crystals, undamaged, were lying loose as if they had floated down gently from their original perch in the cavity. Perhaps the cavity had still been filled with water when the crystals broke loose from the sides and settled softly to the bottom. In any case, they remain the finest known examples of the species to this day, and many collectors feel the color of this one pocket is slightly brighter and cleaner than that of any other discoveries at the mine. The crystals reach 5 cm (2 inches), some of which are floaters (no visible point of attachment to matrix), and are typically almost 1 cm in thickness. In all, about 24 exquisite specimens were recovered from the pocket. Three are shown in Figure 4. Two more are shown on page 191; the center piece was purchased by Harvard from Montgomery in 1938 for $22.50, and the large piece just to the right was donated by Montgomery to the Smithsonian. Yet another, owned by Richard Bideaux, is shown on the cover of this issue. Many of the Over wulfenites were eventually sold through Shortmann's, the well known mineral dealers of the day in Massachusetts, and the Shortmann Brothers were forever after plagued by people wanting to buy more such specimens. One frustration still lingers . . . no one knows where in the mine Over made his discovery.

Much collecting by private individuals took place during the 1960's and 1970's, resulting in many excellent discoveries. Of those made public, the majority occurred in the south stope on or above the 150-foot level. They include:

1963: Robert E. Reynolds (large matrix specimen, 500-level)
1965: Robert E. Reynolds (large specimens, 150-level)
1965: Unknown dealer (large, productive pocket, main incline)
1967: Leigh Price (varied material, 150-level)
1972: Gary Fleck (small pocket, 150-level)
1973: Michael Smith and group (large pocket, 150-level)
1973: Wayne Thompson and group (large pocket, 150-level)
1974: Grant Richards and Gary Fleck (pocket system, 150-level raise)
1975: Grant Richards (pocket system, 150-level)
1975: Garth Bricker (small pockets)

These discoveries are undoubtedly only a sampling of those actually made, but they achieved the most publicity at the time.

In recent years the mine has become increasingly unsafe. Collectors have removed support pillars, timbering and supportive backfill, and have enlarged many open areas by stoping. Currently an operation under the direction of Wayne Thompson is mucking

---

*This section was supplied by Wendell E. Wilson.

out (removing debris from) sections of the mine in preparation for renewed mining for argentiferous galena and specimen-grade wulfenite. Access by other collectors is prohibited, but perhaps these new operations will yield new quantities of the world's finest wulfenite.

ACKNOWLEDGMENTS

I wish to thank Michael Rose and George Bideaux for the loan of specimens; Sidney Williams for data on wulfenite trace element content; David Shannon for data on galena silver content; Garth Bricker for the loan of artifacts for photography; David Shannon, Garth Bricker, Wayne Thompson and Wendell Wilson for information on various species and on the collecting history; Grant Richards, Stanley Keith, and Wendell Wilson for photography; and John Anthony and Richard Thomssen for critically reviewing the manuscript.

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Figure 16. **A view in the inclined shaft near the 150-foot level. Note the collector's hardhat light showing as a beam in the dusty air.**

Figure 17. **Artifacts discovered underground at the Red Cloud mine by Garth Bricker: miner's candleholder and tallow candle, bandana, leather miner's cap and rawhide hoisting rope for hauling leather ore bags up by hand.**

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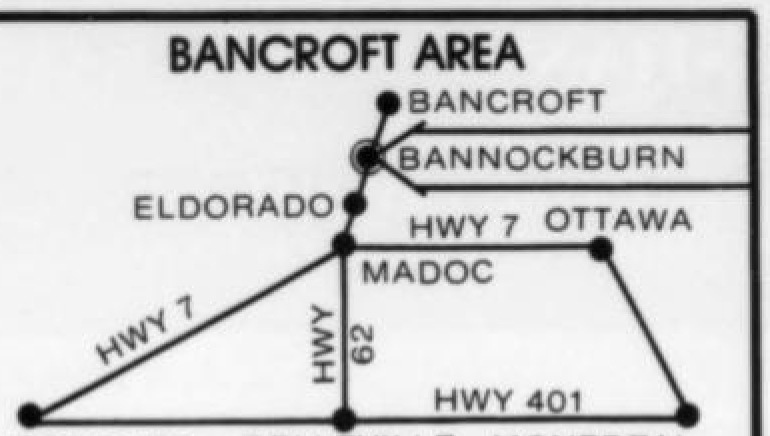
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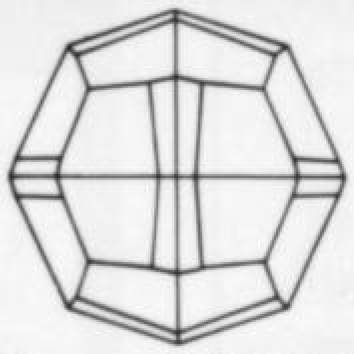

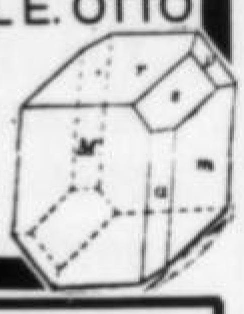

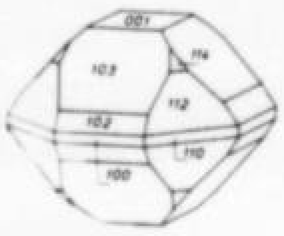
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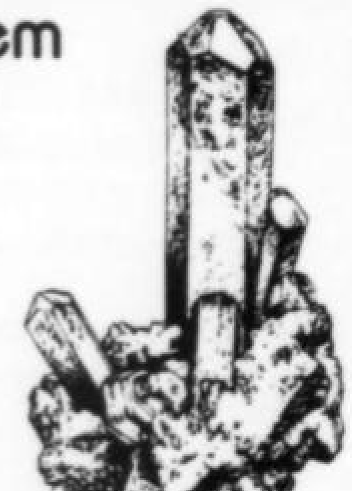

TIGER
ARIZONA

by
Richard A. Bideaux
1144 West Miracle Mile
Tucson, Arizona 85705

From the initial discovery in 1879, over 100 years ago, until the time of their closing in 1953, the Mammoth and Collins mines were producers of spectacular mineral specimens for the collector. Many of the mineral specimens recovered from this deeply oxidized, base and precious metal vein deposit were exceptional examples compared to those found in the numerous similar deposits in Arizona, New Mexico and Sonora. Additionally, the superimposed wulfenite and vanadinite mineralization was outstanding both in quality and volume. Special conditions which obtained in these veins led to a suite of highly unusual copper-lead minerals unmatched in richness and beauty from any other deposit. The nearly 100 species recognized to date seem to occur in endless combinations; while outstanding cabinet specimens of some of the minerals were produced, the full impact and range of the mineralogy can only be appreciated in micromount-size crystals.

LOCATION

The mines are located about 80 km north-northeast of Tucson, near the present town of Mammoth, Pinal County, Arizona, and are today owned by the Magma Copper Company. Access to the grounds is prohibited except by prior arrangement.

MINING HISTORY

Frank Schultz located claims on the Collins vein in 1879, the Mohawk vein in 1881, and the Mammoth vein in 1882. Original workings were an open cut atop a hill on the Collins vein. Mineral specimens from this cut bearing labels with the locality "Schultz gold mine" are still to be seen.

The town of Mammoth, about 5 km northeast of the mine, was established to mill the gold ore. By 1889, the property was in operation by the Mammoth Gold Mines, Ltd., an English company, in turn succeeded in 1896 by the Mammoth Gold Mining Company. At first ore was hauled by 20-mule teams; later connection was made to the town of Mammoth by an aerial tramway, traces of which can still be seen.

In 1901 the workings caved from the 750-foot level to the surface. For this reason and litigation, the mine was not reopened until 1913, by the Great Western Copper Company. Before 1914, the mine was worked for gold alone, but demand for molybdenum during World War I created interest in the mines' wulfenite reserves. The extensive tailings dump was worked for discarded wulfenite, the first of several reworkings by the Arizona Rare Metals Company.

Figure 1. **Mammoth mine in 1891 (photo courtesy of the Arizona Historical Society).**

The Mammoth Development Company acquired the property in 1915, extending the underground workings, then giving way in 1918 to the St. Anthony Mining and Development Company. The collapse in the price of molybdenum necessitated closing the mines in 1919.

By 1943, with increasing demand for base metals due to World War II, the deeper sulfide ores were worked for lead and zinc. Increased mining costs and depleted reserves caused the sale of the property and the town, Tiger, to the Magma Copper Company in 1953; at that time the mine ceased production.

About 400,000 ounces of gold, 1 million ounces of silver, 3.5 million pounds of copper, 75 million pounds of lead, and 50 million pounds of zinc were produced. Six million pounds of MoO_3 and 2.5 million pounds of V_2O_5 were also recovered; these figures correspond to 15 million pounds, or 7500 tons of pure wulfenite concentrates, and 12.5 million pounds, or over 6000 tons of vanadinite-mimetite-descloizite concentrates. The total value at today's prices of all of the seven metals produced would be over $300 million (17, 27, 40).*

GEOLOGY

The area is underlain by Precambrian Oracle granodiorite which has contributed material for younger conglomerate and arkoses. Interbedded with basalt and tuff, these later overlying rocks are collectively known as the Cloudburst formation of Tertiary age. In the area of the mineral deposits, a younger fine-grained to prophyritic intrusive rhyolite is prominent, appearing in places as a breccia of enigmatic origin, which includes fragments of granite and basalt as well as rhyolite.

The Mammoth mine deposit is less than 1 km from the large San Manuel low-grade porphyry copper and molybdenum deposit. The former vein systems are certainly younger than the San Manuel deposit, but their exact age relations are not yet established. Lead-zinc-barite mineralization in the core of the San Manuel deposit may correspond in age to that of the Mammoth mine (L. Thomas, personal communication) (17, 27, 35).

The veins are fault-controlled: the same faults which rhyolite intruded were later mineralized along the granite-rhyolite contacts with vein widths up to 6 m. After emplacement, the sulfide ores were oxidized to great depth. A second period of normal faulting then offset the main vein, forming the separate Collins (lower) and Mammoth (upper) orebodies. The uplifted sulfides in the Collins continued to oxidize to the present water table, while the pre-existing oxidation of the Mammoth orebody extended below it (17, 27, 35).

EARLIER MINERALOGICAL WORK

After vom Rath (1) and Genth (2) originally described vanadinite and descloizite from the Mammoth mine, there was little professional interest in the minerals from the deposit for many years. Blake (8) and Guild (9), in their pioneer Arizona mineralogies, touched on the deposit, but very few species were mentioned. Peterson's PhD thesis (16) and its publication (17) remain the longest description of the geology and mineral occurrences at the Mammoth mine. Galbraith's initial *Minerals of Arizona* (21) summarized Peterson's mineralogical findings.

Following discovery of the rarer minerals about 1940, Palache at Harvard University and Gordon at the Philadelphia Academy

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*Ed. note: Due to the large number of references, this article departs from our usual reference format. Numbers given in parentheses indicate numbered references listed at the end of the article.

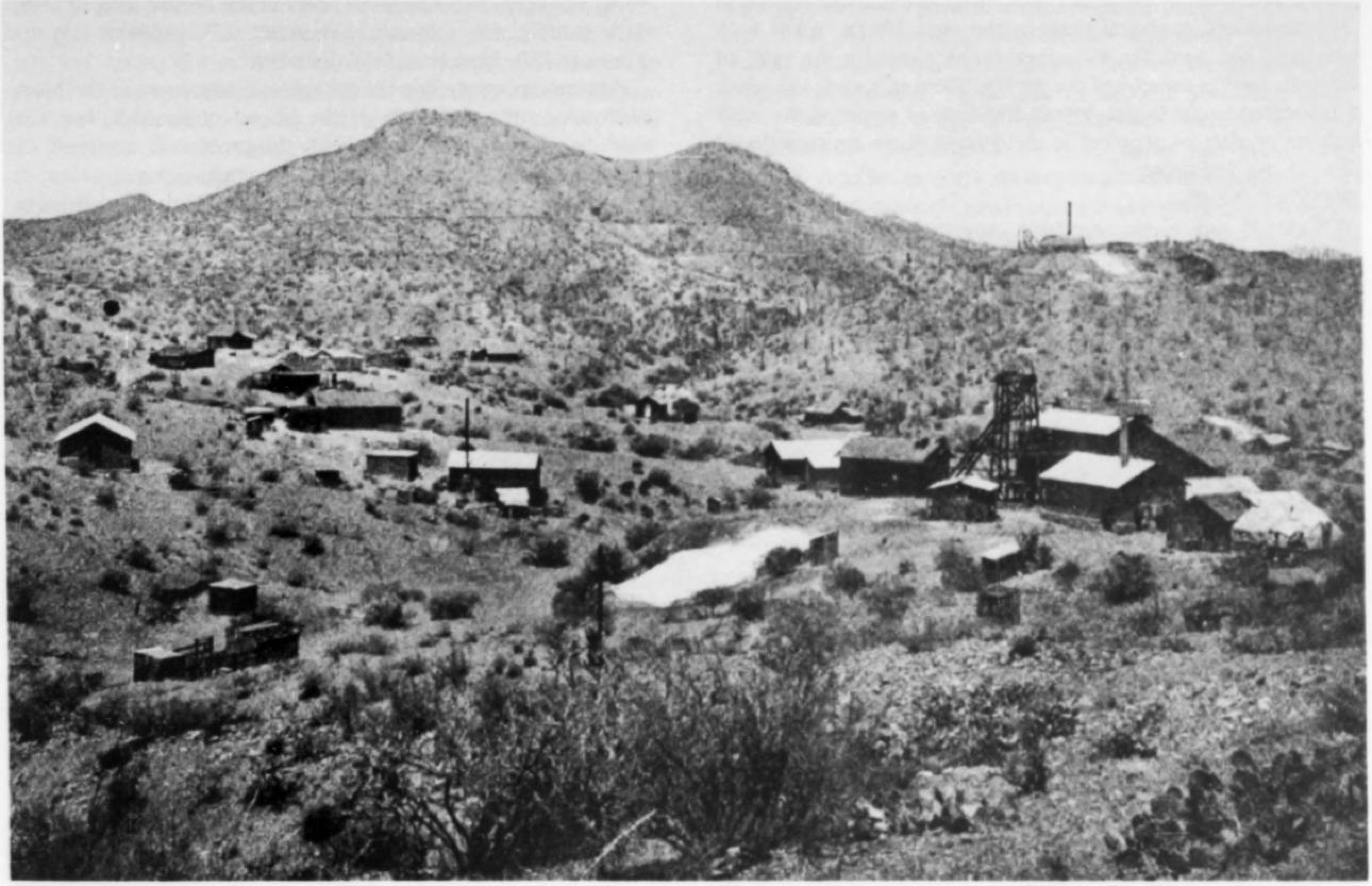


Figure 2. **Schultz, Arizona, in 1903. The headframe of the Mohawk mine is in the foreground, and the Mammoth mine workings are in the saddle of the hills and to the right on the horizon (photo courtesy of the Arizona Historical Society).**

Figure 3. (left) **Generalized geology of the Tiger area (from Creasey (27)).**

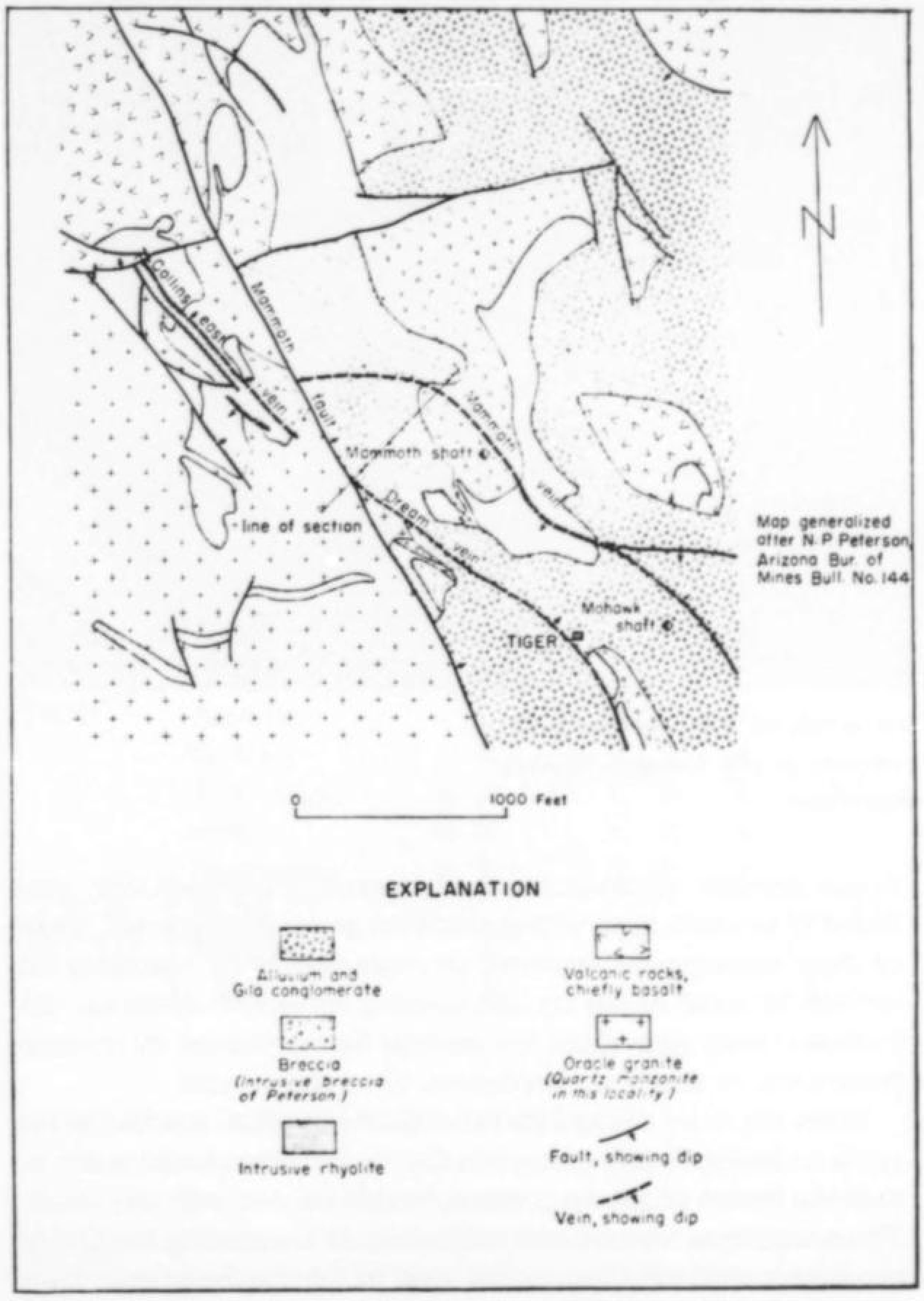
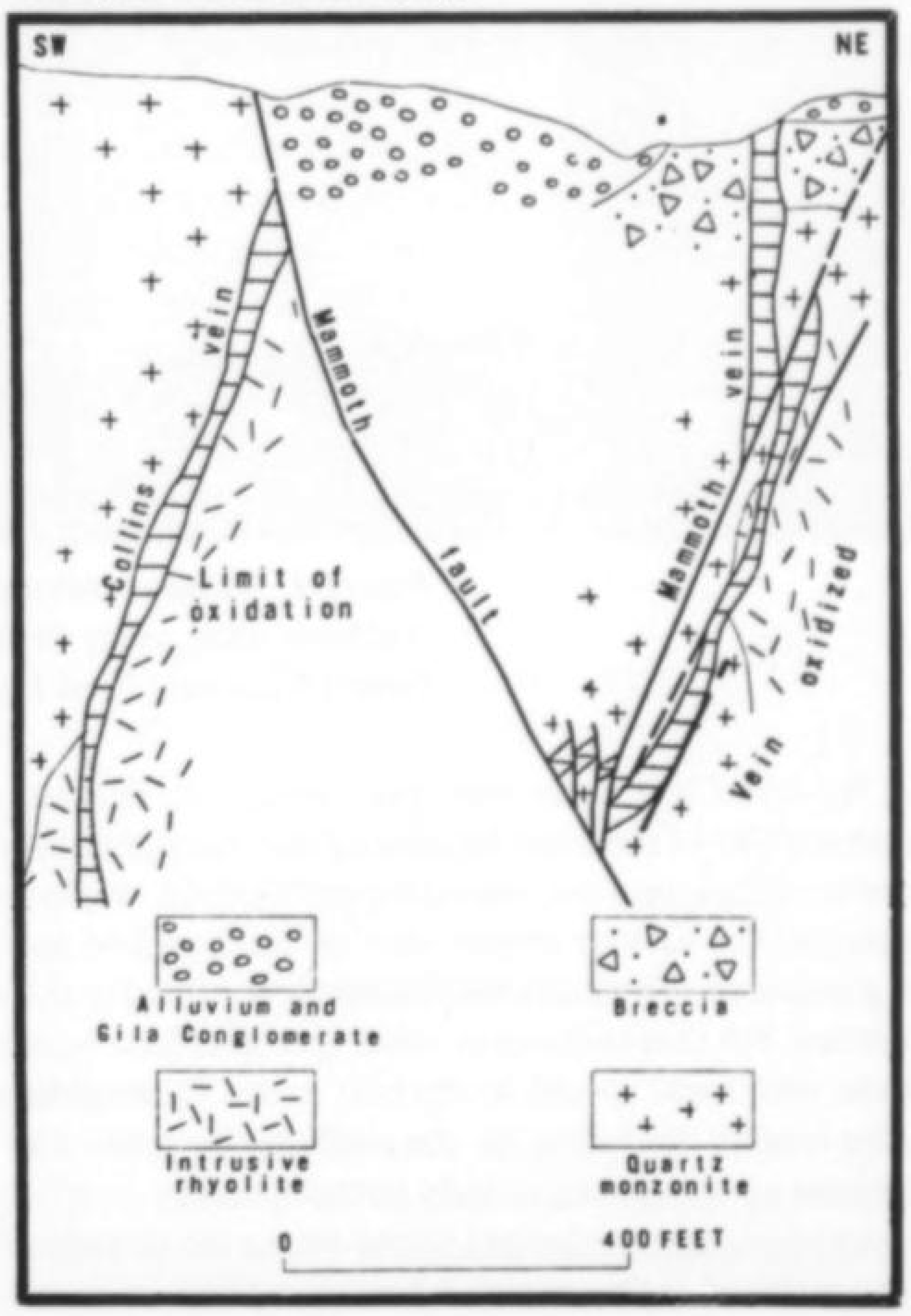


Figure 4. (below) **Vertical section through the Collins and Mammoth veins (from Anderson (35)).**



became interested in the mine. Palache collected at the deposit in 1941, and Gordon several times in the early 1940's. While both recognized the need for a comprehensive paper on the suite of minerals, neither completed the project. Gordon's work did result in numerous unpublished crystal drawings of some of the most complex crystals he observed in the deposit; these are reproduced here for the first time.

PRESENT WORK

This study had several objectives, among which were a detailed examination and confirmation of the minerals known to occur in the deposit, their inter-relationships and sequence of formation. It was hoped also to find minerals new to the deposit and perhaps new to science.

Several thousand specimens were examined, with detailed notes taken on about 600 of the more interesting and significant of these. X-ray powder diffraction was the principal method employed for confirmation of the various species with several hundred such patterns being prepared. The study was primarily confined to the metal bearing species. No thin sections or other special efforts were made to determine additional species in the host rocks. Other than a few visits to the locality to collect on the surface, the study was conducted entirely on specimens already in collections.

There was considerable success in confirming the already known species, as presented in this paper. About two dozen minerals were found not previously known to occur in the deposit and, of these, three entirely new minerals, bideauxite (37), yedlinite (38) and creaseyite (39), have been fully described.

Progress on unraveling the paragenetic sequences of the Mammoth mine suite, especially of the secondary minerals, has been much less marked. The more closely this problem is examined, the more complex it seems to become. More than one generation, on the same specimen, of nearly every secondary species has been seen. There are obvious implications for misjudging the relative ages of these minerals on other specimens.

There is abundant evidence of earlier formed crystals being physically displaced from their positions by other later minerals, giving the appearance of a reversal in their true order of formation. Pseudomorphic replacements, many seemingly contradictory, were found to be much more widespread than previously reported. Some of these replacements appeared to proceed only by breaching the surfaces of some of the crystals possibly subject to alteration. Effects also were seen which are perhaps best explained by contemporaneous, or nearly so, deposition of several species.

While the order of deposition on most individual specimens was easily understood, some showed a drastic difference in the order, or even the groups of species present, in a distance of only a few mm. These problems, coupled with the lack of data regarding location of occurrence within the deposit for most of the specimens examined,

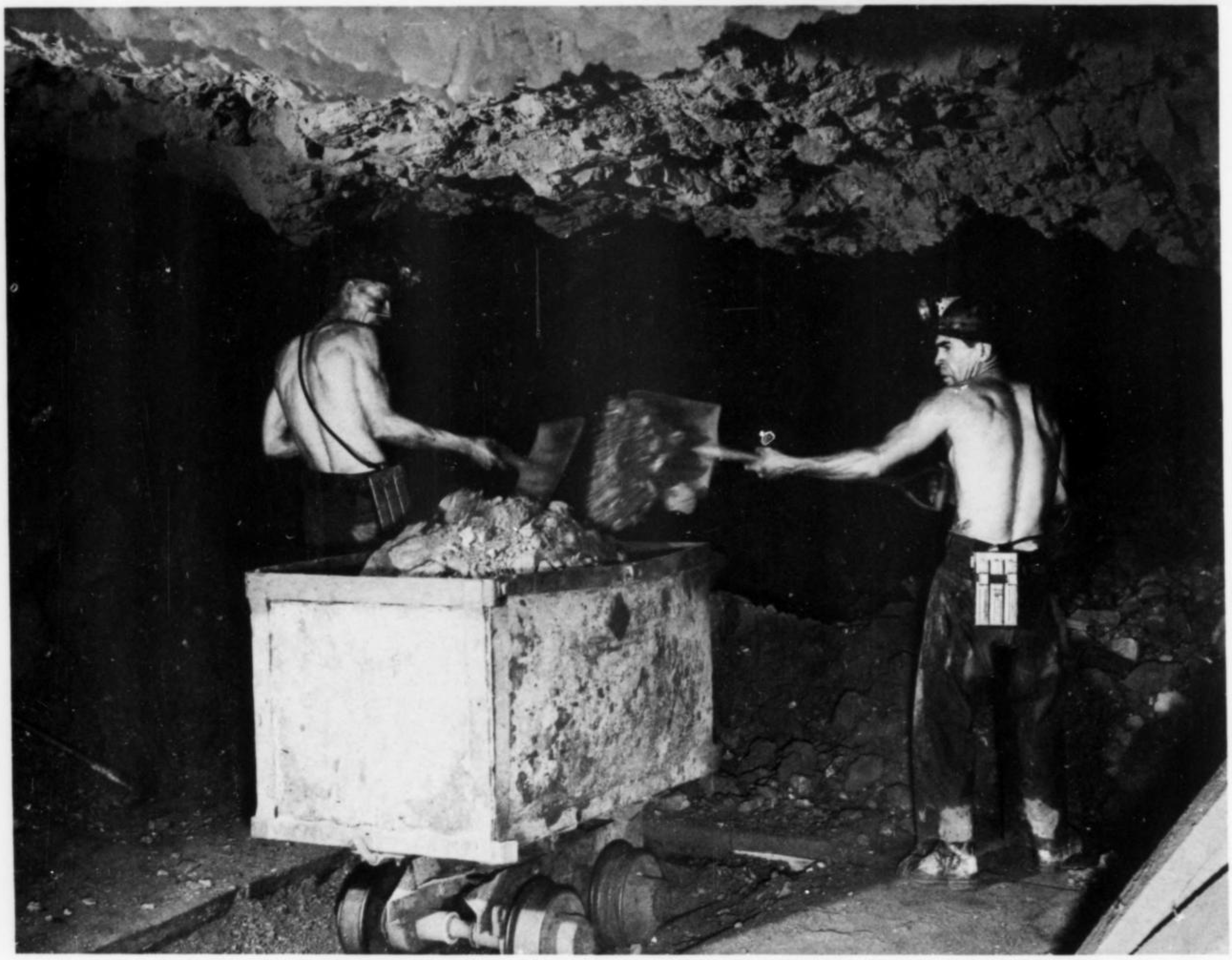


***Figure 5.* Miners working in the lower levels of the Mammoth-St. Anthony mine, early 1940's (photo courtesy of the Arizona-Sonora Desert Museum, Fred Houghton collection).**

make anything other than a gross estimate of the paragenesis difficult, if not impossible. The samples examined, while several thousand in number, obviously have not exhausted the combinations or even the minerals to be observed, and are clearly not samples representative of the entire deposit. Examples of the primary minerals are very rare in collections; those minerals collected have been chosen in large part for their beauty and commercial acceptability, rather than to assist in understanding of the minerals' formation.

Consequently, the minerals known to occur in the deposit have been grouped first by a gross order of formation, as shown in the tables following. These include minerals of the host rocks and gangue, followed by the primary and secondary sulfides. As the result of oxidation of the upper portions of the veins, one group of secondary minerals is defined as a normal alteration sequence, while another group appears to be anomalous. Placement of individual species in either of these groups is based partially on the oxidation sequences reported in deposits with some similar characteristics, and the observed associations in this deposit, especially for some of the quantitatively rarer species. Minerals from one group seem usually not to be found with those from the other, but a considerable number of exceptions could be cited.

The minerals in Table I are also defined by the major rock-forming elements, for the minerals in the wall-rocks and gangue. The qualitative presence of silver, lead, copper, iron or zinc is noted for the secondary minerals listed in the following tables, as these are the principal elements supplied by oxidation of the primary sulfides.

Following the tables, the individual minerals are discussed in alphabetical order. Reference numbers are the last item for each mineral. These are intended to encompass every mention of the species found in the literature listed under references.

Table 1. **Host rock and gangue minerals.**

		K	Na	Ca	Mg	Fe	Al	Silicate	Water	Others
WALL ROCKS	Quartz							X		
	Microcline	X	.	.	.	.	X	X		
	Orthoclase	X	.	.	.	.	X	X		
	Plagioclase	.	X	X	.	.	X	X		
	Biotite	X	.	.	X	X	X	X	X	F
	Magnetite	.	.	.	.	X				O
	Apatite	.	.	X					X	PO_4, Cl F
HYDROTHERMAL ALTERATION	Allophane	.	.	.	.	.	X	X	X	
	Muscovite	X	.	.	.	.	X	X	X	
	Antigorite	.	.	.	X	X	.	X	X	
	Serpentine	.	.	.	X	X	.	X	X	
	Palygorskite	.	.	.	X	.	X	X	X	
	Chlorite	.	.	.	X	X	X	X	X	
	Amesite	.	.	.	X	.	X	X	X	
	Epidote	.	.	X	.	X	X	X	X	
	Tourmaline	.	X	X	X	X	X	X	X	F, BO_3
	Stilbite	.	X	X	.	.	X	X	X	
	Heulandite	.	X	X	.	.	X	X	X	
INTRODUCED	Barite									Ba, SO_4
	Fluorite	.	.	X						F
	Calcite	.	.	X						CO_3

HOST ROCK AND GANGUE MINERALS

The minerals reported as composing the wall rocks are unexceptional, as was the course of their alteration during later hydrothermal mineralization of the veins. Destruction of the feldspars, with loss of soluble potassium and sodium and the introduction of water, resulted in hydrated alumino-silicate minerals. Biotite and the other dark-colored magnesium, aluminum, iron-bearing (mafic) minerals (undoubtedly present but not reported) provided magnesium and iron for the clay species and abundant chlorite. Ba^{2+}, SO_4^{2-} and some F^- were perhaps introduced during hydrothermal mineralization to form barite and fluorite. The elements requires to form these minerals are present in the wall rocks, yet their apparent abundance would argue a wider volume of alteration than seems to occur. For example, the width of the barite zone surrounding the Mammoth vein is considerably greater than the vein itself, or the width of bleaching of the wall rocks. CO_3^{2-} in calcite is probably from intermingled groundwater.

Allophane an amorphous hydrous aluminum silicate.

Undoubtedly many different species are lumped with the general term "clay" as applied to the Mammoth mine suite; they will be discussed here under the heading allophane unless otherwise differentiated. This designation is chosen because of the amorphous nature and high aluminum content of most samples containing thick enough layers for X-ray analyses. Clays in one form or another can be found in association with nearly all of the minerals studied, and at least a little can be found on nearly every specimen; their distinction could form a substantial project in itself.

Allophane formed in abundance in the veins as an alteration product of feldspars from the wallrock, and in turn became copper-stained, finally producing chrysocolla. The various clay minerals in general range in color from white through greens and blues, and are present as powders, films, crusts, sometimes banded, occasionally pisolitic, and range from porous to waxy.

An attractive association is a continuous, smooth but layered coating of allophane over wulfenite crystals and their matrix, the whole then giving a shining porcelaneous appearance. This combination forms a pleasing background for scattered crystals of cerussite, dioptase, later wulfenite, mimetite, fluorite, and quartz.

Clay was noted as entirely replacing a loose cerussite twin, while yet another mass of clay formed a hollow mold of cerussite. Linarite and caledonite have been entirely coated by clay, then dissolved, leaving hollow crystal casts. Atacamite was found to have clay selectively encrusting only certain crystal faces (17, 27, 33, 40, 41).

Amesite $(Mg_2,Al)(Al,Si)O_5(OH)_4$

On one specimen, determined to be the white powdery matrix on which wulfenite occurs (41).

Antigorite $(Mg,Fe)_3Si_2O_5(OH)_4$

On a single specimen, from the 100 level, as white crusts with minute contemporaneous quartz crystals. The quartz includes balls of antigorite just under the surface; later wulfenite and descloizite are also on the specimen (41).

Apatite $Ca_5(PO_4)_3(F,OH,Cl)$

Reported as a very minor accessory in the host rocks, Oracle granodiorite, aplite, and andesite porphyry (17).

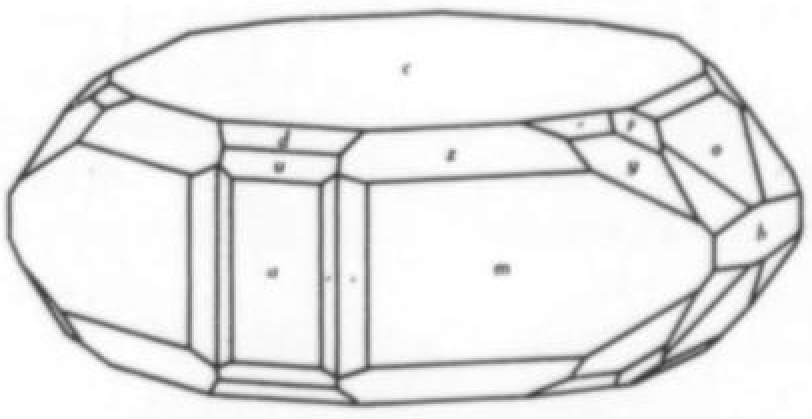


Figure 6. **Barite (Gordon).**

Barite $BaSO_4$

A common gangue mineral, forming the matrix for or intermingled with primary sulfides and their alteration products. Usually as cleavable masses, the mineral occasionally forms in patchily transparent crystal groups with rhombic individuals to several cm.

When not encrusted with metallic minerals, an amethystine druse of fluorite crystals is often noted. Tiny water-clear crystals of a later generation may be confused with anglesite (15, 24, 27, 31, 33, 40, 41).

Biotite $K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$

A constituent of the host rocks, mostly in the Oracle granodiorite, but accessory in aplite and rhyolite. It is largely replaced by chlorite adjacent to the veins (17, 33, 40, 41).

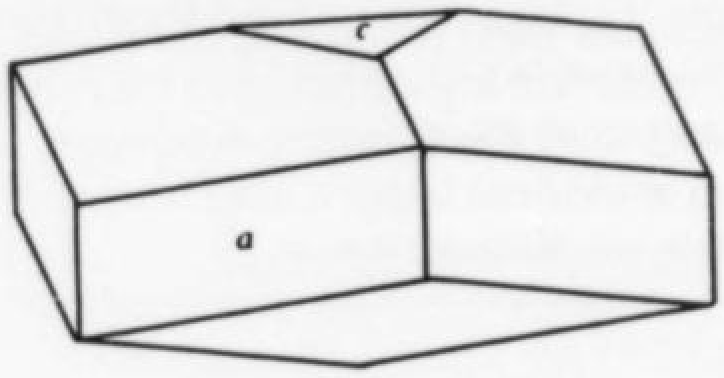


Figure 7. **Calcite (Gordon).**

Calcite $CaCO_3$

A gangue mineral, as cleavable masses up to several inches across veining the wall rock, colorless to black from manganese oxides included along cleavage planes.

Crystals also occur as a very late-stage mineral, alone or with the wulfenite-vanadinite-mimetite-descloizite assemblage. These are usually flat tabular, simple rhombohedral crystals, but occasionally form hexagonal prismatic crystals, investing wulfenite, but often in turn coated by vanadinite-mimetite or descloizite (2, 9, 13, 15, 17, 33, 40, 41).

Chlorite $(Mg,Fe)_{5-6}(Al,Si)_4O_{10}(OH)_8$

A gangue mineral, with barite, quartz, and feldspar, forming part of the matrix for the later primary sulfides. A result of hydrothermal alteration of mafic minerals in the host rocks about the veins.

Powdery to fibrous green masses, usually intimately associated with specular hematite, are to be found on many preserved specimens. Occasionally chlorite is found as inclusions in quartz crystals. Much of the gold for which the deposit was economically mined occurs as micron-sized flakes on chlorite (A. Cockle, pers. comm.). The chlorite sub-species involved have not been determined, but are rich in magnesium and iron. Viridite in part on older lists (15, 17, 27, 31, 33, 40, 41).

Epidote $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$

An alteration product of mafic minerals in the host rocks (S. Williams, pers. comm.). Tiny green needles occur in and on sericitized feldspars, and with chlorite (17, 33, 40, 41).

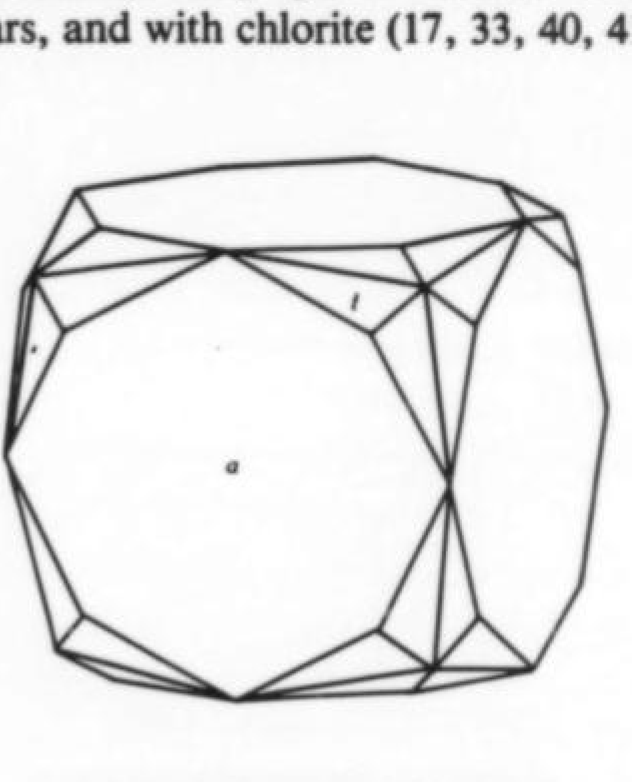


Figure 8. **Fluorite (Gordon).**

Fluorite CaF_2

A gangue mineral with the primary sulfides, and especially with barite. Some large translucent colorless cubic crystals, up to 12 mm, occur rarely in this association. Most crystals are a fraction of 1 mm in size. Colorless to amethystine druses of microscopic crystals often coat barite. Water clear cubic crystals occur along with clay minerals, and frequently on willemite, quartz, and dioptase crystals associated with wulfenite, mimetite and descloizite. They usually can be found including creaseyite fibers on the few specimens bearing that mineral.

Although usually transparent and colorless, and inconspicuous for this reason, delicate shades of purple sometimes are seen, perhaps zoned along faces, edges or corners. The crystals may be etched to opacity; and rarely may have later, smaller clear fluorite grown on them (15, 17, 21, 24, 26, 27, 29, 30, 31, 33, 38, 39, 40, 41).

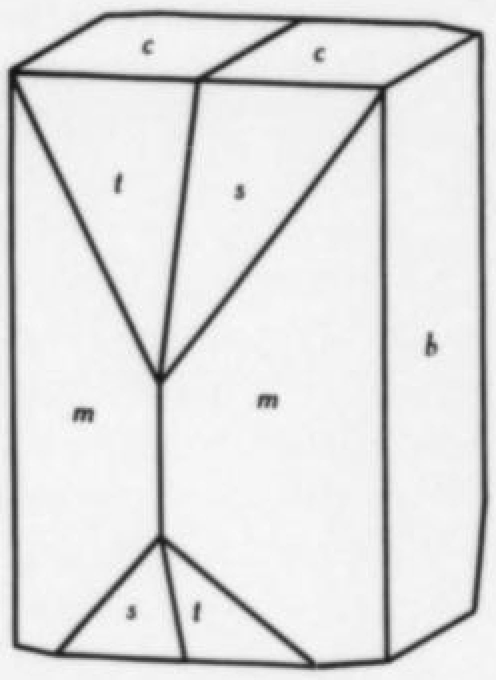


Figure 9. **Heulandite (Gordon).**

Heulandite $(Na,Ca)_{4-6}Al_6(Al,Si)_4Si_{26}O_{72}\cdot 24H_2O$

Two specimens showing microcrystals of translucent white heulandite were seen. On one, it occurs on equally tiny stilbite crystals on large wulfenite plates. On the other, lustrous crystals are strung on loops of gelatinous chrysocolla. The heulandite crystals observed are always twinned. Gordon observed heulandite in the early 1940's; a drawing is extant (41).

Magnetite $FeFe_2O_4$

A minor accessory mineral in the wall rocks, replaced by pyrite near the veins (17, 33, 40, 41).

Microcline $KAlSi_3O_8$

Pink feldspar phenocrysts in Oracle granodiorite and aplite were optically determined to be partially microcline by Peterson (17, 33).

Muscovite $KAl_2(Al_9Si_3)O_{10}(OH)_2$

Feldspars in the wall rock near the veins are entirely converted to sericite, a very fine grained hydrous form of muscovite (17, 27, 33).

Orthoclase $KAlSi_3O_8$

Orthoclase phenocrysts and secondary *adularia,* a variety, occur in the wall rocks (4, 17, 31, 33, 40, 41).

Palygorskite $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4H_2O$

A few specimens of the dull gray, matted, *mountain leather* variety have been preserved from their occurrence in fault gouge. Probably the material listed as actinolite *(mountain leather)* (40).

Plagioclase $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$

An essential component of the wall rocks, varying in composition from albite to andesine and oligioclase (4, 17, 33, 40, 41).

Quartz SiO_2

Some quartz was being deposited throughout all phases of mineralization in the veins, as well as being an important component of the host rocks. It can be found in association with every other species. Primary sulfides were deposited along with early coxcomb quartz encrusting brecciated fragments, and very late drusy quartz can be found encrusting wulfenite with clay, among the last minerals formed. The crystals in general are small, only a few mm in length, and often inconspicuous. Several generations of quartz are commonly found on a single specimen, sometimes in parallel overgrowths.

Early in the history of mineralization, galena was replaced along cleavages by multitudes of distinctive doubly-terminated quartz crystals, usually only a mm or two long. These crystals characteristically enclose microscopic blebs of brilliant galena, giving them a gray cast in mass. Loosely attached to one another, with the continuing removal of galena during oxidation they ultimately formed fragile and very light masses which retain the cubic pattern of the galena, with some parts of the boxwork perhaps entirely filled in to give the appearance almost of a pseudocubic crystal.

These quartz casts of galena crystals form a part of the matrix for many of the rarer minerals. Leadhillite, caledonite, and diaboleite especially can hardly be found without their crystallization having been interfered with by some of these quartz crystals, dislodged from their place in the relict boxworks.

Some crystals show phantoms and inclusions of other minerals. Shining plates of microscopic hematite are very common, giving the quartz crystals a blood-red color. Malachite, dioptase, mimetite and wulfenite crystals and spherules of clay may be entirely suspended in quartz crystals. Gold in quartz was of economic importance but apparently was only rarely visible.

Much of the quartz forms fine-grained masses which have encrusted and enclosed earlier minerals, now gone. Many of these molds are suggestive of scalenohedral calcite crystals. A few free-standing epimorphs of drusy quartz, now completely hollow, were found which had covered cerussite sixlings or hemimorphite crystals.

Much of the quartz is amethystine, or colored pale yellow to green. Thin crusts of chalcedony sometimes cover wulfenite crystals (1, 2, 8, 10, 13, 15, 17, 20, 25, 26, 27, 29, 33, 37, 38, 40, 41).

Serpentine a group of minerals $(Mg,Fe)_3Si_2O_5(OH)_4$

Noted as an alteration product of olivine (17, 33, 40).

Stilbite $NaCa_2(Al_5Si_{13})O_{36}\cdot 14H_2O$

Minute white bow-ties of stilbite, rarely associated with another zeolite, heulandite, can be found on some wulfenite specimens (41).

Tourmaline a group of minerals $(Na,Ca)(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH,F)_4$

Minute brownish crystals with the typical rounded triangular cross-section were X-rayed and proved to be a member of this group. Observed on only one specimen, they were coated with brochantite needles (41).

Table 2. **Sulfides**

		Ag	Pb	Cu	Fe	Zn	Others
PRIMARY	Galena	(X)	X				
	Chalcopyrite			X	X		
	Tetrahedrite			X	X		Sb
	Pyrite				X		
	Sphalerite					X	
SECONDARY	Acanthite	X					
	Djurleite			X			
	Chalcocite			X			
	Covellite			X			
	Bornite			X	X		

SULFIDE MINERALS

The primary sulfides were deposited along with gangue minerals in the veins. Galena and sphalerite are about equally abundant, with lesser amounts of pyrite. Chalcopyrite is a minor mineral, and tetrahedrite is present only in traces.

Oxidation of these primary minerals provided the metals for formation of the wide variety of secondary species obtained during mining of the upper portions of the veins. Attack by ferric sulfate, produced from decomposition of the pyrite by weakly acidic groundwater, initiated the dissolution of the other sulfides. Lead was released by galena, along with much smaller amounts of included silver. Chalcopyrite provided copper, and sphalerite the zinc. Some Fe was set free from pyrite and chalcopyrite, but continuing oxidation of rock-forming mafic minerals and hydrothermal chlorite provided substantial amounts of this element as well.

As an intermediate step, secondary copper and iron sulfides were formed in small amounts, as replacements principally of galena.

PRIMARY SULFIDES

Chalcopyrite $CuFeS_2$

Chalcopyrite, the primary source of copper in the Mammoth mine ores, occurs in minor amounts with galena, as inclusions exsolved from sphalerite, and intergrown with pyrite. Tiny sphenoidal crystals seem uncommon in the few primary ore specimens preserved in collections (17, 27, 33, 35, 40, 41).

Galena PbS

Galena is the important primary lead mineral in the Mammoth mine ores, the alteration of which provided the colorful suite of secondary minerals. Little unoxidized material has been preserved in collections, but descriptions of the ores dating from when the mine was in operation indicate that galena was approximately equal in abundance to sphalerite, with pyrite and minor chalcopyrite deposited later. Some galena-rich ore carried as much as 25 ounces of silver and 0.375 ounces of gold per ton. Gangue minerals were barite, fluorite, chlorite, specular hematite, adularia and quartz. Distinct galena crystals were quite rare at the time of mining.

Galena is also preserved in oxidized nodules, when the alteration process starts with replacement of galena by quartz (which includes galena) and djurleite or chalcocite along cleavage planes. All of these minerals may preserve a relic boxwork structure after the galena has been entirely replaced. These nodules are commonly rimmed first by anglesite, then cerussite, both massive in the shells, but crystals of either may form later on the exterior. Oxidized copper minerals, such as linarite and brochantite, may occur in thin shells between galena and anglesite, or in the anglesite; malachite, azurite, and chrysocolla often encrust the cerussite shell. The course of these reactions can be quite complex; relict galena boxworks have been seen in which every cell had varying combinations of minerals (4, 8, 15, 17, 21, 24, 25, 26, 27, 31, 33, 35, 39, 40, 41).

Pyrite FeS_2

A constituent of the primary sulfide ores, pyrite occurs in lesser amounts than galena and sphalerite. Crystals are rare, and of simple cubic habit (4, 17, 27, 33, 35, 40, 41).

Sphalerite ZnS

Massive to radially crystalline, light yellow to brown and black, with crystals very rare. Minute tetrahedra of sphalerite, often as spinel-law twins, could be found in the primary ore. Sphalerite was the most abundant sulfide mineral, and its alteration provided zinc for later smithsonite, hemimorphite, and willemite. It was earlier than the usually intimately occurring galena, and contained exsolved chalcopyrite, which altered to films of covellite. Pyrite, barite, quartz, fluorite, hematite and chlorite were associated in the sphalerite-bearing gangue (15, 17, 21, 24, 27, 31, 33, 35, 40, 41).

Tetrahedrite $(Cu,Fe)_{12}Sb_4S_{13}$

Sharp tetrahedral crystals, modified with small faces of the negative tetrahedron, and less than 1 mm in size, occur on one specimen collected from the dump. Their matrix is pyrite in about the same crystal size.

SECONDARY SULFIDES

Acanthite Ag_2S

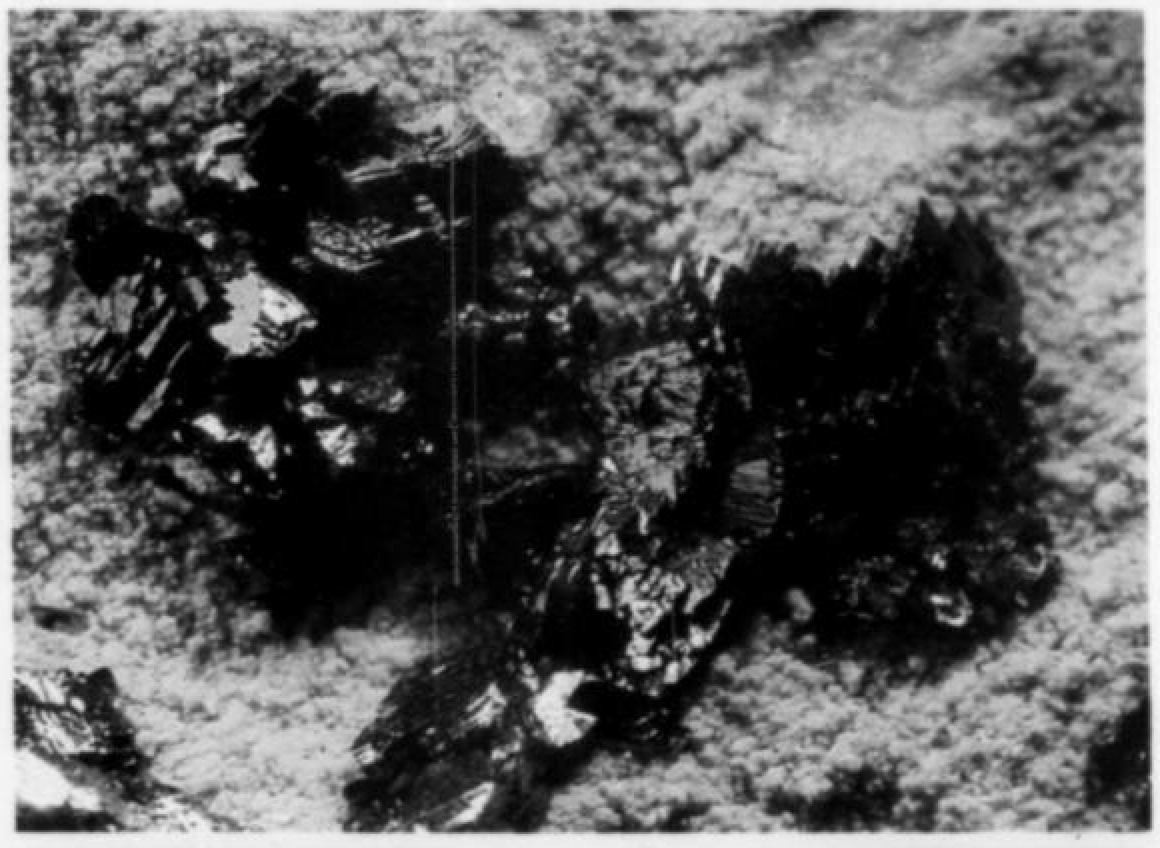
Druses of minute black acanthite crystals partially encrust silver wires and crystals imbedded in leadhillite cleavages. On several similar specimens the acanthite also occurs on and in the leadhillite, to which it imparts a characteristic blackish color. The leadhillite is usually replaced by minor caledonite and brochantite.

Although the acanthite crystals are too small for measurement,

Figure 10. **Caledonite crystals to 4 mm, Arizona-Sonora Desert Museum collection.**

Figure 11. **Malachite pseudomorphs after an azurite crystal (2.4 cm tall) on reticulated cerussite. Jelks collection, Arizona-Sonora Desert Museum.**

Figure 12. **Fornacite group 10 mm across, University of Arizona collection.**



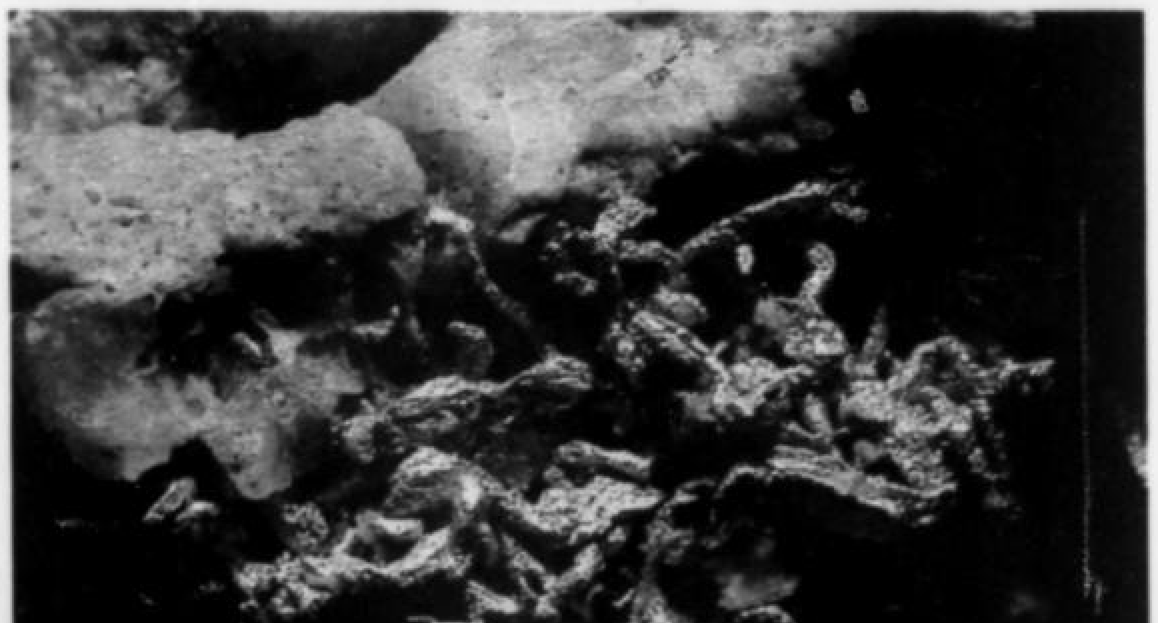


Figure 13. **Gold, 1.5 cm across, Arizona-Sonora Desert Museum collection.**

Figure 14. **Wulfenite, 15 cm across, Arizona-Sonora Desert Museum collection. Photo by William Panczner.**

Figure 15. **Spherical aggregate of dioptase crystals 6 mm across, Jelks collection, Arizona-Sonora Desert Museum.**

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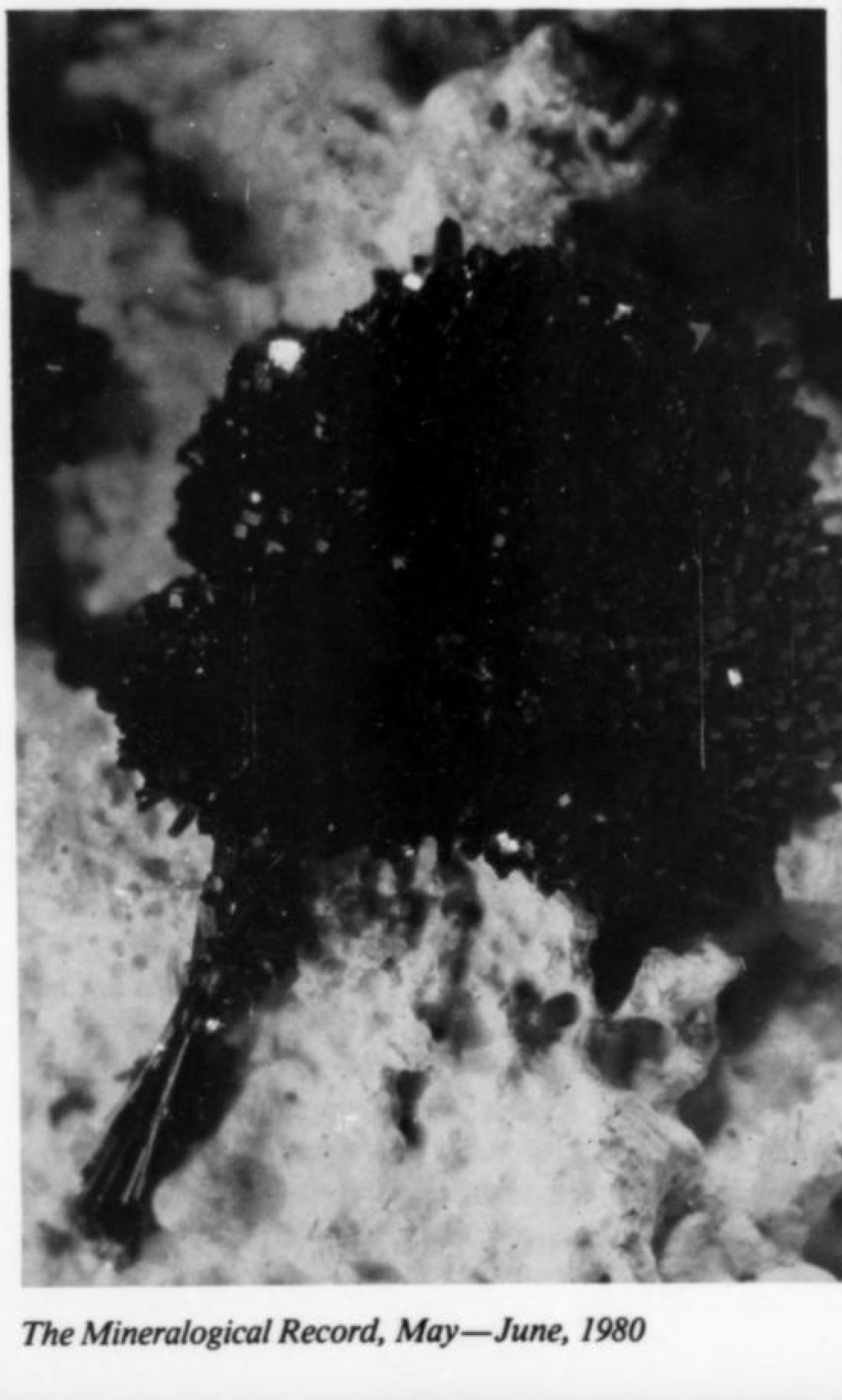

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Figure 16. **Pale bideauxite crystals to 4 mm with blue boleite, Arizona-Sonora Desert Museum collection.**

Figure 17. **Diaboleite crystal pocket 3 cm across, University of Arizona collection.**

WEW

they have bristling and sharply-angled terminations. This indicates crystallization as primary monoclinic acanthite at a temperature below 176° C, rather than inversion from isometric agentite deposited at a higher temperature (41).

Bornite Cu_5FeS_4

Intermixed in small amount with other copper-bearing sulfides replacing galena (17, 33, 40, 41).

Chalcocite Cu_2S

Chalcocite occurs as an alteration product, in thin films, of galena and chalcopyrite. While most suspected chalcocite specimens examined in this study proved to be djurleite, nevertheless its occurrence was confirmed on several pieces (17, 25, 26, 33, 40, 41).

Covellite CuS

At one stage in the oxidation of primary sulfides, galena is partially replaced by sooty djurleite, which is in turn altered to covellite as irridescent films and tiny but distinct metallic purple to red hexagonal crystals. The covellite crystals may be included in anglesite and matlockite crystals, giving them a red color in transmitted light. Pure masses intermixed with pyrite, and veining wall rock, were rarely preserved (17, 21, 24, 27, 31, 33, 37, 40, 41).

Djurleite $Cu_{1.96}S$

Djurleite formed as replacements of galena, sometimes as steel-gray metallic massive nodules rimmed by secondary lead minerals, but more often as fragile shells and crusts of powdery and sooty texture. The crusts usually show relict structure of the replaced galena, and are associated with quartz crystals also replacing galena. The djurleite occurs intermixed in places with bornite and covellite. These alterations are an important step in providing the copper from primary chalcopyrite and lead from primary galena to the formation of the later, more highly oxidized minerals. Most minerals examined during this study which were suspected of being chalcocite proved to be djurleite which is stable only below 93°C (41).

OXIDIZED MINERALS

NORMAL SEQUENCE

The normal alteration sequence for galena, as seen in many deposits other than the Mammoth mine, is first to the lead sulfate, anglesite, then to cerussite, the lead carbonate. In the processes, lead is made available for the formation of the relatively more insoluble molybdates, arsenates, etc., if these anions are present. The copper-bearing sulfates, linarite and brochantite, seem to persist most often along with diaboleite, leadhillite and the other minerals here categorized as anomalous, so they are placed with that group, but the extent of these sulfates in the mine was much wider, up to about 100 meters above the diaboleite occurrences. Copper forms carbonates which have persisted, but much of this element ended up in chrysocolla and some dioptase. Zinc has a geochemical behavior similar to copper; sulfates do not exist in the mine, and either its carbonate, smithsonite, or the silicates, hemimorphite and willemite are the stable forms. Iron was quickly fixed as oxides under a wide range of conditions.

Looking at the other elements in Table 3, only small amounts of manganese are present; but the existence of huge quantities of especially wulfenite, vanadinite and mimetite required introduction of molybdenum, vanadium, and arsenic. Molybdenum at least was probably introduced as a chemical species in solution in groundwater until it encountered lead in solution. It was then fixed as wulfenite, principally in the upper portions of the veins. Wulfenite was found in the deepest level to which the mine was worked, but even these tongues had connection with the surface. The nearby San Manuel copper porphyry deposit is a major producer of molybdenum from molybdenite, MoS_2. The upper oxidized portions of that deposit are relatively depleted in molybdenum (L. Thomas, pers. comm.). Vanadium, arsenic, chromium, etc., may have been leached from the surrounding rocks of dioritic composition. All of the above reactions took place in an aqueous environment; many of the minerals listed contain water in their structure. The somewhat elevated temperatures indicated could have been generated by oxidation within the veins themselves, without necessarily invoking an external source of heat.

Table 3. **Oxidized minerals, normal sequence.**

		Ag	Pb	Cu	Fe	Zn	Others
ELEMENTS	Gold						Au
	Silver	X					
	Sulfur						S
OXIDES	Minium		X				
	Murdochite		X	X			
	Cuprite			X			
	Tenorite			X			
	Goethite				X		
	Hematite				X		
	Ramsdellite						Mn
	Hollandite						Mn, Ba
SULFATES	Anglesite		X				
	Devilline			X			Ca
CARBONATES	Cerussite		X				
	Azurite			X			
	Malachite			X			
	Aurichalcite			X		X	
	Rosasite			X		X	
	Smithsonite					X	
MOLYBDATE	Wulfenite		X				MoO_4
ARSENATE, PHOSPHATE, VANADATE	Mimetite		X				AsO_4, Cl
	Pyromorphite		X				PO_4, Cl
	Vanadinite		X				VO_4, Cl
	Fornacite		X	X			AsO_4, CrO_4
	Tsumebite		X	X			PO_4, SO_4
	Mixite			X			AsO_4, Bi
	Descloizite		X	X		X	VO_4
	Mottramite		X	X		X	VO_4
SILICATES	Chrysocolla			X			Al
	Dioptase			X			
	Plancheite			X			
	Hisingerite				X		
	Creaseyite		X	X	X		Al
	Hemimorphite					X	
	Willemite					X	
	Macquartite		X	X			CrO_4

Anglesite $PbSO_4$

Anglesite occurs frequently but is somewhat rarer than cerussite, with which it is often associated. Other common associates are the sulfate-containing minerals leadhillite, linarite, brochantite, and caledonite; more rarely matlockite, phosgenite, boleite, diaboleite and atacamite.

Anglesite is usually the first alteration product of galena, and is in turn altered to cerussite in the classical sequence. It can either rim the galena or form boxworks within it, sometimes as complete replacements of porcelaneous texture and white to gray color.

Anglesite is notable for a wide diversity of crystal habits, but, in contrast to cerussite, never forms twinned crystals. A commonly occurring, very late type is as powdery to sugary crystalline masses investing crystals of other species. These shining masses are of sparkling white color, or occasionally delicately tinged pink from included iron oxide. Rhombic crystals with the outline of anglesite but with a sugary texture, formed by recrystallization or corrosion, can be seen. These crystals may assume a pseudo-hexagonal

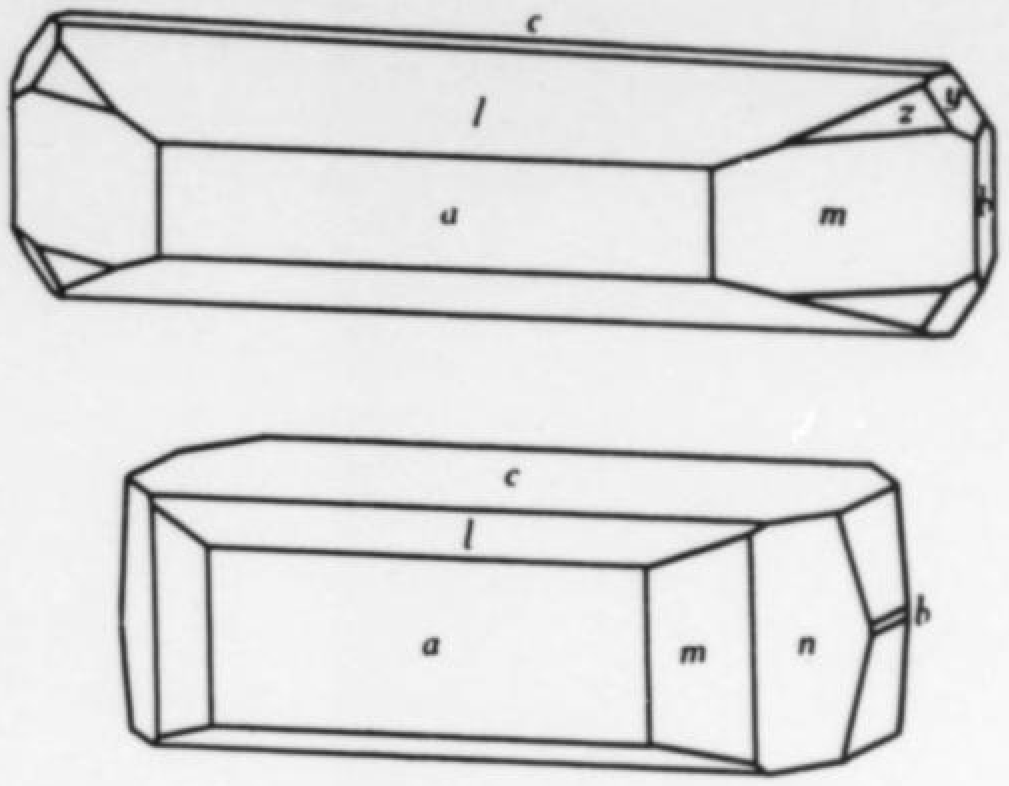


Figure 18. **Anglesite (Gordon).**

outline, and then are sometimes distinguished from leadhillite only with difficulty.

The better-formed crystals are usually of small size, 1 to 2 mm, and can be recognized by their diamond-shaped outlines, or chisel-shaped to Roman-sword-shaped terminations. These crystals are usually glassy-clear and striated parallel to the axis of elongation, and can be as long as 6 mm.

Crystals of covellite are found as inclusions, and linarite and brochantite may replace the anglesite without destruction of the crystal form. Anglesite commonly alters from crystalline matlockite masses, which it rims, and it is a component in pseudomorphs after linarite and caledonite crystals (4, 8, 15, 17, 21, 22, 24, 25, 26, 27, 31, 33, 37, 40, 41).

Aurichalcite $(Zn,Cu)_5(CO_3)_2(OH)_6$

Only two specimens were noted showing this mineral. On one piece, the aurichalcite occurs as sprays of tiny, pale blue crystals on a matrix of corroded calcite cleavages. On the other, aurichalcite is in fibrous radiating balls perched on glassy tabular willemite crystals, with later wulfenite and descloizite (41).

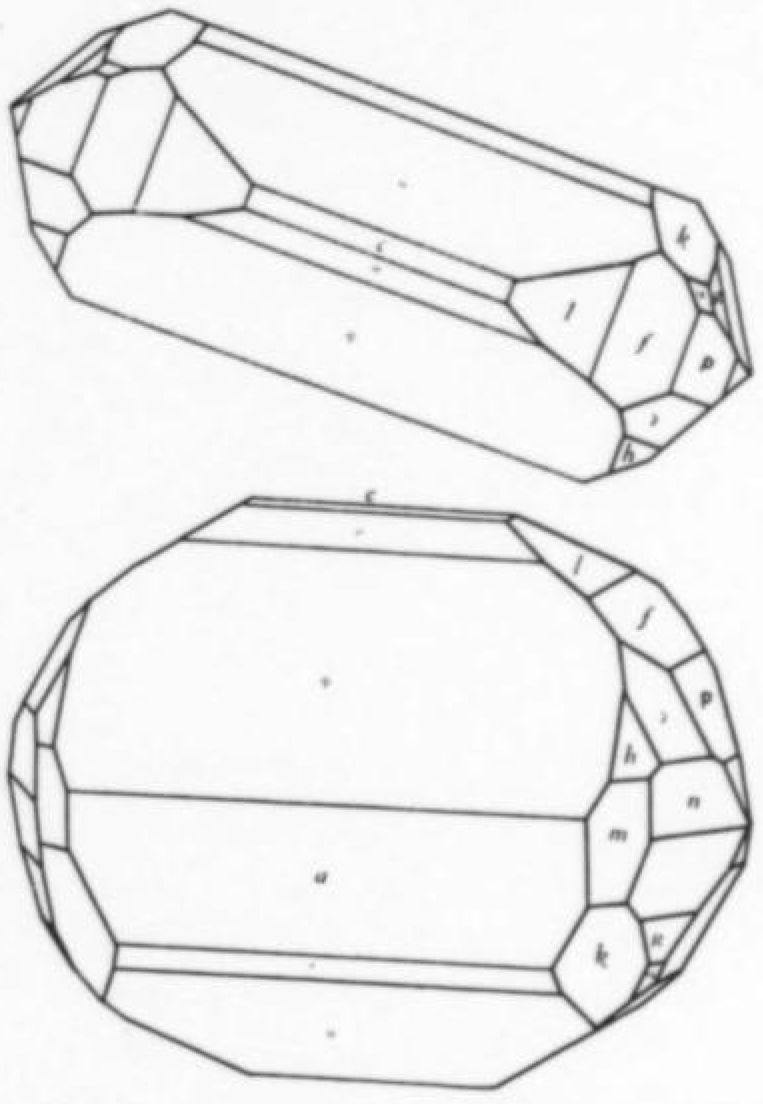


Figure 19. **Azurite (Gordon).**

Azurite $Cu_3(CO_3)_2(OH)_2$

Azurite forms some of the larger crystals of any of the Mammoth mine species, up to 4 cm, with malachite pseudomorphs afte azurite to over 8 cm. Mammoth mine azurite at its best is comparable to azurite from any locality. Prisms of a deep blue-black color associated with cerussite twins are characteristic, as are stouter crystals altered in part or in whole to fibrous malachite. Both types usually also enclose the doubly terminated quartz crystals so common on Mammoth mine specimens. Very rarely azurite crystals are associated on the same specimen with linarite or diaboleite, then also usually with anglesite.

While the cerussite twins are most often on azurite crystals, a few specimens were noted where the azurite was later than cerussite, perched in interstices or on the tips of cerussite in reticulated masses of crystals. The pseudomorphs of malachite after azurite may have a thin veneer of later azurite grown in parallel position to the earlier azurite crystal (4, 14, 15, 26, 27, 33, 34).

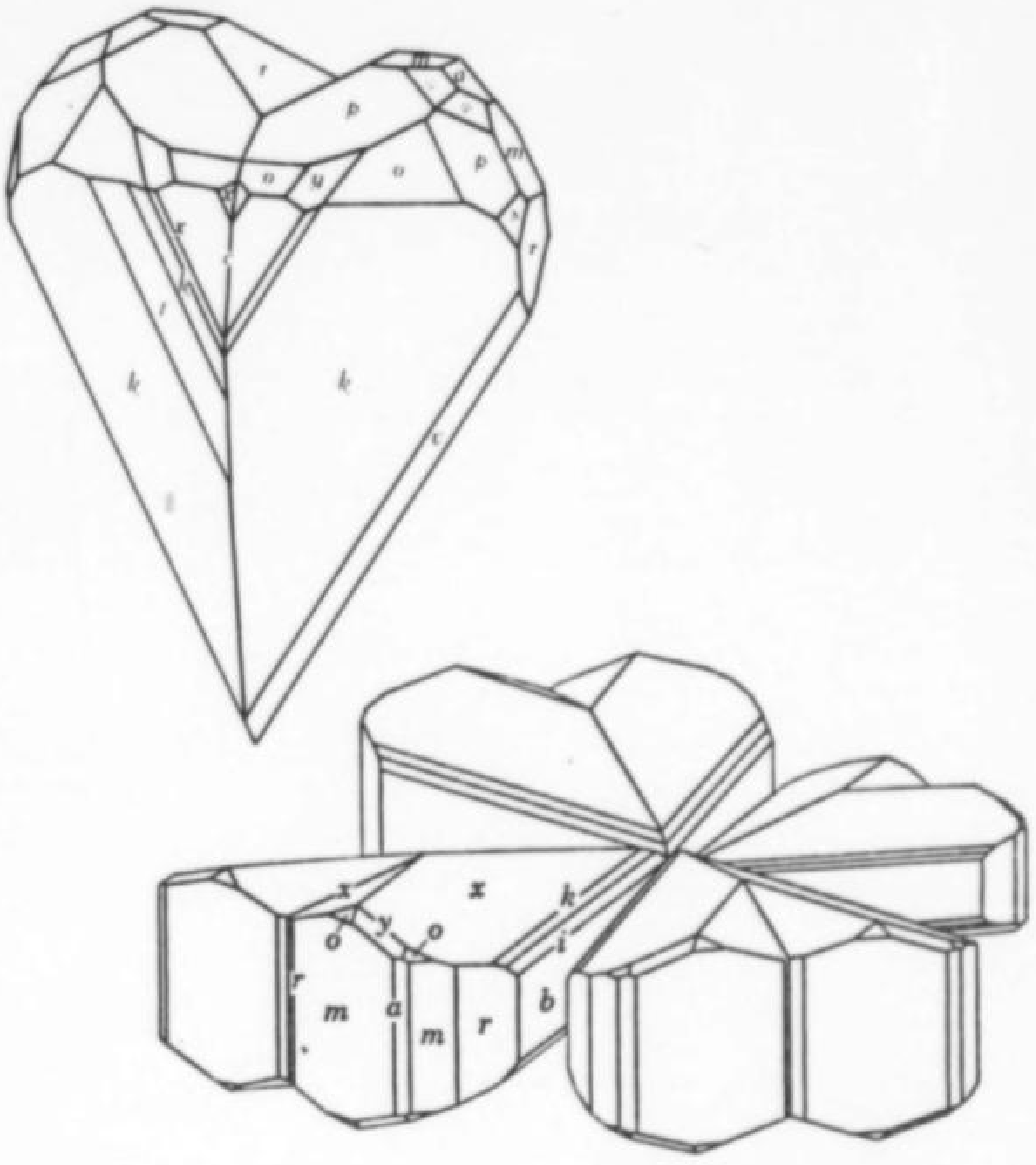


Figure 20. (top) **Cerussite (Gordon);** *bottom* **Cerussite (28).**

Cerussite $PbCO_3$

An alteration product of galena, with massive material rimming anglesite in banded nodules. Later cerussite occurs as fine crystal groups, almost always twinned as pairs of individuals, trillings, sixlings, or finely reticulated masses. Only rarely do single prismatic crystals occur.

These later twinned crystals are among the finest U.S. examples of the mineral, and as they can be found on almost every specimen preserved from the Mammoth mine they can assist in determining the correct locality for many specimens. Some twins have been found weighing more than a kilogram with larger reticulated masses of several times this weight.

While some of the crystals are gem-clear, usually they are milky and can even be chatoyant. These effects are caused by fluid inclusions in long hollow tubes and negative crystals which can make up to 5% of the volume of some crystals. The bubble-filling temperature was determined to be about 50 degrees C (B. Austria, pers. comm.).

The crystals are usually colorless to white, but some crystals are tinted a pale yellowish-green to chartreuse, with the color often arranged in thin parallel bands. These colors are thought to be due to small amounts of chromium; rarely fornacite will be found on crystals of this type.

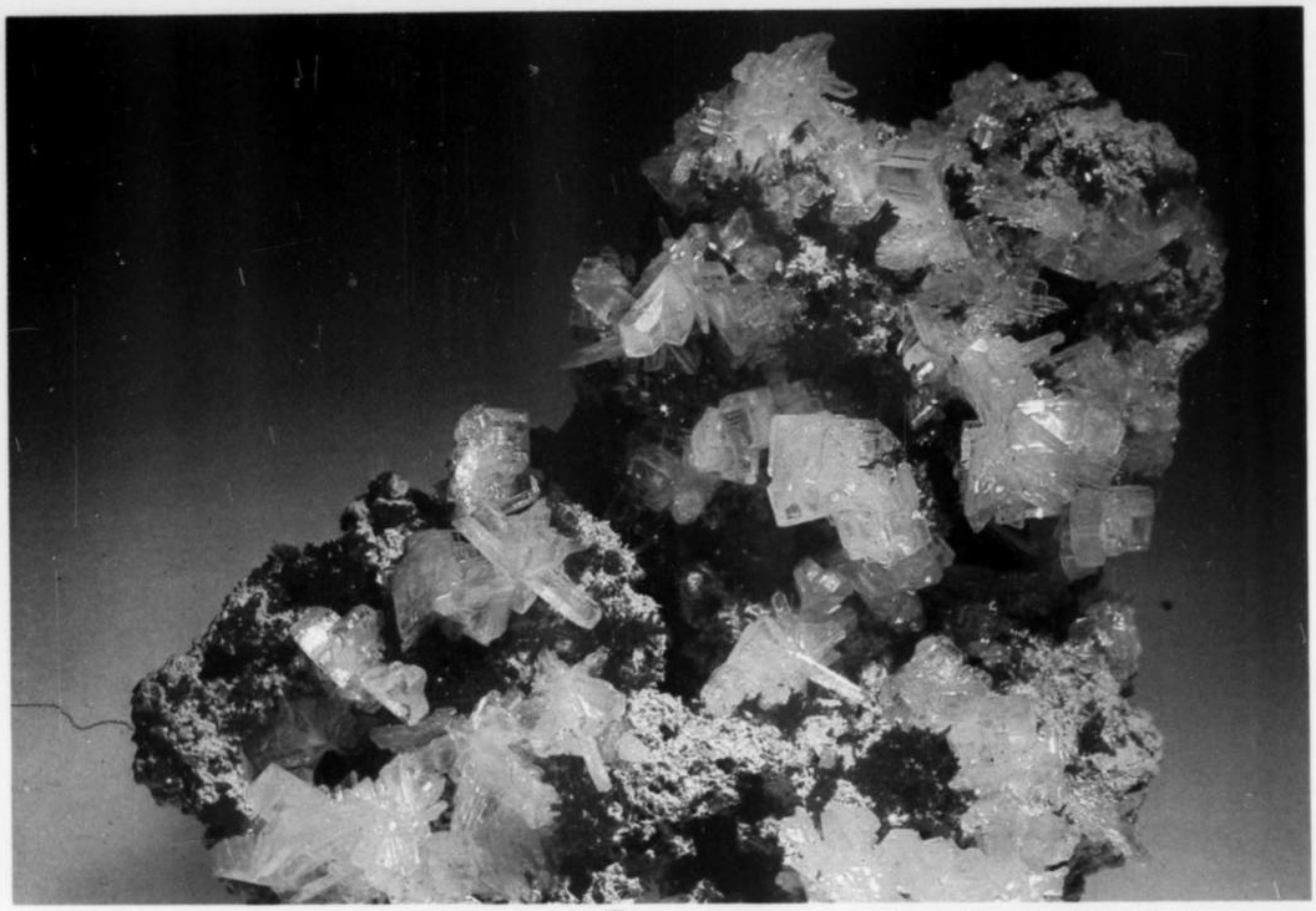


Figure 21. **Cerussite with dioptase and wulfenite on matrix 4.5 cm across, Jelks collection, Arizona-Sonora Desert Museum.**

Figure 22. (left) **Azurite crystal, 5.4 cm across, Curt Van Scriver collection.**

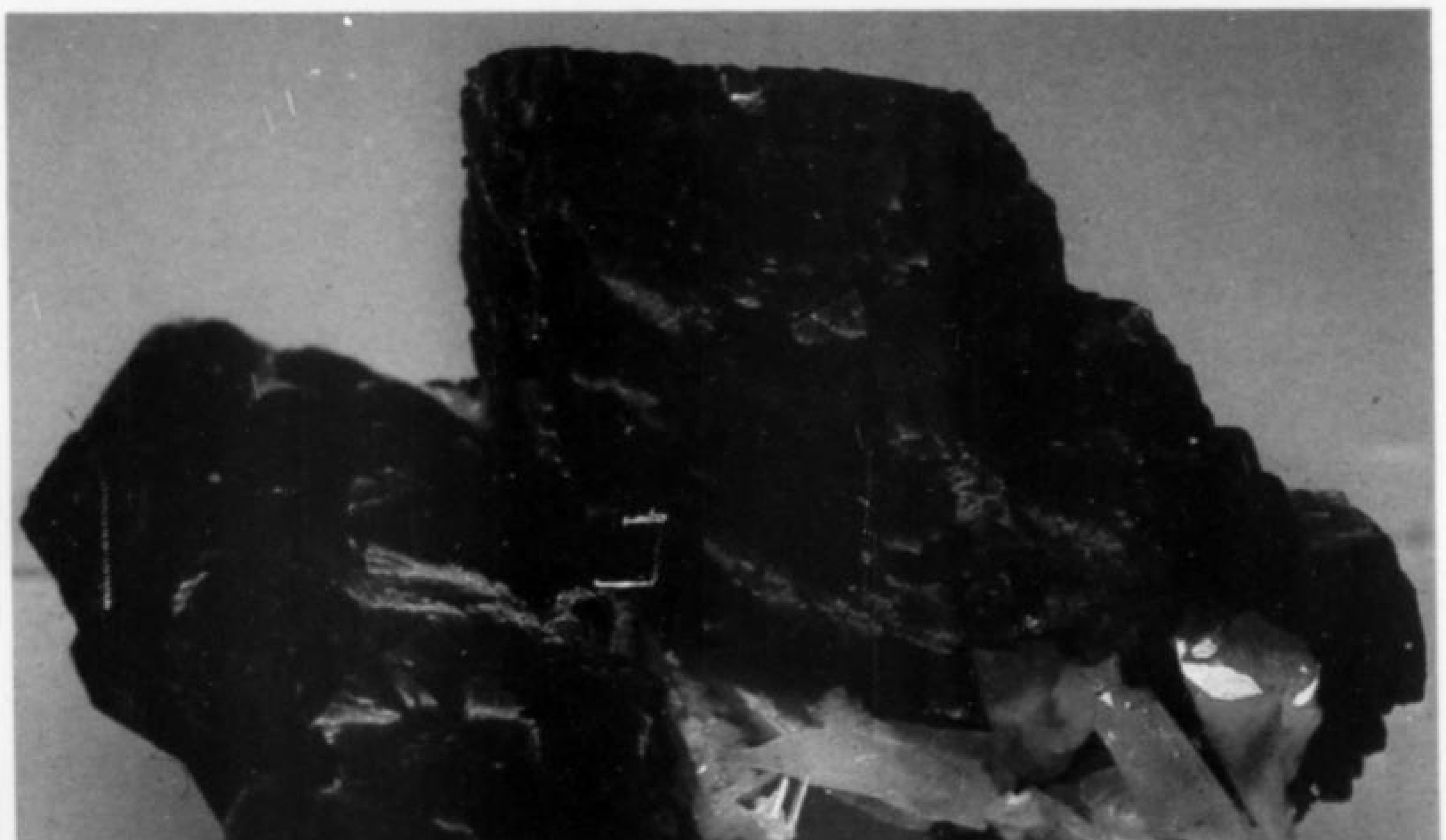


Figure 24. **Malachite pseudomorph after azurite crystals, 5.8 cm across, Curt Van Scriver collection.**

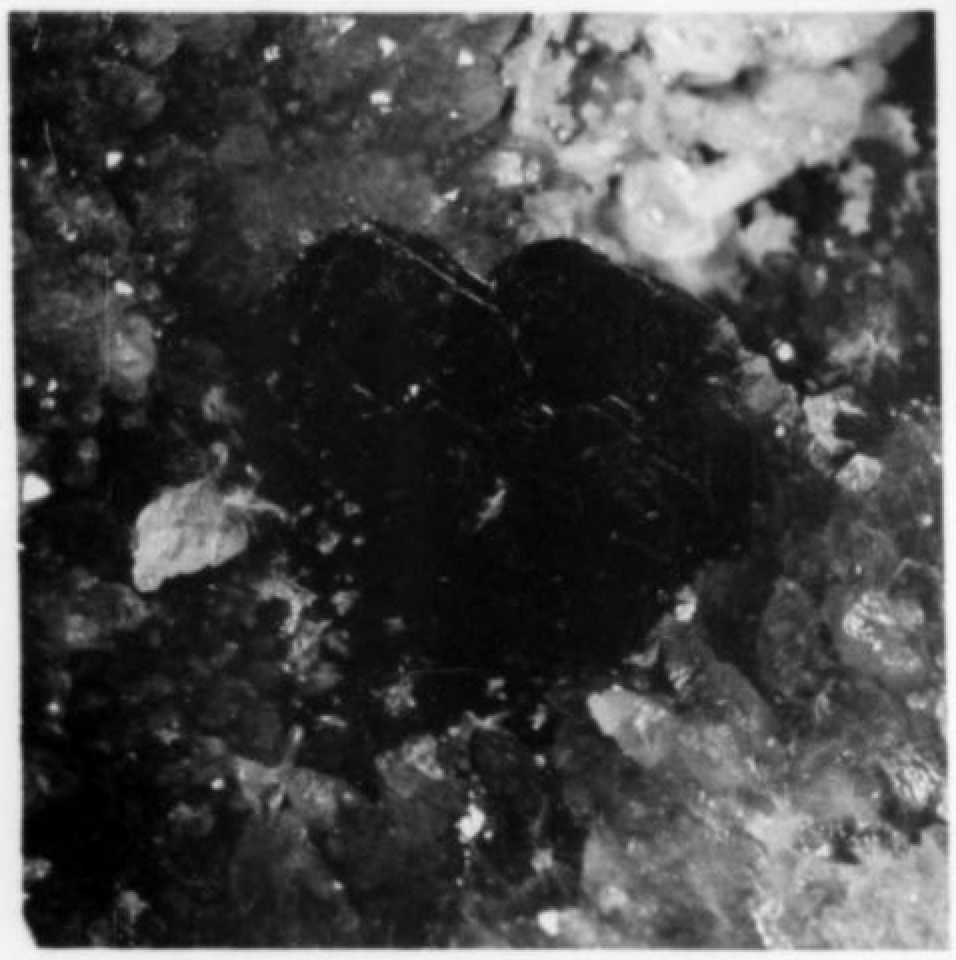


Figure 23. **Linarite crystal 2.3 cm across, on amethyst, Arizona-Sonora Desert Museum collection. Photo by Bob Jones.**

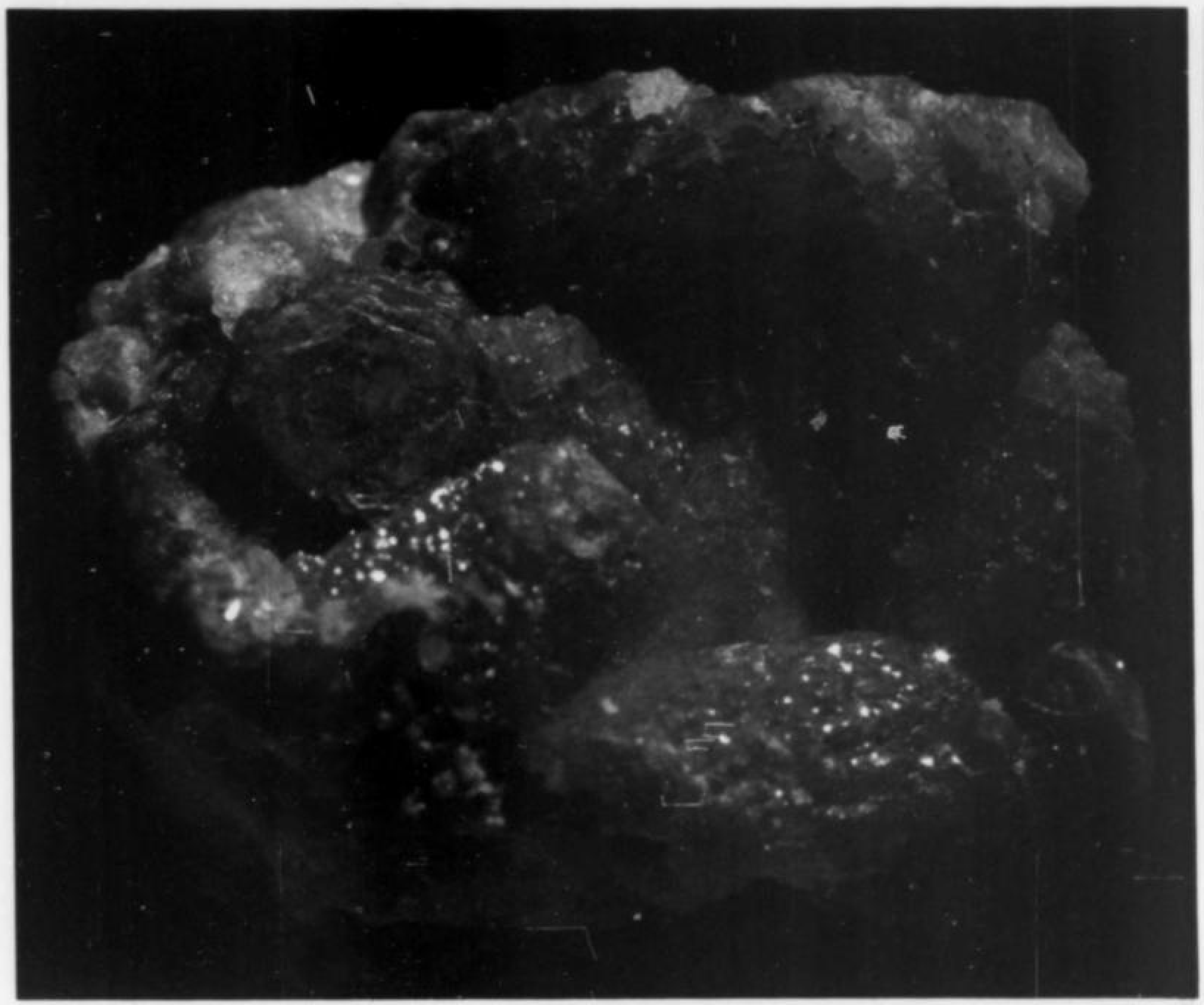


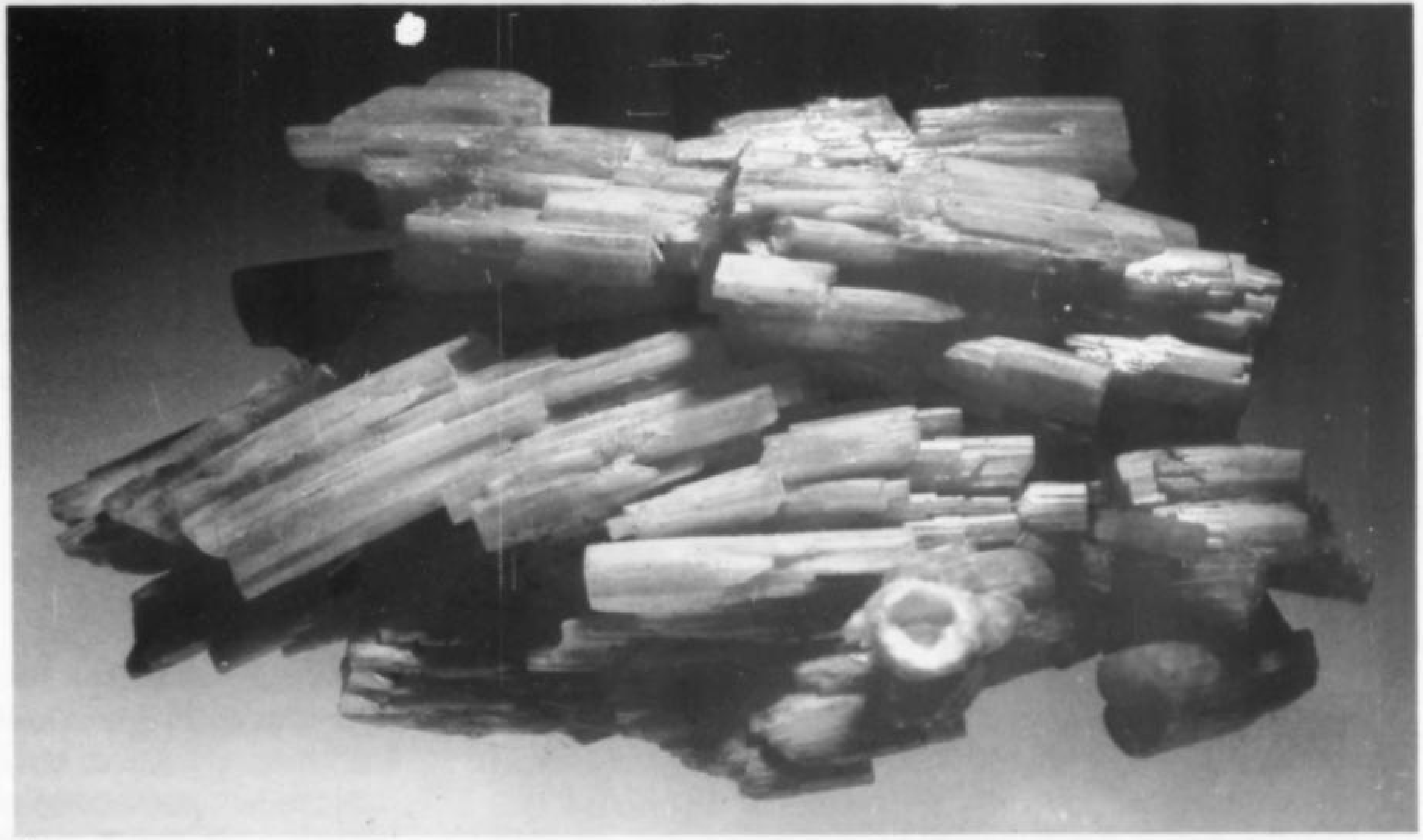
Figure 26. (above) **Wulfenite showing crystal form change from first to second order, 1.6 cm across, Smithsonian Institution collection.**

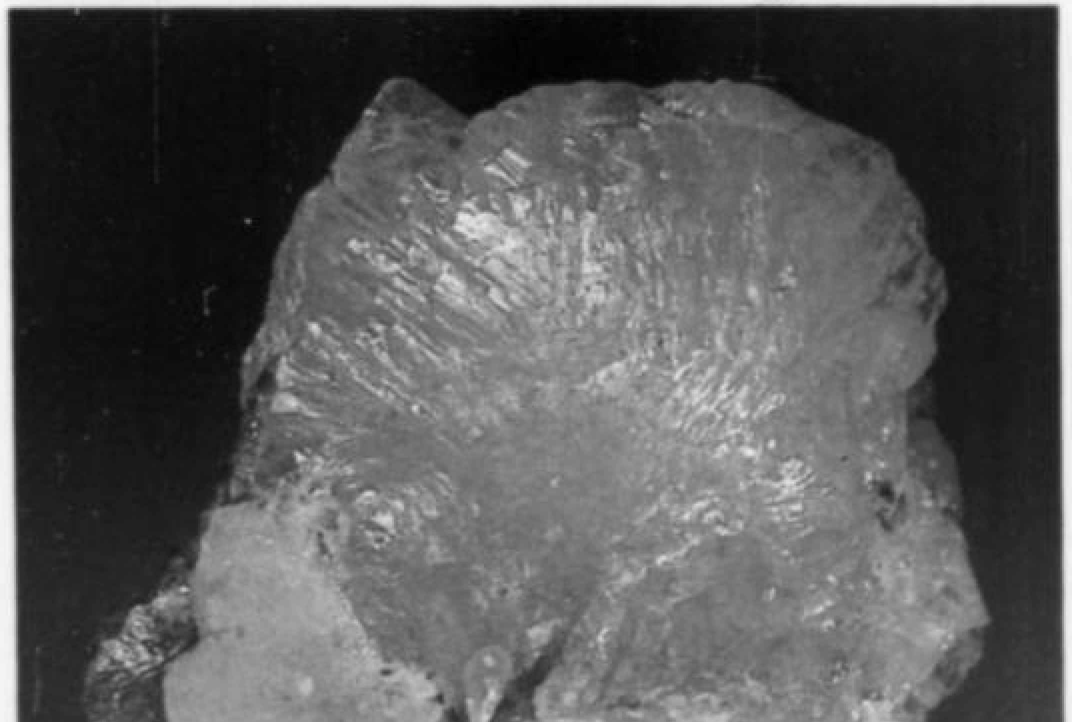
Figure 25. (above) **Leadhillite, 2.3 cm across, Jelks collection, Arizona-Sonora Desert Museum.**

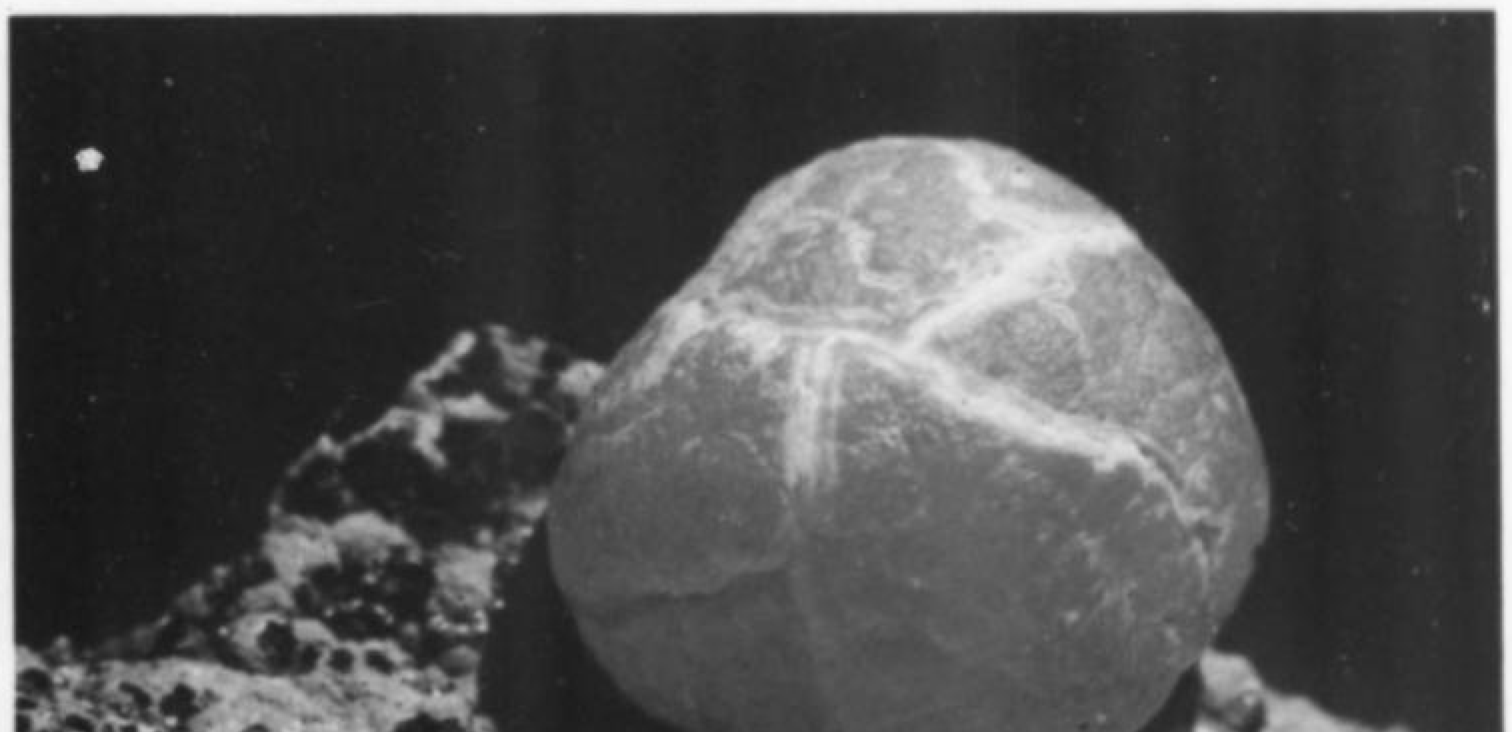
Figure 27. (right) **Vanadinite crystals in sub-parallel group 3.2 cm across, Jelks collection, Arizona-Sonora Desert Museum.**

Figure 28. (lower right) **Smithsonite ball 1.9 cm across on matrix; Jelks collection, Arizona-Sonora Desert Museum collection.**

Figure 29. (below) **Matlockite, one of the largest crystals known, 3.5 cm across; Arizona-Sonora Desert Museum collection.**







Cerussite is especially associated with azurite, and some remarkable reticulated specimens are coated with later silvery-lustered malachite. It forms at the expense of diaboleite crystals, but is in turn itself corroded on these pieces. Leadhillite prisms will alter to somewhat oriented, reticulated aggregates of cerussite which sometimes preserve the leadhillite form quite well. Cerussite twins can be entirely replaced by linarite, in turn partially altered to brochantite. Anglesite crystals are usually associated with these latter two occurrences. In one case the anglesite was as hollow epimorphic overgrowths formerly on cerussite. Two generations of cerussite crystals may be found on the same specimen, sometimes in parallel growth.

Wulfenite specimens will often have later cerussite crystals as overgrowths but on some pieces the wulfenite is on cerussite. Late clay minerals form a matrix for cerussite. One specimen was observed in which clay had entirely replaced a loose cyclic cerussite twin, with only the form of the cerussite preserving the transformation. Another clay specimen has an entirely hollow cast in the shape of a similar cyclic cerussite twin (3, 4, 7, 8, 9, 10, 12, 14, 15, 17, 20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 34, 37, 38, 39, 40, 41).

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$

Noted in the alteration rinds about galena, usually but not always outside the anglesite and cerussite shells. Often there is a black layer with the chrysocolla, commonly misidentified as tenorite. This is more likely to be manganiferous chrysocolla. Relic boxworks after galena are sometimes composed entirely of chrysocolla which then exhibits a pseudo-cubic cleavage.

Highly variable in color, from a translucent, almost gemmy sky-blue, to powdery and nearly white, when it grades insensibly into other clay minerals. It is usually massive in texture, but may form ball-like aggregates. Malachite and rarely plancheite may be intermixed.

Chrysocolla often forms the matrix for later lead and copper minerals. Wulfenite crystals may be imbedded in chrysocolla or formed on the surface, along with cerussite and dioptase. Rarely wulfenite is found entirely replaced by chrysocolla. The chrysocolla may form a hollow shell, formerly around a nodule of galena and its alteration products, now incrusted on the interior and exterior with these later minerals. One interesting specimen shows drusy quartz as epimorphs after cerussite twins, their interiors now partially filled with chrysocolla (17, 19, 21, 22, 24, 25, 27, 31, 33, 40, 41).

Creaseyite $Cu_2Pb_2(Fe,Al)_2Si_5O_{17} \cdot 6H_2O$

Occurs as pale yellowish green fibers, almost always associated with wulfenite, either randomly intergrown or aggregated into spherules less than 1 mm diameter. It is younger than associated wulfenite, cerussite and dioptase. Fluorite, willemite, descloizite and murdochite have been seen on creaseyite fibers. Only a few specimens have been preserved although the mineral was probably relatively common in the upper workings at one time. The Mammoth mine is the type locality. About 1 gram of the mineral is on known specimens in collections. This mineral was noted as beudantite on some other lists (39, 40, 41).

Cuprite Cu_2O

The mineral may have been of substantial occurrence in the Mammoth mine ores to judge from the several nearly pure masses preserved. Otherwise it is of very rare occurrence as crystals, sometimes of the chalcotrichite variety, in chrysocolla, or on specimens with other of the oxidized lead and copper minerals (40, 41).

Descloizite $Pb(Zn,Cu)(VO_4)(OH)$

Usually associated with wulfenite, descloizite is often the last mineral to form on many specimens. Sometimes vanadinite and mimetite will be found on crusts of descloizite, but pseudomorphs of descloizite replacing those minerals have been noted. Fluorite, dioptase, willemite and quartz are also frequently on specimens bearing descloizite, which has a maximum crystal size of only 1 or 2 mm.

Crystals of this species are usually rhombic, nearly square in outline, but it can assume a steeper and more pointed habit. Descloizite forms a complete series with mottramite, $Pb(Cu,Zn)(VO_4)(OH)$, and therefore shows a considerable range of color. Variously described as orangish brown, reddish brown, yellow and dark brown, the relatively zinc-rich descloizite crystals can also show color zoning in these shades. Rare intermediate members (the variety cuprodescloizite in part) can assume a green coloration. Mottramite is coal-black. These species might be confused with wulfenite or possibly fornacite without careful observation. This is the dechenite of Rickard (1, 2, 3, 4, 5, 8, 9, 10, 14, 15, 16, 17, 19, 21, 24, 26, 27, 28, 31, 33, 39, 40, 41).

Devilline $CaCu_4(SO_4)_2(OH)_6 \cdot 3H_2O$

Sparse, scaly blue crusts of this mineral occur on partially decomposed primary sulfides, galena, sphalerite and pyrite, with their gangue minerals barite and chlorite. A little fluorite, covellite and brochantite also occur on one of the two known specimens. The other specimen is in association with caledonite. (X-ray identification by S. Williams, pers. comm.) (41).

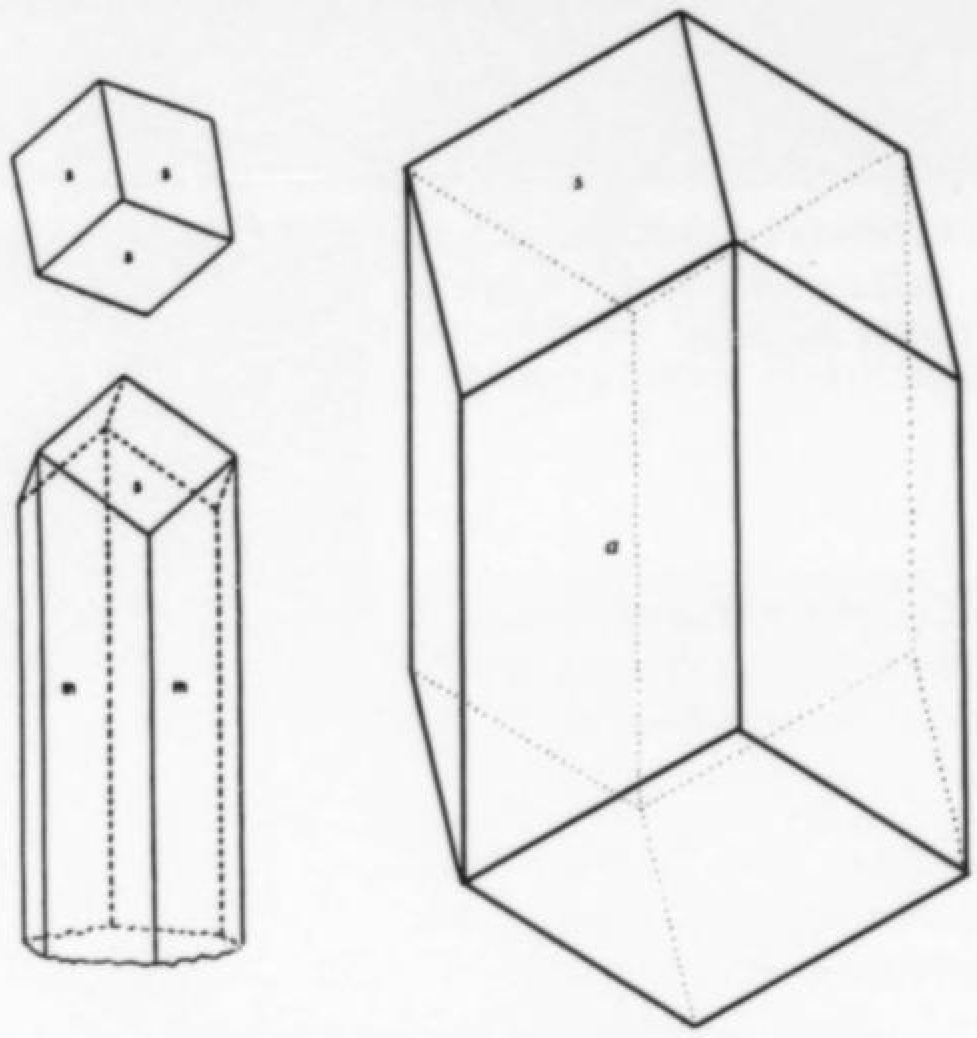


Figure 30. **Dioptase (left, (19); right, Gordon).**

Dioptase $CuSiO_2(OH)_2$

The beautiful specimens with minute needles of brilliant emerald-green dioptase crystals carpeting chrysocolla, clays, cerussite and wulfenite are among the most conspicuous and sought-after of the Mammoth mine specimens. Probably more examples of wulfenite encrusted with willemite and dioptase were preserved than any of the other minerals. Dioptase alone on a clay matrix, perhaps as balls of radiating crystals to about 15 mm, investing clay which has coated earlier wulfenites or, in turn, providing the matrix for large cerussite twins, affords the best examples of this mineral from the U.S.

Scattered among the dioptase needles usually are wulfenite, mimetite and quartz crystals; any of these may be earlier or later than the dioptase. Willemite crystals are often found to be earlier, and fluorite, descloizite, and rarely fornacite crystals are usually later. Dioptase infrequently occurs on and with diaboleite.

One specimen was seen on which the dioptase needles had preferentially incorporated some black mineral, themselves becoming entirely black (4, 19, 20, 21, 22, 24, 26, 27, 28, 31, 33, 34, 38, 39, 40, 41).

Fornacite $(Pb,Cu)_3[(Cr,As)O_4]_2(OH)$

A relatively rare mineral in the Mammoth mine suite, small crystals of this species nevertheless can be found in a variety of associations. The mineral was first properly identified in the mid-1950's, in a lot of material from a single pocket, where crystals several mm long, the largest known from any locality, were scattered on matrix. These occur along with larger wulfenite crystals and etched opaque white fluorite, also up to several mm, large compared to the average size of occurrence of this species at the Mammoth mine. On other specimens, small amounts may be occasionally found with dioptase, hemimorphite, and willemite and on cerussite.

Pseudomorphs, probably after malachite, on chrysocolla, and hollow encrustation pseudomorphs after a mineral with habit and angles similar to crocoite, have also been found. Crystals can be found in old collections, but the mineral was misidentified or overlooked. It can be confused with cuprian descloizite, and has in the past also been identified as olivenite. Its distinctive color, olive to pistachio-green in small crystals, grading to a dark greenish black in the larger ones, as well as more rounded edges and composite faces, should help in visual identifications (32, 33, 38, 40, 41).

Goethite $FeO(OH)$

This mineral is undoubtedly a large component in the limonite frequently found with oxidized specimens, but its presence was confirmed only in a few cases (33, 39, 41).

Gold, Au

In the early days of operation, this was the principal economic metal recovered. The gold occurring in a particular greenish yellow quartz, the richest ore, tended to be fine-grained, with particles only rarely visible. This ore averaged 0.09 ounces per ton in the New Year mine, and 0.15 in the Mammoth mine. Galena ores were assayed up to 0.375 ounces per ton. Rusty films of iron oxide on cracks in host rock occasionally show visible gold flakes. Modern geochemical sampling across the upper portion of the Mammoth vein found more gold in chlorite-rich portions than elsewhere. The scanning electron microscope showed gold particles in this mineral (A. Cockle, pers. comm.).

Wires and nuggets, less than 1 mm, in massive cerussite are rarely seen. One much larger mass of gold with wulfenite plates on matrix was found in the dump several years ago (1, 2, 3, 4, 8, 10, 13, 14, 15, 17, 21, 24, 31, 33, 40, 41).

Hematite, $Fe_2\,O_3$

Earthy, brick-red hematite is abundant on oxidized specimens, with tiny black balls somewhat less so. Shining black masses of specular hematite flakes are intermixed and included in quartz and chlorite. Small specular crystals are to be found along with the boxworks remnant after galena alteration. These tiny crystals, sometimes remarkably red, persist through further changes depositing later minerals, hence are found imbedded in crystals of anglesite, cerussite, diaboleite, boleite and wulfenite (15, 17, 33, 39, 40, 41).

Hemimorphite $Zn_4Si_2O_7(OH)_2{\cdot}H_2O$

Glistening white balls of clear, radiating crystals of hemimorphite can reach 8 mm in diameter, but more usually are only 1 to 2 mm. Elongated, flattened crystals with a sword-like termination, several mm long, could be confused with cerussite or anglesite, but the untwinned habit, vertical striations, and lower luster should aid visual identification.

Common associations are willemite, quartz, smithsonite, mimetite, and wulfenite, with the hemimorphite usually later than these minerals. Very rarely the mineral is found on diaboleite (15, 17, 20, 21, 24, 26, 27, 28, 29, 31, 33, 38, 40, 41).

Hisingerite $Fe_2Si_2O_5(OH){\cdot}2H_2O$

Tiny kernels of earthy hisingerite, hematite, and goethite sometimes are found in the center of creaseyite spherules (39, 41).

Hollandite $Ba(Mn^{+4},Mn^{+2})_8O_{16}$

Various black films, crusts and nodules usually ascribed to psilomelane were X-rayed. All examined proved to be hollandite (41).

Macquartite $Pb_3Cu(CrO_4)SiO_3(OH)_4{\cdot}2H_2O$

Slender orange prisms only as large as 1 mm. This extremely rare, newly described mineral has been recognized only from the Mammoth mine in a few old specimens. It would be easily confused with mimetite, but is monoclinic with a good prismatic cleavage.

The macquartite crystals occur associated with dioptase and wulfenite, imbedded in the quartz matrix along with barite, willemite and hematite (42).

Malachite $Cu_2(CO_3)(OH)_2$

Pale to dark green fibers and crystals are usually found with cerussite and azurite. Remarkable masses of reticulated cerussite were found, coated with a dense mat of shining silky malachite molded to their surface and hanging in veils. Massive cerussite nodules replacing galena often include malachite, and have a rim of that mineral as well.

Radial aggregates of malachite have entirely replaced azurite crystals, which are usually overgrown by azurite again, sometimes parallel to the original azurite. A little later cerussite in crystals is usually associated. Hollow, sugary anglesite epimorphs after cerussite twins may have tufts of malachite in their interior. Wulfenite crystals rarely are imbedded in or coated by malachite, usually with associated cerussite (4, 14, 15, 17, 26, 27, 33, 34, 40, 41).

Mimetite $Pb_5(AsO_4)_3Cl$

Brilliant yellow to orange hexagonal crystals, almost always in association with wulfenite, are usually the mimetite end-member of the series with vanadinite. Microcrystals of descloizite, fluorite, willemite, and conspicuous dioptase are usually also present. A fibrous variety, but still with discernable hexagonal outlines, can completely invest large wulfenite plates and masses—a spectacular combination. Mimetite seems to preferentially occur with wulfenite, in contrast to vanadinite, and further, their colors seem to sympathetically vary, indicating substitution by the same chromophore. The best crystals are less than 1 mm in size, and consist of flat tabular hexagonal pyramids, or, less commonly, equant prismatic crystals with dipyramid and base. Two generations of different habit may be on the same specimen, although it is usually the last mineral to form (9, 17, 21, 24, 28, 31, 32, 33, 38, 39, 40, 41).

Minium Pb_3O_4

Thin films and powders of a distinctive brick-red color were found to be this species. Coatings on cerussite, and one interesting specimen where the mineral was confined to a central square portion of a wulfenite plate, overgrown by later wulfenite, were confirmed (33, 41).

Mixite $Cu_{12}Bi_2(AsO_4)_6(OH)_{12}{\cdot}6H_2O$

Pale green radiating sprays of minute size were found on a single specimen from the Mammoth mine dump, associated with wulfenite and mimetite on a fine-grained barite matrix. (S. Williams, pers. comm.)

Mottramite $Pb(Cu,Zn)(VO_4)(OH)$

Occurs as jet-black thin films and crusts of tiny pointed crystals, usually on quartz. Wulfenite is usually earlier, and may be entirely replaced by mottramite; vanadinite and rarely pyromorphite crystals may occur on the mottramite crusts. Not as common as descloizite, the other end-member of the series (17, 24, 27, 33, 40, 41).

Murdochite Cu_6PbO_8

Minute, brilliant black octahedra on wulfenite and fluorite provided the type specimen for this species, in association with hemimorphite, willemite and quartz. It has since been noted with descloizite and on dioptase and creaseyite. One fine specimen consists of quartz crystals alone incrusted by murdochite (29, 31, 33, 39, 40, 41).

Plancheite $Cu_8Si_8O_{22}(OH)_4 \cdot H_2O$

Indigo-blue sprays, free-standing with fluorite, descloizite and creaseyite, or imbedded in chrysocolla, and of very small size, constitute the occurrence of this mineral in the Mammoth mine (41).

Pyromorphite $Pb_5(PO_4)_3Cl$

Very rarely occurs as olive-green to bright, apple-green, simple hexagonal crystals, sometimes with hollow terminations, reaching a length of 4 or 5 mm. Crystals are usually the last to form on specimens with wulfenite, mottramite, and mimetite-vanadinite. The mineral occurs as overgrowths, both as smaller crystals on itself, then giving turreted forms, and as oriented caps on mimetite-vanadinite (4, 15, 17, 21, 24, 31, 40, 41).

Ramsdellite MnO_2

A several-meter-thick vein of manganese oxide was once crossed by mining operations (J. Strutzel, pers. comm.). A specimen from this vein was found to be ramsdellite, in part microcrystallized and pseudomorphous after groutite MnO(OH) (41).

Rosasite $(Cu,Zn)_2(CO_3)(OH)_2$

A few mm-sized, hard, dark green balls of rosasite were found in association with hemimorphite (41).

Silver Ag

A valuable component of the galena ores which were reported to contain as much as 25 ounces per ton, but averaged only 1.5 ounces per ton. A few specimens with short wires and dodecahedral crystals of silver, encrusted with acanthite, and intergrown with leadhillite, were seen (4, 15, 17, 33, 40, 41).

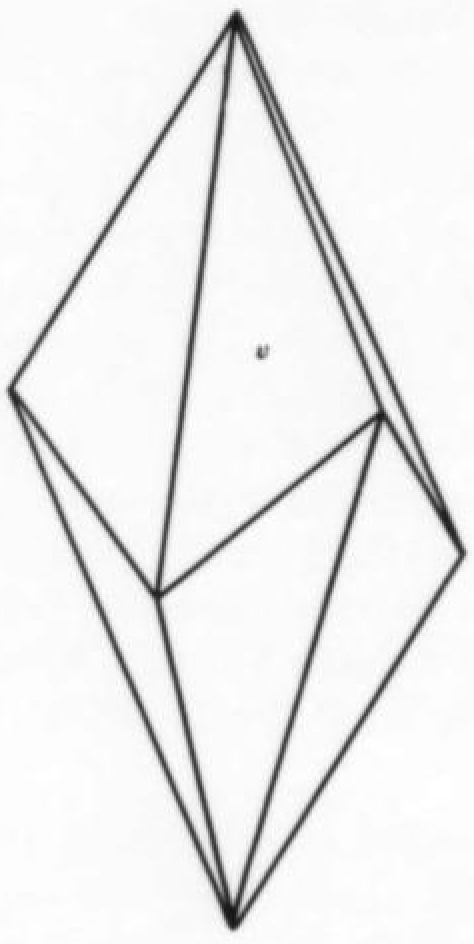


Figure 31. **Smithsonite (Gordon).**

Smithsonite $ZnCO_3$

An alteration product of primary sphalerite, generally inconspicuous although the millheads ran 2–3% zinc when the mine was operating in oxidized material. Specimens are usually waxy balls, up to 15 mm, of white, pale gray, green or rarely blue color. Some sharp crystals about 1 mm in size are occasionally seen. Associated minerals are especially hemimorphite and willemite, as well as wulfenite, mimetite, and fluorite. Calamine, in part, in earlier descriptions (15, 17, 21, 24, 27, 31, 33, 40, 41).

Sulfur S

Some specimens with thin crusts of crystallized sulfur on clay were seen, collected from dump material (24, 31, 33, 40, 41).

Tenorite CuO

Peterson noted "black, coal-like lumps of copper oxide, less than an inch or two in diameter . . . surrounded by thin shells of chrysocolla . . ." These are attributed to tenorite in later lists. Steely nodules of chalcocite or djurleite replacing galena are commonly surrounded by a thin shell of material meeting Peterson's description, in turn layered with chrysocolla. The splendent black mineral is nearly X-ray amorphous, and is probably manganiferous chrysocolla in large part (17, 21, 24, 31, 33, 40, 41).

Tsumebite $Pb_2Cu(PO_4)(SO_4)(OH)$

Apple-green, crystalline spherules less than 1 mm in diameter, coat crystals of a brilliant yellow member of the mimetite-vanadinite series. The X-ray pattern is that of the PO_4 end-member; only traces of AsO_4 and VO_4 were found on analysis (M. Nichols, pers. comm.) (41).

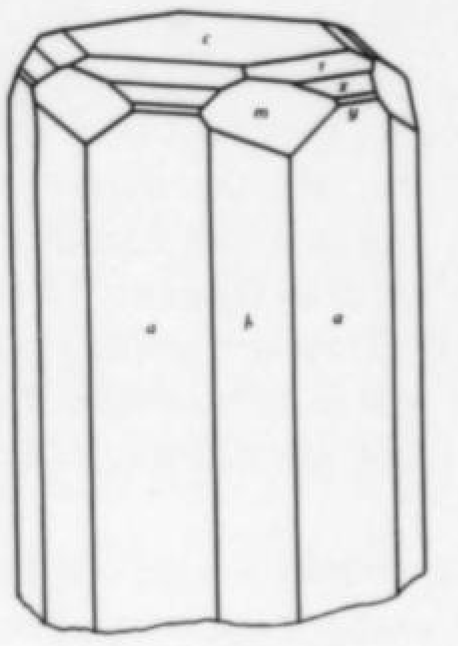


Figure 32. **Vanadinite (Gordon).**

Vanadinite $Pb_5(VO_4)_3Cl$

In short, prismatic hexagonal crystals, often with hollow terminations, this mineral is consistently associated with wulfenite, usually as a encrustation; with fluorite and willemite, and with descloizite or mottramite. It may occur as crystals on crusts of mottramite-descloizite, but even then dusted with tiny crystals of those minerals, or entirely replaced by them.

Vanadinite forms a complete series with mimetite, with the brilliant red crystals usually found to be vanadinite.

The color can range through brown to orange and quite yellow to almost white, with VO_4 still predominanting over AsO_4. Crystals on a specimen can change color from red to orange in the distance of a mm or so. Some crystals are themselves zoned, with red cores and waxy yellow exteriors. Maximum crystal size for individuals is rarely about 22 mm. Endlichite in part (1, 2, 3, 4, 5, 6, 8, 9, 10, 13, 14, 15, 17, 21, 24, 26, 27, 28, 31, 32, 33, 40, 41).

Willemite Zn_2SiO_4

This mineral may be difficult to recognize due to its wide variety of habits, however the diagnostic hexagonal cross-section will usually be visible. It is most usually in isolated, equant barrel-shaped crystals of mm size, colorless to pale green or blue. These often have frosted and opaque white exteriors, sometimes with clear terminations. These crystals might be confused with the frequently associated fluorite cubes. Radial sprays of colorless, long prismatic crystals, white when entirely compact, and up to 8 mm in diameter, simulate the appearance of some hemimorphite. Water-clear, tabular crystals bounded only by a very flat pyramid, are less common, and were seen occasionally strung like beads on mimetite needles.

Rythmically banded crusts of radially fibrous willemite, sometimes alternating with fibrous quartz, or masses of tiny, pale green spherules are often found with wulfenite and dioptase crystals. Specimens consisting of only these three minerals in some combination must have been collected in great quantity, as they are probably the most frequently seen Mammoth mine specimens in collections and on the market.

One specimen shows crusts of willemite which appears to have coated some globular mineral, about 6 mm in diameter. These crusts are now just thin hollow shells, with another generation of willemite formed on the interior of these shells, growing radially outward from the matrix, but not filling the void space.

Several specimens were seen where masses of pale green spherules of willemite had replaced crystallized cerussite. A reticulated mass, entirely replaced, was several cm across. An aggregate of wulfenite crystals at one time had enveloped complete cerussite sixlings up to 2 cm across. These are now voids in the wulfenite, preserving the sixling shape, and almost entirely infilled with the same distinctive willemite spherules which are not elsewhere on the specimens.

Another specimen has these same willemite spherules as an epimorph, now hollow, formerly encrusting cerussite sixlings. The same type of willemite may be found with later cerussite crystals on it as a matrix. Epimorphs of willemite replacing wulfenite plates were also noted. Wulfenite is the most common associate of willemite, and may be earlier or later. Smithsonite rhombs or hemimorphite sprays were also found on willemite. Calamine in part on earlier lists (21, 24, 26, 27, 29, 31, 33, 38, 39, 40, 41).

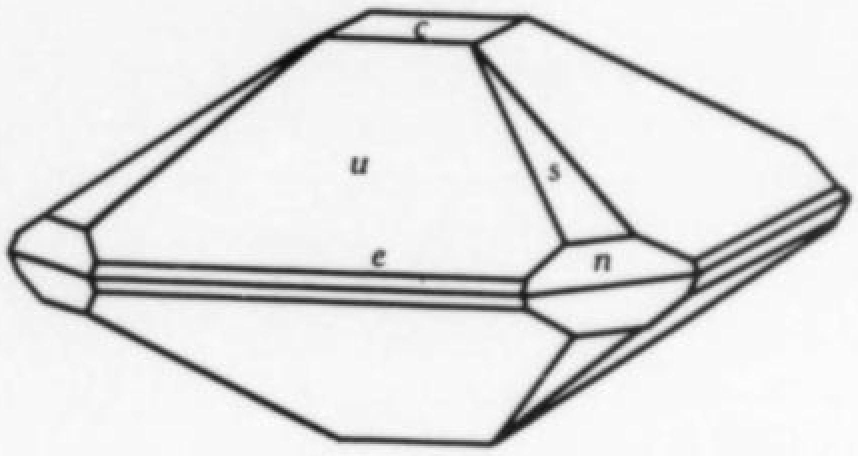


Figure 33. **Wulfenite (Gordon).**

Wulfenite $PbMoO_4$

Formed rather late in the mineralization sequence, and in open places at a distance from the veins as well as in them, immense quantities of wulfenite were recovered at various times during the mining operations. Through World War II, until major molybdenite deposits were brought into production, the Mammoth mine was the principal source of molybdenum in the U.S., all produced from wulfenite. In the top 300 feet of both the Collins and Mammoth veins, fractures up to several feet in width, packed solidly with platy wulfenite, were encountered.

Specimens at their finest from this famous American occurrence are rich masses of large tabular, characteristically orange crystals, with individuals up to as much as 7 or 8 cm across, but more usually in the 1-cm range. These may be thickly encrusted with mimetite of the same color, and less conspicuous later crystals of descloizite, willemite, and fluorite can be found in association.

Other beautiful specimens may have an early generation of wulfenite thickly coated with a slick clay, on which later crystals of brilliant red wulfenite, dioptase and cerussite have been deposited. The wulfenite crystals are usually attached by edges, but occasionally only by their centers, to projections under the clay. In areas of the mine where the wulfenite was exposed to moving surface water, the crstyals appear to be partially dissolved, even with holes, giving them a moth-eaten look. Colors of the crystals are less commonly yellow or brown to nearly black, apparently from included manganese oxide. Analysis of wulfenite concentrates showed up to 2% of contained WO_3, but whether as a substituent tending towards stolzite, $PbWoO_4$, or a separate phase could not be determined.

Parallel overgrowths of wulfenite on earlier wulfenite crystals are not uncommon. Some complete replacements of wulfenite plates by mottramite were seen. Vanadinite deposition on wulfenite appears to etch the crystals, although these two species rarely occur together. Chillagite in part on some earlier lists (3, 4, 5, 8, 9, 10, 13, 14, 15, 17, 19, 20, 21, 24, 26, 27, 28, 29, 31, 33, 34, 35, 38, 39, 40, 41).

Table 4. **Oxidized minerals, anomalous sequence.**

		Ag	Pb	Cu	Fe	Zn	Others
CHLORIDES	Diaboleite		X	X			
	Boleite	X	X	X			
	Pseudoboleite		X	X			
	Matlockite		X				F
	Bideauxite	X	X				F
	Paralaurionite		X				
	Atacamite			X			
	Paratacamite			X			
	Embolite	X					Br
	Iodargyrite	X					I
	Yedlinite		X				Cr
SULFATES	Linarite		X	X			
	Beaverite		X	X	X		Al
	Brochantite			X			
	Connellite			X			Cl
SULFATE-CARBONATES	Susannite		X				
	Leadhillite		X				
	Plumbonacrite		X				
	Caledonite		X	X			
	Wherryite		X	X			Cl
CARBONATES	Phosgenite		X				Cl
	Hydrocerussite		X				
SILICATES	Alamosite		X				
	Melanotekite		X		X		

OXIDIZED MINERALS

ANOMALOUS SEQUENCE

Comparison of Table 4 with Table 3, showing the composition of "normal" sequence minerals, highlights several striking differences. Many of the minerals in Table 4 contain more than one metallic element, with the combination of lead and copper quite noticeable (in fact the Mammoth mine suite has 13 minerals with both lead and copper essential, almost half the total of copper-lead minerals known). A source of both elements is readily seen in the oxidizing galena, coated or entirely replaced by secondary copper sulfides, usually found associated with these anomalous species.

Likewise, there are several minerals containing both sulfate and carbonate. Chlorine was presumably available as a component of dilute hydrothermal solution (the source for fluorine also?), or from groundwater. Other than minor amounts of chlorine in vanadinite and mimetite, the element does not seem to have persisted in any minerals formed except those of the "anomalous" group. The retention of minor amounts of silver in this environment is also evident in the table. It appears as a component in the boleite, altered from diaboleite, and is still present in the rare silver halides, sometimes among the last minerals to form.

Taken together, the minerals in the anomalous sequence argue for formation in a closed system—one from which elements could not escape, and were constrained to react together (S. Williams, pers. comm.). Their persistence to the present time is due to continued protection of this environment, probably by sheathing by quartz and clays of the localized areas in which they were formed.

Turning to some accounts contemporary with the discovery of these minerals, Fahey, Daggett and Gordon's (25) description of the type occurrence of wherryite is pertinent and the only one published (parenthetical comments are mine):

"In May of 1943 one of the authors, E. B. Daggett, then mining engineer at the Mammoth mine, discovered a small vug of leadhillite crystals associated with cerussite, anglesite, phosgenite, paralaurionite, hydrocerussite, diaboleite, boleite, matlockite and quartz. Within the cavity was some friable chalcocite with a relict structure of galena which it has replaced.

"The massive wall of the vug consisted of a light green fine granular mineral (wherryite) enclosing some bluish chrysocolla, and at the cavity some blue diaboleite and greenish paralaurionite. This green matrix was up to 5 cm in thickness and extended to the silicified wall of the vein—an altered quartz monzonite."

A letter from Daggett to Gordon dated March 11, 1949, says, "It (the vug) was a lens about a foot thick and three feet across. The outside shell of the vug was composed of massive minerals with chrysocolla on the outside grading to the apple-green mineral (wherryite) toward the inside, and with the chrystalline (sic) minerals making up the inside core."

Dubins, Mayers and Wenden's paper remarks, under diaboleite, "Two localities are particularly noteworthy. The first, stope #509, produced the finest specimens. Here diaboleite occurs in occasional nodules, associated with leadhillite, caledonite, etc., in magnificent crystals. The stope was, in addition, rich in dioptase, willemite and wulfenite. Diaboleite coming from this stope may be recognized by the abundance and size of the diaboleite crystals, the relative softness of the matrix, and the quantity of associated rare minerals. This stope is now entirely filled and unaccessible.

"The second locality, on the east wall of the main haulage tunnel of the Collins vein, 500 level, is characterized by the occurrence of small crystals of diaboleite in occasional vugs in an exceptionally tough siliceous matrix. The diaboleite crystals are either alone or accompanied by small crystals of caledonite; these latter tend to be more green than are those from other localities. These specimens are readily distinguished by their hard matrix and small, scattered diaboleite crystals. This locality has apparently no connection with the 509 stope adjoining it, as blasting in the direction of the 509 stope revealed entirely barren rock without any trace of diaboleite."

And under willemite, "Both dioptase and willemite are most abundant in and surrounding the diaboleite zone, which centers in the 509 stope. Considerable quantities of both minerals are present directly above the 509 stope on the 400 level, indicating an upward extension of the silicate envelope surrounding the diaboleite zone."

Occurrence of the lead silicates with diaboleite may also be an indication of the unusual degree of silicification protecting this paragenesis or anomalous sequence. The omission of zinc from the table is only an approximation, although hemimorphite and willemite are in fact only rarely present, and then in small quantity.

Alamosite $PbSiO_4$

White, sheaf-like crystal aggregates and spherules to 5 mm in diameter on corroded diaboleite, recrystallized in vugs. On a matrix of the characteristic quartz crystals which have replaced galena, the diaboleite is also associated with corroded phosgenite, cerussite and wulfenite. A few willemite prisms are on the alamosite.

Only a single specimen has been found. The alamosite has been confirmed both by X-ray powder diffraction and qualitative electron probe chemical analysis. It can perhaps be distinguished from the numerous other white minerals by its habit and chalcedony-like luster (41).

Atacamite $Cu_2Cl(OH)_3$

These brilliant green crystals are most often found with leadhillite, anglesite, diaboleite, and its constant associate wherryite. Less often it is with linarite, caledonite, boleite, cerussite and malachite.

Its finest crystallization is as sharp individuals to 3 mm, alone on quartz, or intermixed with anglesite crystals. It is often seen altering from diaboleite, linarite or caledonite, where it forms cross-hatched intergrowths or sugary green crusts.

One specimen exhibited twins, pseudo-octahedral trillings (20, 21, 22, 24, 26, 28, 31, 33, 40, 41).

Beaverite $Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$

A single specimen was found with anglesite crystals, brown to red from included iron oxides, in association with linarite crystals. Shining, golden yellow, powdery beaverite additionally occurs as an alteration product of linarite (41).

Bideauxite $Pb_2AgCl_3(F,OH)_2$

Transparent and colorless when fresh, isometric crystals of this species may be filmed with cerussite and become lavender on exposure to strong light. The specimens known are all in intimate association with both boleite and matlockite, themselves rare species from the Mammoth mine, but additionally indicating a narrow range of stability, so likely little bideauxite was formed in this only known occurrence. Nevertheless, crystals are up to 7 mm in maximum dimension, and are of cuboctahedral aspect with a variety of other forms present on smaller crystals.

The type specimen has a matrix of covellite and quartz replacing galena, with boleite, matlockite, two generations of leadhillite, sugary anglesite and superficial cerussite associated. The specimens were labeled cerargyrite or anglesite prior to confirmation as a new species (37, 40, 41).

Boleite $Pb_9Ag_3Cu_8Cl_{21}(OH)_{16}\cdot H_2O$

When well-formed as cubes, octahedrons and dodecahedrons, the beautiful prussian-blue to sea-green crystals of this mineral are unmistakable. The crystal size is generally only 1 or 2 mm but can approach 7 or 8 mm in crude crystals. The occasionally rich masses form the best U.S. occurrence of this mineral.

The most frequent associate is diaboleite, which it replaces. The cubic outline and slightly different color of imbedded boleite crystals can be found on most diaboleite specimens, but it is not confined to such close association with that mineral. It can also often be found as crystals perched on quartz, anglesite, atacamite, paratacamite, cerussite and leadhillite, and more rarely on caledonite, paralaurionite, and phosgenite. In association with minor matlockite, it forms the matrix for bideauxite.

Crystals can be entirely enclosed in cerussite and anglesite. Occasionally brochantite and boleite will entirely replace anglesite crystals. Boleite is overgrown by other obviously related minerals, here discussed under "pseudoboleite" (20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 34, 37, 40, 41).

Brochantite $Cu_4(SO_4)(OH)_6$

The most common green acicular mineral associated with the other sulfates anglesite, caledonite, leadhillite, and linarite, altering from the latter. In addition to free-standing tufts of crystals, or sugary masses encrusting these species, it also participates in various pseudomorphs. Examples are: as complete replacements of cerussite twins, intermixed with anglesite replacing linarite crystals, and with boleite replacing anglesite crystals. It is usually the last-formed mineral on any specimen, although some striking inclusions in clear quartz crystals were noted (15, 26, 27, 28, 33, 34, 40, 41).

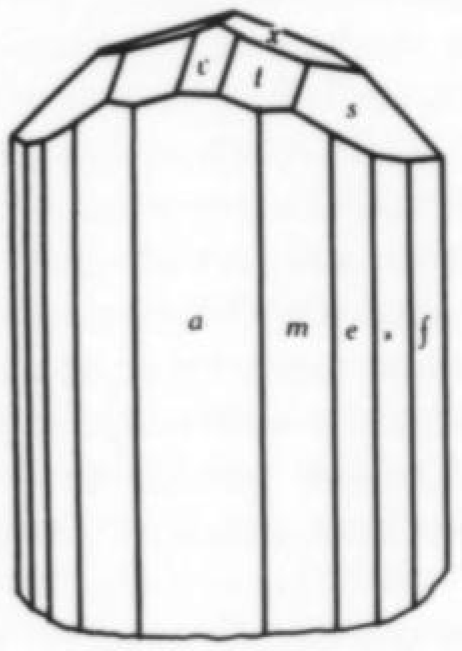


Figure 34. **Caledonite (Gordon)**

Caledonite $Pb_5Cu_2(CO_3)(SO_4)(OH)_6$

Occurs as isolated prismatic crystals to 15 mm long, and intergrown as masses of the pure mineral. Usually the color is a distinctive blue, but this may become sea-green on some specimens, perhaps indicating some degree of chemical substitution. A few crystals show zoning of both colors.

Usual associates are diaboleite and leadhillite with later anglesite and brochantite. Caledonite often appears to replace diaboleite and to be nearly contemporaneous with leadhillite; it is partially replaced by atacamite. Several specimens were seen in which distinct anglesite crystals or linarite crystals had replaced caledonite. In the latter case the replacing linarite has its long axis parallel to the elongation of the caledonite, giving the pseudomorph a foliated appearance.

This is one of the finest occurrences of this mineral in the world. A letter written by Gordon in 1948 contains the sentence, "Specimens in the (Philadelphia) Academy's collection labeled 'linarite and caledonite, Arizona, Genth' were undoubtedly from this locality, and Genth's death in 1893 postponed knowledge of the occurrence of the latter mineral there for many years" (20, 21, 22, 24, 26, 28, 31, 33, 40, 41).

Connellite $Cu_{19}Cl_4(SO_4)(OH)_{32} \cdot 3H_2O$

Slender, microscopic, pale blue needles of connellite can very rarely be found on cerussite and caledonite crystals, forming at the expense of the latter (41).

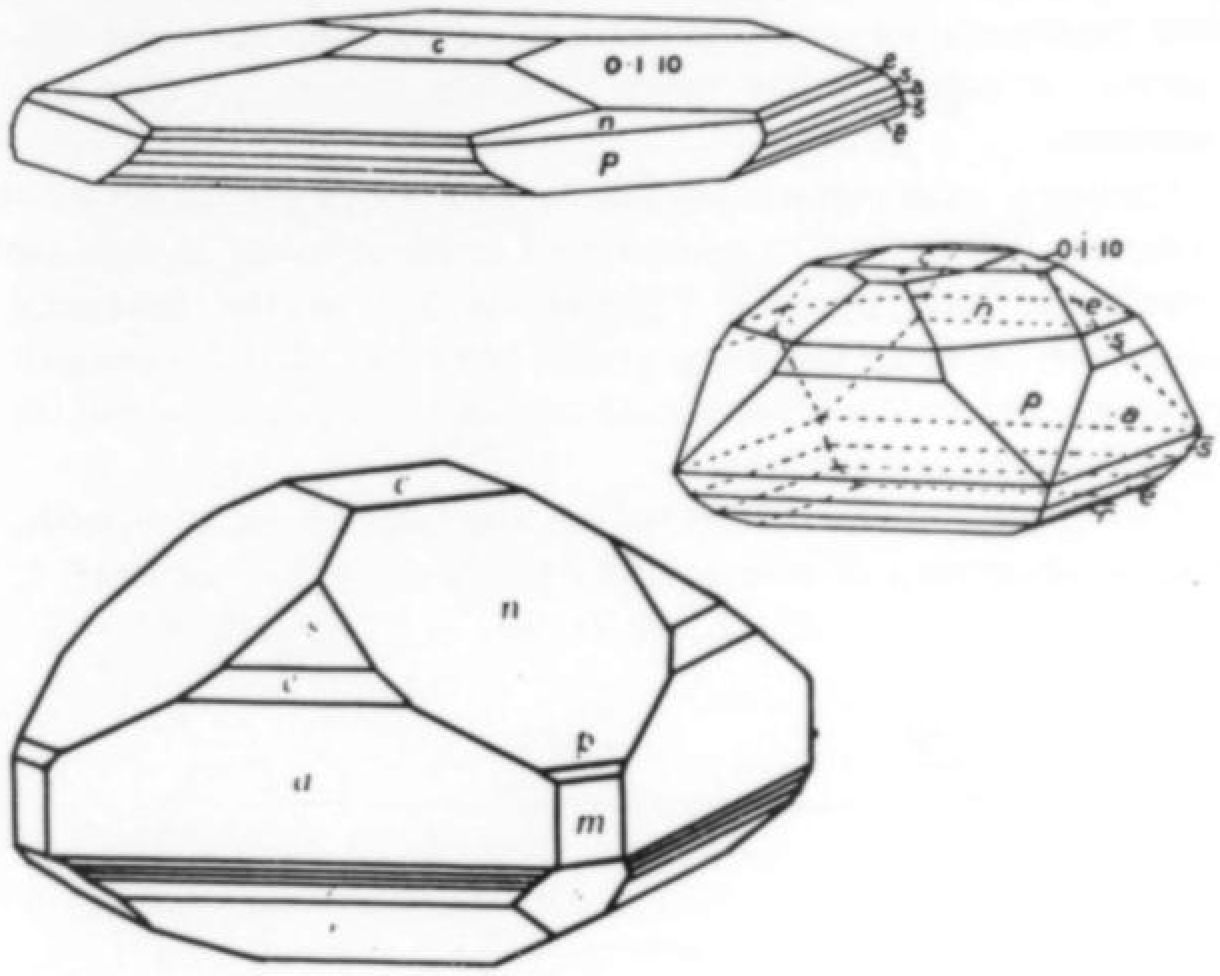


Figure 35. **Diaboleite (top and center (2); bottom, Gordon).**

Diaboleite $Pb_2CuCl_2(OH)_4$

One of the most notable minerals from the Mammoth mine, this is the best world occurrence, with crystals as large as 2 cm. The species was more fully defined by Palache on Mammoth mine material.

The color is a very intense blue, small crystals being nearly transparent. Crystals which are surficially corroded will grade from a powder-blue to nearly white, but this is an effect caused only by the state of aggregation, coming closer to the very light blue streak.

The mineral is usually in flat, tabular, tetragonal crystals or platy crystalline masses, often in parallel growth. A good cleavage in the plane of flattening, and striations caused by a common second-order pyramid, hence meeting at right angles but turned 45 degrees from the crystal outlines, help to visually distinguish diaboleite from linarite, with which it seldom occurs but can be easily confused. Pyramidal hemimorphic crystals are entirely diagnostic but are rarely seen.

Boleite and wherryite are nearly constant associates of diaboleite, of which they are alteration products. The diaboleite plates are usually seen on a quartz matrix, or intergrown with that mineral, of the type that has replaced galena, preserving a boxwork structure. Its alteration provides some of the elements for a number of the other interesting minerals in the Mammoth mine suite.

This is partially due to continued replacement of these later species by yet others, with intermediate crystallization of diaboleite. Some large diaboleite plates were noted on which later tiny diaboleite crystals had formed directly on the earlier.

The sulfate-bearing suite of leadhillite, caledonite and anglesite commonly forms on or at the expense of diaboleite, and these species often include minute diaboleite plates, or these are in turn grown upon them. Cerussite twins may be on diaboleite plates, but diaboleite crystals are as often found on the cerussite. Caledonite and brochantite are frequent associates, as is wulfenite; fluorite, willemite, hemimorphite, yedlinite, and alamosite are much more rare. Diaboleite plates are to be found imbedded in cleavable masses of matlockite and veneering hydrocerussite crystals. Sugary atacamite and paratacamite replace diaboleite. Phosgenite crystals on and in diaboleite plates are usually corroded into a cluster of spires, often tipped by minute diaboleite crystals (20, 21, 22, 24, 25, 26, 27, 28, 31, 33, 38, 40, 41).

Embolite Ag(Cl,Br)

Usually associated with caledonite on the few specimens known, embolite occurs as brilliant yellow cuboctahedral crystals, sometimes flattened, and less than 1 mm in size. The crystals may be implanted directly on caledonite, rarely on cerussite twins, or on quartz crystals. Diaboleite and leadhillite may also be associated (20, 21, 24, 26, 41).

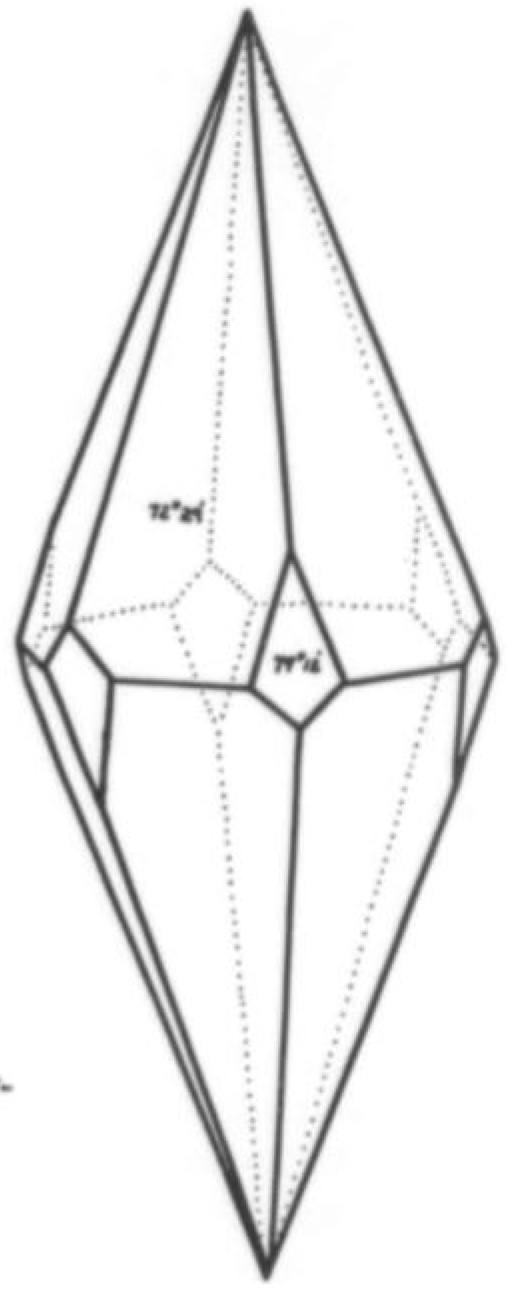


Figure 36. **Hydrocerussite (Gordon).**

Hydrocerussite $Pb_3(CO_3)_2(OH)_2$

The acute hexagonal pyramidal form, giving steep triangular faces, and the perfect basal cleavage, taken together, serve to distinguish this mineral from the numerous other white minerals in the Mammoth mine suite. It is always in close association with diaboleite, which occurs as matrix, a veneer, or as distinct crystals imbedded in the hydrocerussite. Caledonite, paralaurionite, and cerussite are less common associates. These remarkable crystals can attain a length of at least 15 mm. Larger aggregates of these then form some of the best known examples of this rare mineral (22, 24, 25, 26, 28, 31, 33, 34, 40, 41).

Iodargyrite AgI

Minute, pale green globular masses proved to be iodargyrite. They are implanted on caledonite crystals, associated with boleite and cerussite (41).

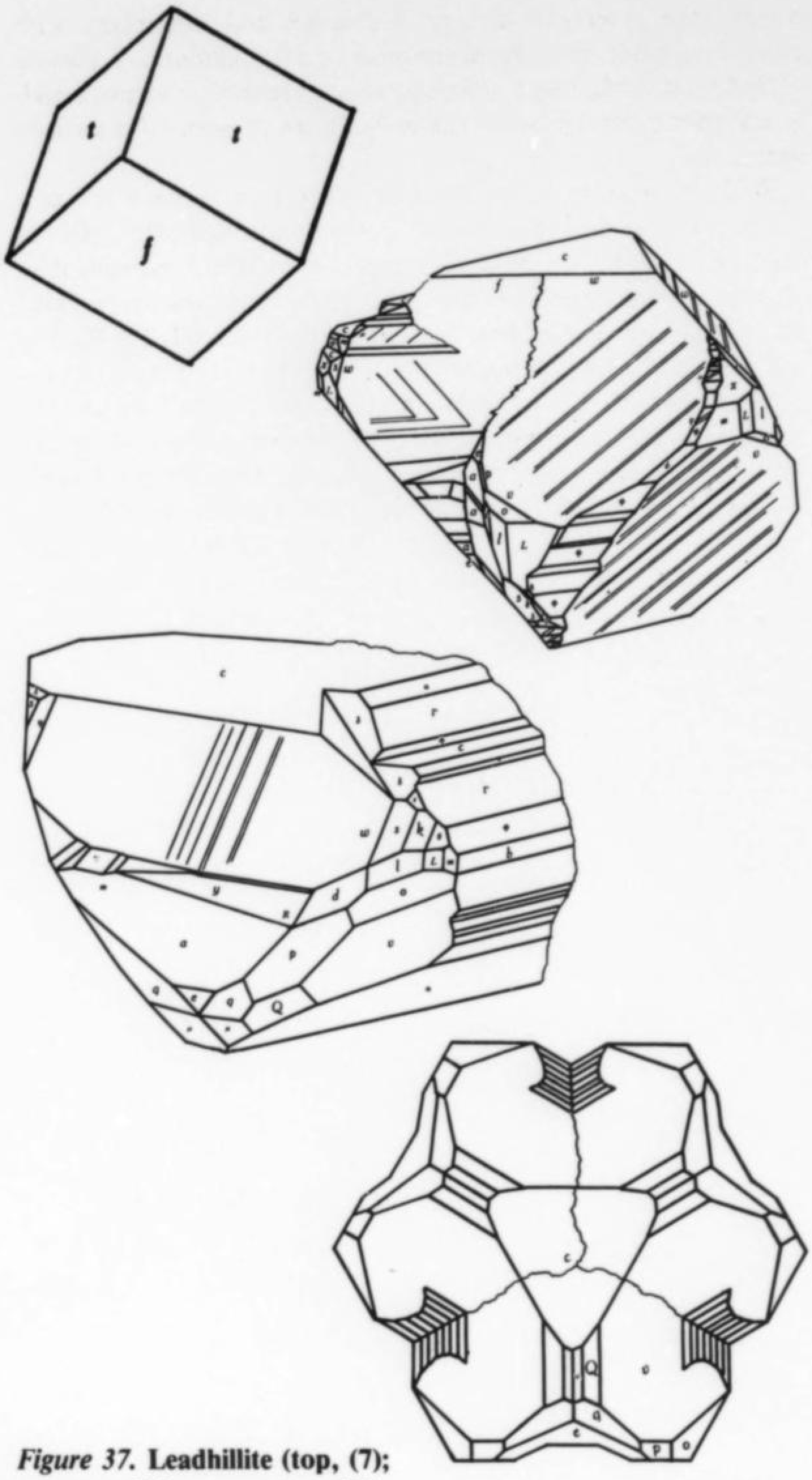


Figure 37. **Leadhillite (top, (7); upper and lower center, (23); bottom, twin on Artini law (23)).**

Leadhillite $Pb_4(SO_4)(CO_3)_2(OH)_2$

A decidedly pearly luster on either the basal termination or highly perfect basal cleavage, and trigonal or hexagonal prismatic crystals, taken together, assist in determination of this mineral. There are two principal crystal habits exhibited.

The first is as simple rhombohedrons, nearly cubic, or short prismatic crystals with large rhombohedral terminations. Transparent and colorless when very small, the mineral as larger individuals is usually opaque and snow-white, ranging to gray from included galena or clay, and sometimes reddish from iron oxides. Very rarely these crystals may be a pale greenish or lemon-yellow, perhaps from chromium. Crystals of white or grayish cast may reach 2.5 cm along an edge. On basal cleavage faces, the rhombohedral crystals often show interior zoning, sometimes with several changes in outline between trigonal and hexagonal, or a 60-degree change between 1st and 2nd order prisms.

While these crystals are now leadhillite, they are probably paramorphic after susannite. Both of these species have the same composition; leadhillite is monoclinic, pseudohexagonal while susannite is rhombohedral and is the stable form above 200°C. Space-group determination by single-crystal X-ray diffraction can reliably distinguish them.

The second predominant habit is as crystals with a hexagonal outline, from flat tabular with a large basal termination, to prismatic with commonly a steep rhombohedral termination. Many are twins, trillings according to the Artini Law, shown by complex three-rayed sutures on the terminations. This material probably crystallized directly as leadhillite rather than susannite.

These leadhillite crystals are usually colorless and transparent, sometimes a delicate sky-blue, but usually with clear tips. Crystals of this type often overgrow those of the rhombohedral habit, always with parallel *c*-axes. Generally much smaller in size, only a few mm long, they then make a forest of projecting crystal spires. When densely overgrown, this effect accounts for the frequent, rounded, barrel-shaped apperance of the best blue crystals, as aggregates to as much as 15 mm long.

Caledonite and associated linarite with brochantite are constant companions, with the leadhillite usually later. Both caledonite and linarite can be found as minute crystals included in leadhillite, accounting in some degree for that mineral's blue color. Leadhillite is often found with diaboleite, and its associated wherryite and boleite. Sometimes it appears to be altering from diaboleite, but also frequently includes small crystals of that species. Leadhillite occurs on paralaurionite when both are present on diaboleite specimens.

Cerussite often replaces leadhillite, as a frosting of the faces to complete replacement. Aggregates of small cerussite crystals are usually at least partially oriented parallel to the hexagonal leadhillite faces. In the more perfect examples of this topotactic replacement, the leadhillite crystal outline is well preserved and the cerussite appears reticulated.

The largest crystals are among the finest known for the species, with an abundance of blue crystals characterizing this locality (3, 7, 9, 20, 21, 22, 23, 24, 25, 26, 28, 31, 33, 34, 37, 38, 40, 41).

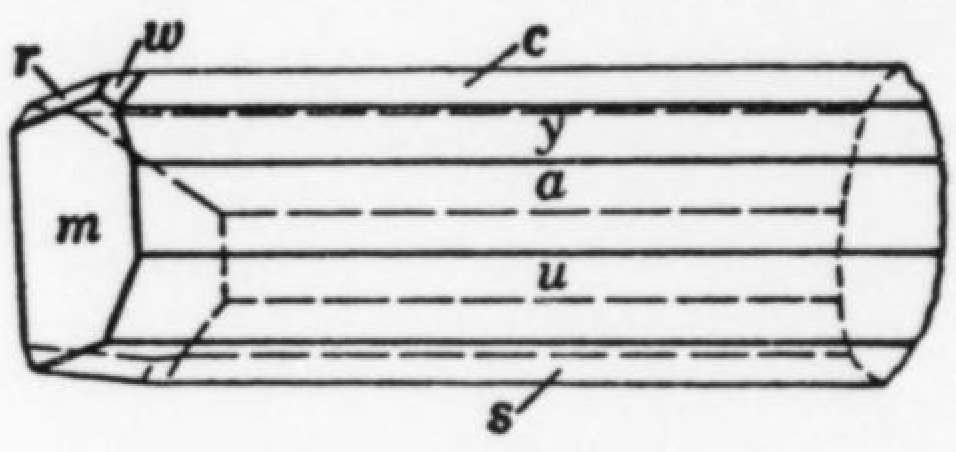


Figure 38. **Linarite (28).**

Linarite $PbCu(SO_4)(OH)_2$

Brilliant blue, thin, prismatic crystals of linarite, transparent when only a few mm long, grew in the Mammoth deposit to the largest size known. These giant crystals were probably from a single pocket or isolated occurrence. Several loose crystals were seen from 6 to over 8 cm long, 3 to 5 cm wide, and 5 to 10 mm thick. These crystal blades are rarely terminated, and must have been entirely imbedded in a sugary mass of brochantite, with traces still in pockets and adhering to the surface of the linarite.

Smaller crystals are not uncommonly found by themselves or with anglesite, caledonite and leadhillite. Usually some crystallized brochantite provides a pleasant color contrast. The relationship between linarite, brochantite, and anglesite is a complex and delicate one. Linarite prisms may occur with tufts of later brochantite and spear-shaped anglesite crystals. Interlocking groups of linarite are found where the linarite crystals are sometimes alternatively individually replaced by white anglesite, or anglesite colored green by included brochantite. Linarite, with brochantite, may grow on anglesite crystals, or the anglesite crystals may be partially or entirely replaced by linarite sprays, in turn sometimes replaced by brochantite. Linarite also replaces caledonite crystals, with the linarite blades roughly parallel to the long axis of the caledonite prisms. These may be encrusted with anglesite spears, while other caledonite crystals on the same piece are replaced by the anglesite crystals alone.

Linarite very rarely occurs with the other blue minerals, diaboleite and azurite, which it then usually replaces. One crystalline bladed mass of linarite included small malachite pseudomorphs after azurite. Linarite crystals sometimes occur on cerussite twins. On one specimen, with a matrix of anglesite crystals, linarite entirely replaced some perched cerussite sixlings, and was then itself replaced by brochantite in several cases.

It can be difficult to visually distinguish linarite from diaboleite and azurite. When linarite is well crystallized, the prismatic habit and one perfect cleavage parallel to the long axis serve to distinguish it from diaboleite, yet the combination of linarite and brochantite is deceptively like diaboleite and wherryite in more massive specimens. Azurite at the same crystal size is a much deeper and more opaque Prussian-blue, without prominent cleavage, and tends to form thicker, more equant crystals (4, 8, 9, 10, 15, 20, 21, 22, 24, 26, 27, 28, 31, 33, 34, 40, 41).

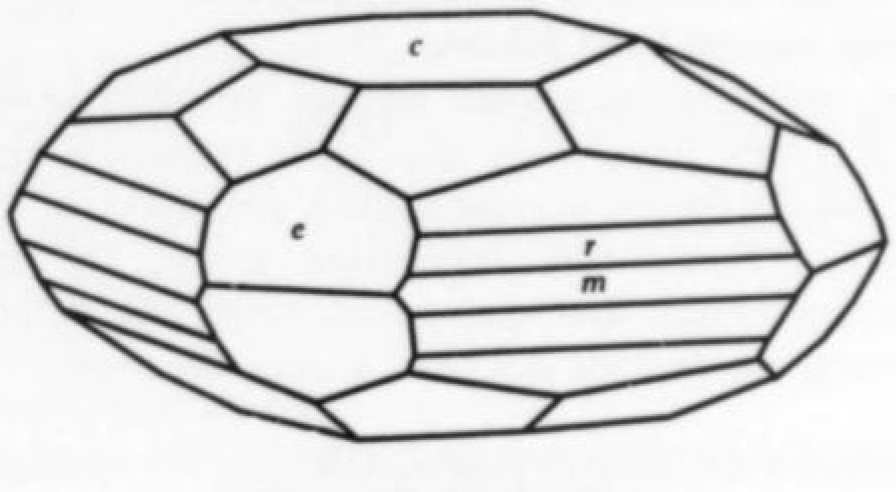


Figure 39. **Matlockite (Gordon).**

Matlockite PbFCl

Large, cleavable, clear to gray masses occurred, altered to anglesite and brochantite on the rims. Very tiny (less than 1 mm), thin, tabular, square or octagonal, transparent crystals occur with diaboleite, boleite, caledonite, and leadhillite. A few crystals were found on altering djurleite, and with anglesite crystals, the matlockite including numerous transparent red covellite crystals. One remarkably large crystal is preserved which is 35 mm in diameter. It is circular in outline, double-convex in cross-section, and deeply striated at right angles on the surface. This crystal is situated on reticulated cerussite (20, 21, 22, 24, 25, 26, 28, 30, 31, 33, 37, 38, 40, 41).

Melanotekite $Pb_2Fe_2Si_2O_9$

During the course of this study, some minute, radially fibrous brown balls imbedded in diaboleite were examined and found to be melanotekite. The mineral has been reported on earlier lists (31, 33, 40, 41).

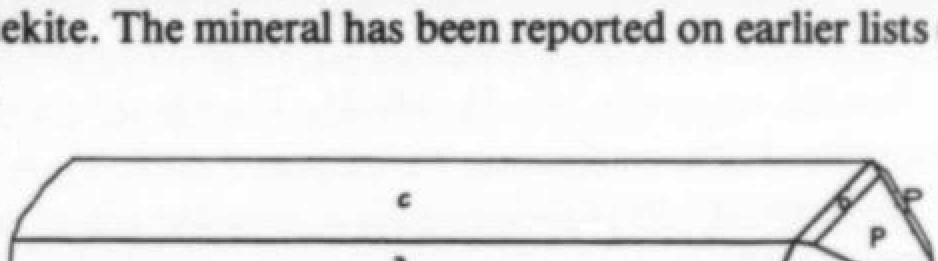


Figure 40. **Paralaurionite (26).**

Paralaurionite PbCl(OH)

Specimens from the Mammoth mine provide, without doubt, the finest examples of this species extant. Elongated crystals as much as 2.5 cm in length, and flattened tabular crystals 15 mm square, occur with diaboleite plates and associated wherryite. The wherryite seems exceptionally rich on the paralaurionite-bearing specimens. Rather than occurring as a minor crystalline alteration of diaboleite, the wherryite is usually massive and intermixed with crystalline diaboleite. Paralaurionite crystals commonly enclose diaboleite crystals, and a late generation of leadhillite prisms usually occurs on paralaurionite when both are present on diaboleite specimens.

This rare species varies from colorless to a more usual pale yellow, and shows the unusual property of flexibility without elasticity. The crystals are often found to be bent, but exfoliate if an attempt is made to restore them. They also have a peculiar rounded and almost melted appearance (22, 24, 25, 26, 28, 31, 33, 40, 41).

Paratacamite $Cu_2(OH)_3Cl$

Often associated with its trimorph, atacamite. Both are a brilliant green and occur as sugary masses altered always from diaboleite. This mineral's frequent companion boleite is often found as cubic crystals on the paratacamite. No guidelines can be offered to assist in the visual distinction between atacamite and paratacamite, other than the fact that atacamite sometimes occurs as distinctive elongated prismatic crystals (41).

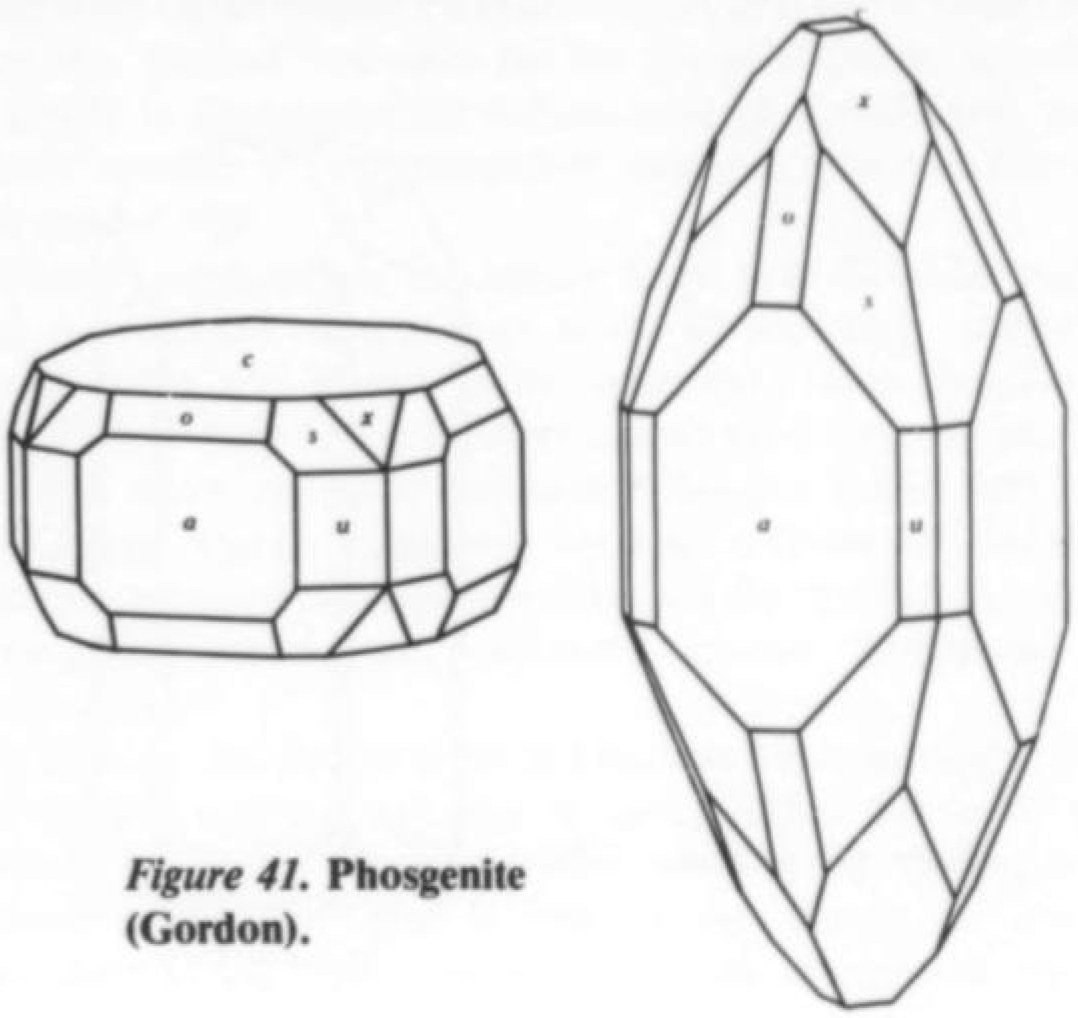


Figure 41. **Phosgenite (Gordon).**

Phosgenite $Pb_2(CO_3)Cl_2$

Sparsely occurring in the diaboleite paragenesis, phosgenite can usually be distinguished by its pale brown color, slender prisms with a square to octagonal outline, acute pyramidal termination, and perfect basal cleavage. It appears to alter from diaboleite, yet is itself corroded into spire-like masses. Crystals frequently enclose minute diaboleite crystals, or have a later generation of these on the tips of its spires. Crystals as long as 35 mm and 25 mm across were seen (20, 21, 22, 24, 25, 26, 28, 31, 33, 38, 40, 41).

Plumbonacrite $Pb_{10}(CO_3)_6(OH)_6O$(?)

Small pearly-white scales, associated with anglesite and linarite on galena, were examined by X-ray diffraction and tentatively assigned to this poorly-defined species, which is easily confused with hydrocerussite (S. Williams, pers. comm.) (41).

Pseudoboleite $Pb_5Cu_4Cl_{10}(OH)_8 \cdot 2H_2O$

Sea-green plates grown parallel to the surfaces of boleite cubes have long been suspected of being pseudoboleite, but their extremely small size has hampered confirmation. On one specimen, the boleite is no longer present, leaving the pseudoboleite (?) plates standing on matrix like a house of cards; this at least indicates a subtle chemical difference. Other, even smaller examples, show six-rayed pyramidal overgrowths reminiscent of cumengite on boleite from Boleo, Mexico (20, 40, 41).

Susannite $Pb_4(SO_4)(CO_3)_2(OH)_2$

Probably occurred in rhombohedral crystals, some with complex modifications, now paramorphed to leadhillite, and discussed under that mineral (7, 23, 28).

Wherryite $Pb_4Cu(CO_3)(SO_4)_2(OH,Cl)_2O$

Still known only from the Mammoth mine, wherryite was originally described as a light-green, fine granular mineral. It has since been found that most of the short, tufted, green, polycrystalline mineral almost always associated with older specimens of diaboleite as an alteration product is also wherryite. Individual crystals suitable for single-crystal X-ray and optical goniometric work have been located in recent years.

In the originally recognized occurrence, wherryite and chrysocolla were components of the shell surrounding a cavity in quartz monzonite resulting from the alteration of galena. In the cavity, one of the few scientifically collected, were crystals of leadhillite, cerussite, anglesite, phosgenite, paralaurionite, hydrocerussite, diaboleite, boleite, matlockite, and quartz.

The crystalline varieties are usually formed directly on diaboleite plates, but sprays may occur on other associated minerals. Usually a pale apple-green, the mineral has been confirmed as having also a yellow-green to brilliant lemon-yellow color (25, 26, 28, 31, 33, 36, 38, 40, 41).

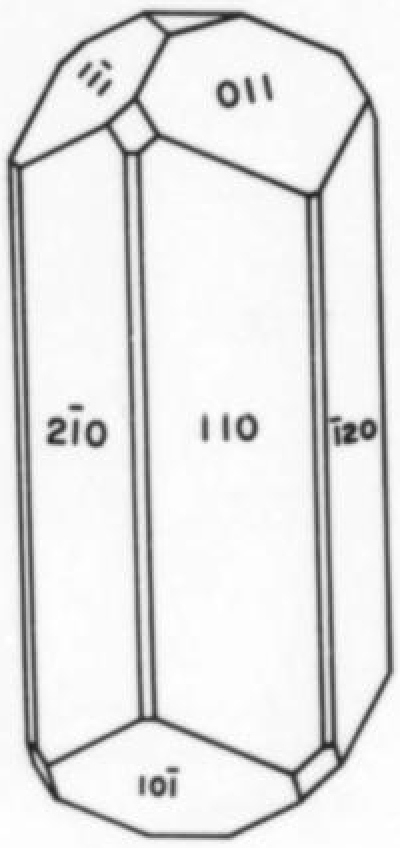


Figure 42. **Yedlinite (38).**

Yedlinite $Pb_6CrCl_6(O,OH)_8$

Red-violet crystals of yedlinite, hexagonal in cross-section with rhombohedral terminations, to a maximum size of 1 mm, are rarely to be found with diaboleite or grown on phosgenite prisms. Crystals of other species such as wulfenite, dioptase, cerussite, mimetite, willemite, hemimorphite, fluorite or quartz may be associated. Yedlinite has been found to date only at the Mammoth mine, with but a few mg known to exist (38, 40, 41).

UNKNOWN MINERALS

Several unknowns have been mentioned or partially described in the literature on the Mammoth mine suite. These are reviewed here, along with three minerals discovered in the present study. There is insufficient material to complete the characterization of the latter three, although enough chemical, optical and single-crystal data has been gathered to verify their status as new species. Their complete description must await better analytical instrumentation or more material.

Unknown mineral of Galbraith and Kuhn (19)

Colorless to very pale blue slender crystals about 0.1 mm in length, isolated or in fan-shaped aggregates, imbedded in chrysocolla. The original material could not be located. Plancheite has been identified from the Mammoth mine, imbedded in chrysocolla, and is an excellent possibility for the identification of this mineral.

Unknown mineral of Palache (20, 28)

"A mineral related to hydrocerussite, in crystals, not certainly of this species, showing a rhombohedral development." These are undoubtedly the leadhillite crystals of rhombohedral habit, so abundantly represented in the Harvard collection, but not sufficiently studied at that time.

Unknown mineral of Palache (20)

"Diaboleite is altered to an aggregate of lighter blue material." Numerous examples of this effect were seen in the Harvard suite of specimens. It is caused by corrosion of the diaboleite, lowering the intensity of the body color due to smaller grain size, but in fact no alteration has taken place, as verified by X-ray diffraction.

Unknown mineral Lead Tungstate Chloride

Transparent golden yellow needles and flattened crystals to 1 mm long, with sword-shaped terminations. Orthorhombic, generally twinned at approximately 90 degrees. Flexible and elastic. Contains approximately 60% lead, 16% tungsten, 7% chlorine (by microprobe; R. Thomssen, pers. comm.). On quartz, usually alone in cavities. Most closely associated with leadhillite of rhombohedral habit, and sometimes enclosed in crystals of that mineral.

Unknown mineral Lead Copper Antimony Sulfate Chloride

Cerulean blue monoclinic crystals, less than 1 mm in size, occurring on crystallized sugary anglesite. Contains approximately 53% lead, 10% copper, 7% antimony, 5% sulfur and 5% chlorine. Behavior under the microprobe indicates that the mineral is probably hydrated (R. Thomssen, pers. comm.). Antimony in tetrahedrite is a minor constituent of the primary ore.

Unknown mineral Lead Silicate

Tapered, colorless transparent needles, probably hexagonal, a fraction of 1 mm long, form into loose cylindrical aggregates. These are radially fibrous in cross-section, perpendicular to the axis of elongation. Found with crystallized quartz, the aggregates wander across cavities and look astonishingly like woolly caterpillars; several may branch out from a common origin.

MINERALS OF QUESTIONABLE OR DISCREDITED OCCURRENCE

Previous published lists have included species, the occurrence of which could not be verified during this study. Most have probably been based on sight identification, perhaps unusually dangerous due to the demonstrated complexity of the Mammoth mine suite. Some are group names, with specific members of the group found to occur during this work. While it is virtually impossible to absolutely disprove the occurrence reported at one time of a mineral, in my judgment further substantiation is required before accepting the following species.

Actinolite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

Variety mountain leather; see sepiolite (40).

Beudantite $PbFe_3(AsO_4)(SO_4)(OH)_6$

Described originally from the Mammoth mine by Peterson as "yellowish-green tufts of fibers associated with wulfenite and limonite . . .," and in his thesis additionally as "also giving a microchemical test for copper."

All such material labeled as beudantite has been found to be creaseyite, including material collected by Peterson, now the type material for creaseyite (16, 17, 21, 24, 31, 33, 40).

Bromargyrite AgBr

Listed as bromyrite in (33).

Chlorargyrite AgCl

Probably the minerals confirmed as embolite and iodargyrite in this study. Listed as cerargyrite (17, 30, 31, 33, 40).

Crocoite $PbCrO_4$

No specimen of this mineral has been authenticated during this study; the few pieces presented have clearly been from the Tasmanian occurrence. The original entry of the species into the literature on the Mammoth mine was based on a single specimen in the University of Arizona collection which could not be located.

Brilliant red vanadinite has occasionally been misidentified as crocoite from other Arizona localities. Very small amounts of chromium do occur in the Mammoth mine ores, coloring wulfenite, cerussite, leadhillite and wherryite, and as essential constituents of yedlinite and fornacite. Some fornacite casts showing the form of an unknown mineral with habit and angles near crocoite were found (10, 21, 24, 28, 31, 33, 38, 40).

Ecdemite $Pb_6As_2O_7Cl_4$

First described from Långban, Sweden, in 1887, it was reported in the Mammoth mine suite prior to 1900, perhaps based on qualitative chemical tests only. The name is usually applied to needle-like encrustations of an orange mineral on wulfenite. Numerous specimens of varying degrees of authentication have been re-examined and all have proven to be members of the mimetite-vanadinite series. X-ray powder films purportedly of this material in the standards files at both Harvard University and the University of Arizona are also mimetite-vanadinite patterns (4, 9, 10, 17, 21, 24, 28, 31, 32, 40).

Gypsum $CaSO_4$

Although several specimens were seen, bearing selenite crystals or cleavages, and labeled as coming from the Mammoth mine, they were not associated with any other minerals unquestionably authenticating them as from this locality. I consider the mineral of doubtful occurrence here (33, 41).

Huebnerite $MnWO_4$

Listed (40).

Kaolinite $Al_2Si_2O_5(OH)_4$

Often reported as one of the clay minerals present; in fact the occurrence of this mineral could not be confirmed on the numerous specimens sampled. It may nevertheless be present (17, 27, 33, 40).

Lanarkite $Pb_2(SO_4)O$

Listed (40).

Lepidocrocite $FeO(OH)$

Trimorphous with goethite, common at the locality, this species is listed as having been identified on a single specimen. A number of specimens having the shining reddish scales visually suggesting this mineral were X-rayed; all proved to be hematite (24, 31, 33).

Molybdenite MoS_2

At one time thought to occur as a primary mineral, its alteration providing molybdenum for the abundant wulfenite. Diligent search in the ores and underground by later investigators was not successful (15, 17, 40).

Olivenite $Cu_2(AsO_4)(OH)$

A specimen from the Mammoth mine labeled olivenite was on display for many years at the University of Arizona. It was later found to be fornacite (31, 33).

Penfieldite $Pb_2Cl_3(OH)$

Listed (33).

Psilomelane Manganese Oxides

A general term for massive, not specifically identified, hard manganese oxides. Botryoidal masses of manganese oxide ranging from the size of peas to some weighing several kg were seen in the broken ore and lying on the surface by Peterson. All manganese oxide minerals identified in this study were found to be hollandite or ramsdellite; but no examples of compact or massive material were available in the collections examined (17, 21, 28, 33, 40).

Pyrolusite MnO_2

Soft manganese oxides, otherwise unidentified, have been collected under this term. In this study, all manganese oxides examined proved to be hollandite or ramsdellite (15, 17, 19, 33, 40).

Sauconite $Na_{0.33}Zn_3(Si,Al)_4O_{10}(OH)_2 \cdot 4H_2O$

Listed (40).

Vesuvianite $Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$

The variety *californite* has been reported as a matrix for dioptase. Undoubtedly this is one of the clay minerals (34).

Wad Manganese Oxides

Used to describe undifferentiated soft manganese oxides; see under pyrolusite above (17, 24, 31, 33, 40).

Wolframite $(Fe,Mn)WO_4$

Listed (40).

Wurtzite ZnS

This hexagonal polymorph of sphalerite was reported to occur below the 900-foot level. If so, specimens do not seem to be preserved in collections. Sphalerite occurs abundantly to the deepest mine levels (24, 31, 33, 40).

Zoisite $Ca_2Al_3(Si_3O_{12})(OH)$

Peterson suggests this identification for tiny prisms of light green mineral, forming a mat over rhyolite. He also suggests epidote, which is probably more likely (17).

COMPARABLE DEPOSITS

It is interesting to compare the mineralogy of the Mammoth mine with other deposits in Arizona and throughout the world. In Arizona, there are several smaller deposits which have mineralogies also resulting from deep oxidation of veins containing simple primary sulfides like the Mammoth vein. This oxidation has produced a set of secondary minerals comparable to those described under the "normal" sequence for the Mammoth mine, but differing greatly in the ratio of the various minerals. In addition, minor amounts of some of the "anomalous" minerals have been found on close inspection.

These deposits include the Apache mine, near Globe (almost entirely a vanadinite deposit with traces of wulfenite, matlockite, boleite, etc.); the Rowley mine, near Gila Bend (notable for wulfenite and vanadinite; localized caledonite-linarite-brochantite-anglesite, minor diaboleite and matlockite); the Grand Reef mine, Gila County (linarite, caledonite, cerussite, anglesite and leadhillite, some fine specimens in small amounts) and the 79 mine, also in Gila County (fine aurichalcite, wulfenite, cerussite, smithsonite and hemimorphite).

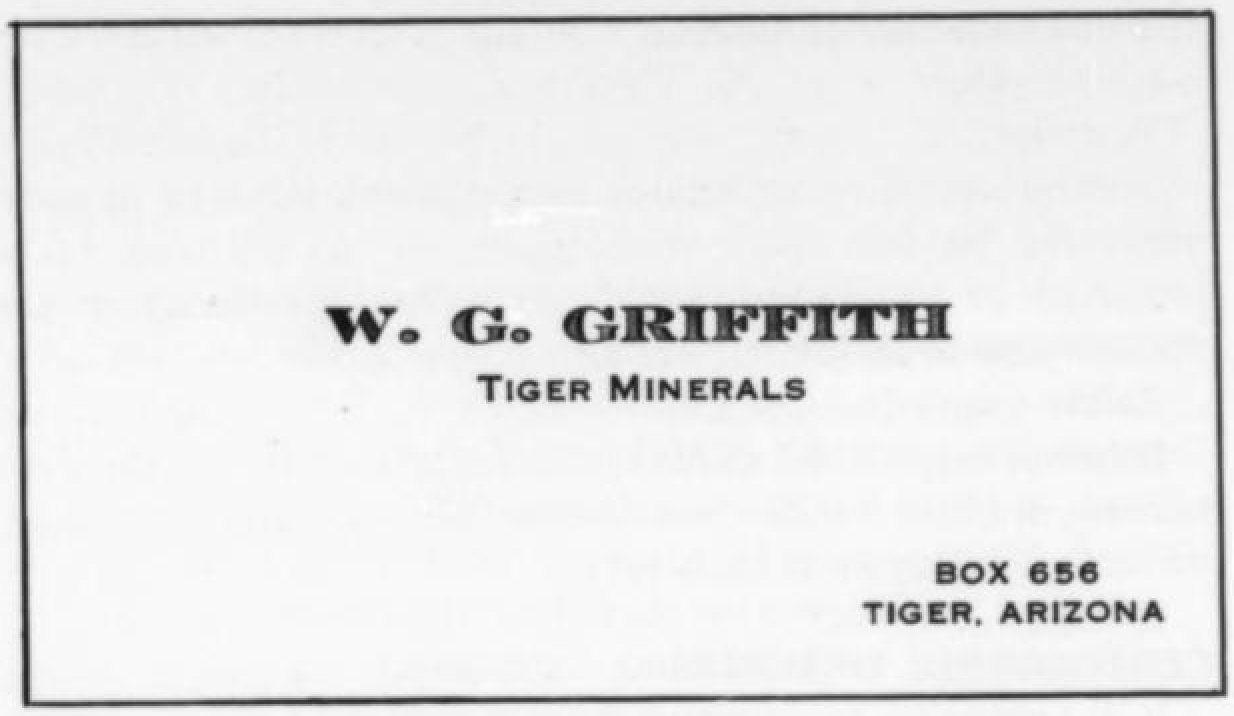
In Mexico, the Ojuela mine in Durango has comparable "normal" sequence mineralogy, but obviously differs due to the great amounts of arsenic in the primary ores, giving the secondary arsenate suite. The same is true of the deposit at Tsumeb, Southwest Africa, which has many minerals in common with the Mammoth mine.

Suites of minerals from the "anomalous" sequence at the Mammoth mine are known elsewhere in the world especially from Leadhills, Scotland; Sierra Gorda, Chile; Matlock and Mendip Hills, England; Laurium, Greece, from the slags; and Boleo, Mexico. The ancient mine workings about Anarak, Iran, provide the closest match to the overall mineralogy of the Mammoth mine.

From the reported mineralogy of the above deposits, some important clues to the difference in conditions in the Mammoth veins may be those minerals not occurring (or not yet recognized). These include the apparent absence of plattnerite, a constant associate of murdochite at the other known localities; lead hydroxy- and oxychlorides other than paralaurionite, such as laurionite, penfieldite, fiedlerite and mendipite; and the rare chloroxiphite, known in association with diaboleite from Mendip. Lanarkite might be expected as well.

DEALERS

The best of the Mammoth mine minerals have long been highly prized by dealers and collectors alike. The *Mineral Collector,* a periodical published around the turn of the century, carried a few advertisements for these specimens. In that journal for April, 1897, Maynard Bixby advertised "Wulfenite, groups of choice crystals, also semi-crystallized masses with descloizite and ecdemite." In May of that same year, George L. English announced "A great strike at Mammoth, Arizona—descloizite and vanadinite; wulfenite and descloizite; a few specimens of leadhillite; massive anglesite with linarite and chrysocolla." The December, 1897 issue carried an advertisement by a Mr. Walker, which offered a variety



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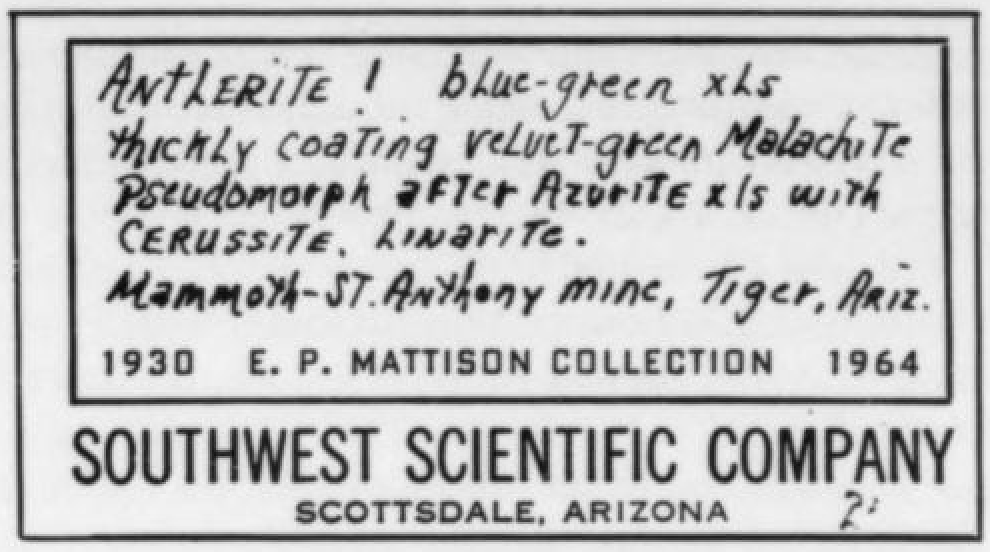

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Mammoth-ST. Anthony mine, Tiger, Ariz.

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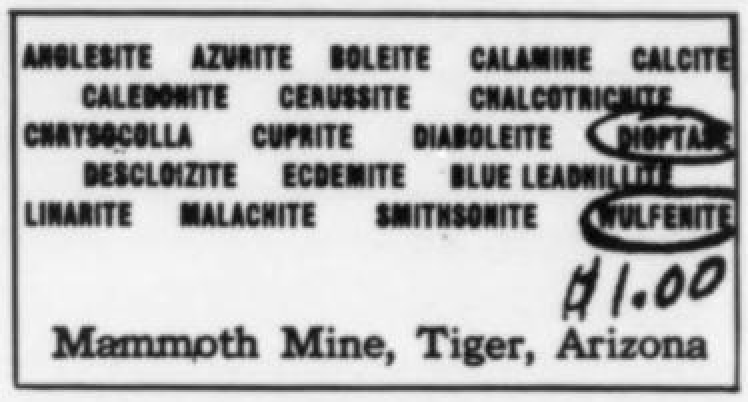

ANGLESITE AZURITE BOLEITE CALAMINE CALCITE
CALEDONITE CERUSSITE CHALCOTRICHITE
CHRYSOCOLLA CUPRITE DIABOLEITE DIOPTASE
DESCLOIZITE ECDEMITE BLUE LEADHILLITE
LINARITE MALACHITE SMITHSONITE WULFENITE

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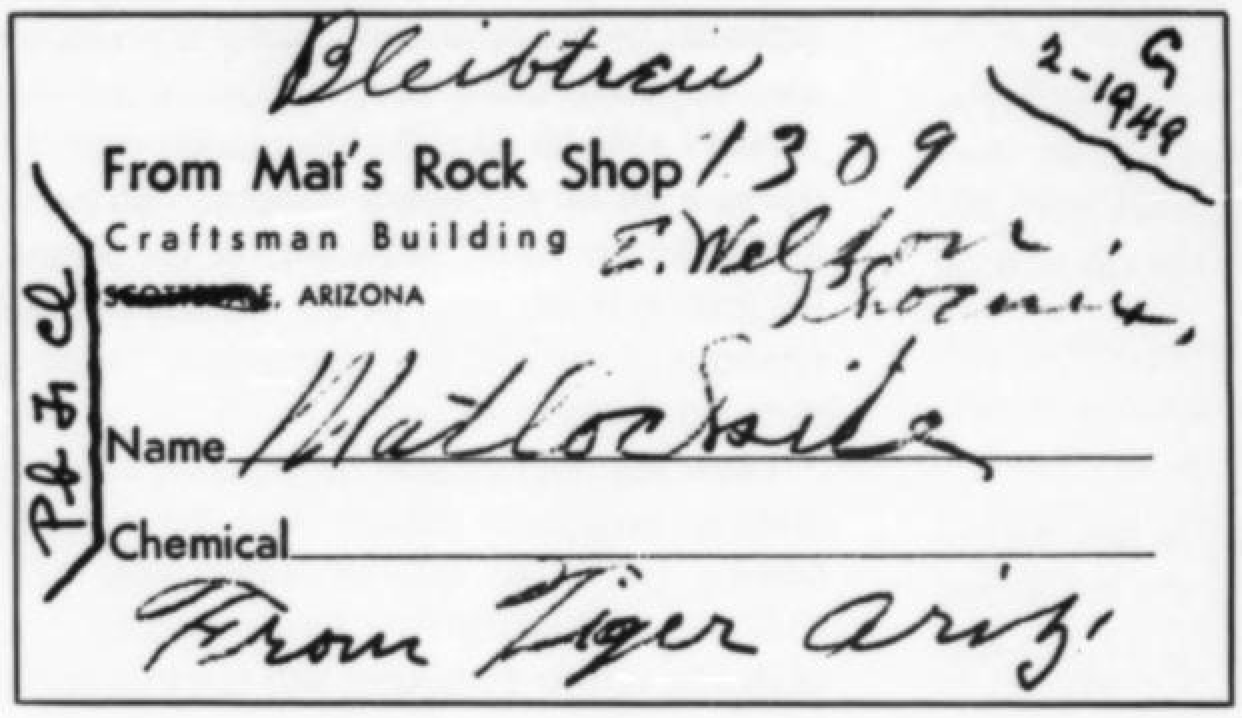
Mammoth Mine, Tiger, Arizona



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9
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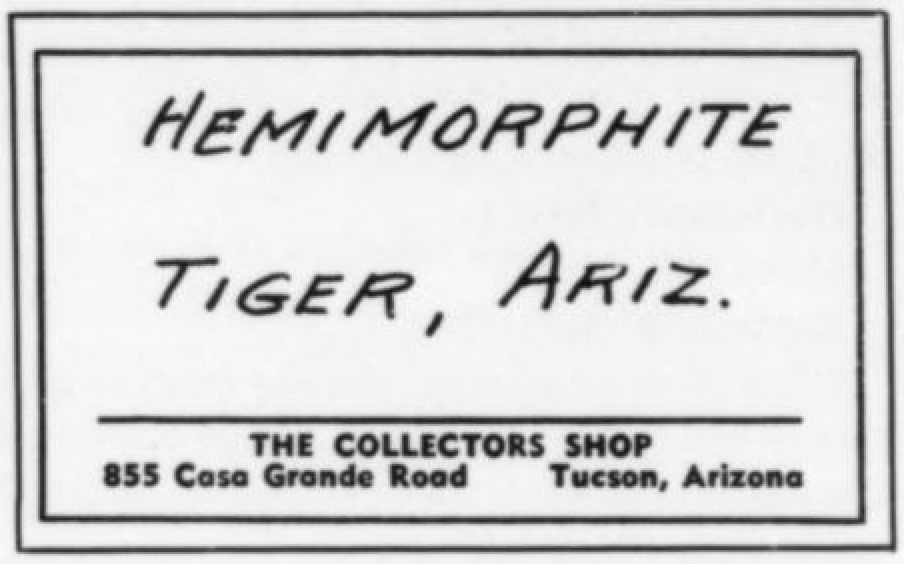
Chemical
From Tiger Ariz.



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TIGER, ARIZ.

THE COLLECTORS SHOP
855 Casa Grande Road Tucson, Arizona

Figure 43. **Mineral labels of prominent dealers in Tiger specimens: W. G. Griffith (top left), Scott Williams (upper right), Bob Roots (center right), Morris J. Elsing (bottom right), and E. P. Mattison (bottom left).**

of minerals from the Southwest without giving their localities. Those possibly from the Mammoth mine included "minium, ecdemite, carbonate of lead after sulfate, caledonite, white carbonate of lead, lead carbonate, black cerussite, descloizite, linarite."

The fine collections of Mammoth mine minerals at Harvard University and the U.S. National Museum are due in large part to Edwin Over, another Colorado dealer. His material during the late 1930's and early 1940's was offered through his partnership with Arthur Montgomery and their arrangement with Schortmann's in Easthampton, Massachusetts. Gordon credits him with the discovery of diaboleite and its rare associates on a trip to the mine in 1939.

N. Weiner operated a small mineral store in downtown Tucson, in the early 1940's, and advertised Mammoth mine minerals in *Rocks and Minerals* magazine.

Bob Roots in Denver handled enough of the Mammoth mine material that he had a special label printed, reproduced along with this article, a record of predominant species being produced during the 1940's. He was still offering considerable Mammoth mine material at the first several Tucson Gem and Mineral Society shows in the early 1950's.

Morris J. Elsing, a retired mining engineer, originally had a mineral store on Meyer Street in downtown Tucson, called the "Collectors Shop," where I purchased my first mineral specimens in 1948. He specialized in Mammoth mine and Bisbee minerals. This store was moved to W. Miracle Mile, then known as Casa Grande road, and later to his home in El Encanto Estates.

David Record also ran a mineral store, the "Mission Curio Mart" on S. Mission Road in Tucson, during this same period. After the Mammoth mine shut down, and before his premature death, he purchased several collections from miners; the best of this material was only recently given to the Arizona-Sonora Desert Museum by his parents, Claude and Bernice Motel.

Probably the best dealer contemporary with mining operations was E. P. Mattison, in Scottsdale, Arizona, at "Matt's Rock Shop" (sometimes spelled "Mat's"). He was a regular visitor to the mine, and supplied many prominent collectors and museum curators with their specimens. The bulk of his private collection was offered at a special sale in 1964 by Southwest Scientific Company, in Scottsdale (Scott Williams and David New, owners). A label printed for the sale is reproduced here. It is of minor interest because antlerite is not known to occur at the Mammoth mine. The best pieces from Mattison's collection were acquired by J. Rukin Jelks, and may now be seen at the Arizona-Sonora Desert Museum; several of these are among the best preserved specimens.

In later years, the mine management assigned one miner entirely to the collection of specimens, which were sold or given away at the main company office. I still have a mental picture of the several drugstore showcases full of wulfenite specimens which I saw on my first visit with my father to the mine in 1952, at the invitation of Jack Richards, mine manager. The lucky miner was W. George Griffith, whose card is shown. After the mine shut down, Griffith moved to Tucson where he dealt in Mammoth mine and Mexican minerals for many years. Most of his private collection of Mammoth mine minerals was later sold by Scott Williams, and a number of the best specimens were purchased by Harry Hill. Many of these are now in the collection at the Arizona State Fairgrounds in Phoenix.

PRESENT STATUS

The Mammoth vein was recently again worked by the present owners, Magma Copper Company, San Manuel Division. They began to open-pit the hill on which the Mammoth shaft was sited, in this case for silica flux for the San Manuel copper smelter. The nearby San Manuel mine is the world's largest underground block caving operation on a deep copper prophyry deposit. Their goal was to produce the silica flux required for copper smelting from as close by as possible, and if it also carried recoverable gold values, so much the better.

A contractor benched the hill at about 7-meter intervals, and a few truck-loads were transported weekly to the San Manuel shafts, railhead for the smelter. Continued operation was halted as the mining operator's ability to control the SiO_2 content for the fluxing material within desired limits was marginal. In general, no collecting was permitted except by a few designated company personnel, however I was allowed to check the exposed mineralogy on one occasion.

Although production was small, the vein was well exposed and there were limited occurrences of minerals for which the mine is already well-known. In the vein itself, amethystine quartz with micromount-sized crystals of wulfenite, descloizite, fluorite, hemimorphite, and cerussite were found. Several specimens of caledonite and linarite were recovered, apparently in dump material. Hexagonal white leadhillite on barite, almost entirely altered to cerussite crystals, was uncovered in the first old stope filling encountered.

Elsewhere on the property (collecting forbidden in recent years except on occasional company-permitted field trips sponsored by the Tucson Gem and Mineral Society, the Mineralogical Society of Arizona (Phoenix), and Friends of Mineralogy), the original Schultz gold mine open cut is capable of producing from the surface representative specimens of wulfenite, vanadinite, descloizite, and minor amounts of creaseyite and fornacite (which therefore could have been described any time during the past hundred years!).

The underground workings have not been entered by company personnel since shortly after the mine was closed. These were completely mapped geologically, and the property offered to contract mining firms. They concluded that insufficient ore was available to justify their efforts, taking into account the dangerous condition of the mine. With the more rigorous governmental safety rules in effect today, it is highly unlikely that the mine could ever be reopened.

Many of the workings filled with water shortly after the mine closed. This has now been drained in large part by the deeper San Manual mine nearby. Eventually the subsidence area above that property will encroach on the Mammoth mine workings, likely causing even more damage underground than now exists, if not complete collapse.

ACKNOWLEDGMENTS

Special efforts have been expended to preserve minerals from the Mammoth mine suite by Harvard University, and I thank Clifford Frondel and Cornelius Hurlbut for access to the collections and to X-ray diffraction equipment. I am also grateful to the U.S. National Museum, where Paul Desautels kindly allowed me to examine their holdings.

I thank John W. Anthony of the University of Arizona for helpful discussions and the use of X-ray diffraction equipment.

The J. Rukin Jelks collection housed at the Arizona-Sonora Desert Museum, was examined by permission of William Panczner, curator, with the assistance of Arthur Roe. Examination of the portion of the E. P. Mattison collection at the Los Angeles County Museum, Bob Gaal, former curator; and the Harry Hill and Joseph J. Strutzel, Jr. collections at the Arizona State Museum, Lee Hammonds, former curator, are gratefully acknowledged.

Many private collectors have assisted in my research by allowing me to examine and in some cases sample their specimens. These include J. Streeter, K. Robertson, J. Klotz, J. Nelson, R. Flagg, J. Hamel, J. Jago, M. Canty, J. Puckett, P. Sonnenberg, D. Boydsten, F. Valenzuela, and J. Ruiz. W. Epler of the *Brewery Gulch Gazette* in Bisbee kindly located early day photographs of the locality.

Personnel of the Mammoth-St. Anthony Mining Company, including E. B. Daggett, J. Richards and J. Strutzel, were helpful in allowing collecting of minerals from the property at various times over the years when the mine was in operation. K. Staley, H. Sweeney, L. Thomas and A. Cockle of the Magma Copper Company have provided helpful discussion and access to the property under San Manuel's ownership.

J. Anthony, S. Williams and R. Thomssen read the manuscript prior to publication, but errors and omissions are my own. C. Olsen and M. Scott kindly typed the various drafts of the manuscript.

REFERENCES (ANNOTATED)

Following are all references touching in any significant degree on the geology, history or mineralogy of the Mammoth mine deposits. Many contain only lists of species observed to that time with little further discussion. The PhD thesis of Nels Paul Peterson, and its subsequent publication, stand above all others as a description and reference to the deposit up to 1938. Unfortunately this work just predates the discovery of the rarer minerals for which the mine is so famous.

The most significant later papers are the formal descriptions of individual species, especially those of Palache and Gordon. While both hoped to publish a description of the mineralogy as a whole, this was never done. Nevertheless, Gordon left some notes and the crystal drawings which are here reproduced for the first time.

A term project was undertaken to study the collection of Mammoth mine minerals at Harvard University by Ira Dubins, Dan E. Mayers, and Henry E. Wenden. I came across a copy of their lengthy but undated paper in the files of Harvard University. Internal evidence indicates it must have been written about 1947 or 1948. Wenden and Mayers were earlier students at the University of Arizona. Mayers had been designated to collect underground at the Mammoth mine on behalf of the University of Arizona. Certain of their observations have been incorporated into this paper.

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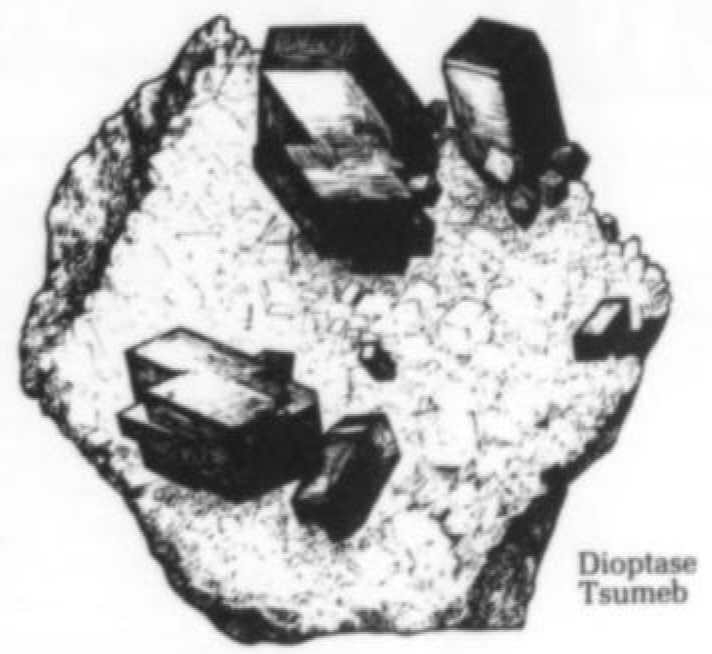
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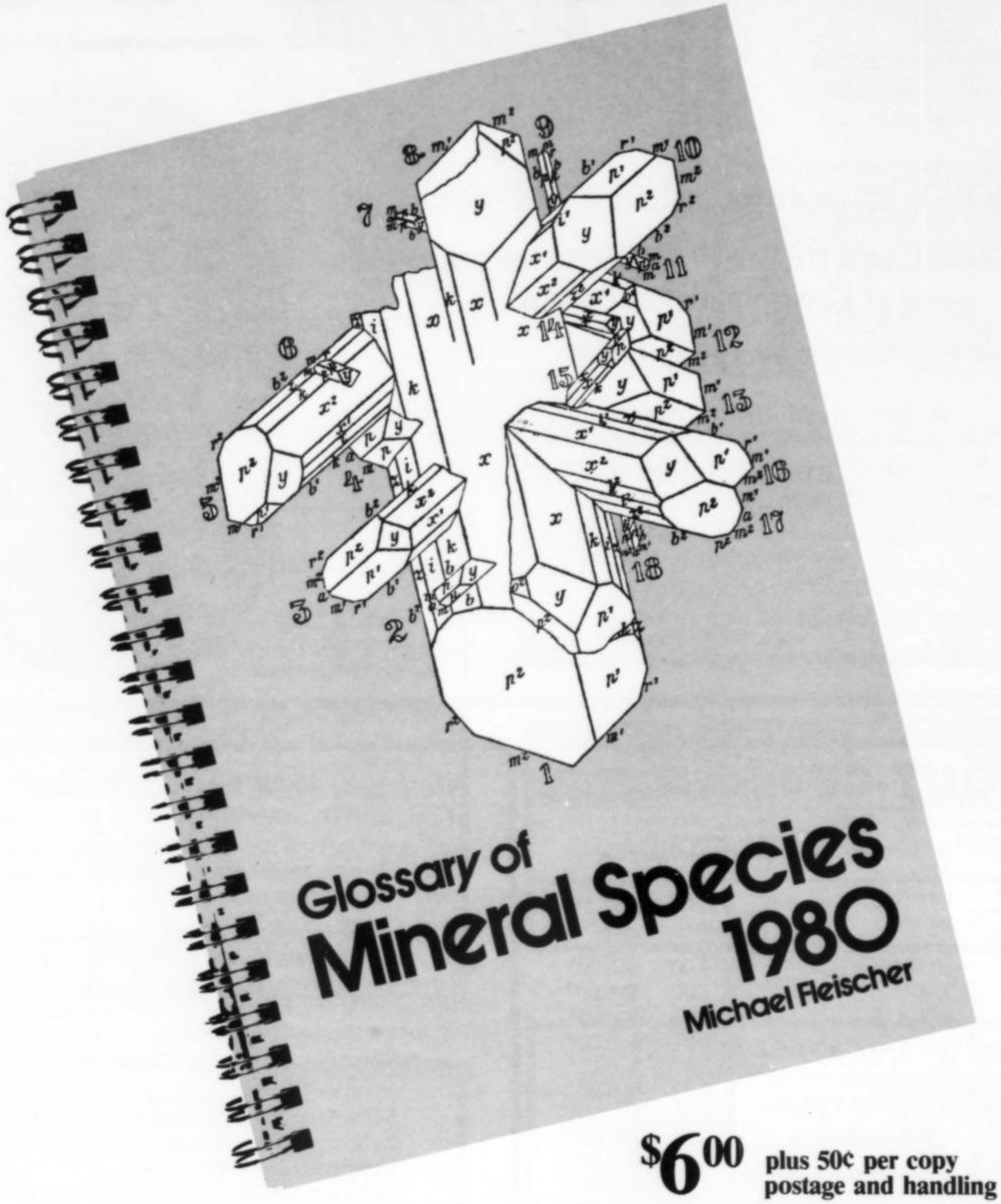
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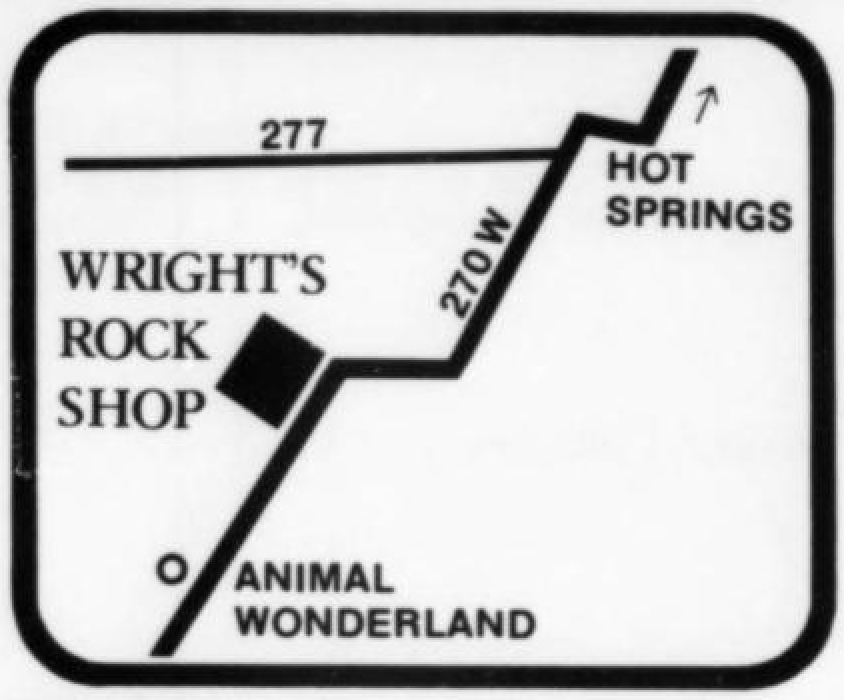

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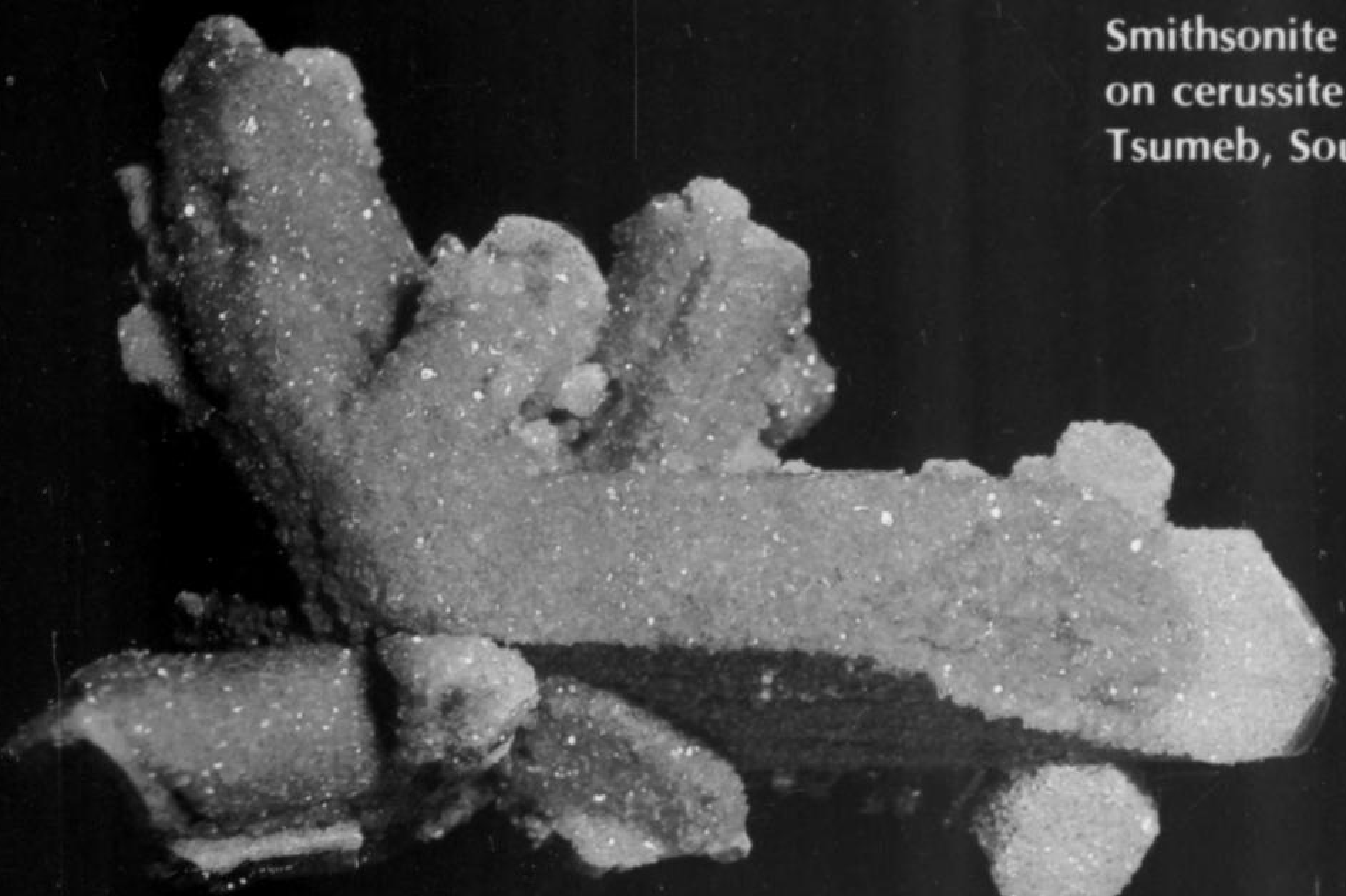

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What's New in Minerals?

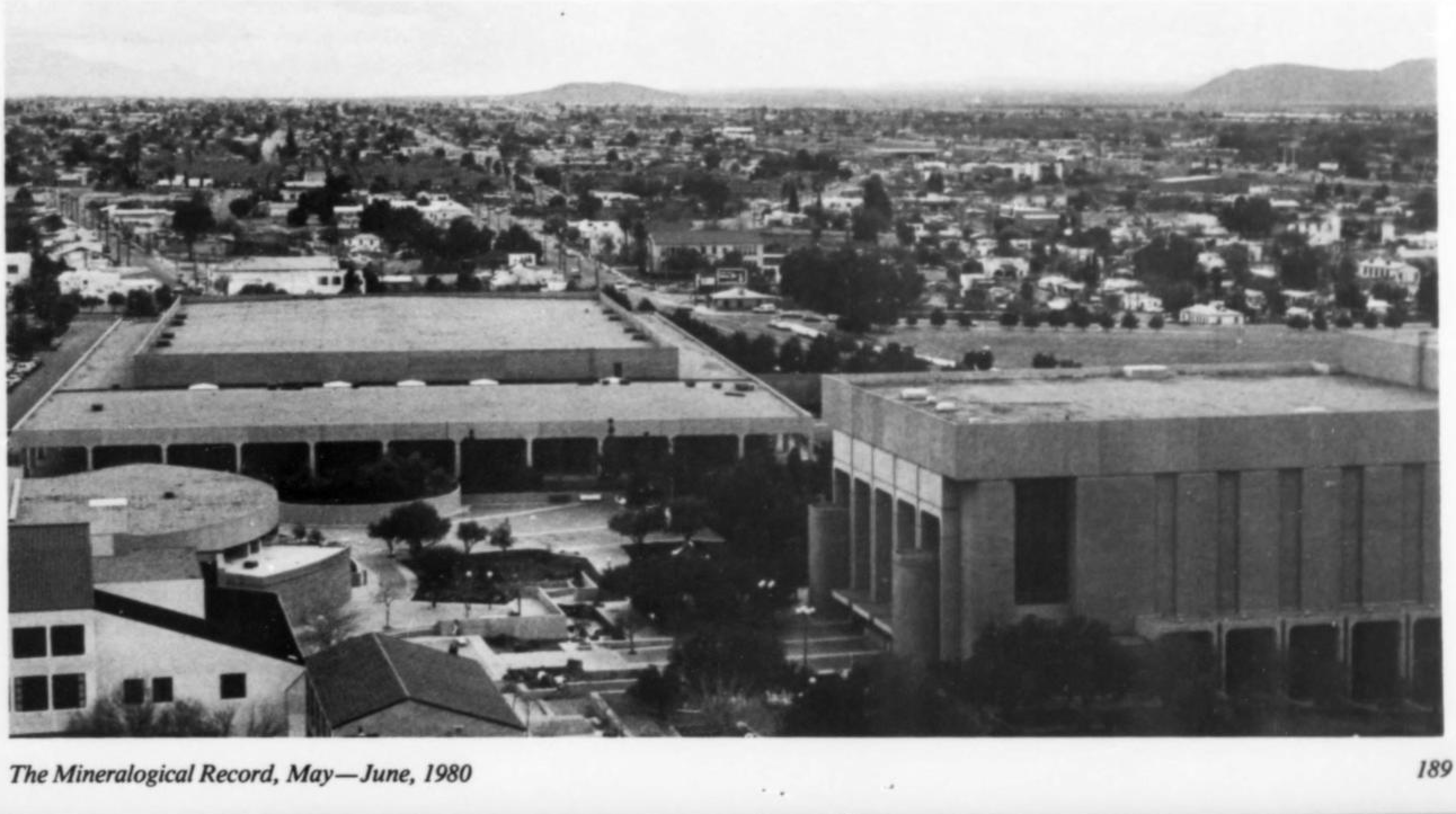
TUCSON 1980

Dealers began setting up in motel rooms and visitors began arriving in force on Friday, one week before the official Friday opening of the show at the Convention Center this year. Although quite a number of European dealers make a habit of visiting the Arizona and California dealers up to a month before the show, there were nevertheless hundreds of dealers arriving regularly early in the week who had not shown their material to buyers previously. The Desert Inn was the center of specimen selling activity as usual, with a mixture of dealers (specimen and lapidary) in the Sheraton Pueblo and Travelodge, and mostly lapidary dealers (with a few outstanding exceptions) at the Holiday Inn South, Holiday Inn North, and the Marriott. The Ramada, La Quinta and Motel 6 generally do not have dealers, although a few may have been hiding there.

Work has been proceeding lately at the Los Lamentos mines in northern Chihuahua, Mexico, and a fine new pocket of wulfenite made its appearance (largely through Gene Schlepp's "Western Minerals," but also through Van Scriver's and a few other dealers). The specimens are generally plates of intergrown crystals which have no matrix, and need none. The crystals reach about an inch across and 1/8 inch thick, with glassy luster and perhaps the finest, cleanest, most pleasing yellow-orange color ever seen in Los Lamentos wulfenite. Several hundred pieces of high quality were available, in all sizes, for prices ranging up to several hundred dollars. This was clearly the finest batch of wulfenite to hit the Tucson Show in many years. Each major discovery at Los Lamentos throughout the years has shown a habit and sometimes a color which is distinctive from other discoveries there, and this latest discovery carries on the tradition. At least a couple of dozen such "editions" of Los Lamentos wulfenite are now known, and it would be thrilling some year to see a display case filled with such examples, all labeled as to date of discovery. (Incidentally, the *Record* would like to have an article on Los Lamentos some day if a qualified author can be found.)

A sad story involving treachery and trickery at the Ojuela mine resulted in a couple of American dealers investing much time and money mucking out the adamite zone, only to be expelled when the zone was reached. Consequently, there was much newly collected adamite at the show, and at reasonable prices, produced by the new occupants who invested so little. A number of dealers carried the adamite, including Artrox (3901 Pershing Dr., El Paso, Texas 79903). The color is the typical yellow-green (none of the striking apple-green seen rarely in the past, nor the even rarer purple), and the quality was as high as any in the past, on the average. It was a good opportunity to fill a hole in one's collection. Adamite from the Ojuela mine is always abundant during the times it is being mined actively, but fine specimens become remarkably scarce almost immediately thereafter. Some collectors tend to yawn when they see ten or twenty flats of the same thing, but they usually regret their complacence later when fine specimens become unobtainable. The time to buy is when there is a glut on the market, however transitory.

Figure 1. **The Tucson Community Center (left), home of the annual Tucson Gem and Mineral Show. Music Hall on the right.**



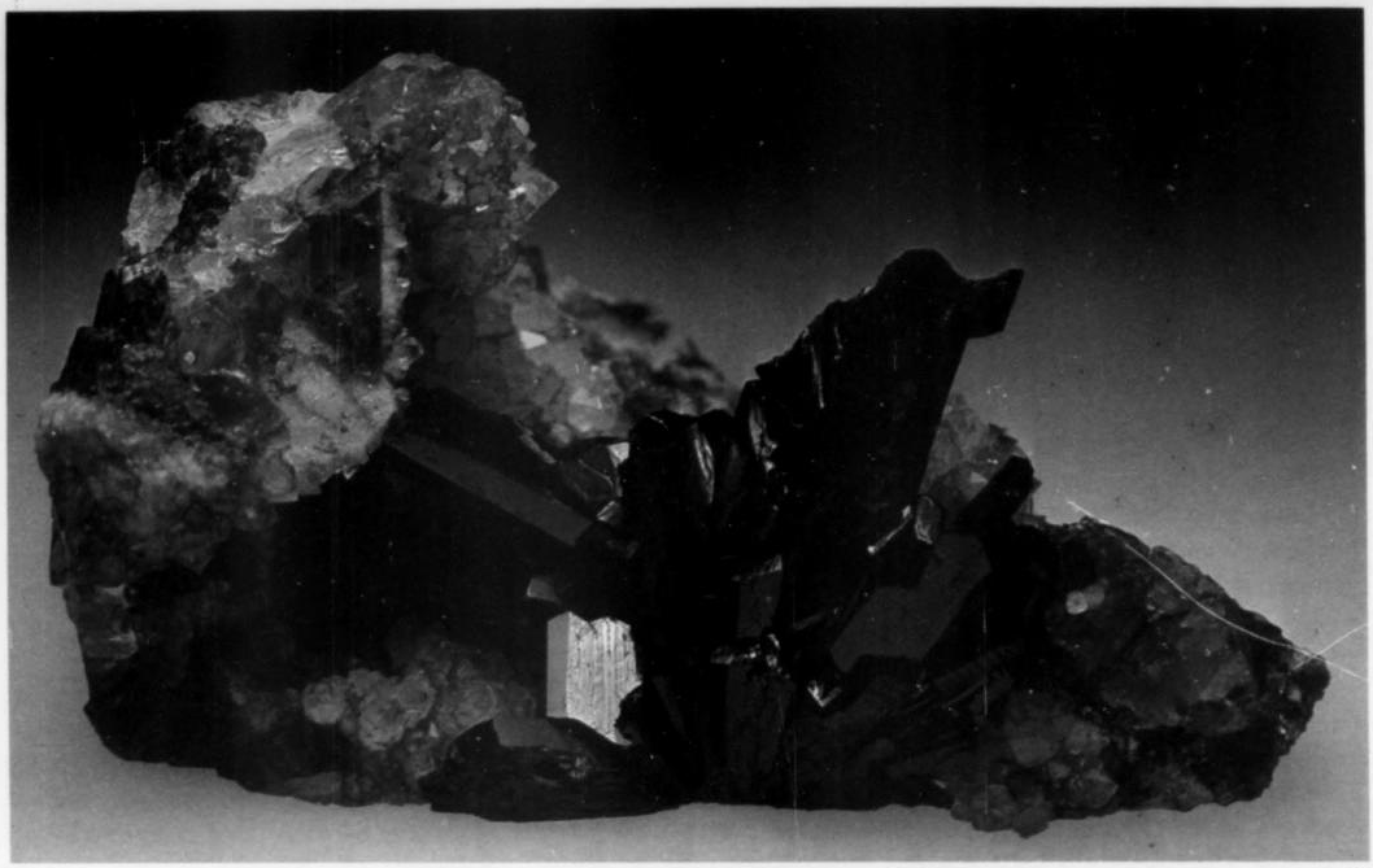


Figure 2. **Superb linarite crystals to over 1 inch on a matrix of linarite and chrysocolla-stained quartz and fluorite about 3½ inches long, from the Blanchard mine, Bingham County, New Mexico. Artrox Inc. specimen (Art Tatum and Delma Perry).**

Figure 3. **Wulfenite from the latest discovery at the Los Lamentos mines, Chihuahua, Mexico. The specimen is a flattish plate nearly 4 inches tall, having no matrix. Specimen loaned for photography by Van Scriver's minerals; now in the Jonathon Weiss collection.**

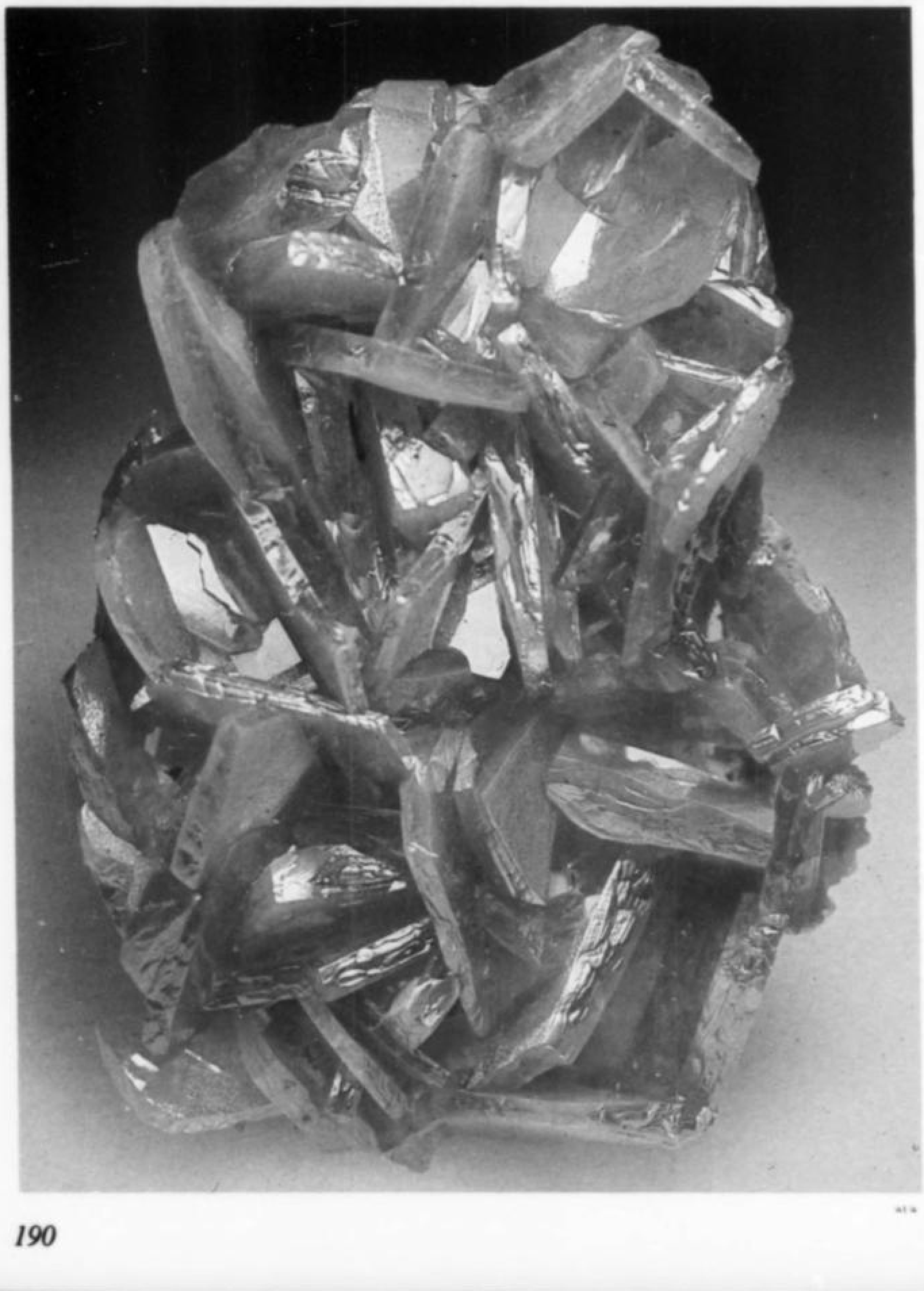


Figure 4. **A dazzling assemblage of wulfenite from the Red Cloud mine, Yuma County, Arizona, displayed by Ken and Betty Roberts. Owners of specimens are as follows, beginning with the top row, left to right: Robert Pederson (La Crescenta, CA), Robert Pederson, Gene La Berge (Oshkosh, WI), Kent England (Merced, CA), Stanley B. Keith (Tucson, AZ). Second row: Garth Bricker (Fallbrook, CA; self-collected), Harvard Mineralogical Museum (Cambridge, MA; purchased in 1938 for $22.50, an Ed Over piece); Smithsonian Institution (Washington, DC; insured for $20,000, an Ed Over piece). Third row: Tony Potucek (Denver, CO), Robert Pederson, Wendell Wilson (Tucson, AZ), Stanley B. Keith, Arizona-Sonora Desert Museum (Tucson, AZ). Bottom row: Brad and Nancy Van Scriver (Garden Grove, CA), Garth Bricker (self-collected), Cliff Krueger (San Francisco, CA), Martie Scott (Tucson, AZ), Morphet collection in the Los Angeles County Museum of Natural History (Los Angeles, CA). Other specimens in the case but not shown here included an excellent, late-arriving miniature belongong to Steve and Clara Smale (collected by Garth Bricker), and another excellent miniature belonging to Lou and Marcia Swartz (pictured in the previous issue of the** ***Record,*** **Figure 5, page 122). For comparative scale, the Harvard and Smithsonian specimens in the second row are both about 2¾ inches wide, the La Berge specimen in the center of the top row is just over 1½ inches across, and the Wilson specimen, third row center, is 7/8 inch across.**

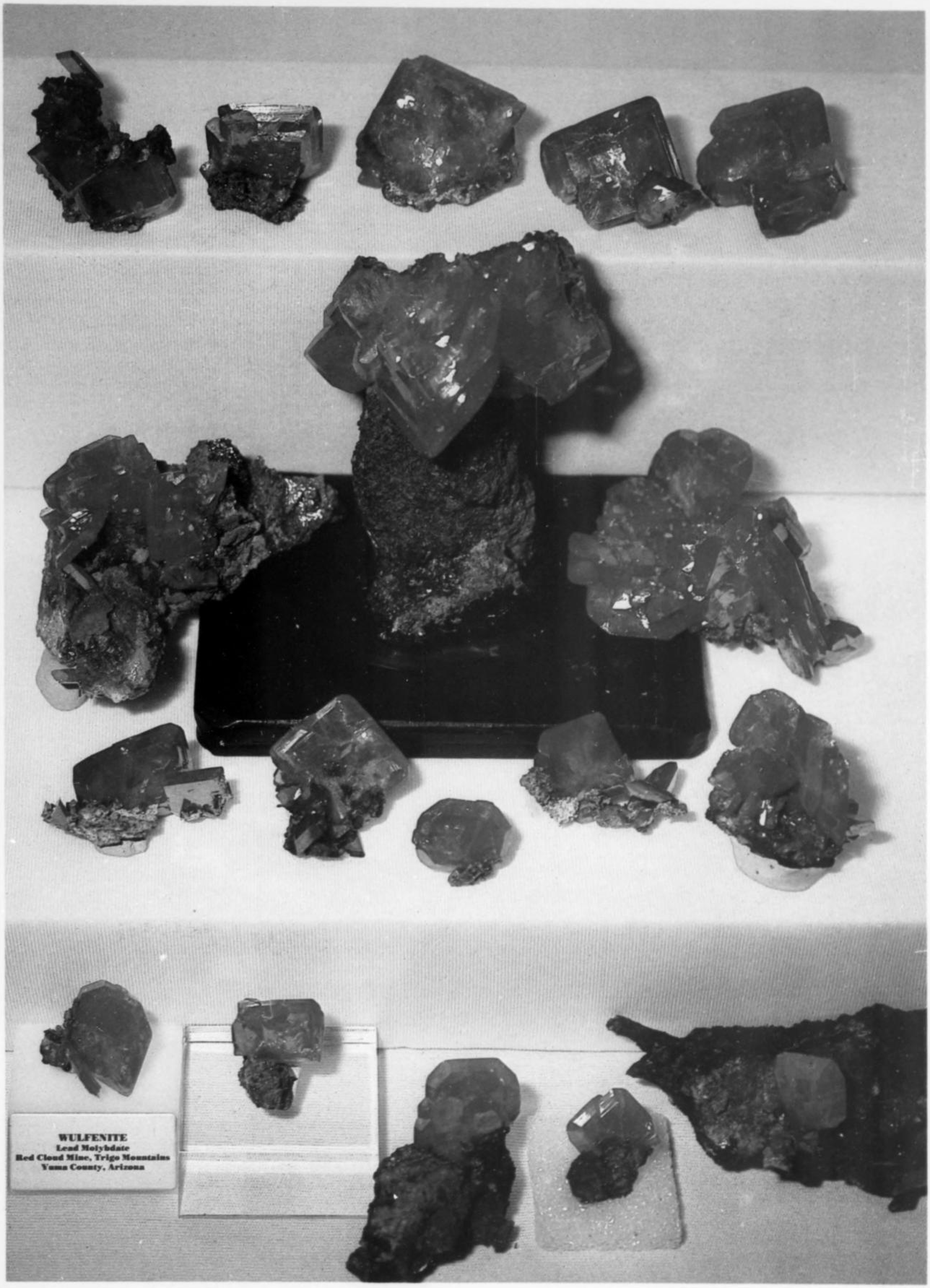

WULFENITE
Lead Molybdate
Red Cloud Mine, Trigo Mountains
Yuma County, Arizona

Figure 5. **Japan-law twinned quartz, 2¼ inches point-to-point on the twin, from near Duquesne, Arizona. Peter Knudson specimen.**

A truly surprising discovery (made since the time of last year's show but kept hidden) surfaced at Artrox. The Blanchard mine, Bingham County, New Mexico, has long been known for sky-blue fluorite and mediocre linarite as fine druses and smears. Not anymore. An incredible pocket of linarite yielded specimens with crystals to over 1 inch by ½ inch and more than ⅛ inch in thickness (bladed crystals), and nearly ½ by ½ by ½ inch (blocky crystals). One specimen carries a fine group of prismatic crystals each approaching ¼ by ⅛ by ⅛ inch. The best of these specimens (including the one pictured, and a superb small miniature purchased by Jonathon Weiss) may well rank as the best linarite known from any locality worldwide. Unfortunately the pocket was small, yielding only about five major pieces. Prices ranged into the low thousands, and the specimens sold promptly.

Peter Knudson and Tom Hughes collected about 30 fine specimens and 100 smaller pieces of Japan-law twinned quartz at a prospect about 1 mile south of Duquesne, Santa Crus County, Arizona. The twins range up to several inches, some with attractive green chlorite inclusions, and come in both "V" shapes and the much rarer bladed habit (flat blades, twin plane passing the long way down the crystal, little if any re-entrant angle at the tip). Bideaux minerals purchased most of the lot wholesale.

Richard Gaines brought along a flat or so of excellent veszeleyite found at the Black Pine mine, Philipsburg, Montana. The veszeleyite occurs as beautiful blue-green crystals to about ¼ inch on white quartz crystals. Gaines is currently preparing an article on the occurrence.

Herb Obodda once again had some nice Afghanistan material; he and his wife Monica were nearly trapped in Afghanistan when the Soviets invaded, but they managed to sneak out discretely . . . with a few specimens of course.

Pala Properties continues to market their tourmalines, and had several superb, gemmy purple fluorite groups from Spain, some of the best I've ever seen. Ed and Rex Harris (Delta, Utah), operators of the red beryl mine in the Wah Wah Mountains, brought along a batch of newly mined specimens ranging up to excellent in quality and the low thousands in price . . . their mine seems to be the only one in the area capable of producing that exquisitely clean, deep rose-red color. Vic Yount, and also Roberts Minerals and Jewel Tunnel Imports, brought along large and fine selections of Peruvian pyrite . . . again some of the best specimens I've ever seen.

And so it went, relatively few new discoveries, some old and famous producers conspicuous by their absence of new material, and a few other old localities enjoying a rebirth. Considering the large quantity of fine specimens in the recycled (previously owned) category, it was a satisfying selection that presented itself in Tucson this year.

The mineral chosen for special attention in the displays this year was pyrite, and the show hall fairly glowed with the reflections of thousands of cool-brassy colored crystal faces. Displays of pyrite included those of Rock Currier of Jewel Tunnel Imports (mostly Peruvian), Miguel Romero (Mexican pyrite), Arizona-Sonora Desert Museum (Arizona and Sonora pyrites), the Smithsonian Institution (worldwide locations), Victor Yount (Peru), Bob and Maudine Sullivan, Denver Museum of Natural History (Colorado pyrite), the Montana College of Mineral Science and Technology (Butte pyrite), the Medici-Ludlum-Pfaff-Hawes case of Washington state pyrite, and the cases for individual pyrite entries in the best-of-species competition.

Nearly stealing the scene among showcases was the case assembled by Ken and Betty Roberts. This case was conceived along the same lines as their case last year entitled "A Distinguished Gathering" . . . one species from one locality. Last year it was green pyromorphite from Corrèze, France. This year it was Red Cloud wulfenite. Especially in Arizona, very fine specimens of Red Cloud wulfenite have a heart-stopping effect. I have never seen such a reaction among passers-by during set-up of any case as I saw during the set-up of the Roberts' case. People rushing to and fro during the hectic pre-show preparations typically stopped in their tracks, eyes bulging, and made unintelligle choking sounds. When their voices returned, unprintable expressions of awe in hushed tones issued forth. Even the most jaded collectors and dealers suffered whiplash when first passing by this case.

Figure 6. **Dave Eidahl cheerfully walked away with both the McDole trophy and the Lidstrom trophy.**

For the Red Cloud case, as last year, the Roberts asked around among collectors to learn who had the best specimens. Then those people or institutions were invited to bring along their specimens to the show, and all were gathered together in one case. What sets this concept apart from other displays (such as the Tucson Show's own best-of-species competition) is (1) the specimens must all be from the same locality (preferrably the same pocket or zone), and (2) institutions and private collectors who might not be interested in competing or in bringing an entire case of specimens to a show are more willing to loan a single specimen for such a display. The chance to see the finest specimens of an occurrence brought together like this is rare and thrilling indeed. The Roberts are performing a service for Tucson show-goers which is nearly unprecedented . . . the chance to compare the *very best* of one particular thing, side by side, under identical lighting conditions, and the chance to be overwhelmed by it all besides.

For the 1981 Tucson Show the Roberts have asked me to announce that the chosen mineral and locality will be rhodochrosite from the N'Chwaning mine, South Africa (Hotazel mine specimens not accepted). Anyone who feels they have a truly superlative specimen is invited to send a slide of it to Betty Roberts (P. O. Box 1267, Twain Harte, CA 95383) and it will be considered. Also, those knowing of a fine specimen in some collection or museum are invited to pass the tip along to Betty for further investigation. In December invitations will be mailed out to the best specimens, sufficient in quantity to fill a case. Labels will then be prepared in accordance with those accepting the invitation. Here's hoping she needs a 6-foot case next year. (Last year it was a 4-foot case, and before that a 2-foot case.)

Among the many interesting cases was a case of hiddenite (many specimens), amethyst, and smoky quartz resurrected from the L. L. Smith Geology Museum at the University of South Carolina. This collection was moribund and almost disappeared from neglect until being recently rejuvenated . . . it's good to see that happen once in a while.

Pierre Bariand of the University of Pierre and Marie Curie (Sorbonne) in Paris brought along a unique display of photographs. These are large (12 x 16 inch) transparencies which must be back-lit and viewed from about 6 feet away, under which conditions they show a remarkable three-dimensional effect. The process has only recently been developed, and has nothing to do with lasers or holography. The full-color pictures of minerals were startling to look at.

Next year the best-of-species competition will center on calcite, a choice which should bring out some incredible specimens in large numbers. Will a rivalry break out between Elmwood and Cumberland? Will Tsumeb or Mexico attempt to steal the show? Make your plane (and motel!) reservations now.

Saturday night . . .

. . . was entertaining as usual. Peter Bancroft talked about six of the famous localities that will be in his forthcoming book (very tantalizing!). Then came the *Mineralogical Record* slide competition (winners shown in a future issue as space permits) . . . Eric Offermann pulled off the difficult feat (unprecedented in the competition) of winning both first and second place in the professional category. Not to be outdone, Dave Eidahl pulled off the equally unprecedented feat of winning both the McDole Trophy (for "best rocks in the show") and the Lidstrom trophy (for best single specimen). His Lidstrom trophy winner was the Colorado Quartz mine gold pictured full-page in the California issue a while back. Finally came what many consider to be the entertainment highpoint of the show . . . the *Record* auction. Special thanks are due the Tucson Show Committee for making the hall available to us; thanks also to Gary Hansen, A. L. McGuinness and John Patrick, our tag-team auctioneers, and the other volunteers who helped the auction run so smoothly this year: Pat Carlon, Ron Bentley, Walt Risch, Jim Logan, Tom Merckle, Bob Jones, Don Olson, Tom Gressman, Jonathon Weiss, my wife Carolyn, and (her first time in Tucson for the show) circulation manager Mary Lynn White.

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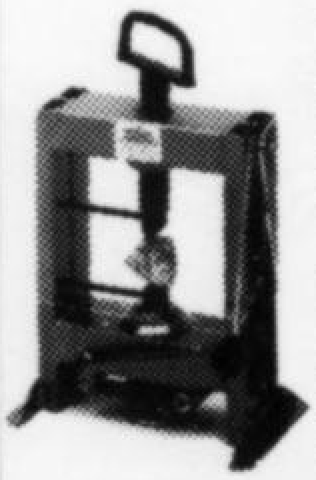

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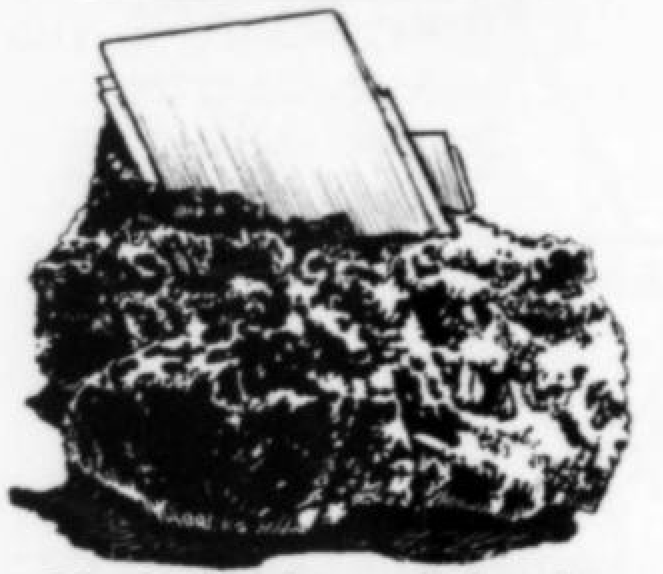

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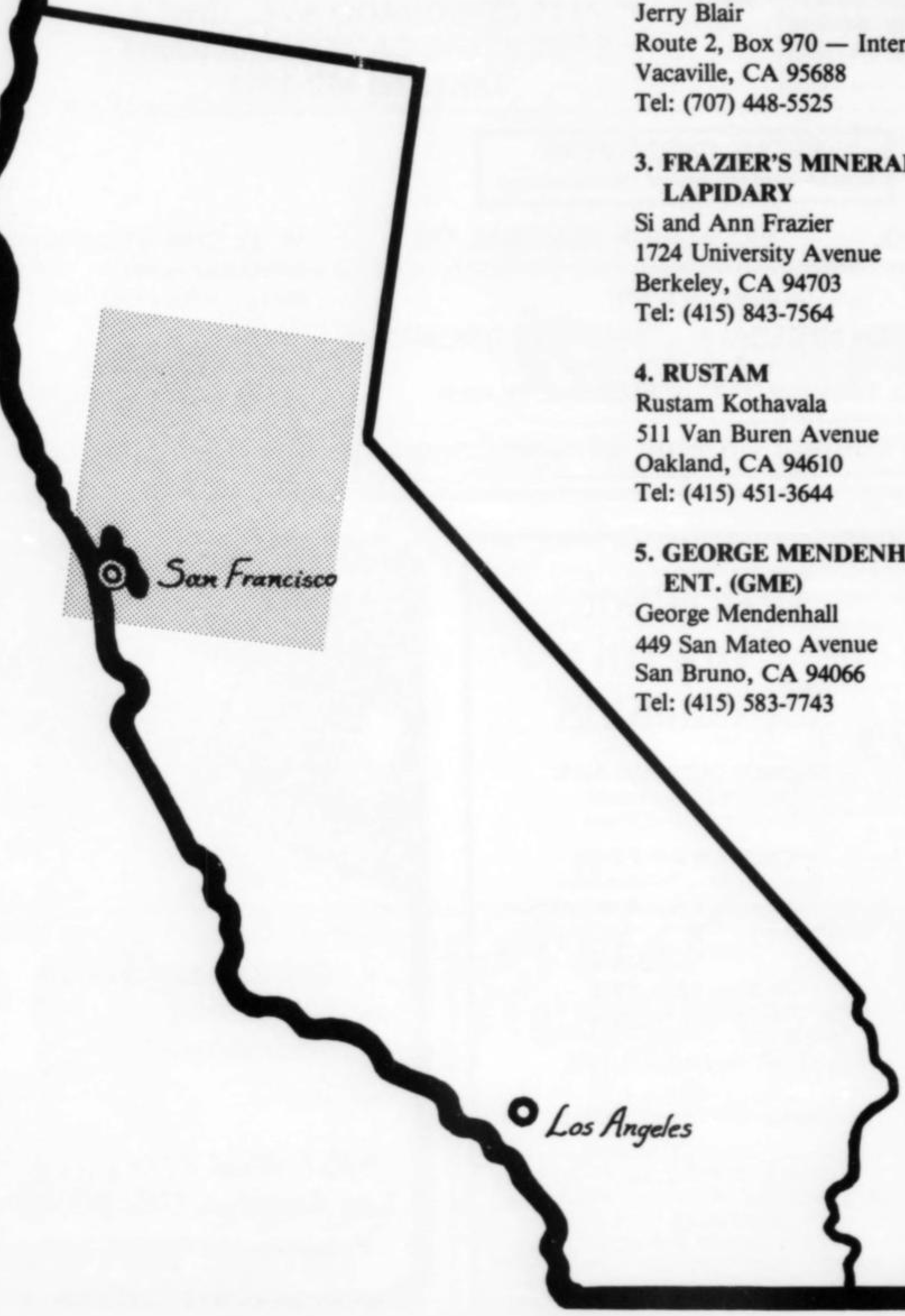
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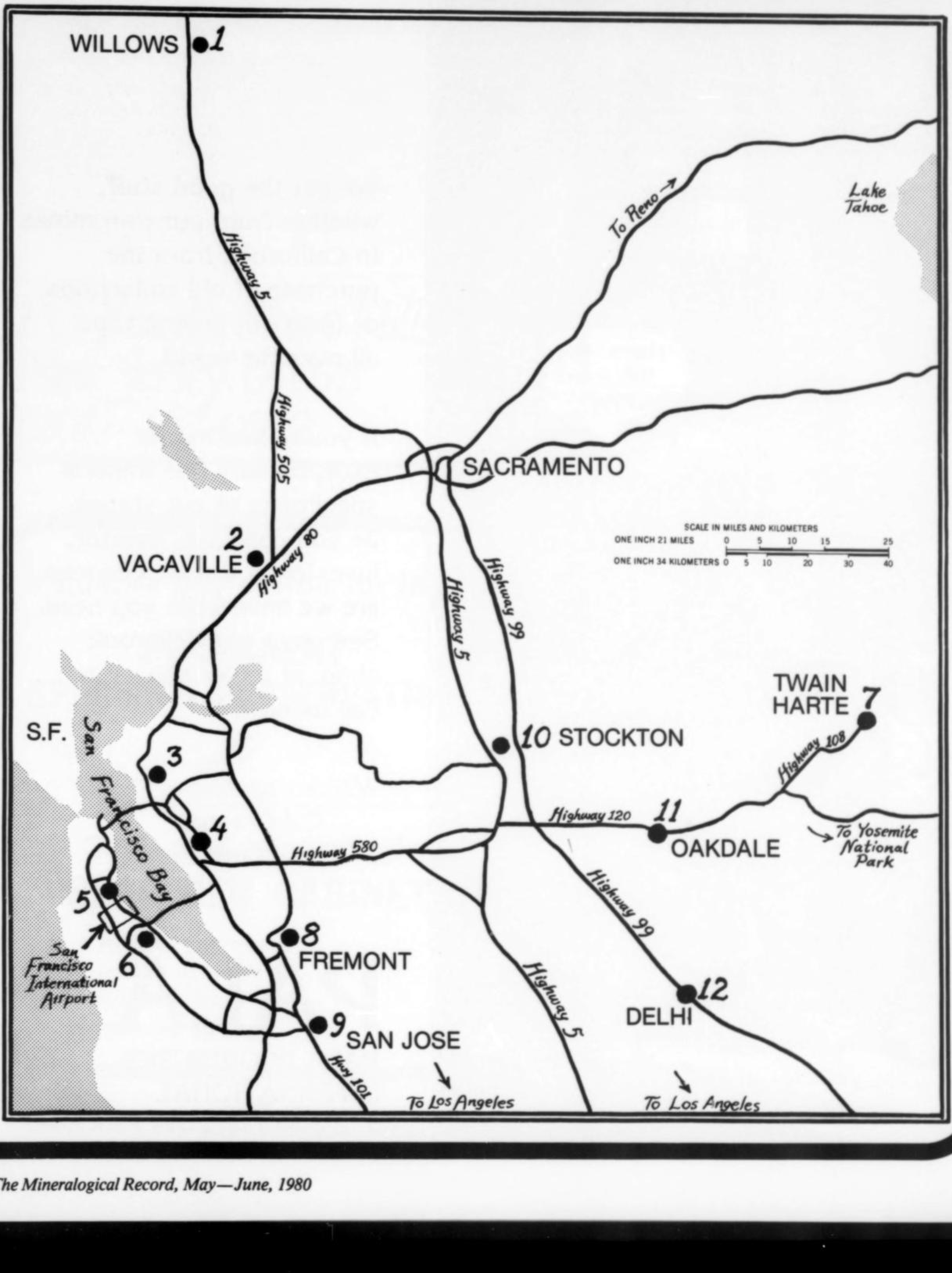

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EDINGTONITE

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New locality for EDINGTONITE, occurring as numerous white xls. from 1 to 8 mm long, on xline Calcite or rock matrix. Some specimens have double terminated xls. which show the unusual hemimorphic habit of the species.

Although EDINGTONITE is found in 5 different areas of the world, all of the other localities are depleted or have produced only a limited amount of non-terminated xls. The EDINGTONITE crystals from Ice River are among the finest examples of the mineral found in the world, and this is certainly a major find for the species!

MICRO to 3/8"	\$4, \$7, \$10.	2 X 2"	\$70, \$85, \$100, \$125, \$150.
½" to 1"	\$12, \$15, \$18.	2 X 3"	\$100, \$125, \$150, \$175, \$200.
1 X 1"	\$25, \$30, \$35.	3 X 4"	\$200, \$250, \$285, \$300, \$325.
1½ X 1½"	\$60, \$70, \$80, \$90, \$100.	4 X 5"	\$425.

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