# TSUMEB!

the
Mineralogical
Record

ISSUE 3 NUMBERED INDEPENDENTLY, BUT
ALSO INCLUDED IN CONTINUOUS PAGE COUNT.

# TSUMEB!

## THE WORLD'S GREATEST MINERAL LOCALITY

edited by
Wendell E. Wilson

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1977

Dedicated to all of the
world's miners, living or
dead, who have ever
stopped to save a
specimen.

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**Front cover:** Mimetite crystals, among the finest in the world, from Tsumeb. The crystals, from the collection of Gerhard Becker, Idar-Oberstein, West Germany, are each about 1.5 cm long. Photo by Olaf Medenbach.

**Frontispiece:** Oxwagon at the foot of the "green hill", the outcrop of the Tsumeb orebody, in 1905. (Archives, Swakopmund Museum)

**Back cover:** Mimetite crystals, among the finest in the world, from the same small pocket at Tsumeb which produced the crystals on the front cover. The specimen is from the Smithsonian Institution and bears crystals over 2 cm in length. Oil painting by Wendell E. Wilson, now in the collection of William and Karla Larson, Fallbrook, California.

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XI RESEARCH

# PREFACE

This book, nearly three years in preparation, is without doubt the single most comprehensive work ever published on Tsumeb. The seed was first planted when Dwight Weber suggested writing his article for publication in the *Mineralogical Record* magazine. The subject was so exciting that we eventually envisioned a project of larger scope. A list of desirable chapter topics was composed; in April of 1976 we began seeking out other knowledgeable authors and asking them to write specific chapters on subjects they knew best. Background chapters on history and geography were added to give perspective and a feeling for the country. Original research on Tsumeb minerals was solicited. With computer assistance, the 1147 Tsumeb specimens in the mineral collection of the Smithsonian Institution were located, studied and, in some cases, photographed to provide a reference base for editing and reconciling the work of the other authors. The concept soon outgrew the scope a regular issue of the *Mineralogical Record*; the result is the book you now hold in your hands.

The history has been summarized from the excellent but poorly circulated work by Söhnge (*Tsumeb, a historical sketch*) and has been brought up to date. Paul Keller, of the University of Stuttgart and a leading authority on the secondary minerals of Tsumeb, has contributed an illuminating and useful chapter on the paragenesis. Dwight Weber has compiled what is undoubtedly the most complete bibliography for the locality ever published. William Pinch, one of America's foremost species collectors and an accomplished part-time mineralogist, has described and discussed every species known to exist at Tsumeb; his descriptive list along with Weber's bibliography constitute an invaluable reference for both collectors and researchers. Charles Key, possibly America's top dealer in fine mineral specimens, has tapped his special knowledge to divulge the current resting places of many of Tsumeb's finest pieces, and also gives us a personal glimpse of Sid Pieters, Southwest Africa's leading collector. The photography has been assembled with special diligence and care. Many of the color photos and some of the black and whites are the magnificent work of German mineralogist Olaf Medenbach, a recent Ph.D. and coauthor of the first description of the new Tsumeb mineral *kegelite*. Additional work by master photographers Nelly Bariand, Werner Lieber, Julius Weber, and others was graciously donated. Many of the species known to occur at Tsumeb are pictured, thereby providing a comprehensive visual reference for sample identification, and a feast of visual enjoyment for collectors. The research chapter is a gold mine (or perhaps we should say a *copper* mine) of data; a trio of new species from Tsumeb are described for the first time, and the knowledge of several other species is expanded by noted mineralogists such as Peter Embrey of the British Museum (Natural History), Richard Erd of the U.S. Geological Survey, Fabien Cesbron of the Sorbonne, and Pete Dunn of the Smithsonian Institution. Finally, a chapter is devoted to the many mineral dealers from whom collectors, researchers and curators may obtain Tsumeb specimens. A mineral index is also provided for reference.

It is conceivable that Tsumeb, as a source of minerals for research and display, will not survive long beyond the publication of this work. It would indeed be unfortunate if our words became the epitaph of the greatest of localities. Nevertheless, the preservation and dissemination of information on Tsumeb would then be even more important. Hopefully this work will serve as a practical, valuable and educational reference to collectors, curators and mineralogists interested in Tsumeb, and will stimulate further study of this unique deposit.

Wendell E. Wilson
December 2, 1976.

# ACKNOWLEDGMENTS

Thanks are due to the photographers who graciously donated their superb skills, and the authors who worked diligently to produce high quality research and still meet our deadlines. Many of these people invested considerable time, expense and travel in order to make their contributions. Thanks also to Paul Seel for translating Paul Keller's chapter from German into English for publication here. The ultimate thanks must be reserved for two groups of people: the miners, collectors and curators who through the years have preserved so many Tsumeb specimens, and the people who have graciously donated to the *Mineralogical Record* much of the funds required to publish this book.

# I INTRODUCTION

by

**William W. Pinch**

Every once in awhile a book or an issue of a magazine comes along which is something special, something to put aside in a special place for reference and continued use, sometimes even to buy an extra copy of (by all means do so) and perhaps have hard-bound. This, the *Mineralogical Record*'s book on Tsumeb, I believe is just such a case. Many of the world's great localities have been the subjects of books and scholarly compilations but, until now, no such work has appeared on what is probably the greatest locality: Tsumeb, Southwest Africa.

In considering the importance of Tsumeb as a mineral locality one must examine several aspects. In so doing, I hope to demonstrate in this brief introduction that Tsumeb is most likely the greatest of the great and will probably remain so for a very long time. As collectors and scientists we all have our favorite localities, but let's put aside our personal preferences (mine included) and look at some facts.

Over the past couple of centuries many fine localities have at one time or another produced "classic" specimens which are well-known for their unsurpassed crystal size and quality and which are generally considered to be the finest specimens of their species ever found. Examples that come to mind include cinnabar from China, stibnite from Japan, silver from Köngsberg, chalcocite from Cornwall, proustite from Chanarcillo, manganite from Ilfeld, brazilianite from Conselheira Pena, torbernite from Musonoi, cuprite from Onganja, legrandite from Mapimi...it's difficult to stop. However it is interesting to note that when the average collector thinks of many of these localities only one or two species come to mind for each locality. Not so with Tsumeb! Not only do many different species come to mind, but many of "classic" proportions and quality as well. At least 26 species (discussed in Chapter VII by Charles Key) occur at Tsumeb in a quality and size unrivaled by any other locality, and these do not include well over 20 species that have yet to be found anywhere else. So the total number of examples of "best in species" from Tsumeb probably exceeds *50*. Many examples are not just a little better than specimens from other localities, but rather are *incredibly* better.

Another aspect to consider is the occurrence of rare species. Over the years a number of localities have come to be known for unique assemblages of rare species, usually a fairly large number of rare species, many of which are unique to that locality. A few that come to mind include Franklin, New Jersey; Långban, Sweden; Binnental, Switzerland; Saint Hilaire, Quebec; Shinkolobwe and Musonoi, Zaire; Llallagua, Bolivia; Tiger, Arizona; the Palermo mine, New Hampshire; and a new locality in northern Yukon Territory, Canada. Tsumeb belongs on this list as well; there is certainly no shortage of rare mineral species at Tsumeb. In addition to the above-mentioned number of species unique to Tsumeb, there are over 150 other species found there, many of them extremely rare.

"Unique" is a word that cannot be avoided in a discussion of Tsumeb. The rare minerals at Tsumeb are a reflection of the unique chemical and physical characteristics of the deposit. The enormous amount of germanium and gallium at Tsumeb has led to a unique suite of minerals which includes germanite, gallite, stottite, söhngeite and fleischerite among others. The unique structure and "plumbing" of the deposit combined with the chemistry to yield other rare species including alamosite, tsumebite, chudobaite, ludlockite, schultenite, schneiderhöhnite, tsumcorite, kegelite, otavite, and many more. Mineralogists will be working for many more decades to sort out the complexities of Tsumeb mineralogy.

Another idiosyncrasy of the deposit is the unexpected array of species varieties, many found nowhere else. Examples include plumbocalcite, cobaltocalcite, cuproadamite, Co-, Mn-, Pb- and Zn-dolomite, Ni-carrollite, Zn-olivenite, Co-smithsonite, Cu-smithsonite, Cd-sphalerite, Ge-sulvanite, Mn-willemite, and a number of others. Geochemists will be puzzling for some time over the peculiar conditions that could have produced so many unusual species and varieties.

One of the more interesting aspects to collectors, and one that is commonly associated with chemical varieties of species, is the tendency for many common species at Tsumeb to form in a wide range of colors. Examples include smithsonite (black, gray, white, pink, yellow, apple-green, deep green and turquoise-blue), willemite (white, yellow, blue, green), and wulfenite (colorless, gray, tan, sherry, reddish brown, orange, brilliant yellow, pale yellow, light blue and dark blue).

Tsumeb is a micromounter's paradise. A dazzling array of beautiful species, extremely well-crystallized, can be found in many combinations. A 2 x 3 inch specimen suitable for breaking up into micromounts may cost as little as five or ten dollars and may provide material for over 100 mounts. The many species found in large, superb crystals are invariably present as even more superb micro crystals.

Combined with all of the above extraordinary aspects of Tsumeb is the amazing abundance of specimens that have been produced. Literally *tons* of extremely fine specimens of a wide variety of species have reached the collections of the world. Cerussite is an example; at almost any mineral show one can find low-priced specimens of Tsumeb cerussite that are still better than the best cerussite from any other world locality. *High* quality specimens at single shows have numbered in the thousands. If cerussite from Tsumeb was taken off the market, what other locality could begin to take its place?

These days Southwest Africa is surrounded on all sides (except the ocean side) by political and social upheaval. Meanwhile mining progresses deeper and production costs continue to rise. Who knows how long the mine will continue to operate? Twenty years? Ten? Perhaps even less? Whenever it comes, the closing of Tsumeb will be felt the world over. Future collectors will consider *us* fortunate indeed to have been alive when Tsumeb was in its heyday. But the legacy of Tsumeb, of which this book is a part, will live forever. Let's enjoy it.

# II GEOGRAPHICAL AND POLITICAL BACKGROUND

by

**Wendell E Wilson**

Southwest Africa* is a vast, sparsely inhabited territory bordering the southwestern Atlantic seaboard of Africa. It is bordered by the Republic of South Africa on the south, by Botswana on the west, and by Angola on the north. A narrow strip of land (the Caprivi Strip) belonging to Southwest Africa extends to the northwest and contacts Zambia.

The total area of Southwest Africa, 318,261 square miles, is just a little under one tenth the area of the United States, but Southwest Africa's population of about 1,000,000 is less than one two-hundredth of the U.S. population. Southwest Africa's population consists of about 10% whites and 90% non-white peoples belonging to 10 major native tribal groups of varying descent.

Nearly the entire expanse of Southwest Africa, except for the extreme northern and southern portions, is desert or semi-desert. The Namib Desert, with the highest sand dunes in the world, extends the length of the seacoast, and the Kalahari Desert partially covers the central eastern and northeastern portions of the country. Most of Southwest Africa is characterized by harsh and forbidding territory lacking perennial rivers; rainfall is low, irregular, and ineffective, resulting in prolonged droughts.

The central plateau of Southwest Africa lies inland from the Namib; varying in elevation from 1000 to 2000 m, it offers a diverse landscape of ragged mountains, rocky outcrops, sand-filled valleys and plains. Rainfall in the Tsumeb area averages about 500 mm (20 inches) per year, and makes this one of the wetter parts of the country, relatively speaking (for comparison, rainfall at Tucson, Arizona, in the Sonora Desert, averages

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*The punctuation of the country's name has never been standardized. Variations include *Southwest Africa, South West Africa, South-West Africa*, and the pre-war name *German Southwest Africa*. Non-English varieties include *Südwestafrika, Südwest Afrika, Süidwes-Afrika, Deutsch-Südwest-Afrika, Deutsch Süd-West-Afrika, Deutsch Südwestafrika*, and *Deutsch-Südwestafrika*. The first-mentioned form will be used here because it follows most closely from the majority of the German versions, and because, conventions aside, it is grammatically the most correct form of the English word "southwest." It is also the form preferred by many mineralogists, including Palache, Pough and Strunz.

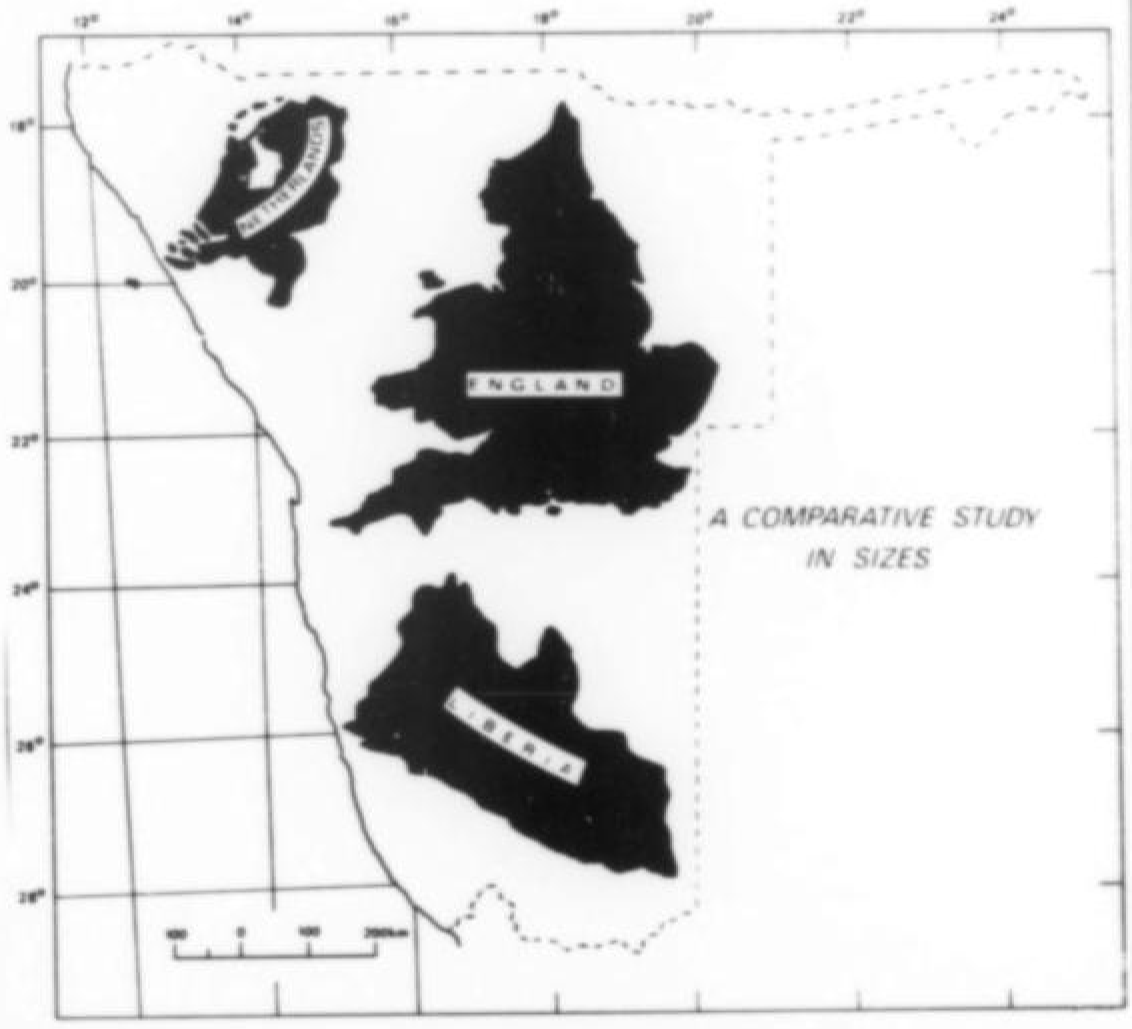

*Figure 1. (opposite page)* **The Namib Desert on Southwest Africa's West Coast where the highest sand dunes in the world have been found. (Photo courtesy of the Director of Information, South African Consulate-General.)**

*Figure 2. (above)* **Southwest Africa's size relative to other countries. (Map courtesy of the Director of Information, South African Consulate-General.)**

*Figure 3. (above right)* **The location of Southwest Africa. (Map courtesy of the Director of Information, South African Consulate-General.)**

*Figure 4. (right)* **Southwest Africa; Tsumeb is near upper center. (Map courtesy of the Director of Information, South African Consulate-General.)**

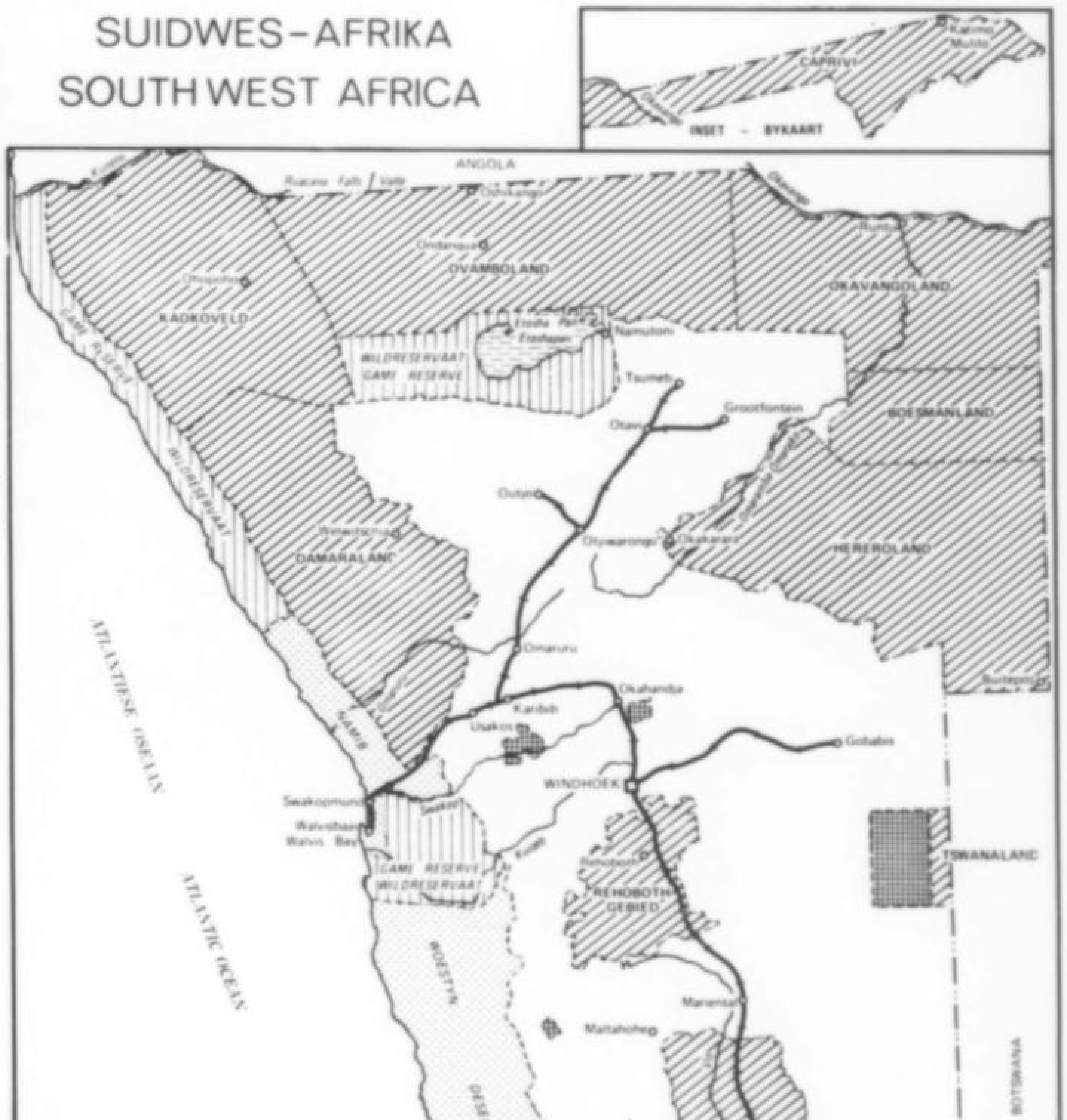

*Figure 5.* **An Ovambo woman in traditional headdress and necklace. (Photo courtesy of the Director of Information, South African Consulate-General.)**

*Figure 6.* **Herero woman in traditional dress adopted from early German settlers. (Photo courtesy of the director of Information, South African Consulate-General.)**

8-16 inches per year). Agriculture and industrial development in Southwest Africa are seriously hampered by lack of water; only 1% of the country is suitable for normal dry-land cropping, and the grazing areas have an extremely low carrying capacity. The average summer temperature in the Central Highlands ranges from 72° to 77°F; temperatures in the Kalahari average 88°F. Winter temperatures average around 60°F in the Tsumeb area.

The political status of Southwest Africa has been debated since the formation of the United Nations and the dissolution of the League of Nations, which granted South Africa a mandate over Southwest Africa at the end of World War I. The arrangement, eventually incorporated into the Treaty of Versailles, specifically made no provision for the revocation of mandates or the substitution of mandatories, nor for payment of the mandatory's expenses by other League members. South Africa has consistently maintained that (a) it is administering Southwest Africa to the benefit and improvement of all of its citizens, and (b) that no other country or organization of countries has any jurisdiction or power over South Africa's relationship with Southwest Africa. The United Nations, which has become increasingly dominated by Third World countries unsympathetic to Western-style, white-dominated governments, disagrees doggedly with both of these assertions and has pushed relentlessly for the removal of South African control from Southwest Africa. The United Nations declared an end to the mandate in October of 1966, and since that time has considered South Africa's administration of the territory to be "illegal." In 1968 a resolution was passed in the United Nations by which Southwest Africa was renamed "Namibia"; the Security Council was requested to take effective measures to insure the immediate removal of the South African presence from the territory and to secure its independence. Resolutions strongly condemning South Africa have been repeatedly passed since then. South Africa has stated that it is for the inhabitants of Southwest Africa to determine their own future. The United States has traditionally supported South Africa, probably in order to protect Western mining interests, chiefly in copper and uranium.

Recently the United Nations passed a resolution endorsing "armed struggle" to end South African control...and this by an organization supposedly devoted to the peaceful resolution of international disputes! While other parties, including the U.S., attempt to find a peaceful solution, the United Nations proposes violence.

Although negotiations seem headed inexorably toward Southwest African independence, there are difficult obstacles to be overcome. Not the least of these are South Africa's rigidity and unwillingness to make good its promise of independence, and the Marxist South West African People's Organization's desire for a guerrilla war that would eventually put the Ovambo tribe in complete power. Most of the other tribal factions seem amenable (even apathetic) to a peaceful, gradual transition of power; such a transition should have a minimal disruptive effect on the economy (including the Tsumeb Corporation) and is the most probable future course for the country.

# III HISTORY

by

**Wendell E. Wilson**

Portuguese navigators landed along the coast of Southwest Africa during their voyages of discovery in the 15th and 16th Centuries but never developed an interest in the territory. In 1652 Jan Van Riebeek landed at the Cape of Good Hope (to the South) and established a colony; through the end of the 17th Century the Governor of the Cape sent sailing ships to periodically survey the coastline.

In 1793 the Cape Governor claimed several Southwest African coastal areas for the Netherlands; when the Cape became a British possession in 1795 these areas also became British. Shortly thereafter missionaries, traders and hunters began to settle and explore the territory.

The German trader, F. A. E. Lüderitz, purchased a section of the Southwest African coast from a Nama chief in 1883, and asked the German Government for protection of his property. Following Anglo/German negotiations, Lüderitz' property became a German protectorate. The Germans gradually extended their boundaries by making treaties with friendly chiefs until eventually the entire area, subsequently known as German Southwest Africa, became part of the German protectorate.

German control continued until after the outbreak of World War I (1914-1918). On July 9, 1915, the German garrison surrendered to South African forces. The territory was under South African Military Government until 1920 when the League of Nations granted South Africa a mandate over Southwest Africa. South African administration of the territory has become increasingly controversial since the League of Nations was dissolved and the United Nations formed in 1945 (see previous chapter).

## EARLY HISTORY OF THE OTAVI AREA

The technique of smelting copper ore (malachite) simply by adding pieces of it to a very hot fire and allowing the molten metal to collect underneath was known to the Mesopotamians before 4000 B.C. These techniques were probably introduced into Southern Africa by immigrants from the North before 500 A.D. The immigrants, who became the Bergdama tribe, were apparently "Hamites" of part Bushman blood by intermarriage. Small smelting furnaces were constructed, sometimes 30 at a time, and measuring about 28 inches high and 15 inches in diameter. They were stoked with wood and malachite, air was blown in using goat-skin bellows, ritual dancing and singing took place, and after about an hour and a half the furnace was broken open to reveal a 15-pound cake of copper. The remains of such smelting sites have been found around Gross Otavi, Otjikoto (just 20 km from Tsumeb), and elsewhere.

The first written record of copper mining in northern Southwest Africa was recorded by Sir Francis Galton in his diary in 1851. While on a journey through Ovamboland, Galton, Charles Andersson and I. Allen camped at Otjikoto Lake, about 19 km from Tsumeb, and observed groups of natives transporting copper ore. The ore later turned out to have been mined at Gross Otavi (Nageib). In 1857 Rhenish missionaries camping near Otjitjika observed Ovambo men transporting copper ore in neatly woven baskets weighing 90 pounds full. H. Hahn, one of the missionaries, eventually learned that the ore was being transported to Ondongua from copper deposits in the Otavi range kept secret by Chief Kangombe of the Bushmen tribe, and that about 60 tons a year were being produced. A hunter named Brooks mentioned finding a copper mine to an American trader, Gerald McKiernan, and his English partner, C. C. Thomas; they located the site at Gross Otavi while on a hunt.

In 1885 the trader and elephant hunter Will Worthington Jordan purchased a tract of land from Bergdama Chief Kambonde, who wished to keep the Herero people out of the Otavi Mountains. The purchase covered an area of about 50,000 square km, including the Tsumeb site (as yet undiscovered by Europeans); the selling price was £300, 25 rifles, an immunized horse, and a barrel of brandy. The area purchased by Jordan was christened *the Republic of Upingtonia*; Jordan gave farms away to settlers but retained the mineral rights. These developments upset the Herero Chief Maharero, and eventually Jordan was murdered. Robert Lewis, a confidant of Maharero who assisted in this overthrow, was awarded the mineral rights for a period of 20 years, in 1885. He was given a lease on the Otavi mine and anything else within a 20-mile radius for 30 years, for an annual fee of £10 plus a small royalty per ton of ore exported.

Southwest Africa had been declared a protectorate of Germany by Otto von Bismarck in 1884; about a month after Lewis received his grant from Maharero in 1885, Maharero signed a treaty with Reichskommisar Dr. H. Göring, and a local German administration was established at Otjimbingwe. By the end of 1886 the protectorate had been extended to include the Republic of Upingtonia. Various intrigues followed, at one point threatening to turn the protectorate over to England, but the Germans retained control.

## DISCOVERY OF TSUMEB*

A group of German financiers developed an interest in the exploration for minerals in Southwest Africa, and formed the South West Africa Company on August 3, 1892. The company obtained a concession from the German government; part of this agreement stipulated the eventual construction of a railroad from the coast inland. It was also stipulated that preference was to be given for a period of ten years to German settlers in Grootfontein and the surrounding area. That same

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*ORIGIN OF THE NAME

*Tsumeb* apparently originated from the Herero word *Otjisume*, meaning "*the frog place*" or "*place of the green algea*," in reference to the green color of the outcrop. The Bergdamas adopted the name, dropping *otji-* ("*the place*") and adding the suffix *-b* to make the masculine form in the Nama-Bushman language, yielding *Sumeb*. First reports of the South West Africa Company listed the locality phonetically as *Soomep*, which was inexplicably changed to *Tsumeb* a few years later.

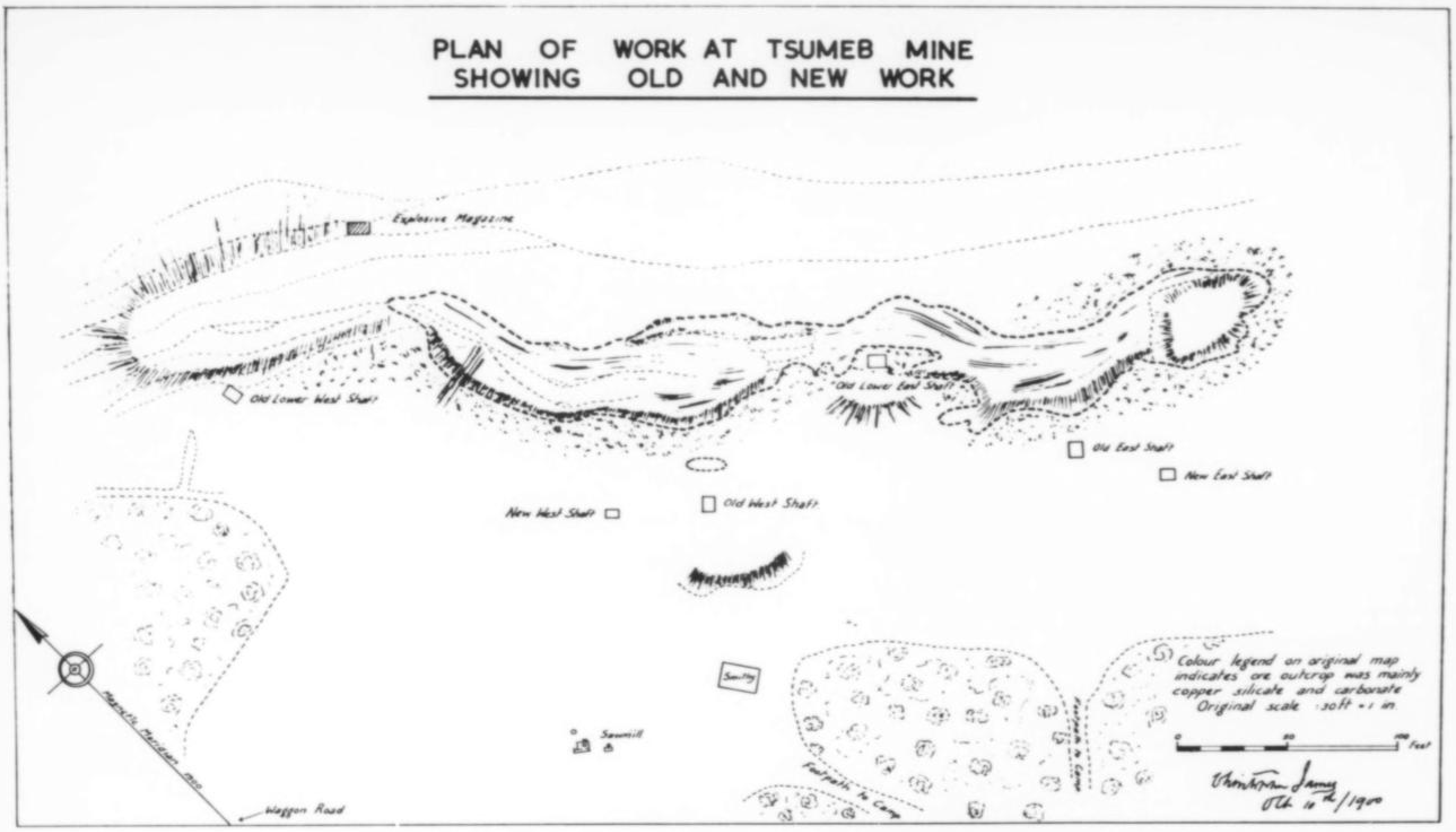
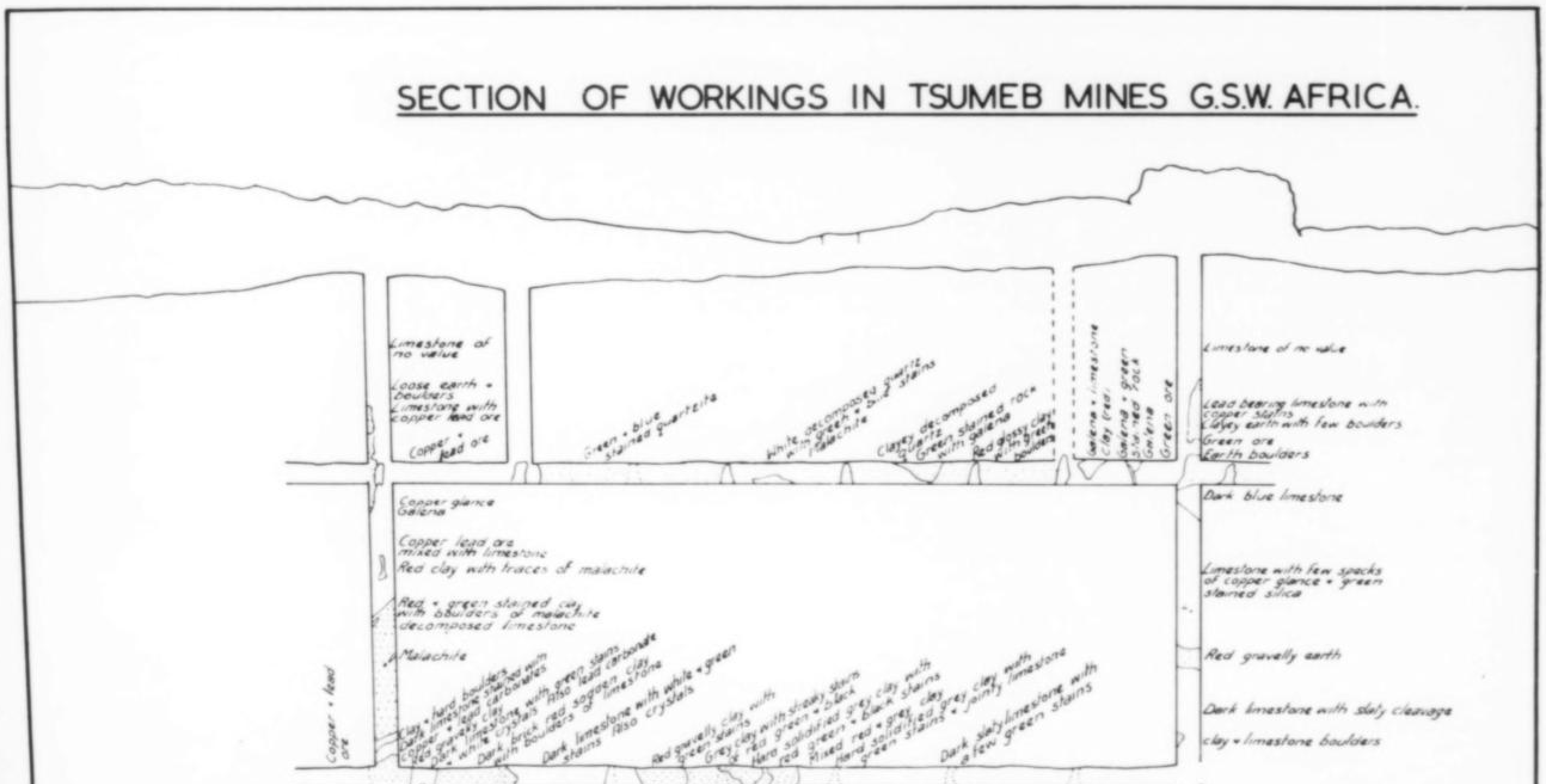


*Figure 1. (above)* **Plan showing four shafts alongside Tsumeb ore outcrop sunk by M. Rogers in 1893. Drawing done by C. James in 1900. (Tsumeb Corporation Ltd.)**

*Figure 2. (below)* **Longitudinal section showing development workings of the Tsumeb ore-body and geological notes made in August, 1901, by C. James after completing his investigations. (Tsumeb Corporation Ltd.)**



year the South West Africa Company sent an expedition under Matthew Rogers to investigate ore occurrences.

After some trouble with the natives, Rogers succeeded in reaching the mines at Gross Otavi and Klein Otavi (Kombat). He had heard rumors that there were other deposits in the area which Bushmen had worked for copper and, on January 12, 1893, he succeeded in finding the Tsumeb outcrop.

On January 21, 1893, Rogers wrote to the board of directors in London:

> "...in the whole of my experience I have never seen such a sight as was presented before my view at Soomep, and I very much doubt that I shall ever see such another in any other locality...The outcrop is in a valley formed by gradually sloping hills. As if the subterranian forces had made one sudden and special effort to force an entrance through the crust of the earth, a large rent is made. This rent has been filled in probably by aqueous solutions with minerals, having as its chief matrix quartz. In this instance the minerals, as far as can be seen, are different ores of copper and lead. In process of time...by...erosion and denudation, the surrounding strata composing the containing rock have been removed, leaving the fissure vein standing in an inclined position...in some places being 40 feet in height—with the green and blue colors of chrysocolla conspicuously covering it. By various causes the hard quartz matrix has been shattered and rent, and the smaller fissures again refilled with the same minerals. ...on first seeing such a grand and prominent outcrop I could scarcely conceal my astonishment and delight...few mineral outcrops present such exceptional indications as this one."

This was the first professional report on what was to become one of the world's most famous mineral deposits.

On January 16 Rogers met with Johannes Kruger and a local native (Winn of Ghaub) who claimed controlling rights over the copper deposits by an earlier discovery. A deal was concluded to allow mining on the condition that compensation was paid.

Controversy over the rights continued, however, and the local natives could not agree among themselves who really owned the mining rights. The chief of the Hereros claimed that Robert Lewis still had the rights (the natives liked the English but did not like the Germans). The Hottentots claimed they owned the rights, and did not recognize the Herero claims. The Ambos, Bushmen and Bergdamas made similar complaints. Various other difficulties and arguments continued until 1895 when Landeshauptmann Major Leutwein arrived at Grootfontein with 70 armed troops and 50 Herero horsemen. The final documents were signed in 1897.

## INITIAL DEVELOPMENT

Preliminary exploration work in the Otavi area was expensive, and further investments were needed to begin production. Part of the South West Africa Company was subsequently refinanced and reorganized into a new company, the *Otavi Minen- und Eisenbahn-Gesellschaft* (Otavi Mining and Railroad Company), conveniently referred to as *O.M.E.G.*, in 1900. In that same year the company sent a well-equipped expedition consisting of 33 miners and chief engineer Christopher James; they eventually spent about £50,000 proving the copper deposit at Tsumeb. James found the timbers in the exploratory shafts rotten and useless, and the buildings of Rogers in ruins.

So little water was available that log huts had to be constructed rather than mud brick buildings. Otjikoto Lake, the nearest source of water, was separated from Tsumeb by 12 miles of nearly impassable roads, and the "lake" itself provided water only after a 30-foot well was dug in the dry lakebed.

James began sinking two shafts 243 feet apart, and complained of the hard ground. In the first crosscut a foot-thick vein of pure chalcocite running through galena was encountered, and James identified a large "horse", or block of country-rock, suspended in the ore body; such structures later proved common at Tsumeb.

The first shipment of ore was sent on December 28, 1900, by oxwagon to Swakopmund; the consignment consisted of 101 bags of ore weighing 9 tons. The ore was carefully sorted and separated: 21 bags of chalcocite, 20 bags of galena, 20 bags of mixed copper and lead ore, and 40 bags each of test samples from three different areas in the mine.

In February of 1901 James mined into a large cavity filled with "carbonic acid gas", and had to suspend mining for four hours while the gas was pumped out. By March James reported that 1269 feet of shaft had been sunk and that he was working on crosscut tunnels at seven different levels.

In August James stopped work at Tsumeb and sent his preliminary report to O.M.E.G. Nearly 240,000 tons of high grade ore (13% copper, 25% lead) had been located between the surface and the second level; but because of the hardships of the location, James was ambivalent about the future of the mine. Nevertheless, O.M.E.G. began construction of the necessary railroad to the coast, which would carry ores from the copper mines of Gross Otavi, Klein Otavi, Anwap (Guchab) and Tsumeb. Construction of the railroad was no small operation, and it was further complicated by the Herero rebellion and the subsequent departing of much of the native labor force. Italians were shipped in but most of them proved to be inefficient workers and disliked the country as much as the job; many quit and sailed for home at their own expense. Eventually Herero prisoners-of-war were put to work, and the railway to Tsumeb was finally completed on August 24, 1906.

After four years of lying idle, Tsumeb was again prepared for mining. Shafts and crosscuts were retimbered, buildings were erected, a new shaft and haulage incline were started, and development began on level 4 (where temperatures were becoming noticeably warmer).

## PRODUCTION UNDER O.M.E.G.

1907 saw a pipeline for water installed from Otjikoto, the beginning of irrigation for growing crops, and the installation of a small electric power plant for lighting of the entire operation. About 25,700 tons of high grade ore were exported to Germany, Wales and America in Jute bags, producing an encouraging profit of over a million marks. In the mine the first important flow of water (900 gallons per hour) was encountered just below the third level. In 1908 even more water was opened and large capacity pumps had to be installed.

Mining at this time was by the room-and-pillar method. Neither timbering nor backfilling was used, and the upper levels were eventually mined out open-pit style. During 1908 44,250 tons of ore were produced.

The first underground fatality occurred in 1909, when the hanging wall collapsed in one area, killing a 14-year-old Ovambo boy. In 1910 broken ground was encountered and stopes had to be filled for support as mining advanced; this immediately doubled the cost of operations. Caving continued and the Ovambos became afraid to go underground, frequently skipping shifts.

On the plus side, a hospital was built for the natives, a school for the white children, and a club house with a library and skittle alley. Since 1906 such things as postal, telegraph and telephone services had been provided by O.M.E.G. In the early years canned goods and beer were imported from Germany.

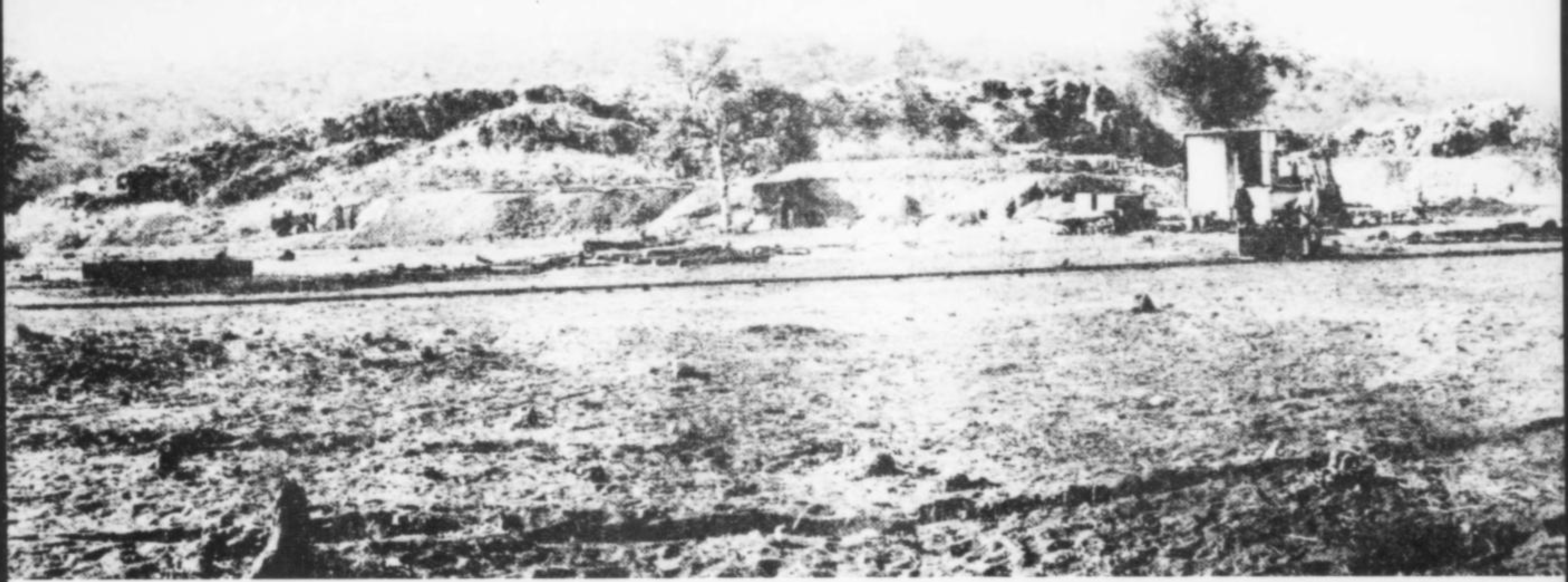


*Figure 3.* **Panorama of the whole "green hill" of ore at Tsumeb, taken about 1906 after arrival of the first rails and ore cars.**

butter from Australia, and potatoes from Las Palmas. And yet meals were exceptionally inexpensive (120 marks per month at the hotel).

The tedium of daily life in Tsumeb was relieved in many ways. Hunting on days off was popular, as game was abundant in the surrounding bush. A shooting range (Schützenplatz) was opened for target practice, and riding horses was always a favorite pasttime. On Sundays it was not uncommon for a locomotive and several flatcars to be appropriated for a picnic ride through the countryside; a brass band composed of part-time musicians well supplied with beer often went along. As Söhnge wrote, "One can imagine the upset caused among the peaceful eland and kudu antelopes in the African bush when the band suddenly burst forth with Prussian fervor." A gymnasium was built under private initiative, and a football field and tennis court were added.

The first school lessons were given in 1912 by the missionary Ferdinand Lang in the bowling alley behind the Minen Hotel.

High grade ore continued to be discovered during the years before World War I. As the new shaft reached Level 6 a new vein was encountered which was mined all the way back up to the surface. Exploration on level 4 led to the discovery of a chalcocite vein 3 metres wide (!). Boreholes, drifts and crosscuts below level 5 continued to strike high grade sulfide and oxide ore. By 1913 production of 75,000 tons was reached. Heavy equipment of various kinds, including compressors, diesel engines, and boilers was installed at regular intervals. In January of 1913 a large flow of water was struck in a crosscut and the mine was temporarily flooded up to the fourth level. Casualties were apparently not sustained or not recorded.

Mineralogical and geological research had never been overlooked by O.M.E.G. Several researchers studied the ore at an early date, but when W. Thometzek took over as mine manager in 1913 he decided that the Tsumeb ore body should be more thoroughly studied by a qualified geologist. O.M.E.G. appointed H. Schneiderhöhn in 1914 to make a detailed study of the complex Tsumeb oxide minerals. He received full support from even the management in Berlin, who gave orders that employees were forbidden from collecting minerals for themselves. Schneiderhöhn, in order to study the opaque ore minerals, invented the reflecting, polarizing petrographic microscope and pioneered ore microscopy methods for which he subsequently became world famous.

Production ceased with the beginning of World War I, and until 1919 only minor exploratory work was done. During 1919 and 1920 over 250,000 tons of ore were raised. The miners still used oil lamps and candles for light, even though a recommendation for converting to carbide lamps had been made. The ore encountered and mapped on the 6-8 levels was mainly sulfidic and in part was zinc-rich; because the main shaft would strike the ore body at level 8 it was decided to begin sinking another shaft farther to the west.

In July of 1919 a native miner carelessly tossed a cigarette down a winze, and started a major fire which spread to Level 2 within two days. The mine was sealed off and the surface area doused with 25,000 gallons of water per hour for over three weeks until the fire was finally extinguished. Four people were gassed during the fire, but recovered. The intense heat of the fire had smelted rock *in situ* down to the third level, and the mine was in danger of collapsing. But by 1921 production was in full swing again, and 85,000 tons of ore were produced in that year.

The new shaft reached Level 8 in 1925; it was named the Friedrich Wilhelm shaft in honor of the mine manager, F. W. Kegel (after whom kegelite was recently named). Because development on Levels 9 and 10 had shown a constriction of the ore body, the proving of reserves below that level became critical and exploratory work was intensified. Mining between 1927 and 1928 took place mainly between levels 13 and 16, and the winze (called No. 4 Shaft) was sunk to level 20. Output reached 236,000 tons in 1930, but the pinch of the world depression was already being felt in the market price of copper and lead. The mine was forced to cease operations in August of 1932.

By 1937 the world metals market had recovered sufficiently for the Tsumeb mine to be dewatered and reopened, and 46,500 tons were produced in that year. The mine prospered and deepened down to level 22 until mining was abandoned in 1940 at the outbreak of World War II. Since Germany lost the war, the holdings of O.M.E.G. passed into the hands of the Cus-

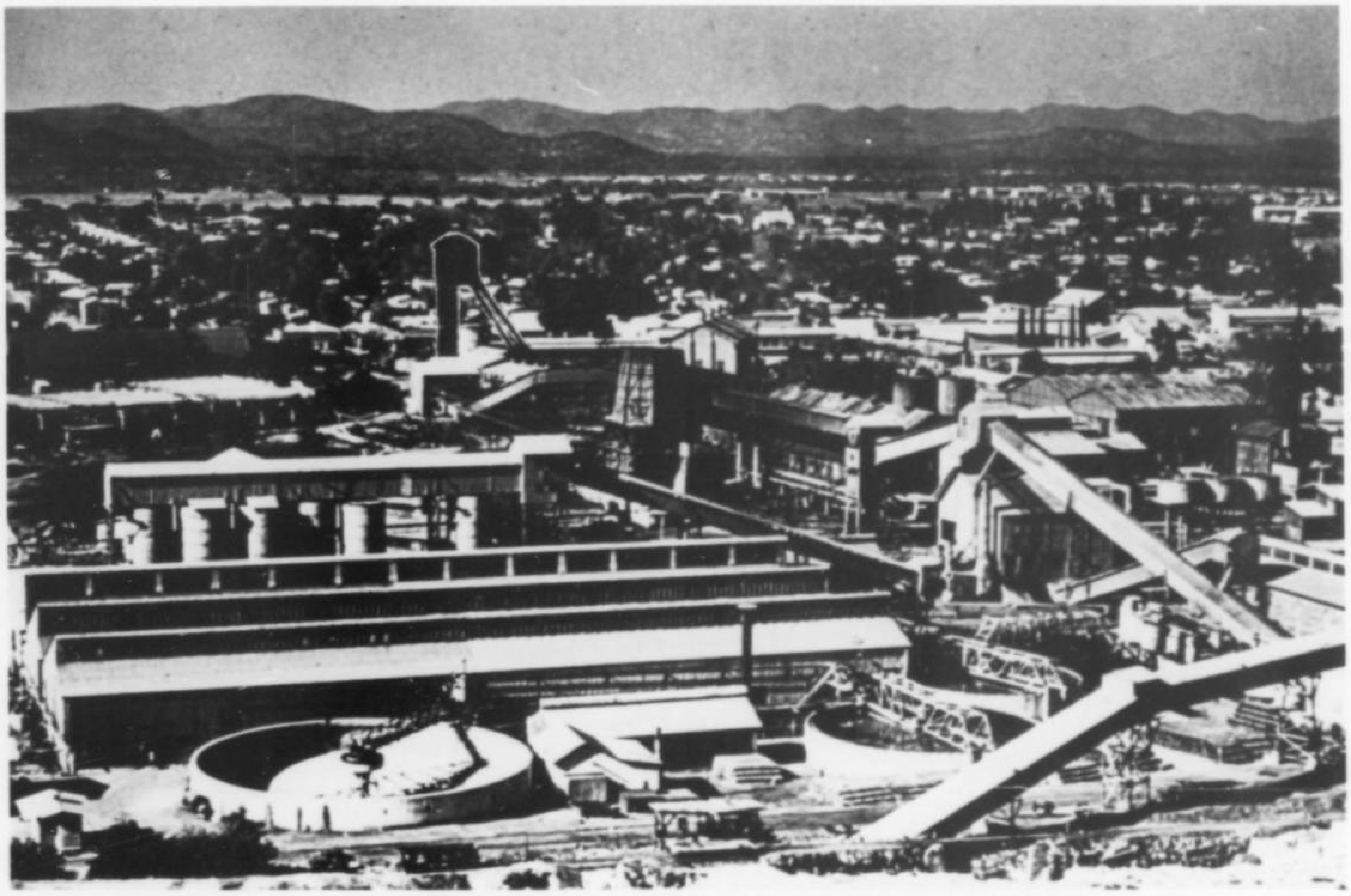


*Figure 4.* **The Tsumeb mine in 1976. The headframe is outlined in white. Photo by Dwight Weber.**

todian of Enemy Property, and no mining took place until 1946.

## PRODUCTION UNDER THE TSUMEB CORPORATION

In 1946 the Custodian of Enemy Property put O.M.E.G. assets, including the Tsumeb mine, up for sale. To purchase the O.M.E.G. properties a syndicate was formed which included Newmont Mining Corp., American Metal Co., Selection Trust, British South Africa Co., Union Corp., South West Africa Co., and the O'okiep Copper Co. The sale was completed in 1947 for a little over £1,000,000...somewhat more than the first selling price of £300, 25 rifles, a horse, and a barrel of brandy!

The syndicate was christened the Tsumeb Corporation, and preparations for renewed mining were begun with military efficiency and speed. The face of Tsumeb was changed from that of a 19th Century small mining town to a modern mining complex with a new hospital, warehouses, employee housing, heavy machinery and generators, and eventually modern milling and smelting plants.

With installation of the first big diesel generators the mine was unwatered, reconditioned, and explored. After a year of pumping water, the bottom workings were found at 1890 feet below the surface. Most of the ore down to the 12th level, and half the ore between the 12th and 16th levels had been removed, while extraction had only begun from the 16th down to the 20th level.

By 1949 the ore zone had widened into the largest mineralized area yet encountered in the mine, but large volumes of water under high pressure were also encountered. Steam turbines using South African coal had to be installed to generate sufficient power for water pumping and ore hauling. The new De Wet shaft, started in 1949, reached Level 30 in 1955, and this shaft alone encountered a flow of over 4,000,000 gallons of water a day. By 1957 mining on the 26th level had commenced, and a second oxide zone was discovered after having passed through 1800 feet of unaltered sulfides! The new oxide zone occurred where a brecciated strata of county rock carrying a heavy flow of deep groundwater intersected the ore pipe. By 1962 oxidized ore had been located down to 4286 feet with no signs of it pinching out.

The 1974 annual report of Newmont Mining Corporation (which owns 29.6% of Tsumeb) stated:

> "Horizontal drilling at the 44-level of the Tsumeb mine has failed to indicate continuation of the ore body to this level. Additional drilling at greater depth is in progress."

Despite the possible discovery of the lower limit of the ore body, ample reserves exist and may still be supplemented. Ore reserves in 1972 were 5,772,000 tons; reserves in 1973 were 5, 497,000 tons, not including undelineated reserves below the 36th level; reserves in 1974 were 6,054,000 tons; reserves in 1975 were 5,568,000 tons of ore containing 4.56% copper, 7.75% lead and 2.06% zinc. Presuming no more ore is ever discovered (which is unlikely), mining could continue at the 1975 rate (467,000 tons of ore per year) until the end of 1987. Newmont currently has no plans for shutting down the mine, according to Vice President Philip C. Walsh.

## ACKNOWLEDGMENTS

This historical summary was prepared from the book *Tsumeb, A Historical Sketch* (1967) by Söhnge, and also from other sources including publications of the Africa Institute of South Africa and annual reports of Newmont Mining Corporation provided by Philip C. Walsh, Vice President of Newmont. Our thanks also to Hugo de Villiers of the South African Embassy for providing resource materials used in this and the preceding chapter.

# IV GEOLOGY

by

**Dwight Weber** and **Wendell E. Wilson**

The Tsumeb mine has been one of the foremost metal-producing mines in Southern Africa. An indication of its richness is given in Söhnge (1967): from 1906 to 1966 the mine yielded 12.5 million tons of ore containing an average of 5% copper, 14% lead and 6% zinc, as well as several thousand tons of cadmium, silver and germanium. The gross income from metals sold during those 60 years was about 623 million Rand (nearly a billion dollars). Thus it becomes obvious that Tsumeb is world famous not only as a producer of fine specimens and a great variety of minerals, but also for production of ore equal in value to that produced by the old Comstock lode in the U.S. The interesting geological features of this deposit have been studied for many decades. A summary of the most important points is offered here.

## REGIONAL GEOLOGY

The formations of the Otavi Highland comprise a great thickness of late Precambrian Damara-Otavi sedimentary beds lying unconformably on Archean metamorphic and igneous rocks. There are three formations:

(1) The Mulden formation (about 750 m thick) at the top of the sequence,

(2) The Otavi series consisting of 11 zones (about 5500 m thick), and

(3) The Nosib formation, two layers (about 800 m thick) on the bottom.

The Otavi group consists of two series containing the Tsumeb stage of eight zones of mostly dolomite and chert, and the Abenab stage of three zones of mostly dolomite and limestone. The rocks are relatively unmetamorphosed to the north of Grootfontein and Otavi; to the south the dolomites and limestones are recrystallized. Graywacke and shale in southern areas have been converted to phyllite and quartz-mica schist. Karst features are common in the limestone units; cavernous openings can be seen on the surface near the town of Tsumeb.

## FEATURES OF THE TSUMEB DEPOSIT

The Tsumeb ore body is a classic example of an ore pipe. Contained within the pipe-like structure are two irregular plugs and associated dikelets of a peculiar rock called pseudoaplite (formerly called "aplite" by early writers), sills of kersantite (a rock type intermediate between diorite and gabbro) and diabase dikes. Both the diabase and kersantite structures are more recent than the episode of ore mineralization, but the pseudoaplite was emplaced before ore-bearing solutions entered the pipe (Schneiderhöhn, 1929, 1931, 1941; Söhnge, 1952, 1963). Petrographically the pseudoaplite most resembles a feldspathic quartzite (70% quartz, 15-20% microcline and orthoclase, 5-10% plagioclase) because the grains are rounded and crushed. Curiously there is no thermal metamorphism associated with the pseudoaplite, although it is definitely intrusive (Söhnge, 1952, 1963). It appears possible that the rock may represent a relatively cold intrusion driven, perhaps, by high pressure gas phases in a manner similar to the emplacement of kimberlite. The exact origin is still an enigma and so, to avoid a premature genetic judgment, the rock has been termed a "pseudoaplite" rather than an aplite or quartzite.

Figures 1-7 illustrate the main features of the ore pipe. The structure is elliptical, pinching and swelling irregularly from the surface down to a depth of over 1400 m (4550 feet). Along constrictions it consists of a sparse network of veinlets, but widens abruptly into plan sections of over 1000 square metres. The largest section (on the 735 m level) measures 185 by 70 m (Söhnge, 1952)(Fig. 7).

The pipe was apparently developed by fracturing, brecciation, and intrusion of the pseudoaplite, although the origin of the structure is still in dispute. Brecciation was restricted to the lower levels, especially where the pipe cuts a fold in the country rock. Reverse faulting along bedding planes of the country rock (which dip at about 45° to the south) has caused drag folding, local thrusts across bedding, and brecciation. The pipe itself is nearly vertical above the 200 m level and below the 600 m level; the intermediate section follows a zone of concentrated bedding-plane faults and is relatively constricted in size. The dip of the intermediate section is about 50°, roughly paralleling the bedding planes. The pseudoaplite was injected after all of the folds and faults had formed; it is centrally located in the upper portions of the pipe but forms

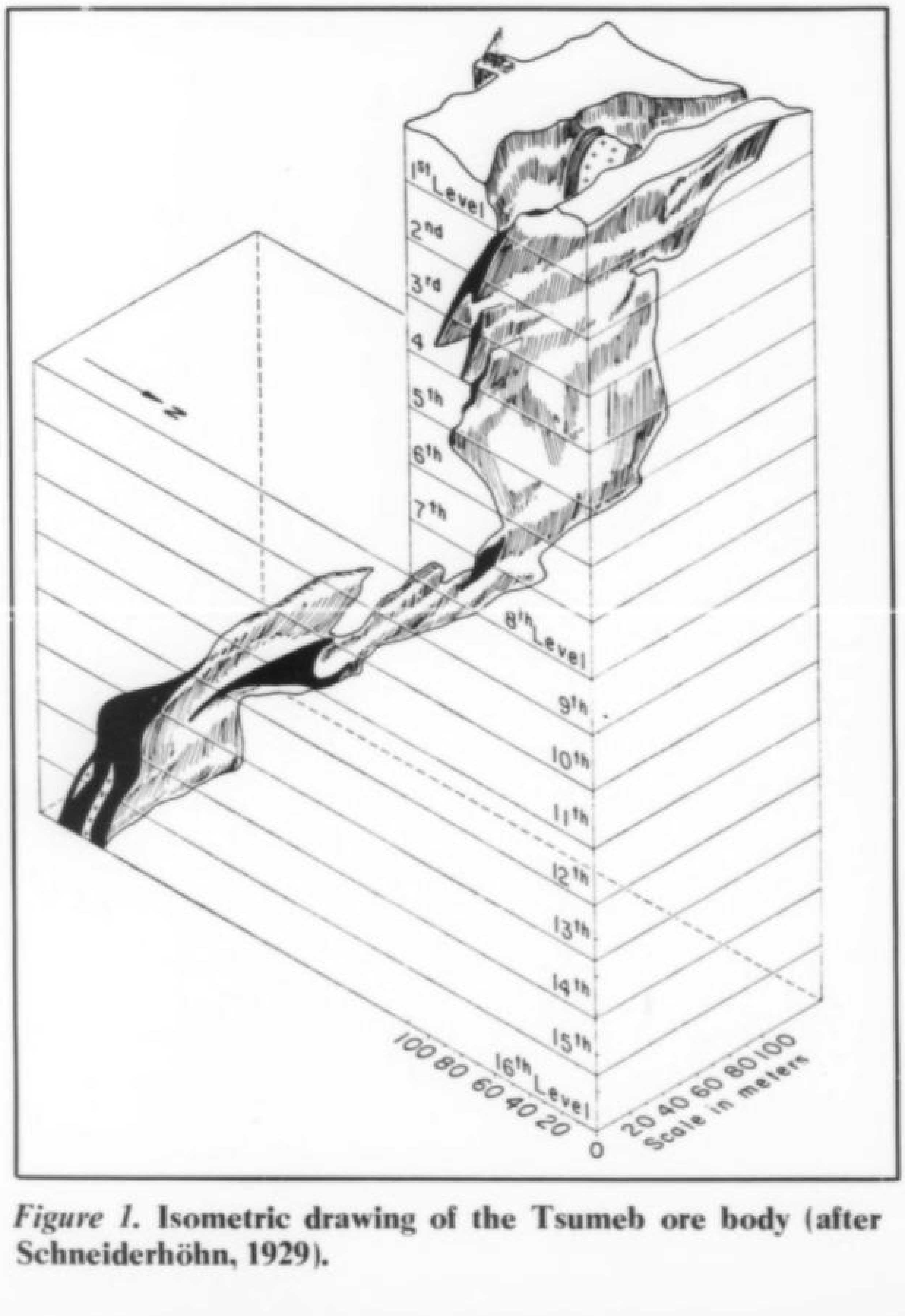


*Figure 1.* **Isometric drawing of the Tsumeb ore body (after Schneiderhöhn, 1929).**

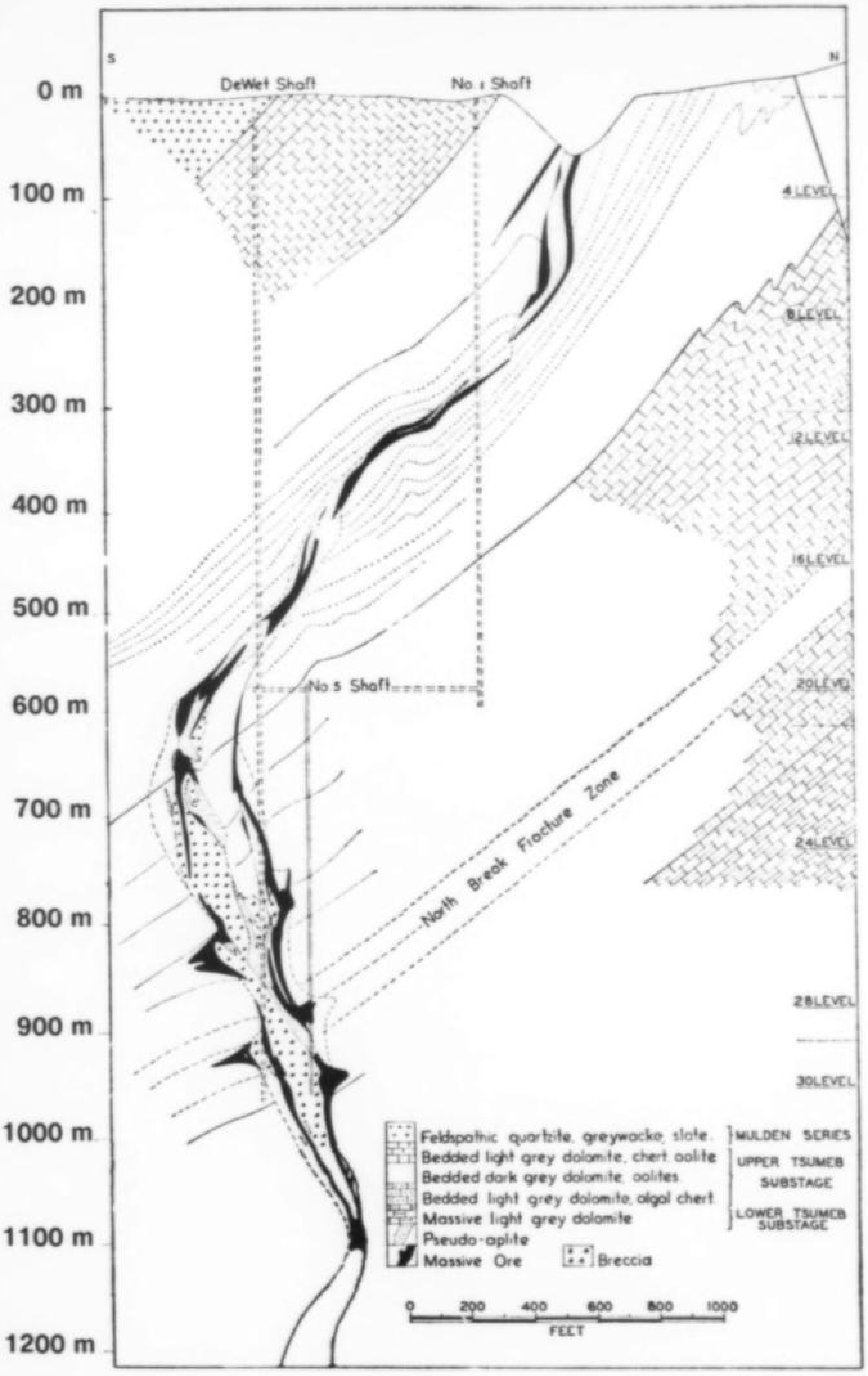
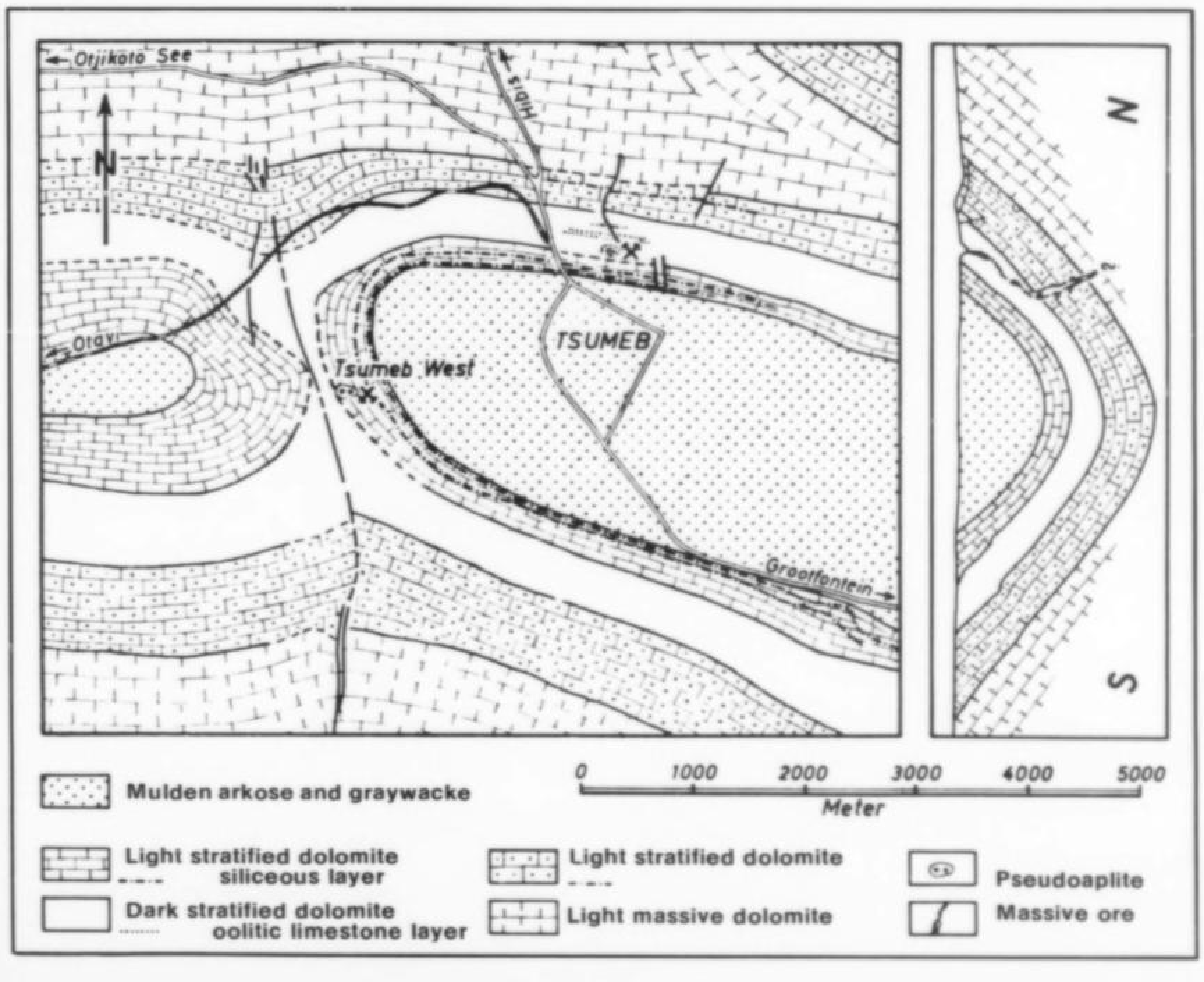
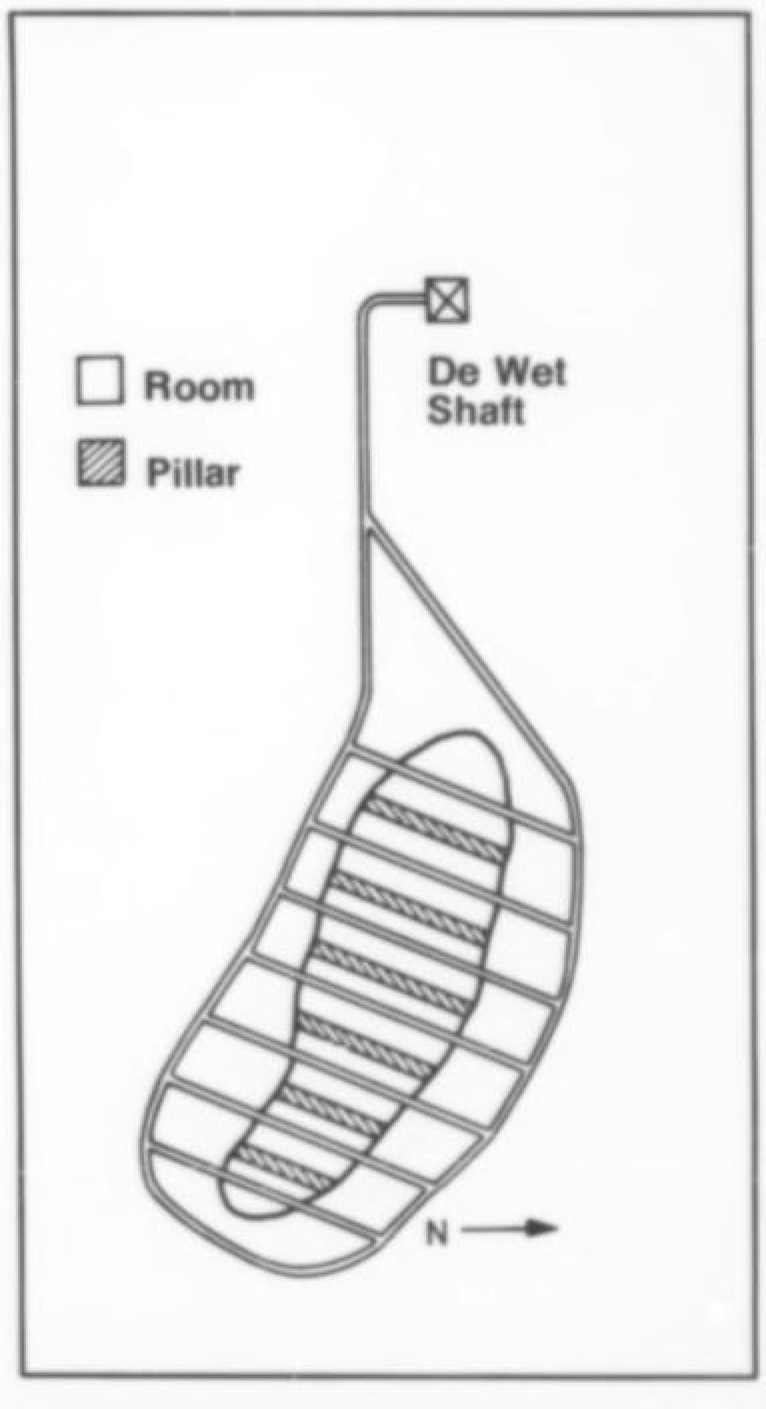


*Figure 2. (left)* **Geologic cross section through the Tsumeb ore pipe (Modified from Tsumeb Corporation staff, 1961, and Geier, 1974).**

*Figure 3. (bottom left)* **Geological sketch of the Tsumeb area; plan view and N-S section (Strunz and Tennyson, 1967).**

*Figure 4. (bottom right)* **Schematic plan-view diagram illustrating the room-and-pillar mining method used at Tsumeb (Bartelke, 1976).**





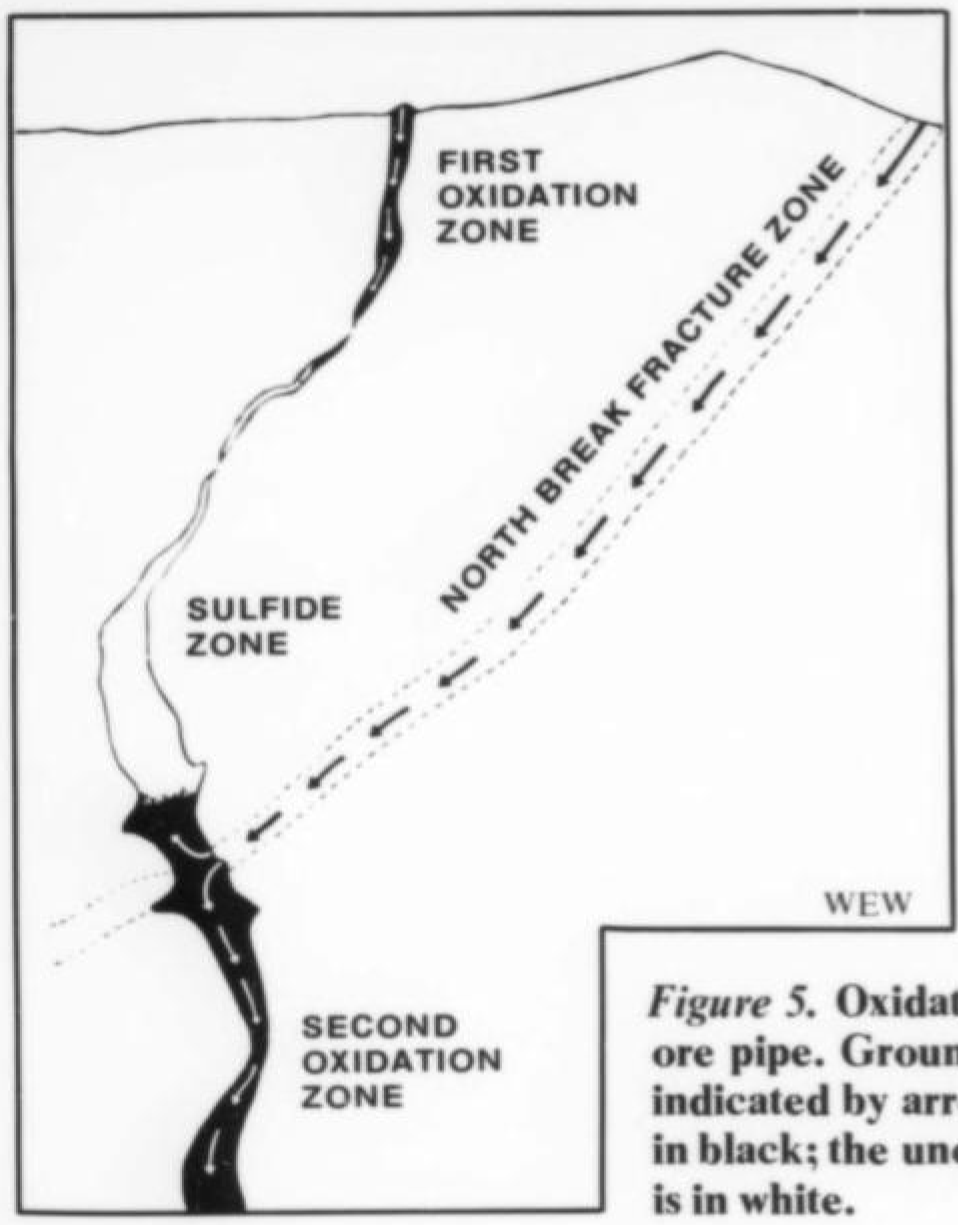
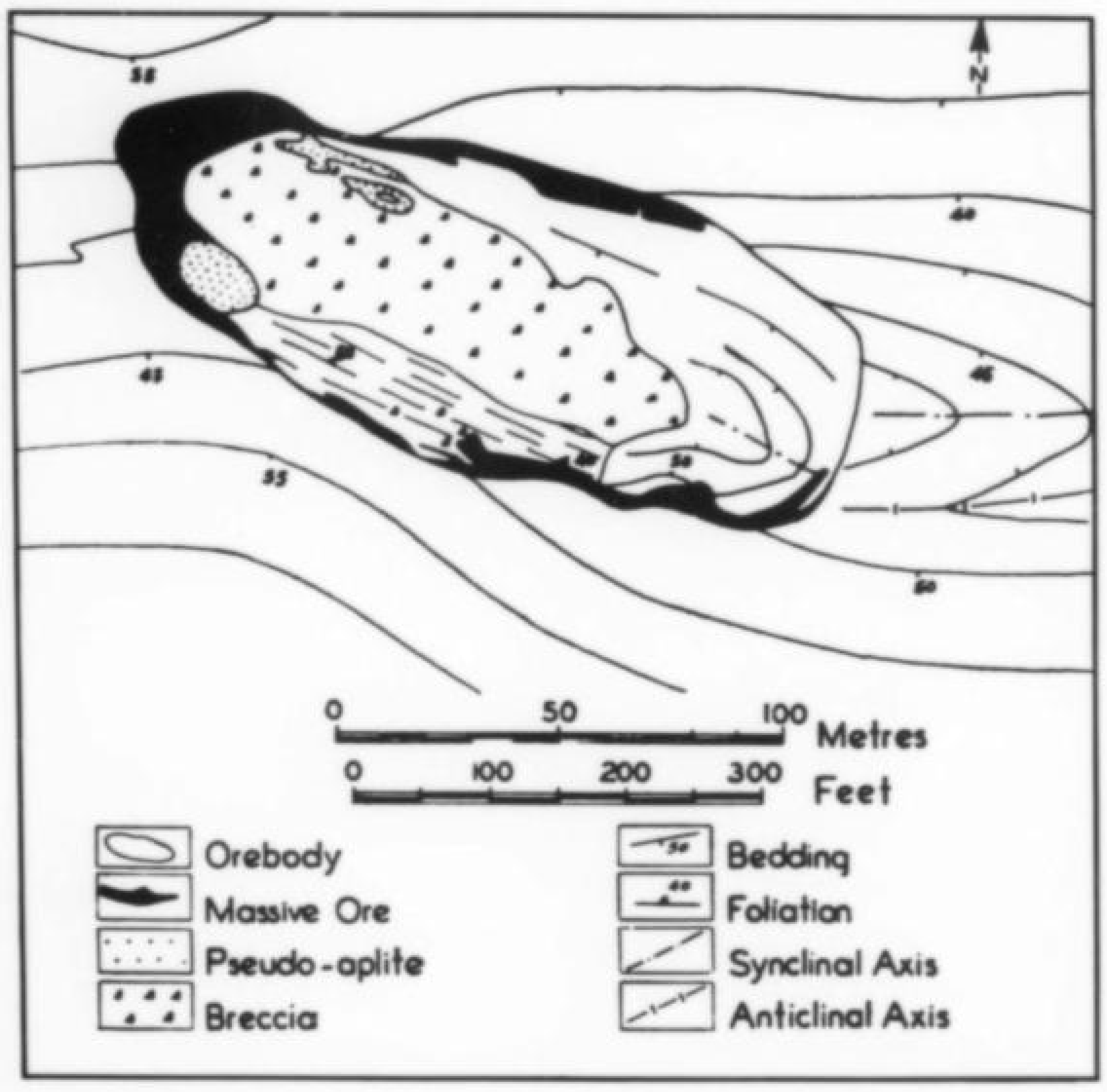


*Figure 5.* **Oxidation pattern of the Tsumeb ore pipe. Groundwater followed the paths indicated by arrows. Oxidized ore is shown in black; the unoxidized section of the pipe is in white.**



branches and lenses in brecciated horizons (Tsumeb Corporation staff, 1961).

Metallization follows the periphery of the pipe, forming rich pods, lenses and veins, but also forms large tonnages of disseminated, low-grade ore. The main pipe consists of a horseshoe-shaped concentration of massive ore and veins intermixed with low-grade ore. High-grade mantos have been located where the pipe intersects brecciated horizons in the country rock; these project as much as 90 m both north and south of the pipe. In general the pipe is narrowest where it parallels bedding of the country rock and is widest where it crosses bedding.

The ratios of lead, copper and zinc vary throughout the orebody but, in general, lead is the most abundant. Massive sulfide bodies have contained as much as 60% metals; one large mass contained 26.7% lead, 12.4% zinc and 3.6% copper. Disseminated ore occurs as stockworks in dolomite and breccia, and also as specks and veinlets in pseudoaplite.

Although minor amounts of sulfides occur even at the surface, oxidation has occurred to very great, virtually unprecedented depths (Fig. 5). Secondary minerals predominate above

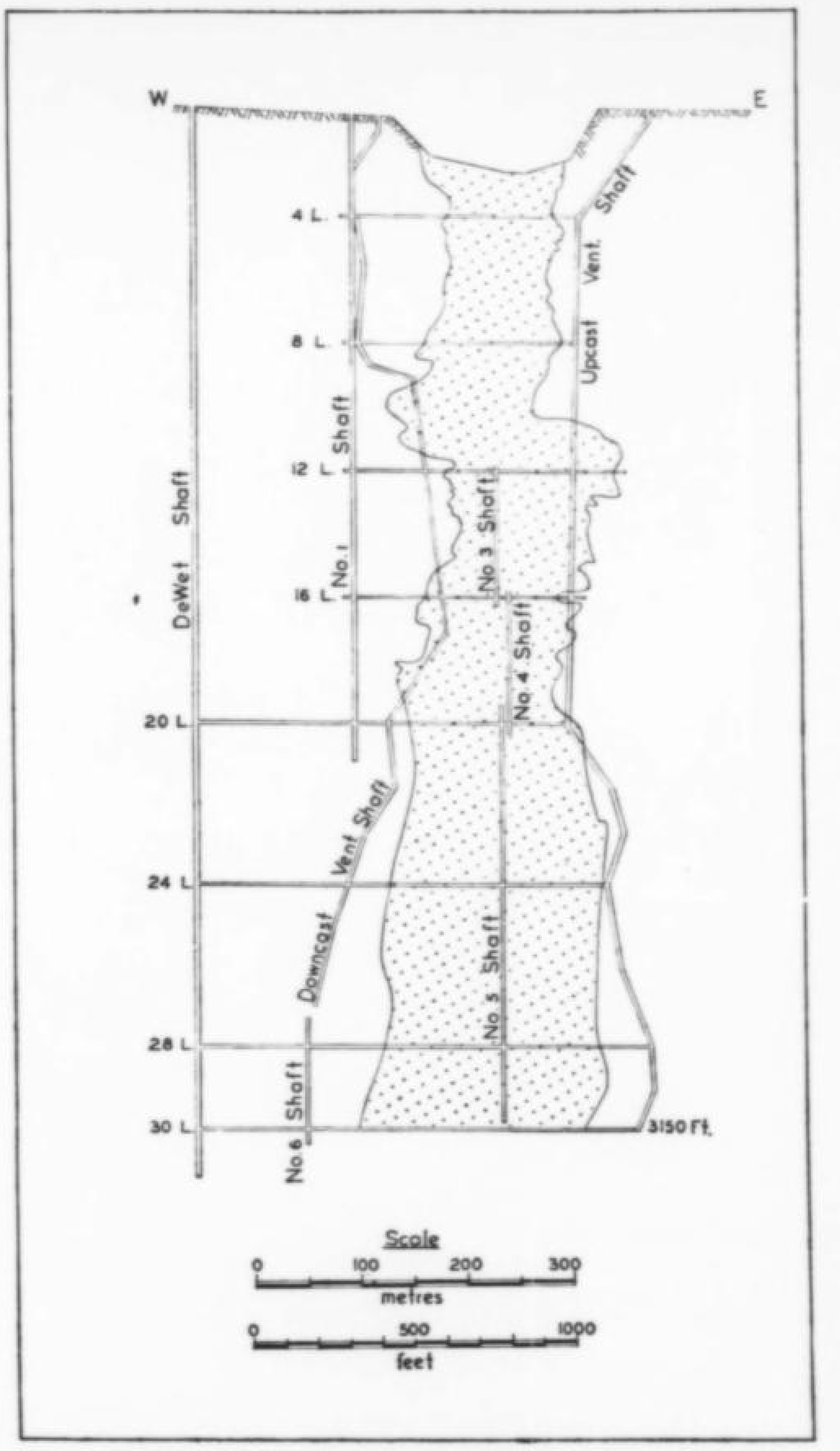


*Figure 6. (above)* **East-West cross section through the Tsumeb ore body (after Tsumeb Corporation staff, 1961).**

*Figure 7. (left)* **Geologic plan of the Tsumeb ore pipe at the 26th level (after Tsumeb Corporation staff, 1961).**

the 300 m level. From 300 m down to 800 m oxidation is very slight, but at 800 m the top of a second oxidized zone was discovered. This second oxide zone extends below 1400 m; it is located where the ore pipe cuts a permeable horizon in the Tsumeb dolomite. Ground waters migrating along bedding planes and brecciated strata have reached the ore pipe at about the 900 m level and moved downward, oxidizing the ores more thoroughly than surface waters had oxidized the first oxide zone. Supergene enrichment increased copper concentrations in upper sections of the second oxide zone but leached away zinc.

Ore pipes of this general character are not geologically unusual, however there are several unique features of the Tsumeb deposit. Certainly the most extraordinary of these is the lower or second oxidation zone which is the product of a peculiar "plumbing" accident of nature. Were it not for this feature, Tsumeb would still have been a remarkable deposit but the production of large numbers of fine secondary mineral specimens would have ceased decades ago. Furthermore, fine specimens are more perfectly developed and more abundant, with only a few exceptions, in the lower zone. Therefore the lower oxidation zone is clearly the most geologically, hydrologically and mineralogically interesting feature of the deposit. The unique geochemical aspects, which have also profoundly influenced the mineralogy, are discussed further in the chapter on Paragenesis.

**REFERENCES may be found at the end of Chapter XII.**

# V MINERALS: A DESCRIPTIVE LIST

by
William W. Pinch
and
Wendell E. Wilson

## INTRODUCTION

The following list contains descriptions of all of the currently known species and varieties from Tsumeb. Crystal drawings are included for many of them; some of the drawings were adapted from references listed in the reference chapter and some were drafted especially for this study. No claim to completeness is made for the crystal drawings; hundreds could have been made and only a sampling is presented here. Similarly, references for the descriptions are not given here because they may be found in the references chapter; many of the descriptions, however, have been significantly supplemented by our own observations. Pseudomorphs are listed in detail in the reference chapter and are mentioned only occasionally here.

The compositions of the minerals are given for reference. Most are drawn from Fleischer (1975) but some are from the original, very recent descriptions of the minerals or, as in the case of many varieties, are from Hey (1955). Only those physical characteristics that are particularly useful for identification are given; details may be found in the standard reference works. Only associations of the rarer minerals are listed in the descriptions because those for the more common species are discussed in detail by Keller in the Paragenesis chapter.

Mineral species names are given alphabetically, in **bold**; mineral varieties are indicated by their common name, in *italics*, and also by the extraneous element characterizing the variety.

In the last column are page numbers where photos of the minerals may be found elsewhere in this issue.

Finally there is a series of tables showing the Tsumeb minerals grouped in various ways according to their compositions.

Certainly additions to the number of known Tsumeb species and varieties will continue to be made in the future; these will be published occasionally in the *Mineralogical Record* magazine under the heading of *Tsumeb Notes*; readers may wish to xerox or remove those notes to insert at the back of this issue.

## FIRST REPORTS

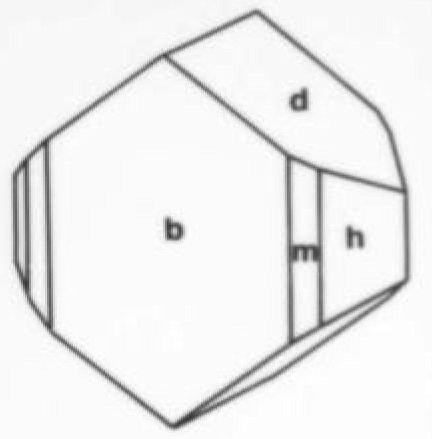
Fourteen minerals are here reported for the first time from Tsumeb. These minerals, along with the source of their identification, are listed below:

1. **Algodonite** (Ulrike Kahn, pers. comm.) (Walter Kahn specimen)
2. **Ankerite** (Ed Ruggiero, personal comm.) (Zweibel specimen)
3. **Bindheimite** (Smithsonian specimen)
4. **Corkite** (W. W. Pinch)
5. **Hedyphane** (W. W. Pinch)
6. **Jarosite** (Dwight Weber)
7. **Keyite** (Embrey and others, this issue)
8. **Leiteite** (Cesbron and others, this issue)
9. **"Mineral GF"** (Paul Keller, this issue)
10. **"Mineral TI"** (Paul Keller, this issue)
11. **"Mineral TK"** (Paul Keller, this issue)
12. **Mixite** (Smithsonian specimen)
13. **Powellite** (W. W. Pinch)
14. **Shattuckite** (W. W. Pinch)

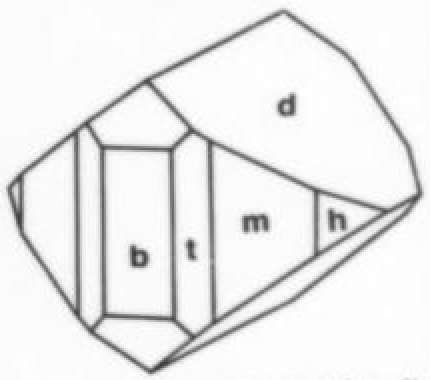
## ACKNOWLEDGMENTS

Much of the information supplied here has been taken from a list prepared by A. Sobrecki of the Tsumeb Corporation, and also from the excellent review by Wolfgang Bartelke (1976) in *Der Aufschluss*. In addition, X-ray confirmations of many species were carried out by one of us (W.W.P.).

Samples studied for this review came from many collections including those of the authors. A computer print-out of the 1147 Tsumeb specimens in the Smithsonian Institution was used to locate and study a large number of interesting specimens. These examinations were supplemented by studies of dealers' stocks and the collections of other private individuals.

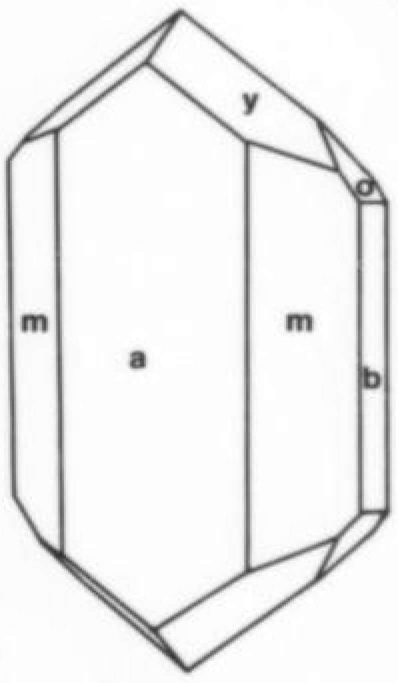


adamite

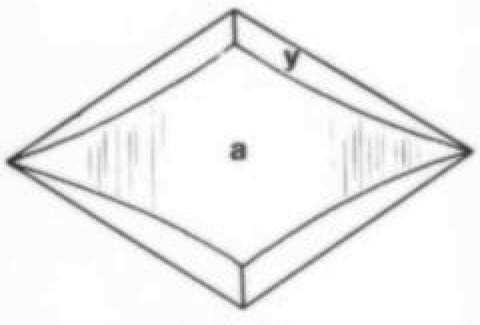


cuproadamite

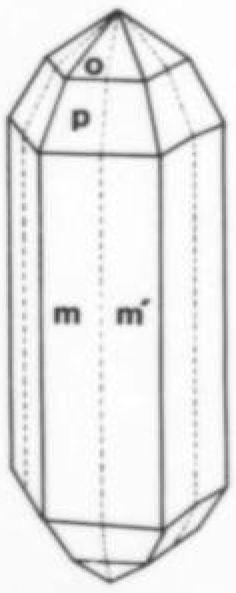
cunroadamite



anglesite

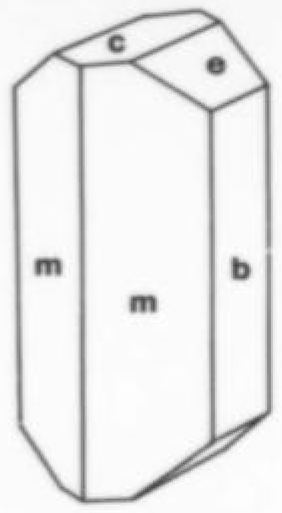


anglesite

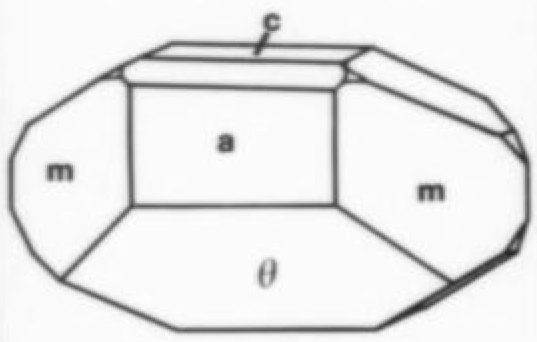


**tarnowitzite** twin

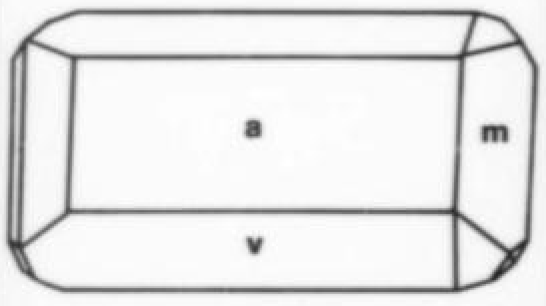
| | | PHOTO(S) ON PAGE |
|---|---|---|
| **Acanthite** | $\mathbf{Ag_2S}$ Finely disseminated in ore containing native silver. | |
| **Adamite** | $\mathbf{Zn_2(AsO_4)(OH)}$ Occurs as very small yellow to yellow-green crystals rarely over a few mm in size. Some crystals have brown edges parallel to the *c*-axis. Copper-free adamite is very rare at Tsumeb; commonly adamite crystals are zoned with varying copper content and varying color. The more intensely green crystals have the most copper. Habits range from equant to prismatic. | 68<br>69 |
| *Cobaltoadamite* (Co-var.) | $\mathbf{(Zn,Co)_2(AsO_4)(OH)}$ Extremely rare at Tsumeb, this variety is an attractive pink color. | |
| *Cuproadamite* (Cu-var.) | $\mathbf{(Zn,Cu)_2(AsO_4)(OH)}$ This variety is supposedly part of a continuous series to olivenite. It forms crystals of bright green to apple-green and olive-green color often associated with bayldonite and schultenite on tennantite. Cuproadamite is much more common than low-Cu adamite. Prismatic crystals up to 13 mm have been found. | 58<br>68 |
| **Alamosite** | $\mathbf{PbSiO_3}$ This very rare species has been confused with leadhillite, with which it is sometimes found. It forms small euhedral crystals to 3 mm in size and also radiating masses of crystals over 25 mm in length elongated along the *a*-axis. The color is white to cream and light gray. About 20 specimens are currently known. The only other locality for alamosite is the type locality in Mexico, specimens from which are vastly inferior to Tsumeb material. Associated minerals include leadhillite, anglesite, melanotekite, hematite, fleischerite and kegelite. | 58 |
| **Albite** | $\mathbf{NaAlSi_3O_8}$ A mineral of the country-rock. | |
| **Algodonite** | $\mathbf{Cu_6As}$ Massive. | |
| **Anglesite** | $\mathbf{PbSO_4}$ Anglesite crystals are most commonly colorless but may be gray, bright yellow (supposedly from inclusions of cadmium, probably in the form of greenockite) or green. They are often flattened and may reach several cm in length. Twinning has not been reported, a fact which may help to distinguish them from cerussite. Matrix for anglesite invariably consists of sulfide minerals. | 69<br>70 |
| **Ankerite** | $\mathbf{Ca(Fe,Mg,Mn)(CO_3)_2}$ So far identified on only a few specimens as drusy coatings of cream-colored crystals with calcite. | |
| **Aragonite** | $\mathbf{CaCO_3}$ Relatively pure aragonite forms slightly greenish to bluish needles and turquoise-colored radially structured masses and crusts; it occurs very rarely in dull, prismatic, pseudohexagonal crystals. It is far more scarce than calcite. | |
| *Nicholsonite* (Zn-var.) | $\mathbf{(Ca,Zn)CO_3}$ The zinc variety of aragonite is very similar in appearance to tarnowitzite but is usually buff to cream-colored and the prismatic crystals may taper toward their bases. Like tarnowtizite they are terminated by a pseudohexagonal pyramid. Nicholsonite may contain up to 10% $ZnCO_3$. | 61 |
| *Tarnowitzite* (Pb-var.) | $\mathbf{(Ca,Pb)CO_3}$ This variety contains up to 3% $PbCO_3$ and forms excellent, prismatic, pseudohexagonal crystals several cm in maximum length, terminated by pseudohexagonal pyramids. Their color is cream to white. They are much more common than pure aragonite at Tsumeb. | 61 |



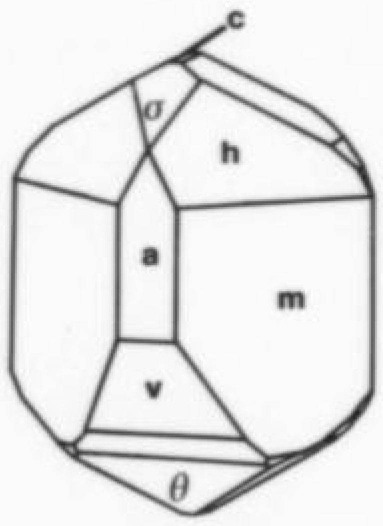
atacamite



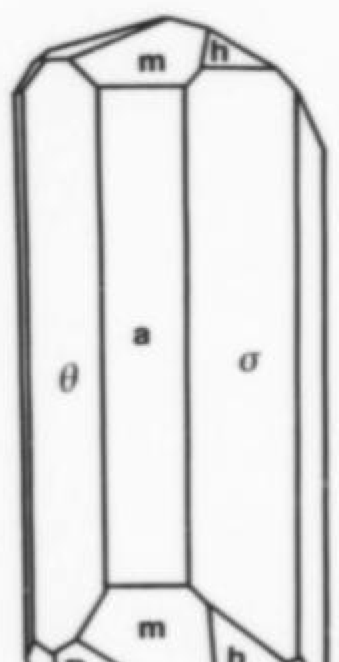
azurite



azurite



azurite



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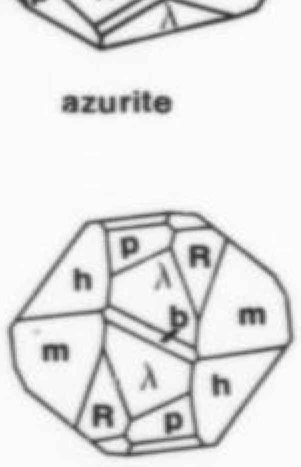

azurite

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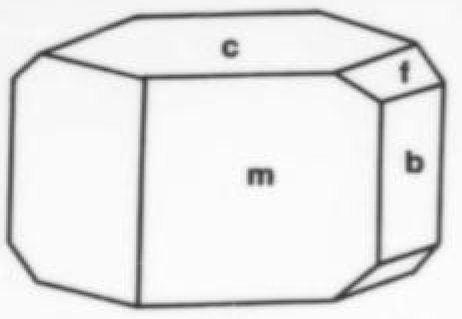
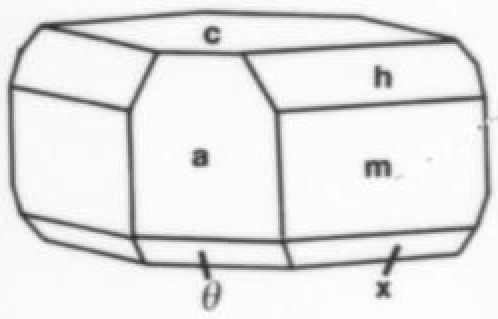
|---|---|---|
| **Arsenbrackebuschite** | **$\mathrm{Pb_2(Zn,Fe)(AsO_4)_2(OH)\cdot H_2O}$** Tabular crystals up to 0.1 by 0.2 by 0.5 mm have been observed. They are a bright brown to honey color and occur in fissures with dolomite on the 30 level. The mineral bears a structural relationship to tsumcorite. | |
| **Arseniosiderite** | **$\mathrm{Ca_3Fe_4(AsO_4)_4(OH)_6\cdot 3H_2O}$** It occurs rarely in the lower oxidation zone as golden-yellow to dark brown submetallic crystals in radial aggregates and granular masses and crusts associated with carminite and other arsenates. | |
| **Arsentsumebite** | **$\mathrm{Pb_2Cu(AsO_4)(SO_4)(OH)}$** Occurs as tiny (less than 1 mm) twinned crystals of an apple-green to ridgeway-zinc-green color. Specimens labeled *"bayldonite pseudomorph after mimetite"* should be checked because many of these which were collected in the 30's have turned out to be arsentsumebite. The mineral has never been thoroughly described, but a comprehensive treatment by R. A. Bideaux and others is about to be published in which ambiguities are resolved and the mineral is renamed. | 84 |
| **Asbestos (Riebeckite?)** | **$\mathrm{Na_2(Fe,Mg)_5Si_8O_{22}(OH)_2}$?** A mineral of the country-rock. | |
| **Atacamite** | **$\mathrm{Cu_2Cl(OH)_3}$** Forms dark green to blackish green prismatic crystals up to 1 cm in size. Most specimens have been found in the upper oxidation zone. | 56 |
| **Aurichalcite** | **$\mathrm{(Zn,Cu)_5(CO_3)_2(OH)_6}$** Forms pale green to sky-blue and turquoise-blue acicular crystals and crusts in the upper oxidation zone. It is sometimes associated with hemimorphite. | 64 |
| **Austinite** | **$\mathrm{CaZn(AsO_4)(OH)}$** Forms colorless to pale green or pale blue microscopic acicular crystals elongated along the *c*-axis. | |
| *Cu-Austinite* | **$\mathrm{Ca(Zn,Cu)(AsO_4)(OH)}$** This variety forms part of a series to conichalcite. Crystals are usually green to dark green and may form spheroidal groups of curved crystals. | 61 |
| **Azurite** | **$\mathrm{Cu_3(CO_3)_2(OH)_2}$** Azurite is one of the most famous minerals from Tsumeb, and justly so. It has been found in lustrous single crystals up to 25 cm in length, as well as magnificent groups of large crystals which are easily the finest examples of azurite in the world. Many crystals have been partially or completely altered to malachite. The color is black to very dark blue when unaltered. Habits range from equant to elongated and bladed. | 74<br>75 |
| **Barite** | **$\mathrm{BaSO_4}$** Forms yellow and amber to brown and dark brown crystals mostly in the areas between a depth of 100 and 300 m. Crystals to 5 cm have been found but the mineral is nevertheless uncommon. Associations commonly include smithsonite or galena. | 70 |
| **Bayldonite** | **$\mathrm{PbCu_3(AsO_4)_2(OH)_2}$** The most common form of bayldonite, which has been found for many years at Tsumeb, is a fine, granular to powdery crust siskin-green to apple-green or yellow-green in color. It is easily confused with duftite but most specimens of powdery bayldonite came from the upper oxidation zone, which may be an aid in identification. | 78 |



azurite



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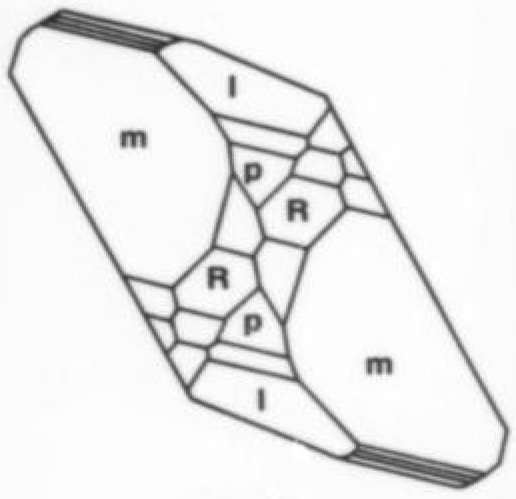

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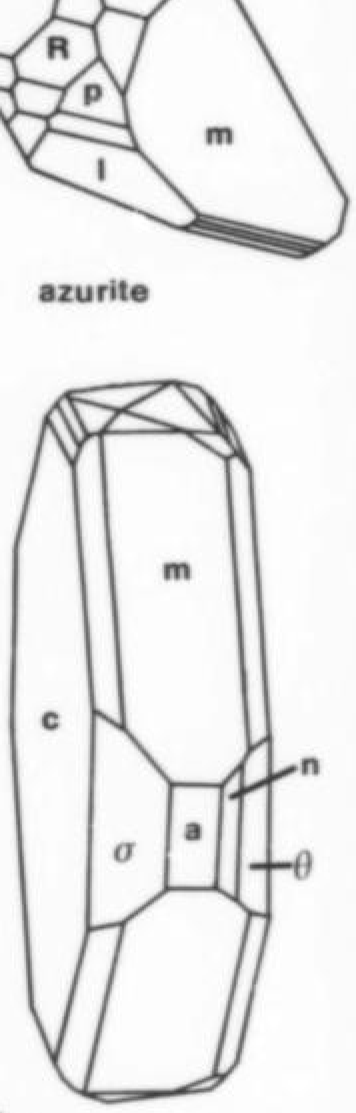

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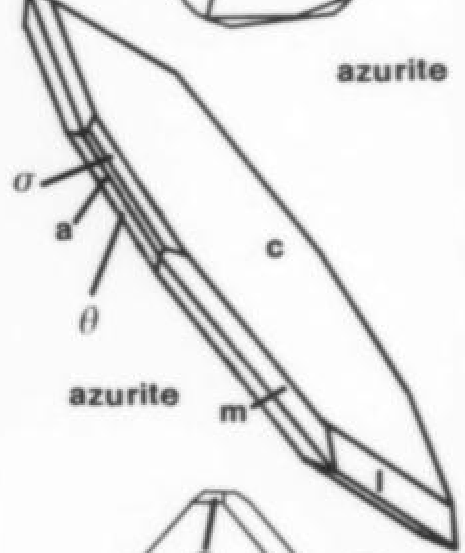

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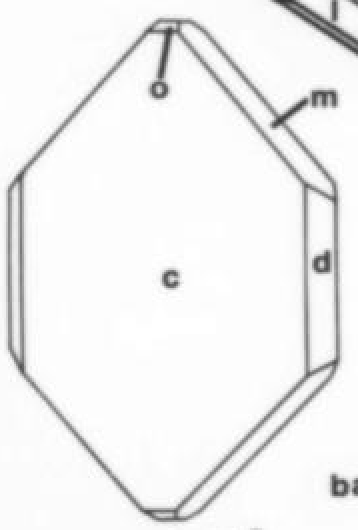
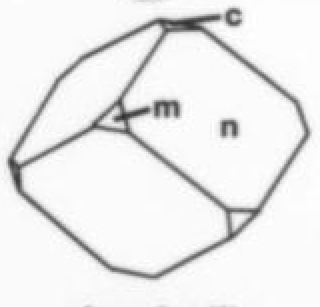


barite



beudantite

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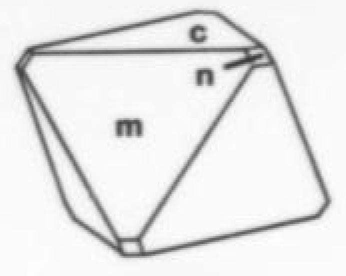
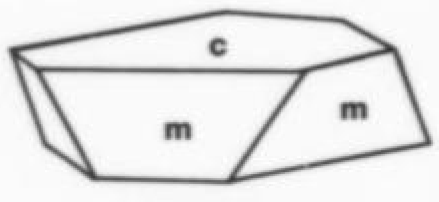
| | The early material was found in association with olivenite, mimetite, azurite and malachite. Tsumebite is also a nearly indistinguishable associate, and commonly occurs with azurite. Old specimens labeled as pseudomorphs after mimetite may be tsumebite if of a light apple-green color; specimens dark green in color are probably bayldonite. Around 1973 a pocket of very large crystals up to 1 cm in length were found associated with cuproadamite, keyite and schultenite. These crystals are dark green to nearly black, and are the finest crystals of bayldonite known; unfortunately they are quite rare and no more are likely to be found. | |
| **Beaverite** | **$Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$** Found near the 1000 m level as powdery canary-yellow crusts with beudantite, adamite, malachite, tennantite and leadhillite; few specimens are known. | |
| **Betekhtinite** | **$Cu_{10}(Fe,Pb)S_6$** Forms microscopic lead-gray needles and masses in chalcopyrite, bornite and galena between the 24 and 32 levels; it is very rare. | |
| **Beudantite** | **$PbFe_3(AsO_4)(SO_4)(OH)_6$** Forms solid, fist-sized masses as well as crystals up to several mm. The crystals range from pseudocubic and pseudo-octahedral to tabular. The luster is frosty to bright and the color ranges from greenish yellow to yellow, brown, reddish brown, reddish orange, red and very dark red. It is most commonly associated with carminite and is widely disseminated in the deep oxidation zone. Tsumeb beudantite crystals are the largest and finest in the world. | 80 |
| **Bindheimite** | **$Pb_2Sb_2O_6(O,OH)$** Occurs as a yellow alteration product of an unknown mineral in bladed masses several cm in size. | 83 |
| **Biotite** | **$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$** A mineral of the country-rock. | |
| **Bornite** | **$Cu_5FeS_4$** Forms massive areas of a copper-red to pinchbeck-brown color which tarnish rapidly to the purplish blue characteristic of bornite. Crystals have very rarely been found. Some bornite ore contains up to 1.5 kg of silver per ton. | 83 |
| **Briartite** | **$Cu_2(Fe,Zn)GeS_4$** In hand specimens briartite is a dull iron-gray mineral with a dark gray streak and a dull, metallic luster; there is a barely perceptible lilac-gray tinge to the color imparted by the germanium content. Tsumeb briartite, unlike briartite from Kipushi, Zaire, is not magnetic. Associations include chalcopyrite, tennantite, renierite and germanite in one suite and sphalerite, tennantite, renierite and galena in another suite. The first specimens were found in the 120 stope at the 954 m level, but later specimens have been found in the area between the 32 and 34 levels. | |
| *Ge-Briartite* | **$Cu(Fe,Zn)Ge_2S_4$?** A germanium-rich variety has been described. Considering that the ionic radii of copper and germanium in the divalent state are almost identical, it is possible that the mineral has the composition indicated above, with Ge substituting for Cu. | |
| **Brochantite** | **$Cu_4(SO_4)(OH)_6$** Forms green to blackish green crystals to 13 mm. Some superb specimens have been found. Most brochantite, however, forms dull to velvety coatings of microscopic green crystals. | 84 |



beudantite



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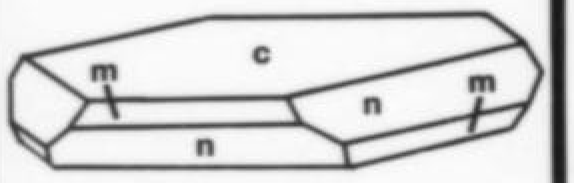

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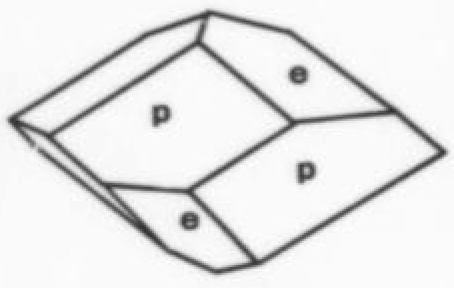
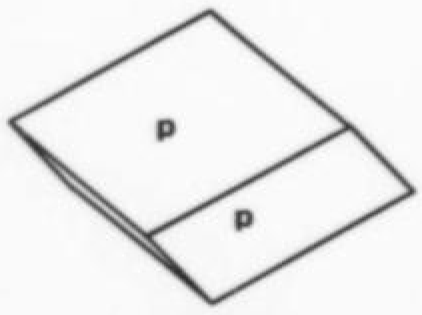


calcite



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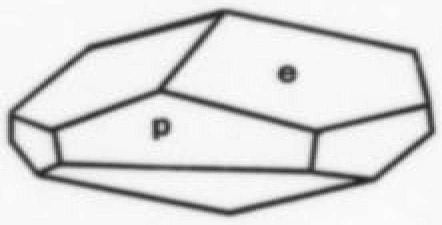

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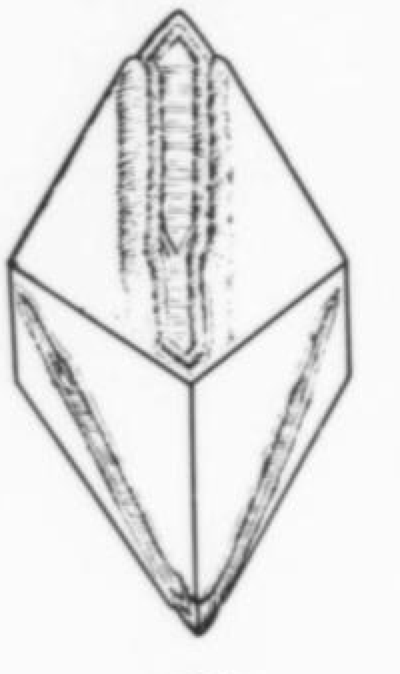

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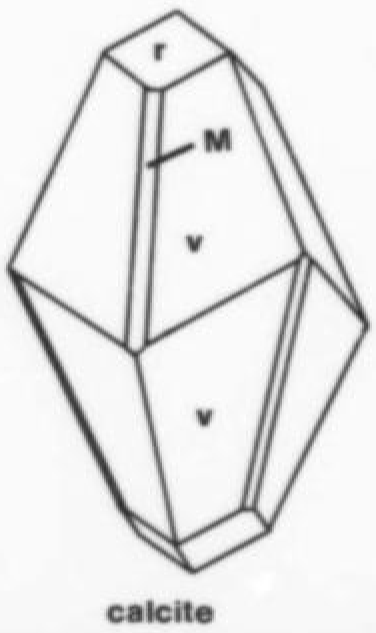

calcite

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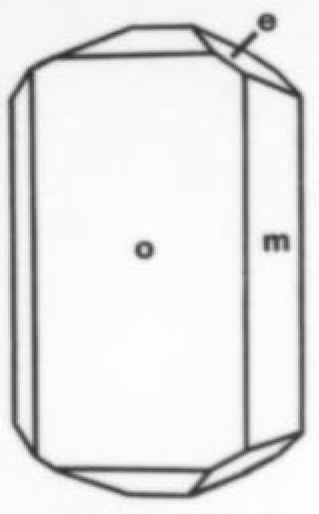
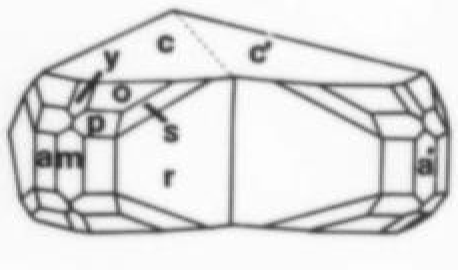
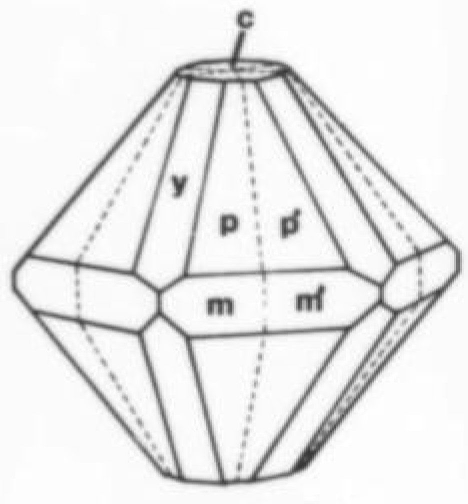
| **Brunogeierite** | $(Ge,Fe)Fe_2O_4$ Found on the 29 level as 30-50 μm thick crusts on tennantite with renierite and also stottite. Black. | 75 |
| **Calcite** | $CaCO_3$ Forms in many different habits and colors. Some rhombohedral groups colored reddish brown by inclusions resemble specimens from Cornwall, England. The most common colors are only white or shades of gray but the mineral is very abundant in the oxide zones; together with dolomite and quartz it forms the bulk of gangue material at Tsumeb. Many fine specimens of water-clear simple rhombs to several cm have been found and may often be obtained at low cost. Fine specimens enclosing copper are also known. | 59<br>66<br>72<br>73<br>82<br>85 |
| *Cobaltocalcite* (Co-var.) | $(Ca,Co)CO_3$ Up to 2% $CoCO_3$ can be accommodated in the calcite structure. | |
| *Cuprocalcite* (Cu-var.) | $(Ca,Cu)CO_3$? Forms attractive apple-green rhombs indistinguishable from cuprosmithsonite, except for a tendency of smithsonite to have curved faces. | |
| *Plumbocalcite* (Pb-var.) | $(Ca,Pb)CO_3$ Calcite may contain 3-4% $PbCO_3$ in solution but greater lead concentrations are probably the result of a fine-grained intergrowth of plumbocalcite and cerussite. Crystals are silky to frosty white rhombs and may reach several cm in size. | 66 |
| **Caledonite** | $Cu_2Pb_5(CO_3)(SO_4)_3(OH)_6$ Forms small crystals less than 1 mm in size and of typical blue-green color and acicular to bladed habit. Caledonite has always been found in association with linarite at Tsumeb, but is much rarer than linarite. Crystals commonly cluster around small grains of cerussite. | |
| **Carminite** | $PbFe_2(AsO_4)_2(OH)_2$ Forms acicular, translucent crystals and radially fibrous spherical aggregates ranging in color from reddish brown to deep red and reddish black. Carminite has been found rarely with tsumcorite on the 30 level, with beudantite and arseniosiderite in the most common suite and with scorodite and anglesite in a third suite. The crystals rarely exceed 1 cm in length. Tsumeb carminite is the finest in the world. | 80 |
| **Carrollite** *(Ni-Carrollite)* | $Cu(Co,Ni)_2S_4$ Hey (1955) indicates that the varietal name *Sychnodymite* should be used for carrollite with 5% or more nickel. At Tsumeb it is found only as tiny, light steel-gray crystals visible under the microscope. | |
| **Cerussite** | $PbCO_3$ The cerussite crystals from Tsumeb are unquestionably the largest and finest found anywhere in the world. Superb, clear, twinned crystals have been found up to 60 cm (2 feet) in length. Most crystals are twinned but a few untwinned specimens are occasionally seen. Cerussite is the most abundant secondary lead mineral at Tsumeb. The color ranges from colorless to yellow, brown, gray and black. The black crystals are filled with inclusions of galena. Twinned groups may form six-pointed "stars" similar in appearance to snow flakes (but much larger!) or they may form large, reticulated groups and masses of complex shape. Some crystals are thick, water-clear and highly dispersive with many crystal modifications; others are bladed to elongated and milky. | 60<br>63<br>64<br>65<br>84<br>100<br>115 |
| **Chalcanthite** | $CuSO_4 \cdot 5H_2O$ Forms beautiful crystals in the upper oxidation zone but is rare in the lower oxida- | |



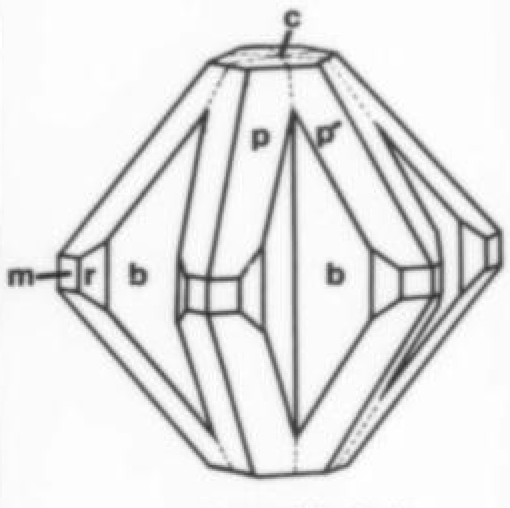
carminite



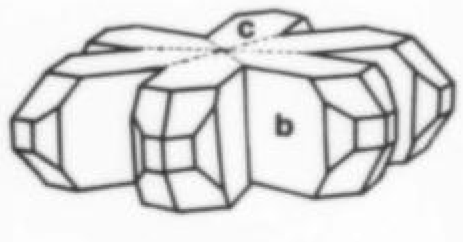
**cerussite** twin



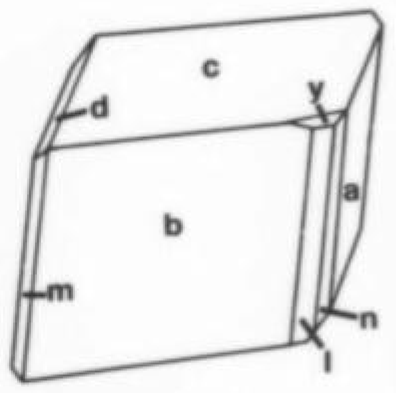
**cerussite** twin



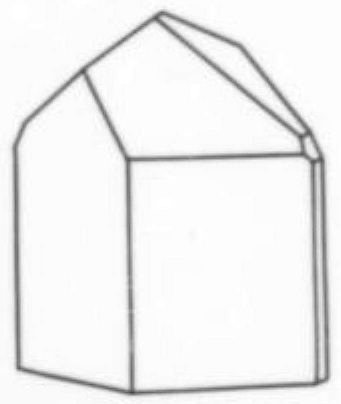
**cerussite** twin



**cerussite** twin



chudobaite



conichalcite

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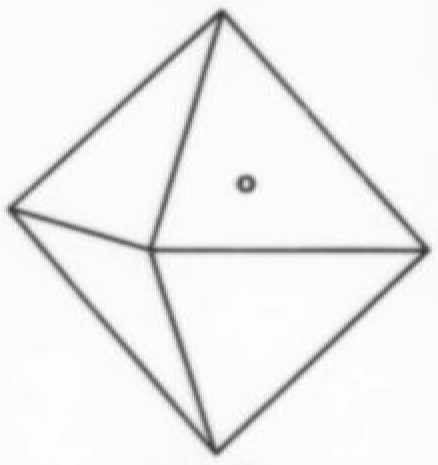
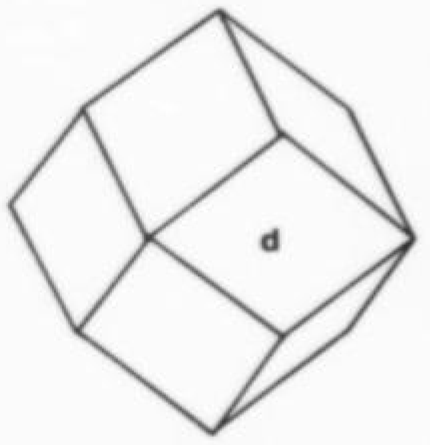
| | tion zone. The crystals and crusts vary in color from attractive blues and greens to nearly white, but they decompose and disintigrate very quickly after being collected. Chalcanthite is commonly associated with sulfide ore. | |
| **Chalcocite** | **$Cu_2S$** Chalcocite is one of the most important of the sulfide ore minerals at Tsumeb. It is found as both primary and secondary chalcocite but the latter is much more common. It usually occurs as dark lead-gray masses and blocks of sometimes immense size, but small, very rare, thick, tabular pseudohexagonal crystals have been observed. Associations include galena, sphalerite, native silver, and other sulfides, as well as an extensive array of secondary minerals. Most Tsumeb "chalcocite" has been found to be djurleite. | **83** |
| **Chalcophanite** | **$ZnMn_3O_7\cdot 3H_2O$** Found very rarely as microscopic particles in other manganese oxides. | |
| **Chalcophyllite** ("Erinite") | **$Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27}\cdot 33H_2O$** This mineral was noted by Maucher in 1908 but has not been observed since. Maucher described it as a gray-green crust on malachite. | |
| **Chalcopyrite** | **$CuFeS_2$** Forms brass-yellow metallic masses intergrown with other sulfides. Whereas chalcopyrite is a common ore at other deposits it is rare at Tsumeb because of the general scarcity of iron there. Associations include germanite, renierite, tennantite, gallite, galena and pyrite. | **83** |
| **Chenevixite** | **$Cu_2Fe_2(AsO_4)_2(OH)_4\cdot H_2O$** Form massive, compact, earthy deposits and masses of a grass-green to olive-green color. | |
| *Pb-Chenevixite* | **$(Cu,Pb)_2Fe_2(AsO_4)_2(OH)_4\cdot H_2O$?** Forms compact, earthy to spongy masses of a brownish color. | |
| **Chlorite** | **$(Mg,Fe)_{5-6}(Al,Si)_4O_{10}(OH)_8$** A mineral of the country-rock. | |
| **Chrysocolla** | **$(Cu,Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$** Bright green to sky-blue masses and crusts but found only rarely. Some masses have a high quartz content. | **83** |
| **Chudobaite** | **$(Na,K,Ca)(Mg,Zn,Mn)_2H(AsO_4)_2\cdot 4H_2O$** Forms pinkish-purple kunzite-colored crystals to 5 mm in size on the 1000 m level. Associations include conichalcite, cuproadamite and Zn-olivenite. | **70** |
| **Cinnabar** | **$HgS$** Forms small, scarlet crystals and powdery masses associated with cerussite; it is extremely rare. | |
| **Claudetite** | **$As_2O_3$** Forms as colorless, flexible white plates to 3 mm in size and also massive; it is extremely rare at Tsumeb. | |
| **Clinoclase** | **$Cu_3(AsO_4)(OH)_3$** Observed only by Maucher (1908) as dark green coatings on malachite. Some investigators feel the identification is questionable. | |
| **Conichalcite** | **$CaCu(AsO_4)(OH)$** Usually forms globular dirty green to bright green masses and small crystals rarely exceeding 3 mm. | **71** |
| *Parabayldonite* (Pb-var.) | **$Ca(Pb,Cu)(AsO_4)(OH)$?** Described as the Pb-variety of conichalcite by Guillemin in 1956. | |
| **Copper (native)** | **$Cu$** Copper is the most abundant native element occurring at Tsumeb. It exhibits a typical coppery-red color which tarnishes to various shades of brown and blackish brown. It is of secondary | **85** |

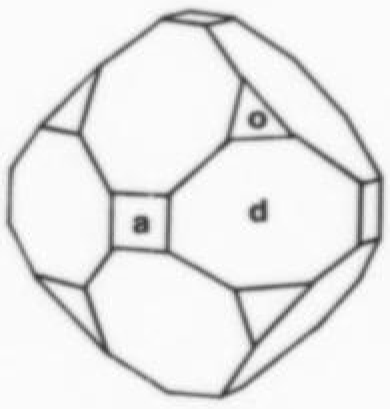
copper



cuprite



cuprite



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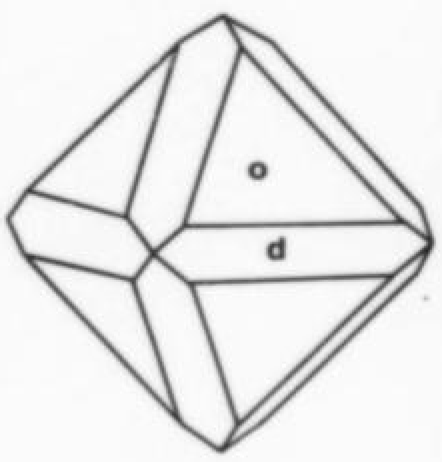

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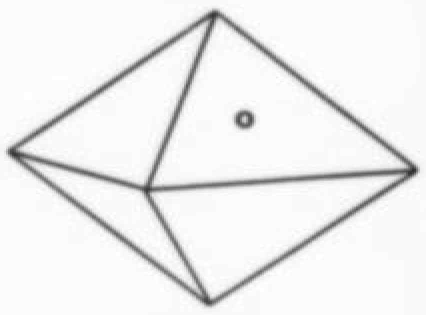
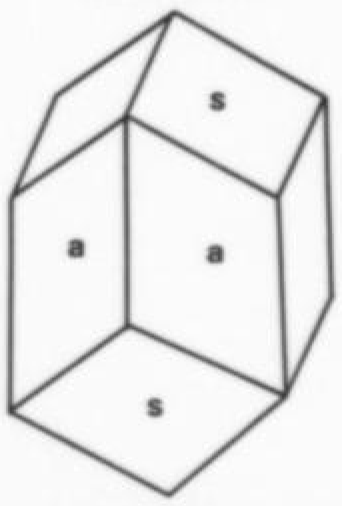


descloizite



dioptase

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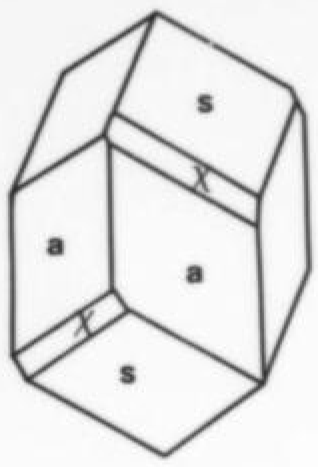
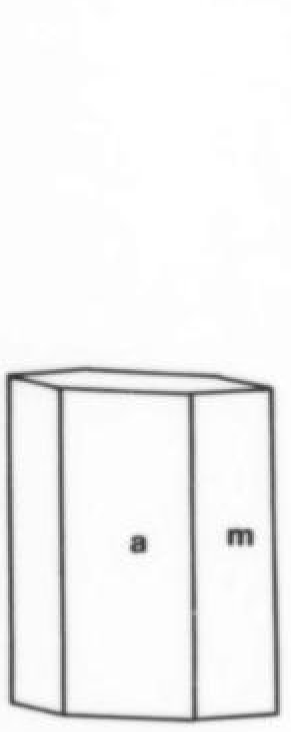
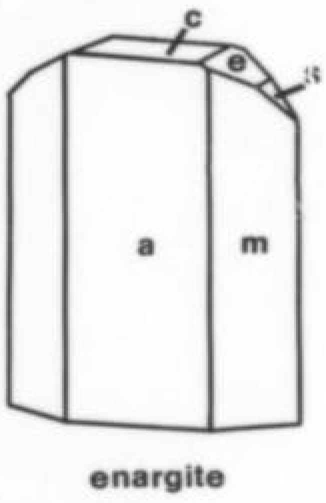
| | origin and is most common in the lower oxidation zone where it forms dendritic aggregates and crystal masses associated with dolomite, cuprite, malachite, cerussite and calcite. | |
| **Corkite** | $PbFe_3(PO_4)(SO_4)(OH)_6$ Forms yellow to yelowish brown pseudocubic crystals easily confused with beudantite. Associations include carminite and quartz. | |
| **Coronadite** | $PbMn_8O_{16}$ Forms massive gray to black sooty crusts and botryoidal masses on dolomite. | 56 |
| **Covellite** | $CuS$ Covellite occurs widely with chalcocite but only in the upper oxidation zone. It most commonly forms extremely thin coatings, crusts and fracture fillings in sulfide ore. Rarely larger, indigo-blue masses have been found. Covellite is nearly always found in close proximity to weathering copper sulfides and commonly forms as an oxidation product of digenite. | |
| **Cubanite** | $CuFe_2S_3$ Forms golden yellow, magnetic masses visible only under the microscope. | |
| **Cuprite** | $Cu_2O$ Forms beautiful cochineal-red crystals to about 3 cm. Crystal forms include the octahedron, cube, dodecahedron, or combinations thereof. Massive cuprite is common with native copper and occasionally with malachite. Other associations include mimetite, smithsonite, dolomite and calcite. | 72<br>73 |
| *Chalcotrichite* (acicular var.) | $Cu_2O$ Hair-like masses of chalcotrichite occur rarely. Similar appearing acicular ludlockite has sometimes been misidentified as chalcotrichite. | 72 |
| **Descloizite** | $PbZn(VO_4)(OH)$ Forms reddish brown to dark brown crystals, masses and stalactites as well as dendritic aggregates to 1 cm in size. Descloizite is rare at Tsumeb, and many specimens labeled as being from Tsumeb are probably from the prolific descloizite localities Abenab, Berg Aukus, Grootfontein, Guchab, Olifantsfontein and Uitsab which are all within about 100 km of Tsumeb. | 62 |
| *Cuprodescloizite* (Cu-var.) | $Pb(Zn,Cu)(VO_4)(OH)$ Forms greenish brown masses. | |
| **Devilline** | $CaCu_4(SO_4)_2(OH)_6 \cdot 3H_2O$ Forms white to bluish white felted masses on tennantite, and also sky-blue crusts on smithsonite. | |
| **Digenite** | $Cu_9S_5$ Forms distinctly irridescent blue masses with concoidal fracture and has also been observed as small crystals with chalcocite. | |
| **Dioptase** | $CuSiO_2(OH)_2$ The dioptase from Tsumeb is the world's finest. Beautiful, lustrous, transparent, dark emerald-green crystals on white calcite crystals make spectacular specimens. Crystals have been found up to 5 cm in size, and crystals 1 cm in size are fairly common. An enormous amount of dioptase was recently encountered in the East 19 stope on the 32 level; the finest dioptase has come from the lower oxidation zone and has been collected during the last 5 years. A small find of unusual blue-green to turquoise-blue dioptase crystals has recently been reported. | 71 |
| **Djurleite** | $Cu_{1.96}S$ Described in 1962 as a component of the massive copper ores. The blue-green to bluish-black color resembles that of chalcocite but the cleavage, when visible, resembles that of galena. | 83 |



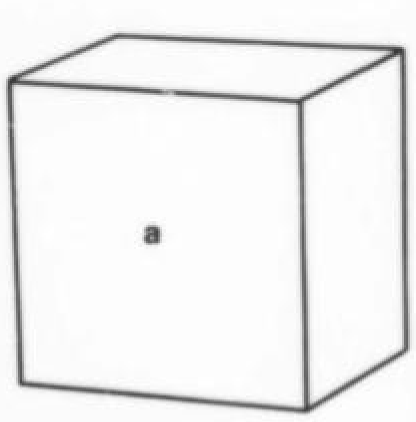
dioptase



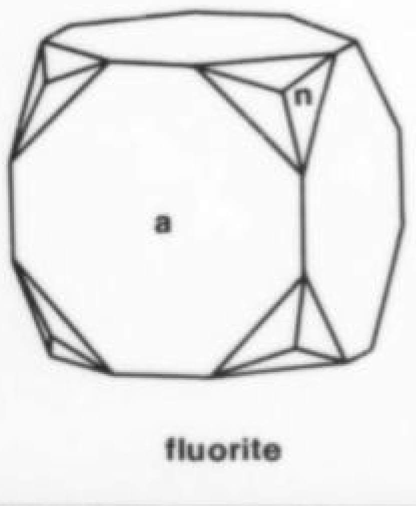
enargite



enargite



fluorite



fluorite

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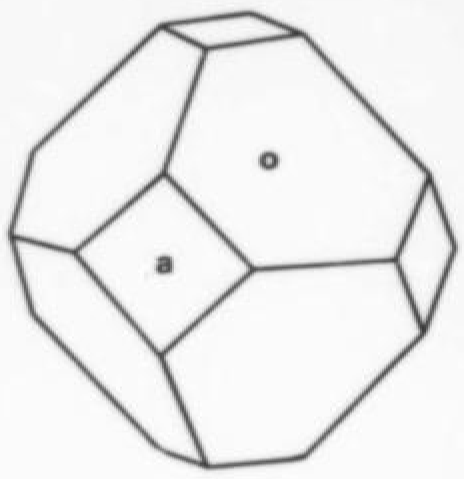
| **Dolomite** | **$CaMg(CO_3)_2$** Dolomite is the main constituent of the country-rock and also forms an important percentage of the gangue material in the Tsumeb deposit. Crusts of crystals are common; the color is usually white to cream. Masses with quartz are very common. | |
| *Co-Dolomite* | **$Ca(Mg,Co)(CO_3)_2$** Forms bright pink crystals. | |
| *Mangandolomite* (Mn-var.) | **$Ca(Mg,Mn)(CO_3)_2$** Pink crystals? | |
| *Plumbodolomite* (Pb-var.) | **$(Ca,Mg,Pb)(CO_3)$** Forms white crystals containing up to 2.26% Pb. | |
| *Zn-Dolomite* | **$(Ca,Mg,Zn)(CO_3)$** White crystals containing up to 21.65% Zn. | |
| **Duftite-alpha** | **$PbCu(AsO_4)(OH)$** Forms olive to gray-green and dark green crusts and distinct crystals to 3 mm. It was relatively common between the 50 and 100 m levels. The crystals are always distorted and have irregular faces. Duftite-alpha is generally darker in color and much rarer than duftite-beta discussed below. | 82 |
| **Duftite-beta** | **$Pb(Cu,Ca)(AsO_4)(OH)$** Forms olive to gray-green crusts, masses and small crystals. Widely disseminated at Tsumeb and found in association with many different minerals including wulfenite, malachite, azurite and beudantite. | 82 |
| **Dundasite** | **$PbAl_2(CO_3)_2(OH)_4 \cdot H_2O$** Forms white to pale blue vitreous to silky needles and fibers in sprays and spherical aggregates associated with azurite, duftite, cerussite and dolomite. The blue crystals give an X-ray pattern slightly different from the accepted dundasite pattern and may therefore represent a copper-rich variety or a new species. | 84 |
| **Enargite** | **$Cu_3AsS_4$** Enargite was one of the earliest minerals to form at Tsumeb. Crystals have the prismatic form and cross-section typical of enargite; they range in size up to 3 by 8 cm but are more commonly in the 2-5 mm range. Some crystals are partially altered to tennantite. The crystals are steel-gray to blackish gray in color and sometimes have an alteration coating of other minerals. | 60 |
| *Stibioenargite* (Sb-var.) | **$Cu_3(As,Sb)S_4$?** This variety(?) has been observed with luzonite in crystals to 2 cm in size. | |
| **Epidote** | **$Ca_2(Al,Fe)_3Si_3O_{12}(OH)$** A mineral of the country-rock. | |
| **Famatinite** (Stibioluzonite) | **$Cu_3SbS_4$** Massive, sooty black metallic. Probably part of a series to luzonite. | 83 |
| **Fleischerite** | **$Pb_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O$** Fleischerite, the lead analog of schaurteite, forms white to pale rose silky aggregates of sometimes radiating structure. The acicular hexagonal crystals are each very small, about 0.3 mm thick and up to 1 cm in length. Fleischerite is usually found in cavities in germanium sulfides associated with alamosite, kegelite, melanotekite, cerussite and mimetite; it sometimes forms on plumbojarosite, mimetite and dolomite. *Very* rare. | 84 |
| *Co-Fleischerite* | **$(Pb,Co)_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O$(?)** Reported (Ulrike Kahn, pers. comm.) as a specimen in the Stellenbosch collection, South Africa. | |
| **Fluorite** | **$CaF_2$** Fluorite is extremely rare at Tsumeb. Previous to this writing it had only been described | 58 |



galena

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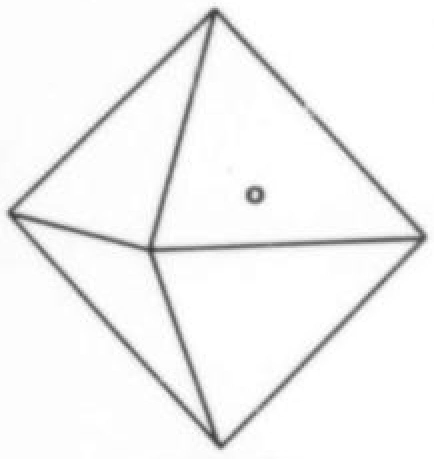
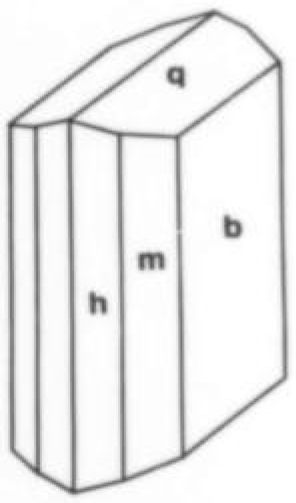
| | as minute bluish inclusions visible only under the microscope. However two excellent specimens, each with crystals over 1 cm, have recently been located, and both are pictured in the photo chapter. One is a medium apple-green of predominantly cubic habit but with trapezohedron faces on the corners; the portions of the crystals bounded by the trapezohedron faces are deep purple! The other specimen is entirely cubic in habit and seems to be zoned with blue and purple layers. | |
| **Galena** | **$PbS$** Galena occurs mostly as massive areas with sphalerite and copper sulfides to form what is known as "complex ore" (so called because of the number of different valuable metals contained, and the attendant milling and separation problems). It also occurs as fine grains and disseminated masses but is in general the most important lead mineral in the Tsumeb ores. Crystals are uncommon and rarely reach 1 cm in size. The habit is usually a combination of the cube and octahedron. Pseudomorphs of galena after calcite are known. | 60 |
| **Gallite** | **$CuGaS_2$** Forms minute metallic grains rarely exceeding 1 mm in size imbedded in renierite and germanite and also as exsolution lamellae in sphalerite. The color is gray with a lilac tinge, very similar to the color of germanite. | |
| **Germanite** | **$Cu_3(Ge,Fe)(S,As)_4$** Occurs as dark reddish gray metallic masses only and is associated with tennantite, enargite, pyrite, galena, sphalerite, azurite, malachite and primary chalcocite. It tarnishes to a dull brown over a period of time. | 83 |
| *W-Germanite* | **$Cu_3(Ge,W,Fe)(S,As)_4$?** This material, either a tungsten-rich variety or a new mineral, has been observed only under the microscope and appears to contain up to 7% tungsten; it has a slightly different color than that of pure germanite. | |
| *V-Germanite A* | **$Cu_3(Ge,V,Fe)(S,As)_4$?** This material, also of unknown status, occurs as inclusion grains of up to 75 microns in size. | |
| *V-Germanite B* | **$Cu_3(Ge,V,Fe)(S,As)_4$?** This material, also of unknown status, occurs as inclusions of the same size as the above vanadium variety type A. | |
| **Glaucodot** | **$(Co,Fe)AsS$** Forms grayish to tin-white masses visible only under the microscope. | |
| **Goethite** | **$FeO(OH)$** Forms yellowish brown, earthy masses and scales and also forms bright brown velvety crusts of fine acicular crystals. It is usually a component of "limonite," a mixture of goethite and lepidocrocite. | 60 |
| **Gold** | **$Au$** Known from a single specimen in the Kegel collection (now in the Smithsonian Institution) wherein it forms a small mass of a few mm in size imbedded in massive, brownish quartz or quartzite. | 83 |
| **Graphite** (var. *Shungite*) | **$C$** Forms granules similar to anthracite in the country-rock. | |
| **Gratonite** | **$Pb_9As_4S_{15}$** Forms dark, metallic, lead-gray microscopic masses found only on the 30 level. | |
| **Greenockite** | **$CdS$** Forms fine fracture fillings and minute masses visible only under the microscope. It has also been observed as a yellow to ochre-colored | 69 |



hematite after magnetite



keyite

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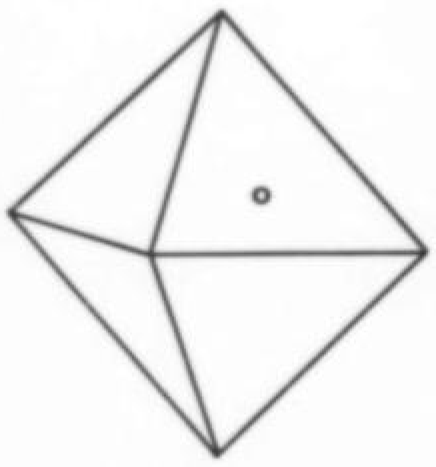
| | dusting on sphalerite and other minerals. As inclusions it can impart a bright yellow color to anglesite and wurtzite. | |
| *Zn-Greenockite* | **$(Cd,Zn)S$** Formerly known as Cd-Voltzite (Ulrike Kahn, pers. comm.). | |
| **Gypsum** | **$CaSO_4 \cdot 2H_2O$** Forms colorless, transparent crystals, druses and cleavages; good crystals to several cm have been found with carbonate minerals. | 59 |
| **Hedyphane** | **$(Ca,Pb)_5(AsO_4)_3Cl$** Forms small (1 mm) crystals of white to grayish white color on calcite crystals from the 860 m level. | |
| **Hematite** | **$Fe_2O_3$** Found only rarely at Tsumeb because of the general scarcity of iron. Forms black crusts of very small, sometimes translucent, red, lustrous crystals. It also occurs as botryoidal "kidney ore" and as octaheral "martite" pseudomorphs after magnetite to about 1 cm in size. | 56 |
| **Hemimorphite** | **$Zn_4Si_2O_7(OH)_2 \cdot H_2O$** Forms colorless to white, pale blue or yellowish masses and small, tabular crystals to a few mm in size. | 64 |
| **Heterogenite (3R or 2H?)** | **$CoO(OH)$** Superb, bright black botryoidal masses to several kg, as well as lustrous black coatings on calcite crystals, have been identified. | 59 |
| **Hidalgoite** | **$PbAl_3(SO_4)(AsO_4)(OH)_6$** Forms rare yellow-green masses. | |
| **Hydrozincite** | **$Zn_5(CO_3)_2(OH)_6$** Forms rare white to gray crusts, stains, powdery masses and dull coatings on smithsonite. It also forms as efflorescences of small, tabular crystals. | |
| **Idaite** | **$Cu_5FeS_6$(?)** An extremely rare mineral at Tsumeb; thus far it has only been identified from the 20 level where it forms reddish brown masses and fibers through the decomposition of bornite and chalcopyrite. | |
| **Ilmenite** | **$FeTiO_3$** A mineral of the country-rock. | |
| **Itoite** | **$Pb_3Ge(SO_4)_2O_2(OH)_2$** Recent studies indicate that the original identification of itoite from Tsumeb was in error. The problem appears to have been that itoite is created in the mortar by the grinding of fleischerite for x-ray analysis. | |
| **Jarosite** | **$KFe_3(SO_4)_2(OH)_6$** Observed as pale brown pseudomorphs after tennantite and azurite to 2 cm in size. | |
| **Kaolinite** | **$Al_2Si_2O_5(OH)_4$** Forms white chalky masses to several cm in size. | 83 |
| **Kegelite** | **$Pb_{12}(Zn,Fe)_2Al_4(Si_{11}S_4O_{54})$** Forms white, brilliant, tabular crystals and rosettes up to 30 microns wide and 1 micron thick. The pseudohexagonal plates have a pearly luster resembling otavite and are associated with hematite, leadhillite, anglesite, fleischerite, alamosite, melanotekite and mimetite. | 63 |
| **Keyite** | **$(Cu,Zn,Cd)_3(AsO_4)_2$** Forms beautiful connellite-blue prismatic crystals usually under a mm in size and associated with cuproadamite. Keyite is described as a new species for the first time elsewhere in this issue. | 59<br>89<br>90 |
| **Köttigite** | **$Zn_3(AsO_4)_2 \cdot 8H_2O$** Acicular white crystals to 2 mm, in groups and rosettes, have been observed associated with cuproadamite. | |



linnaeite

ludlockite

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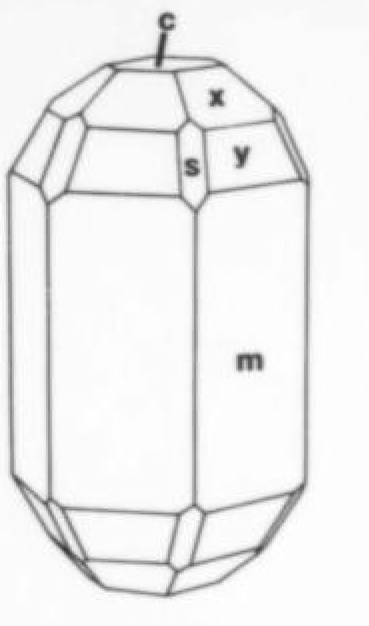
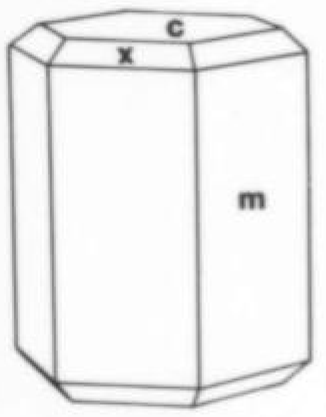
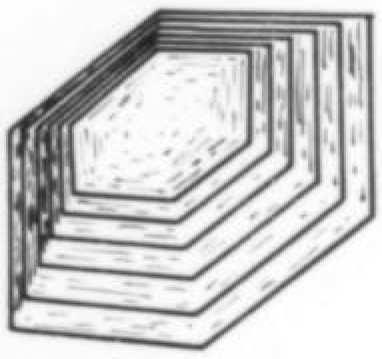
| **Langite** | $Cu_4(SO_4)(OH)_6\cdot 2H_2O$ Langite has been described as bright blue, bladed crystals in aggregates associated with devilline and brochantite. | |
| **Lavendulan** | $NaCaCu_5(AsO_4)_4Cl\cdot 5H_2O$ Has been observed as bluish crusts in the lower oxidation zone. | |
| *Zn-Lavendulan* | $NaCa(Cu,Zn)_5(AsO_4)_4Cl\cdot 5H_2O$ Forms blue, small, rhombohedral crystals and sprays. | 80 |
| **Leadhillite** | $Pb_4(SO_4)(CO_3)_2(OH)_2$ Leadhillite crystals from Tsumeb are the largest and finest known. They range in habit from small and poorly formed to superb pseudohexagonal tablets and pyramids as large as 13 cm, and weighing several kg. The color ranges from white to dark gray and pale yellow. Its softness and micaceous cleavage with pearly luster on the cleavage face are diagnostic. It is most common in the lower oxidation zone where it has been found with melanotekite, anglesite, cerussite and alamosite. | 63 |
| **Leiteite** | $(Zn,Fe)As_2O_4$ Forms white to reddish brown, translucent, cleavable masses to a few cm in size associated with tennantite. The cleavages are flexible and sectile similar to gypsum. Leiteite is described as a new species for the first time elsewhere in this issue. | 59<br>96 |
| **Lepidocrocite** | $FeO(OH)$ Forms yellowish red needles mixed with goethite to form masses of "limonite." | 85 |
| **Linarite** | $PbCu(SO_4)(OH)_2$ Forms deep blue crystals rarely exceeding a few mm in size. The crystals are of a bladed habit and occur with cerussite, tennantite, brochantite and sometimes caledonite. Linarite is relatively widespread at Tsumeb but is often overlooked because of its small size and similarity in color and habit to azurite. | 84 |
| **Linnaeite** | $(Co,Ni)_3S_4$ Forms metallic, steel-gray inclusions and octahedrons visible only through the microscope. | |
| **Ludlockite** | $(Fe,Pb)As_2O_6$ Forms rust-brown to nearly red acicular crystals and fibers up to 3 cm in length. The crystals commonly penetrate small rhombs of Zn-siderite. Ludlockite has been found in a cavity in the germanite ore body on the 30 level in association with carminite, beudantite and stromeyerite. Some specimens labeled "chalcotrichite" in old collections have been shown to be ludlockite. Ludlockite is described in detail for the first time elsewhere in this issue. | 75<br>92<br>93 |
| **Luzonite** | $Cu_3AsS_4$ Forms grayish masses with a pinkish cast associated with tennantite and other sulfides. | |
| **Magnesite** | $MgCO_3$ A mineral of the country-rock. | |
| **Magnetite** | $Fe_3O_4$ A mineral of the country-rock; sometimes in octahedral crystals replaced by hematite. | |
| **Malachite** | $Cu_2(CO_3)(OH)_2$ Malachite is the most abundant secondary copper mineral at Tsumeb. Original, non-pseudomorphous crystals occur rarely as small needles and crusts with cuprite and native copper. The most celebrated specimens are the fine, large pseudomorphs after azurite and other minerals which reach many cm in size; the best of these came from the upper oxidation zone in the 1920's and 1930's and have not been found in any quantity in | 73<br>100 |



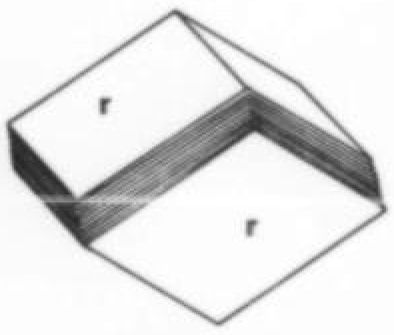
mimetite



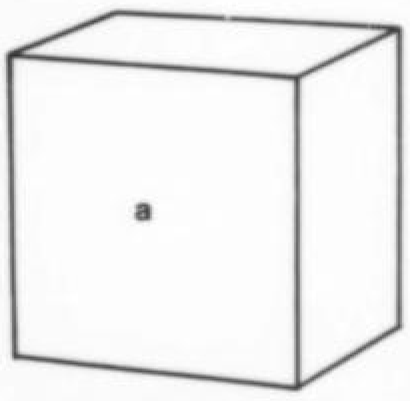
mimetite



molybdenite



otavite



pharmacosiderite

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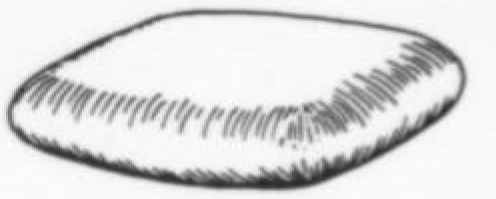
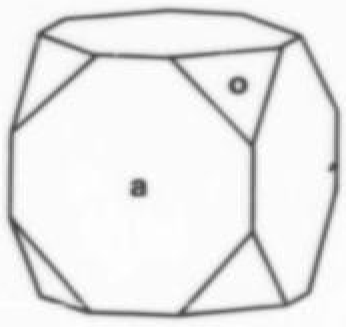
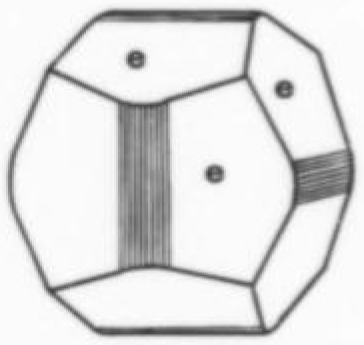
| | recent times. The replacement of the azurite crystals commonly appears to have begun at a few small points and spread through the crystals creating radiating and banded silky-lustered patterns. | |
| **Mangan-Stottite** | **$MnGe(OH)_6$** This manganese analog of stottite forms small crystals with "Ge-Zn-mawsonite." | |
| **Massicot** | **$PbO$** Forms powdery coatings and masses of a lemon-yellow to ochre-yellow color. | |
| **Mawsonite** | **$Cu_7Fe_2SnS_{10}$** Has been described as small, rounded masses and grains in bornite. Mawsonite is magnetic and harder than bornite, with a brownish orange color under the reflecting microscope. | |
| **Melanotekite** | **$Pb_2Fe_2Si_2O_9$** Found with leadhillite and alamosite as small, dull, blackish green spherules and crusts. | 84 |
| **Metacinnabar** | **$HgS$** Observed as gray to black microscopic inclusions in sphalerite. | |
| **Microcline** | **$KAlSi_3O_8$** A mineral of the country-rock. | |
| **Millerite** | **$NiS$** Forms brass-yellow, metallic, microscopic masses. | |
| **Mimetite** | **$Pb_5(AsO_4)_3Cl$** Found at Tsumeb in a wide variety of colors and habits. The crystals range from minute needles and crusts to small rosettes and large, prismatic crystals with pinacoid and/or pyramid terminations. The color ranges from nearly colorless to pale yellow, pale brown, lemon-yellow, orange, red, green, gray and black. The finest specimens of mimetite were discovered in 1972; two of the best of these are pictured on the covers of this issue. They are gemmy, transparent and pale lemon yellow, and reach a size of 5 cm although most crystals in the pocket were less than 2 cm in size.<br>The large, gemmy crystals are very sensitive to temperature changes and will crack or craze with little provocation. | Front Cover<br>Back Cover<br>61 |
| **Minium** | **$Pb_3O_4$** Described as dull red coatings on cerussite. | |
| **Mixite** | **$BiCu_6(AsO_4)_3(OH)_6 \cdot 3H_2O$** Known from only one specimen in the Smithsonian Institution on which it has formed as small white sprays of extremely thin, matted crystals on azurite crystals. | |
| **Molybdenite** | **$MoS_2$** Forms lead-gray metallic cleavages with a slight bluish cast. One specimen exhibiting a hexagonal, pyramidal, 3 cm crystal with stottite and schneiderhöhnite is known. | 59 |
| **Mottramite** | **$Pb(Cu,Zn)(VO_4)(OH)$** Forms yellow-green to dark greenish brown masses and arborescent botryoidal groups. It is widely disseminated at Tsumeb but rarely forms attractive specimens. | 78<br>114 |
| **Muscovite** | **$KAl_2(AlSi_3)O_{10}(OH)_2$** A mineral of the country-rock. | |
| **Oligoclase** | **$(Na,Ca)Al(Al,Si)Si_2O_8$** A mineral of the country-rock. | |
| **Olivine** | **$(Fe,Mg)_2SiO_4$** A mineral of the country-rock. | |
| **Olivenite** | **$Cu_2(AsO_4)(OH)$** Relatively common in both oxidation zones. Olive-green to greenish brown crystals have been found, some of which are the finest olivenite specimens in the world, and reach 2.5 cm. The habit is most commonly radially struc- | 57 |



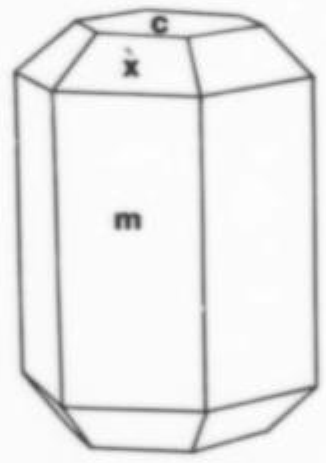
powellite



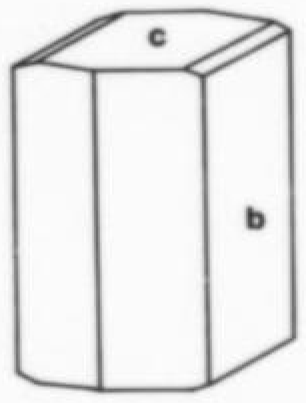
pyrite



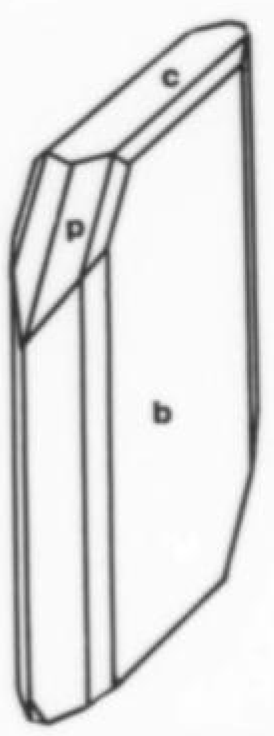
pyrite



pyromorphite



reinerite



schultenite

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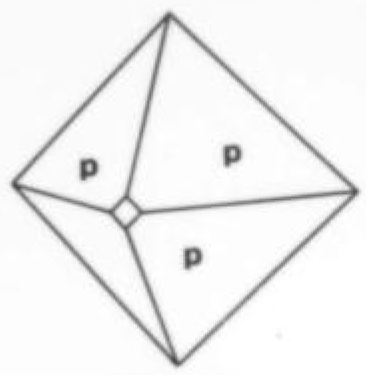
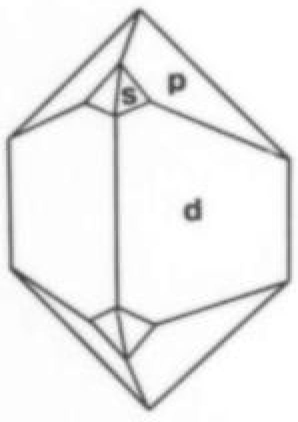
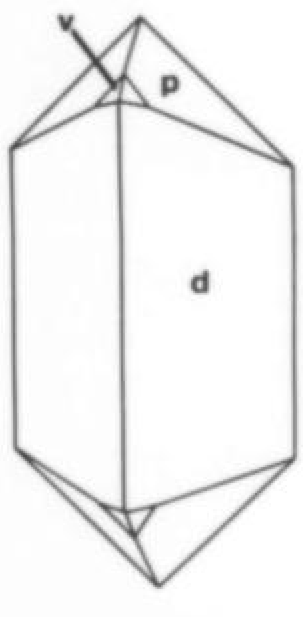
| | tured masses and prismatic crystals or tabular crystals flattened on the *a*-axis. | |
| *Fe-Olivenite* | **$(Cu,Fe)_2(AsO_4)(OH)$** Blackish green; fairly common in the lower oxidation zone. | |
| *Zincolivenite* (Zn-var.) | **$(Cu,Zn)_2(AsO_4)(OH)$** Found as emerald-green prismatic crystals with balydonite crystals on tennantite. | 57 |
| **Orthoclase** | **$KAlSi_3O_8$** A mineral of the country-rock. | |
| **Otavite** | **$CdCO_3$** The cadmium analog of calcite, otavite forms white to light gray pearly coatings on smithsonite. Otavite crystals are very rare, reaching a maximum size of less than 2 mm and forming rounded rhombohedrons. | 58 |
| **Patronite** | **$VS_4$?** Forms greenish black to black microscopic coatings and inclusions in sulfide ore. | |
| **Pharmacosiderite** | **$Fe_3(AsO_4)_2(OH)_3 \cdot 5H_2O$** Formed through the weathering of tennantite and other arsenic minerals, pharmacosiderite has been observed as lustrous yellow to olive-green transparent cubes on the 30 level. | |
| **Phosgenite** | **$Pb_2(CO_3)Cl_2$** Some of the finest crystals thought to be phosgenite have turned out to be mimetite. The true phosgenite crystals are short prismatic and dark brown in color. Cerussite of a greasy luster is also very difficult to distinguish from phosgenite. Associations include anglesite, galena and other sulfides. | 85 |
| **Plancheite** | **$Cu_8Si_8O_{22}(OH)_4 \cdot H_2O$** Forms thick, whitish blue to blue masses and powdery coatings and rarely small, radially structured spheres that have sometimes been misidentified as "bisbeeite." | 82 |
| **Plattnerite** | **$PbO_2$** Forms blackish brown coatings up to 2 mm thick on cerussite and massicot in the upper oxidation zone. Plattnerite has also been observed as minute, blackish brown crystals in the lower oxidation zone. | |
| **Plumbojarosite** | **$PbFe_6(SO_4)_4(OH)_{12}$** First noted in 1960, with fleischerite. It forms intergrowths with mimetite and fleischerite in the upper oxidation zone. | |
| **Posnjakite** | **$Cu_4(SO_4)(OH)_6 \cdot H_2O$** Forms deep blue-green tabular crystals mixed with green acicular brochantite, and associated with malachite, devilline and serpierite as well. It has also been observed on tennantite pseudomorphs after azurite and on cerussite. | |
| **Powellite** | **$CaMoO_4$** Observed as small, straw-yellow tetragonal crystals on scorodite crystals with tennantite; only a few specimens are known. Crystal size reaches 3 mm. | |
| **Psilomelane** | **(various Mn oxides)** Forms iron-black to steel-gray sooty masses. | |
| **Pyrite** | **$FeS_2$** Found with galena, sphalerite and tennantite but, because of the scarcity of iron at Tsumeb, is only very rarely found in significant amounts or sizes. Pyrite usually forms only small inclusions in other sulfides, but a few large crystals in cavities have been found. Most crystals are only a few mm in size but crystals of several cm are known. Pyrite may sometimes contain microscopic inclusions of linnaeite. Cube, pyritohedron and octahedron faces, or distorted combinations thereof, have all been observed. Associations in addition to other sulfides include cerussite and calcite. | 60 |



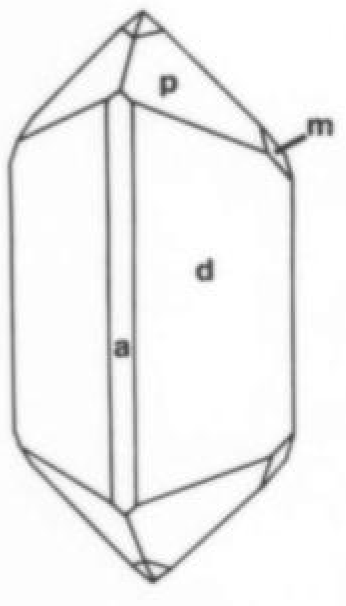
scorodite



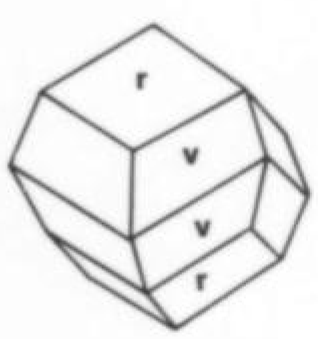
scorodite



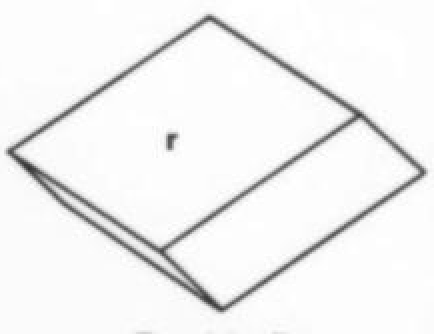
scorodite



scorodite



siderite



*Zn-siderite*

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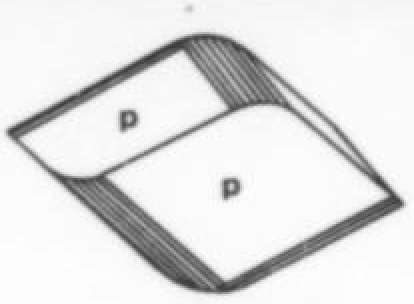
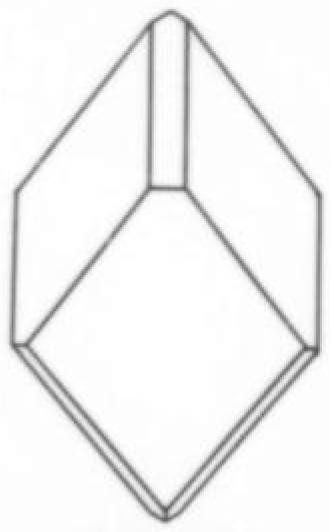
| **Pyrolusite** | **$MnO_2$** Powdery to acicular crystals and masses of a blackish color are widespread, especially as stains on other minerals. | 56 |
| *Asbolane* (Co-var.) | **$(Mn,Co)O_2$** Pyrolusite containing up to 20% cobalt has been observed. | |
| **Pyromorphite** | **$Pb_5(PO_4)_3Cl$** Forms relatively rare hexagonal needles and prisms up to 2 cm. The color ranges from colorless to green, brown, and bright yellow. A series exists between pyromorphite and mimetite, and examples of arsenic-rich pyromorphite and phosphate-rich mimetite have both been found. | 61 |
| **Quartz** | **$SiO_2$** Colorless to milky and gray crystals reaching nearly a cm have been found, but quartz at Tsumeb is most commonly massive and forms a part of the gangue as well as the country-rock. | 63<br>83 |
| *Amethyst* | **$SiO_2$ plus trace Fe** A few violet crystals of amethyst have been observed. | |
| **Realgar** | **$AsS$** Has been observed as small, red inclusions in heterogenous, massive lead and copper arsenates. | |
| **Reinerite** | **$Zn_3(AsO_3)_2$** Found at the base of level 29 right at the ore body's intersection with the north break fracture zone in stopes S 95 and W 120 as nearly 5 cm pseudohexagonal crystals. The color is sea-green to light yellow-green. Associations include chalcocite, willemite and bornite. *Extremely* rare; only a few specimens known. | |
| **Renierite** | **$Cu_3(Fe,Ge,Zn)(S,As)_4$** This orange-red mineral was first described in 1957 and before that was known by the working name "orange bornite." In the present workings it is encountered as frequently as germanite from level 17 downward. It occasionally forms small crystals to 1.5 mm in vugs but most commonly forms small granular inclusions in chalcopyrite, sphalerite, galena and tennantite, and also with germanite and bornite on the 24 level. | |
| **Rhodochrosite** | **$MnCO_3$** Rare pinkish masses have been observed. | |
| **Rosasite** | **$(Cu,Zn)_2(CO_3)(OH)_2$** Forms bluish green mammilary crusts and velvety botryoidal coatings associated with malachite, quartz and cerussite. The Cu:Zn ratio is 1½:1. Also forms superb pseudomorphs after azurite. | 57 |
| *Zn-Rosasite* (high Zn-var.) | **$(Zn,Cu)_2(CO_3)(OH)_2$** This pale green to whitish, copper-poor, zinc-rich variety has been described in which the Cu:Zn ratio is less than 1:1. | |
| *Paraurichalcite* (high Cu-var.) | **$(Cu,Zn)_2(CO_3)(OH)_2$** This deep blue-green variety reportedly has a Cu:Zn ratio of 2:1 and may form part of a series to malachite. A variety of malachite known as *cuprozincite* (not yet reported from Tsumeb) has a Cu:Zn ratio of about 4:1. Paraurichalcite has been observed as pseudomorphs after azurite in attractive groups and also as botryoidal crusts. | 57 |
| **Rutile** | **$TiO_2$** A mineral of the country-rock. | |
| **Schaurteite** | **$Ca_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O$** Forms brittle, very dull to silky needles and fibers to 2 mm long; the crystals have hexagonal cross-sections. Schaurteite is usually found in solution cavities in complex germanium sulfide ores however the crystals do not rest directly on sulfides but rather upon a thin coat- | |



smithsonite



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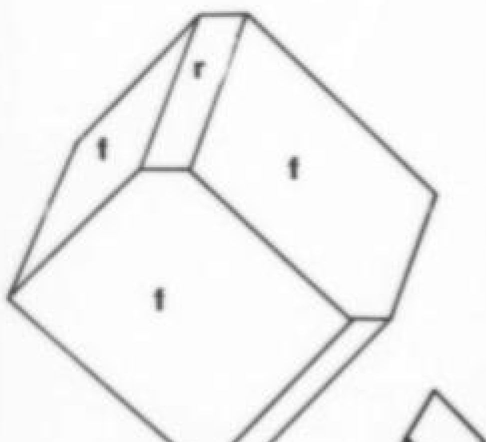

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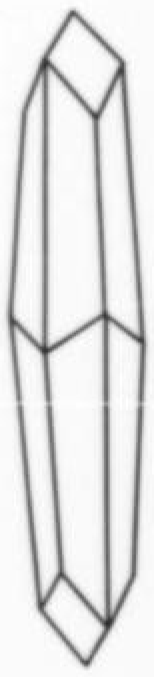

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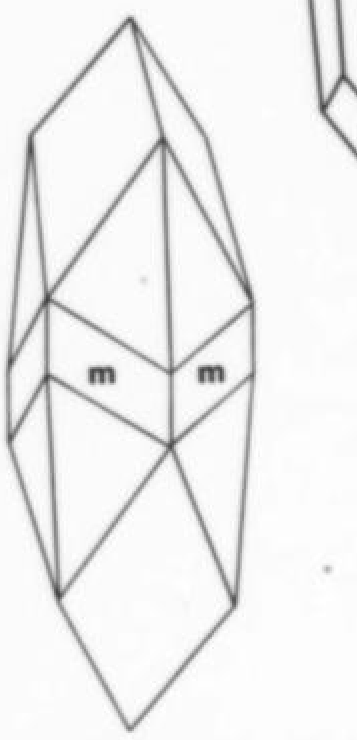

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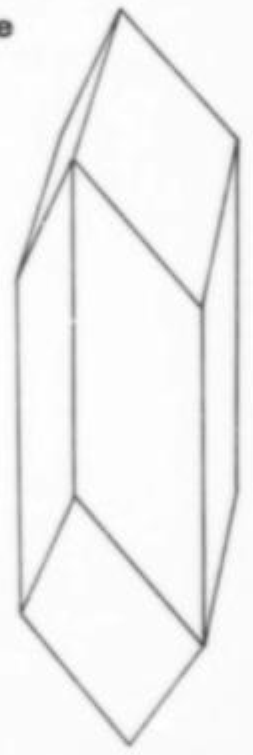

smithsonite

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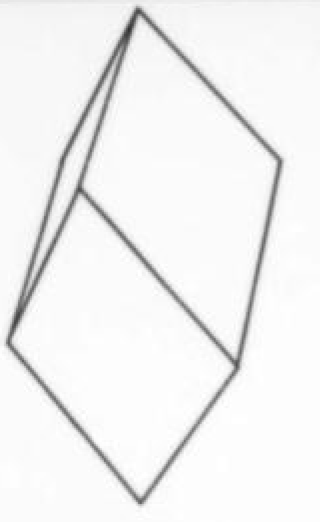
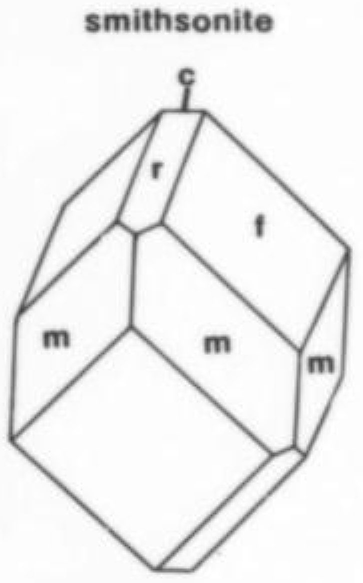
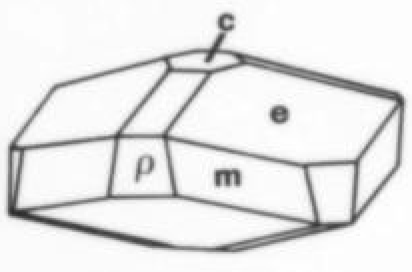
| | ing of carbonates on the sulfides. It is found in the lower oxidation zone and is extremely rare. | |
| **Schneiderhöhnite** | **$Fe_8As_{10}O_{23}$** Occurs in small crystal aggregates with stottite, molybdenite and secondary chalcocite. The color is dark brown to black, the luster is adamantine and the size ranges up to 15 mm. It has three cleavages, one perfect, and many "crystals" are actually only cleavages. Only a few specimens are known. | 59 |
| **Schultenite** | **$PbHAsO_4$** Two occurrences at Tsumeb are known. The first was found in the upper oxidation zone on level 7 at a depth of 190 m; the crystals found there were slender, thin plates 1 cm long and 1 mm thick associated with anglesite, native sulfur, bayldonite and mimetite. The second occurrence has produced superb crystals to 4 cm in length associated with cuproadamite, bayldonite, keyite and chalcocite; the crystals are clear and colorless with an appearance similar to gypsum. A separate article detailing the morphology is presented elsewhere in this issue. | 58<br>98 |
| **Scorodite** | **$FeAsO_4 \cdot 2H_2O$** The scorodite crystals from Tsumeb are among the finest in the world, rivalled only by a few Mexican specimens. The crystals vary in habit from thickly bladed to pseudo-octahedral, and reach a maximum length of about 5 cm. In daylight they are a blue-green color but in incandescent light they exhibit a pronounced "alexandrite effect" and appear to be an intense bluish purple to gray-blue. The pseudo-octahedral faces are adamantine but the other faces tend to be frosty to irregular. Scorodite is usually only associated with tennantite but has been reported with tsumcorite and minute crystals of powellite and anglesite. | 59 |
| **Seligmannite** | **$PbCuAsS_3$** Forms dark blue-gray to lead-gray and black inclusions in sulfides and is visible only under the microscope. | |
| **Serpierite** | **$Ca(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$** Has been observed as very thin, light blue-green to white, glossy scales covering posnjakite and brochantite. | |
| **Shattuckite** | **$Cu_5(SiO_3)_4(OH)_2$** Observed as blue to dark blue compact granular to fibrous masses. | |
| **Siderite** | **$FeCO_3$** Forms dark yellow to golden brown crystals and masses. The crystals range from needles to fine scalenohedral crystals capped by rhombohedron faces and reaching several mm in size; the latter type form attractive druses of water-clear dark golden brown crystals in pockets in sulfides. | 85 |
| *Zn-Siderite* | **$(Fe,Zn)CO_3$** Forms golden yellow simple rhombs pierced by ludlockite crystals. The siderite crystals range between 1 and 3 mm in size and vary in Zn content from about 9% at the surface to near 5% at the core, with a complementary variation in the iron content. A bulk chemical analysis yielded the formula $(Fe_{67\cdot5}Zn_{21\cdot8}Ca_{5\cdot6}Mn_{4\cdot2}Mg_{0\cdot5}Pb_{0\cdot4})CO_3$. Associations in addition to ludlockite include tennantite, chalcocite, pyrite, bornite, germanite and quartz. A full discussion is presented in the formal description of ludlockite elsewhere in this issue. | 75 |
| **Silver** | **Ag** First found in the upper oxidation zone with chalcocite between 280 and 400 m deep. It | |



smithsonite



cobaltsmithsonite



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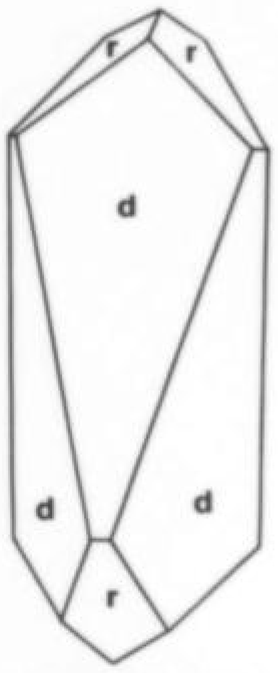
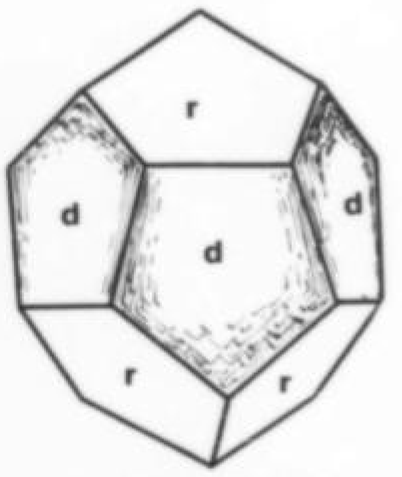


cuprosmithsonite



cuprosmithsonite

**söhngeite**
(hypothetical
idealized twin)

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occurs disseminated as thin platelets and vein fillings associated also with bornite, digenite and tennantite.

**Smithsonite** **$ZnCO_3$** Smithsonite is the most abundant secondary zinc mineral at Tsumeb. Large masses and botryoidal crusts are relatively common; crystals of rhombohedral to scalenohedral habit reach several cm in size and are the finest in the world. Relatively pure smithsonite is colorless to pale gray. Blackish crystals are filled with inclusions of sulfides. 76 77 85

*Cadmiumzinkspath?* (Cd-var.?) **$(Zn,Cd)CO_3$?** Smithsonite with up to 5% $CdCO_3$ has been observed elsewhere, and there may be a complete series to otavite. The most obvious cadmium-rich smithsonite at Tsumeb is bright yellow, but this may be from inclusions of greenockite. Crystals reach several cm.

*Cobaltsmithsonite* (Co-var.) **$(Zn,Co)CO_3$** Forms pale pink to brilliant rose-colored crystals in simple rhombohedrons and rarely other habits. Cobaltsmithsonite is probably part of a continuous series to sphaerocobaltite ($CoCO_3$) (not yet reported from Tsumeb). The rhombohedral faces tend to bulge out slightly and are nearly always frosty. 77

*Herrerite (Cuprosmithsonite)*(Cu-var.) **$(Zn,Cu)\ CO_3$** Herrerite containing up to 3% $CuCO_3$ has been observed. This brilliant green variety has long been a popular mineral from Tsumeb. The crystals range from a frosty apple-green to a nearly adamantine emerald-green. One rare specimen is a brilliant turquoise-blue. Crystals commonly exceed 1 cm. 76

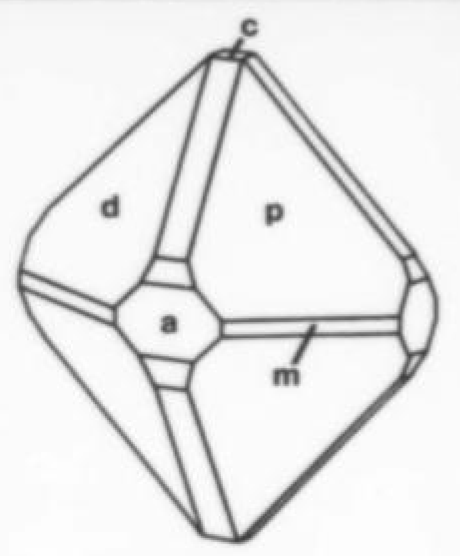
*Mangansmithsonite* (Mn-var.) **$(Zn,Mn)CO_3$** This variety is also pink although not as brilliantly pink as cobaltsmithsonite.

**Söhngeite** **$Ga(OH)_3$** Forms white to pale yellow, pale brown and pale greenish yellow crystal intergrowths in which three sets of crystals intersect at mutually perpendicular angles. Because of this peculiar penetration twinning the mineral was at first thought to be cubic but was later recognized as orthorhombic with very nearly equal axes. Crystals up to 8 mm have been found associated with germanite and gallite from the 900 to 1100 m levels. The crystal faces are curved, confounding efforts to index the faces or identify the twin law (Embrey, personal comm.). 61

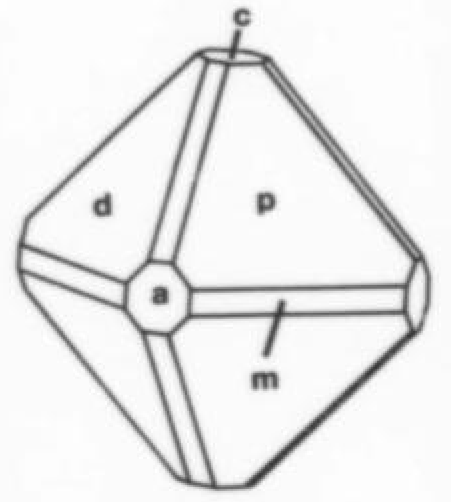
**Sphalerite** **$ZnS$** Sphalerite is the most abundant primary zinc mineral at Tsumeb. It ranges from a bright brown to siskin-green and is usually mixed with galena in large masses and disseminations. Free-growing crystals of complex pseudo-rhombohedral form have been observed but are extremely rare; euhedral crystals completely imbedded in chalcocite have also been observed.

*Pribramite?* (Cd-var.) **$(Zn,Cd)S$** This bright yellow variety contains up to 3% CdS although some or all may be in the form of inclusions of greenockite. Cadmium-rich sphalerite is the major ore mineral of cadmium at Tsumeb.

**Stottite** **$FeGe(OH)_6$** Forms tetragonal pseudo-octahedral crystals to 1 cm in size mostly from level 30. The color ranges from dark brown on the surface to light olive-green or colorless in the interior of the crystals. Associations include germanite and renierite. 75



stottite



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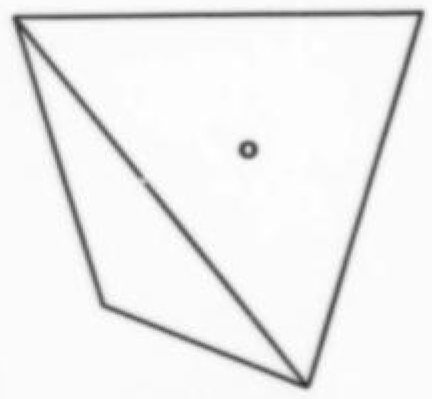
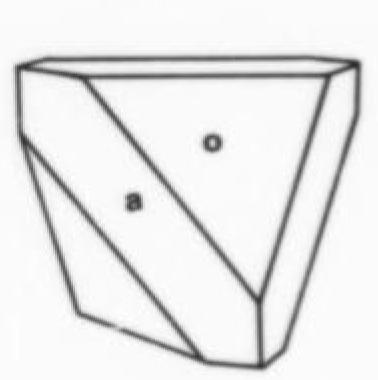


tennantite



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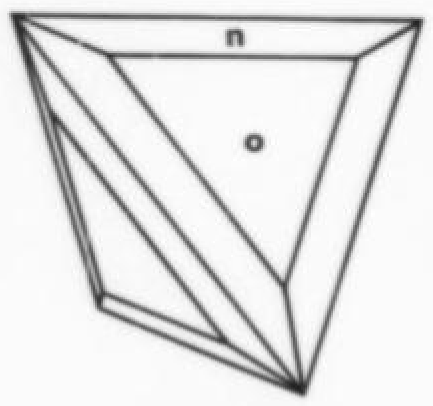

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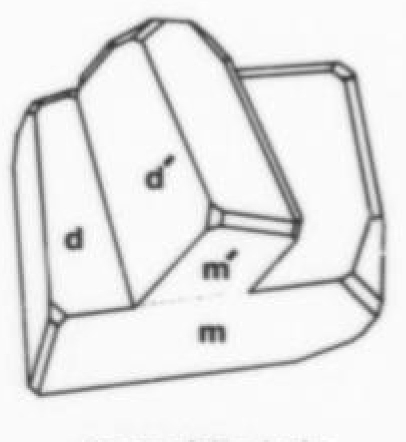

**tsumebite** twin

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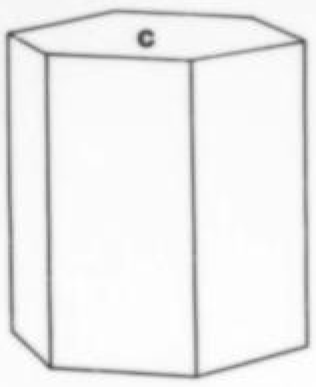
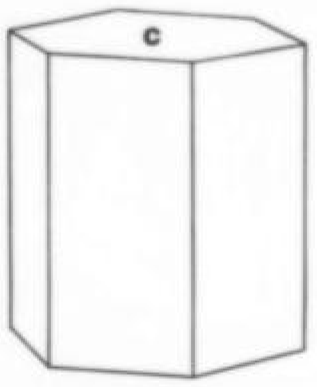
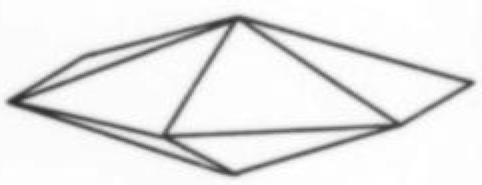
| **Stranskiite** | $\mathbf{Zn_2Cu(AsO_4)_2}$ Forms cyan-blue radiating aggregates and crusts to several mm in thickness sometimes associated with chalcocite. X-ray powder data has never been published so identification is difficult. Only a few specimens are known. | |
| **Stromeyerite** | **CuAgS** Forms metallic, dark steel-gray inclusions and fracture fillings in other sulfides and is visible only with the microscope. | |
| **Sulfur (native)** | **S** Found as light yellow encrustations very rarely in the upper and lower oxidation zones. Occurs with schultenite in the upper oxidation zone. | |
| **Sulvanite** | $\mathbf{Cu_3VS_4}$ Forms metallic bronze-colored tiny inclusions and crystals in other sulfides. | |
| *Ge-Sulvanite* | $\mathbf{(Cu,Ge)_3VS_4}$ This variety has been found in a pit about 1 km east of Tsumeb but it is thought to be genetically related to the main Tsumeb ore body. It forms 3 mm aggregates in other copper sulfides. | |
| **Talc** | $\mathbf{Mg_3Si_4O_{10}(OH)_2}$ A mineral of the country-rock. | |
| **Tennantite** | $\mathbf{(Cu,Fe)_{12}As_4S_{13}}$ Tennantite is part of a series to tetrahedrite, $(Cu,Fe)_{12}\mathbf{Sb}_4S_{13}$, but antimony appears to be extremely scarce at Tsumeb and although tetrahedrite has been looked for it has yet to be positively identified from Tsumeb. Specimens labeled "tetrahedrite" may have been misidentified through the influence of their tetrahedral crystals or may have been victims of mistranslation from the German term "fahlerz" which refers only to the tetrahedrite-tennantite series.<br>Tennantite forms superb tetrahedral crystals up to 30 cm on an edge, and also large masses of steel-gray metallic ore. Pseudomorphs of azurite and malachite after tennantite are known. Crystals of tennantite are occasionally lustrous but are more often frosty or corroded. | 59<br>60<br>81<br>115 |
| **Tenorite** | **CuO** Tenorite is considerably rarer than cuprite, the other copper oxide. It occurs mostly as dull, black, earthy disseminations and crusts on other minerals. However it has been observed rarely as thin, flexible, translucent tablets with irregular borders. | |
| **Thaumasite** | $\mathbf{Ca_3Si(CO_3)(SO_4)(OH)_6\cdot 12H_2O}$ Forms water-clear crystals in radiating groups with siderite on germanite-renierite ore. | |
| **Titanite** | $\mathbf{CaTiSiO_5}$ A mineral of the country-rock. | |
| **Tourmaline** | $\mathbf{(Na,Ca)(Mg,Fe,Al,Li)_3Al_6(BO_3)_3(Si_6O_{18})(OH,F)_4}$ A mineral of the country-rock. The exact species of tourmaline has not been specified. | |
| **Tremolite** | $\mathbf{Ca_2Mg_5Si_8O_{22}(OH)_2}$ A mineral of the country-rock. | |
| **Tsumcorite** | $\mathbf{PbZnFe(AsO_4)_2\cdot H_2O}$ This mineral, named after the **Tsum**eb **Cor**poration, forms bright lemon-yellow to dark yellow-brown and red-brown radially structured crusts and small, tabular crystals. The individual crystals measure up to 0.2 x 0.5 x 0.1 mm and usually occur together in sheafs and bunches. A few distinct crystals to 2 mm have been found. It occurs on specimens of pale green willemite crystals but the finest orange-brown crystals are found on apple-green smithsonite or yellow mimetite crystals. Other associations include scorodite, anglesite, | 65 |



vanadinite



willemite



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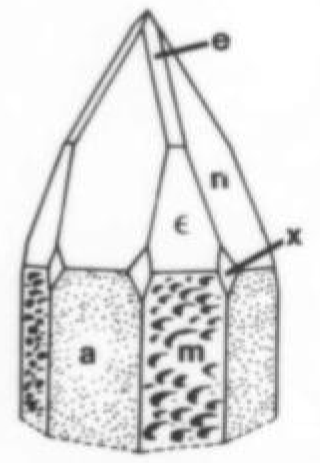
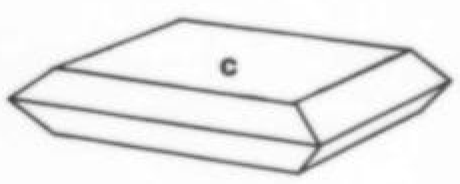


wulfenite



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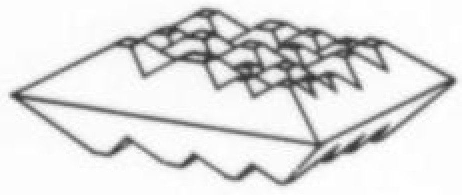

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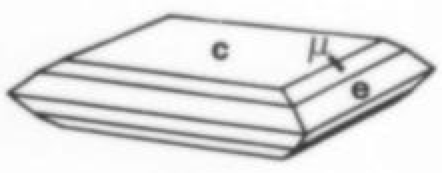

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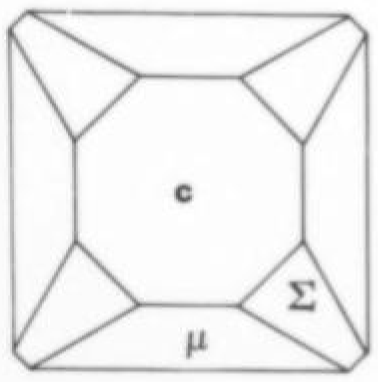

wulfenite

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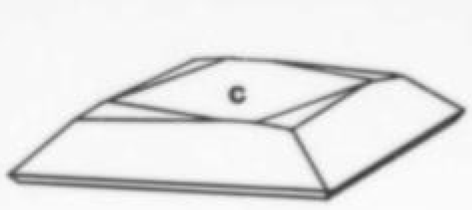
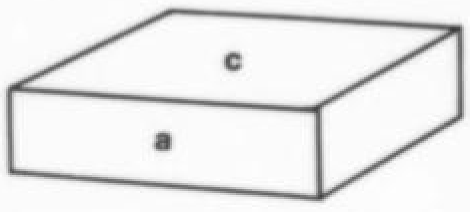
| | arseniosiderite, beaverite, beudantite, carminite and ludlockite. | |
| **Tsumebite** | **$Pb_2Cu(PO_4)(SO_4)(OH)$** Forms small twinned crystals of a light apple-green to bright emerald-green color. The first tsumebite, found around 1910 at a depth of 100 m, remains the choicest and rarest with only a few specimens known. The bright emerald-green, tabular, transparent crystals on white smithsonite reach 2.5 mm and are accompanied by azurite. The other type, which also came out many years ago, consists of tiny (0.25 mm) crystals of an apple-green color and polysynthetically twinned, occurring with azurite, malachite after azurite, and cerussite. One of us (W.W.P.) has checked many specimens labeled "bayldonite" and about half have turned out to be tsumebite: 12 specimens all collected in the 1930's. It appears that tsumebite may be relatively more common that had previously been supposed. | 60 |
| **Tungstenite** | **$WS_2$** Forms dark lead-gray microcrystalline bands near molybdenite. | |
| **Umangite** | **$Cu_3Se_2$** The only selenium mineral at Tsumeb, umangite occurs as dark reddish, metallic, microscopic inclusions in dolomite. | |
| **Vanadinite** | **$Pb_5(VO_4)_3Cl$** Forms brownish red prismatic crystals to several mm. | 62 |
| **Vanadinocker** | **$V_2O_5$** Vanadinocker has never been officially described as a mineral but has long been known as a synthetic compound. Nevertheless, specimens of vanadinocker were reported from Tsumeb in 1920 as yellow coatings on mottramite, and again in 1938 in association with dolomite. | |
| **Willemite** | **$Zn_2SiO_4$** Willemite has been found in attractive blue, green, yellow and gray translucent crusts and also as well-formed hexagonal crystals of various colors including white, yellow, turquoise-blue, blue and gray. The habit of the crystals varies from short prismatic terminated by the pinacoid to long prismatic with pyramidal faces. Associations include malachite, mimetite, rosasite, duftite, cerussite and dolomite. | 67 |
| *Troostite* (Mn-var.) | **$(Zn,Mn)_2SiO_4$** Troostite is generally pale brown in color. | |
| **Witherite** | **$BaCO_3$** Forms milky grayish masses and minute white to cream-colored crystals of flat pseudohexagonal dipyramidal habit; found very rarely in the lower oxidation zone. | 85 |
| **Wulfenite** | **$PbMoO_4$** Superb crystals of wulfenite, among the world's best, have been found at Tsumeb. The habit is generally tabular, modified only by bevelled edges of the pyramid; crystals up to 7 cm across have been found, and one extraordinary occurrence contained large, thin crystals up to 60 cm across intergrown with each other. The color ranges from colorless and clear to very pale brown, pink and yellow, also to yellow, orange, brownish red, sherry-brown, greenish brown, light blue and very dark blue. The very dark blue crystals have an unusual steep pyramidal habit and are described in further detail elsewhere in this issue. Specimens of dark blue wulfenite examined at the British Museum | 79<br>80<br>81<br>82<br>86 |



chillagite



chillagite

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| | (Natural History) and independently at the Smithsonian Institution proved to contain only 0.25 to 1.3% tungsten, not even enough for the material to be considered the tungstatian variety. No connection between the blue color and the tungsten content could be established. | |
| *Chillagite* (W-var.) | **$Pb(Mo,W)O_4$** Wulfenite containing up to 12% tungsten has been recently reported; the color is from blue to colorless and the crystals are tabular. The blue color may be due to inclusions of ilsemannite ($Mo_3O_8 \cdot nH_2O$) and appears unrelated to tungsten content. | 79 |
| **Wurtzite** | **$ZnS$** Orange, brown and green massive wurtzite and microscopic crystals of wurtzite occur rarely between the 18 and 19 levels. | |
| *Cd-Wurtzite* | **$(Zn,Cd)S$** Wurtzite with a Zn:Cd ratio of 1:1 has been reported. | |
| **Zeolites** | **(species unspecified)** Minerals of the country-rock. | |
| **Zinc-Stottite** | **$ZnFeGe_2(OH)_{12}$** Found as small, transparent pink crystals with schniederhöhnite and molybdenite on the 30 level; crystals reach 9 mm in size. | 59 |
| **Zircon** | **$ZrSiO_4$** A mineral of the country-rock. | |

## Incompletely characterized new minerals:

| | |
|---|---|
| **“Ag-Betekhtinite”** | **$Cu_5PbAgS_4$** Probably will be recognized as a new mineral when properly described. It appears to contain up to 11% silver. |
| **“Carnevallite”** | **$Cu(Ga,Fe,Zn)S_2$** In grains up to 40 microns in size recognized under the microscope with bornite. |
| **“Ge-Zn-Mawsonite”** | **$(Cu,Ge)_7(Fe,Zn)_2(Sn,As)S_{10}$** This is soon to be described as a new species by Ottemann and others, at which time the composition will be clarified and the mineral will be given a name. It occurs only as small inclusions in tennantite on the 30 level. Its hardness and color are similar to renierite. Under the reflecting microscope, with nichols crossed, the mineral is fire-red colored, hence the working name “Firemineral.” |
| **“Maygreen”** | **$Cu(Ga,Sn,Zn,V)S_2$** Under the reflecting microscope this mineral has a distinctive green color, hence the working name “maygreen.” It occurs in grains up to 0.1 mm in size in complex copper-germanium ore, associated occasionally with betekhtinite and Ni-carrollite. |
| **“Mineral C”** | **$(Mn,Fe)(Sn,Ge)(OH)_6$** This mineral is similar in composition to wickmannite from Langban, Sweden, except that it contains 3.5% Fe and 4% Ge. It forms small crystals associated with “Ge-Zn-mawsonite.” |
| **“Mineral D”** | **$FeSn(OH)_6$** This material appears to be an alternation product of “Mineral Lu,” and is visible only under the microscope. |
| **“Mineral E”** | **$Sn_6FeO_{13} \cdot 6H_2O$** Found in association with “Mineral Lu.” |
| **“Mineral gamma”** | **Pb-Fe-Cu arsenate** Forms canary-yellow coatings. |
| **“Mineral GF”** | **$GaO(OH)$** Forms yellowish to white scales |

| | |
|---|---|
| | with söhngeite on siderite; the gallium analog of goethite. |
| **"Mineral Lu"** | $\mathbf{Cu_2(Sn,Fe,Ge,Zn)S_4}$ Forms grains in tennantite up to 0.5 mm in diameter. |
| **"Mineral S"** | **Ni-Ge-Cu-Fe mineral** Forms tiny crystals with distinctly tetragonal cleavage. |
| **"Mineral TI"** | **Pb-Ge mineral** Hexagonal, prismatic, water-clear crystals. |
| **"Mineral TK"** | **Pb-Fe-Cu-Zn arsenate.** Dark green tabular to scaly crystals with carminite. |

# CHEMICAL TABLES

Presented in the following tables are the Tsumeb minerals grouped according to seven of the more common or interesting metals. Groupings according to other metals could have been made but were not included here in the interest of brevity. Groupings by anions could also have been presented here, but identification of unknowns or contemplation of chemical trends are often better aided by cation groupings. A list of species grouped traditionally by anions is presented in Bartelke (1976). Minerals of the surrounding country-rocks are not included below. Varietal names are in *italics*.

## CADMIUM

| | |
|---|---|
| Greenockite | $\mathbf{Cd}\mathrm{S}$ |
| *Zn-Greenockite* | $(\mathbf{Cd},\mathrm{Zn})\mathrm{S}$ |
| *Pribramite* | $(\mathrm{Zn},\mathbf{Cd})\mathrm{S}$ |
| *Cd-Wurtzite* | $(\mathrm{Zn},\mathbf{Cd})\mathrm{S}$ |
| Otavite | $\mathbf{Cd}\mathrm{CO_3}$ |
| *Cd-Smithsonite* | $(\mathrm{Zn},\mathbf{Cd})\mathrm{S}$ |
| Keyite | $(\mathrm{Cu},\mathrm{Zn},\mathbf{Cd})_3(\mathrm{AsO_4})_2$ |

## COBALT

| | |
|---|---|
| Linnaeite | $(\mathbf{Co},\mathrm{Ni})_3\mathrm{S_4}$ |
| Carrollite | $\mathrm{Cu}(\mathbf{Co},\mathrm{Ni})_2\mathrm{S_4}$ |
| Glaucodot | $(\mathbf{Co},\mathrm{Fe})\mathrm{AsS}$ |
| *Asbolane* | $(\mathrm{Mn},\mathbf{Co})\mathrm{O_2}$ |
| Heterogenite | $\mathbf{Co}\mathrm{O(OH)}$ |
| *Cobaltocalcite* | $(\mathrm{Ca},\mathbf{Co})\mathrm{CO_3}$ |
| *Cobaltsmithsonite* | $(\mathrm{Zn},\mathbf{Co})\mathrm{CO_3}$ |
| *Co-Dolomite* | $\mathrm{Ca}(\mathrm{Mg},\mathbf{Co})(\mathrm{CO_3})_2$ |
| *Cobaltoadamite* | $(\mathrm{Zn},\mathbf{Co})_2(\mathrm{AsO_4})(\mathrm{OH})$ |
| *Co-Fleischerite* | $(\mathrm{Pb},\mathbf{Co})_3\mathrm{Ge}(\mathrm{SO_4})_2(\mathrm{OH})_6\cdot 3\mathrm{H_2O}(?)$ |

## COPPER

| | |
|---|---|
| Copper | $\mathbf{Cu}$ |
| Covellite | $\mathbf{Cu}\mathrm{S}$ |
| Djurleite | $\mathbf{Cu}_{1.96}\mathrm{S}$ |
| Digenite | $\mathbf{Cu}_9\mathrm{S_5}$ |
| Chalcocite | $\mathbf{Cu}_2\mathrm{S}$ |
| Cubanite | $\mathbf{Cu}\mathrm{Fe_2S_3}$ |
| Chalcopyrite | $\mathbf{Cu}\mathrm{FeS_2}$ |
| Idaite | $\mathbf{Cu}_5\mathrm{FeS_6}$ |
| Bornite | $\mathbf{Cu}_5\mathrm{FeS_4}$ |
| Mawsonite | $\mathbf{Cu}_7\mathrm{Fe_2SnS_{10}}$ |
| Ag-Betekhtinite | $\mathbf{Cu}_5\mathrm{PbAgS_4}$ |
| Betekhtinite | $\mathbf{Cu}_{10}(\mathrm{Fe},\mathrm{Pb})\mathrm{S_6}$ |
| Ge-Zn-Mawsonite | $(\mathbf{Cu},\mathrm{Ge})_7(\mathrm{Fe},\mathrm{Zn})_2(\mathrm{Sn},\mathrm{As})\mathrm{S_{10}}$ |
| Briartite | $\mathbf{Cu}_2(\mathrm{Fe},\mathrm{Zn})\mathrm{GeS_4}$ |
| *Ge-Briartite* | $\mathbf{Cu}(\mathrm{Fe},\mathrm{Zn})\mathrm{Ge_2S_4}?$ |
| Carnevallite | $\mathbf{Cu}(\mathrm{Ga},\mathrm{Fe},\mathrm{Zn})\mathrm{S_2}$ |
| Mineral Lu | $\mathbf{Cu}_2(\mathrm{Sn},\mathrm{Fe},\mathrm{Ge},\mathrm{Zn})\mathrm{S_4}$ |
| Carrollite | $\mathbf{Cu}(\mathrm{Co},\mathrm{Ni})_2\mathrm{S_4}$ |
| Stromeyerite | $\mathbf{Cu}\mathrm{AgS}$ |
| Ge-Sulvanite | $(\mathbf{Cu},\mathrm{Ge})_3\mathrm{VS_4}$ |
| Sulvanite | $\mathbf{Cu}_3\mathrm{VS_4}$ |
| Maygreen | $\mathbf{Cu}(\mathrm{Ga},\mathrm{Sn},\mathrm{Zn},\mathrm{V})\mathrm{S_2}$ |
| Gallite | $\mathbf{Cu}\mathrm{GaS_2}$ |
| Famatinite | $\mathbf{Cu}_3\mathrm{SbS_4}$ |
| *Stibioenargite* | $\mathbf{Cu}_3(\mathrm{As},\mathrm{Sb})\mathrm{S_4}?$ |
| Tennantite | $(\mathbf{Cu},\mathrm{Fe})_{12}\mathrm{As_4S_{13}}$ |
| Renierite | $\mathbf{Cu}_3(\mathrm{Fe},\mathrm{Ge},\mathrm{Zn})(\mathrm{S},\mathrm{As})_4$ |
| Germanite | $\mathbf{Cu}_3(\mathrm{Ge},\mathrm{Fe})(\mathrm{S},\mathrm{As})_4$ |
| *W-Germanite* | $\mathbf{Cu}_3(\mathrm{Ge},\mathrm{W},\mathrm{Fe})(\mathrm{S},\mathrm{As})_4?$ |
| *V-Germanite A* | $\mathbf{Cu}_3(\mathrm{Ge},\mathrm{V},\mathrm{Fe})(\mathrm{S},\mathrm{As})_4?$ |
| *V-Germanite B* | $\mathbf{Cu}_3(\mathrm{Ge},\mathrm{V},\mathrm{Fe})(\mathrm{S},\mathrm{As})_4?$ |
| Seligmannite | $\mathrm{Pb}\mathbf{Cu}\mathrm{AsS_3}$ |
| Enargite | $\mathbf{Cu}_3\mathrm{AsS_4}$ |
| Luzonite | $\mathbf{Cu}_3\mathrm{AsS_4}$ |
| Umangite | $\mathbf{Cu}_3\mathrm{Se_2}$ |
| Tenorite | $\mathbf{Cu}\mathrm{O}$ |
| Cuprite | $\mathbf{Cu}_2\mathrm{O}$ |
| Atacamite | $\mathbf{Cu}_2\mathrm{Cl(OH)_3}$ |
| Malachite | $\mathbf{Cu}_2(\mathrm{CO_3})(\mathrm{OH})$ |
| Azurite | $\mathbf{Cu}_3(\mathrm{CO_3})_2(\mathrm{OH})_2$ |
| *Cuprocalcite* | $(\mathrm{Ca},\mathbf{Cu})\mathrm{CO_3}?$ |
| Rosasite | $(\mathbf{Cu},\mathrm{Zn})_2(\mathrm{CO_3})(\mathrm{OH})_2$ |
| *Zn-Rosasite* | $(\mathrm{Zn},\mathbf{Cu})_2(\mathrm{CO_3})(\mathrm{OH})_2$ |
| *Paraurichalcite* | $(\mathbf{Cu},\mathrm{Zn})_2(\mathrm{CO_3})(\mathrm{OH})_2$ |
| Aurichalcite | $(\mathrm{Zn},\mathbf{Cu})_5(\mathrm{CO_3})_2(\mathrm{OH})_6$ |
| *Cuprosmithsonite* | $(\mathrm{Zn},\mathbf{Cu})\mathrm{CO_3}$ |
| Brochantite | $\mathbf{Cu}_4(\mathrm{SO_4})(\mathrm{OH})_6$ |
| Chalcanthite | $\mathbf{Cu}\mathrm{SO_4}\cdot 5\mathrm{H_2O}$ |
| Langite | $\mathbf{Cu}_4(\mathrm{SO_4})(\mathrm{OH})_6\cdot 2\mathrm{H_2O}$ |
| Posnjakite | $\mathbf{Cu}_4(\mathrm{SO_4})(\mathrm{OH})_6\cdot \mathrm{H_2O}$ |
| Chalcophyllite | $\mathbf{Cu}_{18}\mathrm{Al_2}(\mathrm{AsO_4})_3(\mathrm{SO_4})_3(\mathrm{OH})_{27}\cdot 33\mathrm{H_2O}$ |
| Serpierite | $\mathrm{Ca}(\mathbf{Cu},\mathrm{Zn})_4(\mathrm{SO_4})_2(\mathrm{OH})_6\cdot 3\mathrm{H_2O}$ |
| Devilline | $\mathrm{Ca}\mathbf{Cu}_4(\mathrm{SO_4})_2(\mathrm{OH})_6\cdot 3\mathrm{H_2O}$ |
| Mineral TK | Pb-Fe-**Cu**-Zn arsenate |
| Arsentsumebite | $\mathrm{Pb_2}\mathbf{Cu}(\mathrm{AsO_4})(\mathrm{SO_4})(\mathrm{OH})$ |
| Beaverite | $\mathrm{Pb}(\mathbf{Cu},\mathrm{Fe},\mathrm{Al})_3(\mathrm{SO_4})_2(\mathrm{OH})_6$ |
| Caledonite | $\mathbf{Cu}_2\mathrm{Pb_5}(\mathrm{CO_3})(\mathrm{SO_4})(\mathrm{OH})_6$ |
| Tsumebite | $\mathrm{Pb_2}\mathbf{Cu}(\mathrm{PO_4})(\mathrm{SO_4})(\mathrm{OH})$ |
| Keyite | $(\mathbf{Cu},\mathrm{Zn},\mathrm{Cd})_3(\mathrm{AsO_4})_2$ |
| Stranskiite | $\mathrm{Zn_2}\mathbf{Cu}(\mathrm{AsO_4})_2$ |
| Mineral gamma | Pb-Fe-**Cu** arsenate |
| Olivenite | $\mathbf{Cu}_2(\mathrm{AsO_4})(\mathrm{OH})$ |
| Clinoclase | $\mathbf{Cu}_3(\mathrm{AsO_4})(\mathrm{OH})_3$ |
| *Zincolivinite* | $(\mathbf{Cu},\mathrm{Zn})_2(\mathrm{AsO_4})(\mathrm{OH})$ |
| Duftite-alpha | $\mathrm{Pb}\mathbf{Cu}(\mathrm{AsO_4})(\mathrm{OH})$ |
| Duftite-beta | $\mathrm{Pb}(\mathbf{Cu},\mathrm{Ca})(\mathrm{AsO_4})(\mathrm{OH})$ |
| Bayldonite | $\mathrm{Pb}\mathbf{Cu}_3(\mathrm{AsO_4})_2(\mathrm{OH})_2$ |
| *Parabayldonite* | $\mathrm{Ca}(\mathrm{Pb},\mathbf{Cu})(\mathrm{AsO_4})$ |

| | |
|---|---|
| Mottramite | $Pb(\mathbf{Cu},Zn)(VO_4)(OH)$ |
| *Cuprodescloizite* | $Pb(Zn,\mathbf{Cu})(VO_4)(OH)$ |
| *Pb-Chenevixite* | $(\mathbf{Cu},Pb)_2Fe_2(AsO_4)_2(OH)_4\cdot H_2O$ |
| *Fe-Olivenite* | $(\mathbf{Cu},Fe)_2(AsO_4)(OH)$ |
| Chenevixite | $\mathbf{Cu}_2Fe_2(AsO_4)_2(OH)_4\cdot H_2O$ |
| Mixite | $Bi\mathbf{Cu}_6(AsO_4)_3(OH)_6\cdot 3H_2O$ |
| Conichalcite | $Ca\mathbf{Cu}(AsO_4)(OH)$ |
| *Cuproadamite* | $(Zn,\mathbf{Cu})_2(AsO_4)(OH)$ |
| *Cu-Austinite* | $Ca(Zn,\mathbf{Cu})(AsO_4)(OH)$ |
| Lavendulan | $NaCa\mathbf{Cu}_5(AsO_4)_4Cl\cdot 5H_2O$ |
| *Zn-Lavendulan* | $NaCa(\mathbf{Cu},Zn)_5(AsO_4)_4Cl\cdot 5H_2O$ |
| Dioptase | $\mathbf{Cu}SiO_2(OH)_2$ |
| Shattuckite | $\mathbf{Cu}_5(SiO_3)_4(OH)_2$ |
| Plancheite | $\mathbf{Cu}_8Si_8O_{22}(OH)_4\cdot H_2O$ |
| Chrysocolla | $(\mathbf{Cu},Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$ |
| Mineral S | Ni-Ge-**Cu**-Fe |

## GALLIUM

| | |
|---|---|
| Gallite | $Cu\mathbf{Ga}S_2$ |
| Mineral Gf | $\mathbf{Ga}O(OH)$ |
| Söhngeite | $\mathbf{Ga}(OH)_3$ |
| Carnevallite | $Cu(\mathbf{Ga},Fe,Zn)S_2$ |
| Maygreen | $Cu(\mathbf{Ga},Sn,Zn,V)S_2$ |

## GERMANIUM

| | |
|---|---|
| Ge-Zn-Mawsonite | $(Cu,\mathbf{Ge})_7(Fe,Zn)_2(Sn,As)S_{10}$ |
| Germanite | $Cu_3(\mathbf{Ge},Fe)(S,As)_4$ |
| Renierite | $Cu_3(Fe,\mathbf{Ge},Zn)(S,As)_4$ |
| Briartite | $Cu_2(Fe,Zn)\mathbf{Ge}S_4$ |
| Mineral Lu | $Cu_2(Sn,Fe,\mathbf{Ge},Zn)S_4$ |
| *Ge-Briartite* | $Cu(Fe,Zn)\mathbf{Ge}_2S_4$? |
| *W-Germanite* | $Cu_3(\mathbf{Ge},W,Fe)(S,As)_4$? |
| *V-Germanite A* | $Cu_3(\mathbf{Ge},V,Fe)(S,As)_4$? |
| *V-Germanite B* | $Cu_3(\mathbf{Ge},V,Fe)(S,As)_4$? |
| *Ge-Sulvanite* | $(Cu,\mathbf{Ge})_3VS_4$ |
| Brunogeierite | $(\mathbf{Ge},Fe)Fe_2O_4$ |
| Stottite | $Fe\mathbf{Ge}(OH)_6$ |
| Zinc-Stottite | $ZnFe\mathbf{Ge}_2(OH)_{12}$ |
| Mangan-Stottite | $Mn\mathbf{Ge}(OH)_6$ |
| Mineral C | $(Mn,Fe)(Sn,\mathbf{Ge})(OH)_6$ |
| Schaurteite | $Ca_3\mathbf{Ge}(SO_4)_2(OH)_6\cdot 3H_2O$ |
| Fleischerite | $Pb_3\mathbf{Ge}(SO_4)_2(OH)_6\cdot 3H_2O$ |
| Mineral TI | Pb-**Ge** mineral |
| Mineral S | Ni-**Ge**-Cu-Fe mineral |

## LEAD

| | |
|---|---|
| Galena | $\mathbf{Pb}S$ |
| Gratonite | $\mathbf{Pb}_9As_4S_{15}$ |
| Seligmannite | $\mathbf{Pb}CuAsS_3$ |
| Betekhtinite | $Cu_{10}(Fe,\mathbf{Pb})S_6$ |
| Ag-Betekhtinite | $Cu_5\mathbf{Pb}AgS_4$ |
| Massicot | $\mathbf{Pb}O$ |
| Minium | $\mathbf{Pb}_3O_4$ |
| Plattnerite | $\mathbf{Pb}O_2$ |
| Coronadite | $\mathbf{Pb}Mn_8O_{16}$ |
| Bindheimite | $\mathbf{Pb}_2Sb_2O_6(O,OH)$ |
| Cerussite | $\mathbf{Pb}CO_3$ |
| Phosgenite | $\mathbf{Pb}_2(CO_3)Cl_2$ |
| *Plumbocalcite* | $(Ca,\mathbf{Pb})CO_3$ |
| *Tarnowitzite* | $(Ca,\mathbf{Pb})CO_3$ |
| *Plumbodolomite* | $(Ca,Mg,\mathbf{Pb})CO_3$ |
| Dundasite | $\mathbf{Pb}Al_2(CO_3)_2(OH)_4\cdot H_2O$ |
| Leadhillite | $\mathbf{Pb}_4(SO_4)(CO_3)_2(OH)_2$ |
| Anglesite | $\mathbf{Pb}SO_4$ |
| Linarite | $\mathbf{Pb}Cu(SO_4)(OH)_2$ |
| Plumbojarosite | $\mathbf{Pb}Fe_6(SO_4)_4(OH)_{12}$ |
| Fleischerite | $\mathbf{Pb}_3Ge(SO_4)_2(OH)_6\cdot 3H_2O$ |
| Beaverite | $\mathbf{Pb}(Cu,Fe,Al)_3(SO_4)_2(OH)_6$ |
| Beudantite | $\mathbf{Pb}Fe_3(AsO_4)(SO_4)(OH)_6$ |
| Arsentsumebite | $\mathbf{Pb}_2Cu(AsO_4)(SO_4)(OH)$ |
| Caledonite | $Cu_2\mathbf{Pb}_5(CO_3)(SO_4)(OH)_6$ |
| Corkite | $\mathbf{Pb}Fe_3(PO_4)(SO_4)(OH)_6$ |
| Tsumebite | $\mathbf{Pb}_2Cu(PO_4)(SO_4)(OH)$ |
| Schultenite | $\mathbf{Pb}HAsO_4$ |
| Mimetite | $\mathbf{Pb}_5(AsO_4)_3Cl$ |
| Bayldonite | $\mathbf{Pb}Cu_3(AsO_4)_2(OH)_2$ |
| Tsumcorite | $\mathbf{Pb}ZnFe(AsO_4)_2\cdot H_2O$ |
| Arsenbrackebuschite | $\mathbf{Pb}_2(Zn,Fe)(AsO_4)_2(OH)\cdot H_2O$ |
| Duftite-alpha | $\mathbf{Pb}Cu(AsO_4)(OH)$ |
| Duftite-beta | $\mathbf{Pb}(Cu,Ca)(AsO_4)(OH)$ |
| Ludlockite | $(Fe,\mathbf{Pb})As_2O_6$ |
| Carminite | $\mathbf{Pb}Fe_2(AsO_4)_2(OH)_2$ |
| Mineral gamma | **Pb**-Fe-Cu arsenate |
| *Pb-Chenevixite* | $(Cu,\mathbf{Pb})_2Fe_2(AsO_4)_2(OH)_4\cdot H_2O$? |
| Hedyphane | $(Ca,\mathbf{Pb})_5(AsO_4)_3Cl$ |
| *Parabayldonite* | $Ca(\mathbf{Pb},Cu)(AsO_4)(OH)$? |
| Hidalgoite | $\mathbf{Pb}Al_3(SO_4)(AsO_4)(OH)_6$ |
| Descloizite | $\mathbf{Pb}Zn(VO_4)(OH)$ |
| Mineral TK | **Pb**-Fe-Cu-Zn arsenate |
| *Cuprodescloizite* | $\mathbf{Pb}(Zn,Cu)(VO_4)(OH)$ |
| Mottramite | $\mathbf{Pb}(Cu,Zn)(VO_4)(OH)$ |
| Pyromorphite | $\mathbf{Pb}_5(PO_4)_3Cl$ |
| Vanadinite | $\mathbf{Pb}_5(VO_4)_3Cl$ |
| Wulfenite | $\mathbf{Pb}MoO_4$ |
| *Chillagite* | $\mathbf{Pb}(Mo,W)O_4$ |
| Alamosite | $\mathbf{Pb}SiO_3$ |
| Melanotekite | $\mathbf{Pb}_2Fe_2Si_2O_9$ |
| Kegelite | $\mathbf{Pb}_{12}(Zn,Fe)_2Al_4(Si_{11}S_4O_{54})$ |

## ZINC

| | |
|---|---|
| Chalcophanite | $\mathbf{Zn}Mn_3O_7\cdot 3H_2O$ |
| Zinc-Stottite | $\mathbf{Zn}FeGe_2(OH)_{12}$ |
| Sphalerite | $\mathbf{Zn}S$ |
| Wurtzite | $\mathbf{Zn}S$ |
| *Pribramite* | $(\mathbf{Zn},Cd)S$ |
| *Cd-Wurtzite* | $(\mathbf{Zn},Cd)S$ |
| *Zn-Greenockite* | $(Cd,\mathbf{Zn})S$ |
| Carnevallite | $Cu(Ga,Fe,\mathbf{Zn})S_2$ |
| Ge-Zn-Mawsonite | $(Cu,Ge)_7(Fe,\mathbf{Zn})_2(Sn,As)S_{10}$ |
| Briartite | $Cu_2(Fe,\mathbf{Zn})GeS_4$ |
| *Ge-Briartite* | $Cu(Fe,\mathbf{Zn})Ge_2S_4$? |
| Mineral Lu | $Cu_2(Sn,Fe,Ge,\mathbf{Zn})S_4$ |
| Renierite | $Cu_3(Fe,Ge,\mathbf{Zn})(S,As)_4$ |
| Maygreen | $Cu(Ga,Sn,\mathbf{Zn},V)S_2$ |
| Smithsonite | $\mathbf{Zn}CO_3$ |
| Hydrozincite | $\mathbf{Zn}_5(CO_3)_2(OH)_6$ |
| *Cd-Smithsonite* | $(\mathbf{Zn},Cd)CO_3$? |
| *Cobaltsmithsonite* | $(\mathbf{Zn},Co)CO_3$ |
| *Mangansmithsonite* | $(\mathbf{Zn},Mn)CO_3$ |
| *Zn-Siderite* | $(Fe,\mathbf{Zn})CO_3$ |
| *Nicholsonite* | $(Ca,\mathbf{Zn})CO_3$ |
| *Zn-Dolomite* | $(Ca,Mg,\mathbf{Zn})CO_3$ |
| Aurichalcite | $(\mathbf{Zn},Cu)_5(CO_3)_2(OH)_6$ |
| *Paraurichalcite* | $(\mathbf{Zn},Cu)_2(CO_3)(OH)_2$ |
| *Cuprosmithsonite* | $(\mathbf{Zn},Cu)CO_3$ |
| *Zn-Rosasite* | $(Cu,\mathbf{Zn})_2(CO_3)(OH)_2$ |
| Rosasite | $(Cu,\mathbf{Zn})_2(CO_3)(OH)_2$ |
| Serpierite | $Ca(Cu,\mathbf{Zn})_4(SO_4)_2(OH)_6\cdot 3H_2O$ |
| Mineral TK | Pb-Fe-Cu-**Zn** arsenate- |
| Reinerite | $\mathbf{Zn}_3(AsO_3)_2$ |
| Adamite | $\mathbf{Zn}_2(AsO_4)(OH)$ |
| *Cuproadamite* | $(\mathbf{Zn},Cu)_2(AsO_4)(OH)$ |
| *Cobaltoadamite* | $(\mathbf{Zn},Co)_2(AsO_4)(OH)$ |
| Leiteite | $(\mathbf{Zn},Fe)As_2O_4$ |
| Stranskiite | $\mathbf{Zn}_2Cu(AsO_4)_2$ |
| Austinite | $Ca\mathbf{Zn}(AsO_4)(OH)$ |
| *Zincolivenite* | $(Cu,\mathbf{Zn})_2(AsO_4)(OH)$ |
| *Zn-Lavendulan* | $NaCa(Cu,\mathbf{Zn})_5(AsO_4)_4Cl\cdot 5H_2O$ |
| *Cu-Austinite* | $Ca(\mathbf{Zn},Cu)(AsO_4)(OH)$ |
| Arsenbrackebuschite | $Pb_2(\mathbf{Zn},Fe)(AsO_4)_2(OH)\cdot H_2O$ |
| Tsumcorite | $Pb\mathbf{Zn}Fe(AsO_4)_2\cdot H_2O$ |
| Chudobaite | $(Na,K,Ca)(Mg,\mathbf{Zn},Mn)_2H(AsO_4)_2\cdot 4H_2O$ |
| Descloizite | $Pb\mathbf{Zn}(VO_4)(OH)$ |
| *Cuprodescloizite* | $Pb(\mathbf{Zn},Cu)(VO_4)(OH)$ |
| Mottramite | $Pb(Cu,\mathbf{Zn})(VO_4)(OH)$ |
| Willemite | $\mathbf{Zn}_2SiO_4$ |
| Hemimorphite | $\mathbf{Zn}_4Si_2O_7(OH)_2\cdot H_2O$ |
| *Troostite* | $(\mathbf{Zn},Mn)_2SiO_4$ |
| Kegelite | $Pb_{12}(\mathbf{Zn},Fe)_2Al_4(Si_{11}S_4O_{54})$ |

*Figure 1.* **Water gushing from a cavity in the Tsumeb mine, January, 1924. Perhaps only moments before, this water was precipitating some of the fine secondary minerals for which Tsumeb is famous. Mine Director F. W. Kegel, after whom kegelite is named, is at left. (O.M.E.G. collection of photographs)**

# VI PARAGENESIS: ASSEMBLAGES, SEQUENCES, ASSOCIATIONS

by
**Paul Keller**

The Tsumeb mine, a place of exceptionally beautiful minerals, is again and again a surprising source of new specimens for the collector and the mineralogist. A great number of rare minerals, particularly of unusual chemical composition, are known from Tsumeb. Several of these were described for the first time from this area and the list of type material will certainly continue to grow.

One of the greatest surprises at Tsumeb was the discovery of a second oxidation zone with a great number of secondary minerals at a depth of about 850 m (about the 2800 foot level) which, to the present time at 1200 m (about the 3950 foot level), is still not exhausted. The paragenesis of the secondary minerals shall be the main point of this investigation. The description of the paragenesis can hardly be complete. For this discussion I have selected those minerals which best reveal the conditions of formation, and also those assemblages which are of interest to the mineral collector. Therefore the following discussion centers on specimens collected in the last few years and those with which I am familiar.

The minerals discussed were verified optically, microchemically, and by X-ray analysis.

## USE AND PROBLEMS OF PARAGENETIC STUDIES

The purpose of paragenetic studies is to investigate the physical and chemical conditions that existed during the formation and oxidation of the ore minerals. Laboratory investigation could not be undertaken; therefore this article can serve only as a descriptive foundation for further studies. Several rare assemblages make for interesting discussion, which should create an interest in further experimental and theoretical studies.

Paragenetic investigations are also a help to the mineral collector. The knowledge of typical assemblages at a locality facilitates quicker identification of minute or rare minerals and also makes possible a simple and quick identification of minerals which, macroscopically, can easily be mistaken for each other. Several new minerals are mentioned in this connection although their descriptions according to I.M.A. regulations are not yet complete.

Problems in paragenetic studies can be caused by subjective selection of samples. Mineral collections contain mostly the best and most beautiful specimens, like cerussite or azurite in large crystals; such collections are not very representative of the deposit as a whole. For paragenetic studies such specimens have very little value. Attractive or rare minerals such as dioptase, azurite and cerussite are found in collections more often than, for instance, malachite and mottramite. Through this a distorted picture is obtained of the relative quantities of secondary minerals in a mine.

To overcome the shortcomings of the above-mentioned specimens I have tried to collect with a paragenetic study in mind.

## PARAGENESIS OF THE PRIMARY ORE MINERALS

The parageneses of the hypogene and supergene ore minerals were studied in detail by Schneiderhöhn (1929) and by Moritz (1933). In their studies samples down to a depth of 460 m (about the 16th level) were considered. Later investigations were undertaken by Sclar and Geier (1957), Strunz, Geier and Seeliger (1958) and Geier and Ottemann (1973). These three works considered primarily the occurrence of germanium and gallium minerals and their paragenesis. The results of these three papers are not without certain contradictions, so that a thorough revision would be in order.

Based on what has been discovered thus far, I believe the most probable ages of formation for the most important ore minerals to be as shown on table I.

**Pyrite** occurs in the ores of Tsumeb rather sparingly. It occurs mostly in single grains about 1 to 2 mm in size, frequently showing some crystal faces. Occasionally pyrite crystals occur together with secondary minerals. In such cases they have a more or less heavier rind of galena which probably protected the pyrite from disintegration.

Strunz, *et al* (1958) describe younger pyrite aggregates in which the age relation, based on inclusions, is similar to that shown in table I (for Pyrite II).

**Chalcopyrite** is found rarely in macroscopic, recognizable quantity. According to available research material, two generations of chalcopyrite could occur (indicated on table 1 as "I" and "II").

**Bornite** is also a rather rare mineral at Tsumeb. In contrast to the upper levels it is found in greater abundance at greater depth. Massive pieces of about 1 cm in size occur with germanite.

**Germanite** is not rare but occurs mostly in microscopic grains included within galena and tennantite. Larger masses of germanite occur only rarely. Germanite is one of the older ore minerals at Tsumeb. Strunz, *et al* (1958), describe a germanite aggregate which is younger than the formation of galena. Inclusions of sphalerite and probably also tennantite suggest a second generation of germanite.

**Sphalerite** at Tsumeb is one of the most important ore minerals. It is without doubt older than enargite, tennantite and galena.

**Gallite** occurs in the form of separation lamellae in sphalerite associated with germanite, or as gray metallic grains in the germanite itself.

**Enargite** was the most important ascending copper ore in the upper levels. The grains of enargite, commonly of millimetre size, were often overlooked among the ore minerals.

**Tennantite** is, in greater depth, the most important primary copper ore, and occurs as very fine grains of wide distribution. It occurs frequently in larger solid masses as well. During the last few years large, complete tennantite crystals of tetrahedral form have been recovered. The crystal faces were rough and etched. It is not yet possible to determine whether these crystals formed in open cavities or were freed through the disintegration of surrounding ore material. The latter mode is the most likely.

**Briartite** is a rare, inconspicuous, gray mineral with a dull metallic sheen and gray streak. It is formed as a part of two parageneses: ovoid masses in tennantite, germanite and renierite, as well as minute inclusions in sphalerite, *or* as a very fine intergrowth with tennantite and renierite in sphalerite.

**Renierite** has an orange-brown color and is, in contrast to germanite, highly magnetic. According to Sclar and Geier (1957) renierite is a replacement product of germanite and forms mostly rinds around germanite grains in tennantite, bornite, sphalerite and galena.

**Galena** is the most important ore mineral at Tsumeb and belongs to the latest primary formations.

**Digenite** will, according to Sclar and Geier (1957), be older than galena. Digenite is, according to Schneiderhöhn (1929), the youngest of the primary phases at Tsumeb.

**Chalcocite** covers the primary ores with a crust of varying thickness, and forms veins in the primary ore and gangue. Solid masses of chalcocite up to 20 cubic metres occurred in the first oxidation zone. Chalcocite occasionally forms very beautiful euhedral crystals and penetration twins (twinned on (110)) in solution cavities with other secondary minerals.

**Covellite** is very rare. It is sometimes found as thin scales with chalcocite or with anglesite and cerussite.

**Gangue minerals** at Tsumeb are of little significance compared to the ore minerals. Dolomitic country rock in the vicinity of the ore body is permeated with silicates. Quartz, calcite, dolomite, and rarely barite and witherite, are the only gangue minerals.

## PARAGENESIS OF THE SECONDARY MINERALS

At many mineral localities in the world the number of distinctly separate secondary mineral assemblages is very small, perhaps only one or two. In such cases the discussion of paragenesis is relatively simple and straightforward unless unusual problems exist. The secondary mineral assemblages and crystallization sequences at Tsumeb, on the other hand, are so varied and numerous that they must first be subdivided and discussed individually before they can be worked into a comprehensive scheme for the locality as a whole. The great complexity of the Tsumeb deposit precludes even this adjusted approach from being presented here in full detail. Therefore only the most important or instructive minerals and assemblages will be discussed.

The most plentiful secondary minerals in the second, or lower, oxidation zone include cerussite, smithsonite, malachite, duftite, mottramite, mimetite, willemite, wulfenite, azurite, olivinite, dioptase, adamite and anglesite. Those minerals which I have found to occur in association with the above 13 most plentiful species are listed in table 2.

The most important secondary minerals in the first, or upper, oxidation zone include cerussite, smithsonite, malachite, azurite, anglesite, mimetite, mottramite, bayldonite, olivinite and adamite, according to listings by Schneiderhöhn (1929), Frondel and Ito (1957) and Strunz, *et al* (1958).

Azurite, anglesite and bayldonite were much more prevalent in the first oxidation zone than in the second; duftite and wulfenite were rarer in the first than in the second. Another pertinent difference is the greater abundance of secondary silicate minerals in the second oxidation zone.

### *Conditions of formation*

A mineral crystallizes from a solution when its chemical elements are present in sufficient concentration and when the physical and chemical conditions are within ranges where the mineral is stable. At room temperature the important physiochemical parameters of the solution are the pH (acidity-basicity) and the Eh (oxidation-reduction potential). For several Tsumeb secondary minerals these formation conditions are known and approximate Eh-pH diagrams established, i.e. for anglesite, cerussite, malachite and cuprite (Garrels and Christ, 1965), for wulfenite (Williams, 1963, and Wilson and Miller, 1974), and for smithsonite and hydrozincite (Takahashi, 1960).

Most of the above minerals react more sensitively to changes in pH than to changes in Eh. Therefore I shall address the pH conditions almost exclusively.

It is a characteristic of the Tsumeb mine that oxidation of the primary minerals occurs in association with a very typical karst hydrology (Schneiderhöhn, 1929). Solution cavities in ore with carbonate-type gangue (or country rock) exist in the orebody to a considerable depth. Within these karst canals is a quiet, slow moving, watercourse of constant temperature and having many side branches (Schneiderhöhn, 1958). The water has been oxygenated at the surface and is also in equilibrium with atmospheric carbon dioxide. There exists, through these favorable conditions, an intense oxidation of the primary minerals to a considerable depth. The second oxidation zone was made possible by a permeable formation associated with the karst hydrology as well as a well-developed fault or brecciated zone which has been proven to a depth of about 1000 m (3300 feet) (Strunz, *et al*, 1958).

If a permanent groundwater level had not been present at Tsumeb the weathering-product zones associated with depth would not have formed as they did. Such zoning is mostly localized and can often be observed in hand-size specimens.

The oxidation of the ore minerals occurred in groundwater containing oxygen and carbon dioxide, and having a pH of about 8 (i.e. slightly basic; 7 is neutral). The dissolution of ore minerals follows a systematic sequence. Sphalerite is the most soluble and galena the least soluble of the primary ore minerals at Tsumeb. The sulfosalts are intermediate in solubility. The oxidizing solution therefore contains Zn ions first, then Cu ions, and finally Pb ions in increasing concentrations. These factors influence the order of formation of the important secondary minerals when the weathering solution remains unmixed for considerable periods of time. Therefore, because of concentration differences, smithsonite will form first and only later can cerussite be formed. Such conditions would not exist if the solutions were continuously being mixed. In this connection one must also consider the path which these ion solutions take; it is known that the path for Zn ions is the longest (i.e. they remain in solution the longest) and the path of Pb ions is the shortest (i.e. they remain in solution only a short time).

Sulfate ions develop through the oxidation of sulfide ores and an acidic solution (sulfuric acid) develops with a pH of about 4. By reacting with carbonate country rock along the more or less lengthy path through the karst canals it is possible for most of the acidic solution to eventually be neutralized to a pH of about 8. Because of these two processes it is possible to delineate two types of paragenesis at Tsumeb.

Paragenesis **Type I**: the minerals of this paragenesis were formed at a pH of 6-8 (near neutral). These are primarily carbonates. The solutions forming these minerals probably travelled a relatively long distance; the minerals may occur in the country rock or the larger cavities (but are not restricted to such areas). According to Eh-pH diagrams, this group of minerals includes cerussite, smithsonite, malachite and cuprite.

Paragenesis **Type II**: the most common minerals of this type of paragenesis are the sulfates. They crystallize at a pH of 4-5 (acidic). The path of these solutions is short; these minerals occur to the greatest extent within the ore, and are generally found within small cavities in sulfides. According to Eh-pH diagrams, only anglesite is implicit to this type of paragenesis at Tsumeb. Linarite (Williams, 1963) as well as adamite and olivenite (Guillemin, 1956) can also be formed at a pH of 5.

Wulfenite is stable in a range of pH from 3.0 to 9.4. It is unstable near cerussite and can occur with anglesite only where Pb ions are present in surplus (Williams, 1963).

No definitive data yet exists for the more prevalent minerals such as duftite, mottramite, mimetite, willemite, azurite and dioptase. A consideration of these minerals in view of the paragenesis is presented below.

***Paragenesis Type I***

**Cerussite, $PbCO_3$**

Many of the spectacular, large and beautiful cerussite crystals were found singly in solution cavities in the ore or in gangue. Mineral assemblages rich in cerussite are very numerous. In the samples I investigated, cerussite occurred with a total of 29 other secondary minerals. In order of their occurrence, the most important are duftite, smithsonite, malachite, mimetite, willemite and azurite. Cerussite is relatively rare in assemblages including numerous other minerals such as mottramite, wulfenite, adamite and olivinite. The indications are that these minerals are not stable near cerussite or perhaps they have fundamentally different conditions of formation.

One of the most common assemblages at Tsumeb includes cerussite and duftite; cerussite is usually younger than the duftite on these specimens. Occasionally one observes two generations of duftite. Specimens also occur in which the older duftite generation is missing or in which duftite and cerussite appear to have crystallized simultaneously. Often a fine coating of goethite needles is the earliest mineral to form on these specimens and a white pearly coating of dolomite crystals to 5 mm is the most recent. The paragenesis may be sketched in the manner shown below; *the arrows indicate the direction of the passage of time and do not indicate reactions between minerals.* Roman numerals I and II indicate the generation (first or second).

**Paragenesis I/1: Goethite** →
[$\propto FeO(OH)$]

**Duftite I** → **Cerussite** → **Duftite II** →
[$PbCu(AsO_4)(OH)$] [$PbCO_3$] [$PbCu(AsO_4)(OH)$]

**Dolomite**
[$CaMg(CO_3)_2$]

This shows that duftite is stable under the similar conditions as cerussite

**Smithsonite, $ZnCO_3$**

Assemblages including smithsonite are not as numerous as those which include cerussite. Smithsonite is generally found alone or with, at most, one or two other secondary minerals. It formed in at least two generations which generally have different habits and are therefore easy to recognize. A definitive connection between the habits and the assemblages has not yet been determined.

Smithsonite has been observed in association with 28 other secondary minerals. The most important of these are mimetite, cerussite, duftite, willemite and rosasite. Like cerussite, smithsonite is seldom found in association with mottramite, olivenite and adamite. This is an additional indication of differing stability conditions. Wulfenite is also seldom found with smithsonite. This suggests that the reason why wulfenite is not stable with cerussite has to do with more than just their relative solubilities. Malachite and azurite, in spite of identical conditions of formation, seldom occur with smithsonite. The cause of this may lie in the type of paths which solutions carrying Cu and Zn tend to follow. It is also possible that because of the high concentration of Zn, rosasite formed instead of malachite. Cerussite is, for the most part, younger than smithsonite and is only occasionally older. In specimens where crystals have formed directly on ore minerals or gangue, smithsonite is always older than cerussite. Smithsonite younger than cerussite is definitely of a second generation. Because cerussite is less soluble than smithsonite it must crystallize first in a normal sequence. Therefore smithsonite I (the first generation) must have formed earlier from a different solution than that which formed the cerussite and smithsonite II. These assemblages indicate a fractionalized solubility of the ore minerals and/or differing path lengths for the ion-bearing solutions.

The well known dundasite occurrence is associated with this paragenesis to a certain extent. Very thin, white, radiating fibers of dundasite occur anchored to the matrix and penetrating the smithsonite; therefore dundasite is as old or older than the smithsonite. Not all of the samples studied had cerussite.

**Paragenesis I/2: Dundasite** +
$[\mathrm{PbAl_2(CO_3)_2(OH)_4 \cdot H_2O}]$
**Smithsonite I** → **Cerussite** → **Smithsonite II**
$[\mathrm{ZnCO_3}]$ $[\mathrm{PbCO_3}]$ $[\mathrm{ZnCO_3}]$

Mimetite is the mineral most commonly found in association with smithsonite. Specimens of mimetite and smithsonite on siliceous gangue are found in which smithsonite is by far the older of the two minerals. Mimetite, therefore, is stable under conditions typical of Type I parageneses.

**Mimetite, $\mathrm{Pb_5(AsO_4)_3Cl}$**

Mimetite has been observed in association with 25 other secondary minerals. The most important of these are smithsonite, duftite, wulfenite, cerussite, dolomite, goethite and willemite. The assemblages including mimetite are, in general, not highly variable.

Mimetite is an important link in the age sequence of the secondary minerals. Mimetite occurs with smithsonite and cerussite, on the one hand, and with wulfenite on the other, whereas smithsonite and cerussite occur only very rarely in association with wulfenite. Furthermore, one does not find mimetite of differing generations.

The very widespread assemblage of mimetite, duftite and cerussite is of interest with regard to the discussion of the physio-chemical conditions of formation of the secondary minerals. In contrast to mimetite, duftite formed in two generations. Where duftite II (the younger generation) has formed directly upon mimetite it was observed repeatedly that the older mimetite was partially or completely dissolved. The outlines of these dissolved mimetite crystals are recognized as a crust of goethite and duftite. Some duftite crystals extend into the cavities, others rest upon the corroded mimetite or form pseudomorphs after mimetite. In most cases malachite is also present, and is of the same age or younger than the duftite.

Cerussite can also occur in this assemblage. Where cerussite forms water-clear crystals rich in forms it is more recently formed than mimetite and duftite. It is possible that in such cases duftite II can occur as described in Paragenesis I/1; such specimens exhibit fresh, unaltered mimetite where duftite I is missing. Where the cerussite is older than the mimetite it is partially dissolved and is surrounded by duftite crusts, sometimes also with malachite, both of which are older than the mimetite.

**Paragenesis I/3: Cerussite** → **Duftite** +
$[\mathrm{PbCO_3}]$ $[\mathrm{PbCu(AsO_4)(OH)}]$
**Malachite)** → **Mimetite** →
$[\mathrm{Cu_2(CO_3)(OH)_2}]$ $[\mathrm{Pb_5(AsO_4)_3Cl}]$
**Duftite I** + **Malachite** → **Cerussite** →
$[\mathrm{PbCu(AsO_4)(OH)}]$ $[\mathrm{Cu_2(CO_3)(OH)_2}]$
**Duftite II**

Based on the above paragenetic sequence, one can infer that the arsenates mimetite and duftite form under the same conditions as cerussite but have a lower solubility. As the arsenate ions enter the system they precipitate with Pb and/or Cu rather than allowing Pb to react with carbonate ions to form cerussite. Duftite is more stable than mimetite in the presence of copper and arsenate ions. Malachite occurs with duftite where mimetite is not present, but only as a considerably younger generation and may not have been formed from the same solution as that which formed the mimetite.

When associated with wulfenite, mimetite is always the younger of the two. Frequently a complete covering of goethite on the matrix is the earliest mineral. In such an assemblage the mimetite crystals are deep yellow and have a tabular to pyramidal habit. The yellow wulfenite crystals are more or less pseudo-octahedral because of dominant {114} faces. Occasionally one finds malachite as the youngest generation. The sequence may be written as follows.

**Paragenesis I/4: Goethite** → **Wulfenite** →
$[\alpha\,\mathrm{FeO(OH)}]$ $[\mathrm{PbMoO_4}]$
**Mimetite** → **Malachite**
$[\mathrm{Pb_5(AsO_4)_3Cl}]$ $[\mathrm{Cu_2(CO_3)(OH)_2}]$

**Wulfenite, $\mathrm{PbMoO_4}$**

The association of wulfenite with mimetite and the absence of wulfenite forms {111} and {113} indicate, according to

**Table 1.**

**Age relations of the primary (hypogene) and secondary (supergene) ore minerals.**

| | |
|---|---|
| **Hypogene**: | Pyrite I, $\mathrm{FeS_2}$ (earliest mineral) |
| | Chalcopyrite I*, $\mathrm{CuFeS_2}$ |
| | Bornite, $\mathrm{Cu_5FeS_4}$, Germanite I, $\mathrm{Cu_3(Ge,Fe)(S,As)_4}$ |
| | Sphalerite, ZnS, Gallite, $\mathrm{CuGaS_2}$ |
| | Enargite, $\mathrm{Cu_3AsS_4}$ |
| | Briartite, $\mathrm{Cu_2(Fe,Zn)GeS_4}$, Tennantite, $\mathrm{(Cu,Fe)_{12}As_4S_{13}}$ |
| | ?Pyrite II*, $\mathrm{FeS_2}$ |
| | ?Chalcopyrite II, $\mathrm{CuFeS_2}$, ?Germanite II, $\mathrm{Cu_3(Ge,Fe)(S,As)_4}$ |
| | Renierite, $\mathrm{Cu_3(Fe,Ge,Zn)(S,As)_4}$ |
| | Galena, PbS |
| | ?Digenite, $\mathrm{Cu_9S_5}$ |
| **Supergene**: | Chalcocite, $\mathrm{Cu_2S}$ |
| | Covellite, CuS (latest mineral) |

***I** indicates the first generation of formation for the mineral; **II** indicates the second generation.

Williams (1966), a middle-range pH of 5-6, and a moderate Eh. Apparently wulfenite formed under conditions intermediate between those of paragenesis types I and II.

Duftite, malachite, quartz and goethite are, next to mimetite, the most important secondary minerals that occur with wulfenite. I have thus far identified 25 secondary minerals that occur in association with wulfenite.

At least two generations of wulfenite occur in association with duftite. Large, extremely thin, tabular white wulfenite crystals have been found on a matrix of strongly weathered country rock covered by hematite and goethite. The white wulfenite plates are covered with radiating bundles of fine, acicular duftite which can easily be mistaken for conichalcite. Rhombic calcite crystals formed after these minerals, and were followed by a second generation of small wulfenite crystals as indicated below.

**Paragenesis I/5:** **Hematite** + **Goethite** →
$[Fe_2O_3]$ $[\propto FeO(OH)]$

**Wulfenite I** → **Duftite** → **Calcite** →
$[PbMoO_4]$ $[PbCu(AsO_4)(OH)]$ $[CaCO_3]$

**Wulfenite II**
$[PbMoO_4]$

**Willemite, $Zn_2SiO_4$**

Willemite at Tsumeb is comparatively plentiful. However it is found in association with only 15 secondary minerals. The most important of these are all found in the same assemblage; they are smithsonite, rosasite, cerussite, duftite and mimetite.

Eh-pH parameters for willemite have never been determined. Judging by its most frequent associates at Tsumeb, willemite should without doubt be stable under the conditions of a Type I paragenesis. The following sequence is abundantly widespread at Tsumeb.

**Paragenesis I/6:** **Willemite I** + **Smithsonite)** →
$[Zn_2SiO_4]$ $[ZnCO_3]$

[ **Rosasite** + **Duftite**
$[(Cu,Zn)_2(CO_3)(OH)_2]$ $[PbCu(AsO_4)(OH)]$

**or**

**Mimetite**
$[Pb_5(AsO_4)_3Cl]$ ] → **Willemite II** →
$[Zn_2SiO_4]$

**Cerussite** → **Smithsonite II**
$[PbCO_3]$ $[ZnCO_3]$

Both of the older minerals willemite I and smithsonite I formed directly on siliceous gangue. They were, as indicated in Paragenesis I/2, formed by an older weathering solution than the other minerals. Following these two Zn minerals, radiating bundles of rosasite and duftite crystals or yellow needles of mimetite formed. Mimetite, rosasite and duftite occur together only when cerussite (as in Paragenesis I/3) is the next younger mineral. In most cases, however, willemite II crystallized next and only after that did cerussite form. The youngest mineral of the sequence is the second generation of smithsonite.

**Malachite, $Cu_2(CO_3)(OH)_2$**

Malachite formed at several stages in the sequence of crystallization and is a member of a large number of rich assemblages. I have found 26 secondary minerals to occur in association with malachite at Tsumeb. The most important of these are azurite, cerussite, duftite, wulfenite and mimetite. As mentioned above, of all the minerals formed under these same conditions only smithsonite is rare with malachite.

The pseudomorphs of malachite after azurite are well known, particularly those from the first oxidation zone at Tsumeb. Malachite occurs in place of duftite in several sequences (i.e. I/1 and I/5). Malachite also occurs in the I/3 and I/4 sequences.

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

The exceptionally beautiful azurite crystals from Tsumeb are known all over the world. Crystal studies of groups from the first oxidation zone, and an attempt to order this mineral into certain parageneses, were first attempted by Zedlitz (1929).

I have found azurite associated with only 16 secondary minerals. In spite of this there are several different assemblages which include azurite, none of which are particularly abundant. The most important minerals associated with azurite develop under conditions of formation similar to those of Type I parageneses and also under conditions similar to those of Type II parageneses. These minerals are malachite, cerussite, mottramite, duftite, adamite and olivinite.

Large azurite crystals in association with cerussite are relatively common. The cerussite is as old or older than the azurite. Dundasite and duftite are occasionally part of the assemblage; both are older than cerussite, as indicated below.

**Paragenesis I/7:** **Duftite** → **Dundasite** →
$[PbCu(AsO_4)(OH)]$ $[PbAl_2(CO_3)_2(OH)_4 \cdot H_2O]$

**Cerussite** → **Azurite** → **Malachite (pseudomorphous)**
$[PbCO_3]$ $[Cu_3(CO_3)_2(OH)_2]$ $[Cu_2(CO_3)(OH)_2]$

Minerals typical of type II assemblages are also part of the following paragenesis. Crusts of mottramite form cell-like structures which are formed in part on massive quartz. Following that, elongated olivenite crystals formed. Here and there a second generation of olivenite can be observed: these are often pale olive threads or fibers. The olivenite is often encrusted with duftite. Somewhat younger are small malachite crystals. In the remaining cavities one finds 1-2 cm azurite crystals. Most of the azurite has been altered to malachite. Under the duftite crusts the olivenite is partially dissolved.

**Paragenesis I/8:** **Quartz** → **Mottramite** →
$[SiO_2]$ $[PbCu(VO_4)(OH)]$

**Olivenite I & II** → **Duftite** → **Malachite** →
$[Cu_2(AsO_4)(OH)]$ $[PbCu(AsO_4)(OH)]$ $[Cu_2(CO_3)(OH)_2]$

**Azurite** → **Malachite (pseudo).**
$[Cu_3(CO_3)_2(OH)_2]$ $[Cu_2(CO_3)(OH)_2]$

The above paragenesis is proof that during the crystallization of secondary minerals at Tsumeb the weathering solutions changed from acidic to basic.

The assemblage of azurite and adamite will be discussed under adamite.

**Dioptase, $CuSiO_2(OH)_2$**

The exceptionally beautiful crystals of dioptase at Tsumeb occur almost exlusively in the country rock, and are only rarely associated with other secondary minerals. I have noted the association of dioptase with only 11 other secondary minerals.

One finds dioptase most frequently with older dolomite and younger calcite crystals. Sometimes a second generation of dioptase formed which is younger than the calcite. Duftite and plancheite are the next most common associates, and they are both always older than dioptase.

**Paragenesis I/9: Dolomite** $[CaMg(CO_3)_2]$ → **Duftite** $[PbCu(AsO_4)(OH)]$ →
**Plancheite** $[Cu_8Si_8O_{22}(OH)_4 \cdot H_2O]$ → **Dioptase I** $[CuSiO_2(OH)_2]$ → **Calcite** $[CaCO_3]$ →
**Dioptase II** $[CuSiO_2(OH)_2]$

The above paragenetic sequence is younger than sequence I/6 and is in association with cerussite on a few specimens.

**Cuprite, $Cu_2O$**

Cuprite is comparatively rare at Tsumeb. In the more simple assemblages cuprite occurs with dolomite and rarely with mimetite, duftite and malachite. Mimetite and cuprite are probably of the same age. These facts are further proof of the conditions of formation of mimetite.

***Paragenesis Type II***

**Anglesite, $PbSO_4$**

Anglesite is the only mineral at Tsumeb which forms under the conditions of Type II parageneses, and for which Eh-pH stability diagrams have been prepared. The mineral occurs in association with only a few other minerals; 15 have been observed in this study. The chisel-shaped, yellowish crystals, and also the recently discovered black, glossy, deeply striated blade-like crystals, are usually the only secondary mineral in a pocket, except perhaps for traces of goethite. The pockets occur in masses of sulfide ore.

The most important secondary minerals found to occur with anglesite are beudantite, carminite, and the new **Mineral TK** (not yet fully characterized), which form a distinct assemblage. The assemblage occurs in small alteration cavities in ore. The oldest of the minerals is beudantite in yellowish brown, tabular crystals. Red, acicular carminite crystals are generally younger, followed by water-clear, many-faced, sometimes reddish-colored (because of carminite inclusions) anglesite crystals. On only a few pieces from this assemblage a dark green, tabular to scaly mineral can be seen to have formed on the carminite crystals. This is the new **Mineral TK**, which has not yet been officially described and named. It is a Pb-Fe arsenate containing small amounts of Cu and Zn. Characteristic d-values are **6.75**(4), **4.84**(4), **4.62**(5), **4.49**(5), **4.06**(3), **3.31**(8), **3.20**(10) and **2.96**(10).

**Paragenesis II/1: Primary sulfides** → **Beudantite** $[PbFe_3(AsO_4)(SO_4)(OH)_6]$ →
**Carminite** $[PbFe_2(AsO_4)_2(OH)_2]$ → **Anglesite** $[PbSO_4]$ → **Mineral TK** $[Pb, Fe, Cu, Zn, AsO_4]$

Also typical of this assemblage is anglesite with arsentsumebite. Flat, light bluish green crystals of arsentsumebite on weathered ore can be found. Flattened anglesite crystals to several centimetres in size with arsentsumebite inclusions have also been found, which indicate that arsentsumebite formed before anglesite. Very rarely brochantite occurs as the youngest mineral and scorodite as the oldest mineral of the assemblage. Scorodite, when associated with beudantite, is always the younger of the two.

**Paragenesis II/2: Primary sulfides** → **Scorodite** $[FeAsO_4 \cdot 2H_2O]$ →
**Arsentsumebite** $[Pb_2Cu(PO_4)(SO_4)(OH)(AsO_4)]$ → **Anglesite** $[PbSO_4]$ →
**Brochantite** $[Cu_4(SO_4)(OH)_6]$ → **Cerussite** $[PbCO_3]$ **(pseudomorphous after anglesite)**

Anglesite crystals of the above paragenetic sequence frequently have a porcelainous coating of cerussite or have been completely replaced, forming coarse pseudomorphs of cerussite after anglesite. This is a definite indication that the solutions changed from acidic to weakly basic. Furthermore, this proves that Type I assemblages are younger than Type II assemblages.

**Linarite, $PbCu(SO_4)(OH)_2$**

Linarite occurs in small cavities in ore along with posnjakite and serpierite. The oldest portion of the assemblage is a mixture of deep blue-green tabular posnjakite crystals and acicular brochantite. Malachite is sometimes also present in this mixture. Clear, light blue, elongated tabular crystals of linarite, often in radiating groups, are in most cases the youngest mineral of the suite. Very thin, light blue-green to white, glossy scales of serpierite cover the other minerals in places.

**Paragenesis II/3: Primary sulfides** → **Brochantite** $[Cu_4(SO_4)(OH)_6]$ +
**Posnjakite** $[Cu_4(SO_4)(OH)_6 \cdot H_2O]$ + **(Malachite)** $[Cu_2(CO_3)(OH)_2]$ → **Linarite** $[PbCu(SO_4)(OH)_2]$ →
**Serpierite** $[Ca(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O]$

Williams (1963) suggested a pH of from 4 to 5 for the formation of linarite; therefore Paragenesis II/3 could, without doubt, be a Type II paragenesis. Frequently with this assemblage it can be shown that the minerals are younger than cerussite and smithsonite (in the same zone but of a different sequence). Minerals of Paragenesis II/3 are therefore younger than the minerals of Type I assemblages. Presumably they originated much later and crystallized in minute cracks where circulation was severely restricted. The paths of transport of the ions were certainly very short; a virtually closed system must have existed.

**Adamite-Olivenite, $Zn_2(AsO_4)(OH) - Cu_2(AsO_4)(OH)$**

Adamite and olivenite form mixtures of varying composition at Tsumeb; a solid solution series exists between the end-members, and material with a range of Zn/Cu ratios can often be found on a single specimen. Light green to green cupriferous adamite is the most common; olivenite is much rarer. Both minerals occur as the only secondary minerals in small cavities in sulfides and occasionally in gangue.

Associations with adamite are somewhat more numerous than those with olivenite. I have noted 19 secondary minerals that occur with adamite, but only 9 with olivenite. Most often one finds adamite with conichalcite, whereas for olivenite the paragenetic assemblage I/8 with mottramite is the typical one. The characteristic adamite sequence often begins with conichalcite as the oldest phase. A few specimens show yellowish scales of tsumcorite overgrown on conichalcite, especially where smithsonite is present as the youngest generation. More frequently, however, the Cu-adamite follows directly upon conichalcite. Most of the younger minerals can therefore be divided into two groups based on their conditions of formation.

The hydro-arsenates chudobaite and schultenite also belong to the Type II paragenesis. Schultenite occurs as water-clear crystals that could also crystallize from a very acid solution.

**Paragenesis II/4: Primary sulfides** → **Conichalcite** $[CaCu(AsO_4)(OH)]$ →
**Adamite** $[Zn_2(AsO_4)(OH)]$ → **Schultenite** $[PbHAsO_4]$ **or Chudobaite** $[(Na,K,Ca)(Mg,Zn,Mn)_2H(AsO_4)_2 \cdot 4H_2O]$

Azurite, malachite and smithsonite belong to Type I assemblages and, where found with the above minerals, indicate a change in the pH of the weathering solution.

### TABLE 2.

| | Cerussite | Smithsonite | Malachite | Duftite | Mottramite | Mimetite | Willemite | Wulfenite | Azurite | Dioptase | Adamite | Olivenite | Anglesite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cuprite** | | ☒ | ☒ | ☒ | | ▲ | | | | | | | |
| **Hematite** | ▲ | ☐ | | ▲ | | | | ▲ | | | ☒ | ☒ | |
| **Goethite** | ◢ | ☒ | ▲ | ▲ | ◢ | ◢ | ▲ | ▲ | | | ☒ | | |
| **Smithsonite** | ◘ | | ☒ | ◘ | ☒ | ◘ | ■ | ☒ | ☒ | | ☒ | ☐ | ☐ |
| **Calcite** | ☒ | ☒ | ◢ | ◢ | ◘ | ☒ | ☐ | ◢ | ☐ | ■ | | | |
| **Dolomite** | ▲ | ☒ | ▲ | ◢ | ◢ | ◢ | ☒ | ▲ | ☒ | ◢ | | | |
| **Cerussite** | | ◘ | ◘ | ■ | ☐ | ◘ | ◢ | ☒ | ◢ | ◢ | ☐ | | ◢ |
| **Azurite** | ◢ | ☐ | ◘ | ▲ | ◢ | ☐ | | ☒ | | | ◢ | ◢ | ☐ |
| **Malachite** | ◘ | ☒ | | ◘ | ◢ | ▲ | ☒ | ◘ | ■ | ▲ | ▲ | ◢ | ☒ |
| **Rosasite** | ▲ | ◢ | ▲ | ▲ | ☒ | ☒ | ◘ | ☐ | | | ☒ | | |
| **Dundasite** | ▲ | ▲ | ☐ | ☐ | | ☐ | | | ▲ | | | | ☐ |
| **Anglesite** | ▲ | ☐ | ☐ | | | ☒ | | | ☐ | | | | |
| **Brochantite** | ☒ | | ▲ | | ☐ | | | | | | | | ☒ |
| **Linarite** | ▲ | ☐ | ▲ | | | ☐ | | | | | | | ☐ |
| **Beudantite** | | | ☒ | ☐ | | ☒ | | ☒ | ☐ | | | | ◘ |
| **Leadhillite** | ☒ | | | | | ☒ | | ☒ | | | | | ☐ |
| **Posnjakite** | ☒ | | ☐ | | | | | | | | | | ☐ |
| **Serpierite** | ☐ | ☐ | | | | | | | | | | | ☐ |
| **Wulfenite** | ☒ | ☐ | ◢ | ▲ | | ◘ | | | ☒ | ☐ | | | |
| **Schultenite** | | | | | | | | | | | ▲ | | |
| **Adamite** | ☐ | ☒ | ☒ | ☒ | | | ☒ | | ▲ | | | ☒ | |
| **Olivenite** | | ☐ | ☒ | ☐ | ◢ | | | | ☒ | | ☒ | | |
| **Duftite** | ■ | ◘ | ◘ | | ◢ | ◘ | ◢ | ◘ | ◢ | ◘ | ▲ | ▲ | |
| **Conichalcite** | | ☒ | ☐ | ☐ | | | ☒ | | | ☐ | ■ | ☐ | |
| **Mottramite** | ☐ | ☒ | ▲ | ☒ | | | ☒ | | ▲ | | | ◢ | |
| **Bayldonite** | | | | | | ☒ | | | | | | | |
| **Arsentsumebite** | ☒ | ☐ | ☐ | | ☐ | ☐ | | | ☒ | | | | ◢ |
| **Carminite** | | | | | | ☐ | | | | | | | ◘ |
| **Tsumcorite** | ☐ | ☒ | ☐ | ▲ | | ▲ | ☒ | ☒ | ☐ | | ▲ | | |
| **Mimetite** | ◢ | ◘ | ◢ | ◘ | | | ◢ | ■ | ☐ | ☐ | | | ▲ |
| **Scorodite** | | | | | | | | ☐ | | | | | |
| **Willemite** | ◢ | ◘ | ▲ | ◢ | ☒ | ▲ | | | | ☐ | ☒ | | |
| **Alamosite** | ☐ | | | | | ☐ | | ☐ | | | | | |
| **Dioptase** | ☒ | ▲ | ☒ | ◢ | | ☐ | ☐ | ☐ | | | | | |
| **Plancheite** | ☐ | | ☐ | ☐ | | | | | ☐ | ◢ | | | |
| **Kegelite** | ☐ | | | | | ☐ | | ☐ | | | | | |
| **Quartz** | ☒ | ☒ | ☒ | ☒ | ▲ | ☒ | ☒ | ◢ | ☐ | ☐ | ▲ | ▲ | ☐ |

*Table 2.* Mineral associations of the 13 most common Tsumeb secondary minerals. The 13 most common minerals are listed across the top in their order of abundance (cerussite is most abundant). Listed down the side are the species I have noted in association with the 13 most common species. The symbols where their columns and rows intersect indicate how frequently the mineral at *left* occurs in association with the mineral at the *top*.

| | |
|---|---|
| ■ Most common associate | ▲ less common associate |
| ◘ very common associate | ☒ rare associate |
| ◢ common associate | ☐ very rare associate |

Not shown here are the incompletely described new minerals and minerals which I have not observed in association with any of the 13 most common minerals. For this reason the indications in the test do not correspond exactly with the table for certain species.

Practical application of this table by collectors can be illustrated by the following example: You have a specimen of cerussite and an associated green mineral which you suspect to be either duftite or conichalcite. Looking down the column labeled "cerussite" at the top, you come to "duftite" and then "conichalcite". You see that duftite is extremely common in association with cerussite, but that conichalcite is almost never found with cerussite. Therefore the odds are strongly in favor of your green mineral being duftite and not conichalcite.

**Paragenesis II/5: Primary sulfides** → **Conichalcite** →
$[CaCu(AsO_4)(OH)]$

**Adamite** → **Azurite** → **Malachite**
$[Zn_2(AsO_4)(OH)]$ $[Cu_3(CO_3)_2(OH)_2]$ $[Cu_2(CO_3)(OH)_2]$

**Paragenesis II/6: Primary sulfides** → **Conichalcite** →
$[CaCu(AsO_4)(OH)]$

**Tsumcorite** → **Adamite** → **Smithsonite**
$[PbZnFe(AsO_4)_2 \cdot H_2O]$ $[Zn_2(AsO_4)(OH)]$ $[ZnCO_3]$

Blue, tabular, elongated crystals of the new mineral keyite sometimes occur with adamite as the older of the two. Keyite is a Zn-Cu arsenate (see Embrey, *et al.*, in this issue).

The ideal conditions for the formation of adamite and olivenite exist at a pH of about 5. Adamite is probably stable over a greater range of pH than is olivenite.

**Duftite, Mottramite, Conichalcite, Arsentsumebite, Bayldonite.**

The five green minerals named above can be easily confused visually because their colors, habits and crystal forms are so similar. Help here is given by the paragenesis, as discussed below.

**Duftite, $PbCu(AsO_4)(OH)$**

Duftite often forms equant crystals up to 2 mm in size. The crystal faces are nearly always curved or saddle-shaped. Radially structured solid masses were rare but are now being found coating calcite in cavities on the 35th level. Acicular bundles of duftite that can easily be mistaken for conichalcite occur with wulfenite.

Tsumeb duftite contains small amounts of admixed calcite, and it is therefore very difficult to obtain an uncontaminated X-ray pattern (which could distinguish between the two polymorphs ∝-duftite and $\beta$-duftite, both of which have been reported from Tsumeb. The first is isomorphous with mottramite and the second is isomorphous with conichalcite; they both have essentially the same composition).

Of the five minerals mentioned in this section, duftite is the most abundant at Tsumeb. I noted duftite associated with 23 other secondary minerals, all in the same assemblage. The parageneses of the important minerals such as cerussite, mimetite, malachite, smithsonite, dioptase and willemite have already been discussed; they are included in parageneses I/1, I/3, I/5, I/6, I/7, I/8 and I/9.

The rare mineral tsumcorite is found most often in association with duftite and mimetite. Tsumcorite is always older than duftite but younger than mimetite, and fits easily into paragenesis I/3.

The stability conditions of duftite correspond well with the Type I paragenesis. Guillemin (1954) synthesized duftite at a pH of 2.5 to 4. The limit of duftite stability is the boundary of Type II conditions at a pH of 5 to 6.

**Mottramite, $PbCu(VO_4)(OH)$**

Mottramite occurs in radially-structured masses more commonly than duftite. Moss-like coatings often occur with water-clear calcite crystals; single crystals are rare. Mottramite has formed extensivly in the upper portions of both oxidation zones at Tsumeb. It forms porous masses of nothing but mottramite; it is only rarely associated with other secondary minerals. I have noted 14 secondary species in occasional association with mottramite. The most important are calcite, goethite, duftite, azurite and olivenite. Paragenesis I/8 is typical. The conditions of formation of mottramite have not yet been completely delineated. Vanadate ions are first stable at a pH of 12 (extremely basic) according to Garrels and Christ (1965). Guillemin (1956) synthesized mottramite at a pH of about 5. Several of the other minerals occasionally found with mottramite could also have formed at this pH. The sequence of formation of these minerals is also imperfectly known. Apparently mottramite represents an early period of mineral formation and may occur as several generations.

**Conichalcite, $CaCu(AsO_4)(OH)$**

In contrast to duftite, conichalcite forms in very thin, radiating needles. Conichalcite is less common than the other four green minerals discussed here and, in contrast to duftite and mottramite, almost never occurs with cerussite and wulfenite. Paragenesis II/5 with adamite is typical.

**Bayldonite, $PbCu_3(AsO_4)_2(OH)_2$**

Bayldonite is rather rare in the second oxidation zone and has often been misidentified. I have studied several specimens on which bayldonite occurs as thin yellow-green crusts on centimetre-sized mimetite crystals; in this form it is very easily mistaken for duftite. One especially beautiful specimen consists of 2-4 mm blackish green crystals not intergrown with any other mineral.

**Arsentsumebite, $Pb_2Cu(PO_4)(SO_4)(OH)(AsO_4)$**

The bluish green, platy crystals of arsentsumebite are relatively easy to identify, especially since they occur in essentially only one paragenesis (II/2).

***Rare Parageneses***

**Alamosite, Kegelite and Leadhillite**

Leadhillite has recently been found somewhat more often in weathered sulfide ore. The euhedral crystals are often up to several centimetres in size. The crystals usually represent one of the youngest minerals in the assemblage, and occur on wulfenite or mimetite crystals. The faces of the leadhillite crystals are sometimes covered by a thin, radially-structured crust of cerussite. Alamosite and kegelite occur rarely in this paragenesis. Alamosite forms water-clear crystals easily mistaken for elongate cerussite. They are partially covered by minute, glassy, white scales of kegelite.

**Paragenesis R/1: Primary sulfides** → **Wulfenite** →
$[PbMoO_4]$

**Alamosite** → **Kegelite** →
$[Pb_3(Si_3O_9)]$ $Pb_{12}(Zn,Fe)_2Al_4Si_{11}S_4O_{54}]$

**Leadhillite** → **Cerussite**
$[Pb_4(SO_4)(CO_3)_2(OH)_2]$ $[PbCO_3]$

**Schneiderhöhnite, Brunogeierite and Stottite**

One specimen in the Kahn collection shows black, lustrous, octahedral crystals of brunogeierite on essentially unaltered sulfides. Stottite, in reddish brown, euhedral, 5 mm crystals, formed next and light yellow smithsonite formed last.

**Paragenesis R/2: Primary sulfides** → **Brunogeierite** →
$[(Ge,Fe)Fe_2O_4]$

**Stottite** → **Smithsonite**
$[FeGe(OH)_6]$ $[ZnCO_3]$

Also in the Kahn collection is a specimen of schneiderhöhnite. The black crystals measure about 10 mm and show good cleavage. They rest on quartz and are associated with chalcocite (older) and pink stottite (younger).

**Paragenesis R/3: Quartz** → **Chalcocite** →
$[SiO_2]$ $[Cu_2S]$

**Schneiderhöhnite** → **Stottite**
$[Fe_8As_{10}O_{23}]$ $[FeGe(OH)_6]$

**Rare minerals in Ge-Ga ore**

Several rarities occur in small, often only 1 or 2 mm cavities in Ga-Ge ore (gallite-briartite-germanite). Occurrences are rare. These minerals nearly always occur as single crystals in

TABLE 3

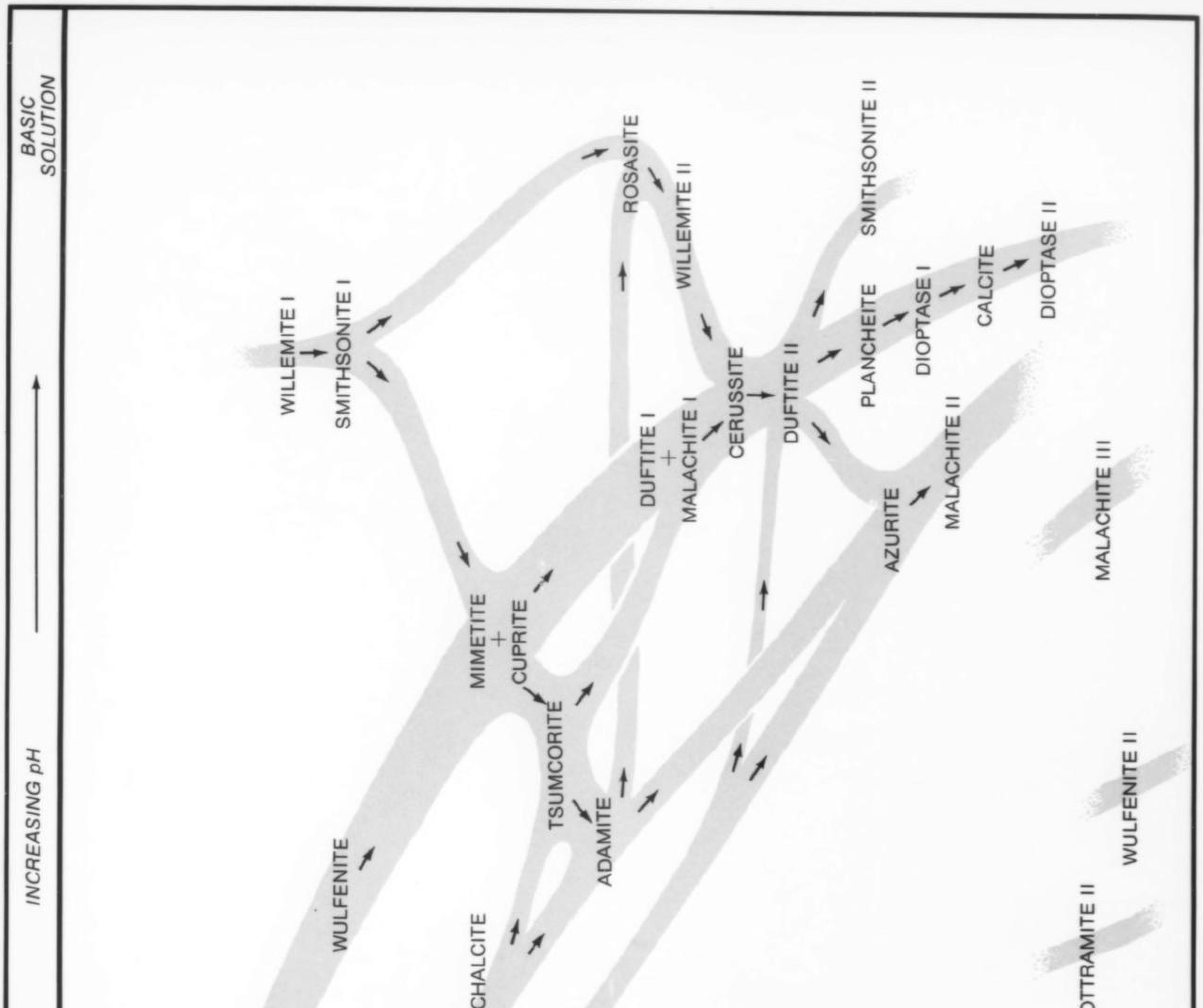

***Table 3.* Sequence of crystallization showing some of the more important secondary minerals at Tsumeb.**

radiating, acicular groups similar in habit, for instance, to **ludlockite** [$\mathbf{(Fe,Pb)As_2O_6}$].

Apparently all of these minerals have very similar conditions of formation. Cavities and minute cracks in the ore have been seen covered by calcite, gypsum, siderite and **thaumasite** [$\mathbf{Ca_3Si(CO_3)(SO_4)(OH)_6 \cdot 12H_2O}$]. The crystals are water-clear along the *c*-axis; they form elongated crystals in radiating groups sprinkled with siderite crystals.

**Schaurteite** [$\mathbf{Ca_3Ge(SO_4)_2(OH)_6 \cdot 3H_2O}$] is found as very fine, felted white needles. In similar cavities near schaurteite a new mineral (**Mineral TI**) was discovered. The crystals are prismatic hexagonal and water-clear. Only Pb and Ge could be detected with the microprobe. Single crystal x-ray studies indicate the following characteristics: $R\bar{3}m$ or $R3m$, $a = 6.07$, $\alpha = 113.8°$. The most important d-values are **5.78** (4), **4.18** (5), **3.38** (6), **2.92** (10) and **2.40** (3).

**Söhngeite** [$\mathbf{Ga(OH)_3}$] occurs in somewhat larger solution cavities. The crystals are white to light brown or green, and are very inconspicuous little grains. Söhngeite associations are siderite crystals with a reddish sheen and a new mineral (**Mineral GF**). Mineral GF forms as yellowish to white scales isomorphic with goethite, and has the composition **GaO(OH)** wherein a small amount of Ga can be replaced by Fe. The cell parameters are somewhat variable depending on the Ga/Fe ratio, but have average values of $a = 4.54$ Å, $b = 9.68$ Å, and $c = 2.99$ Å.

## AGE RELATIONSHIPS AMONG THE SECONDARY MINERALS

When we link together many of the previously described assemblages and sequences a coherent scheme of mineral formation at Tsumeb begins to appear, as diagrammed on table 3. Ground water, which initially dissolved the sulfide minerals and became acidic, precipitated secondary minerals first under acidic conditions. As the acidity was neutralized by various reactions the solutions, with time, became progressively less acidic and deposited minerals stable under progressively higher pH. This general change with time caused the overall trend on table 3 to move from upper left to lower right.

The oldest minerals are the Pb and Fe sulfates and arsenates (beudantite, carminite, scorodite, arsentsumebite and anglesite). They were formed most immediately upon oxidation and dissolution of the primary ore sulfides. The weathering solution was acidic (pH around 4-5) and non-mobile, allowing secondary minerals to form in contact with, or very near to, their parent primary minerals.

All Zn released through weathering and, later, the greater part of the Cu and Pb ions in solution were transported along separate paths by the weathering solution. The Cu-Pb solutions resulted in the main branch of crystallization shown on table 3. The Zn solutions (beginning with willemite I) formed a long, more basic side-branch (on the right), and also a shorter, more acidic path in combination with arsenate ions (on the left).

Along the main branch are wulfenite and then mimetite, the oldest minerals. Both minerals occur, though rarely, as the younger generation with beudantite. The weathering solution here was probably only weakly acid, with a pH of 5.5 to 6.5. Cuprite is of the same age as mimetite.

Where the solution was rich in copper and arsenate ions mimetite altered to duftite I. Sometimes malachite is of the same age as duftite I. Cerussite and a second generation of duftite (duftite II) then formed, doubtless at a pH greater than 6; cerussite is stable at least to a pH of 10.

Beginning at duftite II a split occurs in the main branch of crystallization. Where $CO_3$ ions predominated, azurite and then malachite formed. Where silicate ions predominated, plancheite and dioptase formed. In the most basic branch willemite I and smithsonite I occurred. Both minerals are sometimes older than mimetite because the path of Zn in solution is longer than the path of Pb.

Where mixing of the solutions of the main branch and basic side branch (on the right) occurred, willemite II crystallized and then cerussite, probably at a pH greater than 6, and finally smithsonite II. In place of malachite, rosasite is present, associated with duftite pseudomorphs after mimetite.

Crystallization along the more acid side branch (on the left) began with conichalcite at a pH around 5 and then adamite. A pronounced decrease in acidity at this point, which probably occurred only rarely, led to the formation of rosasite and then willemite II. Mixing of the acidic side branch with the main branch led to the formation of tsumcorite.

Paragenesis I/8 with mottramite and olivenite is difficult to correlate. The same is true for the age relations of dolomite.

Calcite is one of the most recent minerals at Tsumeb. Occasionally one finds dioptase, wulfenite and mottramite of more recent formation than calcite. In all probability these minerals crystallized from new solutions. Several weathering solutions, at differing times and places, could deposit a mineral at differing times, disturbing orderly age relationships.

The youngest minerals undoubtedly include posnjakite, brochantite II, linarite and serpierite. They formed at a pH of 4 to 5 in minute crevices in the ore which were isolated from the main course of solutions.

The role of germanium in the oxidation scheme at Tsumeb has been described in detail by Frondel and Ito (1957).

## ACKNOWLEDGMENTS

I visited the Tsumeb mine during the years 1968, 1970, and 1976. For the friendly reception and support I received from the Tsumeb Corporation Ltd. I would like to thank especially J. P. Ratledge, General Director, and B. H. Geier and B. Schedler, Chief Mineralogists.

In addition to self collected minerals for this investigation I made use of the collection of Walter Kahn, Baiersojen, and several special specimens from the collection of C. Quiet of Tsumeb. I also owe great thanks to these two gentlemen.

I felt most comfortable writing in German, and I therefore wish to thank Paul Seel, of Bala Cynwyd, Pennsylvania, for making this English translation at the request of the editor.

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**(All other references are listed at the end of chapter XII.)**

# VII THE BEST OF TSUMEB

by **Charles L. Key**

Several months ago the editor asked me if I would respond to the question "*Where are the best Tsumeb specimens now?*" with an article for the *Mineralogical Record's* book on Tsumeb. It is a question I trust most readers will understand can only be answered imperfectly at best. Having said that, I submit that what follows will, at least, be devoid of flagrant error. To the extent that I can summon the experience of widely travelled curators, dealers and collectors, and synthesize that into my own experience, I will offer...an opinion.

Quantitatively, nearly all the best Tsumeb specimens are by now in the form of wiring, plumbing, and other mundane copper fabrications. A much smaller quantity no doubt remains under the town of Tsumeb, awaiting an unknown fate. Obviously we can only concern ourselves with that small percentage of superb specimens that survived the explosives, mucking operations, lunch boxes, and prodding indiscretions of idiots, *ad nauseam.* A few qualifications regarding what is "best": for nearly all species listed here, "best" represents a consensus based on the usual criteria of beauty, perfection, *size* and rarity. Typically the smaller the crystal size the greater the quality and perfection, right down to microscopic sizes in most cases; so size does add a dimension to the problem. Furthermore, there are very few species from Tsumeb for which the very best specimen is dramatically better than the next best, although the top ten or so may be very much better than all the rest.

No attempt will be made here to discuss all of the species that occur at Tsumeb (who really cares where the best Tsumeb asbestos is?). Only those Tsumeb specimens that are among the *world's* best for the species, and not just Tsumeb's best, will be covered, and species found only as unspectacular or micromount-size crystals will not be covered. Even with these severe restrictions, an incredible 26 species from Tsumeb still qualify for discussion! I have further constrained the list to specimens that are more or less accessible, and have avoided the murky area of lost specimens, esoteric collections that no one can see, etc.

### THE MINERALS

(Page references are to pages where photos of the specimens are shown.)

**ADAMITE**: This mineral has been found intermittently over the years at Tsumeb, but almost never in exceptional specimens until a few months ago when several superb specimens were recovered: the best is a single bright yellow crystal 1¼ inch in length, with an attached ⅜-inch spray of opaque white smithsonite crystals in the *J. Zweibel* collection, Woodmere, New York.

***CUPROADAMITE*** is a variety of different occurrence from the relatively pure adamite mentioned above. With the exception of several specimens that are nothing but cuproadamite, the others grade insensibly into zincian olivinite, and cannot be distinguished by eye. Most spectacular of the "pure" cuproadamite specimens are examples of two types encountered 3 years ago in an arsenate-rich zone on the 2800-foot level. This vuggy zone in tennantite has produced a plethora of superb arsenates: adamite, olivenite, bayldonite, schultenite, tsumcorite, keyite, duftite, and all gradations between cuproadamite and zincian olivenite. One type of cuproadamite consists of blocky crystals, to 1½ inch, of a dark olive-green color; the best examples are in the *Smithsonian Institution,* Washington, D.C. the *E. Swoboda* Collection, Beverly Hills, California, and the *W. Pinch* collection, Rochester, New York. The finest specimens of the other variety (Pg. 68), characterized by brilliant, prismatic, emerald-green crystals, are in the collections of the *British Museum of Natural History,* London, *J. Zweibel,* and *W. Wilson,* Crofton, Maryland.

**ALAMOSITE:** Less than two dozen specimens are currently known, and most are quite small. The best specimens are in the *British Museum,* a pair of 1½-inch sprays intergrown on matrix, and the collection of *W. Kahn*, Baiersojen, West Germany, a 3-inch spray on matrix (Pg. 58). The grayish white crystals of alamosite are associated with melanotekite.

**ANGELSITE**: Two distinct types occur at Tsumeb. Most well known are the opaque white crystals (with transparent interiors) to 8 inches, resembling huge spear points. Though larger exist, one of the very finest of this type, 4 x 7 inches, is in the collection of *J. Zweibel* (Pg. 70). The larger crystals of this type are almost always broken or badly damaged, but Zweibel's is essentially perfect. The other type of anglesite is much rarer and smaller, but drastically more attractive; it is epitomized by a 2 x 2½-inch cluster of brilliant, transparent, near flawless yellow crystals in the *British Museum.* A similar, larger, though not as bright crystal group is (in storage) in the *Smithsonian* (Pg. 69).

**ARAGONITE**: Two varieties of this mineral reach their zenith at Tsumeb: tarnowitzite and nicholsonite, the Pb and Zn varieties. Light blue divergent clusters of cupriferous (?) aragonite to 3 x 7 inches are standards for the world as well. *A. Buranek,* Salt Lake City, Utah, and the *Smithsonian* each have a fine example of the blue type. Superb nicholsonite specimens can be found in the *Smithsonian* (Pg. 61), *Harvard University,* Cambridge, Massachusetts and the *American Museum of Natural History* in New York City. Excellent tarnowitzite is in the *W. Kahn* collection, the *S. Pieters* collection, Windhoek, Southwest Africa, and *Havard.*

**AZURITE:** Best specimen: a 10 x 10-inch group of undamaged, brilliant (although very dusty) crystals to 5 inches each, both singly and doubly terminated, in the general offices of *Newmont Mines*(part owner of Tsumeb), at 300 Park Avenue, New York City. There are also several incredible azurites in the *Smithsonian,* including possibly the largest bright crystal (most of the big crystals are not very bright) which measures 3 x 6 inches. A superbly aesthetic specimen of bright prisms on a 4 x 7-inch matrix is in the collection of *E. DeRouve,* Paris. A 7 x 8-inch cluster of crystals to 3½ inches is in the *Canadian National Museum*, Ottawa. Excellent cabinet specimens exist in the collections of *A. Buranek*, *R. Kosnar*, Boulder, Colorado, *J. Zweibel*, *J. Barlow,* Appleton, Wisconsin, and *Harvard.*

I'm convinced there are no more than 50 great azurite specimens extant in all the mineral collections of the world. It is a very rare mineral in superb specimens. There are perhaps several thousand good azurite specimens that have been saved over the years but large, bright, perfect crystals or crystal groups number only a few. It has been my experience that most mineral collectors, particularly North Americans, have unrealistically high standards for acquisitions of azurite, as well as many other Tsumeb species; this has been caused by the remarkably large number of superb Tsumeb specimens in American museums, which deceptively suggests that many more must be available, possibly in Germany or Africa. Not true!

As it happened, the U.S. was about the only place to sell mineral specimens both times Tsumeb was producing oxidation zone minerals. This is not to say that there aren't some excellent specimens in Germany and the Republic of South Africa (because of German control of Tsumeb for many years, and South African control since 1920), but nowhere near the quantity or quality one might expect remains in these countries. The Smithsonian and Harvard each have many more superb Tsumeb azurite specimens than any other museum collection in the world.

**BAYLDONITE**: The finest large crystals of bayldonite ever found anywhere are associated with the arsenate zone described above (under adamite) and are invariably implanted on the dark, blocky cuproadamites.They are doubly terminated, nearly ½-inch crystals, very brilliant, and of a deep greenish black color. The top specimens are groups to 3 x 5 inches in the *Smithsonian, E. Swoboda* and *W. Pinch* collections.

**BEUDANTITE:** The best specimen is probably a 1½ x 2⅜x 2¾-inch group of olive-green crystals to ¼ inch, associated with minor carminite, in the *Smithsonian* collection (but part of the *J. J. Trelawney* collection acquired by, but not yet delivered to, the Smithsonian).

**CALCITE**: Many specimens could compete for the best calcite, as this is the most abundant beautiful mineral at Tsumeb. It occurs in many forms, though exceedingly sharp rhombs are the most common habit. It can be flawlessly transparent to opaque, and is usually colorless although color can vary through shades of red and brown. It is found in crystals up to 6 inches in size and occurs associated with everything at Tsumeb except the arsenates. Three of the most spectacular calcites are in the collections of *Abel Selburn*, Detroit, Michigan, and *J. Zweibel* (Pg. 66). A rare and beautiful calcite from Tsumeb is a 2½-inch rhomb of distinctly *purple* color, on matrix, in the *P. Bancroft* collection. Other excellent calcite specimens are on display in the *British Museum*, the *American Museum*, and probably countless private collections.

**CARMINITE**: The best specimen is in the *British Museum*; it consists of brush-like groups of acicular, carmine-red crystals to over ¼ inch on a beudantite crystal matrix of about 1 x 2 inches.

**CERUSSITE:** Best specimen: a 7 x 10-inch cluster of perfectly undamaged, lustrous, reticulated crystals without matrix, weighing perhaps 65 pounds, in the collection of *S. Pieters*. In the same class is a very similar, 12-inch, reticulated group on matrix, in the *Sorbonne*, Paris (Pg. 64). Beyond those specimens, which surmount all others through their remarkable size, it becomes all but impossible to segregate a few "best" cerussite specimens, as there are so many superb and varied pieces to choose from. One could mention the 5-inch "snowflake" reticulated group at *Harvard*, the bright, flawless gem crystals to 6 inches in the *Royal Ontario Museum*, 3-inch sixlings on native copper in the *British Museum of Natural History*, "fish-tail" twins to 8 inches in the *Hellinghausen* collection, Tsumeb, and 4-inch, zoned crystals imbedded in clear gypsum in the *American Museum*. One could go on. Suffice to say that all of the great mineral museums have great cerusssite specimens. They tend to be considerably rarer in private hands, I suspect, because of their large size and excessive fragility.

**CHALCOCITE:** Only one genuine chalcocite in good crystals is known to me as of this writing; a cluster of 1-inch, sharp, dull-black crystals which happen to form the matrix for a superb group of 2-inch azurite crystals in the *Canadian National Museum*. Other so-called chalcocite, in small, bright, twinned crystals from recent workings in the deeper levels, has proven to be digenite.

**CUPRITE**: Good crystal specimens of cuprite from Tsumeb are quite rare, while massive cuprite is abundant. It can be argued that cuprite from several other localities is as good as or better than Tsumeb cuprite, but Tsumeb specimens are still superb at their best. The finest example is probably at *Harvard*; it consists of a group of superb, dark red crystals to ¾ inch each on native copper crystals. Extraordinary, bright red octahedra on matrix in the collections of *Wolf Scholssen* (formerly from Germany, now in Iran) and *R. Kosnar* (Pg. 73) are also among the very best.

**DIOPTASE**: The best cabinet specimen is in the collection of *S. Pieters*. This is a 5-inch mound of intergrown crystals to nearly 2 inches, implanted on a 6 x 12-inch slab of matrix coated by a druse of white calcite. Two other specimens, much smaller but perhaps more perfect and desirable, came from the same pocket in 1975 (on the 3300-foot level). Both of these have superb, gemmy cerussite crystals implanted on the dioptase crystals, which in turn are implanted on white calcite crystals. One is in the collection of *J. Zweibel* and the other is in the *British Museum* (not on public display). These have to be the world's finest dioptase specimens, even though somewhat larger crystals were once found in the Republic of the Congo.

**LEADHILLITE**: Leadhillite is exceedingly rare at Tsumeb, but some Tsumeb crystals rank as the largest leadhillites known. Two specimens stand out as being better than the perhaps two dozen other known Tsumeb leadhillite specimens. One is a very sharp, gray euhedron measuring 1½ x 1½ x 2½ inches, in the collection of *W. Larson*. The other specimen is a cluster of intergrown crystals in the *Canadian National Museum*; it measures about 3 x 4 inches, has no matrix, a good luster, and a tan to sienna color; it is quite translucent.

**LUDLOCKITE**: The best specimen is a 1¾ x 1½ x ⅝-inch group of divergent red sprays on matrix in the collection of *Roger Williams*, the pianist, Encino, California. Three other excellent specimens are in the collections of the *British Museum* (Pg. 75), *E. Swoboda* and *K. Proctor*, Colorado Springs, Colorado.

**MALACHITE**: Several types occur, but by far the most coveted are the incredible clusters of pseudomorphs after azurite. Unexcelled for sharpness and form is the 6 x 7-inch group on display in the *Smithsonian*. A superb group of crystals to 5 inches on matrix is in the collection of *W. Kahn*. These are unusual because many of the other larger malachite pseudomorphs tend to be quite corroded and lack sharp definition. Brilliant, sharp, rhombic crystals to ½ inch solidly lining vugs in chalcocite were found in the deeper workings; two of the best are in the *British Museum* and *Harvard*. Rarely encountered are spherical aggregates, to 2 inches, of velvet malachite implanted on snow-white calcite crystals, with a "dusting" of small, gemmy dioptase crystals, as in the *Key* collection.

**MIMETITE:** Clearly the finest mimetite specimens from Tsumeb or anywhere else were found in 1971 in the deeper workings, and were limited to a few dozen specimens. The best is a group of superb, transparent, billiant, yellow crystals on matrix, the largest of which is 2 inches tall and doubly terminated, in the collection of *K. Proctor*, Colorado Springs, Colorado (Pg. 62). Other specimens have somewhat smaller crystals, but are no less beautiful. The largest single crystal known is 2 inches in length by a *inch* in diameter, and is in the collection of *E. Swoboda*. Superb specimens exist in the *Smithsonian*, (back cover painting), *Harvard*, the *American Museum*, the *British Museum*, and in the collection of *Gerhard Becker*, Idar-Oberstein, West Germany (front cover photo). If it had not been for this spectacular find, the best mimetite would still have been from Tsumeb, but would be quite different in appearance: sheaf-like aggregates of yellow to orange crystals to 1½ inches, but rarely more than translucent. A superb, large matrix piece of this type is in the collection of *A. Buraneck.* A steep, pyramidal, caramel-colored single crystal 2 inches in length, in the *British Museum,* is also quite spectacular.

**OLIVENITE:** About 4 years ago three specimens were brought into the U.S. that are probably the finest olivenite specimens ever found anywhere. They consist of brilliant, equant, greenish-black crystals lining vugs in massive chalcocite. The crystals were up to ⅜-inch size. The best of these three pieces is a 6½ x 7-inch matrix piece in the *Smithsonian*, it is closely rivalled by slightly smaller pieces in the *A. Buranek* collection and in the *American Museum*. Thin prisms to nearly 2 inches have been found rarely; one of the best is in the *British Museum.* A spectacular miniature with a perfect ½ x ⅞-inch crystal in the *W. Pinch* collection must rank with the finest olivenite specimens.

**SCHULTENITE**: The best specimens are glassy prisms to 1½ inch that look very much like cerussite, and were found in the arsenate pocket described under adamite above. The best of these are in the *British Museum, W. Pinch, Canadian National Museum* and the *Carlton Davis* (Columbus, Ohio) collections.

**SCORODITE**: Scorodite is very rare at Tsumeb but occasionally appears in excellent quality. The finest specimen consists of dark, richly-colored, greenish blue crystals to over 2 inches covering a 5 x 7-inch matrix, in the collection of *H. Von Osterstasen,* near Capetown, South Africa. A superb, lustrous, pseudo-octahedral crystal measuring nearly an inch is in the collection of *W. Kahn*, and a similar crystal of a more bladed habit is in the collection of *J. Zweibel* (Pg. 59). Excellent although less well-formed and less lustrous crystals to more than an inch are in the *Smithsonian* and *W. Pinch* collections. Some scorodite is accompanied by small, orange, tabular crystals to 2 mm that could be mistaken for wulfenite, but are actually powellite.

**SMITHSONITE**: This mineral occurs in so many bright, distinctive colors at Tsumeb that specimens must be considered separately according to color, just as one might separate rose quartz from amethyst or smoky quartz. **Deep pink to light rose** colored crystals are perhaps the most desirable; these were found only once, although in moderate abundance, in the lower oxidation zone about 9 years ago. There are four specimens of this kind that can safely be called the best. They are intergrown crusts of ¾-inch rhombs and modified rhombs on matrices up to 6 x 12 inches, in the collections of the *Smithsonian,* the *British Museum, E. Swoboda,* and *S. Singer,* New York City. A unique **pale pink** specimen of 1-inch scalenohedrons covering a 5 x 7-inch matrix is in the collection of *J. Zweibel.* **Green** smithsonite from Tsumeb came in all shades. Early, upper level finds were almost never in distinct crystals; they are typified by oil-green, apple-green, and light emerald-green botryoidal masses on display at *Harvard* and the *Smithsonian.* Stunning, deep green specimens of modified rhombs to ¾ inch on matrix are in the collections of *J. Zweibel* (Pg. 76) and *W. Larson,* Fallbrook, California. An apparently unique group of superb, curved rhombs of a rich **turquoise-blue** color on a contrasting white matrix is in the collection of *J. Zweibel* (Pg. 76). A choice crystal of **yellow** smithsonite, 1½ x 2¼ inches, is in the collection of *R. Webster.* **Colorless** smithsonite has been found in large rhombs and steep schalenohedrons flawless enough to facet. A superb group of colorless crystals to 1 inch is in the collection of *J. Rousseau,* Johannesburg, South Africa, and 2-inch scalenohedra are in the *American Museum* collection. Innumerable tan, brown, gray and black smithsonites exist but they are far less desirable because of their colors.

**SÖHNGEITE**: The best specimen is a pair of ¼-inch twinned crystals of greenish color on a vuggy matrix in the *British Museum* (Pg. 61). A similar but smaller specimen is in the collection of *J. Douglas Scott,* Kingston, Ontario.

**STOTTITE**: The best specimen is a plum-colored crystal which is slightly over ⅜ inch, on matrix, in the collection of *E. Swoboda.*

**TENNANTITE**: One of the most abundant minerals at Tsumeb, and one quite often found in crystals (although most are crude and dull) is tennantite. Among the best is the *Harvard* specimen, with crystals to 5 inches across a face. The largest matrix group consists of sharp crystals to 2 inches on an 8 x 8-inch plate of quartz and massive tennantite in the *Humbolt Universtiy* collection, East Berlin. A superb cabinet specimen with bright, sharp crystals to 1½ inches on a 3-inch matrix is in the *W. Larson* collection (Pg. 115).

**WILLEMITE**: The most beautiful specimens of willemite are lustrous, blue, translucent, botryoidal masses scattered among snow-white calcite on specimens up to 4 x 7 inches, as in the *A. Buranek* and *Smithsonian* collections. Smaller and much rarer are the sulfur-yellow crystal aggregates to 2 x 4 inches. Two specimens of *royal blue* crystals to 3/16-inch, with rosasite, on matrix, are in the *British Museum.*

**WULFENITE**: A variety of colors occurs at Tsumeb, although because bright red crystals have not yet been found, some people will argue that the Red Cloud mine in Arizona is still the source of the *world's* finest wulfenite. Brilliant sulfur-yellow crystals to 1½ inches and ¼ inch thick are in the collection of *E. DeRouve,* along with a large matrix piece about 4 x 7 inches covered by ¾-inch crystals. A superb 2-inch yellow crystal, nearly an inch thick, on a 3 x 4-inch matrix, is in the *Smithsonian.* Not as beautiful but impressive for size are the huge, gray-brown crystals that often have facetably clear areas within; the largest of this type is in the *Canadian National Museum,* and is nearly 3½ inches across the face and nearly an inch thick. A similar, slightly thinner crystal is in the *J. Zweibel* collection (Pg. 81). A great mass of intergrown, caramel-colored wulfenite crystals was encountered about 8 years ago, in association with mimetite and cerussite. These reached the astounding size of 2 *feet* in diameter, but they were so thin and fragile that damage was severe; a sample from this occurrence is on display in the *American Museum.* Another pocket once produced some fine crystals, rarely over ½ inch, of a beautiful reddish-golden sherry color; possibly the best of these is, a 3-inch group on matrix, is in the *Smithsonian* (Pg. 81).

## SOME FINAL COMMENTS

A listing such as this must, of necessity, contain omissions. There are a great many remarkable "association" pieces, for instance, that wouldn't make "best" for any one species but when taken together constitute exceedingly beautiful and valuable specimens. Also, there must certainly be fine pieces which I have yet to see, or which I have forgotten I have seen, which are not included; my apologies to their owners. And, like Peter Bancroft's book, *the World's Finest Minerals and Crystals,* this listing is doomed, by new discoveries, to some degree of obsolescence even before it reaches print. When mining at Tsumeb gets to the stage of "robbing the pillars" in the oxidized zones, which could happen soon, who knows what glorious masterpieces will appear? Is it too much to hope that this listing *is* soon rendered obsolete by even greater treasures discovered in the world's greatest mineral locality?

# VIII KEGEL COLLECTION

by
John Sampson White

In 1949 the curators of the mineral collection at the National Museum of Natural History, Smithsonian Institution, received a letter from Ernst Wohlgemuth of Switzerland. It said, in part: "The late Mr. F. W. Kegel, a national of South Africa and British subject, resident in Switzerland since 1932, has passed away on 8th August 1948. He left his entire estate to his wife, Mrs. Th. Kegel, who continues living at 'Bodanswart,' Landschlacht. Amongst certain possessions Mrs. Kegel has now decided to sell is a *complete and unique collection of Tsumeb Minerals.*

"The late Mr. F. W. Kegel had collected these minerals while he was Managing Director of OMEG, Otavi Minen- und Eisenbahngesellschaft, at Tsumeb, S.W.A., and brought them to Switzerland in 1932. I have been entrusted by Mrs. Th. Kegel with the sale of this collection. By ordinary Sea Mail I forward to you, registered, a complete catalogue of all pieces in the collection. You will judge by these lists that this collection would, for anyone interested, be a most valuable object to acquire."

Fortunately for the Smithsonian, Dr. Mark C. Bandy, a good friend of the curators William Foshag and George Switzer, was at the time stationed in Paris in the Strategic Materials Section of the Economic Cooperation Administration (see *M. R.* **4**; 277-281, 1973). Bandy agreed to visit Mrs. Kegel and look over the collection. This he did, and reported that the collection had a value of about $5,500 but suggested offering $4,000 F.O.B. coastal port, to the owner, or $3,800 F.O.B. Landschlacht, Switzerland. The total weight of the collection was judged by Bandy to be about 1½ to 1¾ tons. There were about 820 labeled specimens, and about 100 small crystals and 7 large specimens. Bandy's comments about the collection included the following:

"There is so much duplication that it would be useless to try to list the specimens with any degree of completeness. Some of the specimens are more or less mis-identified (or I am wrong). Unfortunately the two outstanding cerussites are broken. They are repaired but the glue has come unfastened and would have to be done over again. I don't know what they are worth. #1 is 4" x 6" x ¾. No. 2 is about 3" x 3½" x ½". I am sure they could be repaired so that they would not be obvious but they are still repaired specimens. I valued #1 @ $200, #2 @ $100. There are others. There are two to three rough tabular single xls similar in finish to the large triangular twin you have; one is 1½ " x 3" x ⅜" thick. There are a number of good specimens with reticulated crystals on matrix and one large, roughly triangular reticulated mass about 3" by 1" thick that is good if not superior. A large quantity of small xls.

"**Azurites** were a bit disappointing to me. There are six matrix specimens of good quality with fine blue crystals but not of unusual size, say the largest xl would be 1½" long as an average. Some are 10" specimens. #436 is a single xl made up of two crystals at the termination, it is 8" long, 5" wide and 1" thick. Unfortunately it is spotted with malachite alteration. #437 is a single xl 6" x 2½ " x ½ " with 90% of the surface malachite. They are not bruised and the first I valued at $200, the second at $100. There are a number of loose not bruised pure azurite xls up to 2½ " x 2". There is a large specimen 10" x 10" with 6" platy xls which ran from one wall of a vein to the other, a good specimen in any collection except the U.S.N.M. This had no number and I don't know if it is in the catalog or not.

"**Tetrahedrite** there is one specimen #428, 12" x 12" with a 6" tetrahedron of what they call tetrahedrite but it is badly altered to a dark green surface. Mrs. Kegel said that men who came to Tsumeb and tried to purchase the collection there from Kegel always wanted to buy that specimen and the two azurite xls.

"**Cassiterite**. #268 is a surprising xl, 4", not bruised, prismatic but not well developed on the back side and attached at one end or rather broken from the matrix, brown in color and translucent, brilliant. I would say that $100 would be cheap for the crystal. (This specimen is not from Tsumeb, but is from a nearby locality. J.S.W.)

"**Smithsonite** A great duplication of drusy, green, large specimens in excellent preservation. One is 14" x 16". There must be 20 superior specimens of this mineral.

"**Malachites** are generally dull and uninspiring.

"**Mimetite**. There are at least 5 superior specimens of light yellow material. There is one large slightly bruised specimen 15" x 20" x 4" with xls to 3/16" diameter..."

Not surprisingly the second figure ($3,800) was offered and the offer accepted. The collection, according to Bandy, "has been offered to others but there was no interest in Switzerland for lack of money and the British Museum can't get money out of England to purchase it."

An interesting sidelight in Bandy's letter of 1949—"Recently Mason from Indiana University was here (he is a New Zealander who teaches mineralogy there) and I enjoyed a visit with him." Brian Mason subsequently joined the staff at the Smithsonian after having been curator of mineralogy at the American Museum of Natural History in New York City.

Bandy agreed to go to Switzerland and pack the collection in February 1950. He noted the absence of a number of specimens listed in the catalogue. "In talking with the Wohlgemuths I found that it had been a practice of both Mr. and Mrs. Kegel to offer specimens to friends and allowing them to take their choice. This cleared up the missing specimens." Bandy suggested that the museum negotiate a readjustment of the purchase price to the extent of 10% of the amount originally offered. This was agreed upon by Wohlgemuth, so the collection was ultimately purchased for $3,420. The money that was used to purchase the collection came out of the Roebling endowment so now, technically, the Kegel Collection is part of the W. A. Roebling Collection in the Smithsonian.

From just about any viewpoint the purchase was one of the best that the Museum has ever made. There are approximately 38 specimens from the Kegel collection now on exhibit in the Mineral Hall. Of the 26 large specimens in the special Tsumeb Minerals case, all but seven are from the Kegel Collection. There are, of course, azurites and smithsonites, but there are also anglesite, descloizites, malachites, cerussites, an olivenite, a bayldonite, a mimetite, a gigantic vanadinite from Abenab and a dioptase from Guchab. In addition, there are hundreds of specimens in the reference mineral collection, and probably hundreds more in the ore study collection. The great variety of associations and the diversity of habit and form is perhaps unparalleled in any Tsumeb collection ever assembled.

The paths of many mineralogists have crossed over Tsumeb, and for a few the interactions have been preserved. Samuel G. Gordon, an American collector and mineralogist, visited Tsumeb in 1929 while on a collecting trip for the Philadelphia Academy of Science. He recorded his experiences, including his meeting with Kegel, in letters to his friend Harry Trudell of Philadelphia. The letters provide a rare glimpse into Tsumeb collecting and buying, and the character of Kegel himself. The first of the following letters was reprinted in the *Mineralogical Record* (vo. 5, no. 6, p. 259, 1974) in a series on Sam Gordon, but it bears repeating here.

From Gordon's letter to Trudell, 11 December 1929:

"It was three days and nights to Tsumeb. The best scenery, that near Capetown, was passed during the night. Most of the trip was along the edge of Bechuanaland, particularly along the Kalahari Desert.

"I got to Tsumeb late on Sunday night. The climate is comfortable, quite warm in the sun in the day, but real cool at night. It is about 5000 feet above sea level. The mine is worked as an open cut down to about 100 feet, and thence to a depth of 1800 feet by underground workings. I was told that the upper levels were exhausted and these were the ones which contained all the azurite, cerussite, etc. crystals. That I should have come 15 years ago. Further that some gentlemen visiting the Geological Congress in South Africa had come up in September including one Dr. L. J. Spencer, of the British Museum. So it did not sound as though I was going to be able to gather much at the mine. As I did not expect much in the way of assistance, I had pinned my hopes on the 'silver pick' and was well provided with good pound notes Sterling for the operations.......

"On Monday morning, early, I went around to the office of the company. I found the manager away for a couple of days. However, his assistant or secretary introduced me to the mines superintendent, and arranged for going down the hole. However, I spent Monday going over the dumps and ore piles which contained some smithsonite crystals.

"Tuesday was the first day in the mine. And what a day! Hectic? A few more days like that and I'll be down with nervous prostration. Remember that I did not expect to collect anything, with all the German bosses ready to clean out any crystals and ship them to Maucher in Munich. And that I had expected to get everything with a 'silver pick,' and then perhaps not much.

"In company with the superintendent I went down to the 800 foot level, the uppermost being worked, and pretty deep for crystallized secondary minerals. The workings are of such a nature that only a half dozen places of about 10 ft. square are visible on any level. The first few looked most unpromising. But one of the miners said there was a little azurite showing up above. I climbed up and saw some poor battered crystals, and thought that a little work might produce at least something to show for the trip. The shift boss tried to get me away from the place, but I had the superintendent sit on him.

"The latter, of course, did not expect me to find anything and went off. I got to work in the wall, and cut all around the place where the azurite showing was, and had the extraordinary fortune of busting into a beautiful pocket of azurite crystals up to 6 inches long, and three inches across: one of the prettiest sights you ever saw. I worked slowly and carefully. The mine is very hot and damp, and I nearly drowned in my own perspiration. The air up in the hole would get foul and hot from the lamp and every half hour I had to climb down and lie on the dirt pile from exhaustion. News of the find spread around and at 11:30 the superintendent and his assistant came around. I had already packed away in my bag the best specimens, but the vug continued into a cylindrical vug, lined with smaller crystals. The assistant who came up first, tried to break off some crystals, but I pulled his hand away. He tried all sorts of subterfuges to get into the place. Then the superintendent came up, looked in and became incoherent. All he could say was 'I have been here fourteen years, and never have I seen such crystals.' The best, I had in my bag. He left the shift boss to guard the place, and later sent the assistant down to open it up further. In the afternoon, when I went down again, I found that they had created havoc, just ripped everything out with dynamite and hammers, nearly everything coming out broken. Everybody seemed to be scrambling in trying to get some crystals; particularly since big ones sell for about $100.

"When I got out, I was told that the mine manager (F. W. Kegel), who was also a director, was back, and wanted to see me and the specimens. These were all carted to his office. He seemed all excited, walked around in circles, and asked me what I wanted. I told him that I wanted to ship off the specimens I had collected. He said that was absolutely impossible. Pleasant words after I had sweated all day gathering them. He said that their value was extraordinary and that they had none in the office in Berlin, or the German universities, and how therefore could he let me have them. He had up to this time not seen the specimens, they were being unpacked. He happens to be something of a collector, and naturally did not want any one to cart off the stuff from his mine. He was quite beside himself. I suggested cabling Berlin, but he stated that if I did that, he would also. As a matter of fact, I am sure that they would have upheld him, certainly they would not cross a fellow-director, particularly the mine manager. By this time the specimens were unpacked, and he walked over to them. Apparently they exceeded even his expectations. The superintendent kept muttering 'I have been here 14 years, and never have I seen such crystals.' I was too tired to be obstreperous and hence tried diplomacy. It seemed almost impossible to reason with him, but by appearing magnanimous and appealing to his eagerness to get hold of the specimens, I got him to agree to divide the specimens equally, each of us taking a choice alternately. Certainly under the circumstances I could not hope for more than an equal half of the finds. He could just as easily have taken them all, or perhaps made a generous gesture after picking out the best and giving me the junk.

"At my suggestion we pitched a coin to see who would take first choice as I thought this might give me a look-in on the first specimen. But he won. The division proceeded slowly. While I would be looking them over he would walk over to those he had acquired and then at my specimens. But he became quite happy and after the division, we shook hands and I made arrangements to go through the mine and divide the finds similarly. However, I did not expect to get anything more in the mines, the men were too secretive and would steer me past and well around possible places.

"If I had acted differently, I would have lost everything, now I had a good half, (specimens I had come prepared to pay handsomely for) so could stay longer and gather more if the opportunity presented itself. So while I feel outraged, it might have been far worse. However, what I have will look good back in Philadelphia. They are certainly marvelous specimens. And

**Herr F. W. Kegel, General Manager of the O.M.E.G. 1922-1938.**

finding a vug the first day in the mine, of such extraordinary crystals, particularly below the levels of such things, happens once in a long time.

"This morning I went back to the place, having been greeted by the superintendent with the words 'I have been here 14 years, and never have I seen such crystals'

Gordon continued his narrative to Trudell in his letter of 23 December 1929:

"Further visits to the mine produced but some crystals of cerussite. Further work at the azurite place, which looked worked out, was pronounced 'dangerous' by the mine superintendent, as it was two meters below the fill of the seventh level, beneath which no azurites had been found. As a matter of fact, I had not expected to be able to do much more in this mine, particularly after the manager, during his heated frame of mind, revealed that it was only the dumb stupidity of Herr Keller that enabled me to find anything, that he should not have taken me to a place of promise. As a matter of fact Herr Keller was not to blame—at the time Keller and the superintendent stated that they did not believe there was anything to be found where I had started working.

"I soon got busy with the silver pick, to get such specimens as had been bootlegged from the mine. I got hold of the names of miners who might have specimens, and with one of these I went around to the others at night. In the darkness I would slip into the house. The owner would carefully draw the curtains, then request absolute secrecy on my part. This would be followed by the business of removing carpet, and pulling up a board in the floor and removing sundry broken azurites, etc. concealed therein. In all I purchased over $900 worth of specimens (which is what I paid). So that I was able to ship 12 cases from Tsumeb weighing in all over 500 pounds.

"I was much amused at the casual visit of the manager (Kegel) while I was packing; he drifting into my room with his secretary and hotel manager with the excuse that he was inspecting the hotel—the hotel belonging to the mining company. I suppose he had been told of the great quantities of specimens I had been carrying in at nights, usually having had two niggers to carry the stuff. Most of the specimens were stowed away in bureau drawers, etc., so he did not see much. He afterwards asserted that I had gotten the best in the division."

The specimens Sam Gordon obtained became part of the collections of George Vaux and the Philadelphia Academy of Science; Gordon would doubtless have been less outraged had he known that those specimens which Kegel kept would eventually become part of the collection of the Smithsonian Institution.

As a tribute to Friedrich Wilhelm Kegel, Tsumeb mine manager from 1922 to 1938, the mineral kegelite was recently named in his honor. Many Smithsonian labels for his specimens retain the "Kegel no.", his own catalogue number. It is safe to say that Kegel's name will always be associated in a significant way with the mineral collecting and mining history of Tsumeb.

Specimen acquisition by outsiders in Tsumeb continues today in nearly exactly the same fashion as it did for Gordon in 1929. Minerals and money exchange hands secretly between dealers and miners; mine management seeks diligently to stop the trade and to identify those responsible for "stealing from the mine." The Tsumeb Corporation nevertheless is accomodating to mineralogists and still does allow the removal of specimens for study purposes. Considering Gordon's description of the way miners drop everything to collect when crystals appear, it is easy to understand why the mine management is concerned about the resulting loss of work time and other problems. The best that can be hoped for, in the long run, is that more minerals of the calibre of those in the Kegel collection will be preserved by whatever means.

# IX SID PIETERS: A PERSONALITY SKETCH

by

**Charles L. Key**

Tsumeb, Berg Aukus, Otavi, Karibib, Spitzkopje, Usakos, all names that conjure up visions of superb minerals and gems. Sidney Pieters is the man who transformed those visions into reality. His name is nearly synonymous with Southwest African minerals, as he has been prospecting, mining, collecting, cutting, buying and selling the fabulous mineral treasure from this territory for over 35 years. Sid was born into mining; his father was mining tin as early as 1920 all along the Erongo Flats and had established such mines as the Ariakos, the Sydney mine, and Pieters Hill. The tin ore there was in pegmatites and not infrequently associated with gem minerals such as beryl, topaz and tourmaline. Sid was particularly attracted to the beautifully colored tourmalines, and his life took an early turn toward commercially exploiting these gems when he established the first mineral and gem store in all of southern Africa. That was in 1945, in the small town of Usakos, and it was known simply as the "Usakos Gem Store."

Years later Sid moved to Windhoek, the capital of the territory, where he now resides with his lovely wife, Val, and numerous pets (including an African grey parrot that must be heard to be believed). His children have all grown and gone their way, providing him with several grandchildren and a fine family. Sid owns and operates the "House of Gems," a retail establishment in downtown Windhoek where he sells the wide variety of minerals and gems he acquires, as well as finished jewelry. He has cutters from Idar-Oberstein working full-time on the premises fashioning the tourmalines which he mines mostly for an appreciative local market. It is worth noting that while Southwest Africa is not the prolific producer of tourmaline that Brazil is, Southwest African tourmalines, at their best, are unrivaled for color.

Over a period of many years and many trips to Southwest Africa I've come to know and admire Sidney Pieters; he is one of those very rare individuals who set out, without benefit of blueprint or mentor, to make a success from a passion, and did so beyond all question. In the process many museums and collectors have been enriched by the staggering array of his mineral and gem finds. Perhaps Sid is most widely known for the amazing quantity of superb Tsumeb material he has made available over the years. He has most certainly had more "one of a kind" Tsumeb specimens pass through his hands than any man alive. Many specimens of mimetite, leadhillite, smithsonite, azurite, malachite, cerussite, many of the arsenates, and rarities such as söhngeite and stottite come to mind.

While output from Tsumeb has currently slowed to a mere trickle of dioptase, Sid has shifted his efforts to greener pastures. While he continues to mine tourmaline in the Karibib area (the Neu-Schwaben mine) he has extended his mining activities to the Swakop area where he has had stunning success.

A summation of Sid's successes "by the species" would be ponderous indeed. But here are just a few of the significant mineral finds he has made: cuprite from the Onganja mine—he did all the research and development there and got the first specimens; chalcocite crystals from the Kahn mine; boltwoodite crystals from Arandis; he was, more than anyone else, responsible for an amazing quantity of descloizite and smithsonite specimens from Berg Aukus; the superb, though now virtually extinct, cutting material known everywhere in lapidary circles as "pietersite" (a form of blue, gold and black, silicified, very chatoyant riebeckite. The list goes on, but more noteworthy is the fact that it will probably go on for many years... Sid's energy and craft seem still to be on the ascent.

Sid has traveled widely through Europe and the Orient in conjunction with his business, and made his first visit to the U.S. in February 1977 to attend the Tucson Gem and Mineral show.

Sidney Pieters, the mineral world is indebted to your success.

X

# FOLIO: TSUMEB!

A PHOTOGRAPHIC STUDY
OF 122 SPECIMENS REPRESENTING
81 MINERAL SPECIES FROM TSUMEB

## THE PHOTOGRAPHERS:

NELLY BARIAND
HENRY BUCKLEY
FRANK GREENAWAY
PAT HATHAWAY
RICHARD HAUG
BOB JONES
RICHARD KOSNAR
WERNER LIEBER
OLAF MEDENBACH
ERIC OFFERMANN
DWIGHT WEBER
JULIUS WEBER
WENDELL WILSON

## COLLECTIONS

of the following people and institutions are represented in the following pages. The collectors and curators have our sincere thanks for allowing us to enhance this issue with photos of their specimens.

**Wolfgang Bartelke**, Wiesbaden, West Germany
**Bonn Institut für Mineralogie**, Bonn, West Germany
**British Museum (Natural History)**, London, England
**Tom Gressman**, Delafield, Wisconsin
**Richard Haug**, Esslingen, West Germany
**Gertrude Hauser**, Cincinnati, Ohio
**E. Heinrich**, Johannesburg, South Africa
**Walter Kahn**, Baiersoier, West Germany
**Gunther Keller**, Bettingen, Switzerland
**Richard Kosnar**, Boulder, Colorado
**Werner Lieber**, Heidelberg, West Germany
**Olaf Medenbach**, Bochum-Querenberg, West Germany
**Eric Offermann**, Arlesheim, Switzerland
**Paul Patchick**, Pacific Grove, California
**Keith Proctor**, Colorado Springs, Colorado
**Sorbonne (University of Paris)**, Paris, France
**Hugo Strunz**, Berlin, Germany
**Technical University of Berlin**, Berlin, Germany
**John Tetrick**, Minneapolis, Minnesota
**United States National Museum of Natural History (U.S.N.M.)**, **Smithsonian Institution**, Washington, D.C.
**Dwight Weber**, Hawthorne, California
**Julius Weber**, Mamaroneck, New York
**Miriam and Julius Zweibel**, Woodmere, New York

**CORONADITE**
Color: black. Size: 3.3 cm across
Collection of Wolfgang Bartelke
Photo by O. M.

**ATACAMITE**
Color: dark green. Size of crystal: 9 mm tall
Collection of Hugo Strunz
Photo by O. M.

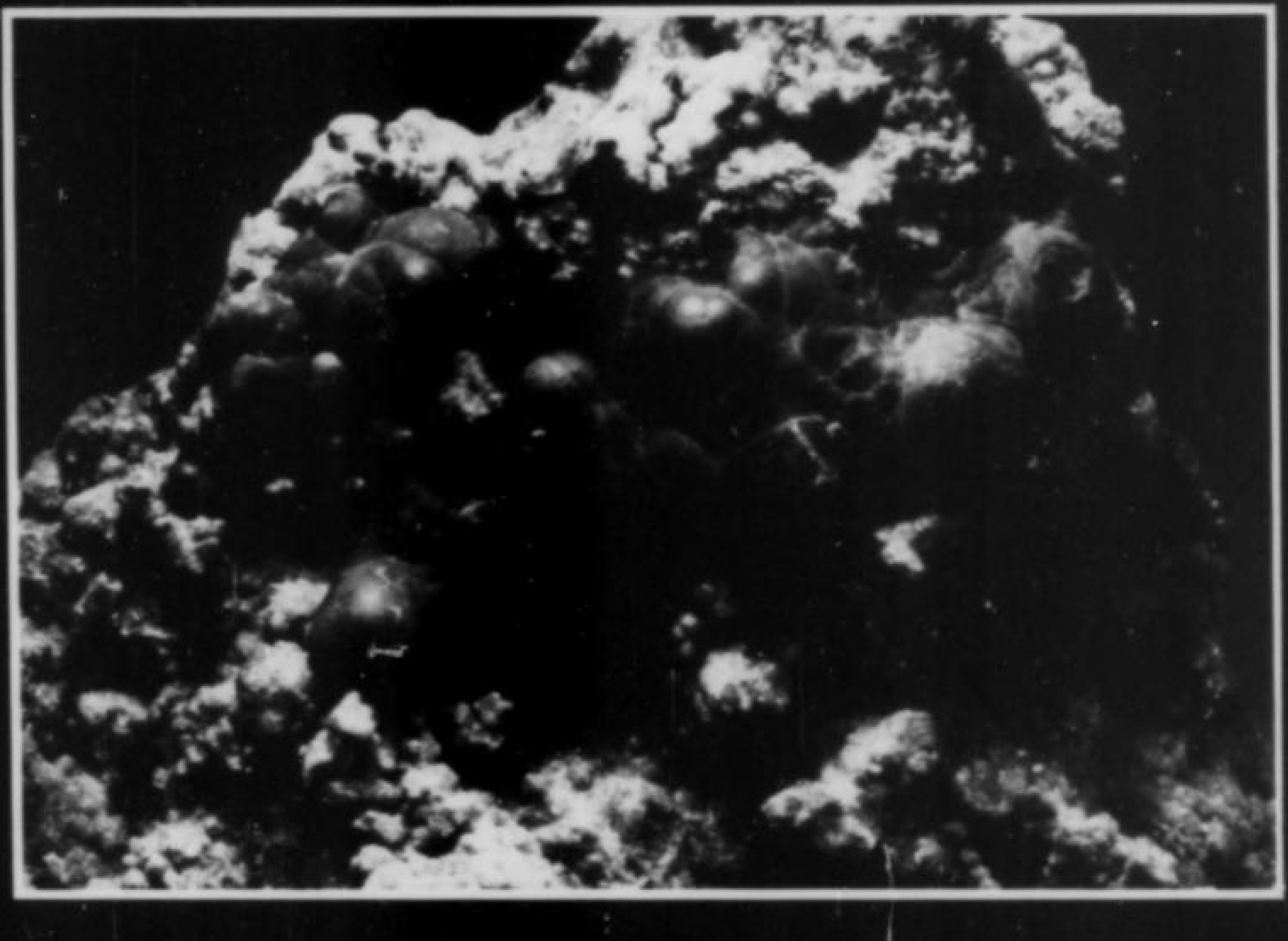
**PYROLUSITE**
Color: black
Size: 6.5 cm across
Collection of U.S.N.M. (#119130)
Photo by W. W.

**HEMATITE** after magnetite
Color: black
Size: 1.3 cm on edge
Collection of U.S.N.M. (#R12210)
Photo by W. W.

**OLIVENITE** var. zincolivenite
Color: grayish avocado-green
Size of sprays: 1 cm
Collection of U.S.N.M. (#R7674)
Photo by W. W.

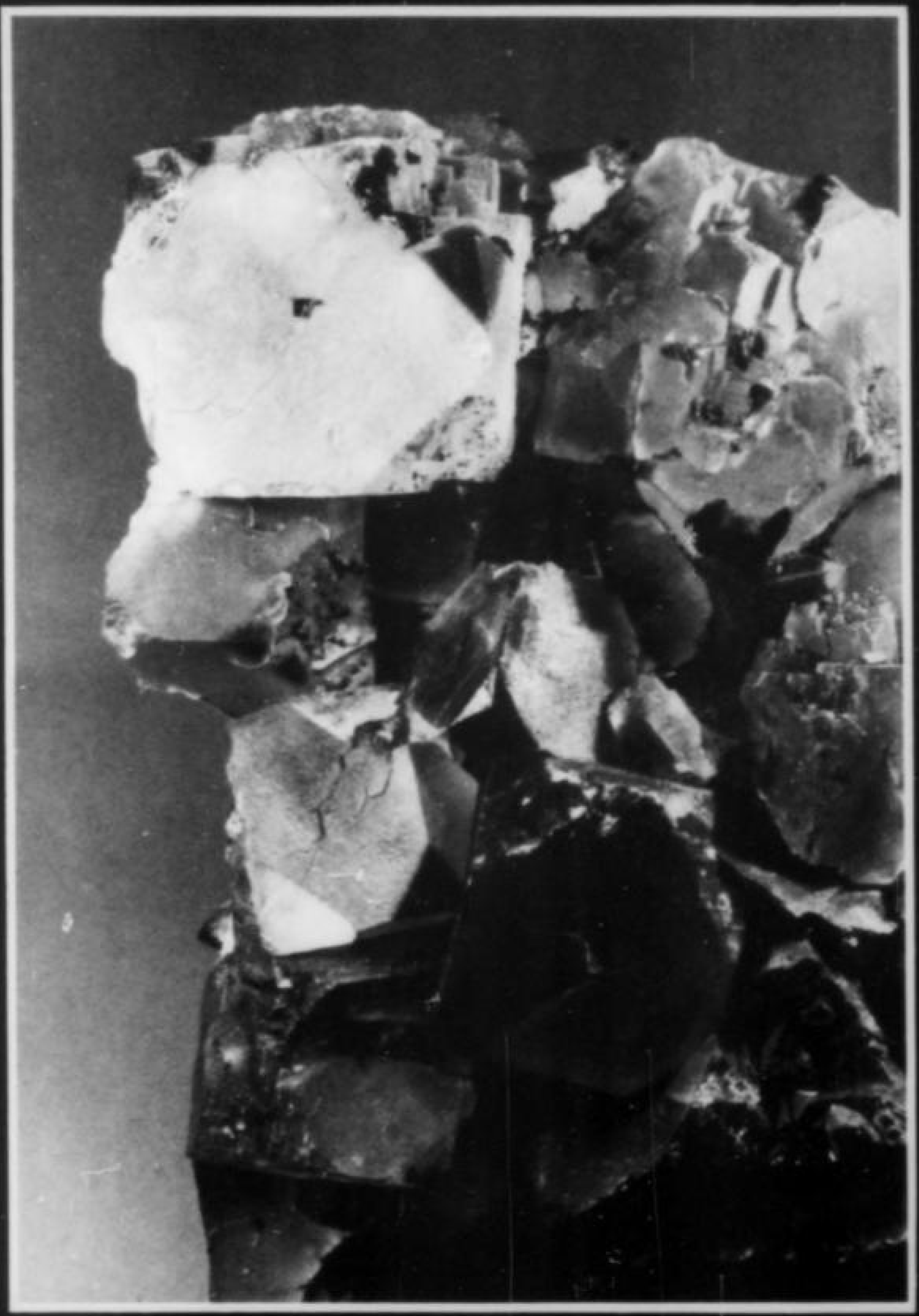
**OLIVENITE**
Color: olive-green
Size: 2 mm wide
Collection of U.S.N.M. (#R8599-4)
Photo by W. W.

**ROSASITE** var. paraurichalcite
pseudomorph after azurite
Color: blue-green
Size: 3.3 cm across
Collection of U.S.N.M. (#C5559-2)
Photo by W. W.

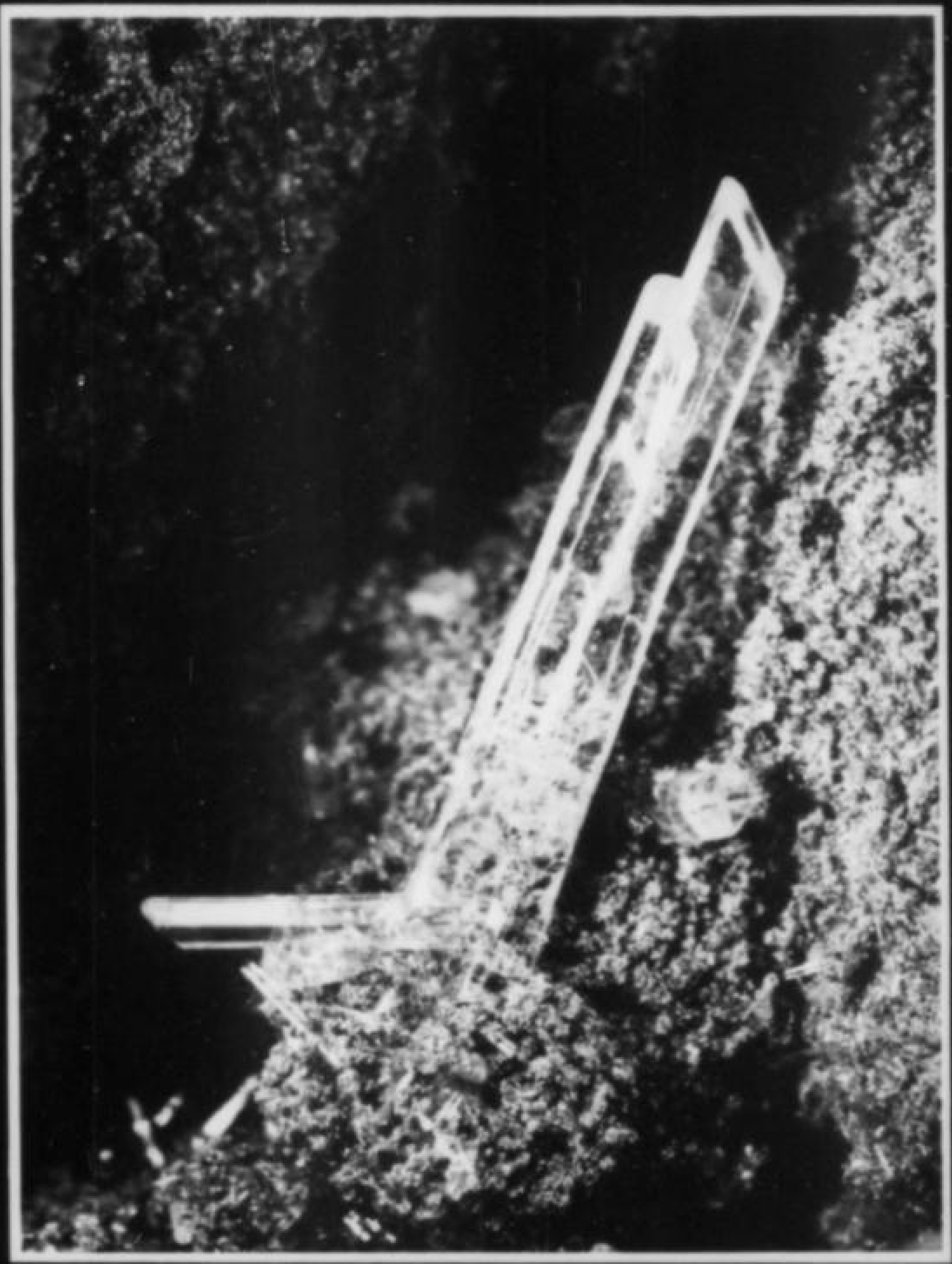


**ROSASITE**
Color: blue-green
Size: 5 cm across
Collection of U.S.N.M. (#B20588)
Photo by W. W.

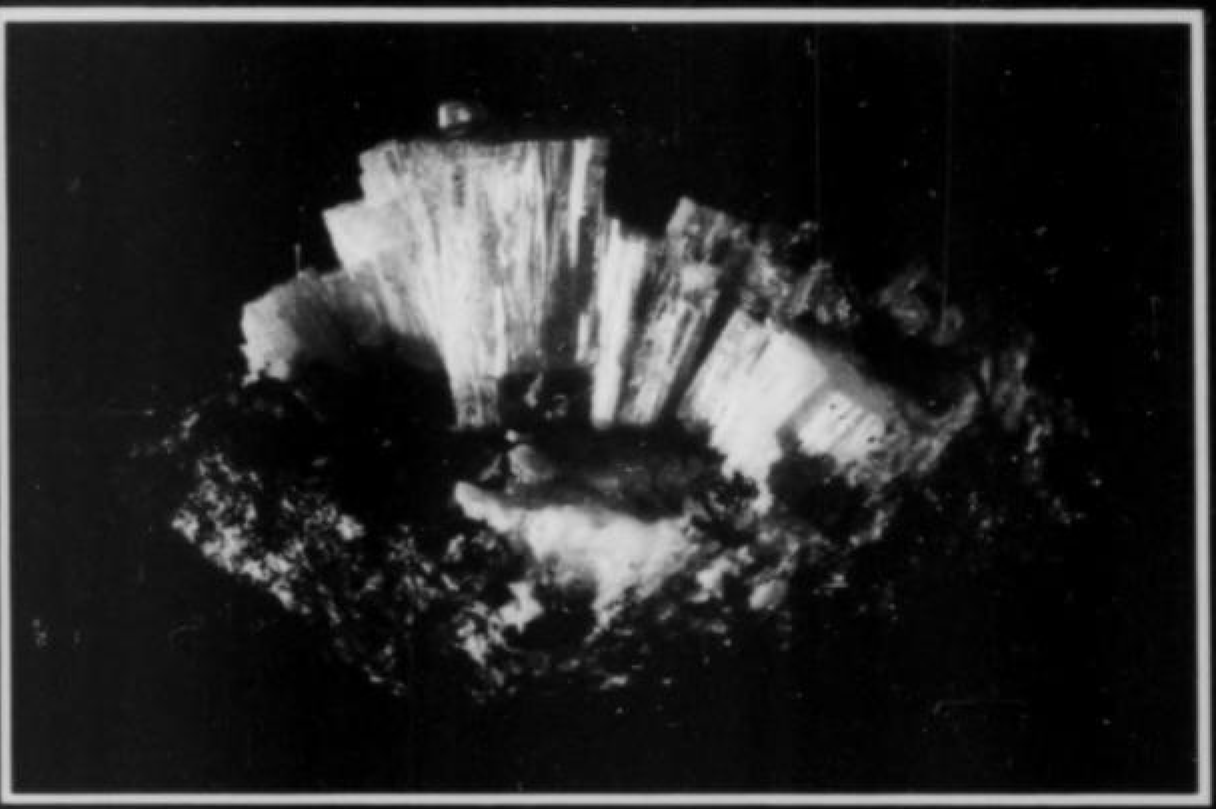
**FLUORITE**
Color: bluish violet. Size of crystals: 2 cm
Collection of Gertrude Houser
Photo by W. W.



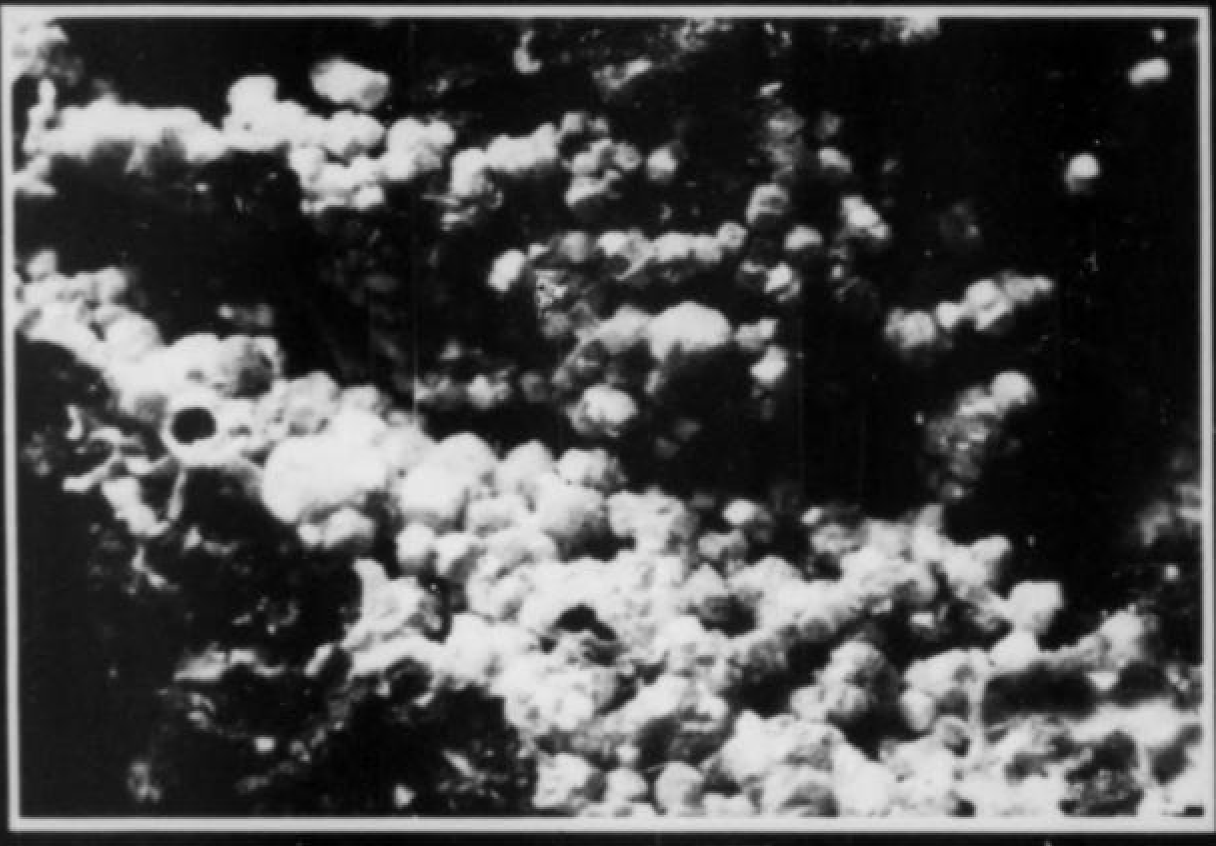
**FLUORITE** Color: green with violet corners
Size of large crystal: 2 cm
Collection of U.S.N.M. (#R9092) Photo by W. W.



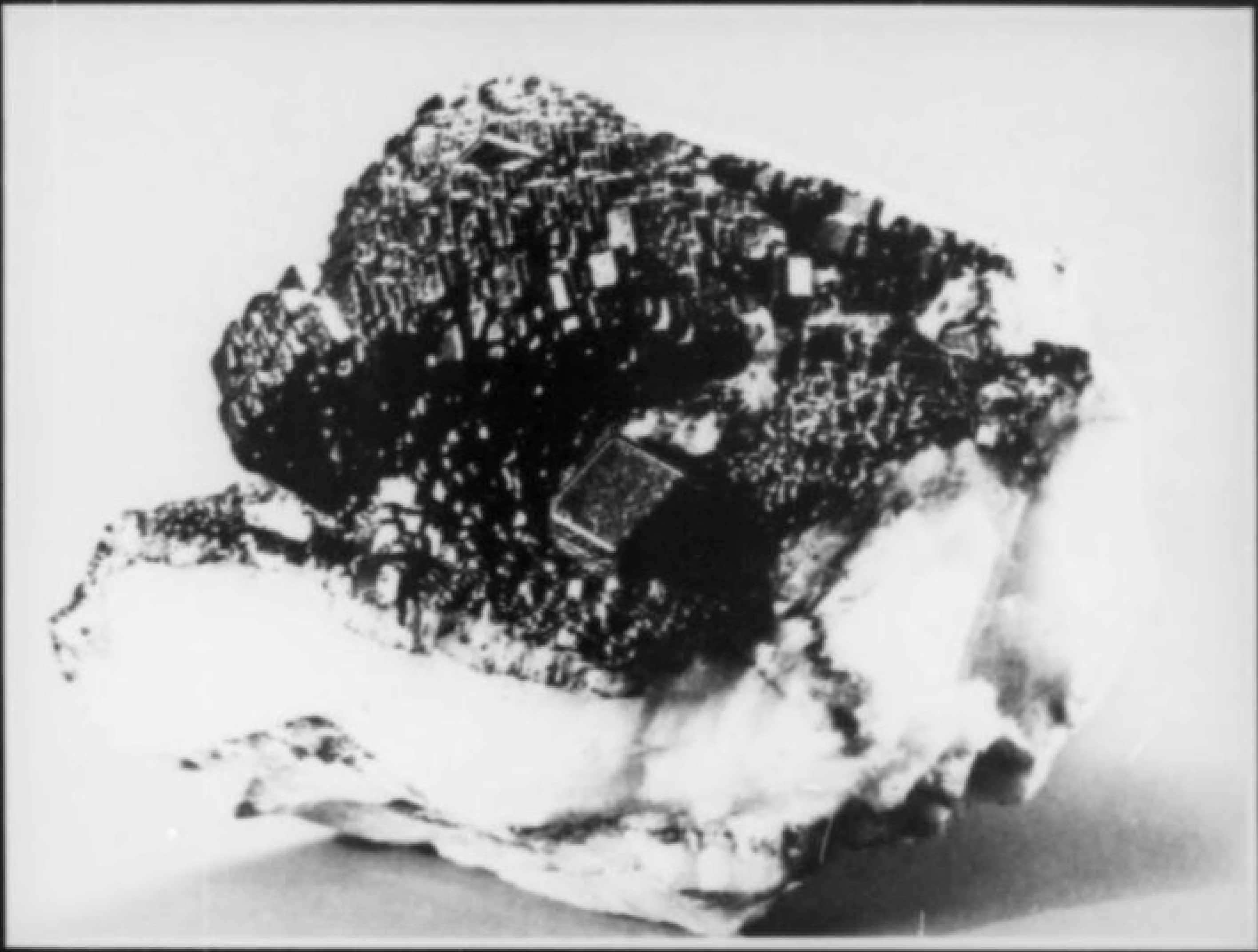
**SCHULTENITE**
on cuproadamite
Color: colorless
Size of crystal: 7 mm
Collection of Walter Kahn
Photo by O. M.



**ALAMOSITE** (above right)
Color: light gray to cream
Size: 8 cm across
Collection of Walter Kahn
Photo by O. M.

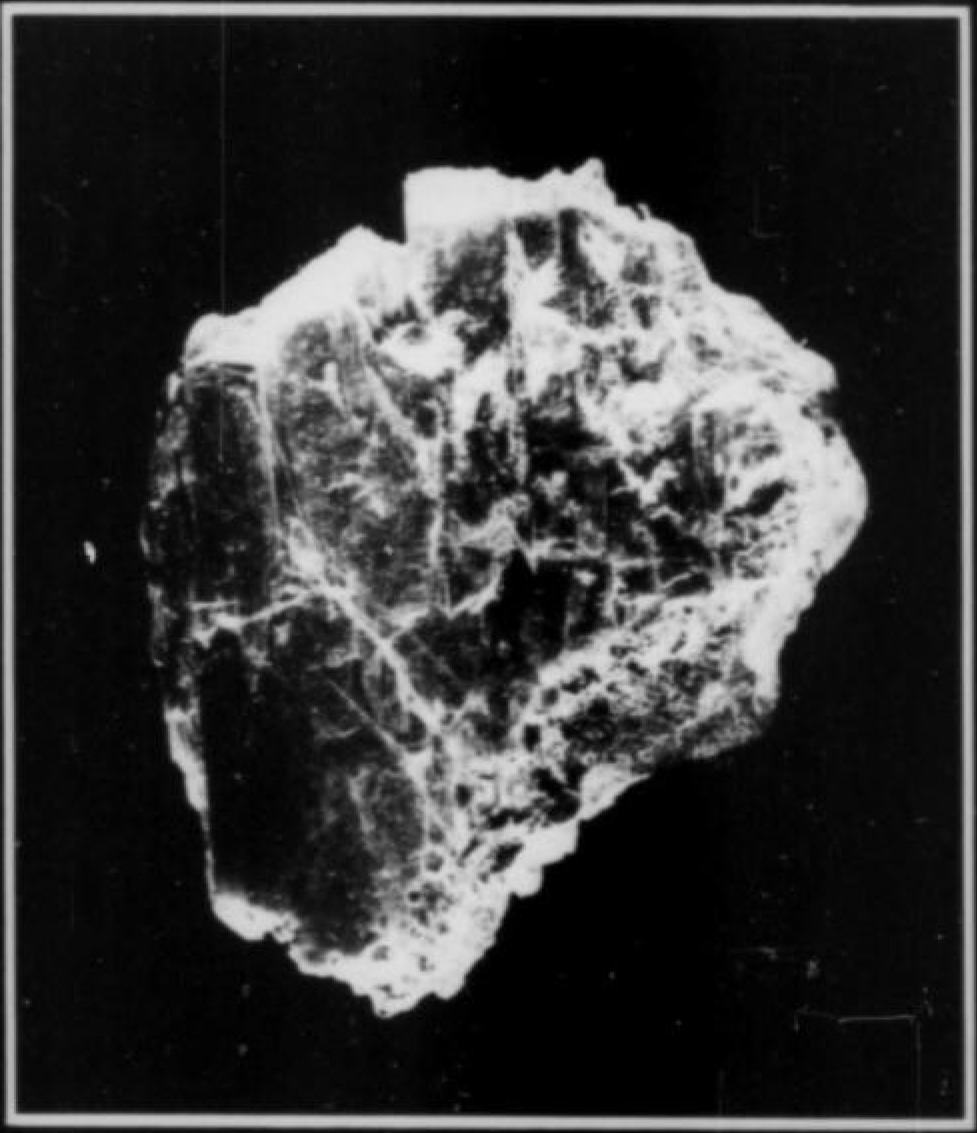


**OTAVITE** (right)
Color: white
Size of crystals: 0.3 mm
Collection of U.S.N.M. (#B10558)
Photo by W. W.

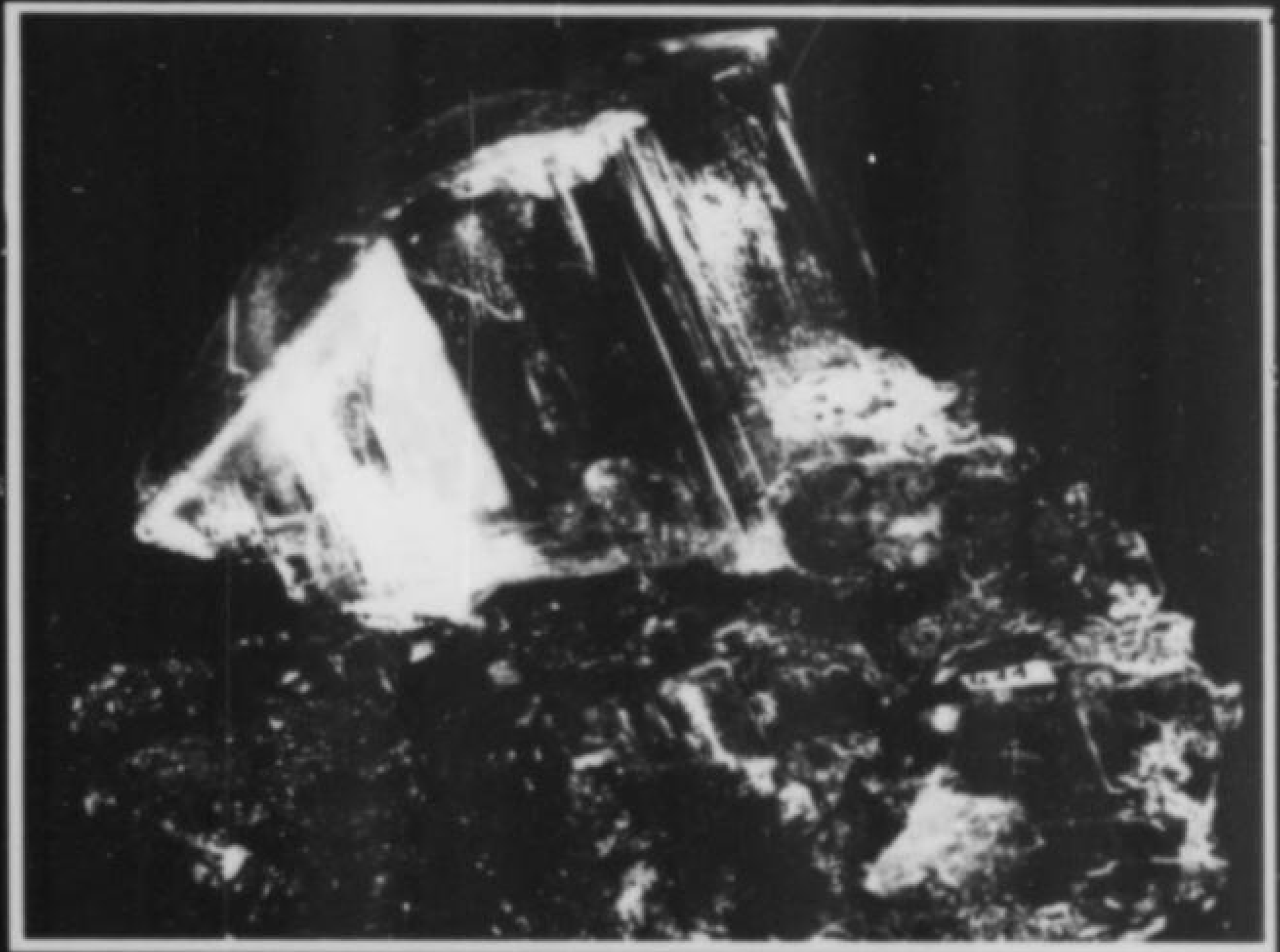


**HETEROGENITE** on calcite
Color: black. Size: 8.5 cm across
Collection of U.S.N.M. (#R17816) Photo by W. W.

**KEYITE**
Color: deep sky-blue. Size: 0.1 mm
Collection of British Museum
Photo (SEM) by H. B.



**LEITEITE** with tennantite
Color: white to reddish brown. Size: 5 by 8 cm
Collection of the Sorbonne
Photo by N. B.



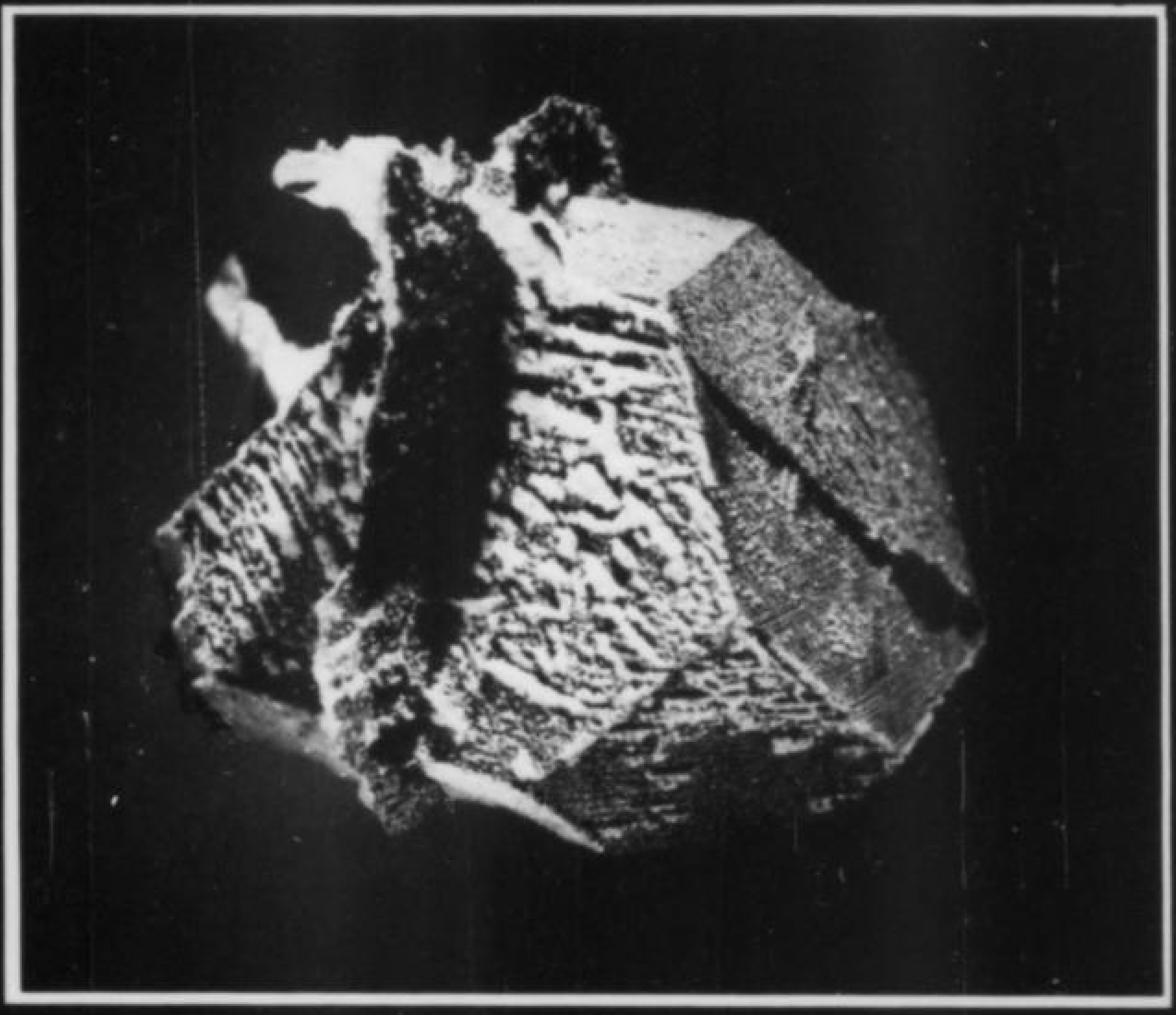
**GYPSUM**
Color: colorless. Size: 7 cm crystal
Collection of Dwight Weber
Photo by D. W.

**SCORODITE**
Color: greenish to
purplish blue
Size: 1.8 cm wide
Collection of
M. & J. Zweibel
Photo by W. W.

**SCHNEIDERHÖHNITE**
(large black crystals)
with **MOLYBDENITE**
(gray crystal, upper right)
and **ZINC-STOTTITE**
(pink crystal below
molybdenite)
Size of molybdenite
crystal: 5 mm
Collection of Walter Kahn
Photo by O. M.

**ENARGITE**
Color: black with light brown coating
Size of large crystal: 8 mm
Collection of U.S.N.M. (#R8629)
Photo by W. W.

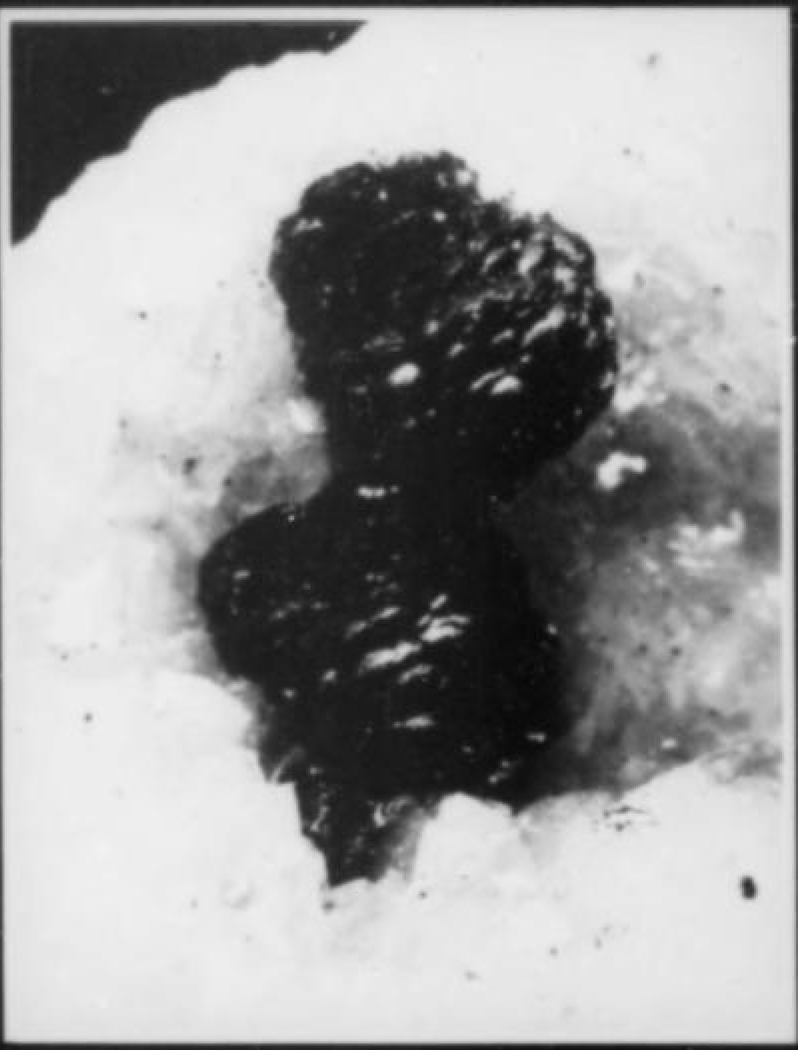
**TENNANTITE** with pyrite
Color: dark gray
Size: 2.5 cm wide
Collection of John W. Tetrick
Photo by W. W.



**GALENA** with cerussite
Color: gray. Size: 6.5 cm wide
Collection of Olaf Medenbach
Photo by O. M.

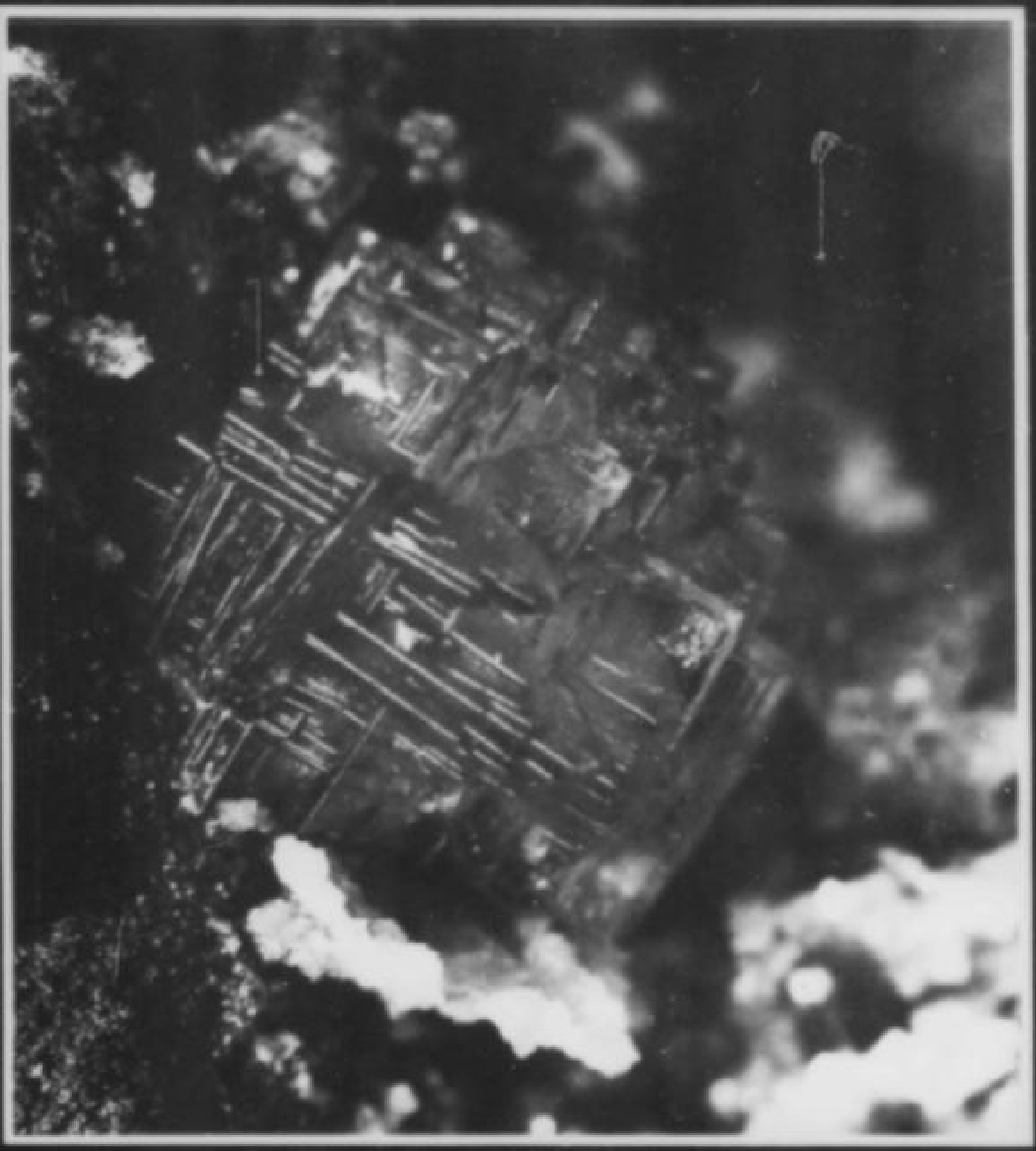
**PYRITE** with cerussite and goethite
Color: brownish yellow. Size: 6.5 cm across
Collection of U.S.N.M. (#R17201)
Photo by W. W.

**TSUMEBITE**
Color: near dioptase-green
Size of crystal: 0.1 mm
Collection of U.S.N.M. (#R5464)
Photo by W. W.



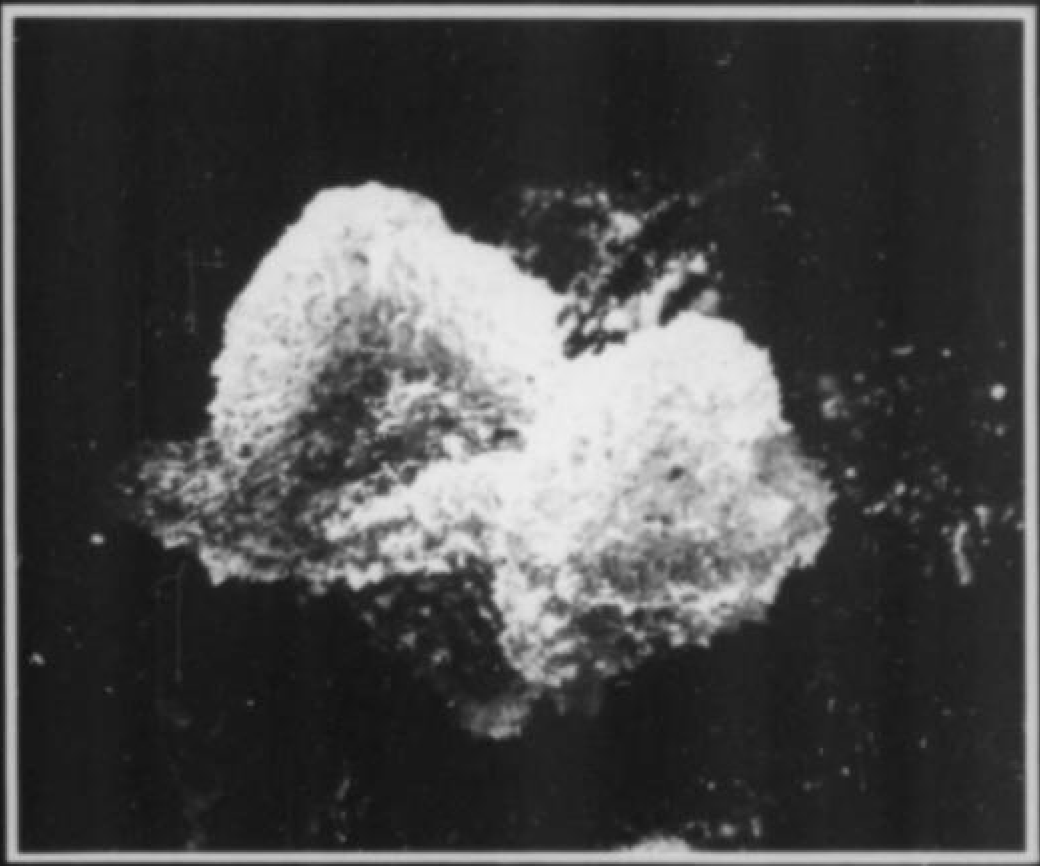
**SÖHNGEITE**
Color: pale greenish
yellowish brown
Size: 8 mm
Collection of British
Museum (#BM 1975,
398)
Photo by F. G.

**AUSTINITE** var. cuprian
Color: dark olive green
Size of aggregates: 2 mm
Collection of U.S.N.M.
(#R11191)
Photo by W. W.



**SÖHNGEITE**
Color: pale brown. Size: 6 mm
Collection of Hugo Strunz
Photo by W. L.

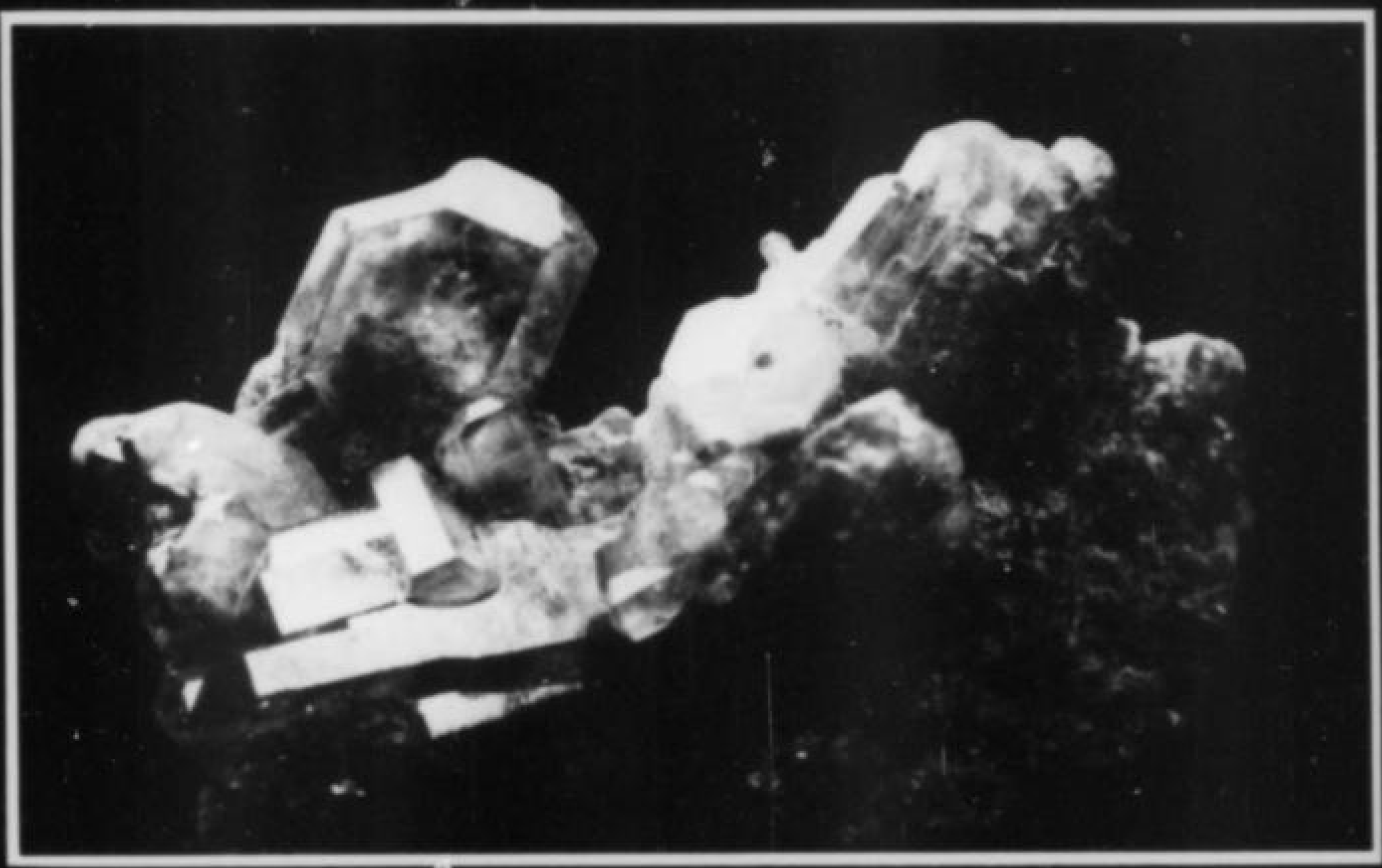
**ARAGONITE** var. tarnowitzite
Color: white. Size: 8 cm across
Collection of Hugo Strunz
Photo by O. M.



**ARAGONITE** var. nicholsonite
Color: pale brownish yellow
Size: 8.5 cm across
Collection of U.S.N.M. (#123688)
Photo by W. W.

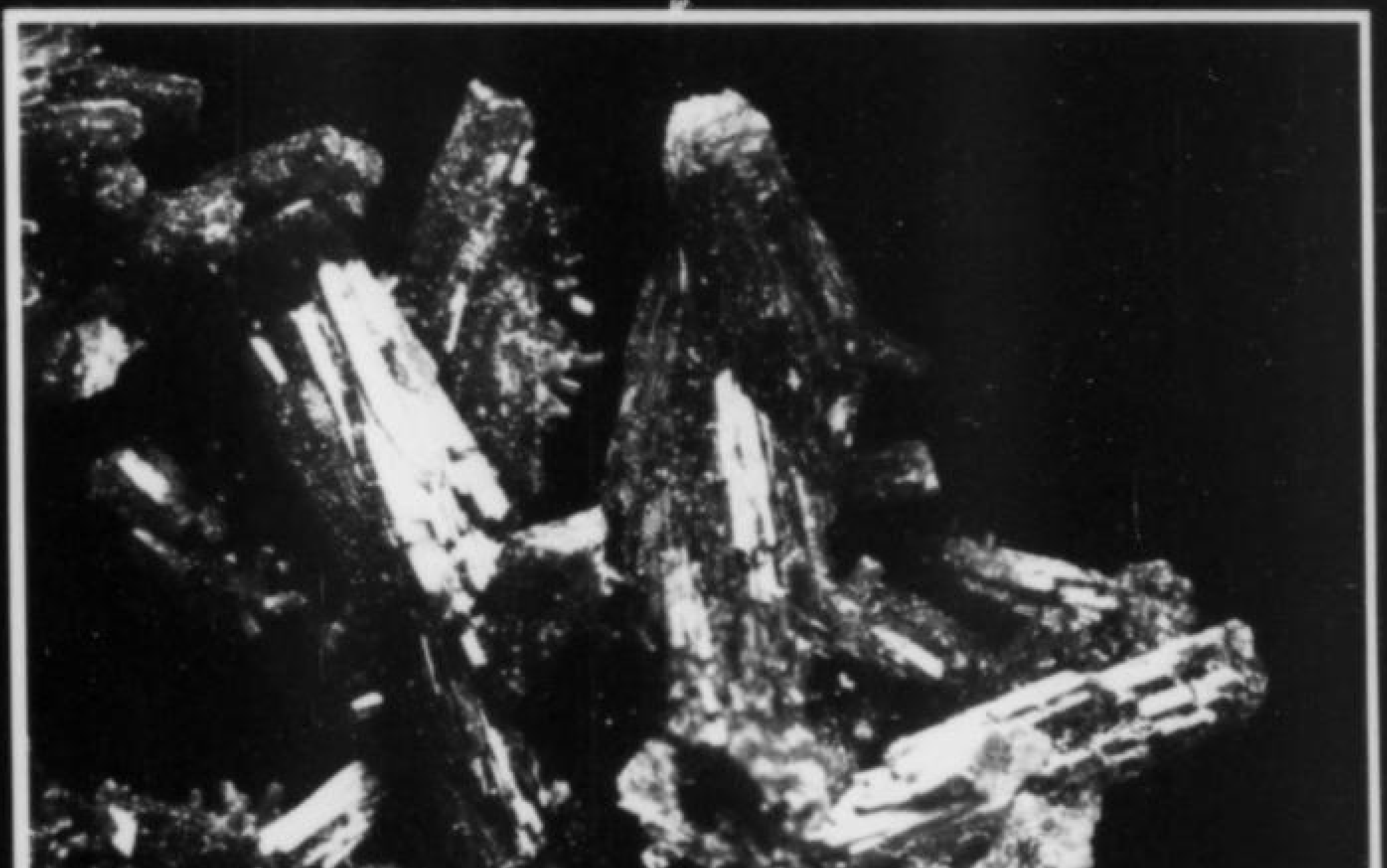
**DESCLOIZITE** (above left)
Color: dark brown
Size: 9 mm
Collection of Eric Offermann
Photo by E. O.

**DESCLOIZITE** (above)
Color: dark brown
Size of crystals: 8 mm
Collection of U.S.N.M. (#119713)
Photo by W. W.



**PYROMORPHITE**
Color: very pale brown
Size of specimen: 3.5 cm wide
Collection of U.S.N.M. (#B13472)
Photo by W. W.

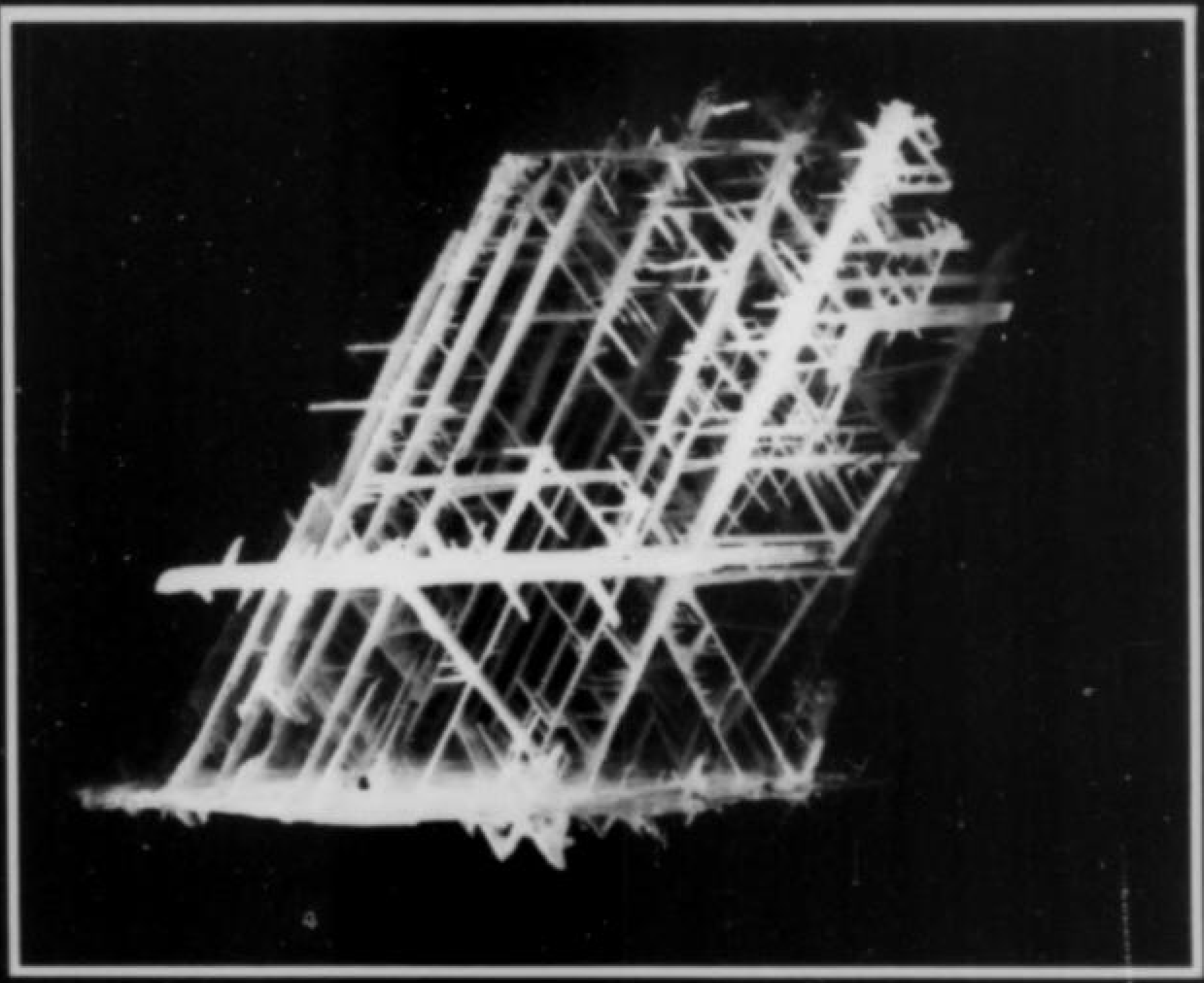
**VANADINITE**
Color: brownish red
Size of crystals: 7 mm
Collection of U.S.N.M. (#R15374)
Photo by W. W.



**MIMETITE**
Color: yellow
Length of large crystal: 6 cm
Collection of Keith Proctor
Photo by W. W.

**QUARTZ**
Color: white. Size: 10 cm across
Collection of U.S.N.M. (#C5562)
Photo by W. W.

**CERUSSITE**
Color: white. Size: 6 cm
Collection of Walter Kahn
Photo by O. M.

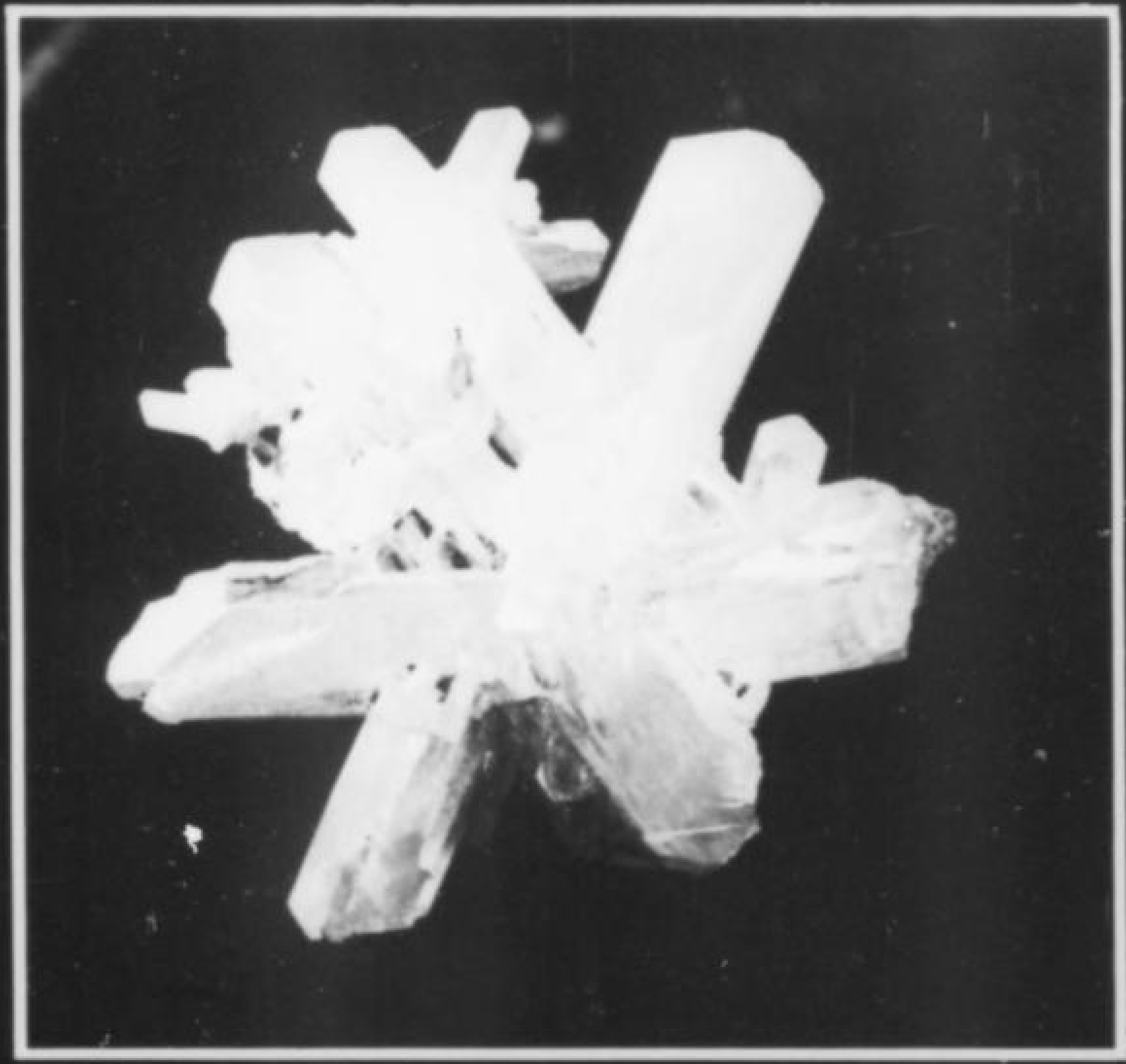


**LEADHILLITE** with small
black **KEGELITE** crystals
Color: light gray
Size: 3 cm tall
Collection of Walter Kahn
Photo by O. M.

**CERUSSITE** var. schwarzbleierz
Color: black. Size: 8 cm
Collection of M. & J. Zweibel
Photo by W. W.

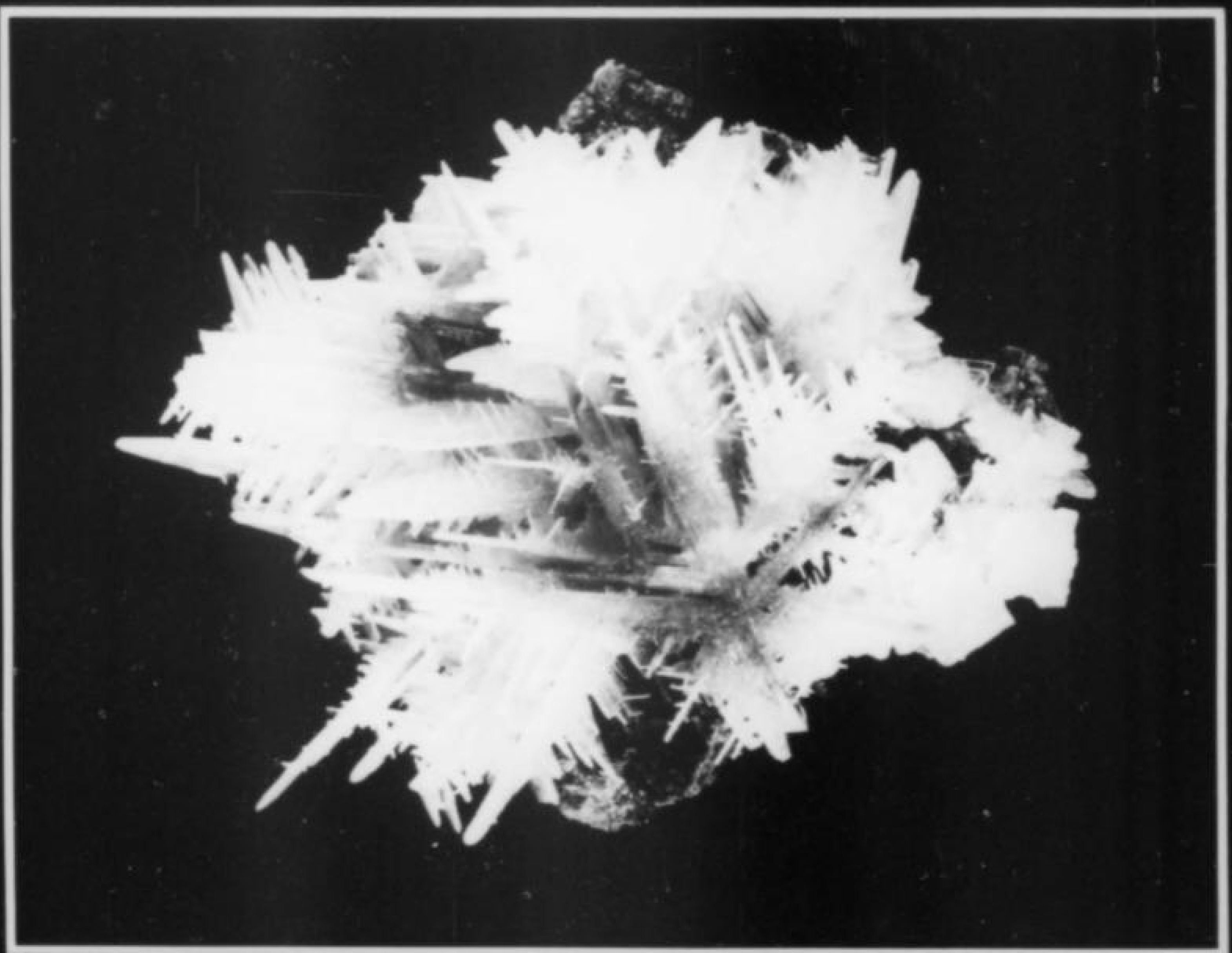
**AURICHALCITE** needles (pale sky-blue)
with **HEMIMORPHITE** (colorless) (above left)
Size: 1 cm across
Collection of U.S.N.M. (#B20593)
Photo by W. W.

**CERUSSITE**
Color: colorless with brownish red phantoms
Size: 6.5 cm tall
Collection of M. & J. Zweibel
Photo by W. W.

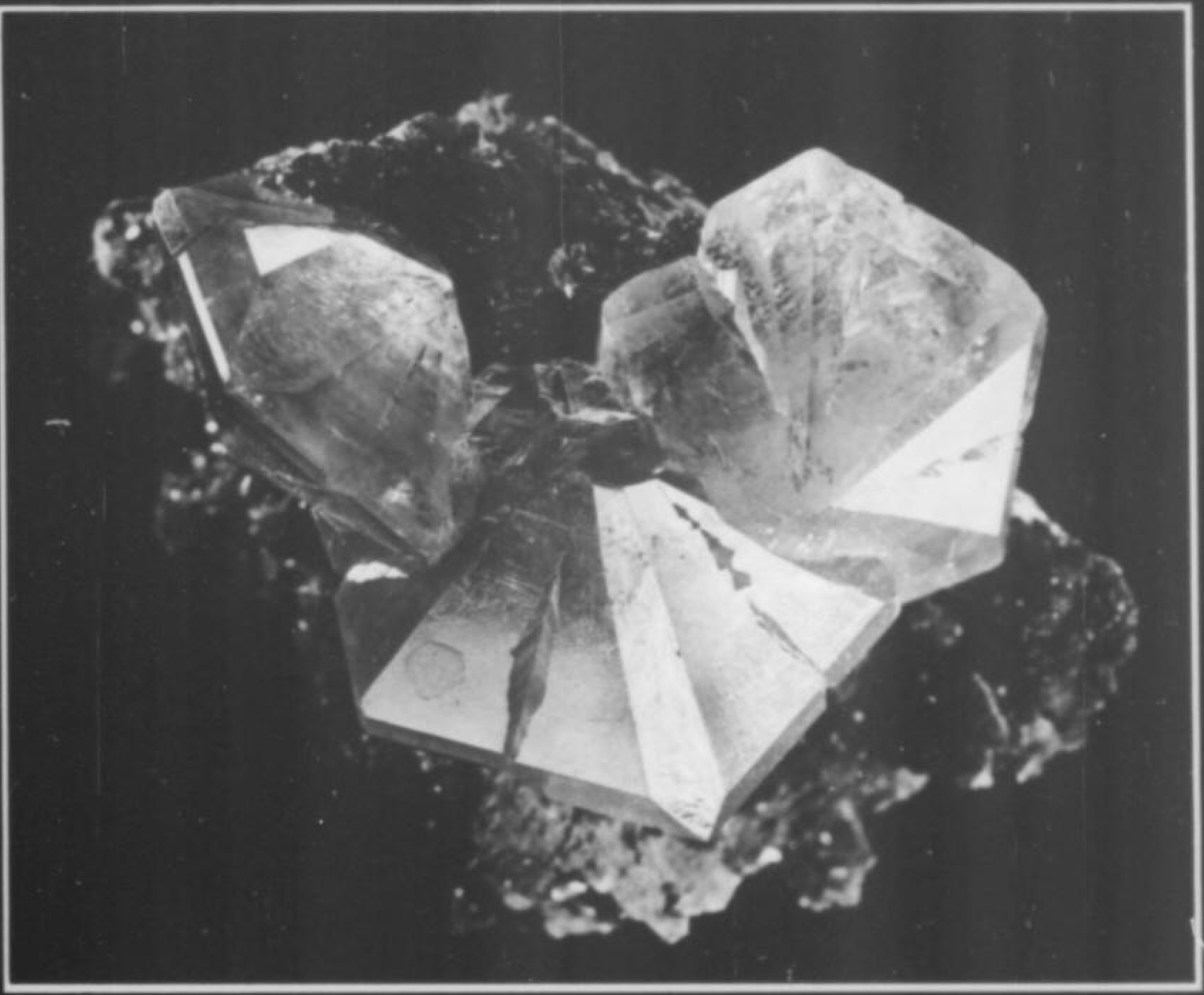


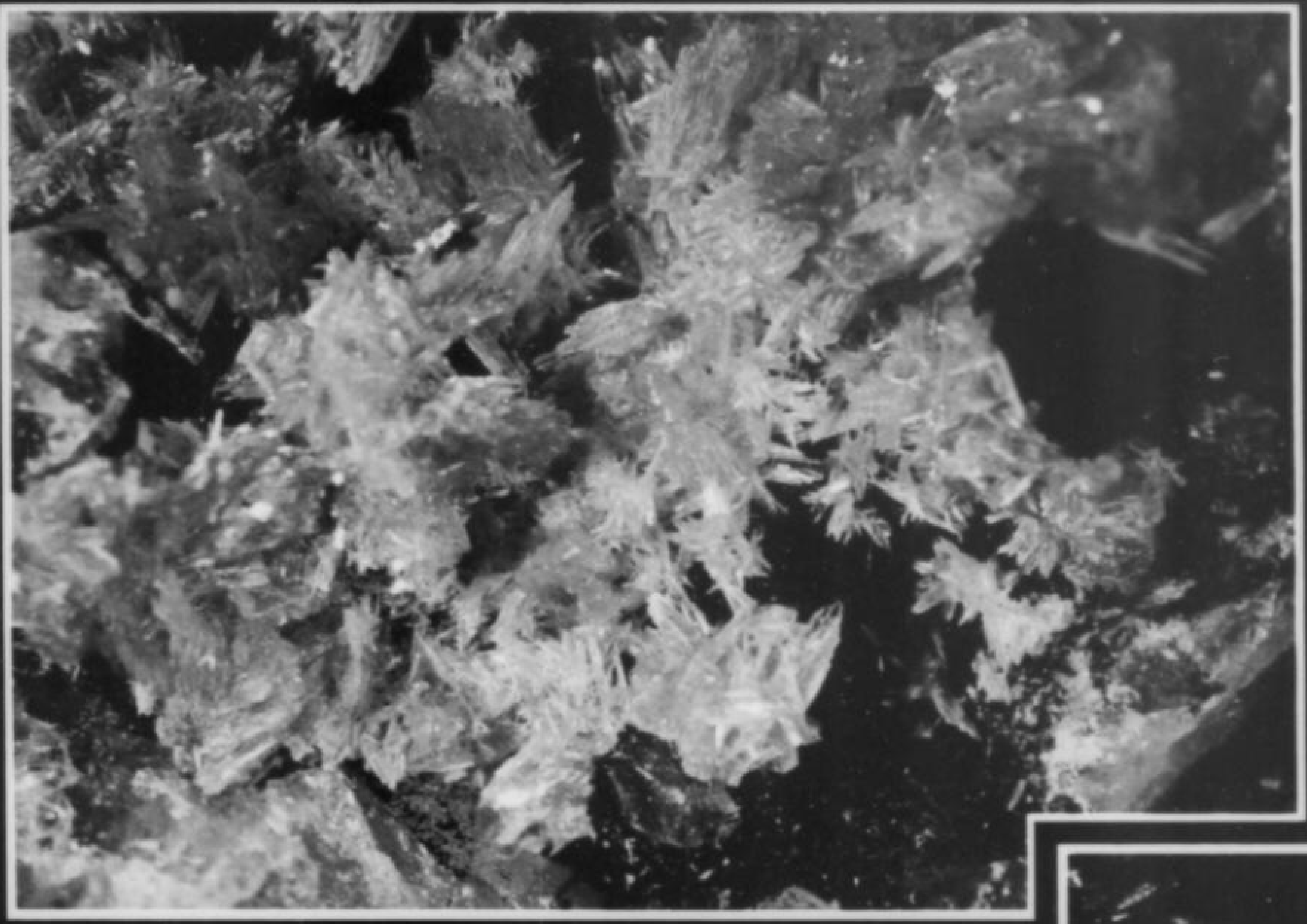
**CERUSSITE** (left)
Color: white
Size: 5.2 cm
Collection of M. & J. Zweibel
Photo by W. W.

**CERUSSITE**
Color: white
Size: 30 cm tall
Collection of the Sorbonne
Photo by N. B.



**CERUSSITE**
Size: 4.5 cm wide
Collection of Walter Kahn
Photo by O. M.

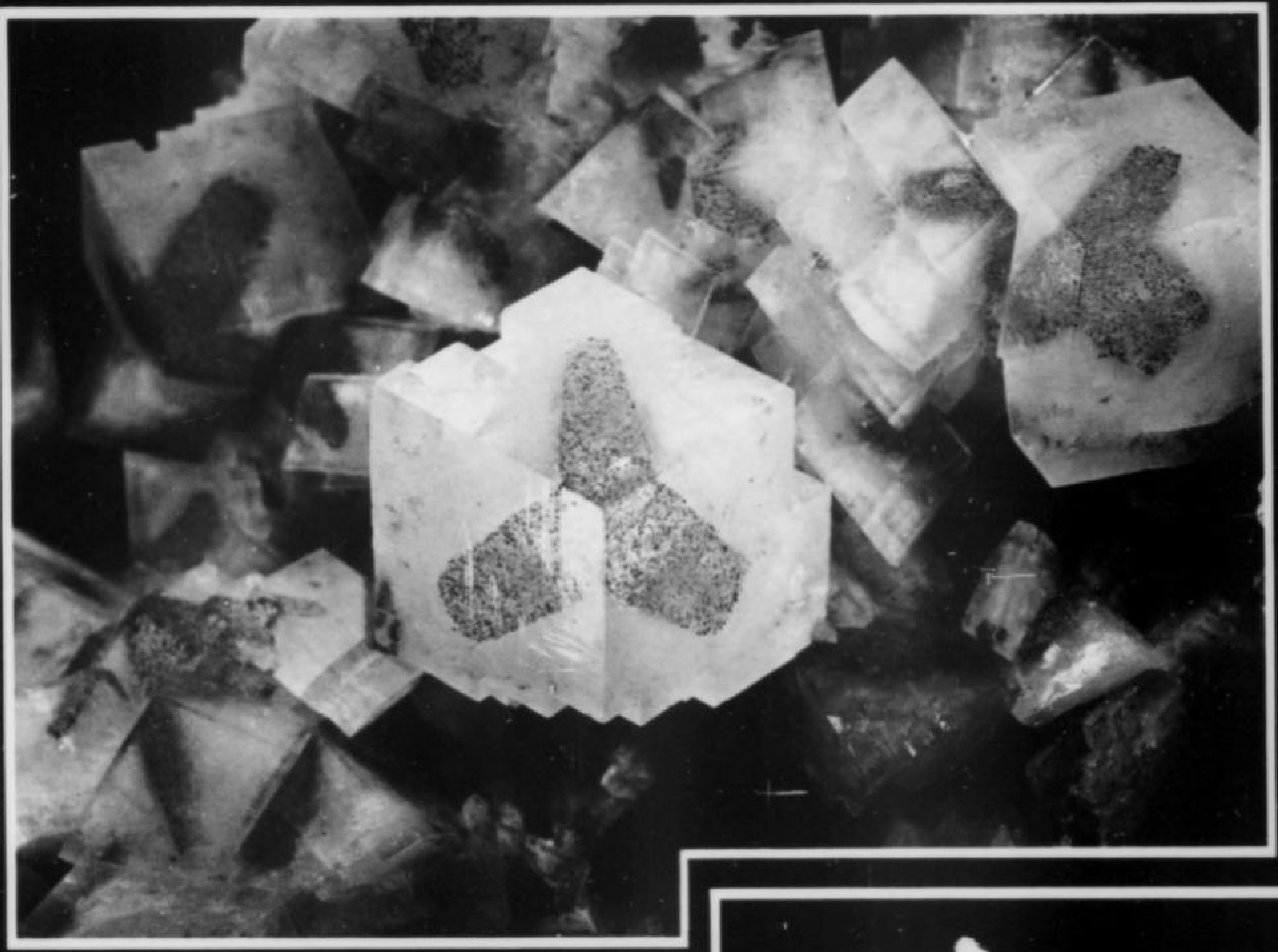




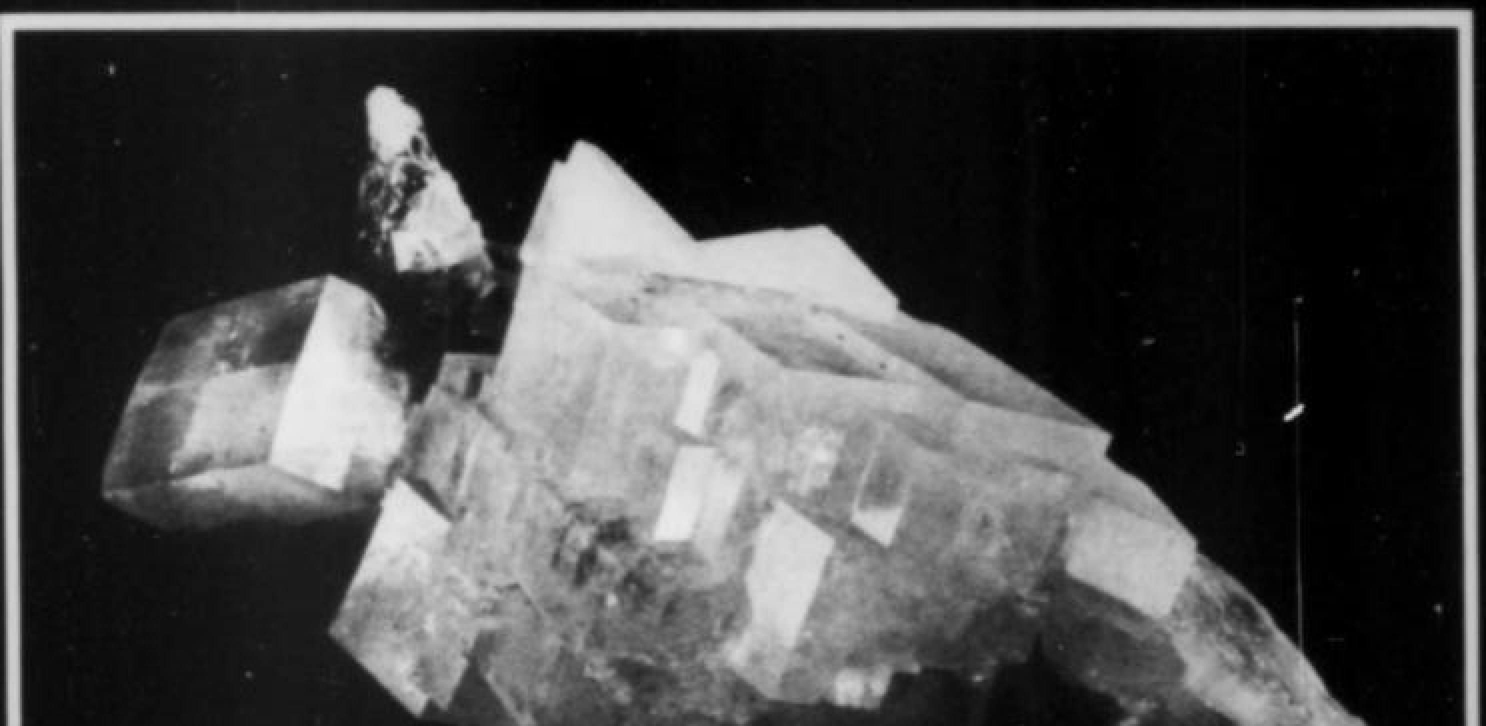
**TSUMCORITE**
Size: 1.2 cm wide
Collection of Walter Kahn
Photo by O. M.

**TSUMCORITE**
Color: yellow
Size: 2.5 mm across
Collection of Gunther Keller
Photo by E. O.

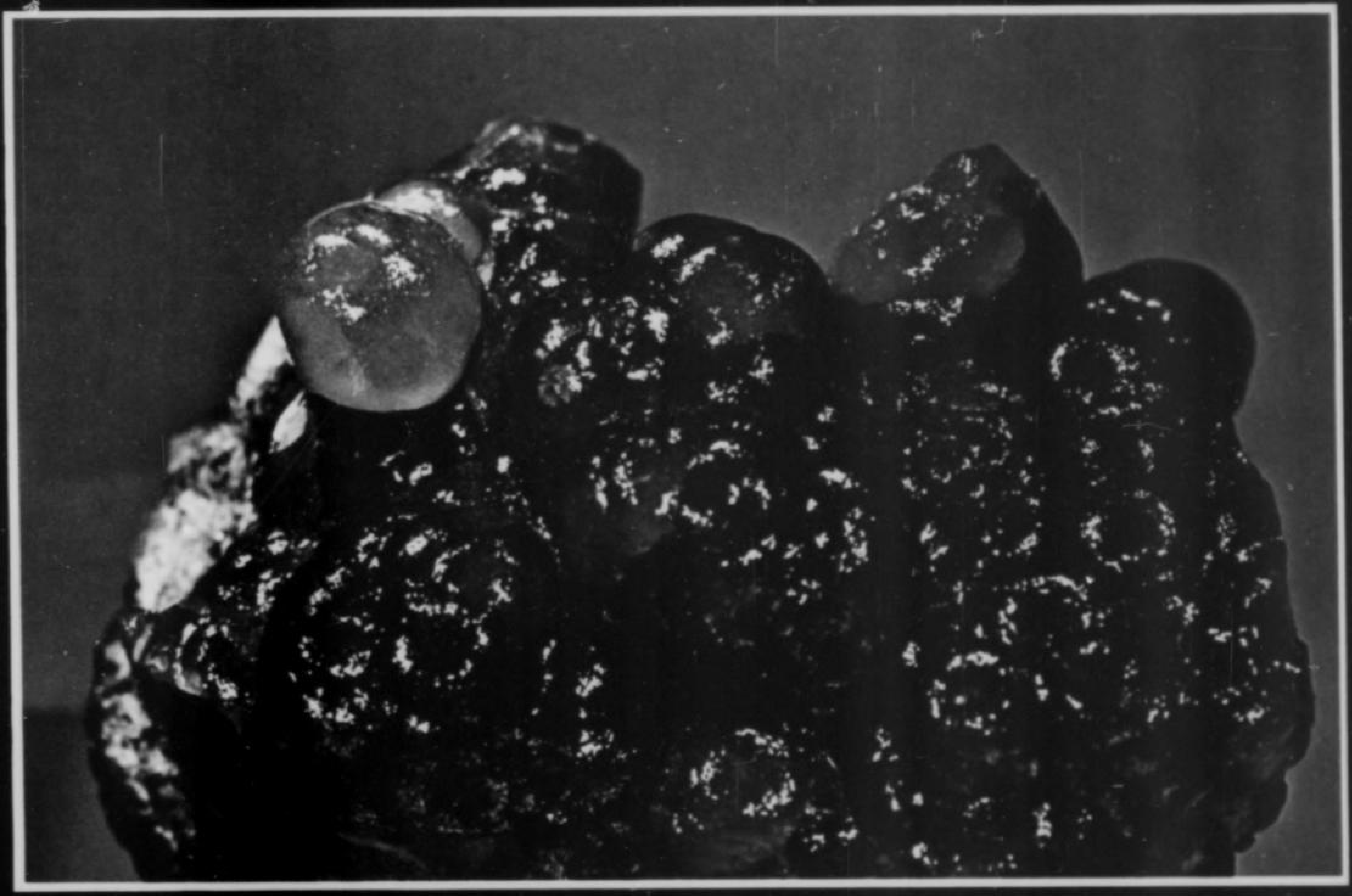
**CALCITE** var. plumbocalcite
Color: white
Size: 11 cm across
Collection of M. & J. Zweibel
Photo by W. W.



**CALCITE**
Size of Crystal: 2.5 cm
Collection of Hugo Strunz
Photo by O. M.

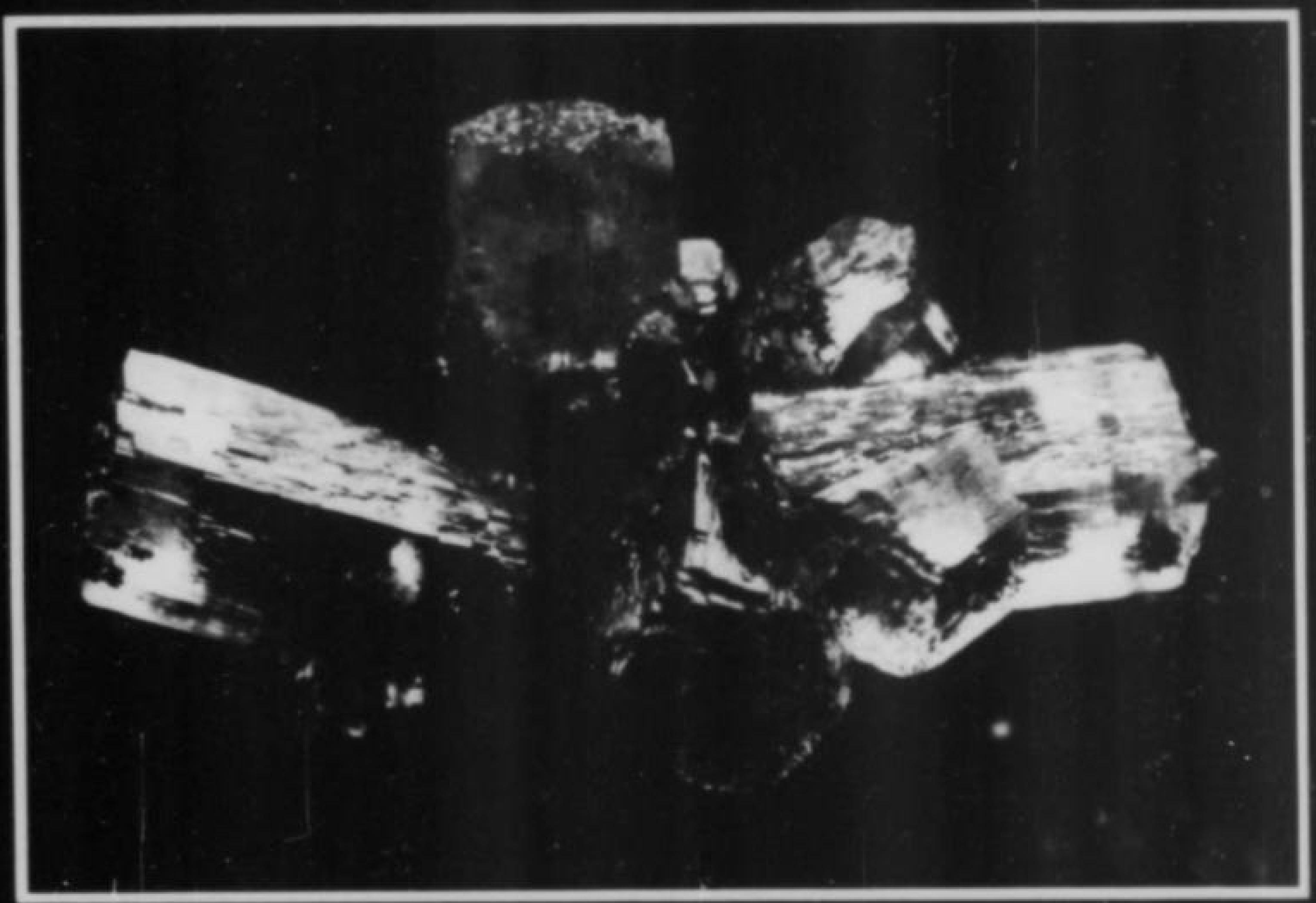


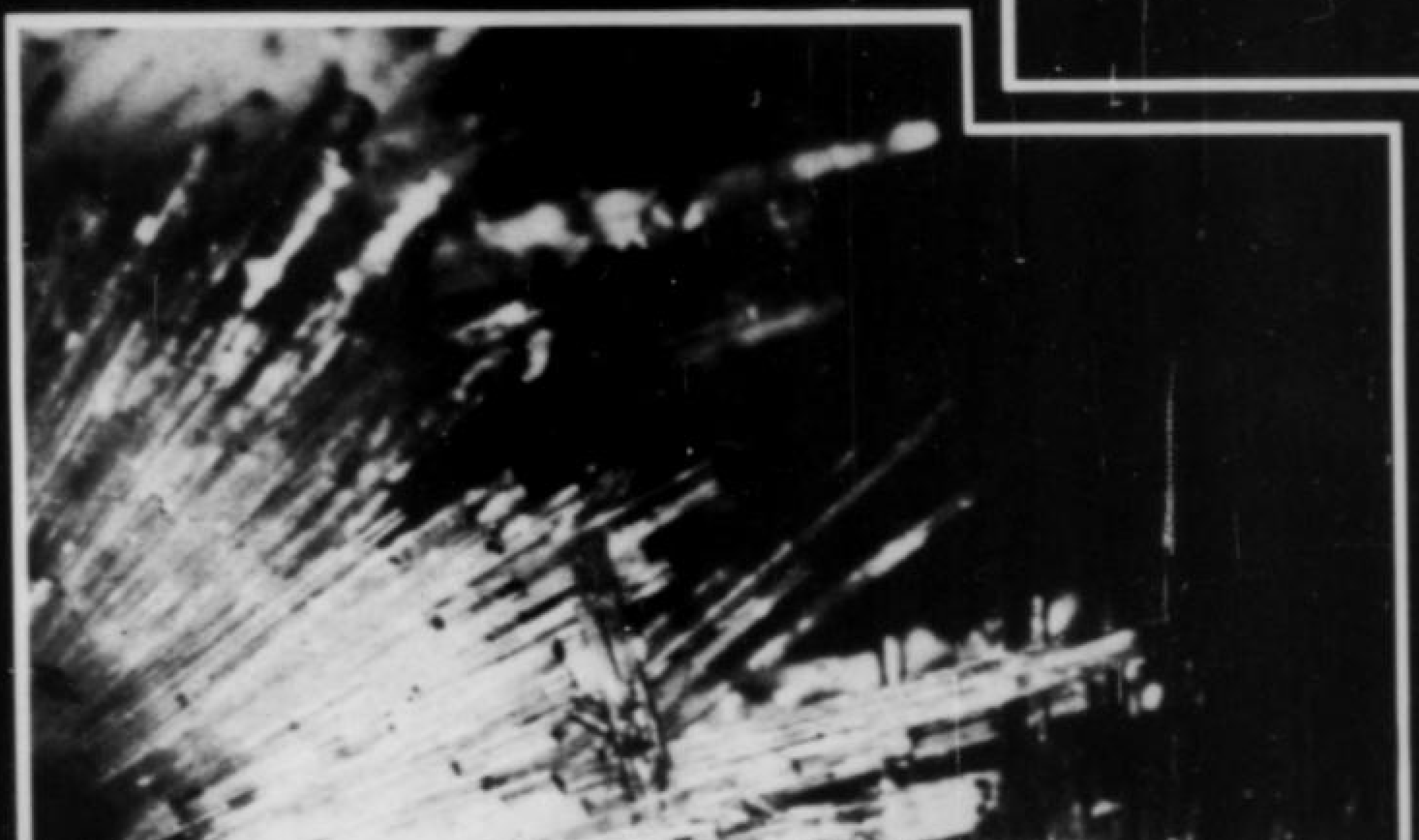
**CALCITE**
Color: white
Size: 15 cm across
Collection of M. & J. Zweibel
Photo by W. W.



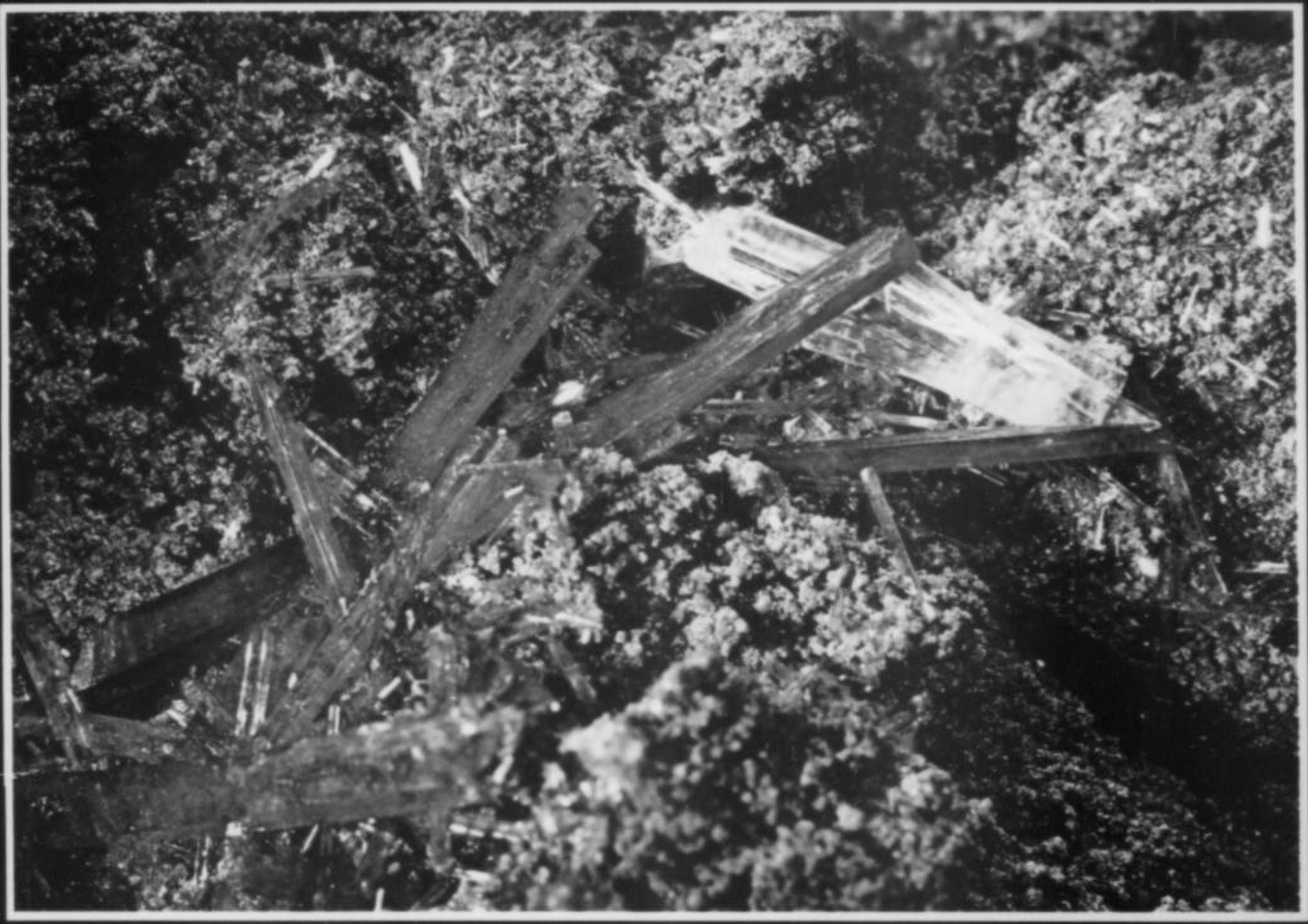
**WILLEMITE**
Size: 9 cm across
Collection of Paul Patchick
Photo by P. H.

**WILLEMITE**
Color: pale green
Size: 6 mm across
Collection of Eric Offermann
Photo by E. O.





**WILLEMITE**
Color: colorless
Size of crystals: 8 mm long
Collection of Richard Haug
Photo by R. H.



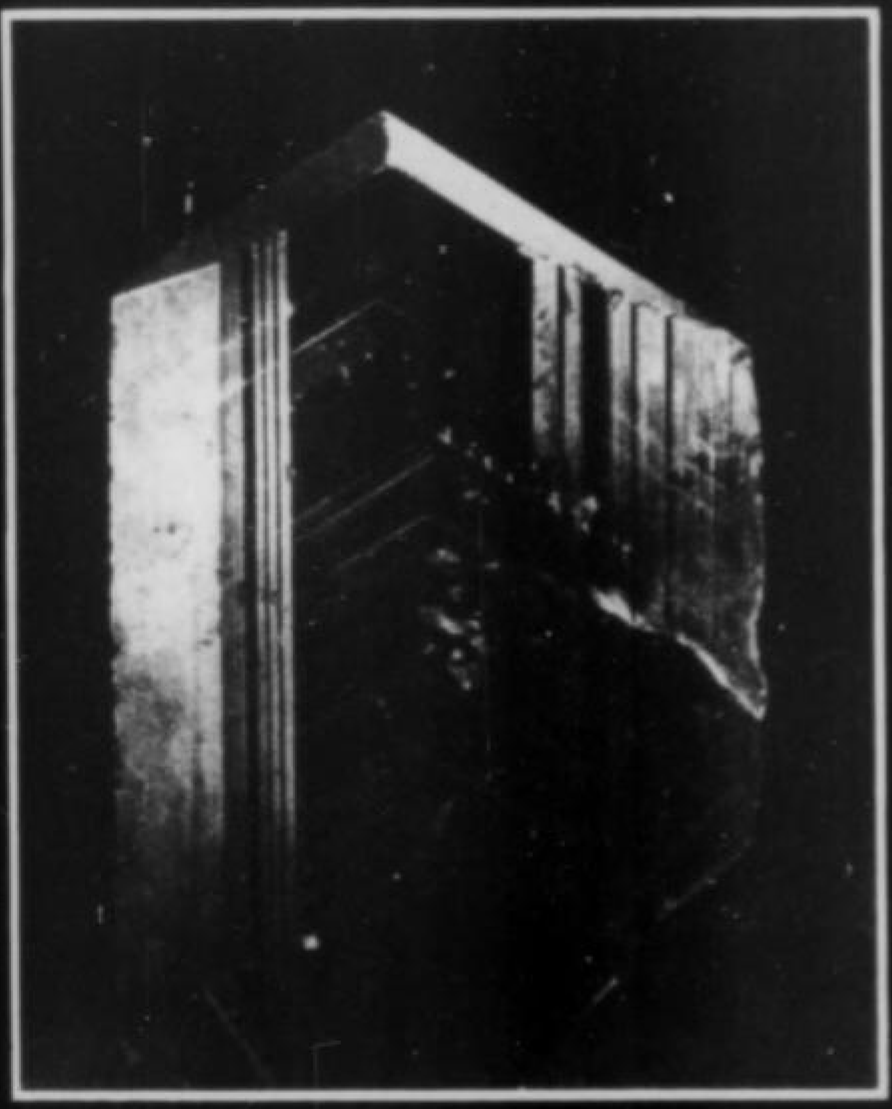
**ADAMITE** var. cuproadamite
with schultenite
Size of crystals: 1 cm long
Collection of Walter Kahn
Photo by O. M.

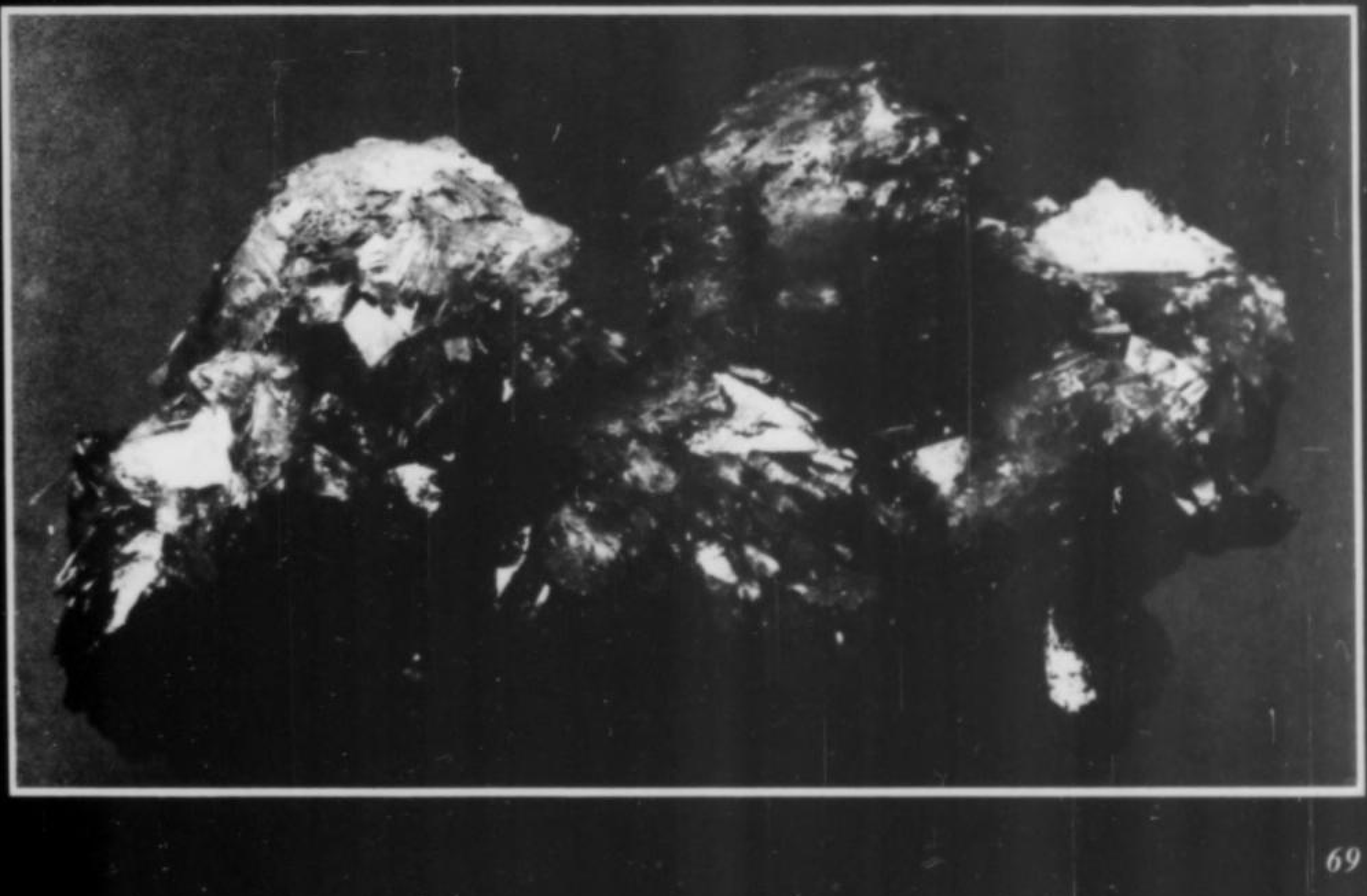
**ADAMITE** var. cuproadamite
Size: 3.3 mm
Collection of Gunther Keller
Photo by E. O.

**ADAMITE**
Color: yellow-green with brown edges
Size of crystals: 4 mm
Collection of U.S.N.M. [#115738]
Photo by W. W.

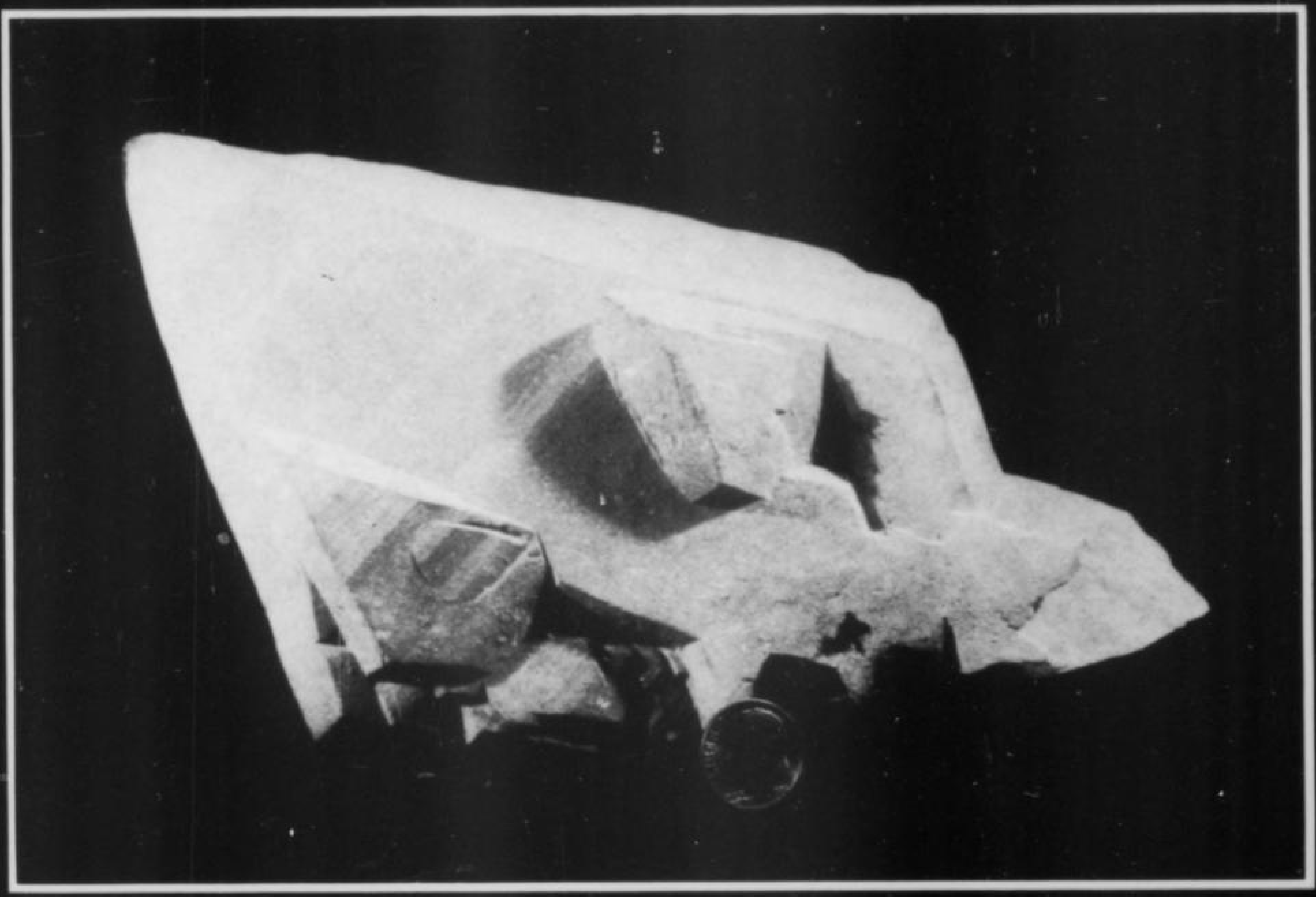
**ANGLESITE**
with inclusions of greenockite
Size: 2.6 cm wide
Collection of U.S.N.M. [#115687]
Photo by W. W.

**ANGLESITE**
Color: pale yellow
Size: 4 cm wide
Collection of U.S.N.M. [#121122]
Photo by W. W.



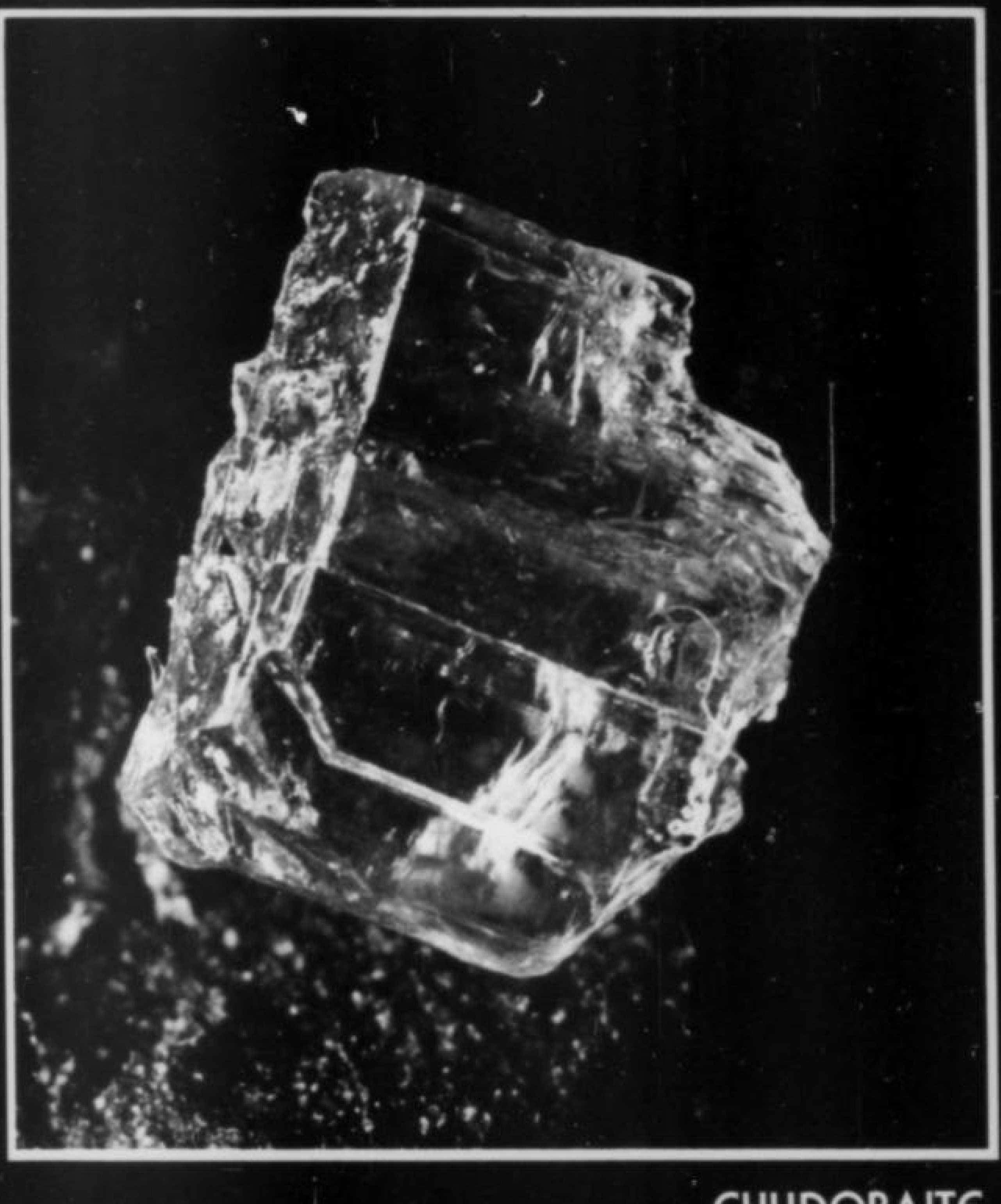


**ADAMITE**
Color: yellow
Size: 3 cm across
Collection of U.S.N.M.
[#135246]
Photo by W. W.



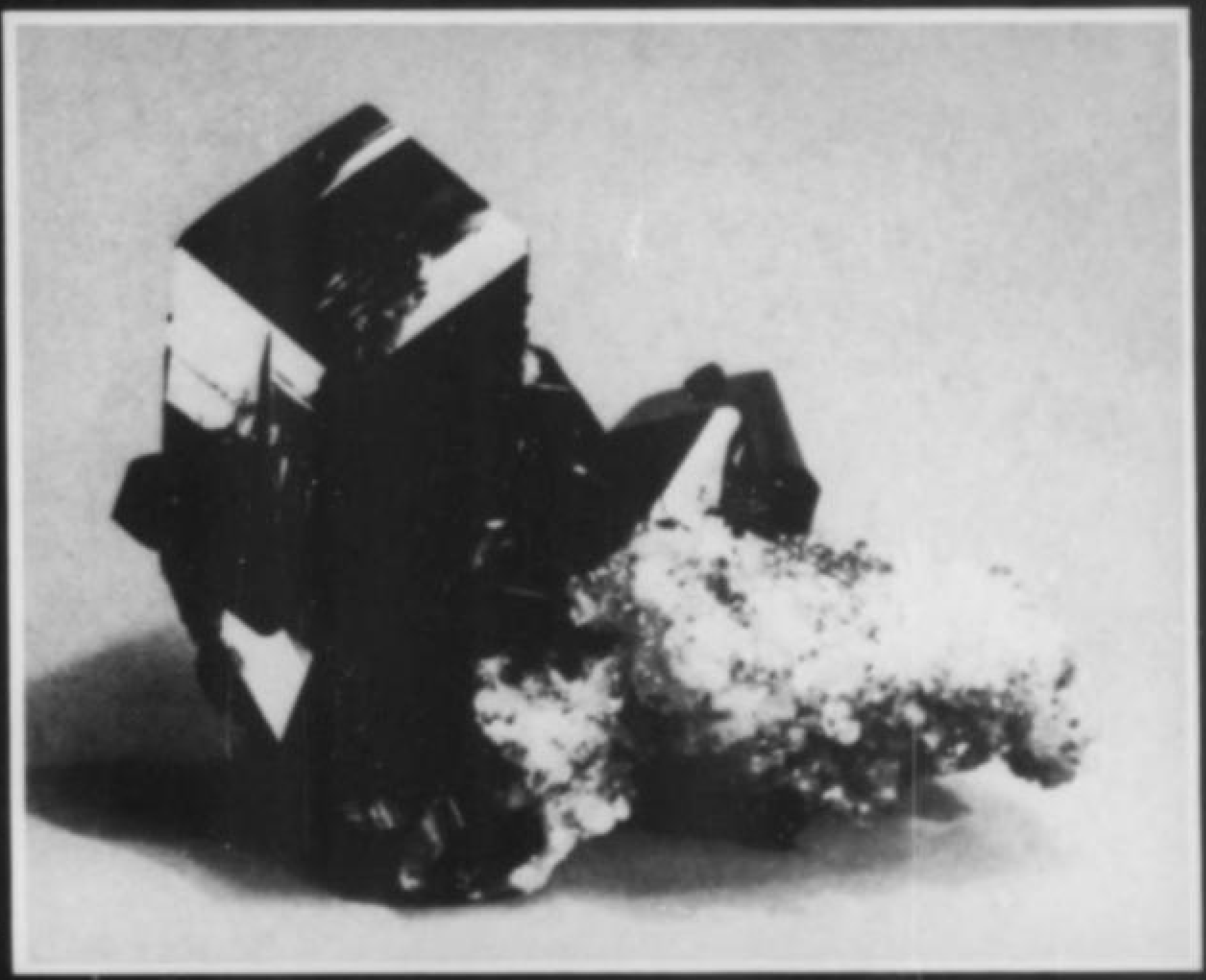
**ANGLESITE**
Color: white
Size: 19.5 cm long
Collection of M. & J. Zweibel
Photo by W. W.

**BARITE**
Size: 5 mm
Collection of the Sorbonne
Photo by N. B.

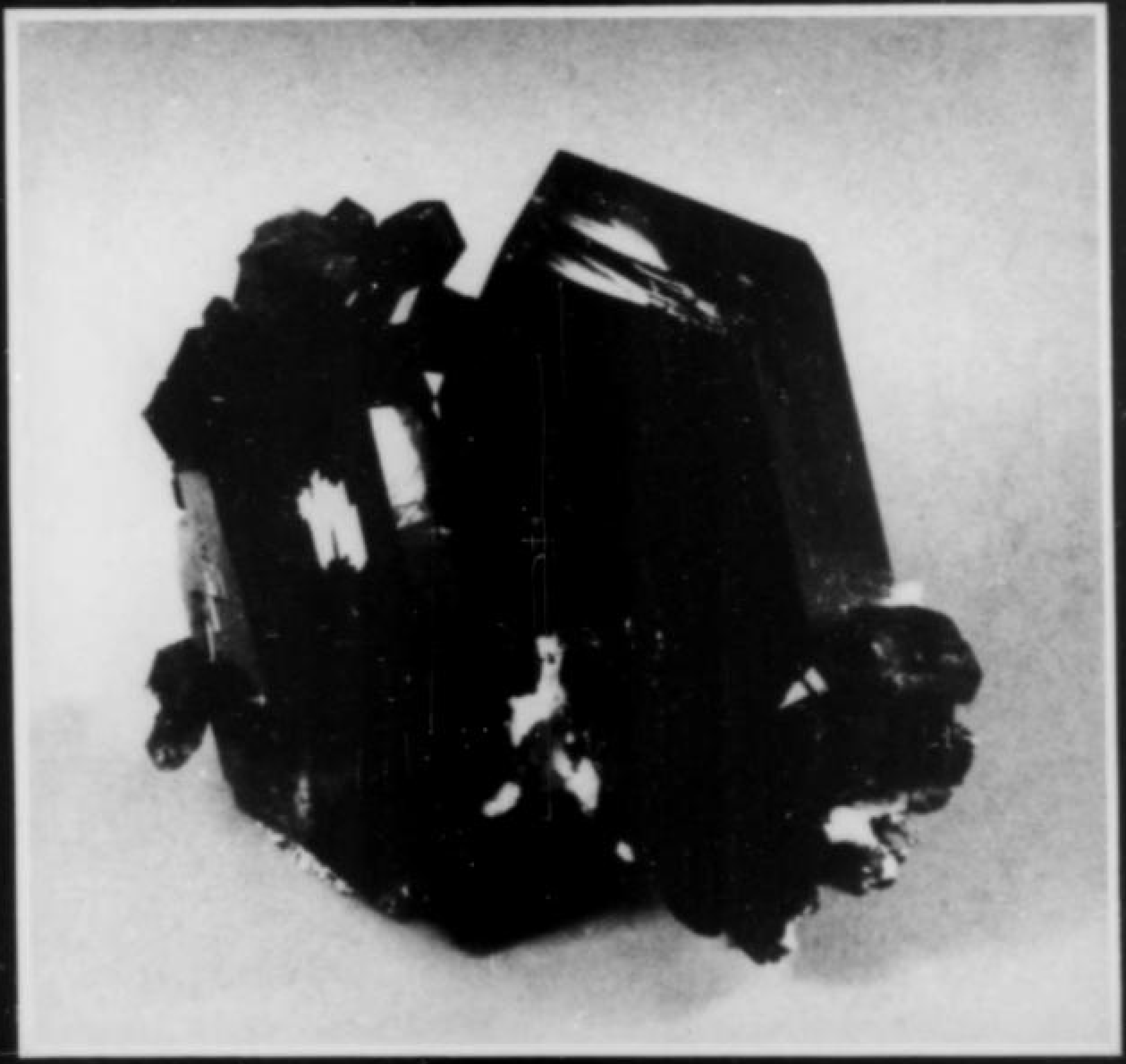


**CHUDOBAITE**
Size: 5 mm
Collection of Technical University of Berlin
Photo by W. L.

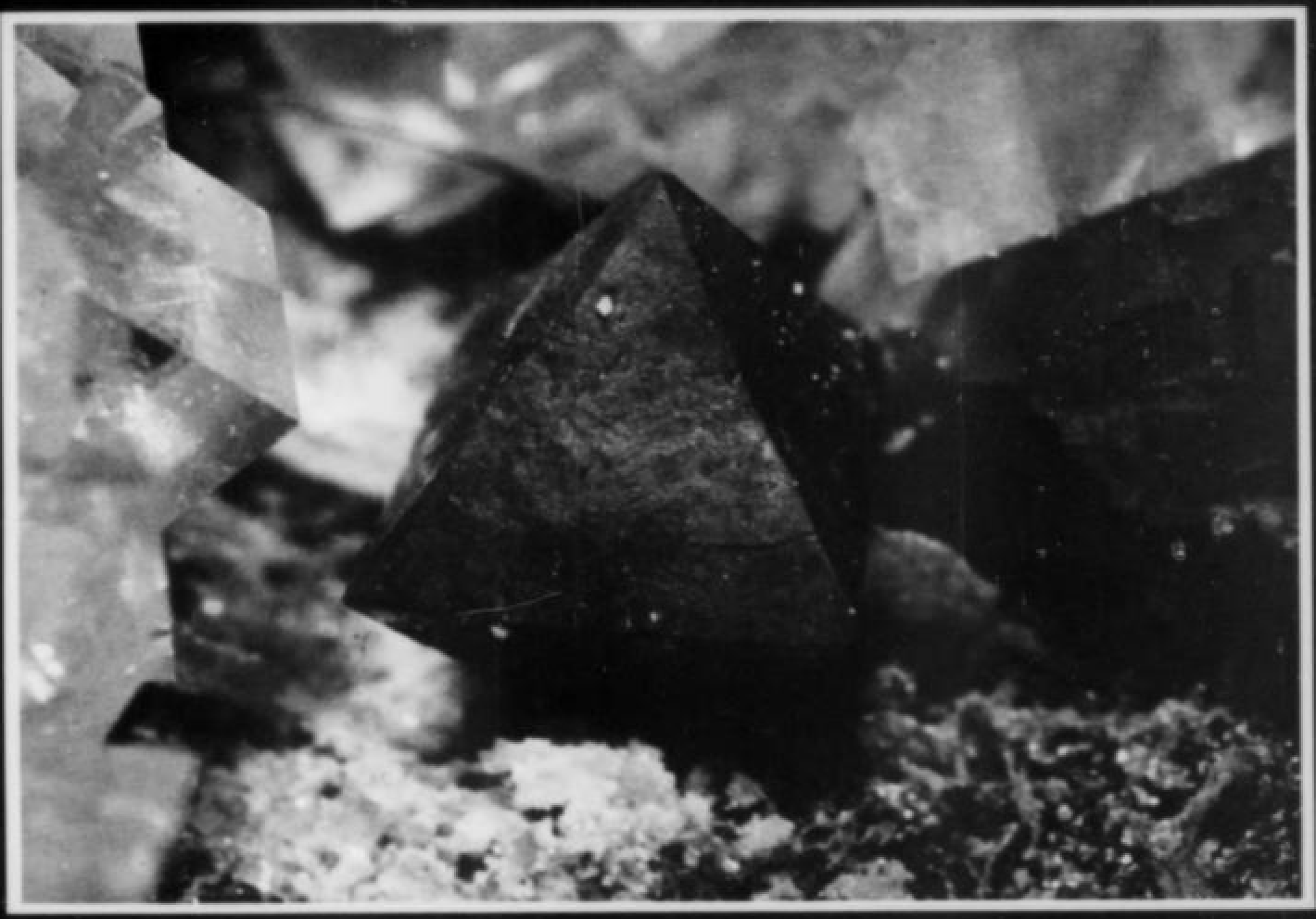
**DIOPTASE** on conichalcite
Size of crystal: 1.3 cm tall
Collection of Olaf Medenbach
Photo by O. M.



**DIOPTASE**
Color: dark green
Size of crystal: 2 cm tall
Collection of Tom Gressman
Photo by W. W.



**DIOPTASE**
Color: dark green
Size: 3 cm tall
Collection of M. & J. Zweibel
Photo by W. W.

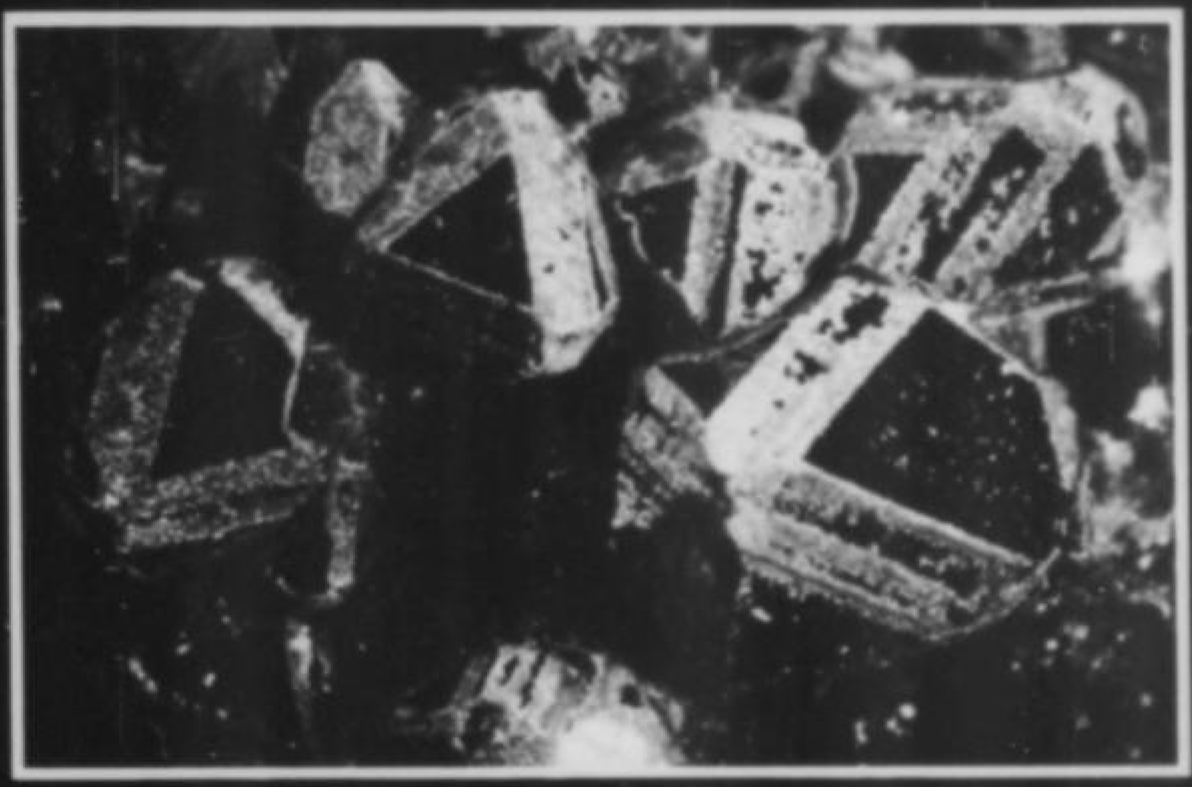


**CUPRITE** on calcite
Size of crystal: 5 mm
Collection of E. Heinrich
Photo by O. M.

**CUPRITE**
Size of crystal: 2 mm
Collection of Werner Lieber
Photo by W. L.

**CUPRITE** var. chalcotrichite
Size: 11 mm across
Collection of Wolfgang Bartelke
Photo by O. M.

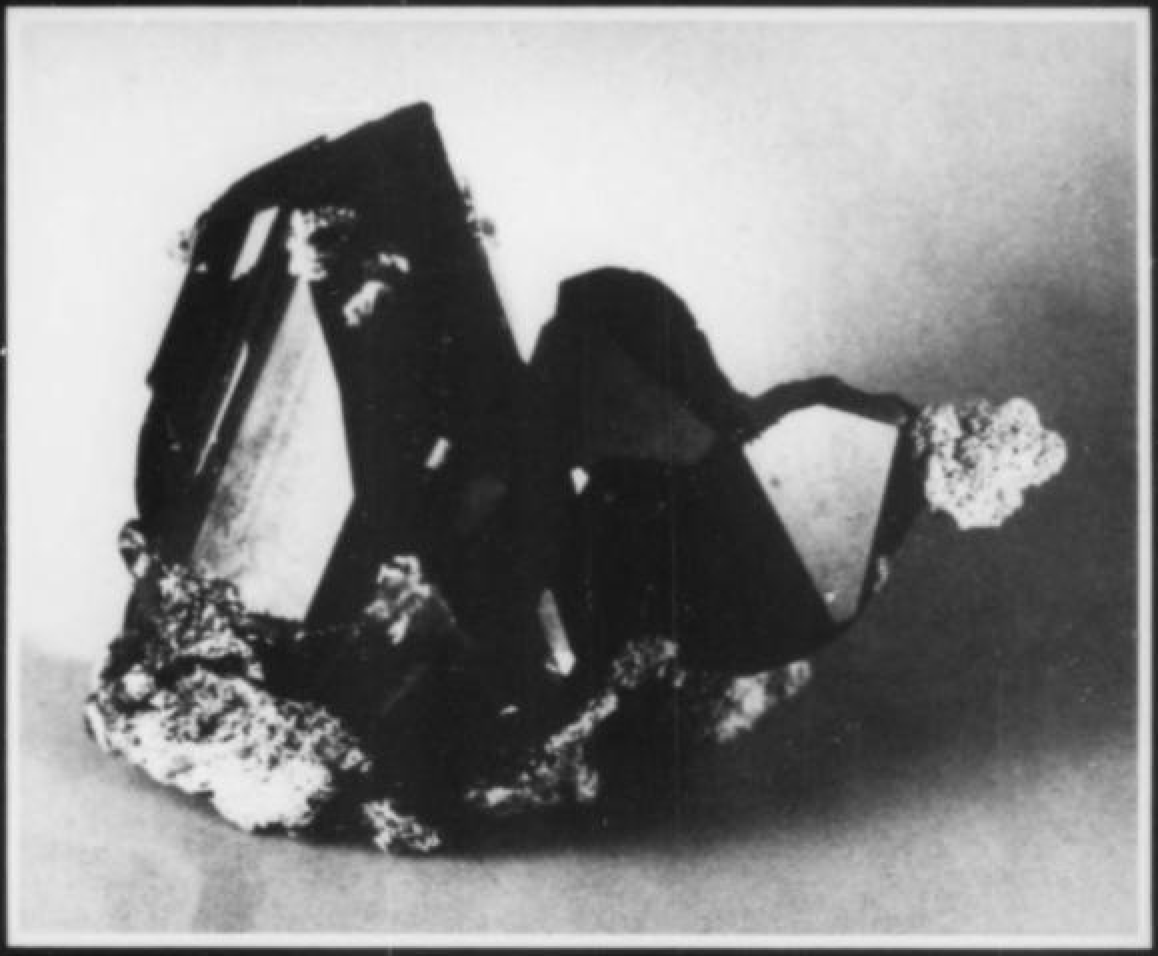
**CUPRITE**
Size: 3 cm
Collection of Richard Kosnar
Photo by R. K.

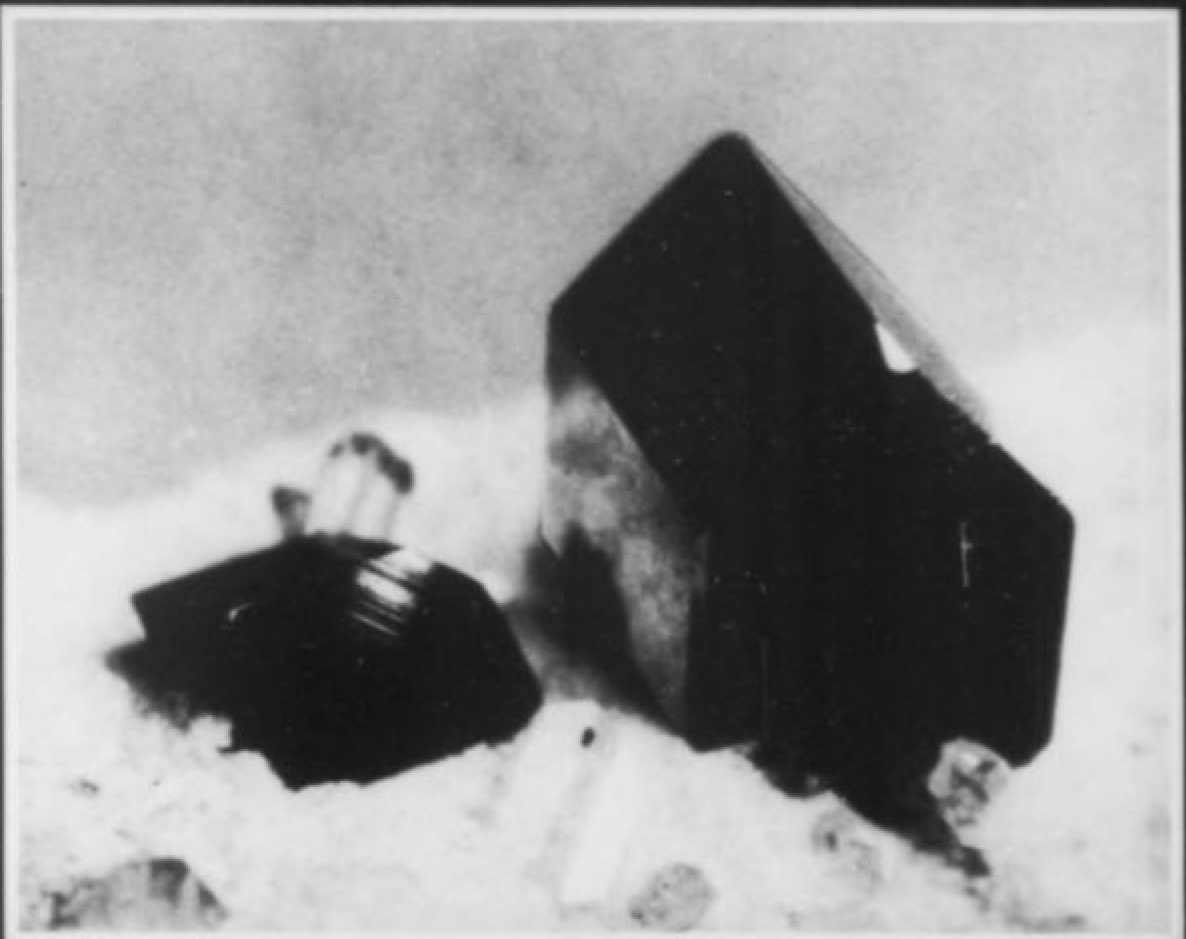


**MALACHITE** on cuprite
Color: pale green
Size of large crystal: 1 cm
Collection of Julius Weber
Photo by J. W. [from The Encyclopedia of Minerals]

**MALACHITE** after azurite
Size: 1 cm wide
Collection of Werner Lieber
Photo by W. L.

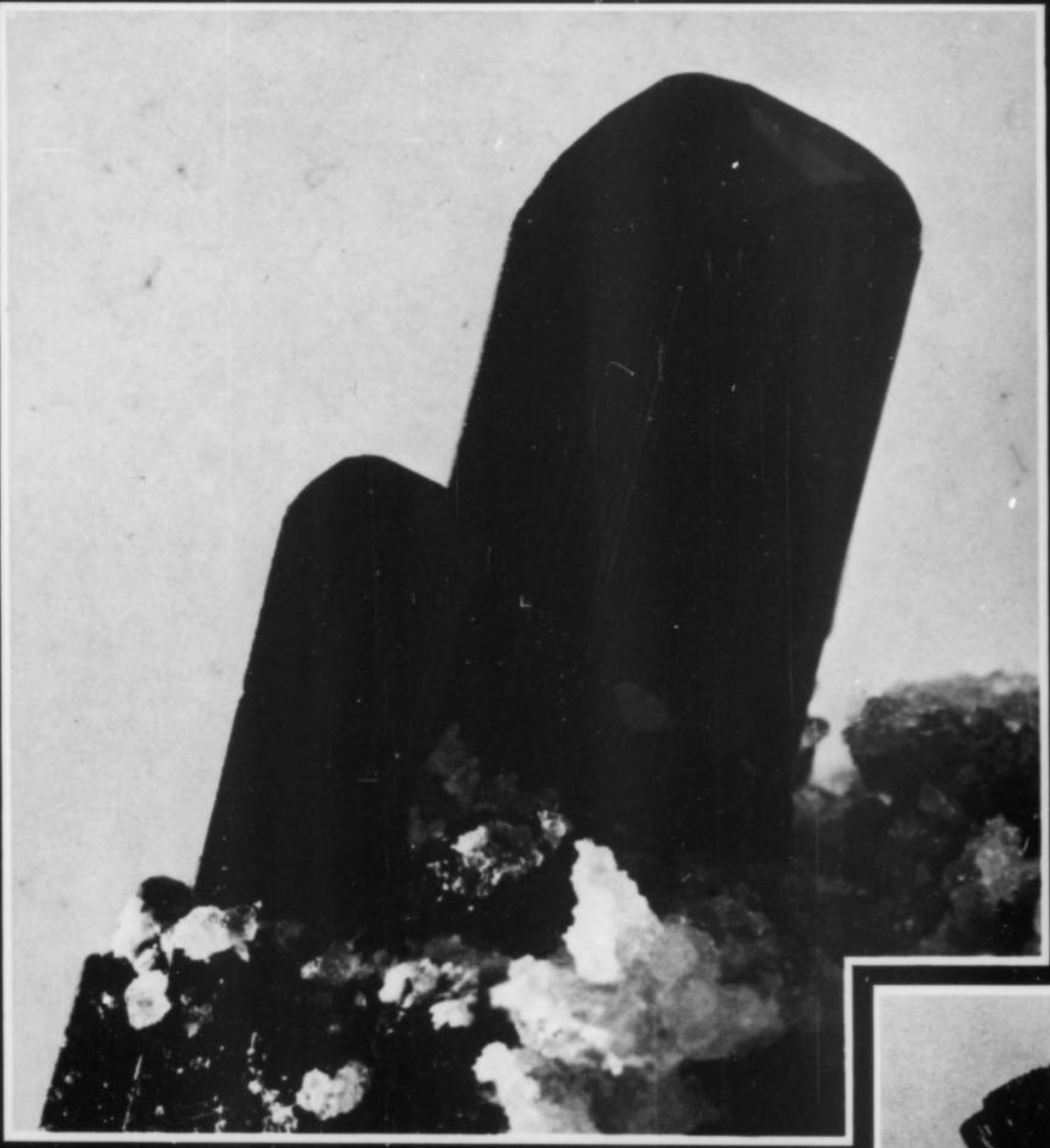
**MALACHITE** on calcite
Size of group: 2.5 cm wide
Collection of Olaf Medenbach
Photo by O. M.



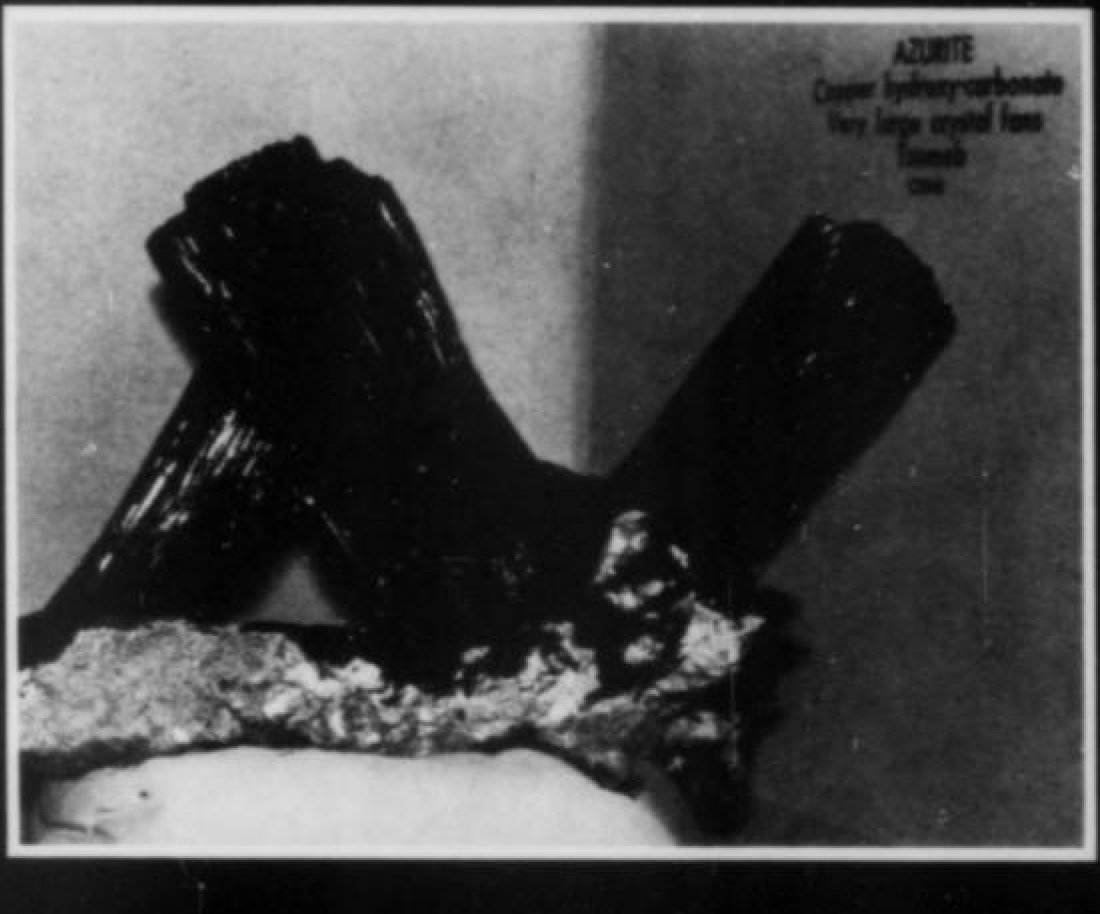


**AZURITE** [above left]
Color: black
Size: 3 cm tall
Collection of M. & J. Zweibel
Photo by W. W.

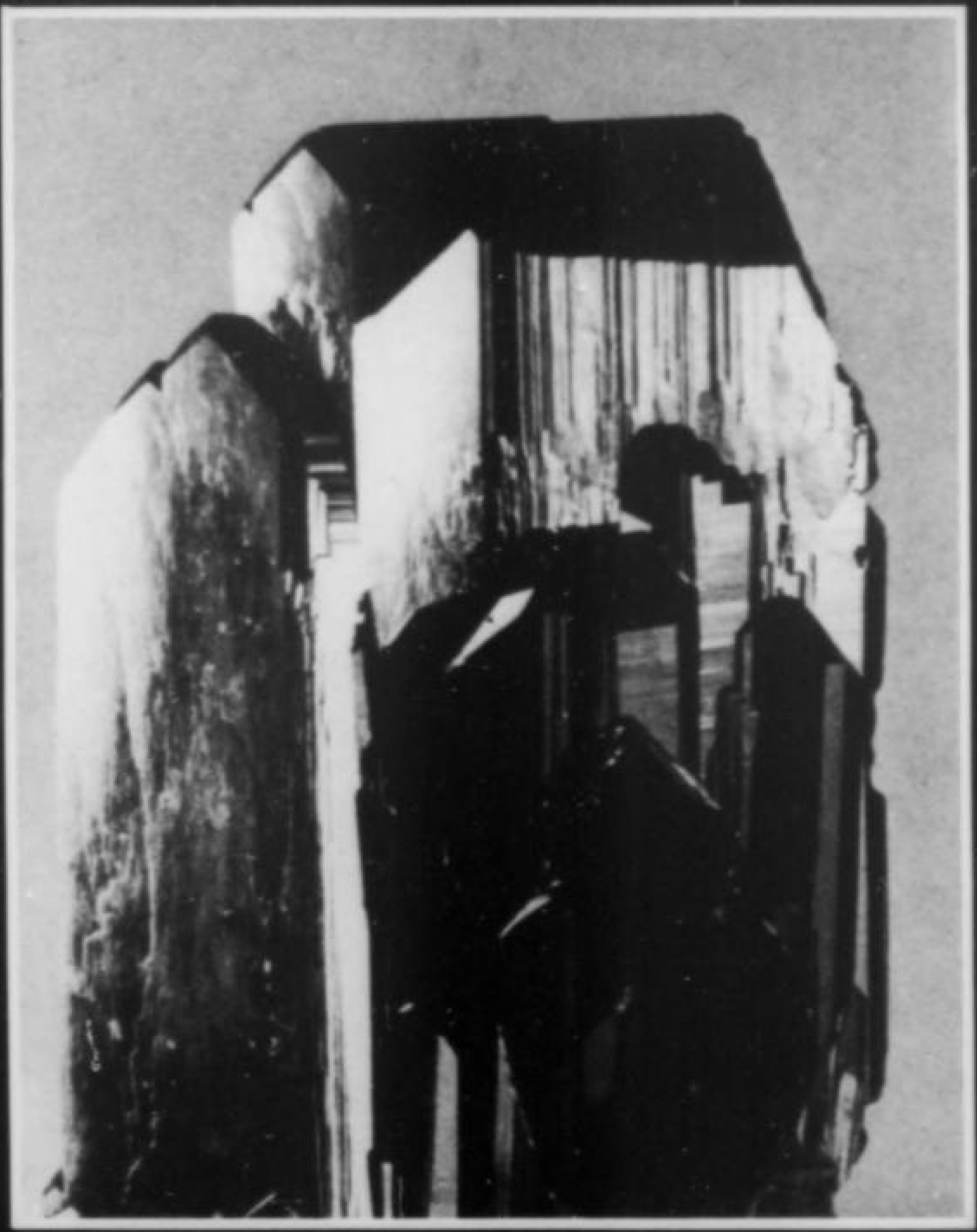
**AZURITE** [above right]
Color: black
Size of crystal: 5 mm
Collection of Eric Offermann
Photo by E. O.



**AZURITE**
Size: 1 cm tall
Collection of Eric Offermann
Photo by E. O.



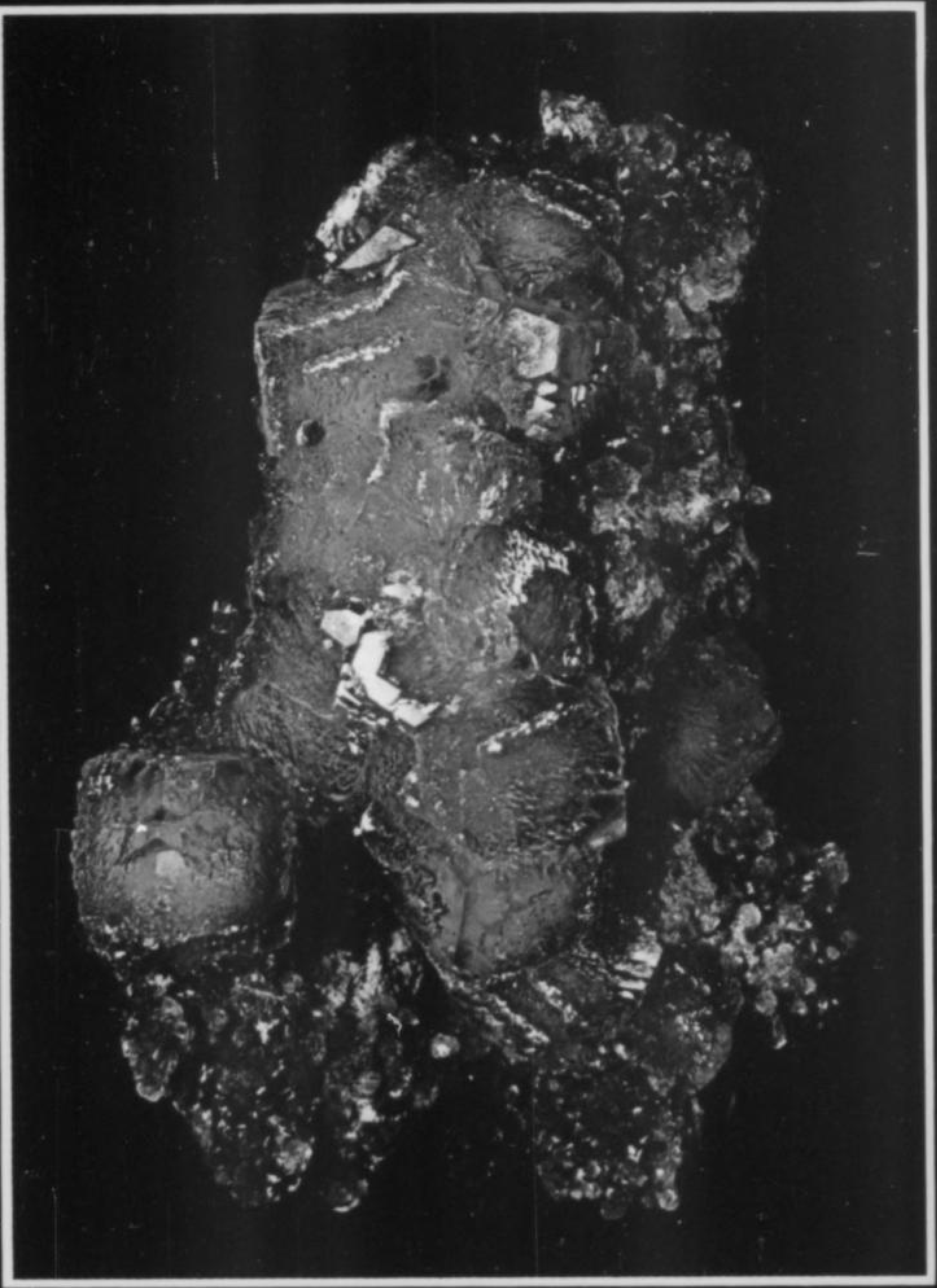
**AZURITE**
Color: bluish black
Size: 22 cm tall
Collection of U.S.N.M. [#C5546]
Photo by W. W.

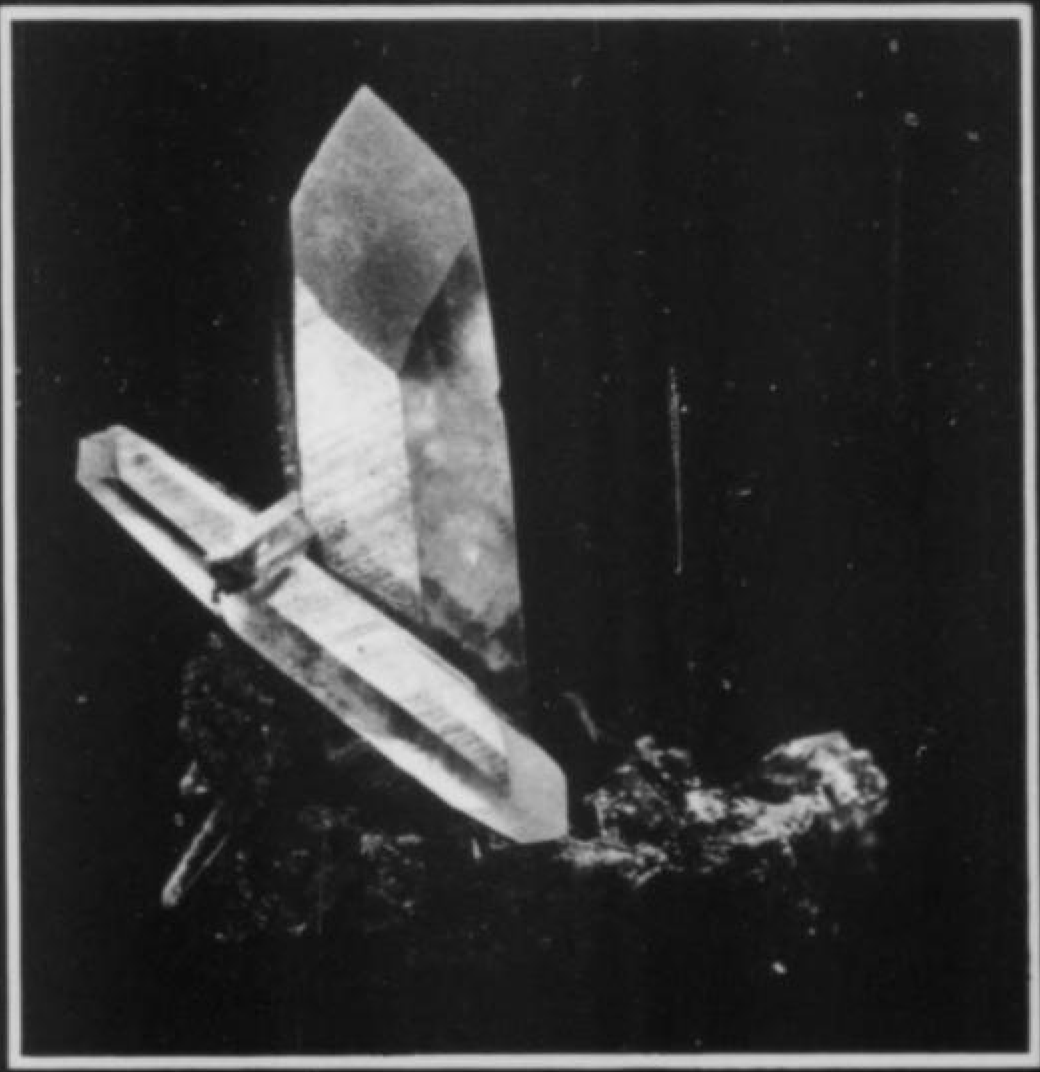


**AZURITE**
Color: black
Size: 3 cm wide
Collection of M. & J. Zweibel
Photo by W. W.

**STOTTITE** [red]
on **BRUNOGEIERITE** [black]
Size of crystal: 4 mm
Collection of Walter Kahn
Photo by O. M.

**LUDLOCKITE** with
zincian siderite
Size: 4 cm wide
Collection: British Museum
[#BM 1969,215]
Photo by F. G.

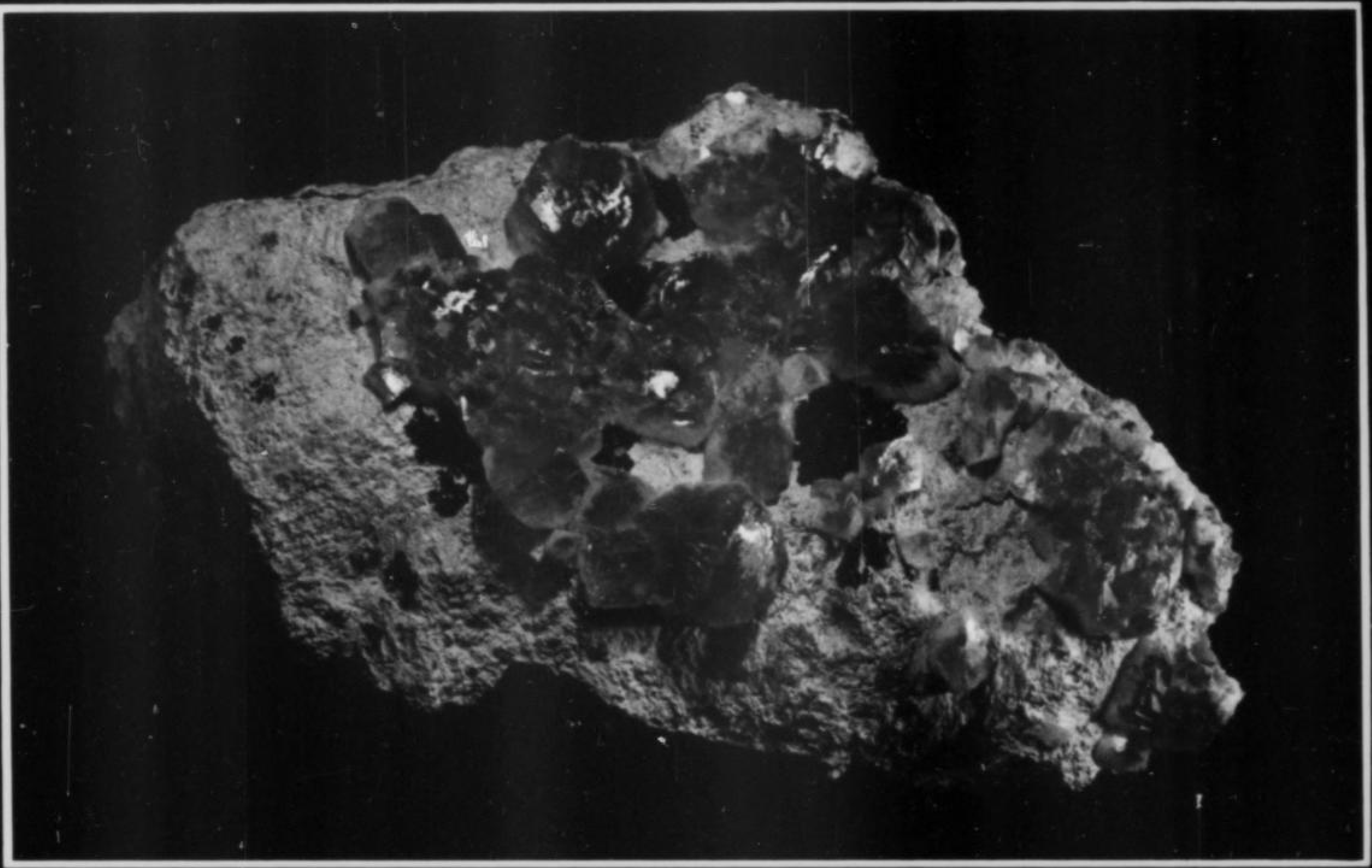




**SMITHSONITE**
Color: pale brown
Size: 2 cm tall
Collection of Olaf Medenbach
Photo by O. M.

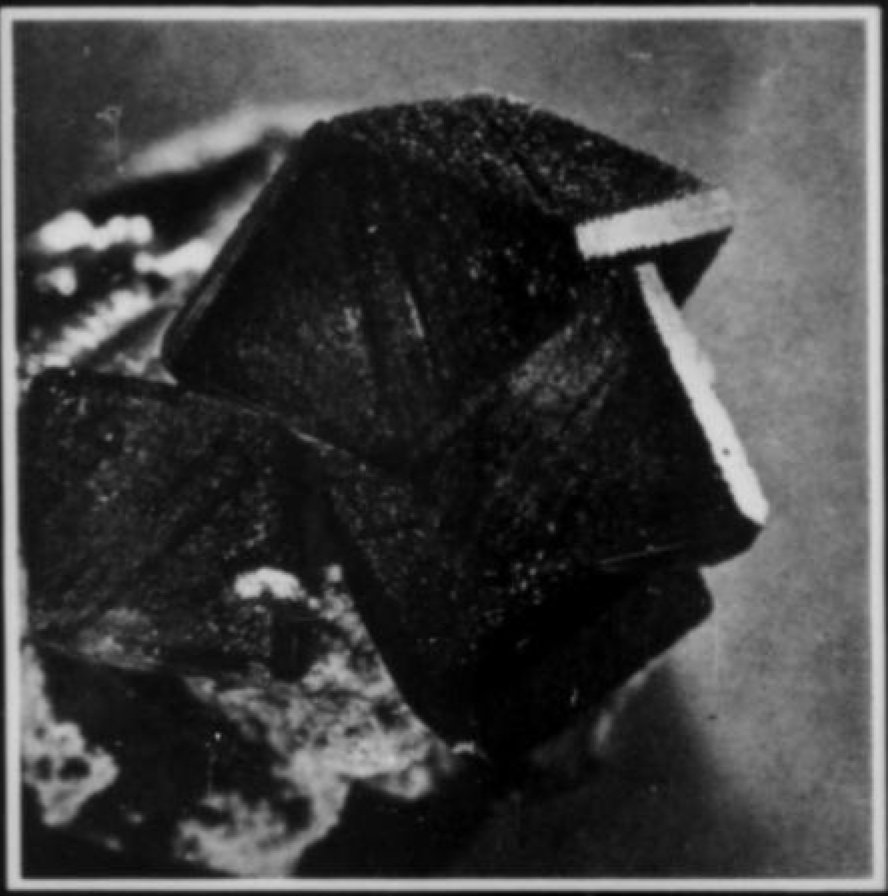
**SMITHSONITE** var cuprosmithsonite
Size: 7.4 cm tall
Collection of M. & J. Zweibel
Photo by B. J.

**SMITHSONITE**
var. cuprosmithsonite
Size: 10 cm wide
Collection of M. & J. Zweibel
Photo by W. W.

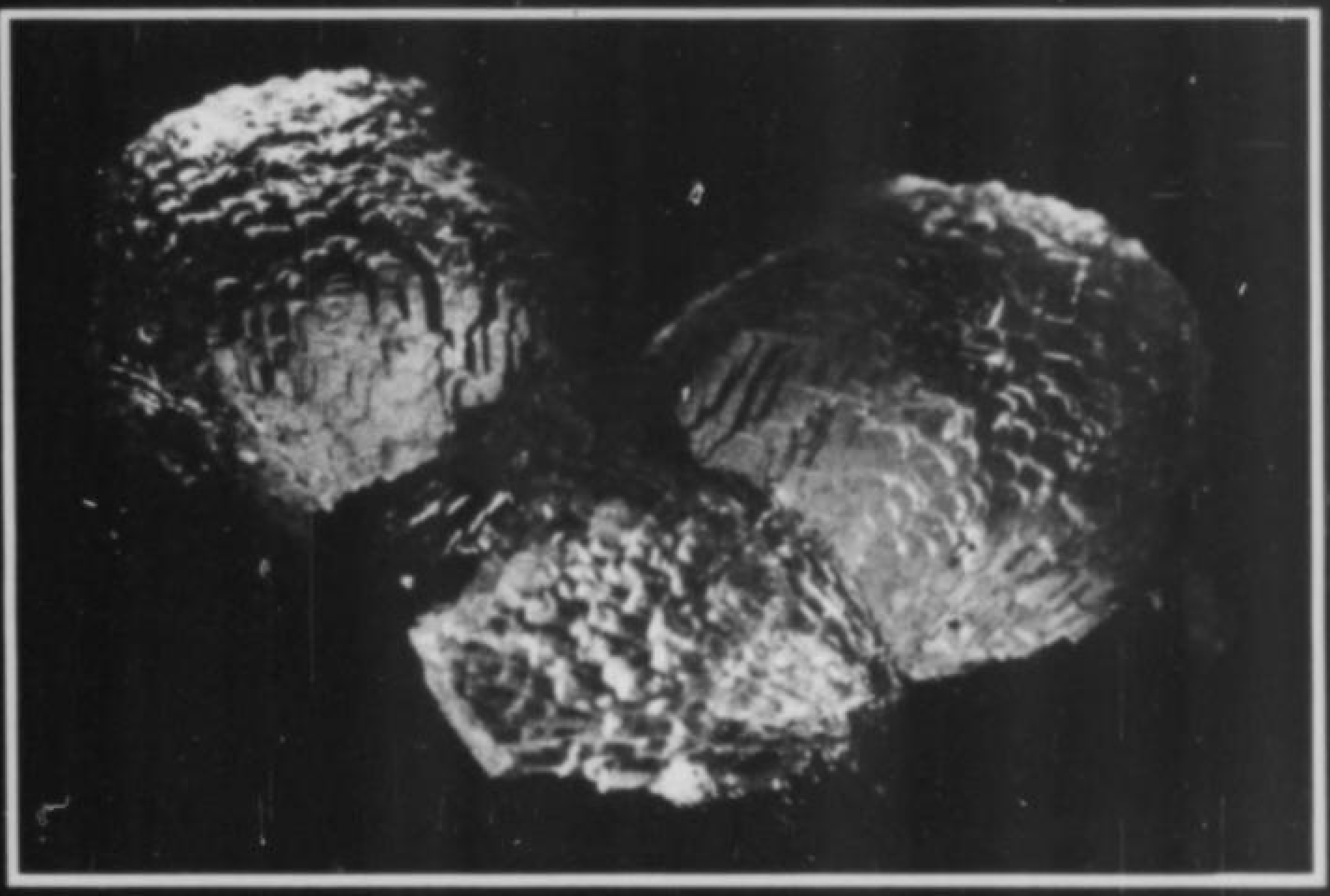


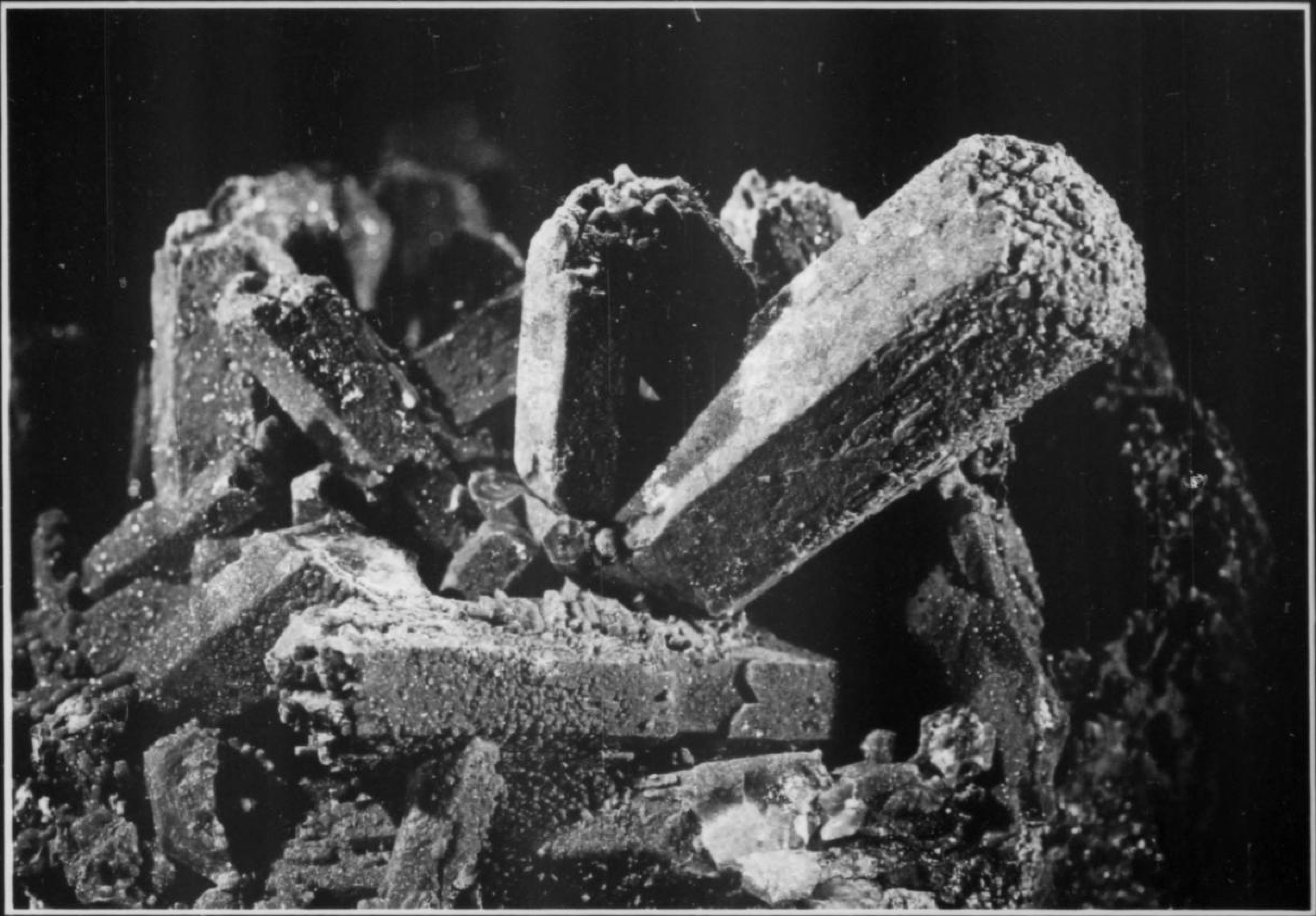
**SMITHSONITE** var. cobaltosmithsonite
Size of large crystal: 2.2 cm
Collection of U.S.N.M. [#135008]
Photo by W. W.

**SMITHSONITE**
Color: yellowish green
Size of crystals: 1 cm
Collection of Werner Lieber
Photo by W. L.



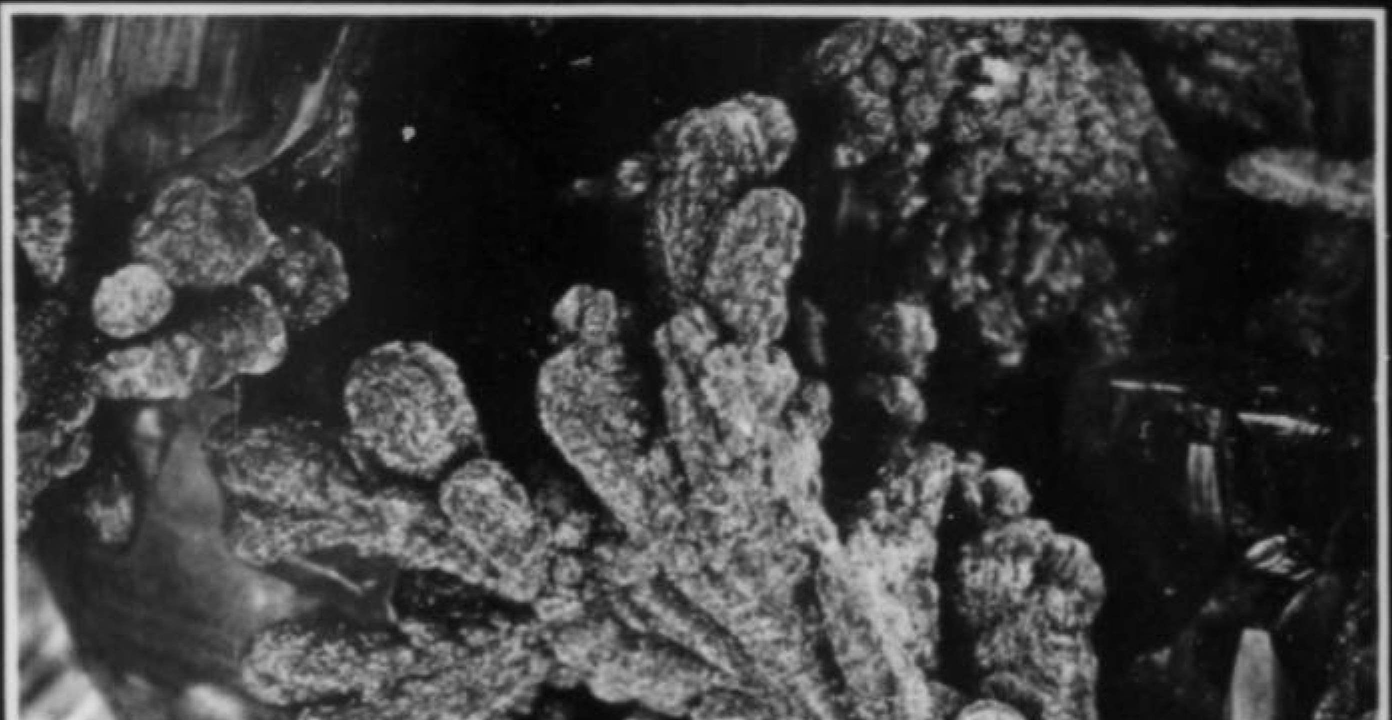
**SMITHSONITE**
Color: white
Size: 2.5 cm across
Collection of Eric Offermann
Photo by E. O.





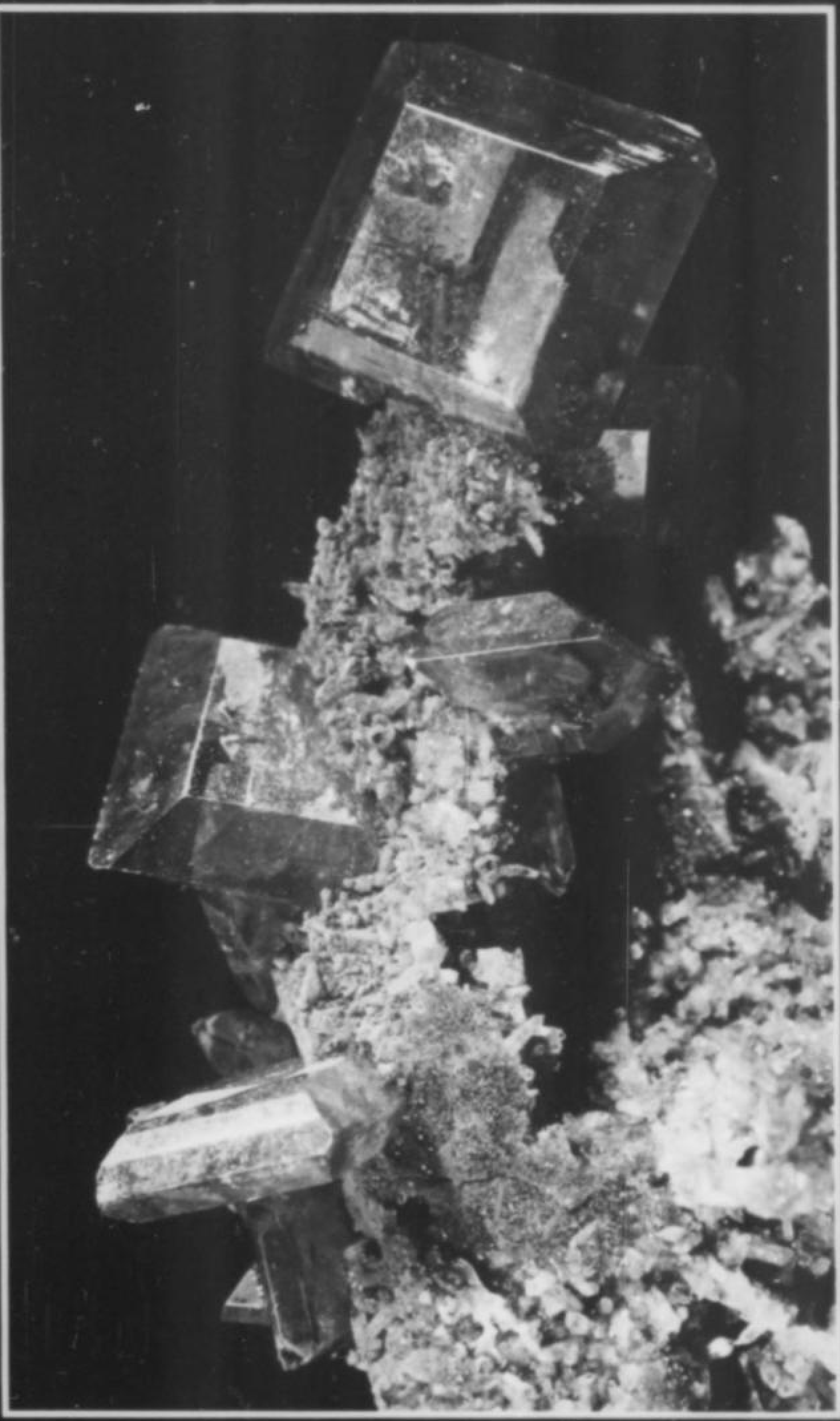
**BAYLDONITE** after mimetite
Size of crystals: 2 cm
Collection of Bonn Institut fur Mineralogie
Photo by O. M.

**BAYLDONITE**
Color: blackish green
Size of crystals: 7 mm
Collection of U.S.N.M. [#135015]
Photo by W. W.

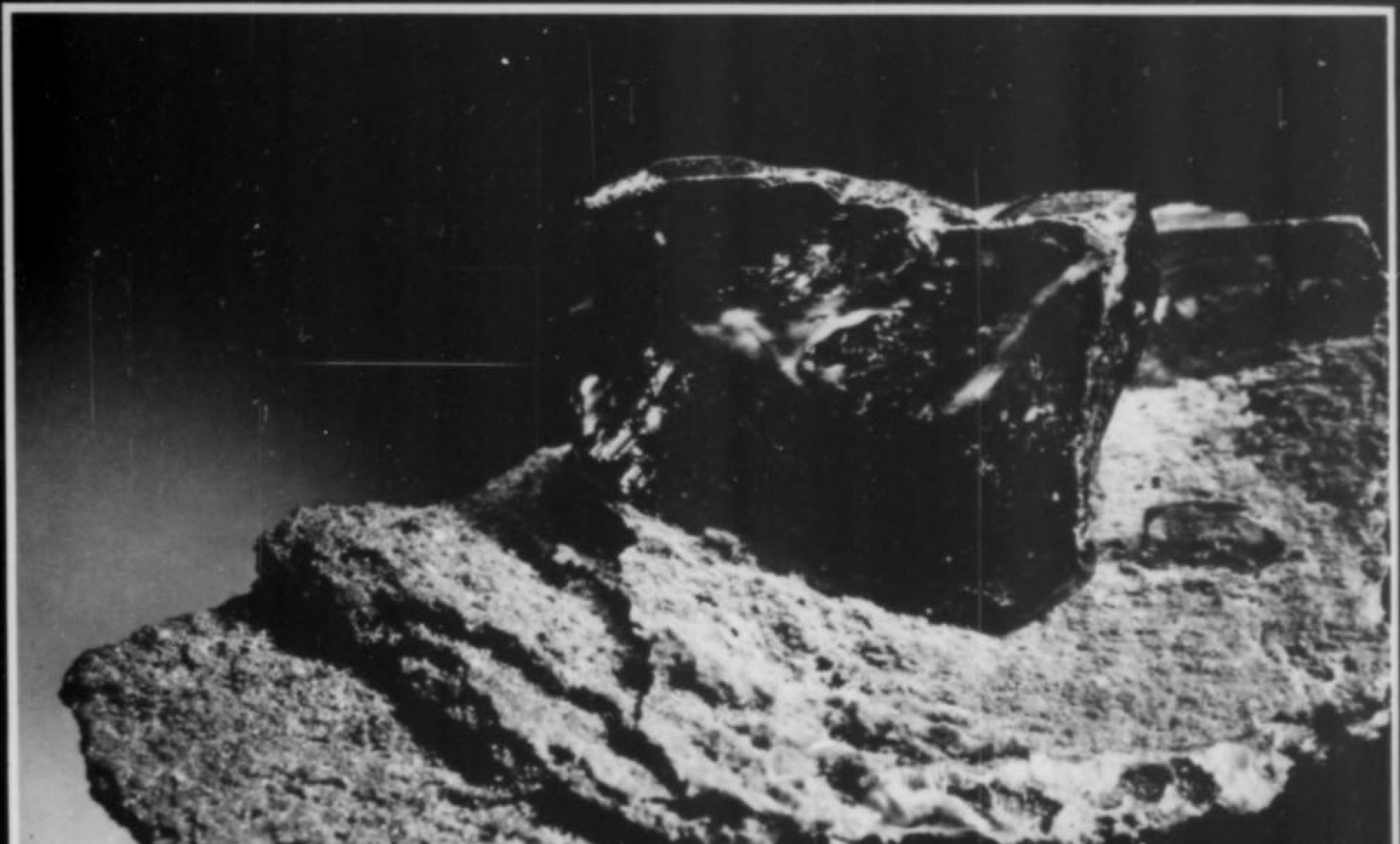


**MOTTRAMITE**
Size: 3 mm wide
Collection of M. & J. Zweibel
Photo by J. W.

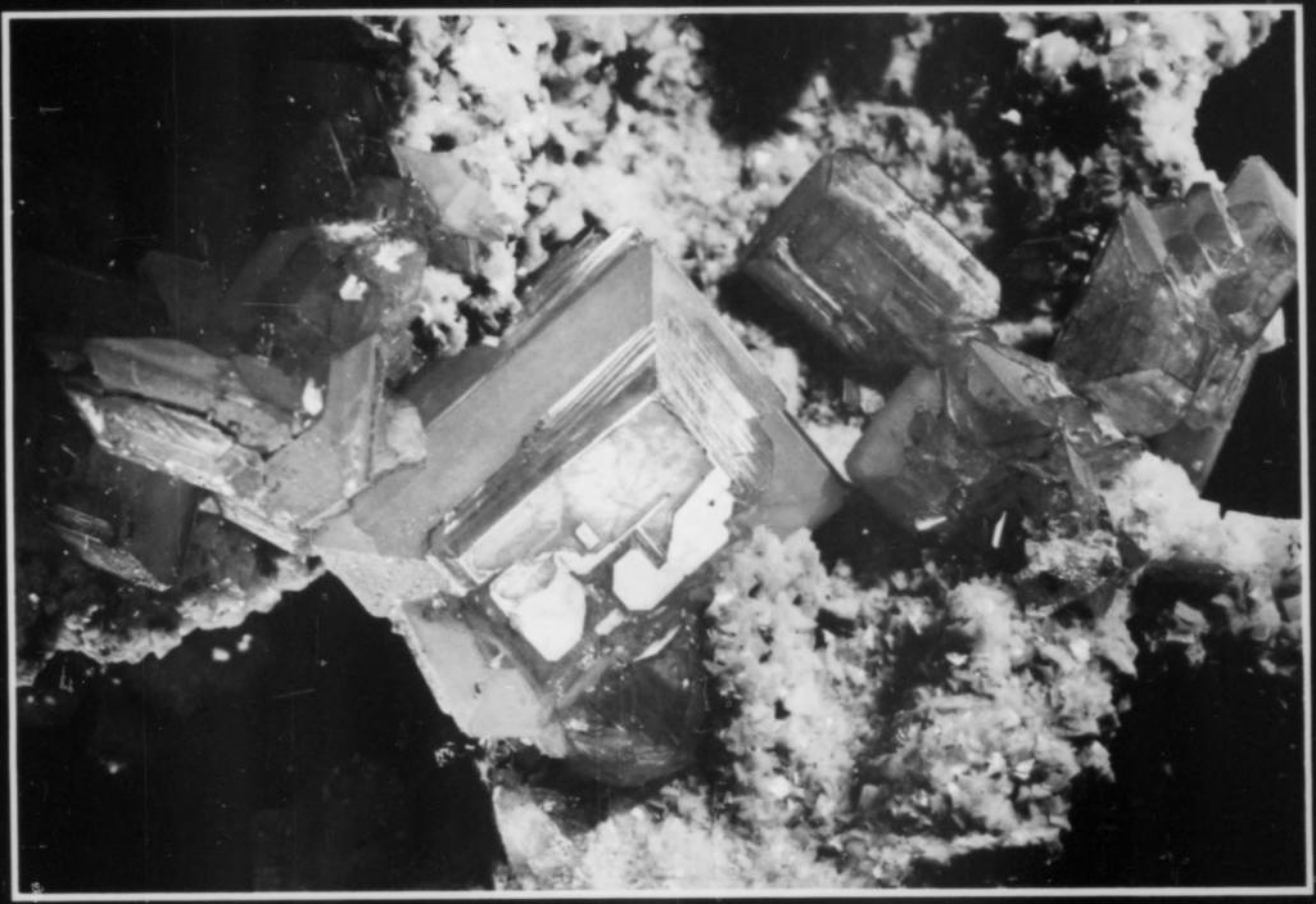
**WULFENITE**
Size: 8 mm
Collection of Eric Offermann
Photo by E. O.



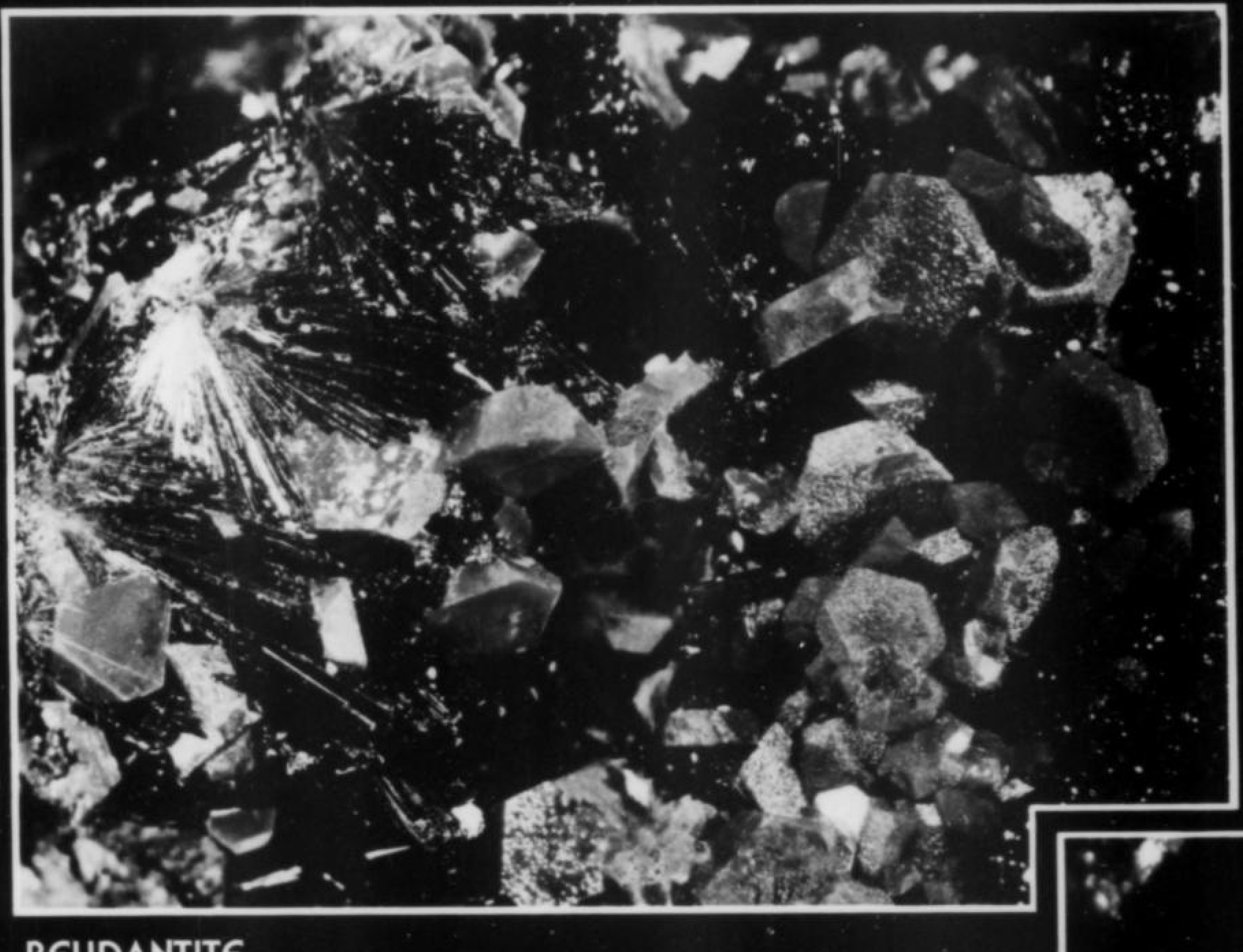
**WULFENITE**
Size of top crystal: 1.2 cm across
Collection of Wolfgang Bartelke
Photo by O. M.



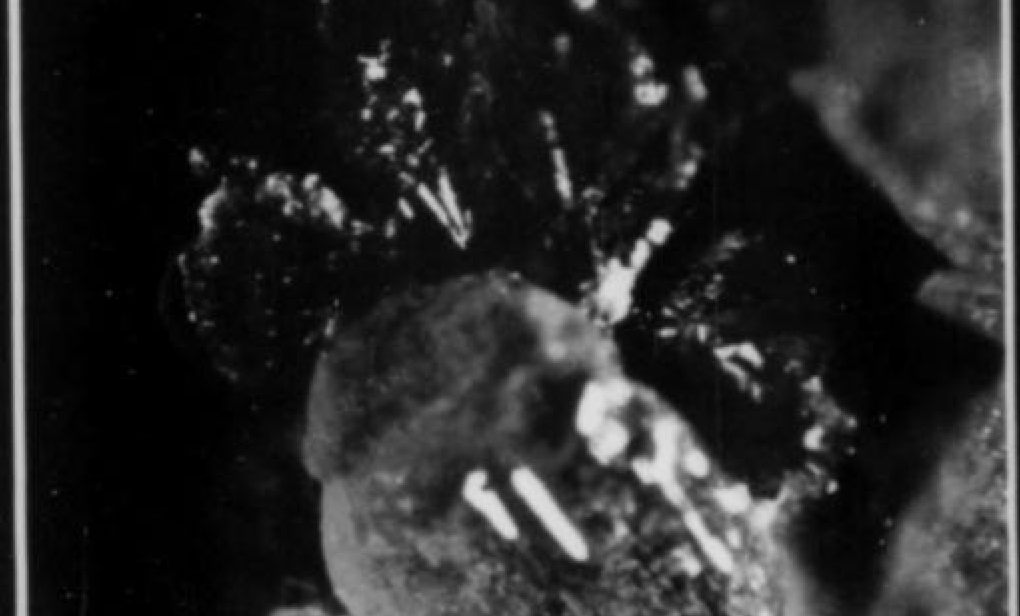
**WULFENITE** var. chillagite
Size of crystal: 1.3 cm across
Collection of Walter Kahn
Photo by O. M.



**WULFENITE**
Size of large crystal: 3 cm across
Collection of Walter Kahn
Photo by O. M.



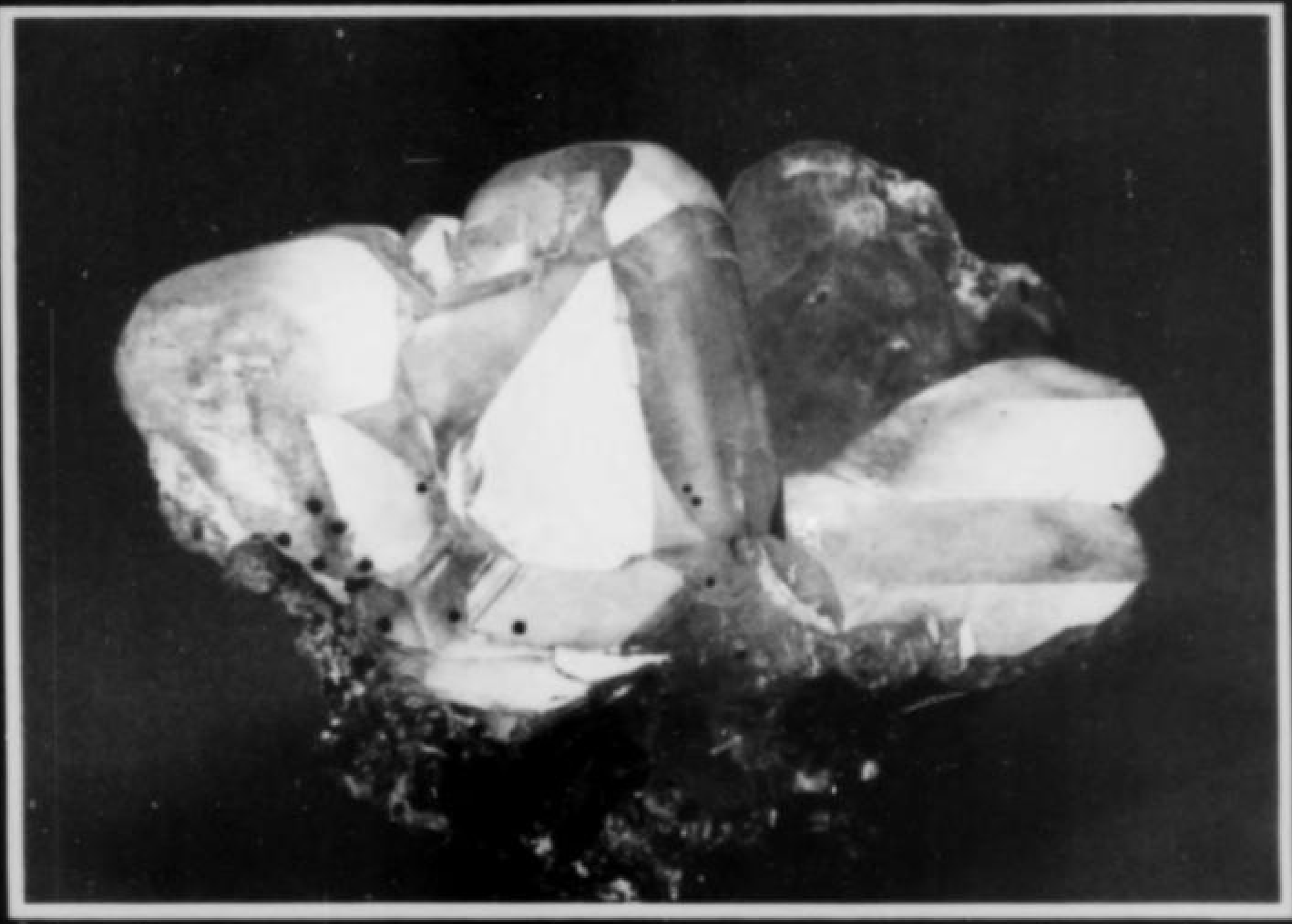
**BEUDANTITE**
with **CARMINITE** [needles]
Size of beudantite crystals: 1 mm
Collection of Walter Kahn
Photo by O. M.



**LAVENDULAN** [dark blue]
Size: 0.1 mm
Collection of M. & J. Zweibel
Photo by J. W.

**WULFENITE**
Color: bright yellow. Size of large crystal: 5 cm
Collection of U.S.N.M. (#115725)
Photo by W. W.

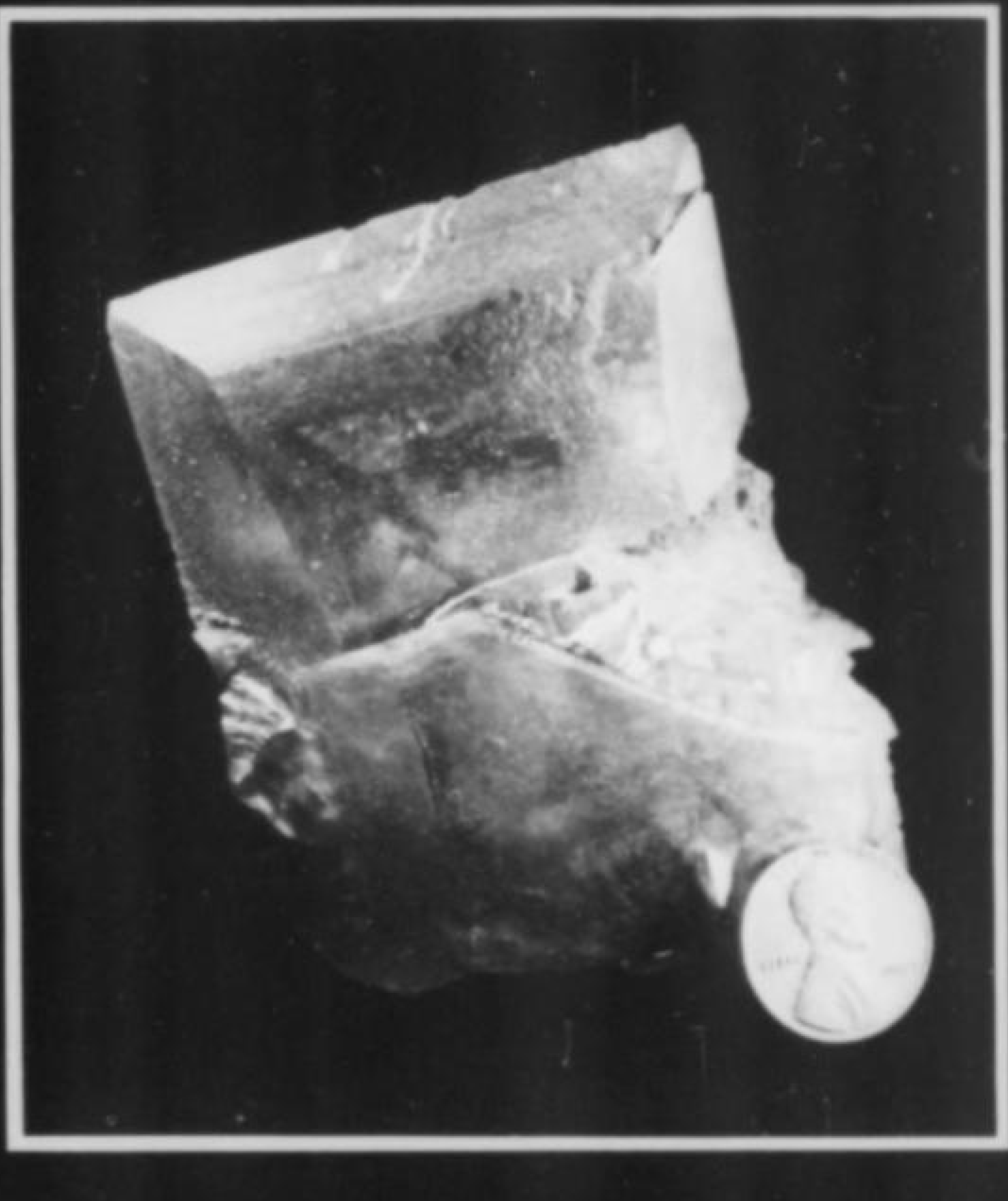
**WULFENITE** on tennantite
Color: gray
Size of large crystal: 9 mm
Collection of U.S.N.M. (#113240)
Photo by W. W.

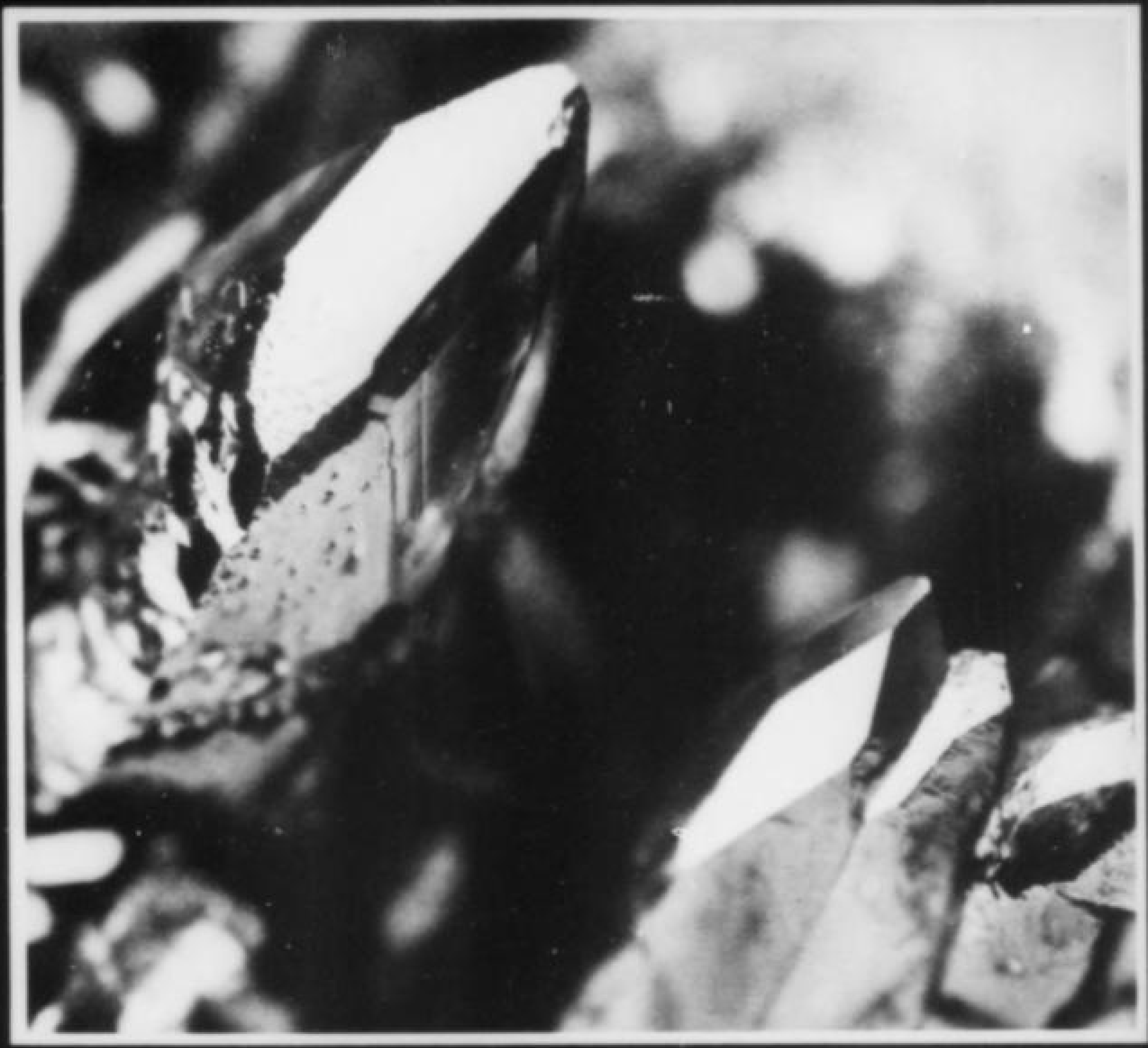


**WULFENITE**
Color: very pale yellow. Size: 7.5 cm wide
Collection of U.S.N.M. (#121119)
Photo by W. W.

**WULFENITE**
Color: sherry brown
Size: 3.5 cm wide
Collection of U.S.N.M. (#115726)
Photo by W. W.

**WULFENITE**
Color: pale purplish brown
Size: 8 cm tall
Collection of M. & J. Zweibel
Photo by W. W.



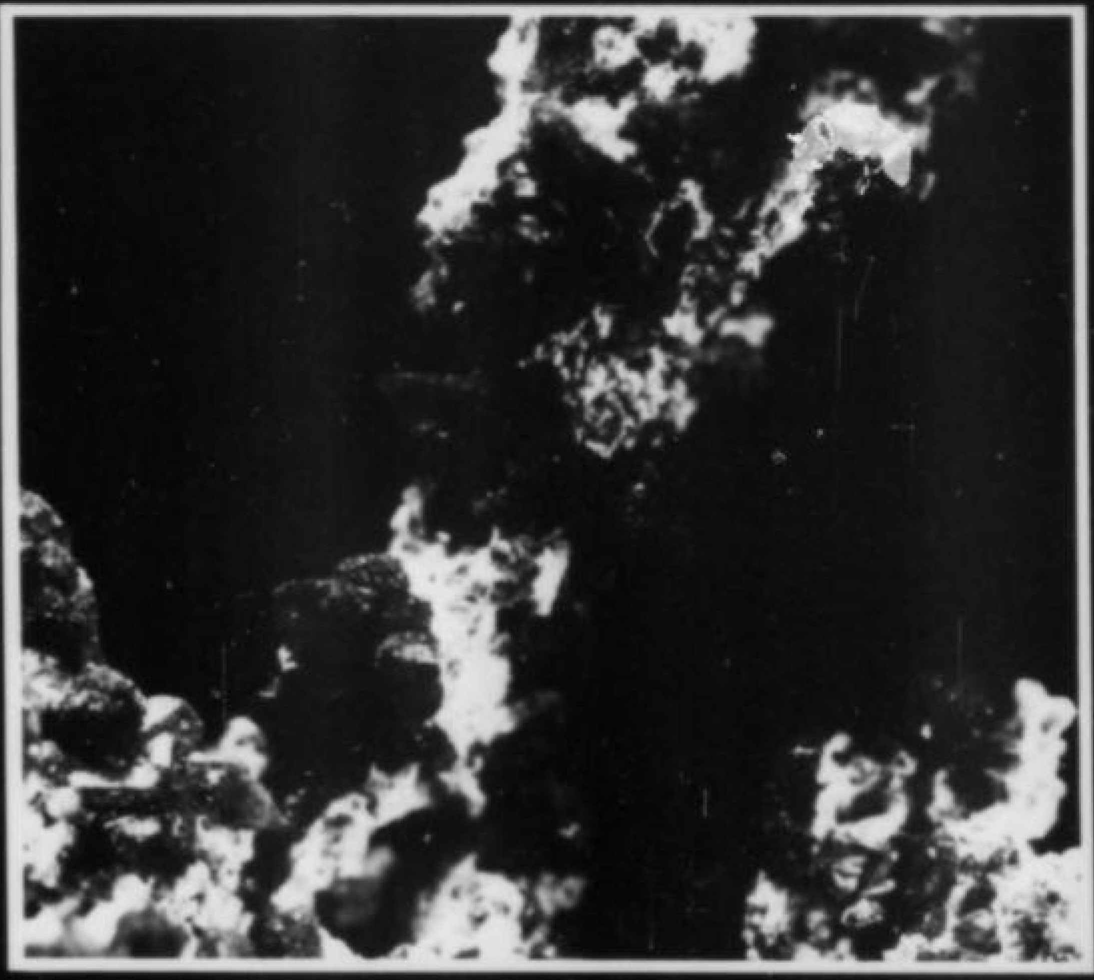


**PLANCHEITE**
Color: medium cyan-blue
Size: 0.3 mm across
Collection of M. & J. Zweibel
Photo by J. W.

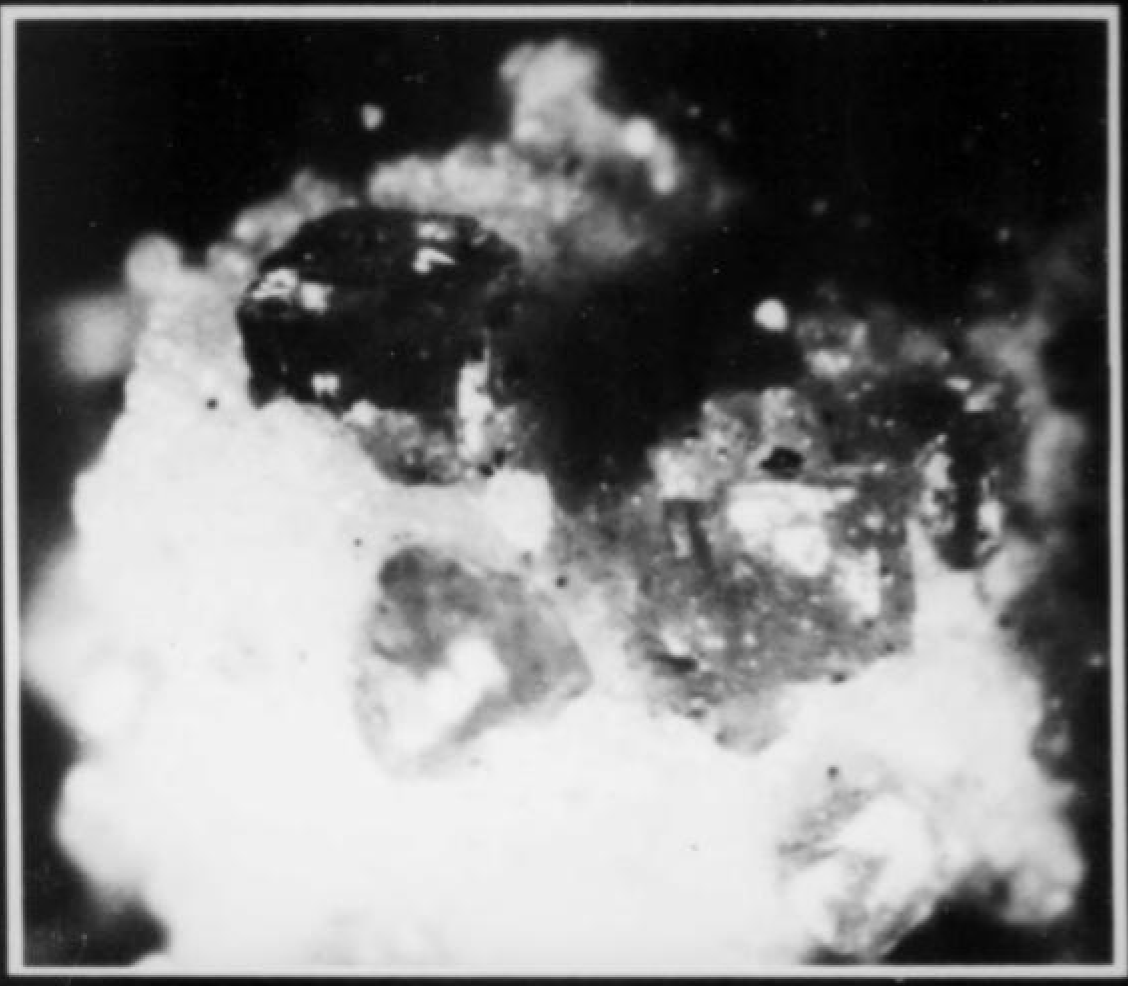
**WULFENITE**
Color: very dark blue
Width of crystal: 1.5 mm
Collection of Gunther Keller
Photo by E. O.

**PLANCHEITE** coating on
malachite after azurite
Color: very pale blue
Size: 6.5 cm across
Collection of U.S.N.M. (#B10984)
Photo by W. W.

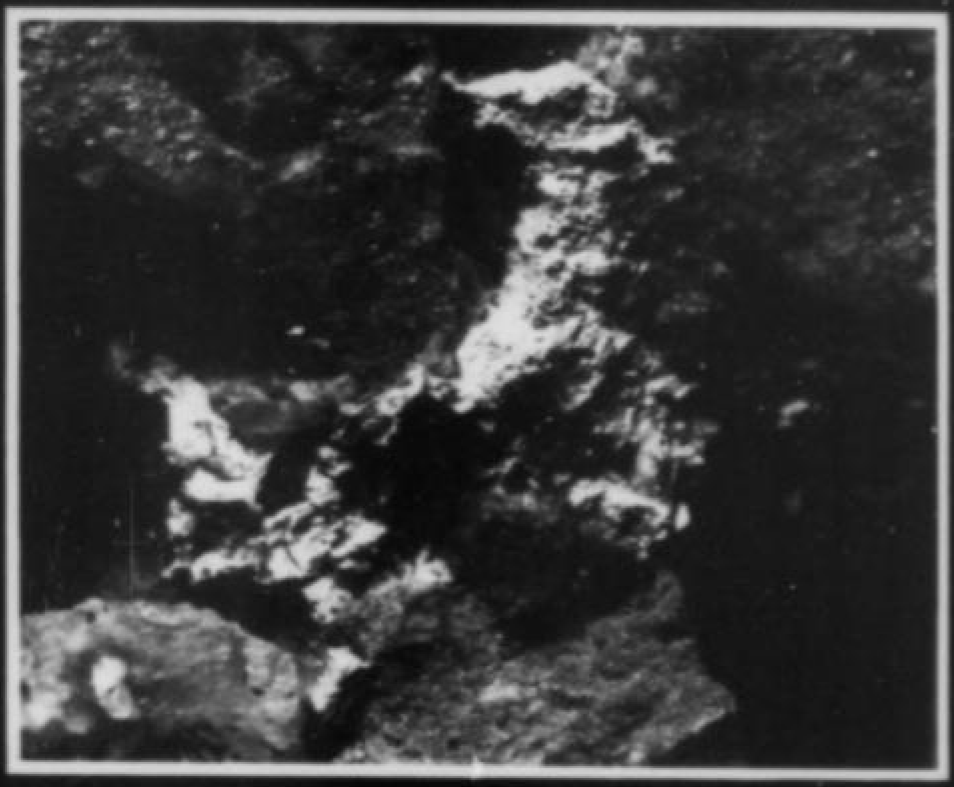
**DUFTITE-ALPHA**
Color: dark green
Size of crystals: 0.3 mm
Collection of U.S.N.M. (#R4101)
Photo by W. W.



**DUFTITE-BETA** on calcite
Color: yellowish green
Size of crystals: 0.2 mm
Collection of M. & J. Zweibel Photo by J. W.



**GOLD** in quartz
Color: golden yellow
Size of gold mass: 1 cm across
Collection of U.S.N.M. (#R8638)
Photo by W. W.



**CHRYSOCOLLA** in chalcedony
Color: bluish green. Size: 7.5 cm wide
Collection of U.S.N.M. (#B17037)
Photo by W. W.

**BINDHEIMITE**
Color: yellow
Size: 3 cm across
Collection of U.S.N.M. (#R8696-2)
Photo by W. W.

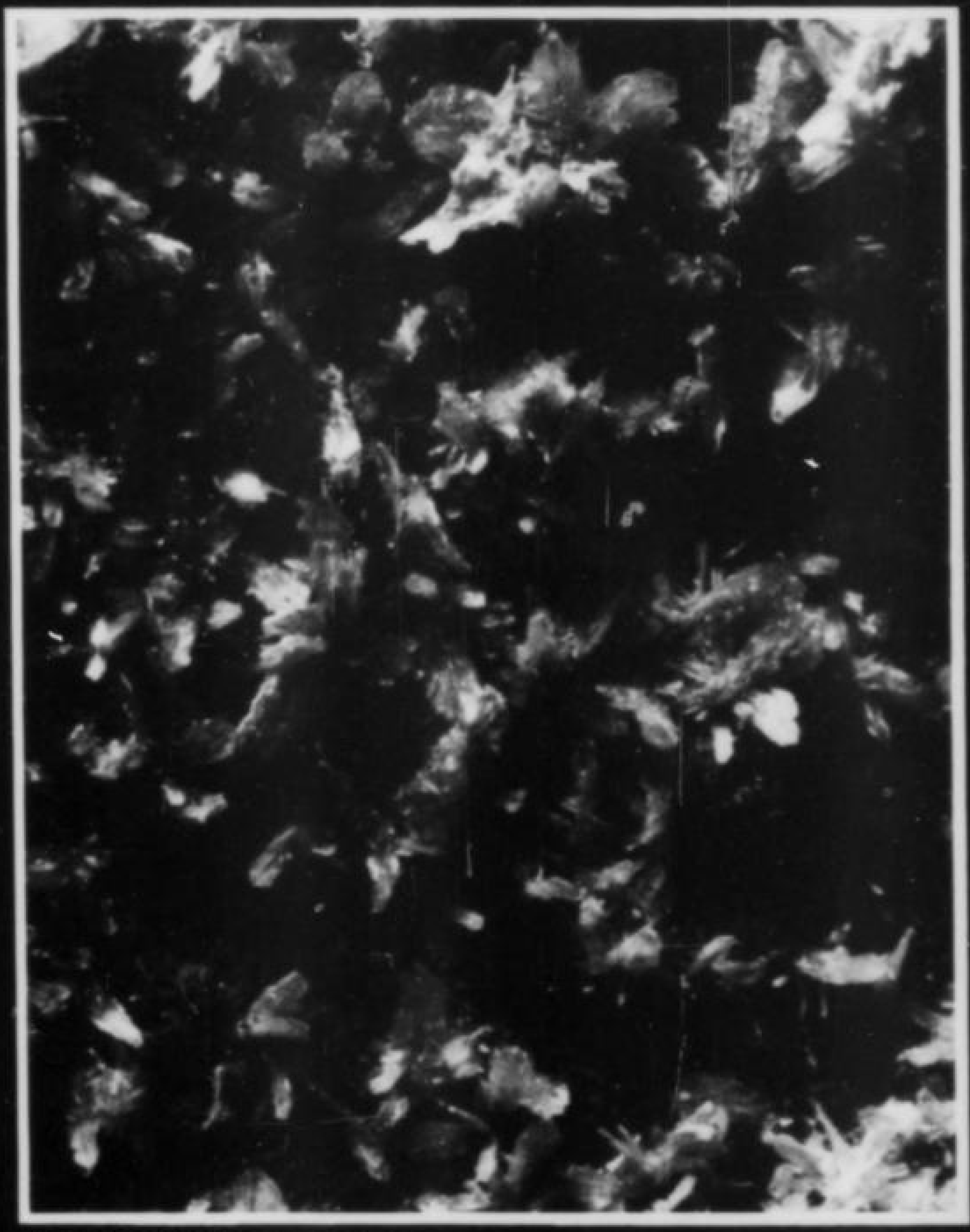
**KAOLINITE**
Color: white. Size: 4 cm
Collection of U.S.N.M. (#R8649)
Photo by W. W.

Massive ore minerals:
(a) **CHALCOPYRITE**; red and yellow tarnish; U.S.N.M. #B2925
(b) **FAMATINITE**; sooty black; U.S.N.M. #B3698
(c) **GERMANITE**; pinkish purplish gray; U.S.N.M. #R8685
(d) **DJURLEITE**; gray; U.S.N.M. #C387
(e) **CHALCOCITE**; gray; U.S.N.M. #C5577
(f) **BORNITE**; pale blue and yellow tarnish; 10 cm wide; U.S.N.M. #B3255
Photo by W. W.

**BROCHANTITE**
Color: very dark green
Size of crystals: 1 mm
Collection of U.S.N.M. (#B8145)
Photo by W. W.

**FLEISCHERITE** (pink, radiating)
with **MELANOTEKITE** (black spherules)
Size of fleischerite spray: 8 mm
Collection of Olaf Medenbach
Photo by O. M.

**LINARITE** with cerussite
Color: deep blue
Size of crystals: 2 mm
Collection of U.S.N.M. (#R8639)
Photo by W. W.

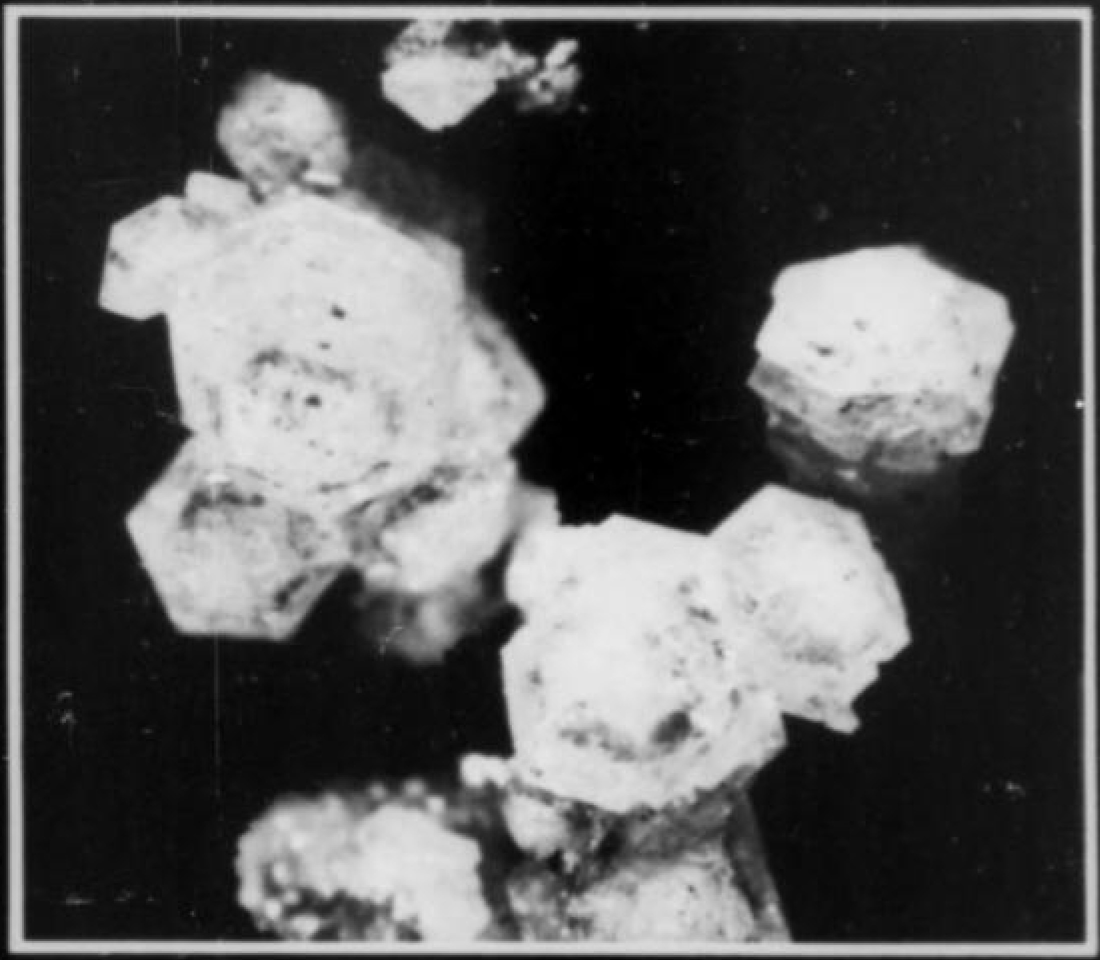


**ARSENTSUMEBITE**
Color: medium green. Size of crystals: 0.5 mm
Collection of U.S.N.M. (#C6651)
Photo by W. W.

**DUNDASITE**
Color: very pale blue
Size: 1 mm
Collection of
Olaf Medenbach
Photo by O. M.

**PHOSGENITE** cleavage fragment
Color: dark brown. Size: 3.5 cm
Collection of U.S.N.M. (#B11981)
Photo by W. W.

**COPPER** on calcite
Color: copper-red
Size: 5.5 cm across
Collection of U.S.N.M. (#115743)
Photo by W. W.



**WITHERITE**
Color: white. Size of crystals: 0.3 mm
Collection of Julius Weber
Photo by J. W.

**SIDERITE**
Color: reddish brownish yellow
Size of crystals: 3 mm
Collection of U.S.N.M. (#R11313-2)
Photo by W. W.

**LEPIDOCROCITE** (black)
with smithsonite crystals
Size of smithsonite crystals: 2 mm
Collection of Dwight Weber
Photo by D. W.

# XI RESEARCH: PAPERS ON TSUMEB MINERALOGY

## Blue wulfenite from Tsumeb

by

**Peter G. Embrey*, Pete J. Dunn**, and Andrew M. Clark***
**(*Dept. of Mineralogy, British Museum (Natural History),**
**Cromwell Road, London SW7 5BD, England.)**
**(**Dept. of Mineral Sciences, Smithsonian Institution,**
**Washington, D.C. 20560)**

Crystallized specimens of dark blue sub-transparent wulfenite, from Tsumeb, Southwest Africa, have recently been brought to the authors' attention by Charles Key and William Larson (independently of each other). The specimens were said to be of high tungsten content, and were tentatively named "chillagite." This note combines investigations carried out separately at the British Museum (Natural History) and the Smithsonian Institution.

"Chillagite" (Ullman, 1912) was found as tabular, translucent, orange crystals at the Christmas Gift north mine, Chillagoe, Queensland, Australia, associated with cerussite. It is a tungstatian wulfenite with 28.22% $\mathbf{WO_3}$; subsequent analyses on lemon-yellow material (Mingaye, 1916) showed a variation from 21.10 to 29.52% $\mathbf{WO_3}$, with a corresponding inverse variation in $\mathbf{MoO_3}$ content. Our studies of pyramidal-prismatic crystals (Figure 1) from Tsumeb show that they are in no way comparable to "chillagite" in color, habit, or $\mathbf{WO_3}$ content. Blue wulfenite of tabular habit (photo, P. 79) has also been found at Tsumeb, but we have neither seen nor studied such material.

We have studied five of the pyramidal-prismatic crystals, two of which are shown in Figure 1, and their unusual habit resembles none of the figures in Goldschmidt's Atlas nor of any others that we have seen in the literature (compare Williams, 1966). The length of the crystals is from 6 to 15 mm, and the diameter is from 3 to 11 mm, with roughly equal lengths of prism and pyramid; the development is essentially polar, with good pyramidal faces at one end only. Three crystals were measured on a two-circle goniometer for identification of the forms present, and on a large single-circle goniometer (Fuess, model 1a) for an accurate determination of the axial ratio because of the perfection of the pyramid faces ***n***{011} and ***e***{112}. Prism forms are ***a***{010}, with dull faces, and ***m***{110}, with rounded and deeply pitted faces: neither gave measurable signals. The dominant pyramid forms are ***n***{011} and $\epsilon$ {111}, with narrow strips of ***e***{112}. Some of the edges are rounded and stepped, but no trace was found of any forms other than $\chi$ {121}*, and that only on the crystal on matrix (BM 1976,108)

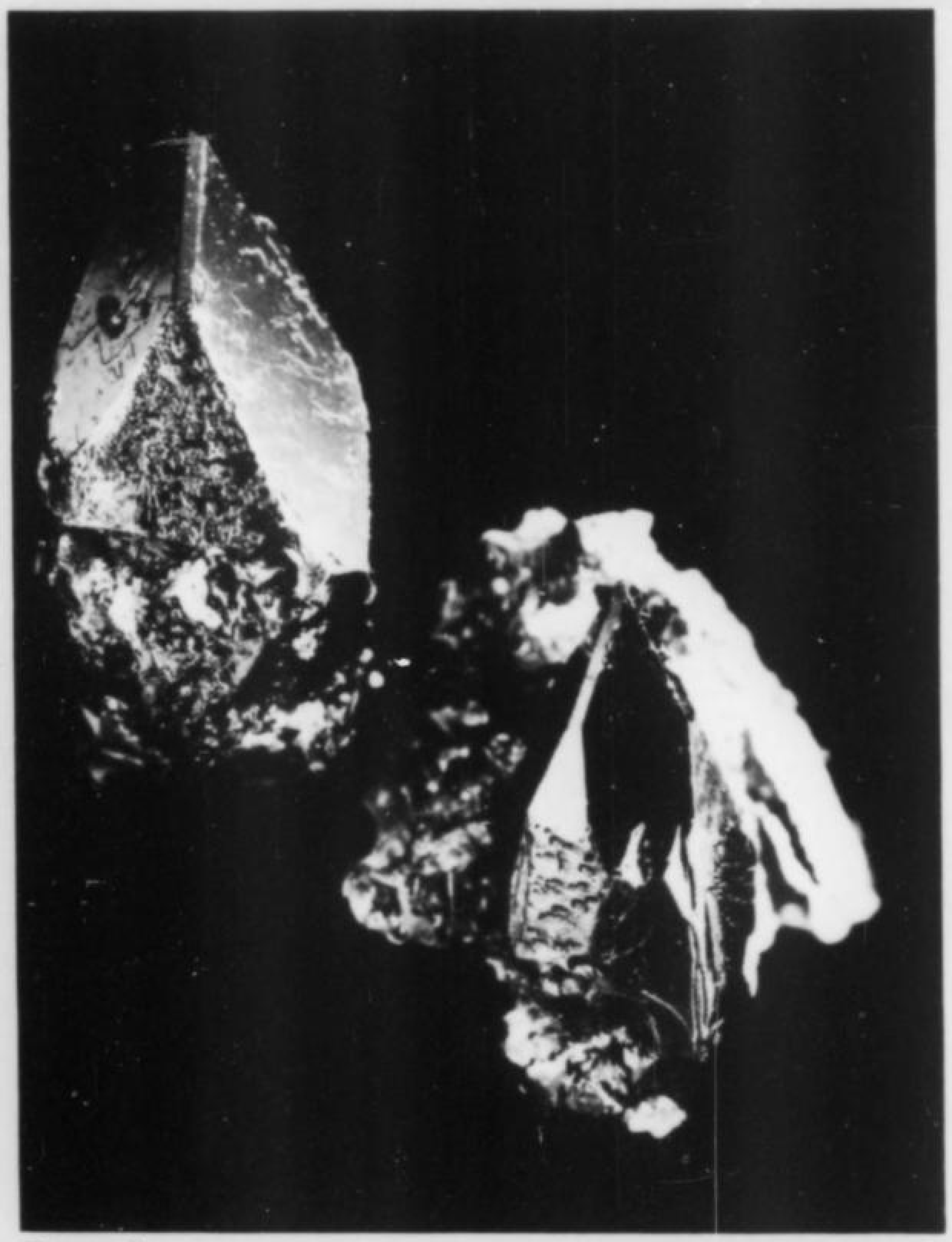


*Figure 1.*

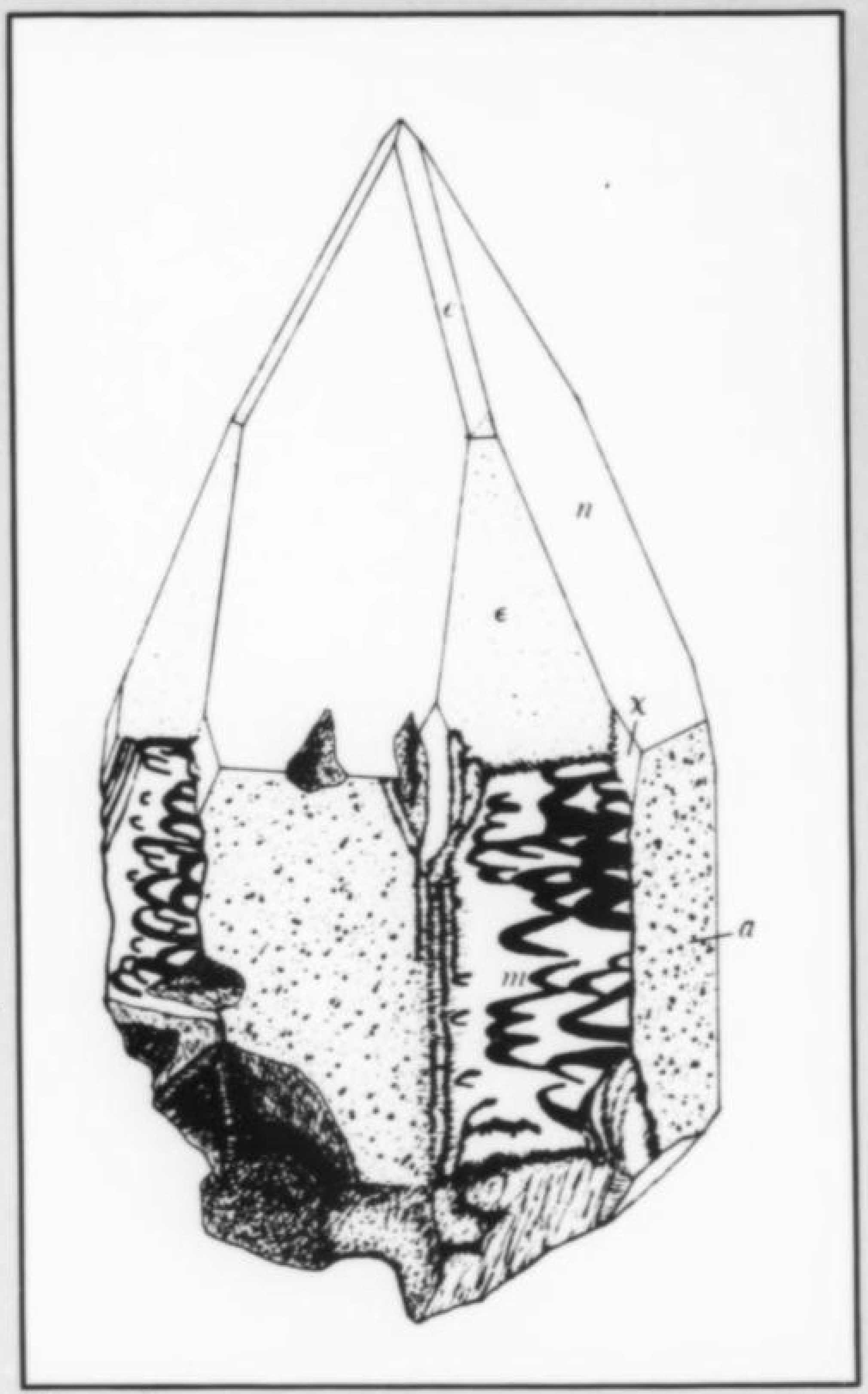


*Figure 2.*

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*The same as ***s***{131} of Bach (1926).

(Figure 1). Form {121} is a rare form, of rank 21 in order of increasing rarity (Bach, 1926), and is only mentioned here because the faces are comparatively large, give good signals on the goniometer, and would have been expected to demonstrate the tetartohedrism of wulfenite. However, instead of occurring on alternate corners only, it is present on all five corners of the measured crystal (the remaining three corners are not present, being in contact with the matrix); a possible explanation is that both right- and left-handed forms are represented, of equal perfection and development. Tetartohedrism, as illustrated in the figure, is shown by the shape of the pits on ***m***{110}, and by small dull areas on the faces ***e***{112}.

Measurements of the angles, 10 in all, between faces of {011} and between faces of {112}, lead to values of 65°49.5′ ± 0.5′, 65°49.3′ ± 0.3′, and 65°49.2′ ± 0.6′ for the fundamental angle, and 2.2275 ± 0.001 for the axial ratio ***c/a***. Williams (1966) has plotted values of ***c/a*** against content of Cr, As, V, and W in wulfenite, and shows it rising slowly from 2.2268 to just over 2.228 as the W content arises to 1.1%, thereafter (perhaps) dropping very rapidly with further increase in W content. Our value is entirely consistent with Williams' results. X-ray powder photographs of the Tsumeb material are a perfect match for wulfenite, and do not show the strong line at 4.96Å which serves to distinguish stolzite (PbWO$_4$) from wulfenite, and which is present as a weak line in the pattern of a specimen of "chillagite" from Chillagoe.

The crystals are strongly, but irregularly, zoned. A brown core is overlain by blue wulfenite around the prism and lower pyramid, while the tips of the crystals and perhaps the whole outer surfaces are essentially colorless. Internal reflections show flaws round the core material, but the detail of the color distribution is obscured by the high refractive index and the brilliant luster of the faces. Small rough crystals on the matrix are pale blue or colorless. The material has been examined by electron microprobe in both laboratories and, although Ca, As, Cr, V, Ti, and W were looked for as minor constituents, only W was detected. About 1.3% WO$_3$ was found in the Smithsonian specimen, and 0.25% WO$_3$ in a fragment of BM 1976, 108. The latter, about 10 x 8 mm, showed all three colors but there was no detectable difference in composition between them. It seems probable that the blue color is caused by partial reduction of Mo$^{6+}$ to Mo$^{4+}$ (compare ilsemannite).

We thank Paul Hicks, BM(NH), for the crystal drawing.

**References**

BACH, L. (1926) Ueber Wulfenit. *Jahrb. Mineral., B.-B.*, **54**, 380 - 419.

MINGAYE, J. C. H. (1916) Notes on chillagite. *Rec. Geol. New South Wales*, **9**, 171.

ULLMAN, A. T. (1912) A new mineral. *Journ. Proc. Roy. Soc. New South Wales*, **46**, 186.

WILLIAMS, S. A. (1966) The significance of habit and morphology of wulfenite. *Amer. Mineral.*, **51**, 1212 - 1217.

# Keyite: a new mineral from Tsumeb

**by**
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**British Museum (Natural History)**
**Cromwell Road**
**London SW7 5BD, England**

**Abstract**

Keyite, **(Cu,Zn,Cd)$_3$(AsO$_4$)$_2$**, occurs as small blue prisms in cavities in tennantite ore from Tsumeb, Southwest Africa, associated with cuproadamite (Cu:Zn 3:2) and schultenite.

Microprobe analyses gave **CuO** 18.81, **Zn** 17.90, **CdO** 14.08, **PbO** 0.63, **CaO** 0.80, **MnO** 1.07, **As$_2$O$_5$** 45.36 (means of 6 analyses on 5 crystals), **Sum** 98.66%. D$_{obs}$ n.d., but $>$ 4.2. Cell contents for 48 oxygens $6[(\mathrm{Cu}_{1.19}\mathrm{Zn}_{1.11}\mathrm{Cd}_{0.55}\mathrm{Mn}_{0.08}\mathrm{Ca}_{0.07}\mathrm{Pb}_{0.01})$-sum$_{3.01}\mathrm{As}_{1.99}\mathrm{O}_8]$, ideally $6[(\mathrm{Cu,Zn,Cd})_3(\mathrm{AsO}_4)_2]$ with Cu:Zn:Cd near 2:2:1, for which D$_{calc}$ = 4.95. Soluble in conc. HCl or HNO$_3$, no water detected, blackens on heating. Monoclinic I2, Im, or I2/m; *a* 11.65, *b* 12.68, *c* 6.87 Å(± 0.01), *β* 98.95° (± 0.05°), V 1002.5 Å$^3$. Strongest powder lines 3.29 vs(2), 2.876 vs(3), 2.795 vvs(1) (Cu-K$\alpha$); 48 lines recorded.

Crystals prismatic [001] to tabular {010}, commonly tapering or showing sub-parallel stacking on {010}. Dominant forms observed on SEM photos {010}, {110}, {210}, {011}, and perhaps $\{\bar{2}01\}$. Cleavage {001}, good. No twinning observed. Color deep sky-blue, streak pale blue. H 3½ - 4. Biaxial, sign and 2V not determined, optic axial plane {010}. $\alpha$ 1.80, $\beta$ n.d. (= *b*), $\gamma$ 1.87. Strong dispersion of indicatrix: $\alpha$:[001] 10½° (Cd red), 11½° (Hg yellow), 12½° (Hg green), 9½° (Hg violet).

Named for the mineral dealer Charles L. Key, who supplied the mineral for investigation. Name approved by IMA Commission in 1975. Type specimens in BM(NH).

**Occurrence**

Keyite was brought to our attention by Charles Key, who submitted for identification some minute blue crystals nestling at the base of much larger ($<$ 2 mm) crystals of cuproadamite on a matrix of tennantite. Since the specimen was from Tsumeb, we at first suspected the crystals of being stranskiite (triclinic CuZn$_2$(AsO$_4$)$_2$; Strunz, 1960), for which no powder data have yet been published. However, on discovering major cadmium in our mineral and establishing its symmetry as monoclinic, we became convinced that we were dealing with a new species. Stranskiite occurs on chalcocite at the 1000 m level at Tsumeb, but we have no information about which part of the mines our specimens came from.

Cuproadamite, the copper-rich variety of adamite, as small but abundant green prisms, has been associated with keyite on all the specimens we have seen, and it was the only other arsenate present on our original specimen (BM 1973,236). A subsequent specimen (BM 1975,660), first loaned by and later acquired from Mr. Luis Teixeira-Leite, carried large (ca. 2 cm) prisms of schultenite as well. The unusual habit of this new schultenite is the subject of a short note elsewhere in this volume. Keyite and cuproadamite appear to have crystallized more or less at the same time, since the keyite sometimes sits on and is sometimes partly enclosed by cuproadamite.

**Table 1. Keyite: microprobe analyses**

| | 1 | 2 | 3 | 4 | 5 | 6 | Mean | |
|---|---|---|---|---|---|---|---|---|
| **CuO** | 19.23 | 18.76 | 20.22 | 16.84 | 19.80 | 18.01 | **18.81** | |
| **ZnO** | 17.94 | 18.14 | 17.59 | 18.57 | 16.78 | 18.41 | **17.90** | |
| **CdO** | 13.98 | 13.58 | 13.64 | 14.93 | 14.59 | 13.78 | **14.08** | |
| **PbO** | 0.14 | 0.40 | 0.62 | 1.42 | 0.65 | 0.55 | **0.63** | |
| **CaO** | 1.11 | 0.91 | 0.83 | 0.41 | 0.97 | 0.59 | **0.80** | |
| **MnO** | 1.27 | 1.16 | 1.07 | 0.94 | 1.21 | 0.79 | **1.07** | |
| **$As_2O_5$** | 45.54 | 45.40 | 45.57 | 45.02 | 44.96 | 45.68 | **45.36** | |
| Total | 99.21 | 98.35 | 99.54 | 98.13 | 98.96 | 97.81 | 98.65 | |
| Cations calculated to 8 oxygen atoms | | | | | | | | |
| | | | | | | | | S.D. |
| **Cu** | 1.209 | 1.189 | 1.271 | 1.084 | 1.258 | 1.148 | 1.193 | 0.070 |
| **Zn** | 1.102 | 1.124 | 1.076 | 1.169 | 1.041 | 1.147 | 1.110 | 0.047 |
| **Cd** | 0.544 | 0.533 | 0.531 | 0.596 | 0.574 | 0.544 | 0.554 | 0.026 |
| **Pb** | 0.003 | 0.009 | 0.014 | 0.033 | 0.015 | 0.013 | 0.014 | |
| **Ca** | 0.098 | 0.082 | 0.073 | 0.037 | 0.087 | 0.053 | 0.072 | |
| **Mn** | 0.089 | 0.083 | 0.075 | 0.068 | 0.086 | 0.056 | 0.076 | |
| **As** | 1.982 | 1.992 | 1.983 | 2.006 | 1.976 | 2.015 | 1.992 | 0.015 |
| (Sum) | 3.045 | 3.020 | 3.040 | 2.987 | 3.061 | 2.961 | 3.019 | |

Columns 1 & 2, one crystal from BM 1973,236; columns 3 - 6, four crystals from BM 1975,660.
S.D. = standard deviation (major cations only).

### Chemistry

There is too little keyite for a full wet microchemical analysis, so all the analytical work has been done on a Geoscan electron probe microanalyzer. Element scans on a grain from the original specimen showed the presence of major Cu, Zn, Cd, and As, with minor amounts of Pb, Ca, and Mn; this was confirmed later on grains taken from four other specimens loaned to us. Six quantitative analyses were performed, two on opposite ends of a single grain from the original specimen and the remainder on four separate grains from a second specimen (table 1). Anglesite and wollastonite were used as standards for Pb and Ca, and pure elements for the others. Assuming Z = 6 (see below), the mean of the six analyses leads to the formula $\mathbf{6[(Cu_{1.19}Zn_{1.11}Cd_{0.55}Mn_{0.08}Ca_{0.07}Pb_{0.01})_{sum\ 3.01}As_{1.99}O_8]}$, idealizing to $\mathbf{6[(Cu, Zn, Cd)_3(AsO_4)_2]}$, with Cu:Zn:Cd nearly 2:2:1. The three principal cations show only a limited tendency to replace one another in the grains examined, with standard variations of 4 - 6%. It is interesting to note that, despite the evidence that keyite crystallized at about the same time, optical spectrography of the cuproadamite showed no trace of cadmium. This suggests that cadmium cannot be accommodated in the cuproadamite structure. A survey of several different specimens of cuproadamite shows considerable variation in the Cu:Zn ratio, but the crystals associated with keyite have Cu:Zn near 3:2; we are continuing work on this problem.

Keyite is readily soluble in concentrated acids. Tests for the presence of water were made, but no water was found; the mineral blackens on heating, and presumably loses much of the arsenic.

### Crystal geometry

Single crystal rotation and Weissenberg X-ray photographs show keyite to be monoclinic, with a body-centered unit cell (systematic absences for h+k+l odd). The space group possibilities are thus I2, Im, or I2/m, but we have not tested for centrosymmetry. Unit cell dimensions are given in Table 2, and were refined from the powder data in the same table using the Weissenberg data in the indexing. Calculated *d*-spacings are not listed, but they are in close agreement for the assigned indices.

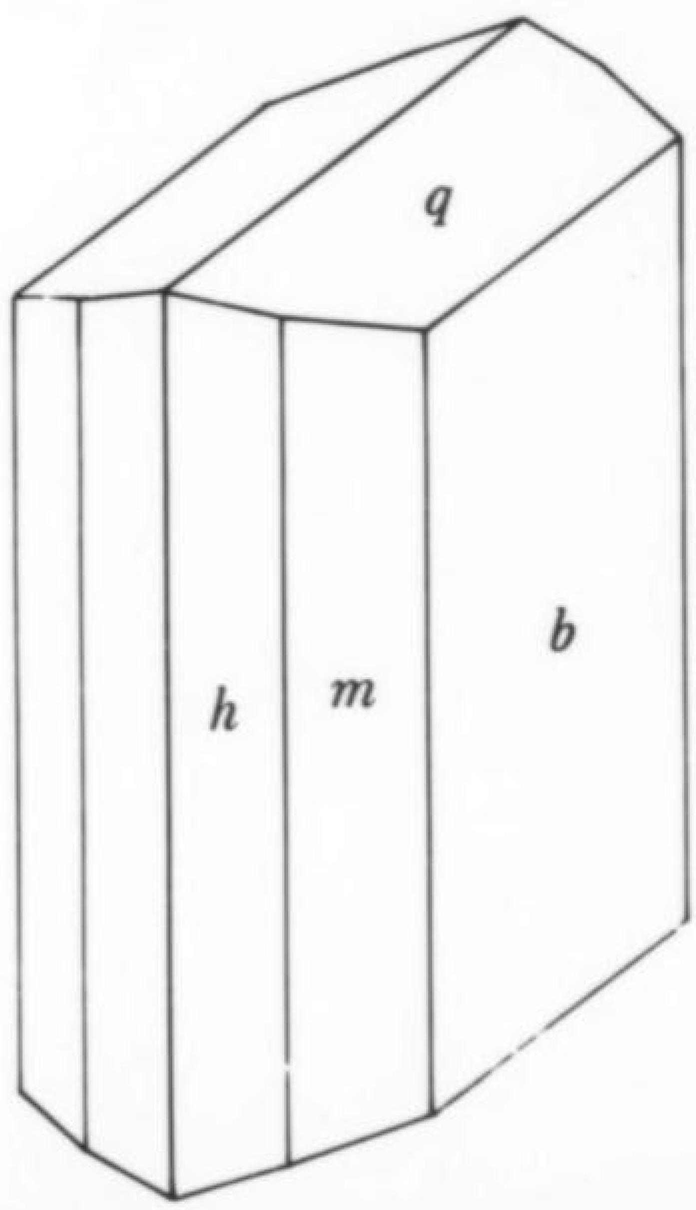

***Figure 1.*** **Idealized drawing of keyite, showing forms h {210}, m {110}, b {010}, and q {011}.**

*Figure 2.* **Keyite crystals showing forms h{210}, m{110}, b{010}, and q{011}; the largest crystal shows the terminal form {201} (?). SEM, 500x.**

*Figure 3.* **Keyite: a typical sub-parallel group of crystals. The apparent size of (011):(011) is increased by divergence. SEM, 500x**

The specific gravity is greater than 4.2, shown by crystals sinking in Clerici solution, but we were unable to measure it more accurately than this. To obtain a density of this order, bearing in mind that the possible space groups require an even number of formula units in the unit cell, we are proposing that Z = 6 leading to a calculated density of 4.95. A second approach to the estimation of the unit cell contents was made using the average value of 20 Å³ for the volume occupied by oxygen atoms in other copper arsenates of known structure. The unit cell volume is 1002 Å³, so we get about 50 oxygen atoms, and the nearest multiple of 8 to this (there are eight oxygen atoms in two $AsO_4$ groups) is 48, once again suggesting that Z = 6.

**Crystal morphology**

Keyite crystals are as large as 0.25 x 0.1 x 0.04 mm, but are usually much smaller, and it may be seen from the scanning electron microscope (SEM) photographs (Fig. 2-5) that the larger 'crystals' are aggregates of tablets in sub-parallel position. We had no success in trying to measure crystals with the optical goniometer, but comparison of calculated angles with the SEM photographs shows the dominant forms to be ***b***{010}, ***m***{110}, ***h***{210}, ***q***{011}, and perhaps {$\bar{2}$01} (seen only on the largest, tapering crystal in Figure 2). An idealized crystal is drawn in Figure 1. Under the microscope separated tablets lie flat on {010}, and give a measured value of $\beta$ 98°50′. There is a good {001} cleavage. No twinning has been observed, re-entrant angles being caused by the sub-parallel growth. Calculated interfacial angles are (110):(1$\bar{1}$0) 84.45°; (011):(0$\bar{1}$1) 56.31°.

**Physical properties**

Keyite appears to scratch adamite, but not fluorite, so H = 3½ - 4. The color is deep sky-blue, and the streak is pale blue; on hand specimen, green light reflected from the associated cuproadamite tends to mask the color of keyite. There is no fluorescence in U.V. radiation.

**Optical properties**

Keyite is strongly pleochroic in shades of blue: $\gamma$ (deep blue) > $\beta$ (greenish blue) > $\alpha$ (pale blue). The optic axial plane is {010}. Refractive indices for sodium light are $\alpha$ 1.80, $\beta$ not determined, $\gamma$ 1.87. There is strong dispersion of the indicatrix, and crystals lying on {010} show purple and greenish extinctions in white light. Extinction angles $\alpha$:[001], all in the acute angle $\beta$, are 10½° (Cd red), 11½° (Hg yellow), 12½° (Hg green), and back to 9½° (Hg violet). Interference figures showing the optic axes and their dispersions have not been observed, and 2V and the optic sign have not be determined.

**Discussion**

The superficial resemblance between keyite and stranskiite is striking, and it is unfortunate that we have not been able to obtain any of the latter for study. Apart from the cadmium and the Cu:Zn ratio, the simple formulae and the refractive indices are much the same. The crystal symmetry, however, is entirely different and there is no integral ratio between the unit cell volumes. The higher symmetry of keyite, and the non-integral numbers of the cations in the unit cell, taken in conjunction with a larger oxygen volume (20.9 Å³) than for stranskiite (19.1 Å³), lead us to speculate that keyite may be a disordered polymorph of stranskiite, possibly stabilized by the cadmium. Sidney Williams has recently sent us for comparison a powder photograph of a fragment of the type specimen of stranskiite, given to him by the Tsumeb Corporation. The strongest lines are 3.131 (10), 2.789 (5), and 2.505 (5); neither they nor the pattern as a whole show any resemblance to those of keyite. We are working to complete our description of the morphology and optical properties of keyite.

**Name and type specimens**

Keyite was approved by the I.M.A. Commission on New Minerals and Mineral Names in March 1975. The name is for Charles L. Key, mineral dealer of Canton, Connecticut, who has supplied the Museum with many fine and rare specimens over the last few years. Holotype specimens, BM 1973,236 and BM 1975,660, are in the mineral collection, British Museum (Natural History).

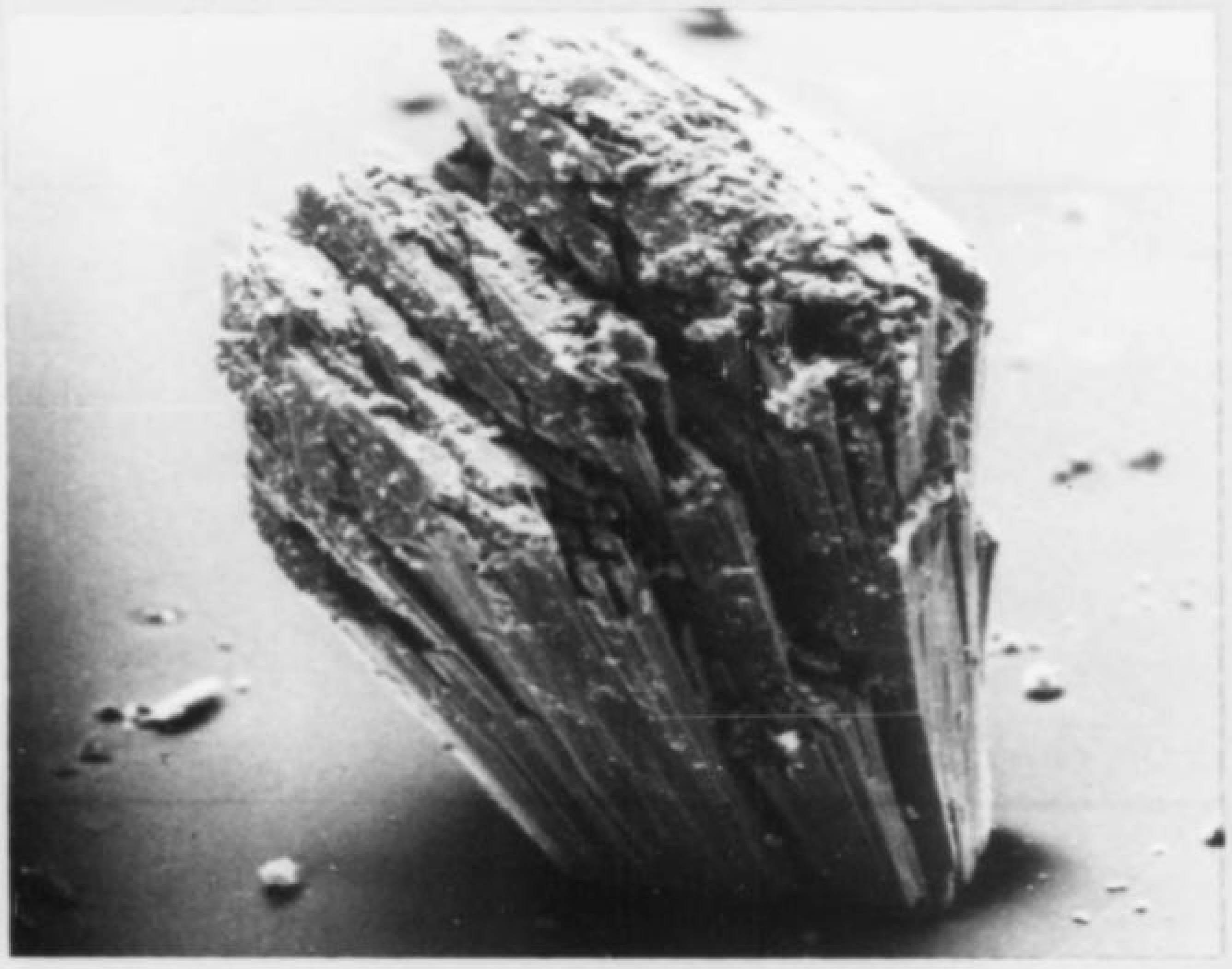

***Figure 4.*** **Keyite: composite crystal showing typical roughness of faces. SEM, 500x**

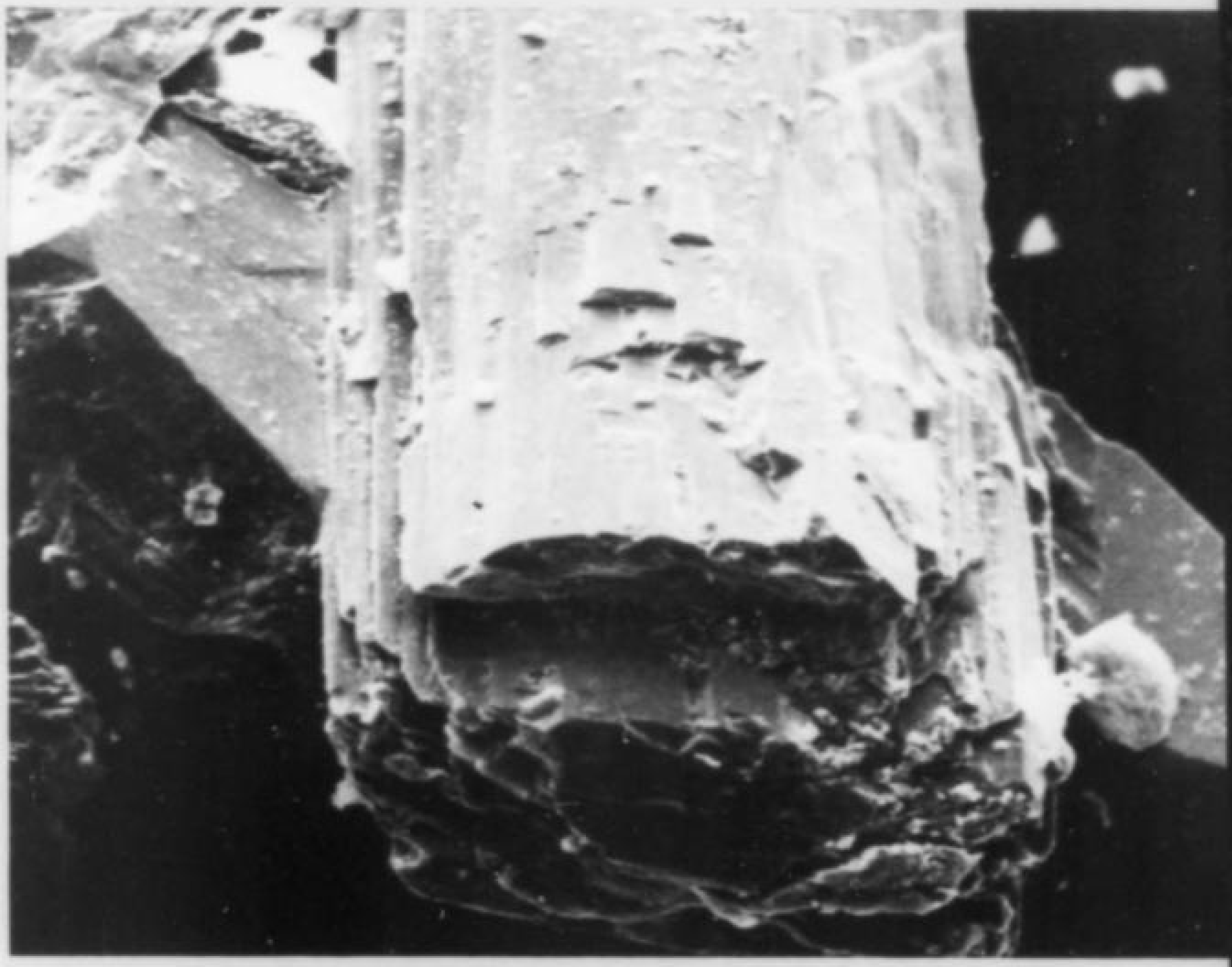

***Figure 5.*** **Keyite: composite crystal lying on and in a 'cuproadamite' crystal. SEM, 500x**

### Acknowledgements

We thank our friends Pierre Bariand, Prosper Williams, Luis Teixeira-Leite, and Charles Key for the generous loan of specimens for microprobe examination, Sidney Williams for the loan of his powder photograph of stranskiite, and Henry Buckley for the SEM photographs.

### Reference

STRUNZ, H. (1960). Stranskiit, ein neues Mineral. *Naturwiss.* **47**, 376 [Abstracts in *Amer. Mineral.* **45**, 1315; *Mineral. Abstr.* **15**, 213]. See also structure determination by K. Plieth and G. Sanger, *Zeits. Krist.* **124**, 91-100 [*Mineral. Abstr.* **19**, 271]

**Table 2. Keyite: X-ray powder data**
(Cu-K$\alpha$, camera dia. 114.6 mm)

| *d* obs | I obs | hkl | *d* obs | I obs | hkl | *d* obs | I obs |
|---|---|---|---|---|---|---|---|
| 6.41 | ms | 020,$10\bar{1}$ | 2.515 | mwB | 222, 132 | 1.718 | w |
| 5.97 | vvw | 011 | 2.386 | w | $40\bar{2}$, $34\bar{1}$ | 1.700 | m |
| 4.46 | vw | $21\bar{1}$, $12\bar{1}$ | 2.320 | mw-mB | 312, 042, $33\bar{2}$ | 1.644 | ms |
| 4.27 | vvw | 220 | 2.266 | vw | 510 | 1.602 | vwB |
| 4.15 | w | 121 | 2.230 | w | $25\bar{1}$, $42\bar{2}$, $24\bar{2}$, 341, 013 | 1.566 | mwB |
| 3.89 | vw | 211 | 2.160 | vvw | 431, 103, $52\bar{1}$, | 1.534 | w |
| 3.69 | mw | 310 | | | 251 | 1.529 | vw |
| 3.59 | vw | $30\bar{1}$, 031 | 2.131 | w | 440 | 1.498 | vw |
| 3.40 | w | 002 | 2.080 | vw | 501 | 1.485 | vw |
| 3.29 | vs(2) | $11\bar{2}$ | 2.036 | w-mw | 402, 123, $51\bar{2}$, $15\bar{2}$ | 1.456 | w |
| 3.15 | m | $23\bar{1}$, $20\bar{2}$, 301, $32\bar{1}$ | | | | 1.437 | vw |
| | | | 1.990 | w | 033, 323 | 1.413 | w |
| 3.02 | vw | 112 | 1.980 | vw | 260, 521, 213 | 1.406 | w |
| 2.978 | vw | 022 | 1.911 | vvwB | | 1.384 | mw |
| 2.876 | vs(3) | 400 | 1.868 | vwB | | 1.379 | vvw |
| 2.795 | vvs(1) | $22\bar{2}$, 321, 240 | 1.805 | vvw | | 1.346 | vwBB |
| 2.740 | mw | 141 | 1.760 | mw | | | |
| 2.638 | wB | 132, 420 | | | | | |

Unit cell dimensions: *a* 11.65 Å (± 0.01), *b* 12.68 (± 0.01), *c* 6.87 (± 0.01), $\beta$ 98.95° (± 0.05), V 1002.5 Å$^3$.

Space group I2, Im, or I2/m. Z = $6[(Cu,Zn,Cd)_3(AsO_4)_2]$. $D_{obs} > 4.2$, $D_{calc}$ 4.95.

# Ludlockite: a new mineral from Tsumeb

by
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## Abstract

Ludlockite, $\mathbf{(Fe,Pb)As_2O_6}$, was found as red needles in a cavity in sulfide ore from the 'germanite section' of the mines at Tsumeb, Southwest Africa, associated with zincian siderite. Analysis gave **PbO** 9.32, $\mathbf{Fe_2O_3}$ 21.63, $\mathbf{As_2O_5}$ 70.82, less 'oxygen deficiency' 1.69, sum 100.08 percent. Empirical cell content $Pb_{1\cdot2}Fe^{3+}_{7\cdot9}As^{3+}_{3\cdot1}As^{5+}_{14\cdot9}O_{55\cdot0}$ for $D_{obs.}$4.40, simplifying to nearly $9[(Fe,Pb)As_2O_6]$. $Fe^{3+} >> Fe^{2+}$ by Mössbauer and E.S.R. Readily soluble in conc. HC1 or $HNO_3$, more slowly in dilute acids. On heating turns yellow, then black, losing $As_2O_3$; DTA curves given. Infra-red and Raman show no As-O bonds of $AsO_4^{3-}$ or $AsO_3^{3-}$ anions. Triclinic, P1 or P$\bar{1}$, $a$ 10.41, $b$ 11.95, $c$ 9.86 Å (± 0.02), $\alpha$ 113.9°, $\beta$ 99.7°, $\gamma$ 82.7° (± 0.2°), V 1103 Å$^3$. Strongest powder lines (Co-K$\alpha$) 8.81 vvs(1), 3.330 ms(3), 2.935 vs(2). Crystals elongated [100], flattened $\{0\bar{1}\bar{1}\}$, other prominent forms {021}, terminal faces not determined. Cleavage $\{0\bar{1}\bar{1}\}$ micaceous, {021} perfect. Twinning lamellar, composition plane $\{0\bar{1}\bar{1}\}$, twin law not established. Color red, streak light brown, lustre sub-adamantine. No fluorescence. Biaxial positive $\alpha$ 1.96, $\beta$ 2.055, $\gamma$ >2.11; $\gamma$ near [100], optic axial plane $\perp$ {011}. Pleochroic $\gamma$ (orange yellow) > $\beta$ (deep yellow) > $\alpha$(yellow). Named for mineral dealers Frederick **Lud**low Smith and Charles **Locke** Key who found and supplied specimens for investigation. Name approved by IMA Commission in 1970. Type specimens in BM(NH).

## Occurrence

Ludlockite was first observed in 1968 by Smith and Key, as an orange-brown earthy mass on the surface of a lump of ore that they had obtained from the 'germanite section' of the mines at Tsumeb, Southwest Africa. On splitting the lump they found a cavity lined with sharp brownish-yellow, 1 - 3 mm rhombs of zincian siderite, from which grew slightly diverging bundles of red-brown needles up to 4 mm long. These needles, the subject of this paper, have not been observed in contact with the sulfide ore. Siderite rhombs also occur singly and in groups on and impaled by the ludlockite needles (Fig. 3). An electron microprobe scan, by S. J. B. Reed, of a section of a siderite rhomb showed about 9% zinc at the surface, falling irregularly to about 5% zinc at the core, with corresponding variation in the iron content. An X-ray powder photograph confirms the identification as zincian siderite, and a bulk chemical analysis yields the formula $\mathbf{(Fe_{67\cdot5}Zn_{21\cdot8}Ca_{5\cdot6}Mn_{4\cdot2}Mg_{0\cdot5}Pb_{0\cdot4})CO_3}$ with 3.6% admixed $\mathbf{Fe_2O_3}$. Textural relationships have not been determined in the sulfide matrix, but the following species have been identified: tennantite, chalcocite, pyrite, bornite, germanite, siderite, and quartz.

## Chemistry

Ludlockite is readily soluble in concentrated nitric or hydrochloric acids, more slowly when they are diluted. On heating it remains unchanged up to 400°C; between about 550° and

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† Note: the pale yellow product is unoriented with respect to the original fibers, and is fine-grained. It has not been identified. The three strongest powder lines are 3.10Å (1), 3.02 (2), and 3.33 (3), and the highest observed spacing was 8.3 Å.

*Figure 1.* **Ludlockite: D.T.A. curves in air and in nitrogen (marked L). The bottom curve (marked K) is of karibibite in argon (after von Knorring *et al.,* 1973).**

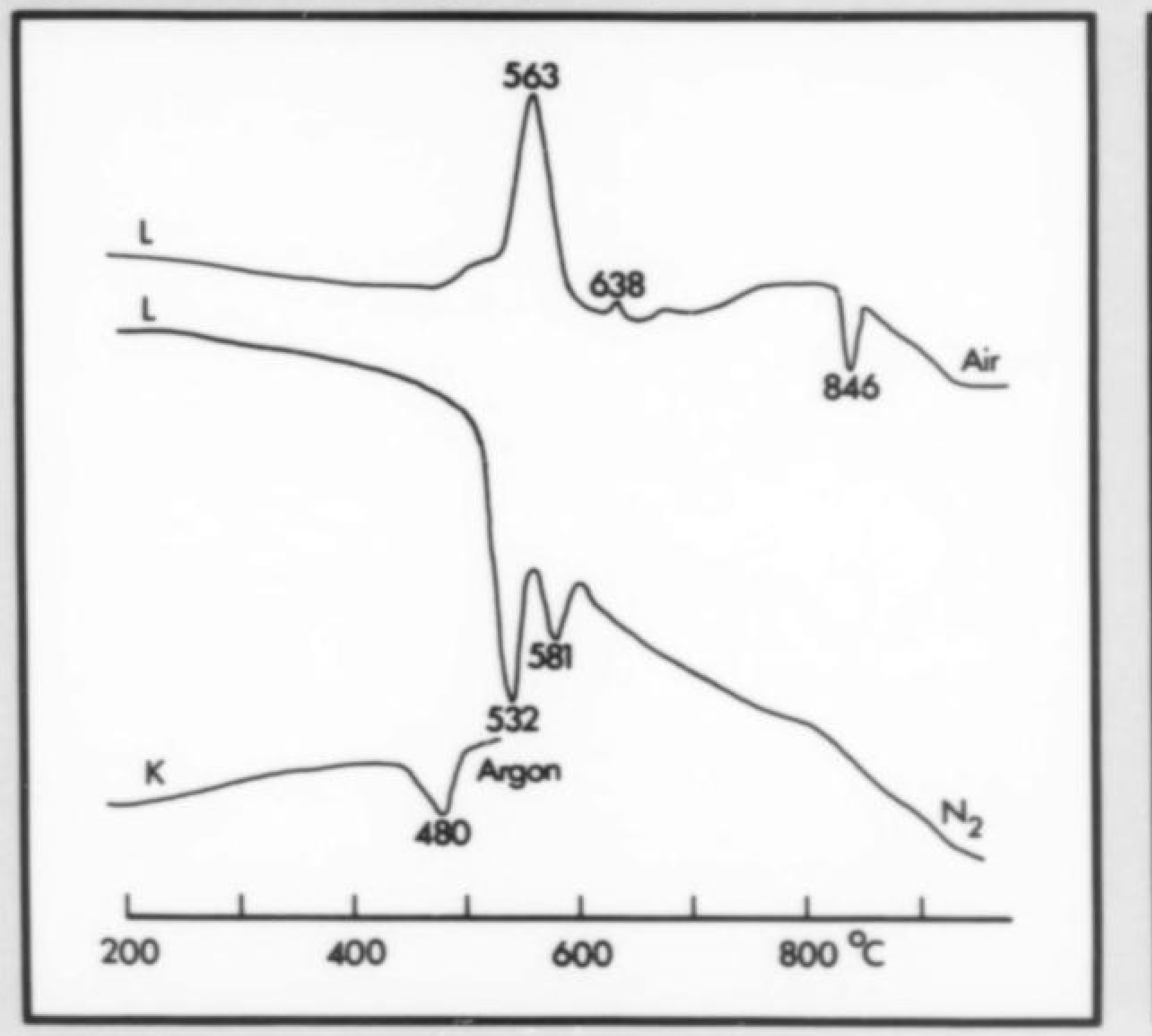
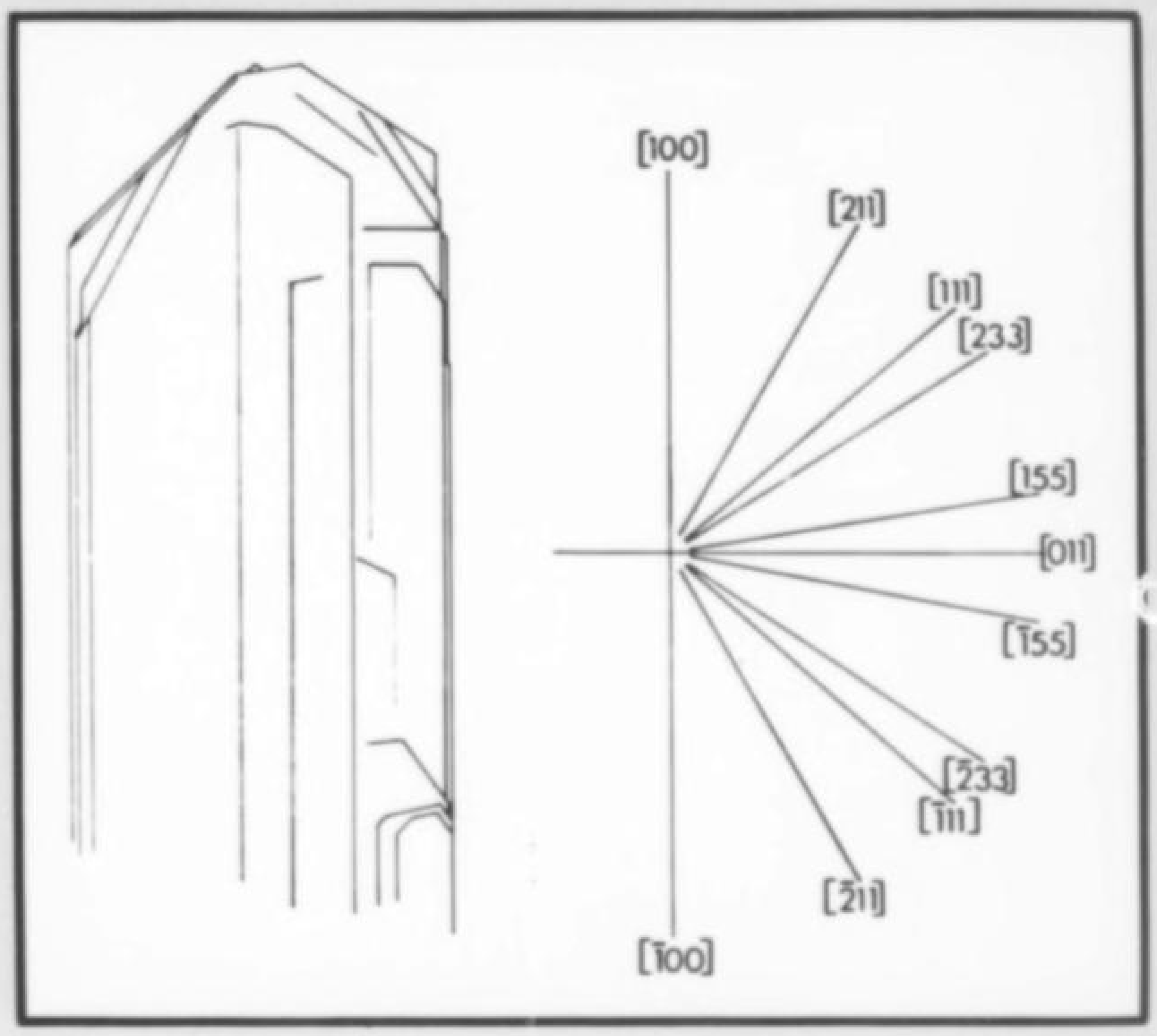


*Figure 2.* **Ludlockite: composite drawing on {011} showing traces of terminal edges, and the possible zones to which they may be referred.**



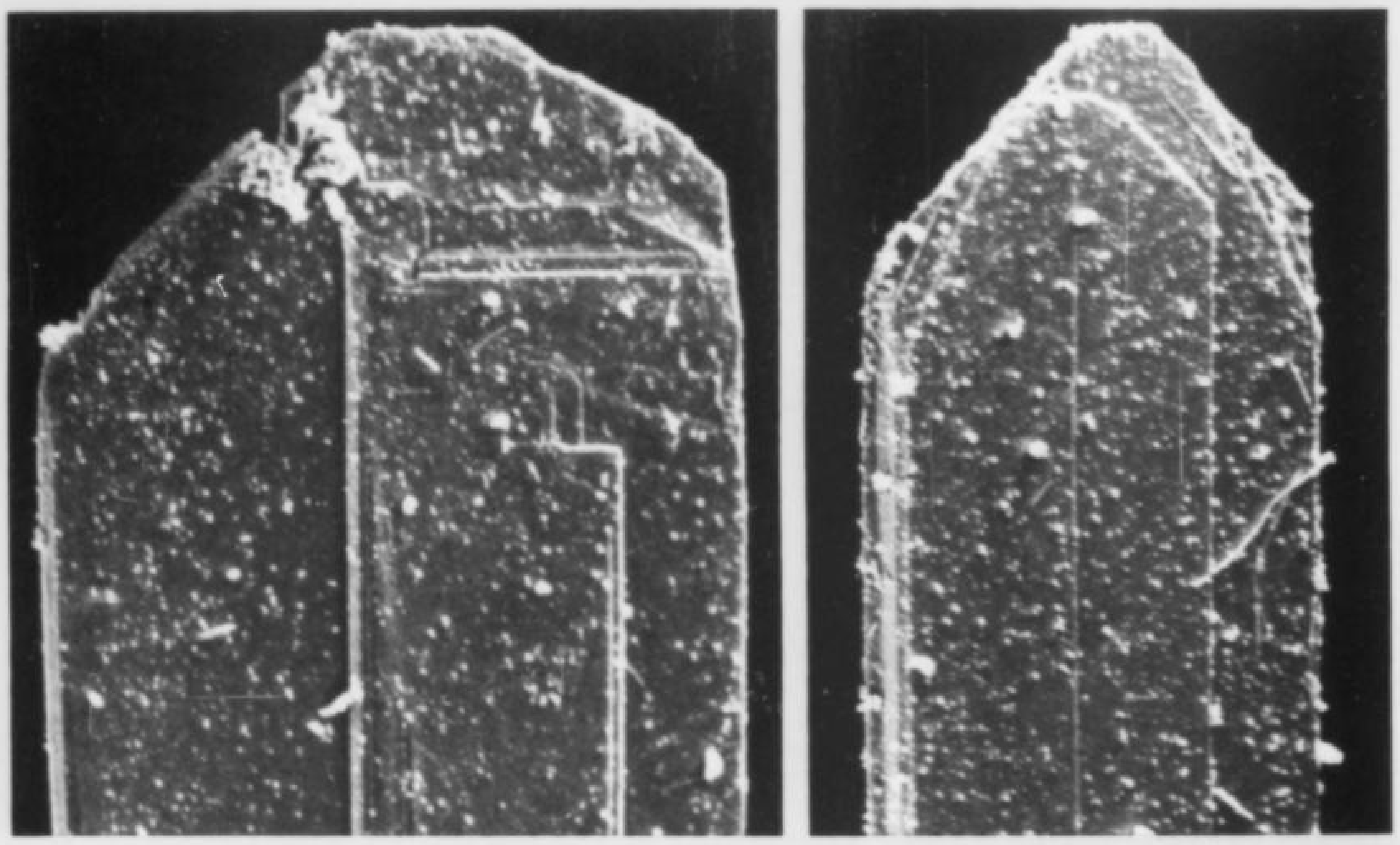


*Figure 3 and 4.* **Ludlockite: crystal laths on {011}, showing terminal edges and twinning. SEM, 1000x**

640°C, it becomes khaki and then pale yellow, losing nearly 29% of its weight in 20 hr.† In the closed tube a sublimate of $As_2O_3$ is formed. Above 780°C it becomes brownish black, with the formation of $Fe_2O_3$. It was not observed to fuse before decomposition.

Qualitative optical spectrography showed major lead, iron, and arsenic, with minor amounts of germanium and aluminum that were not detected chemically nor by microprobe. Electron microprobe analyses at 30 points on three crystals showed no sign of inhomogeneity; they have not been repeated since 1969, when methods of accurately determining lead and arsenic in the presence of each other had not been perfected (their spectra contain overlapping lines), and the results are not given here.

Wet microchemical analyses were made on several portions varying from ⅓ to 16 mg, to develop the method of separation and to determine the state of oxidation. Briefly, the mineral was dissolved in a mixture of conc. HC1 and IC1, and titrated with $KIO_3$ solution to obtain the 'oxygen deficiency' or overall state of oxidation (Hey, 1974). The resulting solution was then reduced with hydrazine hydrochloride, the arsenic precipitated and separated as $As_2S_3$, and finally weighed as ammonium magnesium arsenate. Iron was extracted from the solution after acidification with HC1, and weighed as the 8-hydroxyquinolate. After removal of chloride, lead was precipitated from nitric acid solution as the 'thionalide' complex, and weighed.

The average of the results considered to be most reliable is given in table 1. Wet chemistry did not distinguish between $Fe^{2+}$ and $Fe^{3+}$, nor between $As^{3+}$ and $As^{5+}$, but the determined 'oxygen deficiency' corresponds to 10.4% $As_2O_3$. Semiquantitative Mössbauer measurements by A. D. Law, and electron spin resonance measurements by J. R. Thyer, showed $Fe^{3+}$ to be considerably in excess of $Fe^{2+}$, so part of the arsenic is present in ludlockite as $As^{3+}$. The analysis is presented with all the iron expressed as $Fe^{3+}$; to do otherwise at this stage would be an empty exercise in numerology.

Unit cell contents based on the measured specific gravity of 4.40 and cell volume 1103 Å³ are given in table 1. Since these can only be a guide, in the absence of a full structure determination, we have recalculated to a basis of 54 oxygen atoms per unit cell in order to obtain a provisional simplified formula (and for no other reason): $\mathbf{9[(Fe^{3+},Pb)(As^{5+},As^{3+})_2O_6]}$. The reduction to 54 oxygen atoms, etc., leads to a calculated specific gravity 4.32.

Differential thermal analysis (in air and in nitrogen) curves were obtained by B. D. Mitchell on 10 mg samples, and are reproduced in fig. 1 together with that of karibibite in argon (von Knorring *et al.*, 1973, p. 270). The exothermic peak (563°C) in air may be due to oxidation of the small amount of $Fe^{2+}$, and the endothermic effects (530 - 580°C) in nitrogen may be connected with the loss of $As_2O_3$, but since we have done no further work in this direction any interpretation must remain speculative.

Preliminary attempts were made to synthesize ludlockite, without success.

### Crystal geometry

Ludlockite is triclinic, Laue class $\bar{1}$, space group P1 or P$\bar{1}$ (centrosymmetry not determined). Unit cell dimensions and angles were obtained from precession photographs, and are given for the Donnay-Nowacki reduced (primitive) cell in table 2. The powder data were obtained on a Philips 114.6 mm camera (Co - Kα radiation) and are given in table 4. These data, together with Guinier data, were used in the refinement of the cell dimensions; details will be given in another paper, to be published elsewhere, dealing with the twinning geometry and morphology at greater length.

The structure has yet to be determined. Unit cell contents are given in table 1.

### Crystal morphology

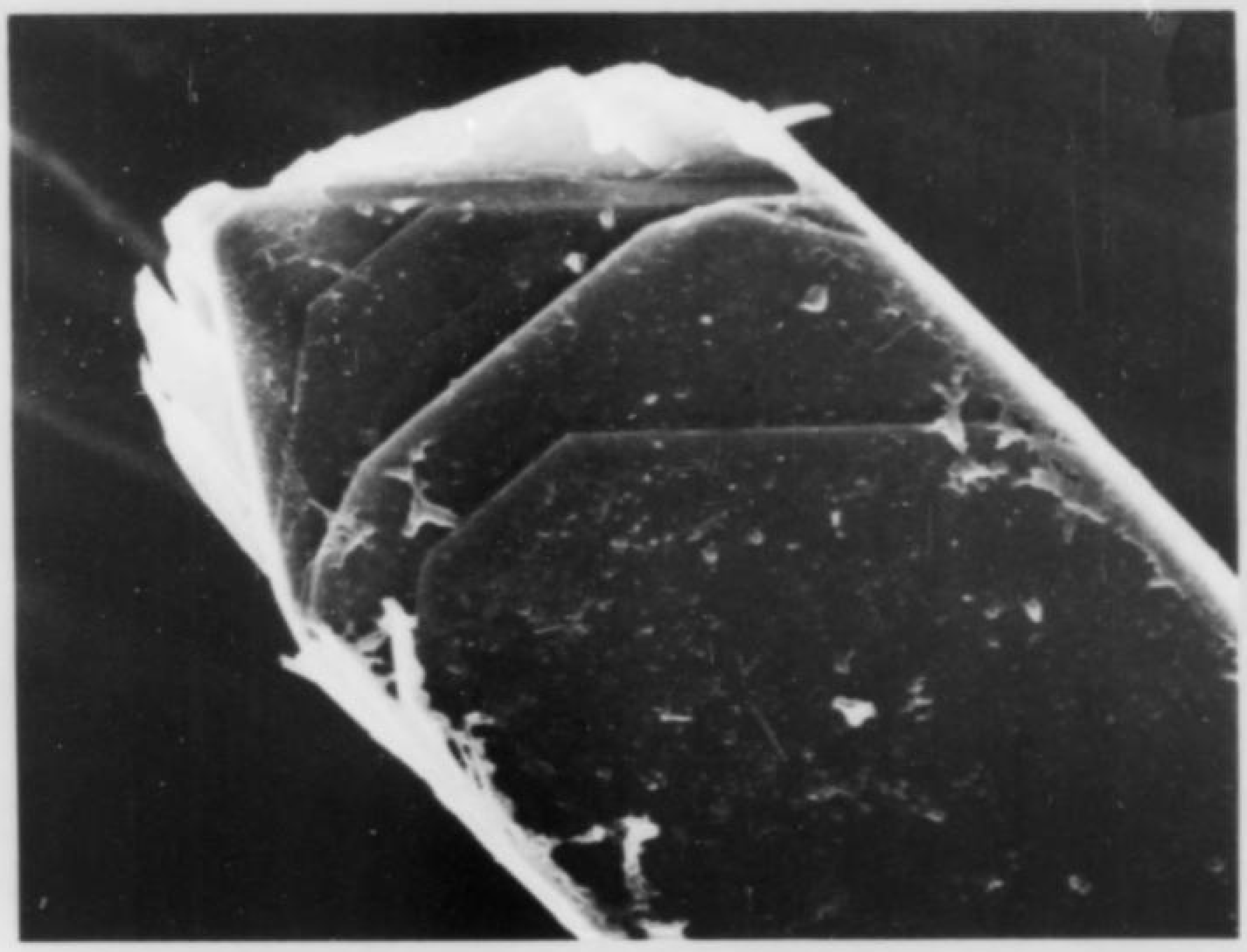
Ludlockite crystals are commonly lath-shaped, but a few are almost equant in cross-section. Most of them are 15 - 40 mm long, 0.05 - 0.1 mm wide, and 0.008 - 0.025 mm thick. Many taper slightly, some have a twist about the needle axis, and the

**Table 1. Ludlockite: Chemical analysis and cell contents**

| | | Ratios | | Cell contents | | |
|---|---|---|---|---|---|---|
| PbO | 9.32 | Pb | 0.04175 | 1.22 | 1.20 | 1.24 |
| $Fe_2O_3$ | 21.63 | Fe | 0.2709 | 7.91 | 7.77 | 8.05 |
| $As_2O_5$ | 70.82 | As | 0.6163 | 18.00 | 17.67 | 18.33 |
| | 101.77 | O | 1.8833 | 55.00 | [54] | [56] |
| Less O | 1.69 | Sum of cations | | 27.13 | 26.64 | 27.62 |
| Total | 100.08% | $D_{obs.}$ /$D_{calc.}$ | | 4.40 | 4.32 | [4.48] |

Empirical formula $\mathbf{Pb}_{1\cdot2}\mathbf{Fe}^{3+}_{7\cdot9}\mathbf{As}^{3+}_{3\cdot1}\mathbf{As}^{5+}_{14\cdot9}\mathbf{O}_{55\cdot0}$ (assuming all iron to be ferric)

Note: water was sought, but not found; minor Ge and Al were detected spectrographically, but not chemically.



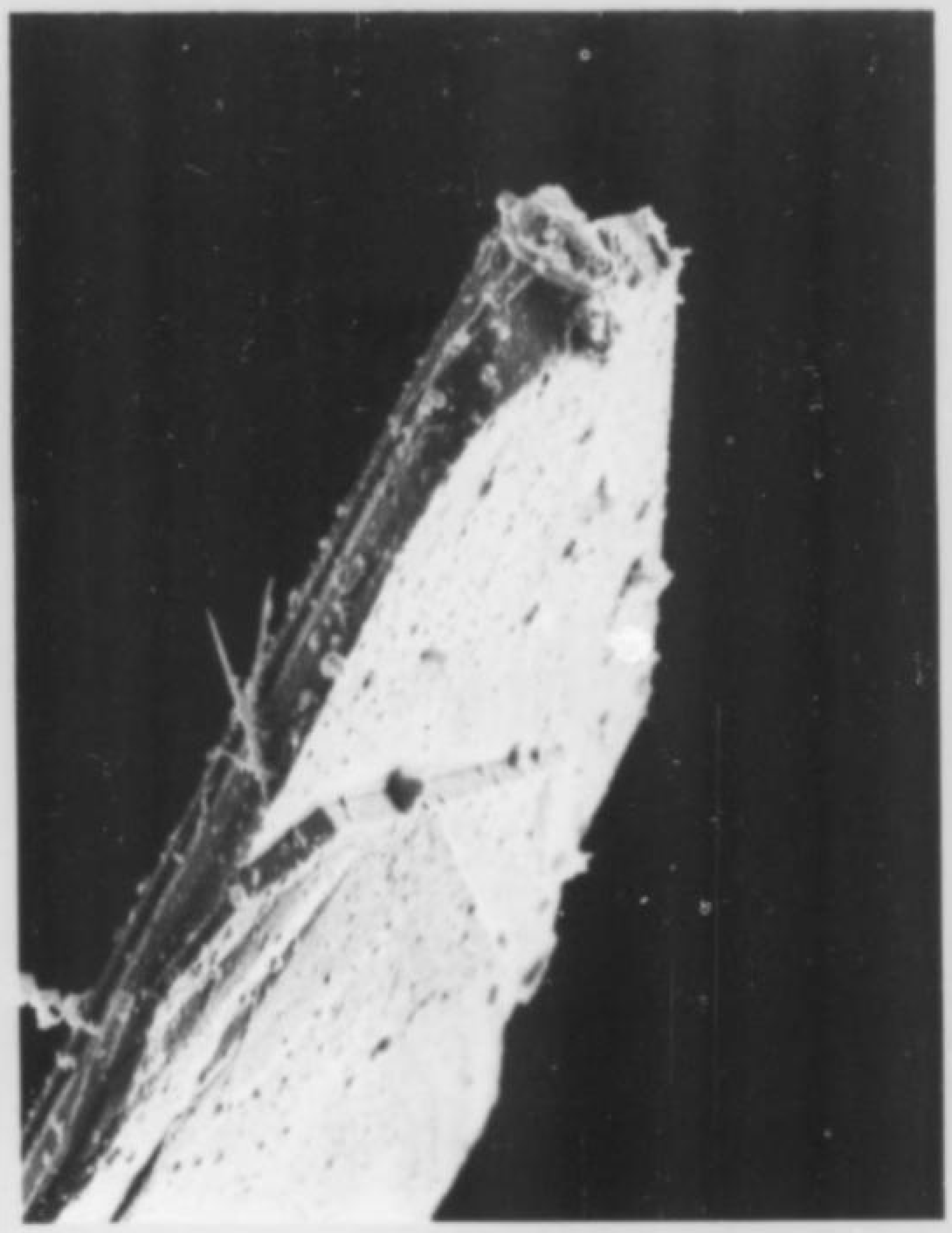


**Table 2. Ludlockite: crystallographic data**

| | | |
|---|---|---|
| Triclinic, P1 or P$\bar{1}$ | $a$ 10.41 Å ± 0.02 Å | $\alpha$ 113.9° ± 0.2° |
| | $b$ 11.95 ± 0.02 | $\beta$ 99.7° ± 0.2° |
| Cell volume 1103 ± 3 Å$^3$ | $c$ 9.86 ± 0.02 | $\gamma$ 82.7° ± 0.2° |

$D_{obs}$ 4.40 ± 0.05, $D_{calc.}$ 4.32 (see text).

Z = 9[$(Fe^{3+},Pb)(As^{5+},As^{3+})_2O_6$] (simplified, see text and Table 1)

*Figure 5. (top left)* **Ludlockite: crystal on {011}, showing multiple twinning. SEM, 2000x**

*Figure 6. (above)* **Ludlockite: crystal with bruised point, showing {011} (broad), {021} (narrow), and unindexed terminal faces; tapering edges of the latter suggest that the twin plane may not be the plane of composition. SEM, 2000x**

*Figure 7. (below)* **Ludlockite: crystal lath distorted by handling, demonstrating flexibility and the two perfect cleavages. SEM, 1000x**

**Table 3. Ludlockite: morphological data - some possible angles**

Interfacial angles in zone [100]

| (0$\bar{1}\bar{1}$): | (0$\bar{4}$1) | (001) | (0$\bar{5}$1) | (011) | (0$\bar{4}$1) | (0$\bar{3}$1) | (021) |
|---|---|---|---|---|---|---|---|
| calc. | 47.4° | 48.0° | 51.1° | 77.7° | 79.1° | 82.9° | 90.6° |
| obs. | | *ca* 50° | | | *ca* 79° | | *ca* 90° |

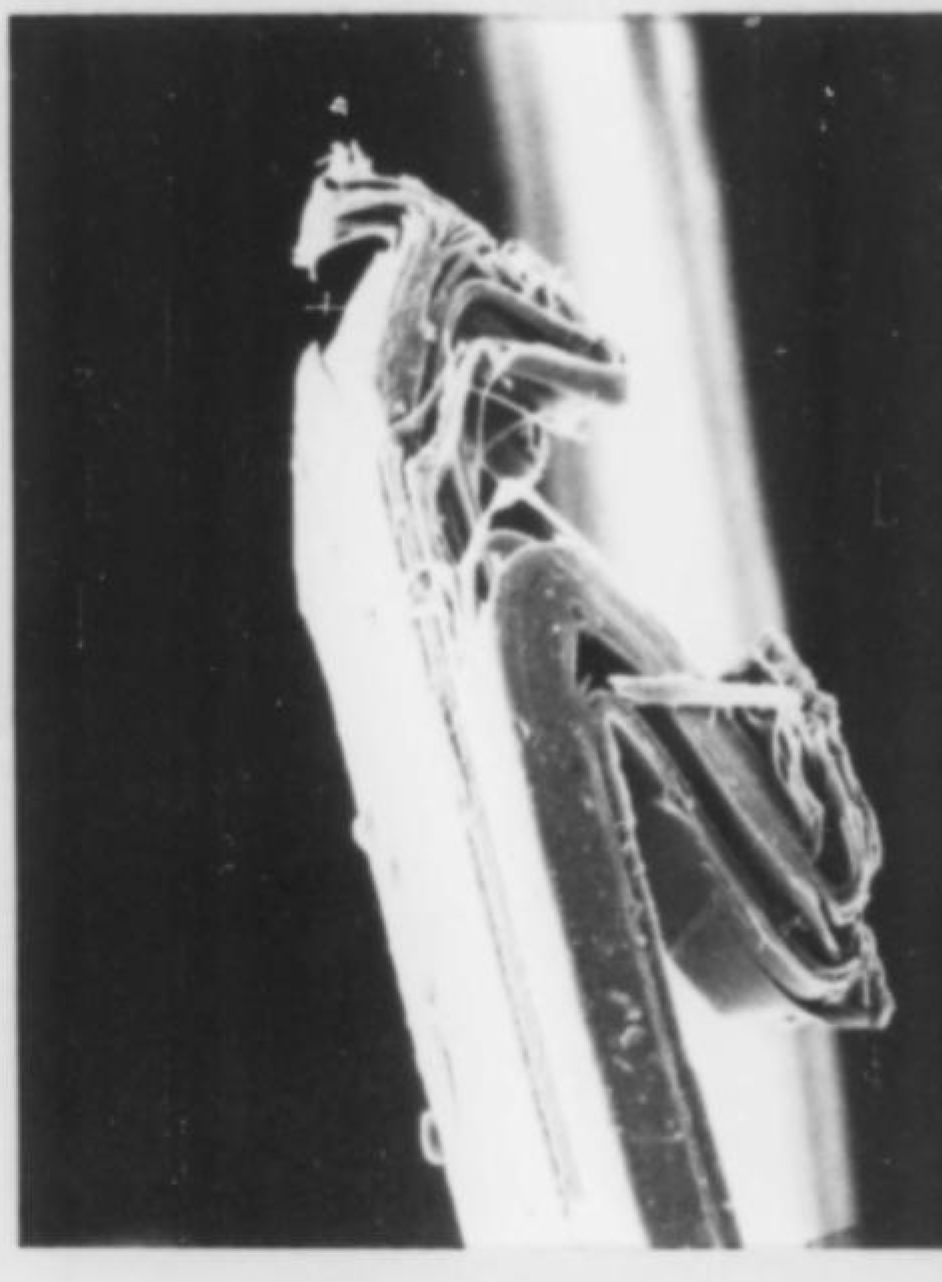
Interzonal angles (angles between edges on {0$\bar{1}$1})

| [$\bar{1}$00] or [100]* | [011]* | [155] | [$\bar{1}$55]* | [233] | [233]* | [111] | [$\bar{1}\bar{1}$1]* | [211] | [$\bar{2}$11]* |
|---|---|---|---|---|---|---|---|---|---|
| calc. | 90.7° | 99.2° | 100.5° | 122.5° | 123.5° | 130.5° | 131.3° | 149.8° | 150.2° |
| obs. | 90 ± 1° | 99½ + 1° | | 121 ± 4° | | 134 ± 2° | | 148 ± 2° | |

**Table 4. Ludlockite: X-ray powder data**

(camera dia. 114.6 mm; Co-K$\alpha$ radiation).

| $d$(Å) | $I_{obs}$ | hkl | $d$ (Å) | $I_{obs.}$ | hkl | $d$ (Å) | $I_{obs.}$ | hkl |
|---|---|---|---|---|---|---|---|---|
| 10.90 | m | 010 | 4.47 | mB | 002 (&c) | 3.330 | ms(3) | 23$\bar{1}$ (&c) |
| 8.81 | vvs (1) | 011 | 4.41 | mw | 0$\bar{2}\bar{2}$ | 3.216 | vw | 1$\bar{3}$2 (&c) |
| 7.76 | vvw | 110 | 4.20 | vvw | 201 | 3.160 | ms | 3$\bar{2}\bar{1}$.$\bar{2}\bar{2}\bar{1}$ |
| 7.22 | vvw | 10$\bar{1}$.1$\bar{1}$0 | 4.11 | w | 2$\bar{1}$1 | 3.060 | w | 3$\bar{1}$2 (&c) |
| 5.88 | w | 011 | 3.94 | wB | 0$\bar{3}$1.2$\bar{1}\bar{1}$ | 2.978 | mw | 003 (&c) |
| 5.41 | vvw | 12$\bar{1}$ | 2.69 | m | 22$\bar{2}$ | 2.935 | vs (2) | 0$\bar{4}$1 (&c) |
| 5.19 | vw-w | $\bar{1}\bar{1}\bar{1}$ | 3.60 | mw | 20$\bar{2}$.2$\bar{2}$0 | 2.863 | ms | 212,1$\bar{3}\bar{1}$ (&c) |
| 4.98 | vw | 120 | 3.57 | vw | 2$\bar{2}$1 | 2.793 | mw-m | 3$\bar{2}$0,122 |
| 4.74 | mB | 210 (&c) | 3.453 | vvw | 130 (?) | | | |



only reflections we have been able to get on the optical goniometer have been very poor and confined to the prism zone [100]. Scanning electron micrographs, fig. 3 - 6, show that the terminations of the needles are variable and that all crystals are multiply twinned.

The crystals are all elongated along the *a*-axis [100], and are flattened on $\{0\bar{1}1\}$; the only other face that we have identified with certainty is $\{021\}$. It is a feature of the geometry of ludlockite that some of the angles are close to 90°, making for difficulty in identifying unambiguously the inter-edge angles measured from SEM photographs. Thus $(0\bar{1}1)$:(021) is 90.6°, and [100]:[011] is 90.7° (Fig. 2); further, the face normal (021) and the zone axis [011] are within 0.9° of each other so that we can say no more at present about the twinning than that the composition plane is $\{0\bar{1}1\}$. Some relevant comparisons between calculated and observed interfacial and inter-edge angles are given in Table 3.

Cleavage on $\{0\bar{1}1\}$ is perfect and micaceous, and on $\{021\}$ perfect, with the result that the crystals readily fray at the ends to a bunch of cleavage fibers (Fig. 7).

### Infra-red and Raman spectra

Infrared spectra have been recorded for us by C. J. Elliott, and Raman spectra by W. P. Griffith, but the curves are not reproduced here. The infrared spectrum is very similar to that of karibibite. Neither type of spectrum shows any sign of As-O bonding, with the oxygen atoms attached singly to arsenic as in compounds containing isolated $AsO_3^{3-}$ or $AsO_4^{3-}$ anions. Instead, both show strong bands at around 480 $cm^{-1}$ which are characteristic of -As-O-As- 'stretches', and which are shown by arsenolite and claudetite (minerals with structures known to contain fully-shared oxygen atoms).

### Physical properties

Crystals of ludlockite are very flexible and sectile, and cleave readily. The color is a rich red (R. H. S. 182A), and the streak is light brown (R. H. S. 172C). There is no fluorescence visible in either long- or short-wave U.V. (compare karibibite, which fluoresces yellow). The lustre is sub-adamantine. The hardness is difficult to determine, but appears to be about 1½ - 2. The specific gravity was determined on samples of about 10 mg, using a Berman balance and ethylene dibromide as immersion liquid; values of 4.40 to 4.33 were obtained, and it was assumed that the higher value was more reliable with an estimated accuracy of about 1%. We may be wrong, and the true value may prove to be lower (see Table 1).

### Optical properties

Ludlockite has near-orthorhombic optics, and laths are length-slow with straight extinction. An obtuse bisectrix interference figure is to be seen through the laths, with the optic axial plane perpendicular to the plane of flattening and parallel to the length. The optic sign is positive, but the optic axes were not observed on the universal stage even at the limits of tilt; sections were cut across the crystals (embedded in resin), but no acute bisectrix figure was seen. Thus 2V(+) and the dispersion are not known. An extinction angle of about 3° ($\gamma$:[100]) was observed on a few laths with $\{0\bar{1}1\}$ vertical, but the sense was not determined. Attempts were made to 'un-twin' the crystals by pulling off $\{0\bar{1}1\}$ cleavage flakes, but the extinction remained straight. Refractive indices for sodium light were obtained by immersion in Cargille liquids: $\alpha \approx 1.96$, nearly $\perp$ $[0\bar{1}1]$; $\beta = 2.055 \pm 0.005$, nearly // [011]; $\gamma > \sim 2.11$, with $\gamma$:[100] $\approx$ 3°. The pleochroism scheme is $\gamma$ (orange-yellow) > $\beta$ (deep yellow) > $\alpha$ (yellow), and all colors deepen rapidly with increasing thickness.

### Name and type specimens

Ludlockite was approved by the I.M.A. Commission on New Mineral Names in February 1970. The name is for Frederick **Lud**low Smith III and Charles **Lock**e Key, who found the mineral and presented it to the Mineral Department, British Museum (Natural History). Type specimens are numbered BM 1969,215 and 216.

### Discussion

The only other species that are essentially arsenates or arsenites of iron and lacking structural water are angelellite ($Fe_4As_2O_{11}$; 1959), karibibite ($Fe_2As_4(O,OH)_9$; 1973) and schneiderhöhnite ($Fe_8As_{10}O_{23}$; 1973). Karibibite comes closest to ludlockite in appearance and Fe:As ratio, but the possibility of identity was disposed of in correspondence with Professor Sahama before its description was published (von Knorring *et al.*, 1973); the quickest field distinction between the two is that karibibite fluoresces yellow in short wave U.V., whereas ludlockite does not fluoresce at all.

Despite the As:O ratio of 1:3, most of the As in ludlockite is present as $As^{5+}$. Pending determination of the structure, the evidence that we have given above and its physical resemblance to claudetite suggest that ludlockite contains sheets or bands of $AsO_6$ octahedra sharing the corner oxygen atoms with each other. The volume per oxygen atom is a measure of the closeness of packing of a structure, and for ludlockite is 20 Å³ (1103/55). This value is about the same as those for scorodite (19) and for parasymplesite and symplesite (20 ± ); claudetite (25½), arsenolite (28), schneiderhöhnite (25½), and karibibite (24½) are more loosely packed, and angelellite (17) is more closely packed.

### Acknowledgements

We thank the many colleagues who have generously contributed to this description: B. D. Mitchell (Macaulay Institute for Soil Research) for the D.T.A.; S. J. B. Reed and R. F. Symes (BM(NH)) for the microprobe analyses; A. D. Law (Oxford University) for the Mössbauer measurements; J. R. Thyer (University of Bradford) for the E.S.R. measurements; W. P. Griffith (Imperial College of Science and Technology) for the Raman spectra; C. J. Elliott (BM(NH)) for the infrared spectra; and H. A. Buckley (BM(NH)) for the S.E.M. photographs. We owe them an apology for the delay in publication: so many interesting issues have arisen, which we have been intending to follow up, that we have found it difficult to draw the line and publish.

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# Leiteite: a new mineral from Tsumeb

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## ABSTRACT

Leiteite ("lā'-tīt") is a new zinc arsenite found associated with tennantite, chalcocite, smithsonite, and schneiderhöhnite at Tsumeb (Southwest Africa). It occurs as cleavable masses to 7 cm in greatest dimension, colorless to brown and transparent; the Mohs hardness is 1½ - 2 and the observed density is 4.3(1). The cleavage lamellae on {100} are flexible but inelastic and have a pearly luster. Leiteite is optically biaxial positive with $\alpha = 1.87(1)$, $\beta = 1.880(5)$, $\gamma = 1.98(1)$, and $2V = 26\frac{1}{2}(1)^\circ$; $X \wedge a = 11^\circ$, $Y = b$, $Z \wedge c = +10^\circ$; $r < v$, very strong. X-ray diffraction shows space group $P2_1/a$ with $a = 17.645(5)$ Å, $b = 5.019(2)$, $c = 4.547(2)$, and $\beta = 90^\circ\ 59(4)'$. The most intense powder diffraction lines (in Å) are **3.133** (100) (211), **3.163** (76) ($\bar{2}11$), **1.685** (49) (911), **3.320** (39) ($\bar{1}11$), **3.302** (32) (111), **4.833** (31) (110), but strong preferred orientation due to perfect cleavage can change this order. Wet chemical analysis yields the formula $\mathbf{(Zn_{0{\cdot}98}Fe_{0{\cdot}02})As_2O_4}$ with four formula units in the cell. The name is for Luis Teixeira-Leite, mineralogist, of Pretoria, Republic of South Africa.

## INTRODUCTION

The new mineral leiteite was discovered some years ago by Luis Teixeira-Leite among specimens from Tsumeb (Southwest Africa); unfortunately it is impossible to determine from the miners the exact location in this deposit from which the specimens were obtained. The leiteite was found as a single specimen, 7 x 4 x 0.3 cm, which was subsequently divided into several pieces for mineralogical studies and museum specimens (one of these is shown as figure 1). Parts of the original specimen have been deposited in the Smithsonian Institution (National Museum of Natural History), Washington, D.C., in the British Museum (Natural History), London, and in the Mineralogical Collection of the P. and M. Curie University, Paris. Leiteite (pronounced "lā' tīt") is named in honor of its discoverer.

The name and species have been approved by the Commission on New Minerals and Mineral Names, I.M.A.

## OCCURRENCE

Leiteite occurs as colorless to brown cleavable masses; one of the larger fragments of the single known specimen is shown as Figure 1. Although the study of leiteite did not begin until after it had been brought from the mine and broken into several pieces, we can make some fairly good guesses as to its location in the mine and its paragenesis based on the minerals associated with it. Almost all of the fragments we examined were leiteite only, but on one piece we found platelets of leiteite with smithsonite on a matrix of tennantite. Most fortunately, at a later date, Peter Embrey sent us a description of the leiteite specimen in the Mineralogical Collection of the British Museum (Natural history) "Specimen B.M. 1976,235. Several bruised and cleaved crystals 4 to 10 mm across, near 6 mm and smaller cleaved black grains of schneiderhöhnite on a matrix of mixed sulfides, mainly chalcocite. No morphology is observable." Schneiderhöhnite, $8(Fe_{0{\cdot}96}Zn_{0{\cdot}03}Ge_{0{\cdot}01})O{\cdot}5As_2O_3$, is a rare arsenite known so far only from a single occurrence in the Tsumeb mine (Otteman *et al.*, 1973). It was discovered here a few metres below the 29 level (908 m) in a small druse in the dolomite-chert breccia near its contact with pseudo-aplite in the "deep oxidation zone." The schneiderhöhnite was associated with chalcocite and zincian stottite with traces of relict pyrite, tennantite, and galena as accessory minerals. According to Otteman *et al.* (1973) schneiderhöhnite is a secondary mineral which probably formed at a temperature of 40°C. Thus, while the schneiderhöhnite found on the leiteite specimen in the British Museum may be a second occurrence of the mineral at Tsumeb, it seems likely that it came from the vicinity of the original discovery and that leiteite formed under the same conditions. It is worth noting that the zinc orthoarsenite, reinerite, $3ZnO{\cdot}As_2O_3$, was found in cavities about 10 metres below the 29 level associated with bornite and chalcocite (Geier and Weber, 1958).

## PHYSICAL AND OPTICAL PROPERTIES

Leiteite exhibits no crystal forms, but a perfect {100} cleavage was observed. The cleavage lamellae are flexible, inelastic, and somewhat sectile. The mineral has hardness between 1½ and 2 (Mohs). Density, measured with a pycnometer on an uncrushed 500 mg sample, was 4.3(1); the value is slightly low due to air entrapped between cleavage surfaces.

Leiteite is colorless to pale brown and transparent, with a pearly luster on the cleavage. Optically it is biaxial positive. Accurate determination of indices of refraction with high immersion media is difficult as the mineral is slowly attacked by these liquids. Leiteite is nonfluorescent. Optical data and orientation are given in table 1 and figure 2.

## X-RAY DIFFRACTION STUDY

A small cleavage fragment, carefully squeezed between two glass slides to flatten it, was examined by precession techniques using MoK $\alpha$ ($\lambda = 0.7107$ Å) radiation. Leiteite is monoclinic, pseudo-orthorhombic, and systematic absences show the space group to be $P2_1/a$.

Unit cell parameters, after least-squares refinement of the powder diffraction data, are $a = 17.645(5)$ Å, $b = 5.019(2)$, $c = 4.547(2)$, and $\beta = 90^\circ\ 59(4)'$. The calculated density with $4[(Zn_{0{\cdot}98}Fe_{0{\cdot}02})As_2O_4]$ is 4.61 g/cc.

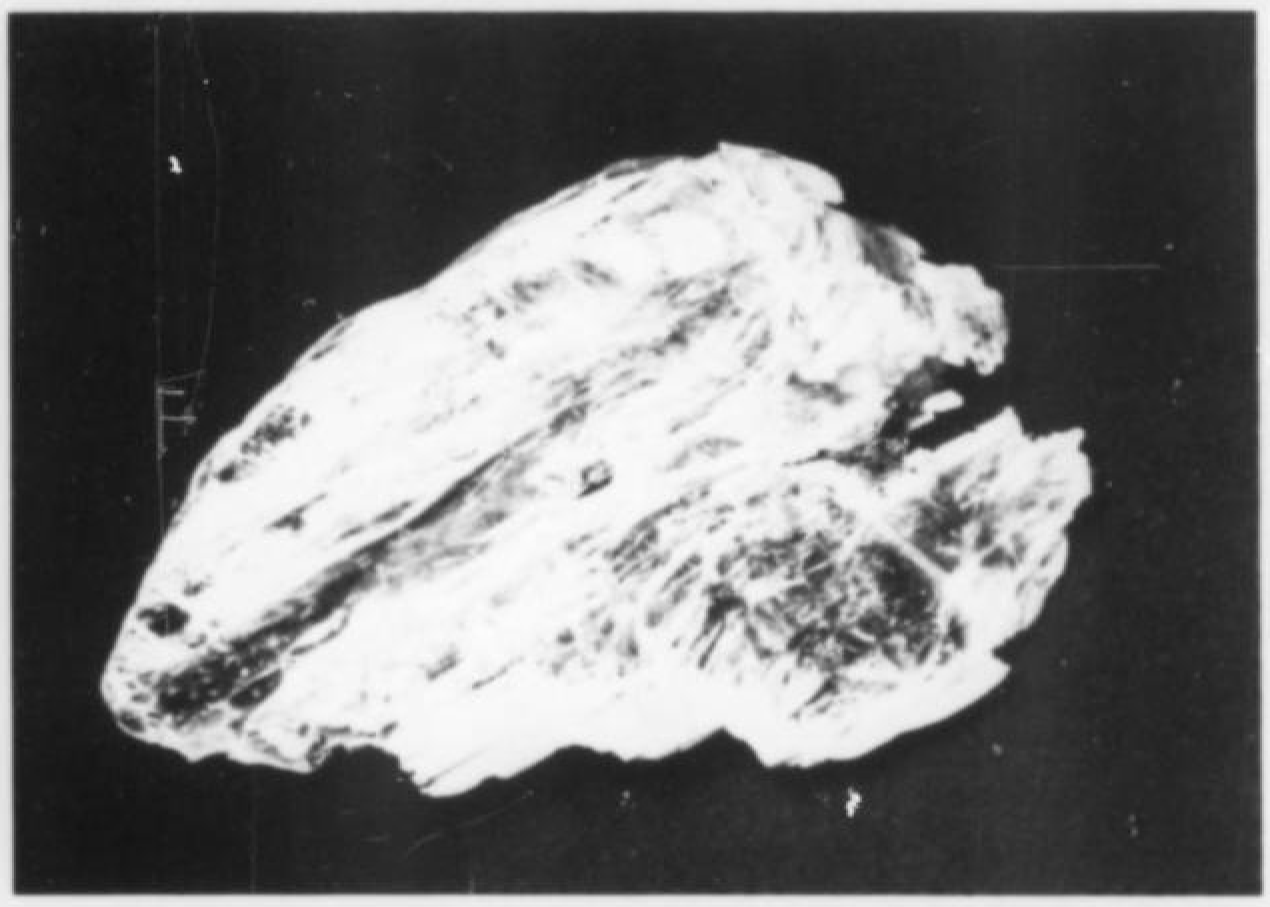
A powder diffraction pattern was obtained using a Nonius Guinier camera and quartz as the internal standard. Relative intensities were obtained by measuring the film with a Joyce microdensitometer. X-ray powder data for leiteite are given in table 2. Because of its perfect {100} cleavage, diffractometer traces of leiteite show strong preferred orientation; the diffractometer intensities ($I_D$) are compared in table 2 with those measured from the Guinier film ($I_G$).

## CHEMICAL COMPOSITION

Leiteite was analyzed by two different methods. **(1)** Samples were analyzed with an ARL EMX-SM electron microprobe using an accelerating voltage of 15 KV and a specimen current

*Figure 1.* **Leiteite fragment in** ***(above)*** **transmitted and** ***(below)*** **reflected light. The fragment is 22 mm long.**

*Figure 2. (right)* **Edge view of plate showing optical orientation for leiteite.**



of 2 x $10^{-8}$ amperes on benitoite. The K$\alpha$ lines of both As and Zn were analyzed using LiF crystals. (The L$\alpha$ line of As, though exhibiting a better peak-to-background ratio as analyzed by an ADP crystal, encounters heavy absorption by Zn that is apparently overestimated by Heinrich (1966), and consequently overcompensated by FRAME, the theoretical data reduction program utilized.) Recrystallized reagent grade $As_2O_3$ and ZnO were used as standards. Because $As_2O_3$ is noticeably affected by even a defocussed beam, counts were taken on it with a beam 10 microns in diameter, whereas the fine-grained ZnO standard and micaceous plates of leiteite required a well-focussed beam. Two independent analyses of the new mineral were made, each relying on 10 counts of 10 seconds each for both the standards and the mineral. Count termination was made in the fixed beam current mode to compensate for possible fluctuation in beam energy. Count data were corrected by the computer reduction scheme, FRAME, of the U.S. National Bureau of Standards (Yakowitz *et al.*, 1973). Assigned error limits represent one standard deviation as determined from counting data on the new mineral. **(2)** Samples were also analyzed by wet chemical analysis. Arsenic, after oxidation with $HNO_3$, was determined by the molybdenum blue colorimetric method. Both zinc and iron were determined by atomic absorption spectrophotometry. Leiteite dissolves slowly in cold

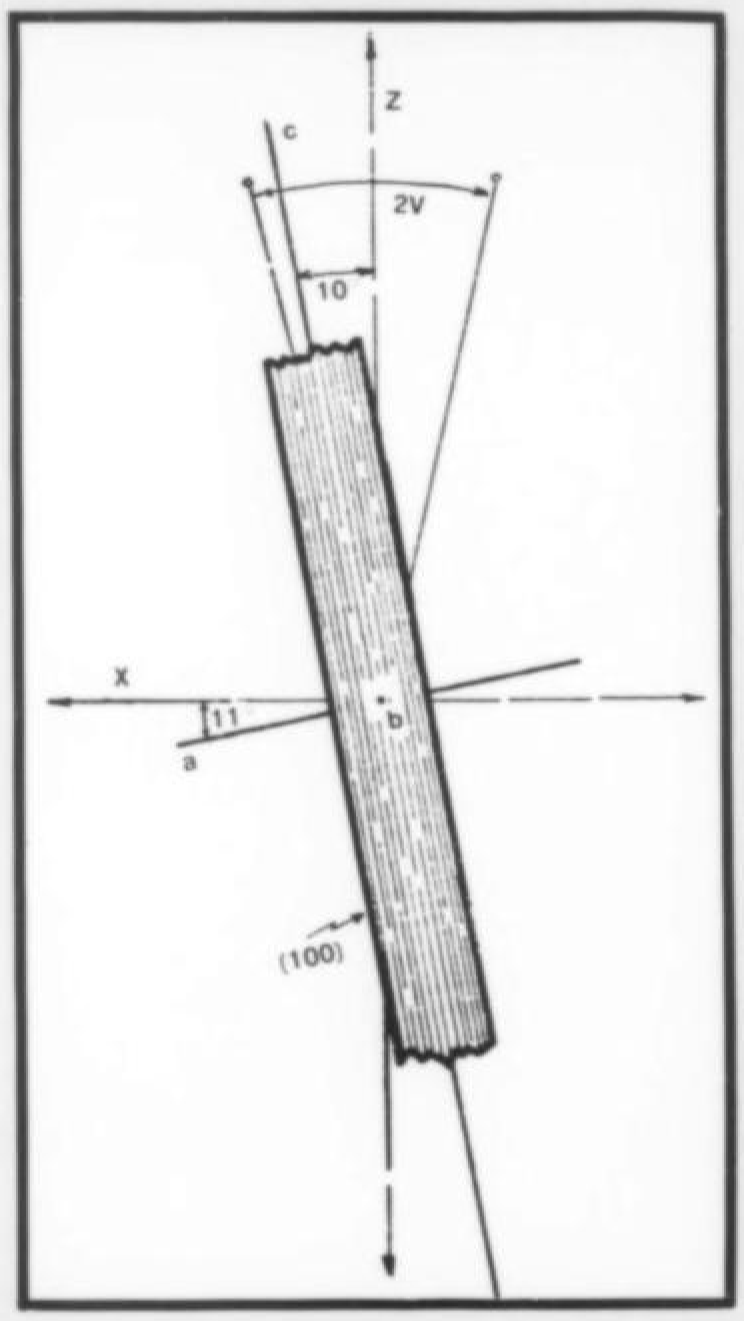


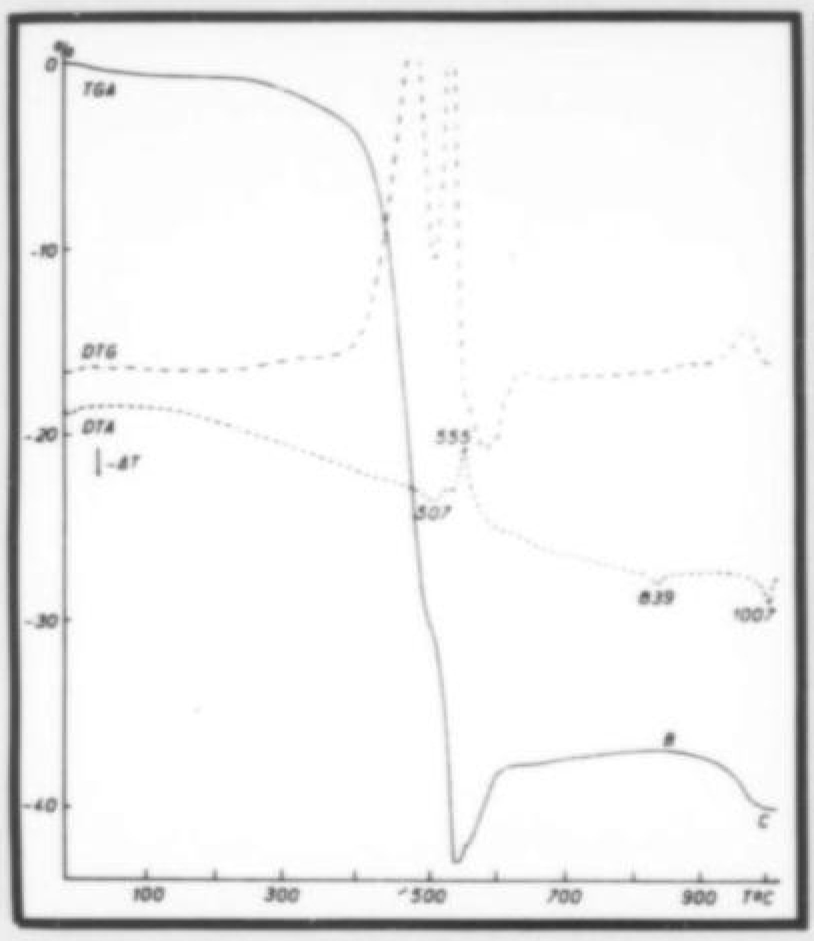
**Table 1.**
**Optical properties of leiteite.**

$\alpha$ = 1.87(1)
$\beta$ = 1.880(5)
$\gamma$ = 1.98(1)
(+)2V = $26\frac{1}{2}(1)°$
X ∧ *a* = +11°
Z ∧ *c* = +10°
Y = *b*
$r < v$, very strong
optic axial plane {010}
Indices determined in both sodium light and white light.

**Table 2. Indexed powder pattern for leiteite (CuK$\alpha_1$ radiation, $\lambda$ = 1.5405981 Å).**

| *hkl* | *d* calc.(Å) | *d* obs.(Å) | I (G) | I (D) |
|---|---|---|---|---|
| 200 | 8.818 | 8.808 | -- | 32 |
| 110 | 4.828 | 4.833 | 31 | 6 |
| 400 | 4.409 | 4.405 | 4 | 100 |
| 011 | 3.369 | 3.369 | 4 | -- |
| $\bar{1}11$ | 3.318 | 3.320 | 39 | -- |
| 111 | 3.302 | 3.302 | 32 | 6 |
| $\bar{2}11$ | 3.162 | 3.163 | 76 | 18 |
| 211 | 3.135 | 3.133 | 100 | 21 |
| 600 | 2.941 | 2.940 | 26 | 400 |
| $\bar{3}11$ | 2.940 | -- | -- | -- |
| 311 | 2.908 | 2.908 | 10 | -- |
| 510 | 2.887 | 2.884 | -- | 19 |
| $\bar{4}11$ | 2.695 | 2.694 | 8 | 2 |
| 411 | 2.661 | 2.660 | 3 | 1 |
| 020 | 2.510 | 2.510 | 19 | 1 |
| $\bar{5}11$ | 2.452 | 2.452 | 3 | 2 |
| 220 | 2.414 | 2.414 | 19 | 3 |
| 002 | 2.273 | 2.273 | 18 | 1 |
| $\bar{2}02$ | 2.210 | 2.211 | 9 | -- |
| 202 | 2.192 | 2.193 | 17 | 3 |
| 420 | 2.181 | 2.180 | 26 | 5 |
| 112 | 2.053 | 2.053 | 7 | -- |
| 321 | 2.053 | -- | -- | -- |
| $\bar{4}02$ | 2.035 | 2.034 | 14 | 2 |
| 402 | 2.007 | 2.006 | 10 | 2 |
| 811 | 1.856 | 1.856 | 2 | 7 |
| 811 | 1.835 | 1.835 | 2 | 8 |
| 10·0·0 | 1.764 | 1.761 | -- | 22 |
| 911 | 1.685 | 1.685 | 49 | 3 |
| 022 | 1.685 | -- | -- | -- |
| 130 | 1.666 | 1.665 | 7 | -- |
| 10·1·0 | 1.666 | — | — | |
| $\bar{1}31$ | 1.565 | 1.565 | 6 | 2 |
| $\bar{2}31$ | 1.547 | 1.547 | 18broad | -- |

I(G). Intensity measured from Guinier film.
I(D). Intensity measured from diffractometer trace.



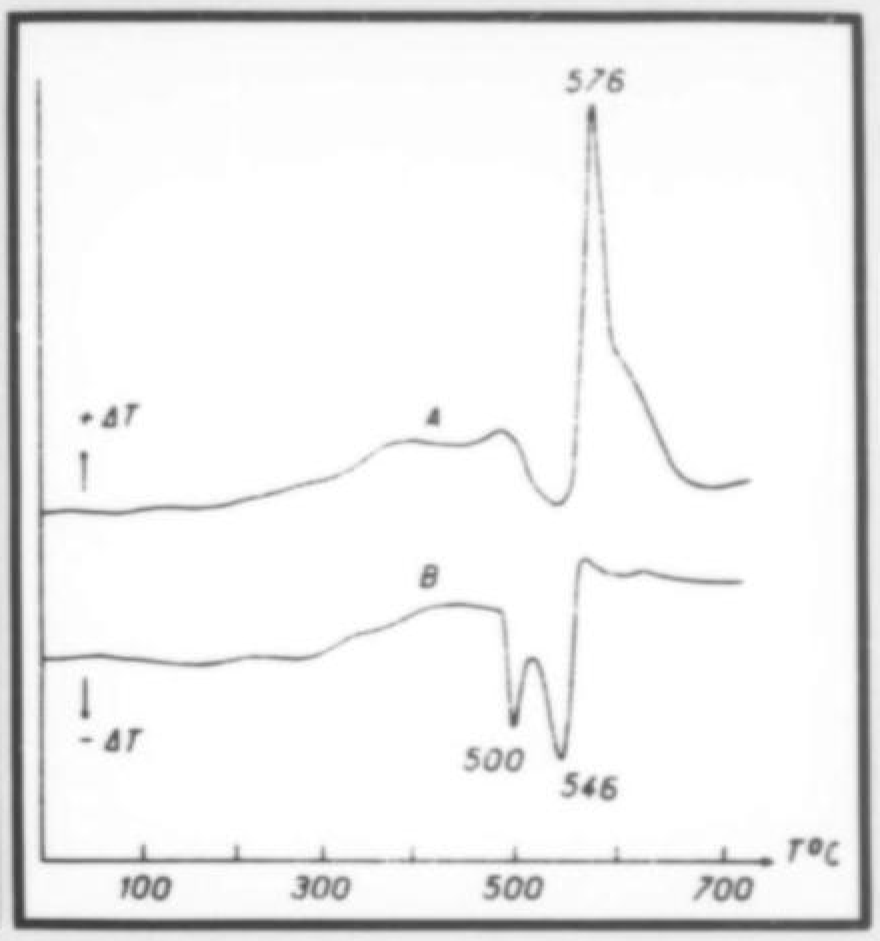


***Figure 3. (far left)*** **Thermogravimetric (TGA), differential thermogravimetric (DTG), and differential thermo-analysis (DTA) curves for leiteite.**

***Figure 4. (left)*** **DTA curves for leiteite in normal atmosphere ("A") and in nitrogen ("B").**

**Table 3. Chemical analyses of leiteite.**

*Microprobe*

| | Analysis 1 | Analysis 2 | Calculated Composition for $ZnAs_2O_4$ |
|---|---|---|---|
| Zn | 23.6 ± 0.4 % | 23.6 ± 0.3 % | 23.41 % |
| As | 53.7 ± 1.1 | 53.4 ± 1.7 | 53.84 |
| 0 | — | — | 22.75 |

*Wet Methods*

| | Analysis | Molecular Ratios | | | Calculated Composition for $ZnAs_2O_4$ |
|---|---|---|---|---|---|
| ZnO | 28.5 % | 0.3503 | 0.971 | 0.99 | 29.14 |
| FeO | 0.5 | 0.007 | 0.019 | | |
| $As_2O_3$ | 71.4 | 0.3609 | 1 | | 70.86 |
| Total | 100.4 | | | | 100.00 |

1:1 HC1. Analytical data are presented in table 3. The wet chemical analysis yields the formula $(Zn,Fe)O \cdot As_2O_3$ or $\mathbf{(Zn,Fe)As_2O_4}$, with Zn:Fe = 98:2.

Leiteite is a zinc metaarsenite; the compound was first synthesized by Avery (1906) and has some industrial importance as a wood preservative. Chemically it can be related to trippkeite, $CuAs_2O_4$, but trippkeite is tetragonal (Zemann, 1951). As noted above, zinc orthoarsenite, $Zn_3(AsO_3)_2$, reinerite, is also found at Tsumeb and apparently formed under similar conditions.

## THERMAL BEHAVIOR

The thermal behavior of leiteite is shown in figure 3 by the thermogravimetric (TGA), differential thermogravimetric (DTG), and differential thermo-analysis (DTA) curves presented. At first there is a major loss of $As_2O_3$, followed by the oxidation of a part of the remaining $As_2O_3$ to $As_2O_5$; the A position on the TGA curve corresponds to the temperature (507°C) where the increased weight induced by oxidation equilibrates the loss of weight due to sublimation of $As_2O_3$.

When oxidation is complete (position B, 839°C), the composition $Zn_3(AsO_4)_2$ is obtained, following the reaction

$$\mathbf{3\,ZnAs_2O_4 + O_2 \rightarrow Zn_3(AsO_4)_2 + 2\,As_2O_3 \uparrow}$$

A chemical analysis of the resulting product gave (wt. %): $As_2O_5$ 47.9, $Fe_2O_3$ 0.84, and ZnO 49.9; this, disregarding the $Fe_2O_3$, yields the formula $2.94ZnO.As_2O_5$ or $Zn_3(AsO_4)_2$.

Between 900° and 1000°C, incongruent melting occurs with additional loss of $As_2O_3$ due to partial reduction; a chemical analysis of the sample at position C (1007°C) gave (wt. %): $As_2O_5$ 42.8, $Fe_2O_3$ 1.18, and ZnO 56.2.

The endothermic peak (507°C) on the DTA curve corresponding to the loss of $As_2O_3$, is very small and suggests that oxidation (exothermic) begins earlier than expected; when oxidation becomes preponderant, it gives a large exothermic peak (555°C). There is a small endothermic peak at 839°C and a more important one at 1007°C, corresponding to the melting point.

The DTA curves of figure 4 represent behavior in normal and inert atmosphere. Curve "A" shows the thermal behavior of leiteite in normal atmosphere: the large exothermic peak at 576°C corresponds to the oxidation of $As_2O_3$. Curve "B" shows the behavior of leiteite in an inert atmosphere (nitrogen); the two definite endothermic peaks at 500° and 546°C corresponding to the loss of $As_2O_3$: oxidation does not occur.

## ACKNOWLEDGMENTS

We are grateful to Miss M. C. Sichère for her help in making the thermal analyses. The manuscript has benefitted from the helpful criticism of Howard T. Evans, Jr., and Mary E. Mrose, U.S. Geological Survey. Some of the specimens studied were supplied by A. L. McGuinness and P. Bariand. We thank Peter Embrey for the information concerning the British Museum specimen.

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# Schultenite from Tsumeb: a note on its morphology

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## Abstract

A new occurrence of schultenite, **$PbHAsO_4$**, is reported from a different part of the type locality, Tsumeb. Cleavages and prisms up to 25 x 8 x 5 mm lie on dark red tennantite, associated with cuproadamite (the cupriferous variety of adamite) and the new arsenate keyite. Type schultenite crystals were plates flattened on ***b***{010}, with ***l***{130}, ***n***{140}, ***c***{001}, ***e***{011}, ***p***{111}, ***q***{$\bar{1}$11}, ***u***{121}, ***s***{$\bar{2}$11} and other less common forms. The new crystals are prisms elongated parallel to [001] and flattened on ***h***{210}, with narrow ***b***{010}. Terminal forms were observed on one crystal only, with prominent ***c***{001}, ***p***{111}, ***u***{121}, ***e***{011}, and the new forms ***y***{101} and ***z***{113}; smaller faces of the other forms were observed.

## Introduction

Schultenite, **$PbHAsO_4$**, was described fifty years ago by L. J. Spencer as a new mineral from Tsumeb. Until now the type specimen (BM 1926,205) has remained the only one recorded in the literature, although Spencer was of the opinion that "doubtless there are others in collections amongst the rich series of crystallized material that has come from the locality." The artificial compound is the common "lead arsenate" of commerce, and its crystallography was studied by Baron de Schulten for whom the mineral was named.

The original specimen of schultenite was obtained from the Munich mineral dealer Wilhelm Maucher, who had labelled it "lanarkite." The largest crystal on it is shown in figure 1. We now have two more specimens, obtained from the mineral dealers Luis Teixeira-Leite and Charles Key, on which the schultenite had already been identified. On both specimens the schultenite crystals are associated with and partly surrounded by massive and crystallized cuproadamite (the cupriferous variety of adamite), close to patches of the new species keyite, on a matrix of massive dark-red tennantite and (on one specimen) milky quartz.

## Morphology

Artificially prepared schultenite forms crystals of platy or tabular habit, showing the forms ***b***{010}, ***l***{130} and ***p***{111}. The type schultenite crystals are of similar habit, with the addition of a prominent ***c***{001} face and smaller faces of ***n***{140}, ***u***{121}, ***e***{011}, ***s***{$\bar{2}$11}, ***q***{$\bar{1}$11} and other less common forms (Fig. 2, and inset drawing with Fig. 1). The association of these crystals with anglesite and bayldonite, and the absence of sulfides, indicates that they came from near the surface of the deposit in the oxidized zone.

The new specimens, in different association, clearly came from a deeper part of the deposit and are of very different habit. One specimen, BM 1975,399, has rough cleaved prisms lying on the matrix and a complete but deeply etched crystal 13 x 13 x 8 mm too enclosed by cuproadamite for examination. The other specimen, BM 1975,660, one of the two keyite holotypes, has parallel groups of prisms elongated [001], up to 25 x 8 x 5 mm, lying on edge on cuproadamite; most are cleaved on {010} by previous handling, and have broken ends. One termination only was found and, although broken, had remained loosely attached and was removed for goniometric measurement.

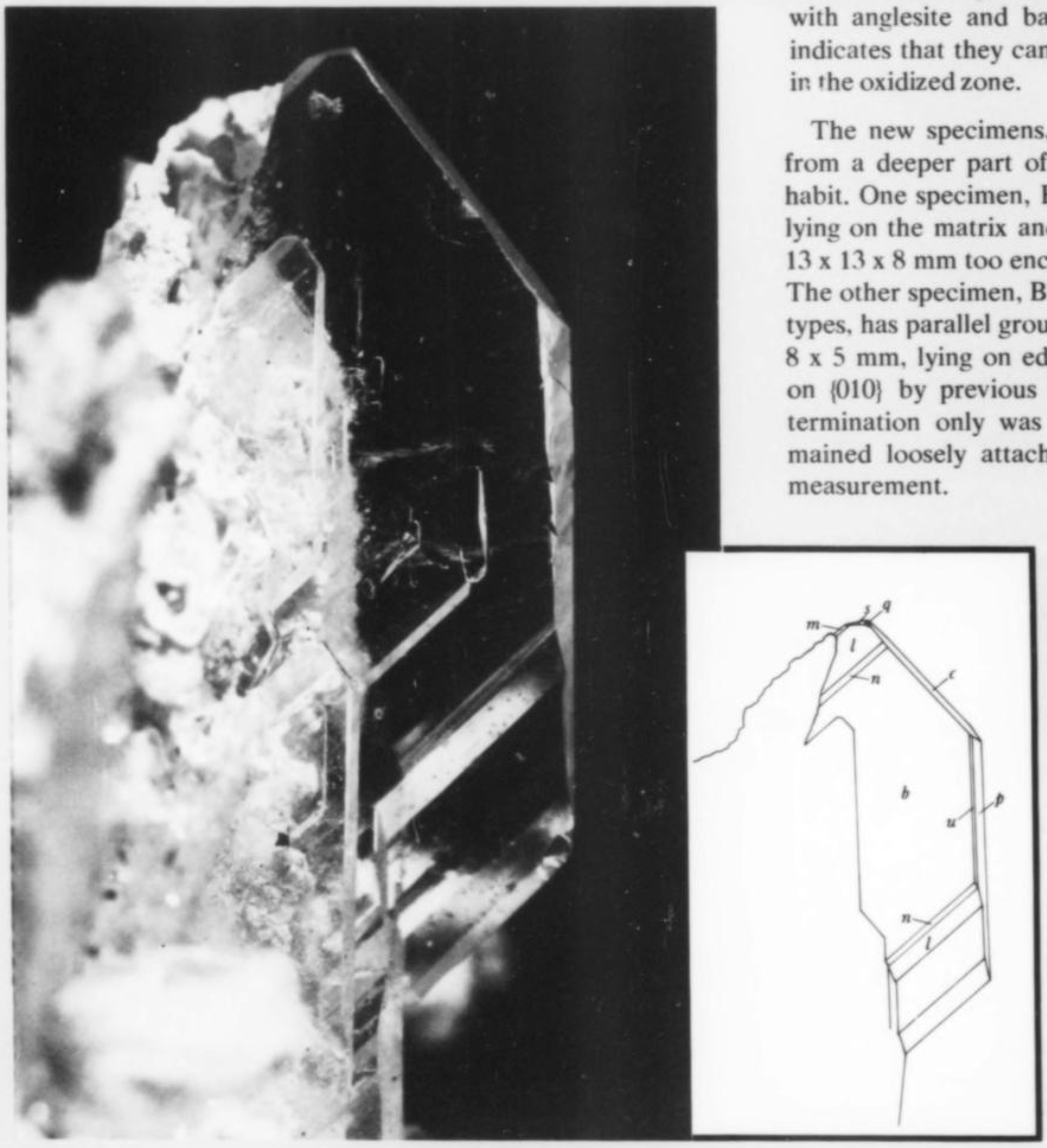

*Figure 1.* **Schultenite: the largest crystal on the type specimen, BM 1926,205. Length of crystal, 8 mm. Inset drawing shows the forms present: *b*{010}, *n*{140}, *l*{130}, *m*{110}, *c*{001}, *p*{111}, *q*{111}, *u*{121} and *s*{211}. Photograph by Frank Greenaway, BM(NH).**

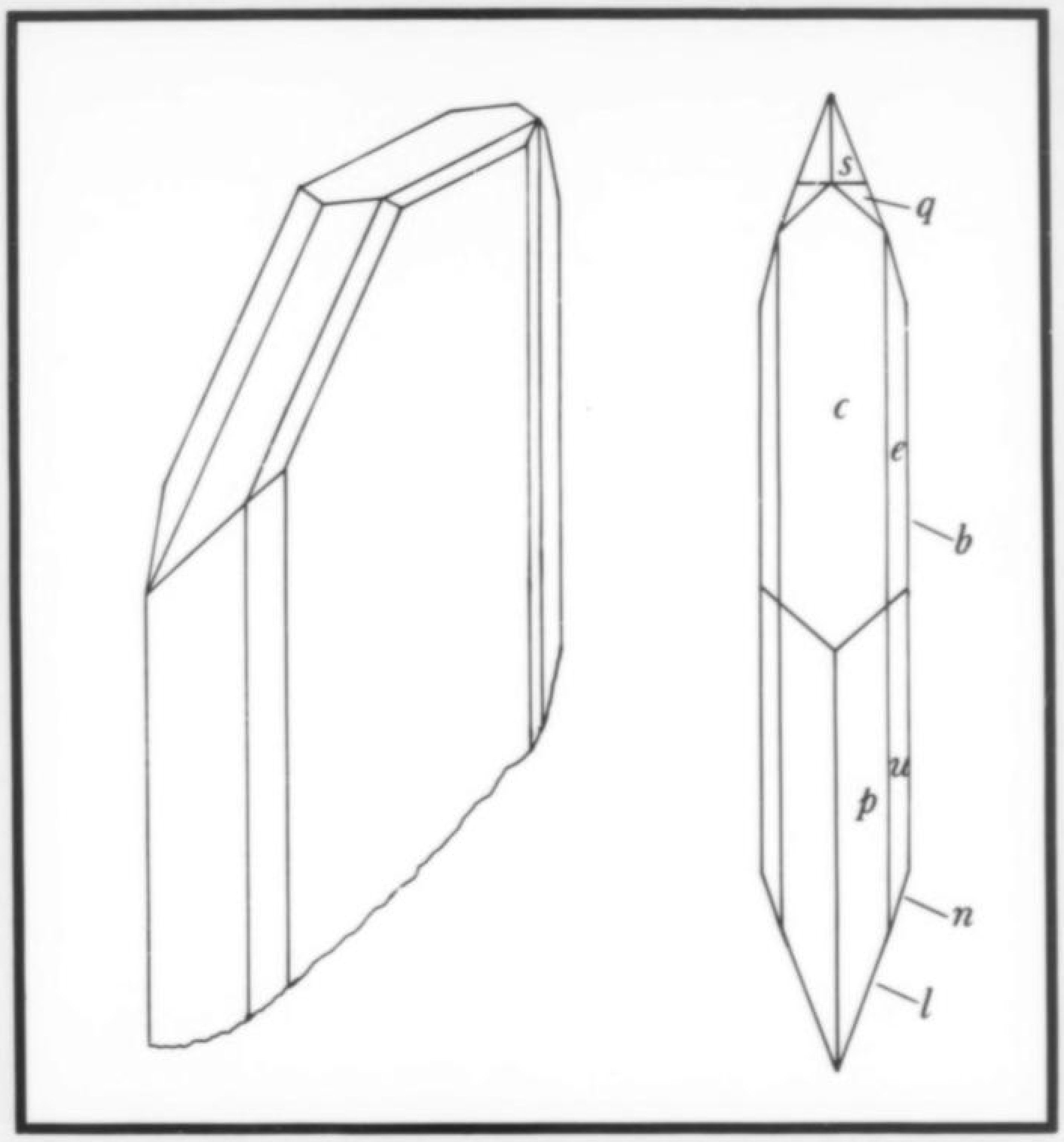

*Figure 2. (above)* **Schultenite: plan and elevation of a crystal of habit similar to that in figure 1.**

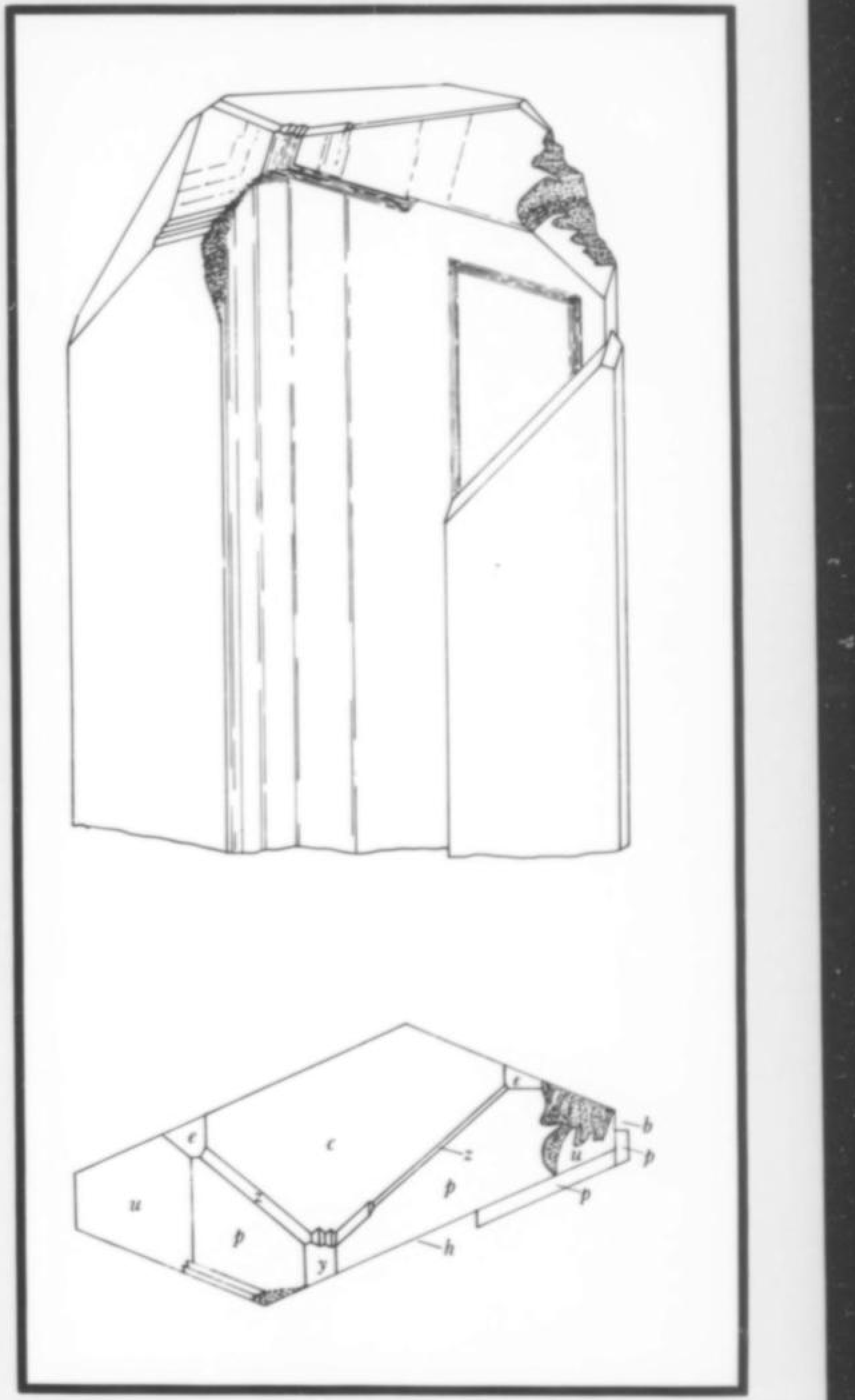

*Figure 3. (right)* **Schultenite: plan and elevation of a measured crystal from BM 1975,660. Forms: *h*{210}, *b*{010}, *c*{001}, *p*{111}, *u*{121}, *e*{011}, *y*{101} and *z*{113}.**

The prominent prism zone on these crystals, as for the original crystals, is the ***c***-axis [001], the axis of elongation, but the plane of flattening is now one of the ***h***{210} faces and ***b***{010} is reduced to a pair of narrow strips (Fig. 3). The resulting prisms, of acute-lozenge cross-section, are reminiscent of anglesite prisms with dominant ***l***{101} and elongated along [010], although the angles are different: schultenite, (210):$(2\bar{1}0)$ 66°50′; anglesite, (102):$(\bar{1}02)$ 44°38′. The faces of ***h***{210} are striated, more so than we have shown, and apart from ***b***{010} the only other forms seen in this zone were single, very narrow strips of ***k***{120} and ***m***{110}. Two tapering faces, not quite in the zone, were high-index vicinals near the {410}.

The development of the terminal faces is also different, as are their shapes, because of the changed direction of flattening. The ***c***{001} is the largest face; ***p***{111} and ***u***{121} are also large, with ***e***{011} small but perfect. Of the other forms reported by Spencer, only ***r***$(\bar{1}22)$ was seen as a single minute reflection. On the other hand, in addition to poor point reflections from $(\bar{1}12)$ and $(\bar{2}03)$ which may be ignored, the new forms ***y***{101} and ***z***{113} are clearly developed and are shown in the drawing; ***y*** is heavily striated, and ***z*** forms stepped strips along the edges between ***c***{001} and ***p***{111}.

Since we have seen and measured only the one crystal, we can draw no conclusions about the constancy of this new habit, apart from the dominance of the prism ***h***{210} which also occurs on the broken prisms. Suffice it to say that we would not have recognized the mineral by visual inspection alone, and the forms developed are such that goniometric measurements would not have suggested schultenite on comparison with the classification angles in the Barker Index (where it is entered for artificially prepared $PbHAsO_4$ under M.797 A & B). The identification has been confirmed by X-ray powder photographs; powder data and angle tables are well established in the literature and so are not repeated here. The lettering of forms follows Spencer's usage.

## Reference

SPENCER, L. J. (1926) Schultenite, a new mineral, from South-West Africa. *Mineral. Mag.* **21**, 149 - 155. [also Dana's *Syst. Min.*, 7th edn. 2, 661].

# Malachite inclusions in Cerussite from Tsumeb

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Recently there have appeared on the mineral market a few specimens of transparent cerussite crystals with inclusions of a green acicular mineral (see photo) from Tsumeb, Southwest Africa. The author received two specimens and a portion of a third from Miriam and Julius Zweibel, of Mineral Kingdom, with the request that the unknown green mineral be identified. Suggestions for what it might be included tsumebite, bayldonite, brochantite, malachite, or possibly even a new mineral.

The unknown mineral could be seen without magnification as bright green needles or felt-like aggregates within transparent, terminated cerussite crystals. The vivid green color of the samples suggested that a high percentage of the green mineral might be present. However a point count taken on a crushed portion of a specimen showed the unknown to constitute only one or two percent of the sample.

Mechanical or chemical separation of the unknown from the cerussite was not feasible. Both the unknown and the cerussite are soluble in acids. A wet chemical analysis showed the presence of copper and lead. The copper is obviously present in the unknown while the lead is part of the cerussite and could possibly have been present in the unknown as well.

An X-ray diffraction pattern was obtained for the specimen. However, because the concentration of unknown was so low relative to the cerussite, essentially only the peaks for cerussite appeared, and nearly all those of the unknown were lost in the background. One minor peak at $d = 2.85$ not belonging to cerussite did appear, and this corresponds to the principle peak of malachite. However a positive identification could not be made on this point alone.

Finally an ARL electron microprobe was employed. A section of a cerussite crystal was lapped down to expose some of the unknown green needles at the surface. Though these were minute, they were large enough to focus the electron beam upon without interference from the surrounding cerussite. Use of the scanning electron microscope on the probe was an aid in locating the unknown and in assuring that the beam was centered on the unknown.

A complete elemental scan was performed using LIF, ADP, RAP, and Pb-S-D analyzing crystals. Only copper, carbon, and a minor amount of lead were found.* Suspecting a carbonate in general and malachite in particular, quantitative data were taken using a known malachite standard. The results showed essentially the same copper and carbon counts in the unknown as in the malachite standard thereby positively identifying the unknown as malachite. This identification was repeated on all of the specimens in my possession.

This is not to say that all of the specimens of this type on the market are malachite. However it is likely that they all came from a single pocket and, if so, they would probably all be malachite.

Although neither cerussite nor malachite can be considered rare, the occurrence of malachite crystals as inclusions within transparent cerussite crystals is uncommon and this may well constitute a first occurrence. In addition, the attractiveness of the specimens should make them highly desirable to collectors.

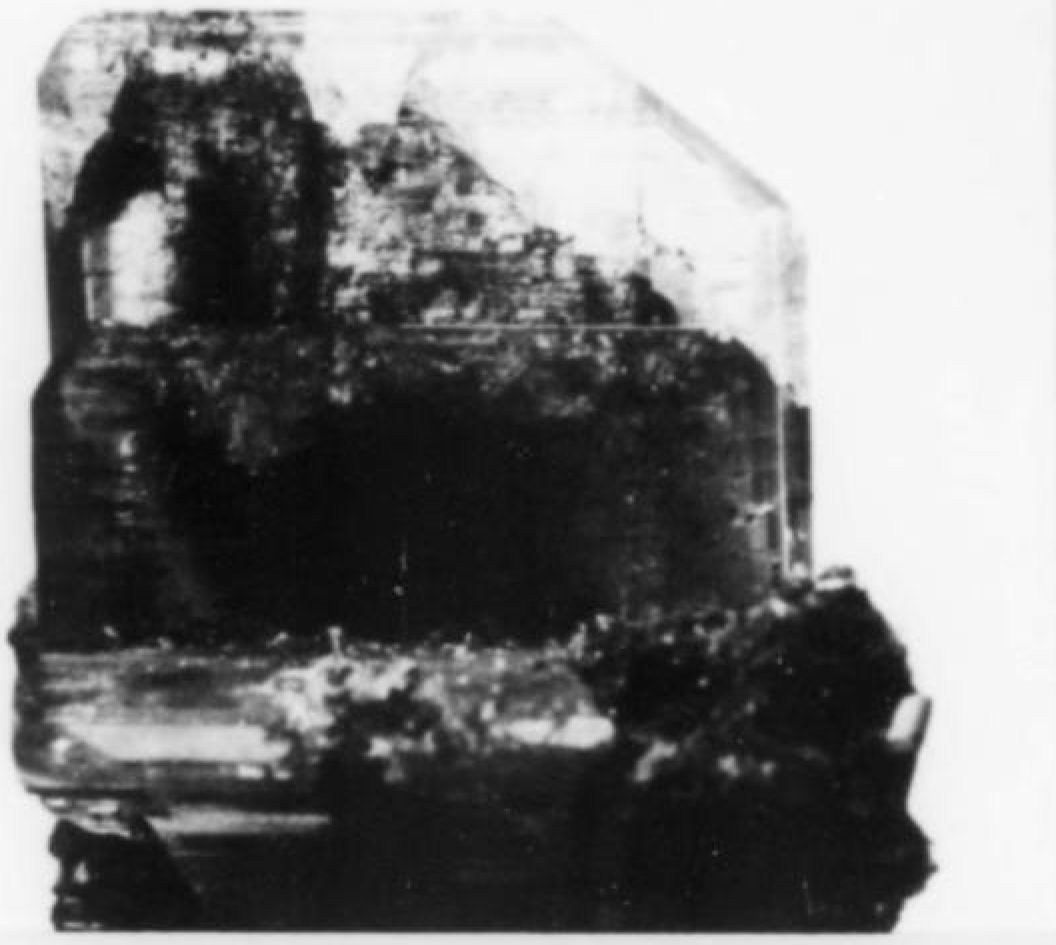

*Figure 1.* **Cerussite (transparent) with inclusions of bright green malachite (dark felt-like aggregates). Tsumeb, Southwest Africa. Overall size: 3 x 2 cm. Ed & Jeri Ruggiero specimen. Photo by Ed Ruggiero.**

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*The electron microprobe is relatively insensitive to most elements lower in atomic number than sodium (carbon is somewhat of an exception) and totally insensitive to elements lighter than boron. As such, hydrogen and oxygen are essentially undetectable. Oxygen, if present, is determined by assigning standard oxides to the elements present. Water is either assigned or determined by difference.

# XII MINERALS: A REVIEW OF THE LITERATURE

by

**Dwight Weber**

The minerals described in the accompanying tables and reported from Tsumeb are taken almost exclusively from the professional literature. In many cases the more important minerals (especially the sulfides) are either mentioned or discussed in a large number of papers. Only principal references for the former are listed, and many of these contain little, if any, discussion of the secondary minerals. Many of the very rare species (or those rarely found at Tsumeb) may be mentioned only once. All references are listed by number in the tables to aid the reader who may wish to investigate further. The underlined reference number is either the one which describes the mineral for the first time or, in the case of the better known minerals, contains more details than usual with respect to its occurrence at Tsumeb. All the known references on the rarer minerals are listed, except some abstracts. The latter have been deleted entirely for the commoner minerals, because these in particular are adequately described in such works as Roberts, Rapp, and Weber (1974), Ramdohr and Strunz (1967), Kostov (1968), or Palache, *et al.* (1944 & 1951). Other such texts have been omitted from the bibliography either because they are in foreign languages less known to the average reader or, if in English, add essentially nothing to the references already listed except for the manner of presentation of the subject of mineralogy or the classification of minerals rather than the description of mineral properties (e.g., Betekhtin, 1967, Fovarennykh, 1972, or Dana, as revised by Ford 1966). Though some of these books have much useful information, many which have been considered standard in the English language are (unfortunately) rapidly becoming obsolete, as far as mineral descriptions and the removal of discredited species are concerned. Other possible references are deleted because they are largely picture books containing photographs of Tsumeb minerals among others. While in a few cases these are very fine (e.g., Lieber, 1972), they are not sufficiently pertinent to be included in this review.

Formulas are, for the most part, taken from Fleischer (1975), except for a few found only in Strunz (1970) or Roberts, *et al.* (1974), or new minerals not yet listed. It should be emphasized, however, that in the case of certain minerals, especially those with the more complex formulas, a degree of "disagreement" may be observed among various professional authors.

Unfortunately little reference is made in the literature to pseudomorphs, except malachite after azurite. Because pseudomorphism is a subject of considerable interest to many collectors in particular, a separate table of what is known to the author regarding the existence of these at Tsumeb is included. This list was compiled from observations of the Pieters collection, other large collections and those acquired personally. Wendell Wilson added a significant number of observations through a study of the extensive Smithsonian Institution collection. It is highly probable that many other types of pseudomorphs exist in a mine with the complex assortment of minerals contained at Tsumeb.

The level in the mine is listed for those species which are generally found in one small area or for which this data may be available. Regarding the levels where the minerals have been found, it should be made clear that there is considerable overlap between the main sulfide zone and the two oxidation zones at each end of it, and that some sulfides exist at all levels, whereas the occurrence of secondary minerals is minimal or even nonexistent in parts of the largely unoxidized zone between levels 12 and 24.

In addition to the minerals and subspecies from Tsumeb listed or described in the references, specimens which have been seen in collections or upon which unpublished work has been done (but not mentioned in the literature examined) are also noted. Of course, just being mentioned in print or found written on a label does not guarantee that a specimen was correctly identified, and numerous mistakes have been made by professional mineralogists, as can be determined from the long list of discredited mineral names to date.

In addition to incorrect identification, another source of error can sometimes occur when an old collection ends up in an estate to be sold by one who knows or cares little or nothing about minerals, or in a museum where, for example, the curator is a paleontologist. Labels can be easily mixed up or lost, and in the case of some species a good deal of work may be required to correct the error, if that is possible. European collections have been particularly subject to a special hazard, namely the two World Wars, during which many collections or specimens were lost, stolen, or partly destroyed. For example, it is known that one of the larger and finer early collections of Tsumeb minerals (collected by Schneiderhöhn) was completely destroyed by the Americans when they bombed the University of Freiberg in 1944 (Schneiderhöhn, 1958).

Another possible error can arise from a source which many collectors do not usually consider: carelessness or downright misrepresentation on the part of some miners, who frequently are the prime source of supply for specimens to both collectors and dealers. While there is not much difficulty with Tsumeb minerals in this regard, specimens of such common species as descloizite, mottramite, malachite, and a few others have been found at Otavi, Berg Aukas, Uitsab, Abenab, and several other mines and prospects in the Otavi Highland, in addition to Tsumeb.

The tables include, where possible, data on whether the secondary minerals have been found in the first or the second oxidation zones, or both, based largely upon information in two papers (Strunz, 1967, and Strunz, Söhnge, and Geier, 1958). If mentioned in early papers, it may be reasonably assumed that the upper (first) zone alone is considered.

As early as 1916 Wagner reported, after listing the quantity of minerals already found there: *"Beautiful specimens of all of these minerals are obtainable, and many of them occur in large, perfectly formed crystals, so that Tsumeb is a veritable paradise for the specimen hunter. Indeed, it is doubtful if it is rivalled in this respect by any other ore-deposit."* As the title of this book indicates (*TSUMEB! The World's Greatest Mineral Locality*), Wagner's observation was accurate.

The Tsumeb mine has probably been more fortunate than some other famous localities in having retained the interest of several prominent mineralogists and geologists over the years, especially in Germany, who have collected there, have worked for the Tsumeb Corporation, have written many papers and reports, and probably have had some influence on company management to permit the preservation of a fair number of the fine specimens for posterity which might otherwise have been destroyed. It is to be hoped that future discoveries of fine specimens from deposits of the quality of Tsumeb will not be completely destroyed just to produce more metals for industry and governments.

**ACKNOWLEDGMENTS**

The author is indebted to W. Kahn for a number of obscure references to the German literature and for his own list of minerals. The latter has been compared with different lists compiled independently by W. Pinch, J. Weber, and others and with the published literature. Wendell Wilson made the final update through a comparison with the extensive mineral collection of the Smithsonian Institution (Washington, D.C.) and with very recent literature.

## MINERAL TABLES

***Abbreviations used:***

**VC** = Very Common
**C** = Common
**MC** = Moderately Common
**MR** = Moderately Rare
**R** = Rare
**VR** = Very Rare
**ER** = Extremely Rare

**P** = Primary (relatively unoxidized) zone, see p. 16, Fig. 5.
**$S_1$** = Secondary (oxidized) zone #1 (upper oxide zone), see p. 16, Fig. 5.
**$S_2$** = Secondary zone #2 (lower oxide zone), see p. 16, Fig. 5.
* Minerals of the country rock
** Minerals first reported from Tsumeb

**Numbers** in the REFERENCES column refer to numbered references at the end of this chapter.

**Mineral species** are in **bold**; *varieties* are in *italics*.

### TABLE 1. VERIFIED SPECIES REFERENCES.

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **Acanthite** (after argentite) | 1a | | | | | |
| **Adamite** | 7, 9, 15, 51, 52 | R | | $S_1$ | | $S_2$ |
| *Cuproadamite* (Cu-var.) | 45, 46 | MR | | | | $S_2$ |
| *Cobaltoadamite* (Co-var.) | 1a, 31b | VR | | | | |
| **Alamosite** | 24, **25** | ER | 28 | | | $S_2$ |
| **Albite*** | 38, 44 | | 12-24 | $S_1$ | P | $S_2$ |
| **Algodonite** | 31b | | | | | |
| **Anglesite** | 7, 8, 9, 10, 15, 23, 24, 25, 38, 39, 51, 52 | MC | | $S_1$ | | $S_2$ |
| **Ankerite** | 31b | MR? | | | | |
| **Aragonite** | 7, 9, 51, 52 | MC | | $S_1$ | | $S_2$ |
| *Nicholsonite* (Zn-var.) | 9, 29, 51, 52 | MC | | $S_1$ | | $S_2$ |
| *Tarnowitzite* (Pb-var.) | 31b, 51, 52, 9, 29 | MR | | $S_1$ | | $S_2$ |
| **Arsenbrackebuschite**** | 1a, **16b.** | | | | | $S_2$ |
| **Arseniosiderite** | 10 | VR | 30 | | | $S_2$ |
| **Arsentsumebite**** | **1**, 9, 52, 49 | VR | | $S_1$? | | $S_2$ |
| **Asbestos** | 1a, 31b | | | | | |
| **Atacamite** | 52 | VR | | $S_1$ | | |
| **Aurichalcite** | 2, 9, 23, 51, 52 | R | | $S_1$ | | $S_2$ |
| **Austinite** | 1a, 31b | VR | | | | |
| *Cu-Austinite* | 31b | | | | | |
| **Azurite** | 4, 7, 9, 15, 20, 23, 31a, 32, 38, 39, 41, 51, 52 | MC | | $S_1$ | | $S_2$ |
| **Barite** | 7, 9, 38, 51, 52 | R | | $S_1$ | | $S_2$ |
| **Bayldonite** | 7, 9, 15, 23, 51, 52 | MR | | $S_1$ | | $S_2$ |
| **Beaverite** | 9, 10 | R | 30 | | | $S_2$ |
| **Betekhtinite** | 9, 12, **14**, 52 | ER | 24-34 | | P | |
| **Beudantite** | 9, 10, 52 | R | 30 | | | $S_2$ |
| **Bindheimite** | 31b | ER | | | | |

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **Biotite*** | 38, 34 | C | | $S_1$ | P | $S_2$ |
| **Bornite** | 7, 9, 11, 12, 13, 14, 15, 26, 38, 39, 42, 44, 50, 51, 52 | MC | | | P | |
| **Briartite**** | 9, 11, 12, **13**, 52 | ER | 30-34 | | P | |
| *Ge-Briartite* | 11, 13 | ER | | | P | |
| **Brochantite** | 2, 9, 23, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Brunogeierite**** | 9, **28** | ER | 29 | | | $S_2$ |
| **Calcite** | 7, 27, 38, 44, 51, 52 | VC | | $S_1$ | P | $S_2$ |
| *Cobaltocalcite* (Co-var.) | 31b | R | | $S_1$ | | $S_2$ |
| *Cuprocalcite* (Cu-var.) | 31b | VR | | | | $S_2$ |
| *Plumbocalcite* (Pb-var.) | 31b, 27 | C | | | | |
| **Caledonite** | 7, 23, 51, 52 | VR | | $S_1$ | | |
| **Carminite** | 9, 10, **52** | VR | 30 | | | $S_2$ |
| **Carrollite** | 9 | VR | | | P | |
| *Ni-Carrollite* | 12 | VR | | | P | |
| **Cerussite** | 7, 8, 9, 15, 23, 27, 28, 38, 39, 51, 52 | VC | | $S_1$ | | $S_2$ |
| **Chalcanthite** | 9, 51, 52 | VR | | $S_1$ | | |
| **Chalcocite** | 7, 9, 11, 12, 13, 14, 20, 23, **26**, 28, 29, 38, 39, 42, 44, 46, 50, 51, 52 | VC | | | P | |
| **Chalcophanite** | 9 | VR | | | | $S_2$ |
| **Chalcophyllite** ("erinite") | 23 | | | | | |
| **Chalcopyrite** | 9, 12, 13, 15, 26, 28, 38, 39, 42, 44, 51, 52 | R | | | P | |
| **Chenevixite** | 23 | VR | | $S_1$? | | |
| *Pb-Chenevixite* | 1a | | | | | |
| **Chlorite*** | 20 | | | $S_1$ | | $S_2$ |
| **Chrysocolla** | 15, 23, 51, 52 | R | | $S_1$ | | $S_2$ |
| **Chudobaite**** | 8, **46**, 52 | ER | 30 | | | $S_2$ |
| **Cinnabar** | 9, 51, 52 | VR | | | P | |
| **Claudetite** | 9, **45**, 46, 51, 52 | VR | | | | $S_2$ |
| **Clinoclase** | 23, 52 | VR | | | | |
| **Conichalcite** | 7, 9, 15, 23, 45, 46, 51, 52 | R | | $S_1$ | | $S_2$ |
| *Parabayldonite* (Pb-var.) | 15b | | | | | |
| **Copper** | 9, 23, **26**, 27, 51 | MC | | $S_1$ | | $S_2$ |
| **Corkite** | 31b | | | | | |
| **Coronadite** | 9 | VR | | | | $S_2$ |
| **Covellite** | 9, 26, 38, 42, 51, 52 | MR | | | P | |
| **Cubanite** | 37, 38 | VR | | | P | |
| **Cuprite** | 7, 9, 15, 23, 38, 51, 52 | MR | | $S_1$ | | $S_2$ |
| *Chalcotrichite* (acicular-var.) | 51, 52 | R | | $S_1$ | | $S_2$ |
| **Descloizite** | 4, 7, 9, 51, 52 | R | 31 | $S_1$ | | $S_2$ |
| *Cuprodescloizite* (Cu-var.) | 31b | | | | | |
| **Devilline** | 1a, 31b | VR | 32? | $S_1$? | | $S_2$ |
| **Digenite** | 9, 18, 42, 44, 51, 52 | MR | | | P | |
| **Dioptase** | 2, 9, 15, 51, 52 | MC | | $S_1$ | | $S_2$ |
| **Djurleite**** | 36 | ER | | | P | |
| **Dolomite** | 7, 9, 20, 23, 26, 38, 39, 40, 42, 44, 52 | VC | | $S_1$ | P | $S_2$ |
| *Co-Dolomite* | 15, 17 | R | | $S_1$ | | $S_2$ |
| *Mangandolomite* (Mn-var.) | 38 | R | | | | $S_2$ |
| *Plumbodolomite* (Pb-var.) | 15, 17, 51 | MR | | $S_1$ | | $S_2$ |
| *Zn-Dolomite* | 9, 15, 17, 51 | MR | | $S_1$ | | $S_2$ |
| **Duftite-alpha**** | 7, 9, 15, 32, 51, 52, 54 | R | | $S_1$ | | $S_2$ |
| **Duftite-beta** | 54 | VR | | $S_1$ | | $S_2$ |

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **Dundasite** | 1a, 31b | ER | | | | $S_2$? |
| **Enargite** | 7, 9, 14, 20, 23, **26**, 38, 39, 40, 42, 44, 50, 51, 52 | MC | 1-16, 30 | | P | |
| *Stibioenargite* (Sb-var.) | 23 | | | | | |
| **Epidote*** | 2 | | | | | |
| **Famatinite** (stibioluzonite) | 26 | VR | | | P | |
| **Fleischerite**** | **8**, 24, 25, 52 | VR | 26 | | | $S_2$ |
| *Co-Fleischerite* | 31b | | | | | |
| **Fluorite** | 31b | ER | | | | |
| **Galena** | 7, 9, 11, 12, 13, 14, 20, 23, 26, 28, 29, 38, 42, 44, 50, 51, 52 | VC | | $S_1$ | P | $S_2$ |
| **Gallite**** | 8, 9, 11, 12, 13, 28, 44, 45, **50**, 52 | R | | | P | |
| **Germanite**** | 9, 11, 12, 13, 14, 15, 26, 28, **33**, 39, 40, 42, 44, 50, 51, 52 | R | | | P | |
| *W-Germanite* | 9, 11, 23 | VR | 24 | | P | |
| *V-Germanite A* | 11, 9, 12 | | | | | |
| *V-Germanite B* | 11, 9, 12 | | | | | |
| **Glaucodot** | 1a, 31b | | | | | |
| **Goethite** | 9 | MC | | $S_1$ | | $S_2$ |
| **Gold** | 26 | VR | | | | |
| **Graphite*** | 9, 44, 51, 52 | C | | $S_1$ | P | $S_2$ |
| *Shungite* (organic var.) | | | | | | |
| **Gratonite** | 1a, 31b | | | | | |
| **Greenockite** | 9, 17, 44, 51, 52 | VR | | $S_1$ | P | |
| *Zn-Greenockite* | 31b | | | | | |
| **Gypsum** | 7, 9, 51, 52 | R | | | | $S_2$ |
| **Hedyphane** | 31b | | | | | |
| **Hematite** | 9, 15, 25, 52 | MR | | | | $S_2$ |
| **Hemimorphite** | 2, 9, 15, 23, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Heterogenite** | 9 | VR | | | | $S_2$ |
| **Hidagoite** | 9 | VR | | | | $S_2$ |
| **Hydrozincite** | 2, 15, 23, 52 | VR | | $S_1$ | | $S_2$ |
| **Idaite** | 9 | ER | 20 | | P | |
| **Ilmenite*** | 44 | MC? | | $S_1$ | | S |
| **Itoite** | **8**, 52 | ER | 26 | | | S |
| **Jarosite** | (Pers. obs.) | VR | | | | |
| **Kaolinite** | **20**, 38, 44 | MC | | $S_1$ | | $S_2$ |
| **Kegelite**** | **24**, 25 | ER | 28 | | | $S_2$ |
| **Keyite**** | 5c | ER | | | | |
| **Köttigite** | 1a | | | | | |
| **Langite** | 29b | | | | | |
| **Lavendulan** | 9, 51 | VR | | | | $S_2$ |
| *Zn-Lavendulan* | **45**, 49 | VR | | | | $S_2$ |
| **Leadhillite** | 9, 24, 25 | VR | | $S_1$ | | $S_2$ |
| **Leiteite**** | 1d | ER | | $S_1$ | | $S_2$ |
| **Lepidocrocite** | 9 | VR | | $S_1$? | | $S_2$ |
| **Linarite** | 2, 7, 9, 20, 23, 51, 52 | R | | $S_1$ | | $S_2$ |
| **Linnaeite** | 9 | VR | | | P | |
| **Ludlockite**** | 3, **5d**, 9 | ER | | | | $S_2$ |
| **Luzonite** | 9, 20, 23, **26**, 44, 51, 52 | MR | | | P | |
| **Magnesite*** | 44 | | | | | |
| **Magnetite*** | 44 | | | | | |
| **Malachite** | 7, 9, 15, 20, 23, 27, 32, 38, 39, 51, 52 | VC | | $S_1$ | P | $S_2$ |
| **Mangan-Stottite**** | 9, 11 | ER | | | | $S_2$ |

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **Massicot** | 1c, 32, 51 | | | $S_1$ | | |
| **Mawsonite** | 1a | | | | | |
| **Melanotekite** | 24, 25 | VR | | | | $S_2$ |
| **Metacinnabar** | 1a, 31b | ER | | | | $S_2$ |
| **Microcline*** | 38, 53 | MC? | | $S_1$ | | $S_2$ |
| **Millerite** | 9 | VR | | | P | |
| **Mimetite** | 4, 7, 8, 9, 10, 15, 23, 25, 32, 39, 46, 51, 52 | VC | | $S_1$ | | $S_2$ |
| **Minium** | 1c, 52, 51 | | | $S_1$ | | |
| **Mixite** | 31b | ER | | | | |
| **Molybdenite** | 9, 11, 44, 51, 52 | R? | | | P | |
| **Mottramite** | 4, 7, 9, 15, 23, 34, 38, 39, 41, 51, 52 | MC | | $S_1$ | | $S_2$ |
| **Muscovite*** | 20, 26, 39, 44, 51 | C | | $S_1$ | P | $S_2$ |
| **Oligoclase*** | 38 | | | | | |
| **Olivenite** | 4, 7, 15, 23, 38, 39, 51, 52 | R | | $S_1$ | | $S_2$ |
| *Fe-Olivenite* | 1a | | | | | |
| *Zincolivenite* (Zn-var.) | 46, 52 | R | | | | |
| **Olivine*** | 20, 38, 44 | | | | | |
| **Orthoclase*** | 38, 44 | | | $S_1$ | | $S_2$ |
| **Otavite**** | 7, 23, 51, 52 | ER | | $S_1$ | | |
| **Patronite** | 9, 54 | VR | | | P | |
| **Pharmacosiderite** | 9, 10 | ER | 30 | $S_1$ | | $S_2$ |
| **Phosgenite** | 7, 9, 51, 52 | ER | | $S_1$ | | |
| **Plancheite** | 9 | MR | | | | $S_2$ |
| **Plattnerite** | 9, 51 | ER | | $S_1$ | | |
| **Plumbojarosite** | 8 | VR | | | | $S_2$? |
| **Posnjakite** | 1a, 18b | VR | | | | |
| **Powellite** | 31b | | | | | |
| **Psilomelane** ("wad") | 9, 52 | | | | | $S_2$ |
| **Pyrite** | 7, 9, 12, 13, 14, 16, 20, 23, 26, 28, 38, 39, 40, 42, 44, 50, 51, 52 | C | | $S_1$ | P | $S_2$ |
| **Pyrolusite** | 9 | | | | | $S_2$ |
| *Asbolane* (Co-var.) | 1a | | | | | |
| **Pyromorphite** | 5a, 7, 51, 52 | VR | | $S_1$ | | |
| **Quartz** | 7, 9, 14, 20, 23, 26, 38, 39, 44, 51, 5 | VC | | $S_1$ | P | $S_2$ |
| *Amethyst* | 1a | ER | | | | |
| **Realgar** | 1c | | | | | |
| **Reinerite**** | 8, 9, **15**, 45, 46, 51 | ER | 29 30 | | | $S_2$ |
| **Renierite** | 7, 9, 11, 12, 13, 14, 28, 40, 42, 44, 45, 50, 51, 52 | R | | | P | |
| **Rhodochrosite** | 7 | VR | | | | |
| **Rosasite** | 7, 15, 51, 52 | MC | | $S_1$ | | $S_2$ |
| *Paraurichalcite* (Cu-var.) | 31b | | | $S_1$ | | $S_2$ |
| *Zn-Rosasite* (Zn-var.) | 45 | | | | | $S_2$ |
| **Rutile*** | 9, 44 | | | | | |
| **Schaurteite**** | 9, **52** | ER | | | | $S_2$ |
| **Schneiderhöhnite**** | **29** | ER | 29 | | | $S_2$ |
| **Schultenite**** | 7, 9, **30**, 51, 52, 5e | VR | | $S_1$ | | $S_2$ |
| **Scorodite** | 9, 10 | R | 30 | | | $S_2$ |
| **Seligmanite** | 1a, 31b | VR | | | | S |
| **Serpierite** | 1a, 18b | | | | P | |
| **Shattuckite** | 31b | VR | | | | |
| **Siderite** | 7, 9, 51, 52 | R | | $S_1$ | | $S_2$ |
| *Zn-Siderite* | 31b | R | | | | |

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **Silver** | **14**, 26, 51, 52 | MR | | $S_1$ | P | $S_2$ |
| **Smithsonite** | 7, 9, 15, 23, 27, 28, 38, 39, 51, 52 | MC | | $S_1$ | | $S_2$ |
| *Cadmiumzinkspath?* (Cd-var.) | 31b | | | | | |
| *Cobaltsmithsonite* (Co-var.) | 1a, 15 | R | | | | $S_2$ |
| *Herrerite* (Cu-var.) | 1a | | | | | |
| *Mangansmithsonite* (Mn-var.) | 1a | | | | | |
| **Söhngeite**** | 9, 12, **48**, 52 | ER | 26 | | | $S_2$ |
| **Sphalerite** | 9, 11, 13, 14, 20, 23, **26**, 28, 38, 39, 42, 44, 50, 51, 52 | C | | $S_1$ | P | $S_2$ |
| *Pribramite?* (Cd-var.) | 29, 44 | | | | | |
| **Stottite**** | 8, 9, 13, 15, 28, 29, 40, 45, **51** 52 | ER | 26, 30 | | | $S_2$ |
| **Stranskiite**** | 9, **47**, 52 | VR | 30 | | | $S_2$ |
| **Stromeyerite** | 9, 11, 14, 44, 51, 52 | VR | | | P | |
| **Sulfur** | 9, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Sulvanite** | 9, 12 | VR | | | P | |
| *Ge-Sulvanite* | 12 | VR | | | P | |
| **Talc** | 44, 53 | MC | 28-30 | | | |
| **Tennantite** | 7, 8, 9, 11, 12, 13, 14, **26**, 28, 29, 38, 39, 40, 42, 44, 50, 51, 52 | VC | | $S_1$ | P | $S_2$ |
| **Tenorite** | 9, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Thaumasite** | 1a, 18b | ER | | | | |
| **Titanite*** | 44 | | | | | |
| **Tourmaline*** | 44 | | | | | |
| **Tremolite*** | 20, 44 | | | | | |
| **Tsumcorite**** | 9, **10** | VR | 30 | | | $S_2$ |
| **Tsumebite**** | 7, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Tungstenite** | 9, 11 | ER | | | P | |
| **Umangite** | 9 | ER | | | P | |
| **Vanadinite** | 7, 9, 32, 51, 52 | VR | | $S_1$ | | $S_2$ |
| **Vanadinocker** | 32 | | | | | |
| **Willemite** | 9, 15, 51, 52 | MR | | $S_1$ | | $S_2$ |
| *Troostite* (Mn-var.) | 1a | R | | | | S |
| **Witherite** | 51, 52 | VR | | | | $S_2$ |
| **Wulfenite** | 5b, 7, 15, 51, 52 | MC | | $S_1$ | | $S_2$ |
| *Chillagite* (W-var.) | 1a | ER | | | | $S_2$ |
| **Wurtzite** | 17, 44, 51, 52 | R | | | P | |
| *Cd-Wurtzite* | 9 | R | | | P | |
| **Zeolites*** | 44 | | | | | |
| **Zinc-Stottite**** | 9, 11, 29 | ER | | | | $S_2$ |
| **Zircon*** | 44 | | | | | |

### TABLE 2. REFERENCES TO INCOMPLETELY DESCRIBED SPECIES.

| SPECIES | REFERENCES | RARITY | LEVEL | $S_1$ | P | $S_2$ |
|---|---|---|---|---|---|---|
| **"Ag-Betekhtinite"**** | 1a | ER | | | | |
| **"Carnevallite"**** | 9, **12** | ER | 29-34 | | P | |
| **"Ge-Zn-Mawsonite"**** | 1a | ER | | | | |
| **"Maygreen"**** | 9, **12** | VR | 29-34 | | P | |
| **"Mineral C"**** | 11 | ER | | | P | |
| **"Mineral D"**** | 11 | ER | | | P | |
| **"Mineral E"**** | 11 | ER | | | P | |
| **"Mineral gamma"**** | 9 | ER | | | P | |
| **"Mineral GF"**** | 18b | | | | | $S_2$ |
| **"Mineral Lu"**** | **12** | ER | 29-34 | | P | |
| **"Mineral S"**** | 11, **45** | ER | | | P | |
| **"Mineral TI"**** | 18b | | | | | $S_2$ |
| **"Mineral TK"**** | 18b | | | | | $S_2$ |

### TABLE 3. PSEUDOMORPHS REPORTED OR OBSERVED FROM TSUMEB*

| | | | Reference |
|---|---|---|---|
| 1. Anglesite | after | Schultenite | 30 |
| 2. Aurichalcite | after | Azurite | S.I.#: B8092 |
| 3. Bayldonite | after | Dolomite | pers. obs. |
| 4. Bayldonite | after | Azurite | 30 |
| 5. Bayldonite | after | Mimetite | S.I.#: C4308 |
| 6. Bayldonite | after | Wulfenite | pers. obs. |
| 7. Betekhtinite | after | Chalcocite | 14 |
| 8. Brochantite | after | Azurite | S.I.#: B12115 |
| 9. Cerussite | after | Anglesite | S.I.#: B11218 |
| 10. Chalcocite | after | Enargite | 45 |
| 11. Chalcocite | after | Tennantite | S.I.#: B16181 |
| 12. Chrysocolla | after | Azurite | S.I.#: C3868 |
| 13. Cuprite | after | Copper | S.I.#: R8621 |
| 14. Descloizite | after | Calcite | 4 |
| 15. Descloizite | after | Pyromorphite | pers. obs. |
| 16. Enargite | after | Azurite | pers. obs. |
| 17. Enargite | after | Tennantite | S.I.#: 133655 |
| 18. Hematite | after | Magnetite | S.I.#: R12210 |
| 19. Itoite | after | Fleischerite | 8 (discredited) |
| 20. Jarosite | after | Azurite | pers. obs. |
| 21. Jarosite | after | Tennantite | pers. obs. |
| 22. Malachite | after | Azurite | S.I.#: 94754 |
| 23. Malachite | after | Aragonite | pers. obs. |
| 24. Malachite | after | Copper | S.I.#: R8682 |
| 25. Malachite | after | Enargite | S.I.#: R11350 |
| 26. Malachite | after | Tennantite | S.I.#: B10701 |
| 27. Mimetite | after | Cerussite | S.I.#: 113226 |
| 28. Mottramite | after | Wulfenite | pers. obs. |
| 29. Olivenite | after | Bayldonite | pers. obs. |
| 30. Plancheite | after | Azurite | S.I.#: B10984 |
| 31. Smithsonite | after | Aragonite | S.I.#: R8611 |
| 32. Tennantite | after | Azurite | pers. obs. |
| 33. Tennantite | after | Enargite | S.I.#: 134021 |
| 34. Tsumebite | after | Mimetite | S.I.#: B19022 |
| 35. Tsumebite | after | Pyromorphite | S.I.#: 93854 |
| 36. Vanadinite | after | Pyromorphite | S.I.#: B13415 |

*Pseudomorphs documented by actual samples in the Smithsonian Institution are indicated by their Smithsonian catalog numbers (S.I.#); others are referenced by numbers found in the list of references cited; unreferenced pseudomorphs have been observed by the author.

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## TSUMEB NOTES TO BE PUBLISHED IN FUTURE ISSUES OF THE MINERALOGICAL RECORD

Work on the minerals of Tsumeb, and studies of the geology there, as well as news items of interest, will be published on a continuing basis in the Mineralogical Record magazine under the heading of **Tsumeb Notes**. The notes will be arranged on full pages suitable for xeroxing and including with this present work.

Articles and notes on Tsumeb mineralogy are solicited for this continuing feature. Manuscripts should be sent to Wendell E. Wilson, Editor, the Mineralogical Record, P.O. Box 783, Bowie, Maryland 20715 U.S.A. Foreign language manuscripts can be translated for publication if necessary.

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Naturally, with a work of this size and complexity, there are bound to be errata. Readers are encouraged to bring any errors to our attention.

# XIII DEALERS

Collectors often mourn the passing of long-dead famous mineral localities. They point to ads in old magazines and to old price lists, marvelling at what low prices and what abundance prevailed for the minerals of famous localities many years ago. At one time English barites and calcites were so common on the market as to be scoffed at by many shortsighted collectors of the day; A. E. Foote once offered Japanese stibnite crystals at $1 per inch. "Had I been around then," you say, "I would have really stocked up on the superb things of the day that are now so rare on the market. How I envy those collectors alive then who could obtain such treasures so easily from their dealers."

But time passes on. In 50 years, what are collectors liable to be thinking of *our* generation? They will say, "How I envy those collectors who were alive when Tsumeb was in its heyday, when dealers had ample supplies of the superb Tsumeb minerals." They will doubt that we realized how lucky we were...do we?

It is still possible today to build an excellent Tsumeb collection represented by a very large number of species and habits in nearly all ranges of quality and price. Virtually none of us can personally collect at Tsumeb; that means that we must obtain our specimens solely from dealers (or trade with collectors who obtained *their* specimens from dealers). The following pages put you directly in touch with most of the dealers in the world who handle Tsumeb specimens...these people are all at your service and are anxious to help you build the kind of collection you would like. Write to them asking for their price list (if they offer one), send them your want-list, visit them personally at home or at shows and look over their stock for yourself. It may help to refer to photos or descriptions in this issue when discussing your wants, but remember that we have had access to the finest collections in the world; it may be very difficult or very expensive to obtain pieces as fine as those pictured in this issue. Nevertheless, extremely high quality specimens are still available for those who seek them out because Tsumeb is *still producing* them; if such pieces are your goal you have a fair chance of encountering them while Tsumeb lives. If you are *not* necessarily after that one-in-a-million piece, a vast array of many thousands of fine specimens is available to you through the following pages. We suggest that you build your Tsumeb collection now, and take advantage of being alive while Tsumeb is alive.

Ed.

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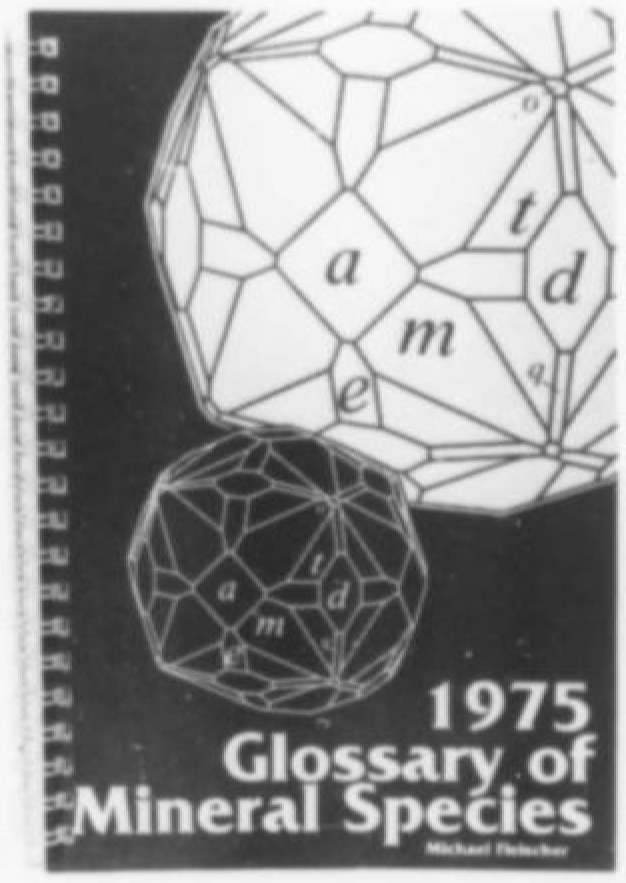

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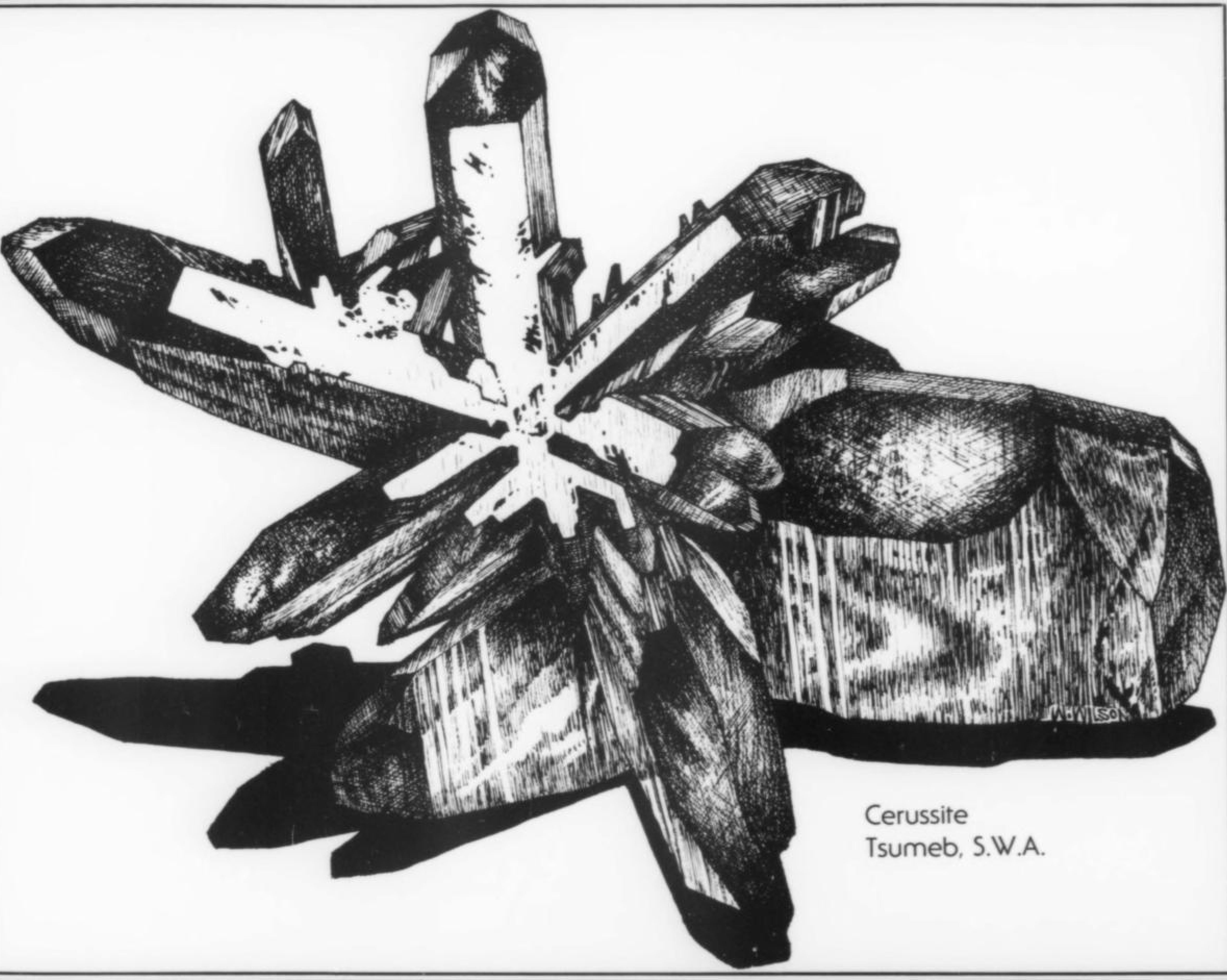

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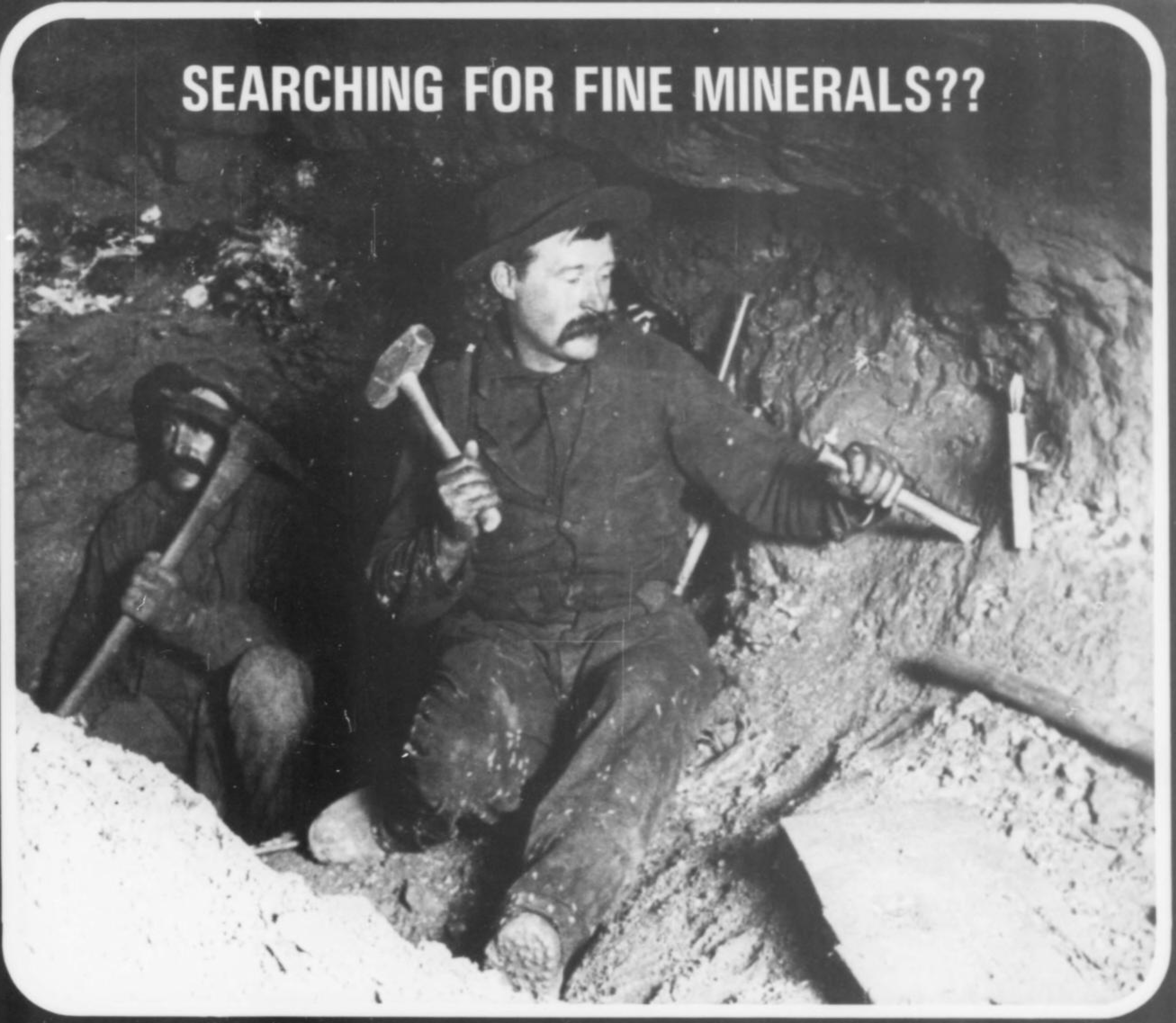
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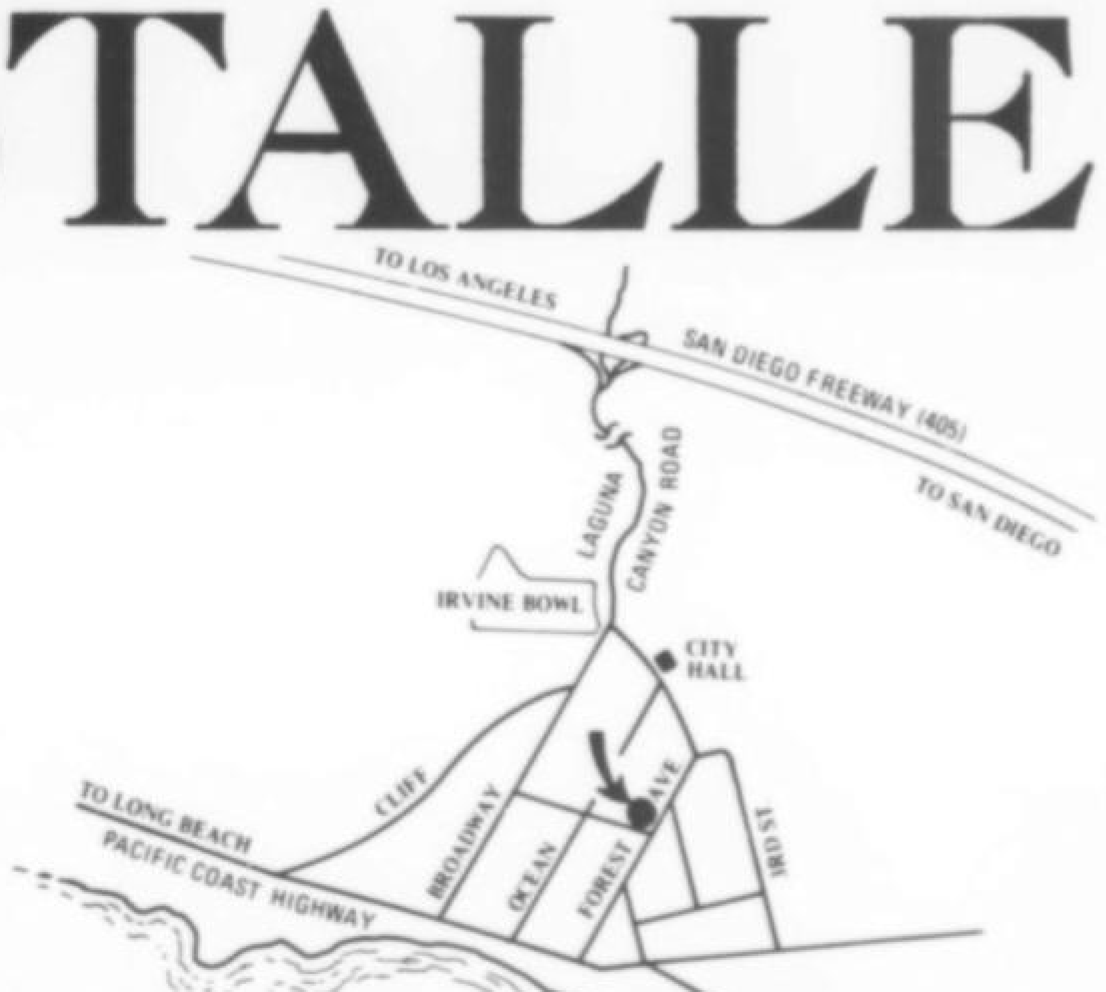
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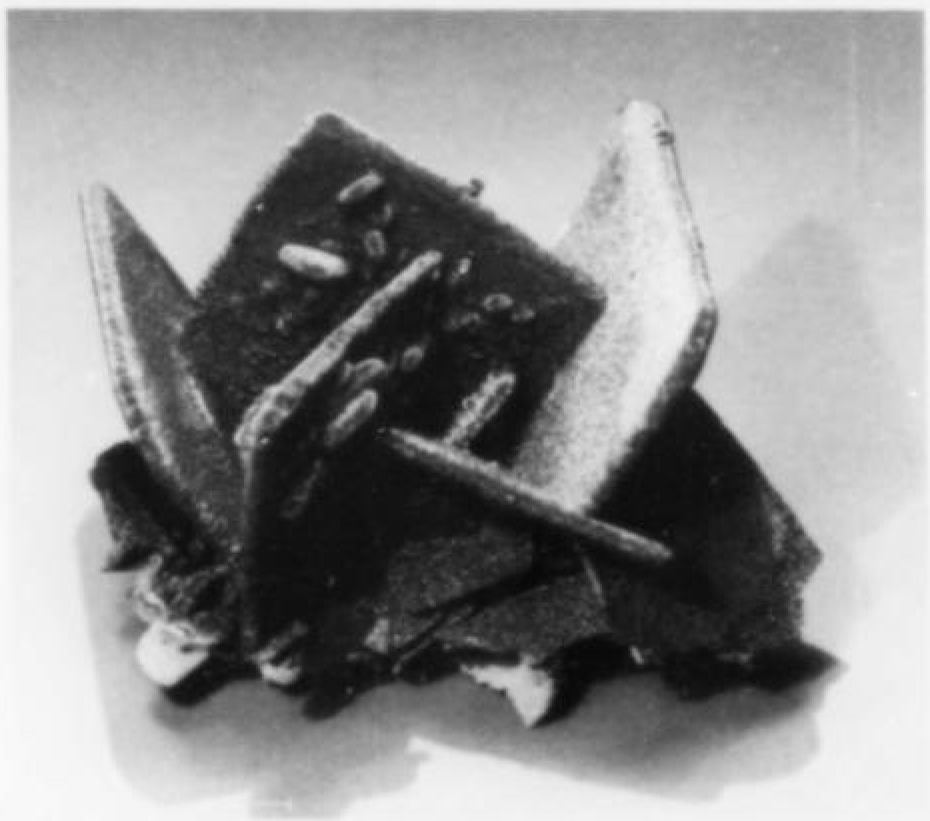

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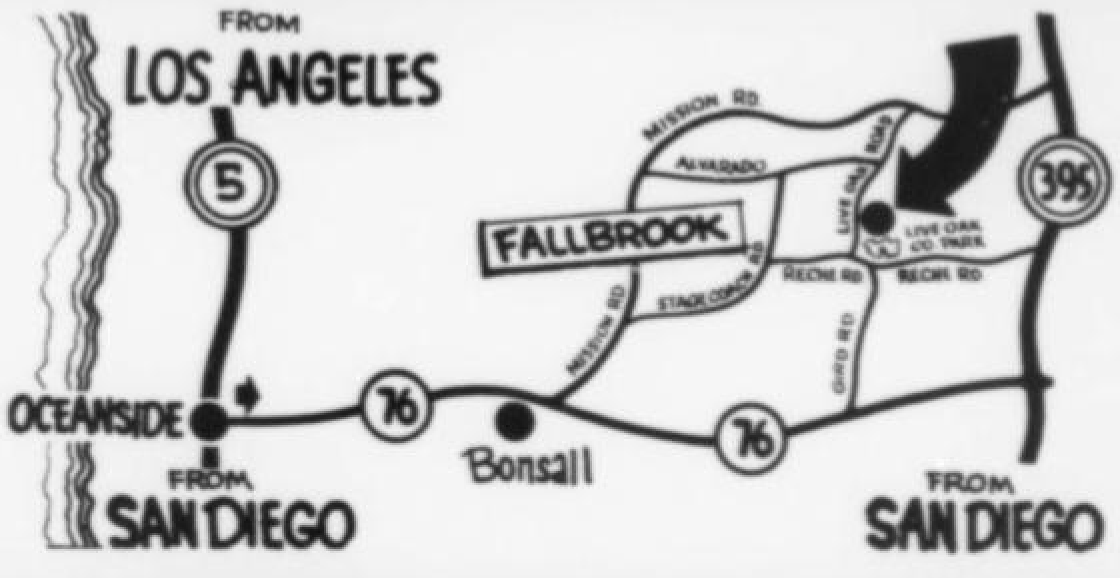

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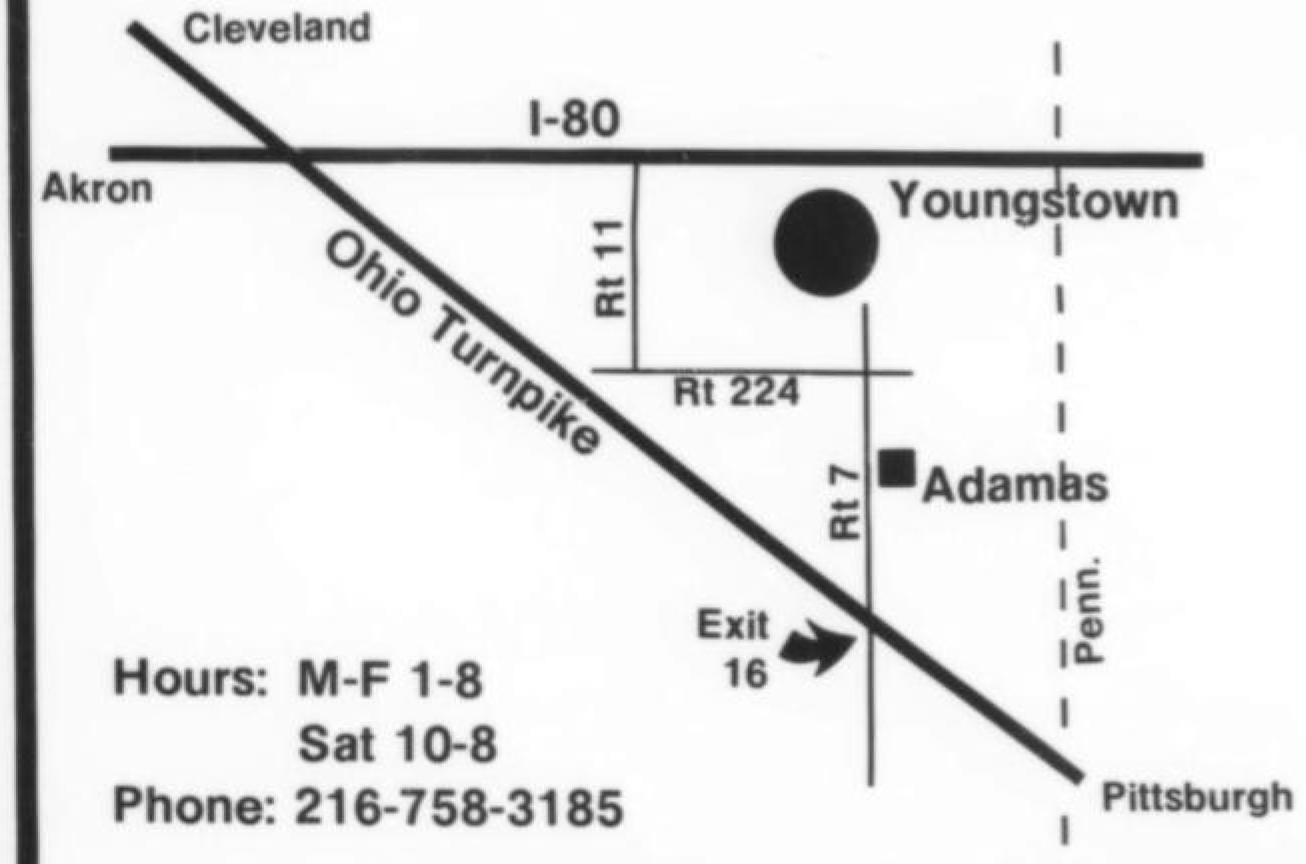

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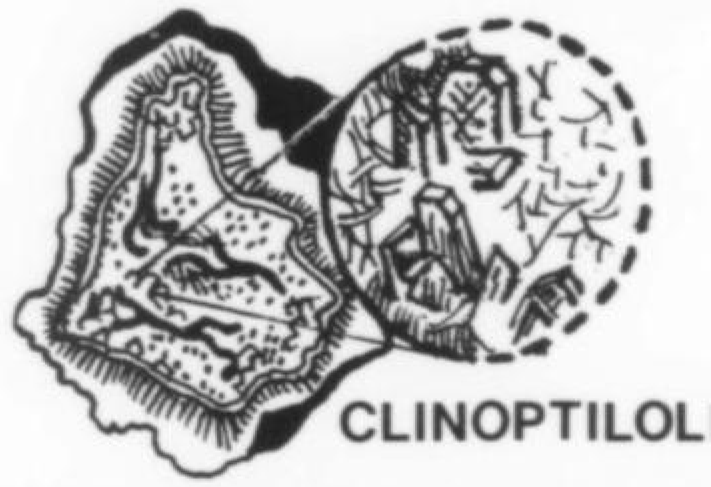

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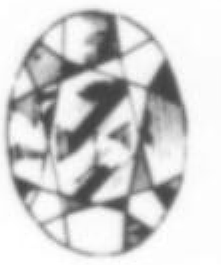

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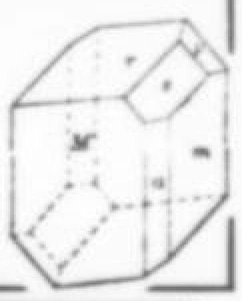

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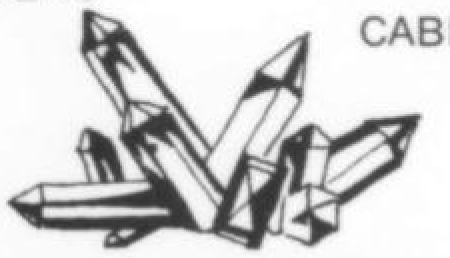

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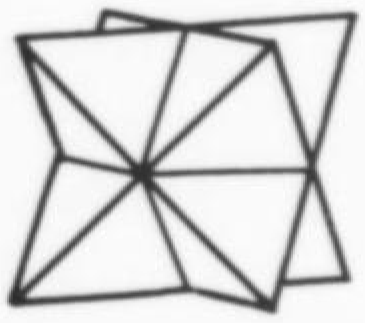

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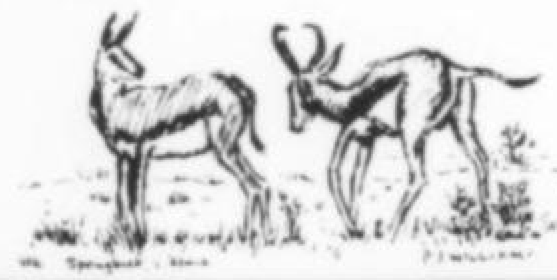

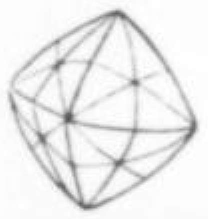

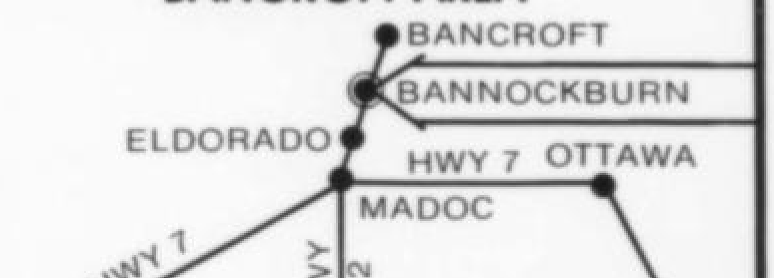
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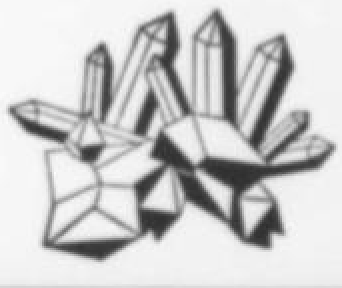

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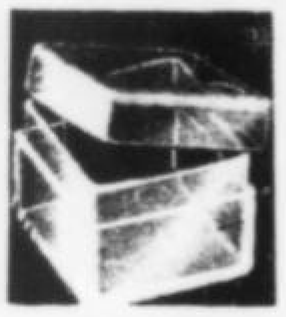

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