the Mineralogical Record

Volume Twenty-four, Number Six
November–December 1993
$10

the Mineralogical Record

November–December 1993
Volume Twenty-four, Number Six

Editing, advertising
Wendell E. Wilson
4631 Paseo Tubutama
Tucson, AZ 85715
602-299-5274
FAX: 602-299-5702

Circulation Manager
Mary Lynn Michela
(Subscriptions, back issues, reprints, book sales, shows)
P.O. Box 35565
Tucson, Arizona 85740
602-297-6709
FAX: 602-544-0815

Subscriptions
- **Individuals (U.S.):** $36 for one year; $69 for two years. (First-class mailing available; write to circulation manager for rates.)
- **Individuals (outside the U.S.):** $39 for one year, $75 for two years. (Airmail mailing available; write to circulation manager for rates.)
- **Libraries, Companies and institutions (worldwide):** $60 for one year. (First-class or Airmail mailing available; write to circulation manager for rates.)

Printed in the U.S.A.

The Mineralogical Record (ISSN 0026-4628) is a bi-monthly publication of the Mineralogical Record, Inc., a non-profit organization. Special second-class postage (USPS 887-700) paid at Tucson, Arizona, and additional mailing offices. POSTMASTER: Send address changes to: The Mineralogical Record, 7413 N. Mowry Place, Tucson, AZ 85741

*Continued on p. 495

Articles

Columns

COVER: FERROAXINITE crystal group, 4.8 cm, from the Polar Urals, Russia. Wayne and Dona Leicht collection; photo by Harold and Erica Van Pelt.

notes from the EDITOR

CHECKLIST FOR AUTHORS
Submitting Articles to *the Mineralogical Record*

All authors should take note of the following guidelines. Adherence to these guidelines will reduce the amount of time required to process your article, and will greatly endear you to the editor.

1. Paper. All manuscripts must be submitted on 8½ x 11-inch (22 x 28-cm) paper. Foreign authors please cut your paper down to size . . . our files are not designed for larger sheets.

2. Typing. All manuscripts must be typed and double-spaced throughout, including references and figure captions. The first line of each new paragraph must be indented.

3. Word processors. Manuscripts printed on non-letter-quality printers will not be accepted.

4. Extra copies. Submit all manuscripts in triplicate. Photos and figures may be submitted as one set of originals and two sets of photocopies.

5. References. References must be typed precisely according to our usual format (see published articles for examples). Spell out all journal titles in full.

6. Photographs. Prints must be submitted loose in numbered envelopes. Do not write on the front or back of photos; doing so can ruin them for publication,

7. Measurements. All measurements must be given in metric units, except for: (a) historical purposes and quotations, (b) car mileage distances to U.S. localities, (c) addition of parenthetical English equivalents for special emphasis or clarity, and (d) proper names, e.g., mine levels.

8. Credits. Caption data for specimen photos must include (a) species name, (b) specimen or crystal size, (c) color (if photo is B&W), (d) name of photographer, and (e) name of specimen owner.

9. Mineral names. Use of new mineral names not approved by the International Mineralogical Association is forbidden. Use of varietal names (except for a few entrenched gemological terms such as emerald) is discouraged except in a historical context, and proper definition should always be given.

10. More detailed suggestions may be found in our *Author's guide to writing locality articles* (vol. 17, no. 6, p. 393–400) and *Photographer's guide to taking mineral specimen photographs* (vol. 18, no. 3, p. 229–235).

SOME ADDITIONAL NOTES

Author's Guide

Need some help in planning a locality article? See *An author's guide to writing locality articles for the Mineralogical Record* (vol. 17, no. 6, p. 393–400).

Photographer's Guide

Need some help in preparing specimen photography? See *A photographer's guide to taking mineral specimen photographs for the Mineralogical Record* (vol. 18, no. 3, p. 229–235). Also see: *Photography of microminerals* (vol. 22, no. 6, p. 471–476), *Mineral stereophotography* (vol. 18, no. 6, p. 399–404), and *High magnification mineral stereophotomacrography* (vol. 21, no. 5, p. 475–480).

Advertiser's Guide

Need some help in preparing an advertisement for publication in the *Mineralogical Record*? Write for our free 24-page booklet, *Advertising Your Minerals*. It contains much practical advice developed over many years.

Collector's Guides

Since we are reviewing "guide" articles here, it is worth mentioning that the *Mineralogical Record* has published many guides to various collecting activities and concerns. Here are some examples.

Building a Library

The collector's library—part I: General works (vol. 9, no. 1, p. 5–13).

The collector's library—part II: Minerals of the United States (vol. 10, no. 1, p. 13–28).

The collector's library; minerals of the United States—updates and additions (vol. 18, no. 3, p. 211–227).

The collector's library—part III: Minerals of Mexico (vol. 10, no. 3, p. 169–171).

Reflections upon perusing a 1942 bookseller's catalog (vol. 11, no. 2, p. 127).

Investing in Minerals

Investing in minerals: no guarantees (vol. 7, no. 6, p. 266–267).

An experiment in specimen appraisal (vol. 8, no. 1, p. 38–40, 47–48).

Collecting on a Budget

Mineralogie sans argent (vol. 14, no. 1, p. 2–3).

Recognizing Fakes and Falsehoods

Mineral fakes (vol. 12, no. 4, p. 197–219).

Mineral fraud (vol. 12, no. 4, p. 194).

Mineral specimen mislabeling (vol. 17, no. 2, p. 99–103).

Connoisseurship

Connoisseurship in minerals (vol. 21, no. 1, p. 7–12).

Specialization in mineral collecting (vol. 21, no. 6, p. 511–513).

Underground Collecting

A guide to underground collecting (vol. 5, no. 3, p. 128–137).

Collecting in abandoned mines (vol. 20, no. 3, p. 178–180).

Staking Claims

Mining claims for the mineral collector (vol. 8, no. 1, p. 43–46) (responses: vol. 8, no. 5, p. 412–413).

Understanding new minerals

From unknown to known; the characterization of new mineral species (vol. 8, no. 5, p. 341–349).

Is there a limit to the number of new minerals? (vol. 11, no. 5, p. 333–335).

New minerals: what collectors can do to help (vol. 23, no. 1, p. 2–3).

So you think you have found a new mineral? (vol. 6, no. 5, p. 220–221).

The discreditation of mineral species (vol. 22, no. 2, p. 91–93).

The unethical use of mineral names (vol. 14, no. 3, p. 138).

New minerals 1973–1977: a perspective (vol. 9, no. 6, p. 363–365).

New minerals 1978–1982: a perspective (vol. 14, no. 4, p. 211–214).

Formal definitions of type mineral specimens (vol. 19, no. 4, p. 227–228).

The preservation of type mineral specimens (vol. 19, no. 4, p. 226–227).

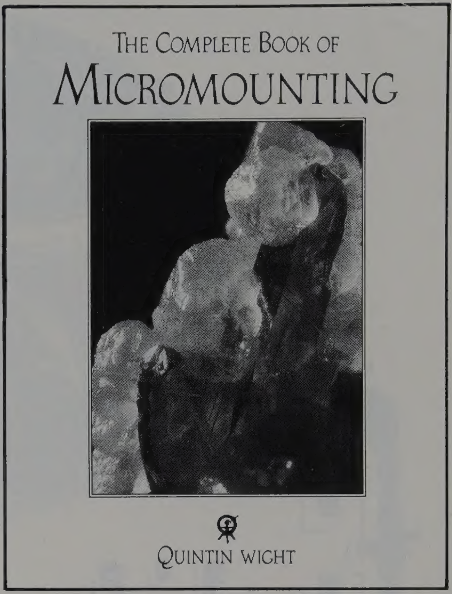
The Commission of New Minerals and Mineral Names of the International Mineralogical Association: Its history, purpose and general practice (vol. 19, no. 5, p. 319–323).

Indispensable!

The beauty of the Mineral Kingdom is most exquisitely demonstrated in the smallest specimens, those requiring optical magnification to be best appreciated. Collecting these microcrystals and mounting them for easy handling and storage is a fascinating and satisfying hobby combining the keen observation of the scientist, with the fine eye and delicate craftsmanship of the artist.

In this book Quintin Wight, a widely known and respected micromounter, author, lecturer, and member of the Micromounters Hall of Fame, brings together the many diverse facets of mineral collecting at the microscopic level. Chapters cover the history of micromineral studies and collecting from the 17th century to the present; trading and field collecting methods; specimen preparation, identification, mounting and conservation techniques; microscopes; micromineral photography; micromounting symposia worldwide; the Micromounters Hall of Fame; and a wide range of tools and equipment useful to the micromounter.

Also included is a color album of 165 beautiful micromineral photographs taken by some of the world's most talented and skilled specialists. These portraits amply demonstrate the unique allure of nature's tiny mineral masterpieces.


THE COMPLETE BOOK OF
MICROMOUNTING

QUINTIN WIGHT

- Hardcover
- 283 pages
- 165 color photos
- ***$62*** *plus $3 postage and packaging*
(non-U.S. orders add $1)

Over 20 years in preparation by the leading experts!

THE MINERALOGICAL RECORD

GOLDSCHMIDT'S
WORLD MINERAL LOCALITY
INDEX

A cross-index by locality to the 23,606 crystal drawings in Goldschmidt's famous *Atlas der Krystallformen* • An invaluable reference on mineral localities worldwide.

$11 postpaid

Allow 4–6 weeks for delivery. Sorry, no credit card orders or group discounts.

Order from:
The Mineralogical Record
P.O. Box 35565
Tucson, Arizona 85740

Tel:
602-297-6709
FAX:
602-544-0815

California dealers

Bourget Bros.
Anthony Chavez, Leonard Bourget
1636 11th Street
Santa Monica, California 90404
Tel: (213) 450-6556
FAX: (213) 450-2201
Wholesale and Retail

Coogan Gold Company
Ed and Kay Coogan
P.O. Box 1631
Turlock, CA 95381
Tel: (209) 634-5222
Micromounts, TN's, Min., Cab.

Si and Ann Frazier
Si and Ann Frazier
Suite 306, 6331 Fairmont Ave.
El Cerrito, California 94530

Galas Minerals
Chris and Agatha Galas
6000 Fulkerth
Turlock, California 95380
Tel: (209) 634-4292

The Gemmary Rare Books
Rick and Faye Blankenhorn
P.O. Box 816
Redondo Beach, CA 90277
Tel: (310) 372-5969 (Ans. & FAX)
(310) 372-6149
Call for Appointment
Specialties: Rare Books and antique scientific instruments

Cal Graeber Minerals
Cal and Kerith Graeber
P.O. Box 47
Fallbrook, California 92028
Tel: (619) 723-9292
By Appointment Only

Jewel Tunnel Imports
Rock H. Currier
13100 Spring Street
Baldwin Park, CA 91706-2283
Tel: (818) 814-2257
FAX: (818) 338-4617
Wholesale Only

Kassionas
John and Dolores Kassionas
P.O. Box 578
Alviso, California 95002
Tel: (408) 263-7784

Kristalle
332 Forest Avenue, #8
Laguna Beach, California 92651
Tel: (714) 494-7695

Pala International & The Collector
912 So. Live Oak Park Road
Fallbrook, California 92028
Tel: (619) 728-9121
US Wats 1-(800)-854-1598

D. J. (Doug) Parsons
1119 S. Mission Road
Suite 243
Fallbrook, CA 92028
Tel: (619) 728-8251
FAX: (619) 728-8255
TELEX: 710 111 5543

Roberts Minerals
Ken and Rosemary Roberts
P.O. Box 1267
Twain Harte, California 95383
Tel: (209) 586-2110

Silverhorn
Mike Ridding
1155 Coast Village Road
Montecito, California 93108
Tel: (805) 969-0442

Weber's Minerals
Ed & Naomi Weber
605 San Dieguito Drive
Encinitas, California 92024
Tel: (619) 436-4350
Irregular hours; please call

BISBEE REVISITED

AN UPDATE ON THE MINERALOGY OF THIS FAMOUS LOCALITY

Richard W. Graeme
Mining Remedial Recovery Company
6501 East Grant Road, Suite L
Tucson, Arizona 85715

The research for the original study of the minerals of the Warren Mining District, Bisbee (Graeme, 1981), was completed in mid-1980, more than a dozen years ago. Since then, much new work has been carried out independently by several researchers, contributing immensely to a better understanding of Bisbee mineralogy. As a result, 71 species new to the district have been confirmed, bringing to 285 the number of known species from these prolific mines.

MINING AND EXPLORATION 1980–1991

Leaching of the existing rock piles from the open pit continues and, up until mid-1985, some of the underground workings were being leached as well. This clean, safe, hydrometallurgical recovery process has been largely responsible for the 50 million pounds of copper produced from 1980 through the end of 1991. Small-scale mining took place in the Campbell and Shattuck mines for a short time as well. Both of these efforts focused on precious metals.

The early 1980's were a difficult time, economically, for the production of metals in general and copper in particular. Prices for the red metal plummeted, reaching levels equaled only in the Depression years of the early 1930's. A sad consequence of this low value of copper for Phelps Dodge Corporation was the most pressing need to reduce expenses everywhere possible. One way to do this was to stop pumping water from the extensive underground workings. In mid-1985 the pumps were stopped. Even though the mines had not operated for ten years, Phelps Dodge had continued to keep the pumps operating, removing in excess of 3,000 gallons per minute. This kept the workings accessible for the collection of copper-rich solutions from the underground leaching project while also allowing exploration for precious metals. However, the very real need to conserve cash forced the cessation of pumping, saving "millions of dollars per year" (Anonymous, 1985).

Currently (January 1993) the water level is just above the 1100-level and continuing to rise. Early reports (Junction Mining Company, 1906) indicate that the pre-mining water level was just below the 770 level. But, because the many miles of workings above this level have formed a vast collection network, it is probable that the final water level will be somewhat higher.

Having acquired additional property in the district, Phelps Dodge continued a copper exploration program, first initiated by Occidental Petroleum, on the north side of the Dividend fault. This major structure had traditionally been considered a boundary feature for the economic ores in the district. However, the presence of low-grade copper mineralization had long been recognized in this part of the district. By 1910 both the Cochise and Copper King mines had cut into the largely Precambrian metamorphic rocks, finding only cupriferous pyrite with some secondary chalcocite, none of which approached economic levels at the time.

Today the economics of low-grade ore are markedly better. In its 1991 Annual Report, Phelps Dodge notes that 210 million tons of 0.40 % copper have been delineated. Preliminary tests on the ore have been conducted using solvent extraction/electrowinning recovery techniques on leach solutions. The results, while not wholly encouraging (Phelps Dodge, 1992), were sufficiently good for the corporation to announce that it intends to move forward with a project to mine 170 million tons of the outlined ore (*Bisbee Daily Review,* October 6, 1992). Of course, this is contingent on receiving the necessary permits as well as copper prices remaining at satisfactory levels. At some

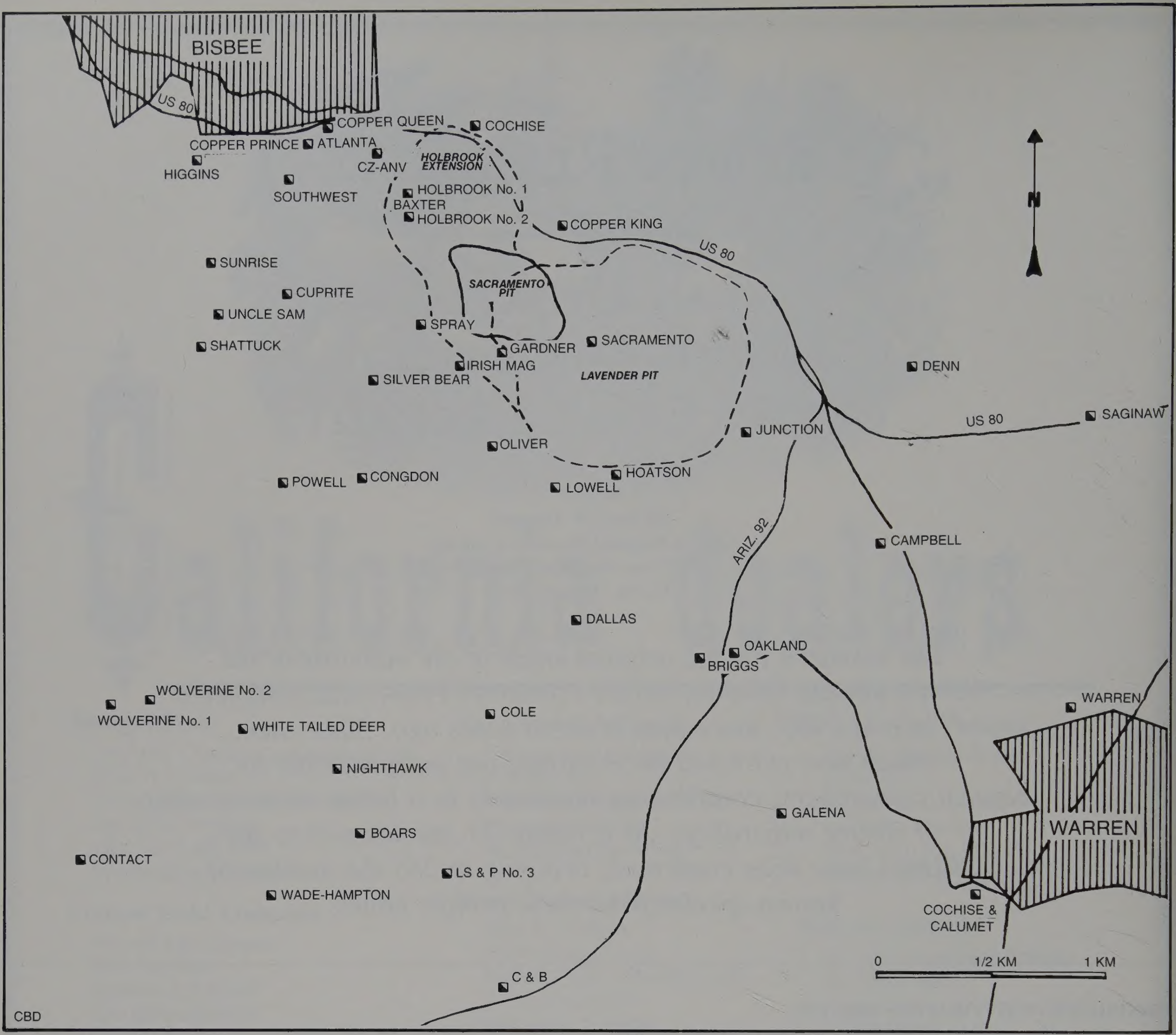


Figure 1. **Major mines in the Warren district.**

future date copper may once again be produced in significant volumes from Bisbee. However, because of the very different geologic environment that host the low-grade deposits, it is improbable that minerals of the quality for which Bisbee is famous will be found there.

MINERALOGY

The significant number of additional species that have been confirmed from Bisbee during recent years, as well as the important new locations for previously reported species, are the result of several intensive studies and much field work. These efforts, coupled with a continued review of the literature and access kindly granted the author to a number of collections, both public and private, have yielded significant growth in the understanding of Bisbee's mineralogy.

Alan Criddle and Chris Stanley, both of the Natural History Museum in London, conducted an extensive study of the previously unrecognized wide assemblage of minerals associated with the precious metals of the Campbell orebody (Phelps Dodge, personal communication, 1983). Their work was conducted under the auspices of Phelps Dodge, and resulted in the identification of a number of additional minerals for the district as well as the description of two new mineral species, henreyite and kiddcreekite.

Independently, S. A. (Sid) Williams also looked in detail at a number of samples from the Campbell orebody, confirming many of Criddle and Stanley's observations as well as recognizing additional species. Williams also studied the minerals from several of the many surface manganese deposits. Here too, additional species were recognized.

Williams has also worked closely with me and my sons (Richard IV and Douglas), identifying a broad suite of minerals found in boulders of cuprite from the Southwest mine, as well as identifying or confirming the identity of dozens of specimens found in the field.

The original work on Bisbee mineralogy (Graeme, 1981) repeated the widely held belief that the chemistry of the mineralizing fluids was not particularly complex. The above noted studies by Criddle and Stanley, and those of Williams, coupled with determinations made by Williams on samples from the Cole mine, clearly indicate that at least one late-stage pulse of mineralization brought with it a broader suite of elements. Criddle reports evidence of multiple influxes of

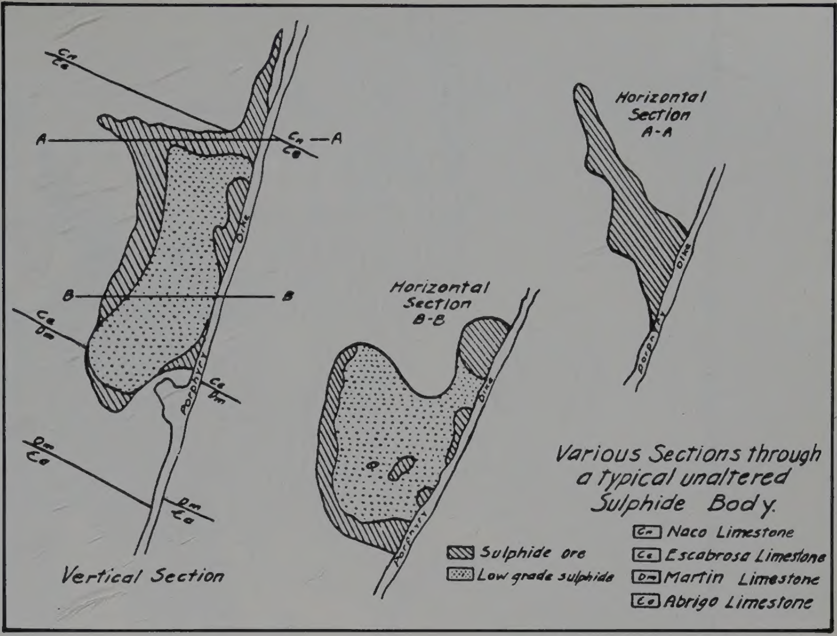
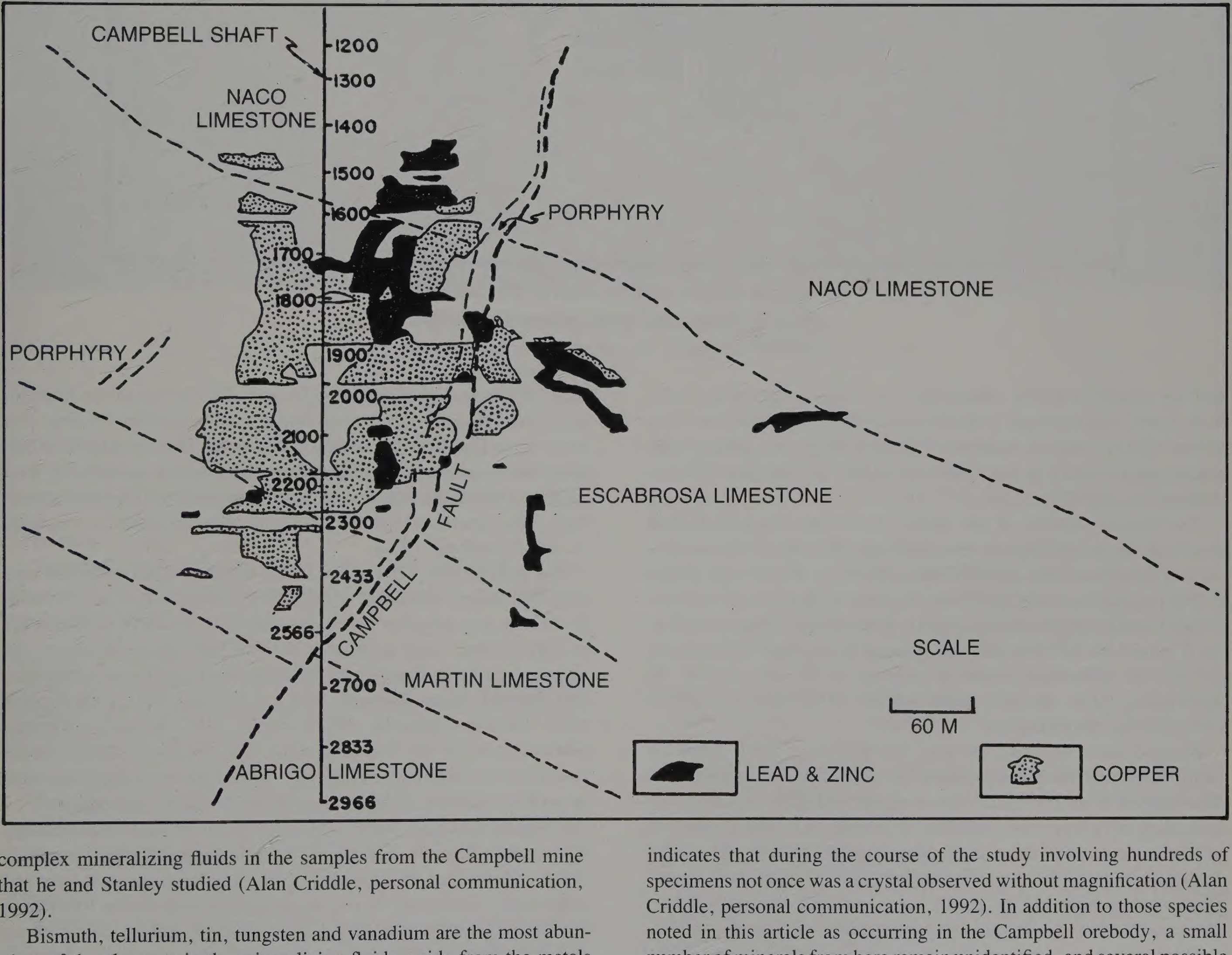


Figure 2. **Various cross-sections through a typical unaltered orebody with barren sulfide core (Trischka, 1938).**

Figure 3. **East-west vertical section through the Campbell shaft, showing the vertical extent of the orebody (Hogue and Wilson, 1950).**



complex mineralizing fluids in the samples from the Campbell mine that he and Stanley studied (Alan Criddle, personal communication, 1992).

Bismuth, tellurium, tin, tungsten and vanadium are the most abundant of the elements in the mineralizing fluids, aside from the metals of primary economic importance (copper, lead, zinc, silver and gold) that were deposited during the late stage mineralization. The majority of the species new to the district are combinations of the aforementioned elements and are found as minor accessory minerals. With very few exceptions, these minerals occur as microscopic grains. Criddle indicates that during the course of the study involving hundreds of specimens not once was a crystal observed without magnification (Alan Criddle, personal communication, 1992). In addition to those species noted in this article as occurring in the Campbell orebody, a small number of minerals from here remain unidentified, and several possible new species have also been found (Alan Criddle, personal communication, 1992).

Only the Campbell orebody was studied in sufficient detail to allow even the most general conclusions about the late stage mineralization to be developed. Criddle suggests the presence of geochemical trends

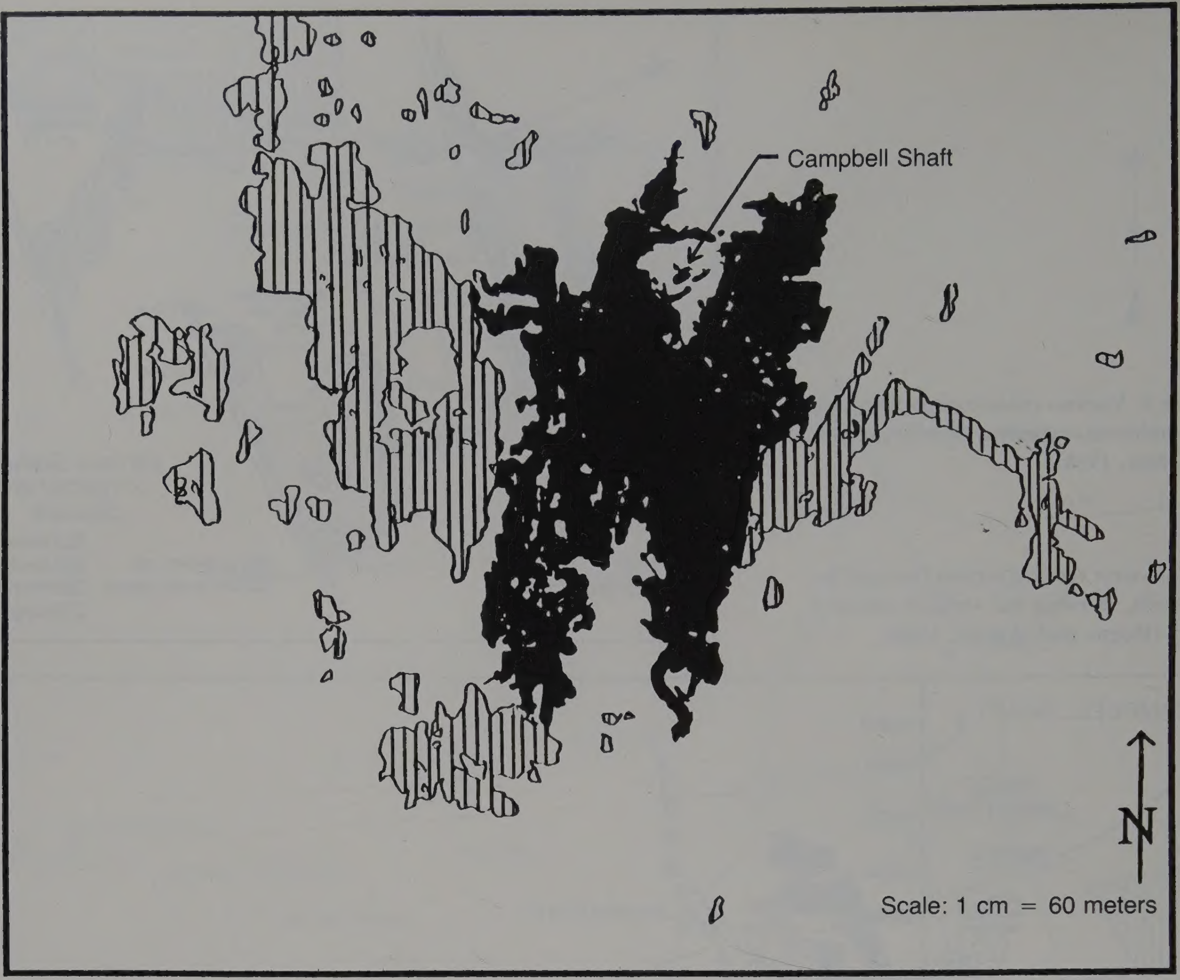


Figure 4. **Horizontal projection of the Campbell orebody (black) and some adjacent orebodies (striped).**

that are related to matrix mineralogy. The matrix mineralogy varies with depth, ranging from a siliceous hematite at the 1600 level to a pyrite/calcite mixture at about the 2100 level and grading into a pyrite-calcite-quartz matrix by the 2566 level (Alan Criddle, personal communication, 1992).

The vertical zonation of the matrix mineralogy noted by Criddle may well be a reflection of the lithologic differences between the various Paleozoic units that host the orebodies. Hogue and Wilson (1950) project the contacts between the units quite close to the levels where Criddle recognized the matrix mineralogy changes (see Fig. 3). If indeed the different units do play a role, it would be a function of both the differential chemical response of the host rock to the mineralizing fluids, and the variable porosity of the units as a function of fracturing, brecciation etc.

Because the Campbell mine area had been so heavily mined for many years, the samples studied by Criddle, Stanley and Williams were largely from the pyritic cores of the orebodies. These cores, while they were known to contain ore minerals, were often considered to be barren because the overall metal content typically did not approach the high cut-off grades required in early underground mining. Discussions concerning the pyritic cores and their supergene equivalents can be found in Bryant and Metz (1966) and Trischka (1938).

There is reason to believe that the conditions which produced the assemblage of minerals at the Campbell mine were not unique in the district. Williams found a similarly intermixed suite of tungsten, tin and vanadium minerals in a specimen lot purchased from a local miner; I believe these came from the lower levels of the Cole mine. Several tellurium-bearing minerals had previously been recognized from the Cole (Williams and Matter, 1975), and also the vanadium mineral, sengierite (Hutton, 1957). Descloizite, also vanadium-bearing, has been recognized from the nearby Dallas mine (Bonillas *et al.*, 1916). Examination of massive sulfides from the Junction mine in my own collection reveal the presence of bismuth-bearing and tin-bearing minerals. The presence of tellurium has long been recognized at this mine as well (Crawford, 1930).

The mines in the western part of the Warren district produced ores that were largely composed of supergene minerals. It is very difficult to identify any possible supergene alteration products of minor accessory minerals such as those at the Campbell mine. However, vanadium-bearing supergene minerals have been found in the Sacramento and Shattuck mines (Bonillas *et al.*, 1916) and also in the Higgins mine (Taber and Schaller, 1930; Graeme, 1981). I found a bismuth-rich chalcocite in the Southwest mine. The Southwest also produced cassiterite as inclusions in cuprite. These inclusions appear to be a relic of the primary sulfides from which the cuprite was derived.

Given the apparent district-wide distribution of most of the elements that combined to make the mineral assemblage noted in the Campbell, and the occurrences of a number of the same minerals in at least one other mine, it may well be that mineralization was similar throughout the district. Unfortunately it has been fully 18 years since the mines ceased production and eight years since the main pumps in the Junction shaft were stopped, allowing the mines to slowly flood. Today, few, if any, of the areas that could answer this question are accessible. There are, however, a great many specimens preserved in collections that, upon examination, might provide a more complete understanding of Bisbee's wonderful mineral legacy.

Figure 5. **The Campbell mine in 1935, at the time when exploitation of Campbell orebody was most intense.**

MINERALS

The following list of mineral occurrences noted since 1980 should be considered as an addendum or update to Graeme (1981).

Acanthite Ag_2S*

Campbell shaft, from the upper part of the Campbell orebody, associated with silver and stromeyerite (Alan Criddle, personal communication, 1992).

Aikinite $PbCuBiS_3$

Campbell shaft*—2200 level,* identified in samples from the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Arsenosulvanite $Cu_3(As,V)S_4$

Campbell shaft, as yellowish gray metallic grains in a massive pyrite-chalcopyrite ore; also associated with minor hodrushite (Sid Williams, personal communication, 1987).

Atacamite $Cu_2^{+2}Cl(OH)_3$

Southwest mine*—5th level;* this location has produced exceptionally fine specimens, some of which may well be the finest from any American locality. The atacamite forms thin crystals up to 2 cm in length with paratacamite; also as stout, 1.4-cm crystals with hopper-growth terminations.

Aurichalcite $(Zn,Cu^{2+})_5(CO_3)_2(OH)_6$

As previously noted (Graeme, 1981), this is a common mineral in the district, however the following localities have produced especially fine specimens:

Southwest mine*—6th level,* thick crust of fibrous crystals on altered limestone. This occurrence is in the lower portions of a small cave.

Uncle Sam shaft*—"B" level,* areas of fibrous crystals up to 1.25 meters across associated with minor rosasite along the lower walls of a small cave overlying a copper orebody.

Azurite $Cu_3^{+2}(CO_3)_2(OH)_2$

Junction shaft, as modified monoclinic crystals of 2.5 cm or more (Mitchell, 1920).

Shattuck shaft*—200 level, 45 raise,* as large masses composed of small crystals, often partially or completely altered to malachite and on malachite that is frequently stalactitic.

Bayldonite $PbCu_3(AsO_4)_2(OH)_2 \cdot H_2O$

From an unnoted mine in the district, represented by specimen number 21,475 in the collection of the American Museum of Natural History (J. Peters, personal communication, 1992).

Southwest mine*—6th level,* as spongy, resinous, greenish yellow linings of small voids in a silica breccia associated with minor calcite.

Beaverite $Pb(Cu^{2+},Fe^{3+},Al)_3(SO_4)_2(OH)_6$

Southwest mine*—6th level,* as an earthy, yellow material with plumbojarosite in a silica breccia.

---

* Formulas are taken from Fleischer and Mandarino (1991).

Figure 6. Atacamite crystal group, 4.5 cm across; 5th level, Southwest mine.

Figure 7. Aurichalcite crystals (1.8-cm view), in uncommonly random orientations; "B" level, Uncle Sam mine.

Figure 8. Aurichalcite crystal crust, about 1 meter across, in place in a small cavern above "B" level, Uncle Sam mine.

Figure 9. Calcite crystal group, 11 cm; 6th level, Southwest mine.

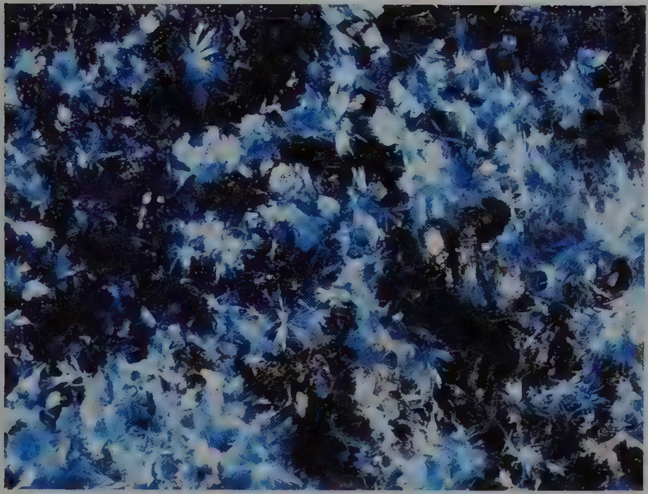


Figure 10. Carbonate-cyanotrichite crystals on azurite (8-mm view); Holbrook mine.

Figure 11. Claringbullite crystals to 6 mm (blue) with paratacamite and spangolite; 5th level, Southwest mine.

Figure 12. Connellite crystals (acicular) to 5 mm with claringbullite crystals to 3 mm; 5th level, Southwest mine.

Bilinite $Fe^{2+}Fe_2^{+3}(SO_4)_4 \cdot 22H_2O$

Higgins mine*—100 level,* as a white to tan fibrous crust on decomposing pyrite.

Bismite Bi_2O_3

Campbell shaft*—1600 level,* associated with silver-bearing wittichenite and native bismuth, as well as a number of sulfide minerals, in a compact silicified hematite matrix (Alan Criddle, personal communication, 1992).

Bismuth Bi

Campbell shaft*—1600 level,* from the Campbell orebody with wittchenite, bismuth and sphalerite in a matrix of silicified hematite (Alan Criddle, personal communication, 1992).

Bismuthinite Bi_2S_3

Campbell shaft*—1600 level,* as an accessory, microcrystalline phase in the complex ores studied by Criddle and Stanley from the Campbell orebody (Alan Criddle, personal communication, 1992).

Bismutite $Bi_2(CO_3)O_2$

Campbell shaft, as pseudomorphs after prismatic alkinite embedded in a quartz-hematite gangue (Sid Williams, personal communication, 1992).

Bogdanovite $Au_5(Cu,Fe)_3(Te,Pb)_2$

Campbell shaft, as tiny bronze-colored grains with pyrite, chalcopyrite and quartz (Sid Williams, personal communication, 1987).

Botallackite $Cu_2^{+2}Cl(OH)_3$

Southwest mine*—5th level;* a rare species occurring as pale blue tabular crystals in massive cuprite, associated with paratacamite and atacamite.

Braunite-II $Mn^{2+}Mn_6^{+3}SiO_{12}$

White Tailed Deer shaft, *(a nearby surface outcrop),* as cores of large braunite crystals with minor neltnerite (Sid Williams, personal communication, 1987).

Calaverite $AuTe_2$

Campbell shaft*—2300 level—124 stope,* as a rare inclusion in the common ore minerals (Alan Criddle, personal communication, 1992).

Calcite $CaCO_3$

Campbell shaft*—2566 level,* as large plates of complex, 2 to 5-cm crystals that range from colorless to milky. These groups often have an attractive iridescence caused by an almost imperceptible coating of goethite.

Southwest mine*—6th level,* as pale red-brown, opaque, rhombohedral to scalenohedral crystal groups that formed below the solution level in the bottom of a small cave. The largest of these crystals exceeded 20 cm. This location is at the interface between a silica breccia and the Martin Limestone.

Carbonate-cyanotrichite $Cu_4Al_2(CO_3,SO_4)(OH)_{12} \cdot 2H_2O$

Holbrook shaft, as pale blue fibrous crystals found as partial overgrowths on azurite.

Cassiterite SnO_2

Campbell shaft, as a very minor accessory mineral in the pyritic ores of the Campbell orebody (Alan Criddle, personal communication, 1992).

Southwest mine*—5th level,* as microscopic, anhedral grains in a massive cuprite-hematite mixture. These grains are, most probably, a relic from the primary sulfide ores.

Cerussite $PbCO_3$

Briggs shaft*—1300 level,* as an unusual occurrence of small crystals with chalcocite (Bateman and Murdoch, 1914).

Gardner shaft, as yellow-white to tan opaque sixling twins on siderite boxwork occasionally associated with smithsonite.

Southwest mine*—6th level,* as cream-colored to tan masses replacing galena; also, as 2-mm intergrowths with fibrous malachite.

Claringbullite $Cu_8Cl_2(OH)_{14} \cdot H_2O$

This species, formally described from an occurrence in Zambia in 1977, was found earlier on a specimen of cuprite from Bisbee submitted by Joe Urban to the University of Arizona in the late 1960's. Even though the X-ray work of John Anthony and, independently, Sid Williams indicated a possible new species, too little material was available for the necessary descriptive work.

Southwest mine*—5th level;* the finest known examples of this rare species are from this locality. As 6-mm, tabular crystals frequently in composite growths, associated with atacamite, paratacamite and less commonly, spangolite or connellite.

Colusite $Cu_{26}V_2(As,Sn,Sb)_6S_{32}$

Campbell shaft (noted from here by Criddle and Stanley, 1986); one of the more widely distributed of the vanadium-bearing minerals in samples from the Campbell orebody studied by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Connellite $Cu_{19}^{+2}Cl_4(SO_4)(OH)_{32} \cdot 3H_2O$

Southwest mine*—5th level,* as acicular crystals in voids in massive cuprite forming exceptional specimens, occasionally associated with paratacamite.

Coronadite $Pb(Mn^{4+},Mn^{2+})_8O_{16}$

As massive to botryoidal, gray to black material from an ***unrecorded locality*** in the district (U.S.N.M., Natural History specimen number 99494).

White Tailed Deer shaft *(a nearby surface outcrop),* as tiny grains in braunite II (Sid Williams, personal communication, 1987).

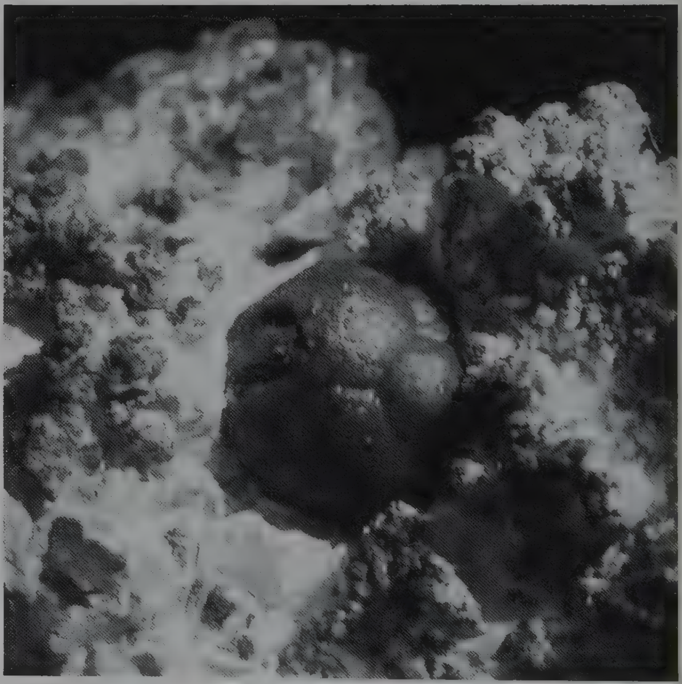


Figure 13. **Crednerite spheroid, 1 cm, with copper and clay; 1,400 level, Dallas mine.**

Crednerite $CuMnO_2$

Even though the following are the first confirmed occurrences of this species in the district, crednerite undoubtedly is far more common than indicated. The marked similarity in appearance as well as association of this mineral with delafossite have almost certainly resulted in crednerite being mistaken for the more common delafossite.

***Dallas shaft**—1400 level,* as lustrous black sphearoids to 1 cm with cuprite and copper in an unidentified clay-like material.

Hoatson shaft, as a compact, black, massive material with cuprite (University of Arizona specimen number 6993).

Cryptomelane $K(Mn^{4+},Mn^{2+})_8O_{16}$

***White Tailed Deer shaft** (a nearby surface outcrop),* as sprays of gray needle-like crystals in calcite associated with braunite (Sid Williams, personal communication, 1987).

Cuprite $Cu_2^{1+}O$

From its very beginnings, Bisbee has been the source of fine specimens of this handsome mineral. However, the find described here has produced the best specimens ever recovered from the district.

***Southwest mine**—5th level,* found in 1986 as slightly modified cubes up to 5 cm on an edge, on acicular atacamite. These large crystals are uncommonly transparent. Other associated minerals include paratacamite and connellite.

Cupropavonite $AgPbCu_2Bi_5S_{10}$

***Campbell shaft**—2300 level—126 stope,* as a very minor component of copper-lead ores associated with chalcopyrite, bornite, sphalerite, chalcocite and galena as well as minor hessite, silver and wittichenite (Alan Criddle, personal communication, 1992).

Digenite Cu_9S_5

Campbell shaft, recognized by Criddle and Stanley from the upper part of the Campbell orebody (Alan Criddle, personal communication, 1992).

Djurleite $Cu_{31}S_{16}$

Campbell shaft, recognized from several areas in the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Higgins mine, as isolated patches up to several centimeters across, with occasional crystal faces, in a recrystallized limestone.

Emplectite $CuBiS_2$

***Campbell shaft**—1600 level,* as a minor accessory mineral associated with a wide assemblage of copper, lead and silver sulfides (Alan Criddle, personal communication, 1992).

Eugenite $Ag_{11}Hg_2$

***Southwest mine**—5th level,* as dispersed, loosely clustered grains a micron or less in size imbedded in massive cuprite (Sid Williams, personal communication, 1992).

Ferricopiapite $Fe_{2/3}^{+3}Fe_4^{+3}(SO_4)_6(OH)_2\cdot OH_2O$

Campbell shaft, as post-mining material in silky yellow to greenish yellow rounded crystals as an alteration product of granular pyrite (specimen provided by Sid Williams).

Ferrimolybdite $Fe_2^{+3}(Mo^{6+}O_4)_3\cdot 8H_2O$

Lavender pit, as a yellow, earthy material occurring as very small blebs in quartz veining along the foot-wall of the Dividend Fault near the concentrator site.

Freibergite $(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$

***Campbell shaft**—2700 level,* as silver-gray, irregular masses to several cm in bornite with minor pyrite.

Goldfieldite $Cu_{12}(Te,Sb,As)_4S_{13}$

Campbell shaft, as an accessory mineral in the main ore assemblage of the middle part of the Campbell orebody (Alan Criddle, personal communication, 1992).

Gormanite $Fe_3^{+2}Al_4(PO_4)_4(OH)_6\cdot 2H_2O$

As 0.5-mm sprays of deep green-blue crystals in quartz associated with pyrite (Joseph Cilen specimen number 16,483). Found in drill core by Occidental Minerals from the Cochise orebody in about 1975 and carried as an "unknown" until described from Canada.

Graemite $CuTeO_3\cdot H_2O$

Shattuck shaft, as pseudomorphs after large (2 x 20-mm teineite crystals largely veneered by thin, oriented overgrowths of second-generation teineite. Minor euhedral cuprite is associated with this specimen (Arizona Sonora Desert Museum specimen #10694).

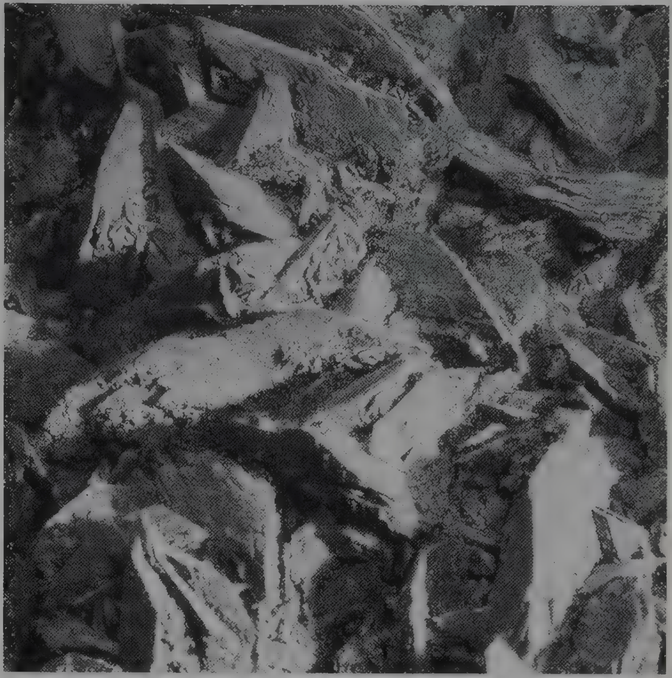


Figure 14. **Hematite crystals to 1.7 cm, coated with microcrystalline hematite; 600 level, Shattuck mine.**

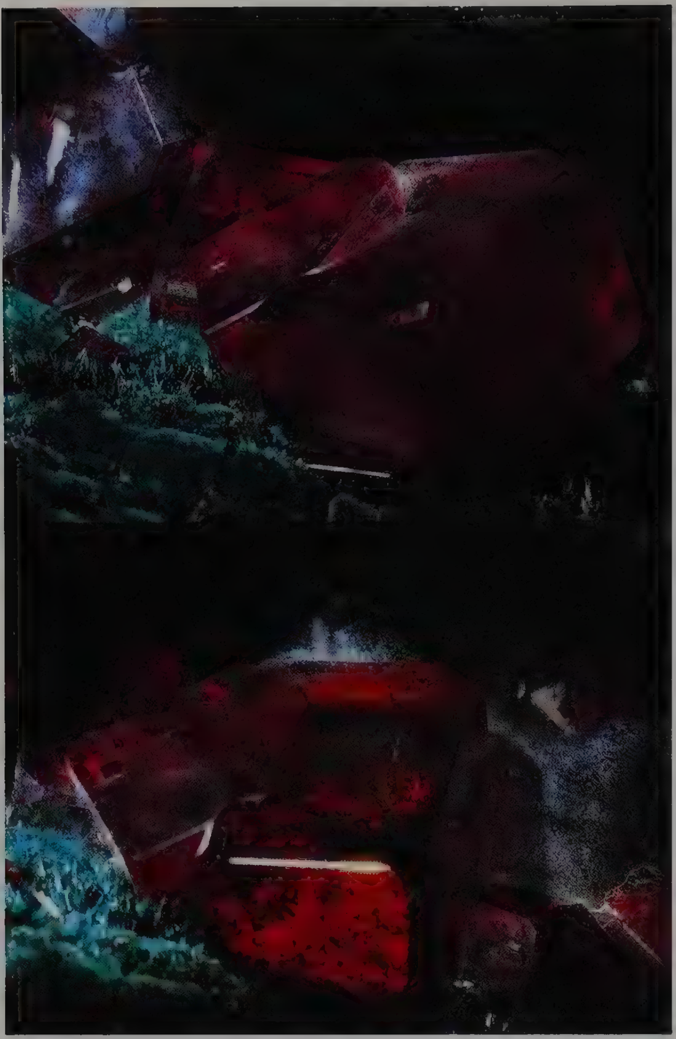
Figure 15. **Hematite in botryoidal habit, 6 cm across; 600 level, Shattuck mine.**

Hematite Fe_2O_3

***Shattuck shaft**—600 level, 98 crosscut.* An unusual occurrence of several forms of this mineral in a breccia that developed in massive, compact hematite. Apparent remobilization of some of the hematite following brecciation developed three distinct periods of deposition. First lustrous, botryoidal to pisolitic material up to 1 cm thick was deposited, followed by local deposition of dull, black, hexagonal, tabular crystals to 3 cm, in turn followed by bright specular hematite. The last phase occurred as very thin crystals to 4 mm.

Hemimorphite $Zn_4Si_2O_7(OH)_2\cdot H_2O$

***Southwest mine**—6th level,* as colorless to pale mauve aggregates



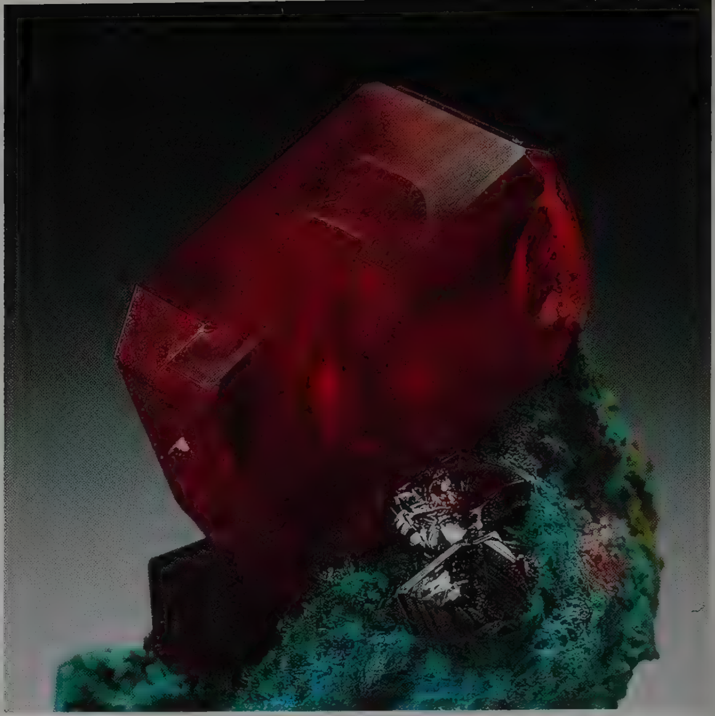


Figure 17. **Cuprite crystal, 2.6 cm; 5th level, Southwest mine.**

Figure 16. **Cuprite crystals (two views) to 3 cm; 5th level, Southwest mine.**

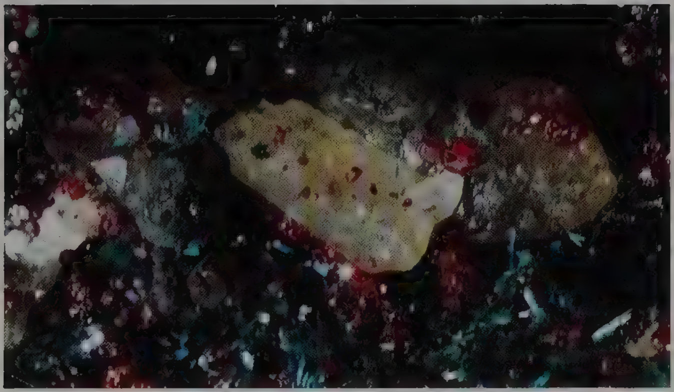


Figure 18. **Nantokite crystals to 5 mm with red cuprite and green atacamite; 5th level, Southwest mine.**

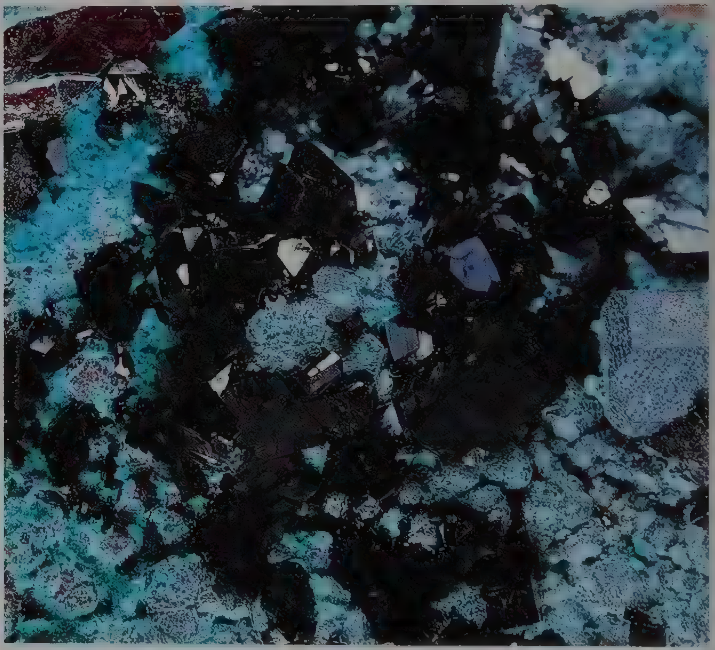


Figure 19. **Paratacamite crystals (blackish) to 7 mm on cuprite coated by pale green paratacamite; 5th level, Southwest mine.**

of 2-mm crystals on calcite in a cave.

Uncle Sam shaft— *"A" level,* as colorless 2-mm crystals on rosasite.

Henryite $Cu_4Ag_3Te_4$

Bisbee is the type locality for this recently described mineral.

Campbell shaft, as pale blue (in reflected light) irregular grains to 0.5 mm occurring as intergrowths in hessite and petzite. The latter are interstitial in pyrite (Criddle *et al.,* 1983).

Hessite Ag_2Te

Campbell shaft (noted from here by Criddle and Stanley, 1986), recognized by Criddle and Stanley in samples from several areas of the Campbell orebody (Alan Criddle, personal communication, 1992).

Hetaerolite $ZnMn_2^{+3}O_4$

White Tailed Deer shaft *(a nearby surface outcrop),* as exceptionally large (6 mm) crystals in calcite associated with braunite (Sid Williams, personal communication, 1987).

Hocartite Ag_2FeSnS_4

Campbell shaft, noted by Williams as one of the many microcrystalline minerals in the complex ores of the Campbell orebody (Sid Williams, personal communication, 1992).

Figure 20. Paratacamite (black) crystal, 1.5 cm, on cuprite; 5th level, Southwest mine.

Figure 21. Spangolite crystals (black, blue-black) to 4 mm with acicular green atacamite; 5th level, Southwest mine.

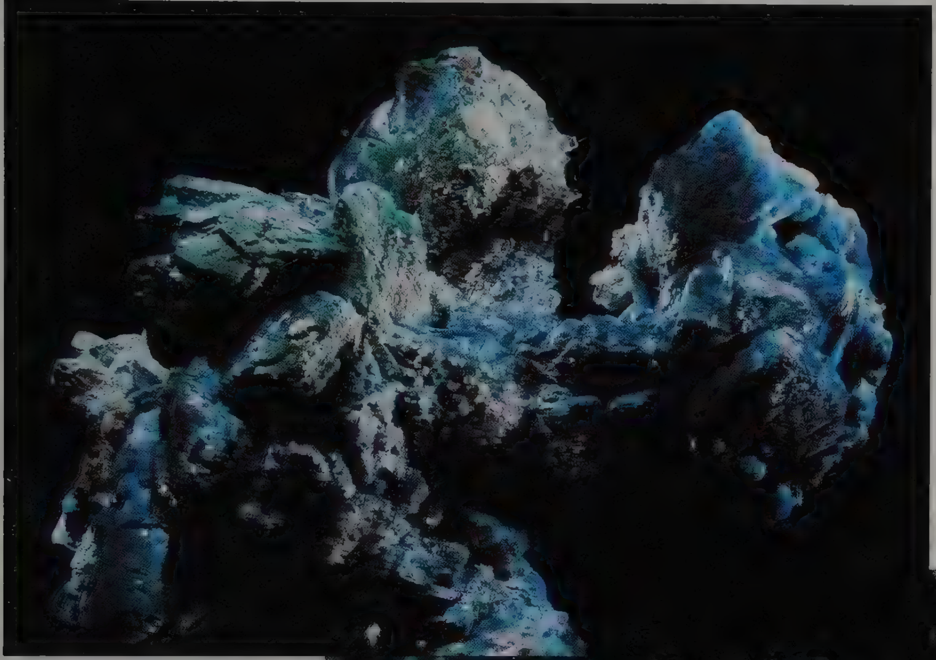


Figure 22. Rosasite partially replacing malachite pseudomorphs after azurite, 3.5 cm across; "A" level, Uncle Sam mine.

Figure 23. Tolbachite (white) partially coating red cuprite crystals to 0.4 mm, with blocky cream-colored nantokite crystals and acicular green atacamite; 5th level, Southwest mine.

Hodrushite $Cu_8Bi_{12}S_{22}$

Campbell shaft, steel-gray laths to 0.5 mm with pyrite, chalcopyrite and arsenosulvanite (Sid Williams, personal communication, 1987).

Hübnerite $Mn^{2+}WO_4$

Cole shaft*—1300 level, 39A stope,* as grains in bornite associated with kiddcreekite, scheelite and pyrite (Sid Williams, personal communication, 1987).

White Tailed Deer shaft *(a nearby surface outcrop),* as tiny grains included in braunite II (Sid Williams, personal communication, 1987).

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

Occurs as a milky white coating on cerussite in a quartz-galena vein outcropping immediately west of the Lavender pit (Sid Williams, personal communication, 1992).

Iodargyrite AgI

Campbell shaft, associated with mottramite, argentite, silver and kettnerite (Sid Williams, personal communication, 1987).

Jalpaite Ag_3CuS_2

Campbell shaft*—1600 level,* as a very minor constituent of the ores from the Campbell orebody studied by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Kesterite $Cu_2(Zn,Fe)SnS_4$

Campbell shaft, noted in several samples from the lower part of the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Kettnerite $CaBi(CO_3)OF$

Campbell shaft, recognized in samples from the Campbell orebody by Williams, associated with aikinite, argentite and silver (Sid Williams, personal communication, 1987).

Kiddcreekite Cu_6SnWS_8

Bisbee is a co-type locality for this new species.

Campbell shaft, as pale gray (in reflected light) anhedral grains associated with tungsten-bearing colusite, stützite and altaite in pyrite (Harris *et al.*, 1984).

Kostovite $CuAuTe_4$

Campbell shaft (noted from here by Criddle and Stanley, 1986), as small grayish grains in quartz with pyrite, chalcopyrite, altaite, goldfieldite and very minor melonite (Sid Williams, personal communication, 1987).

Krennerite $AuTe_2$

Campbell shaft (noted from this mine by Criddle and Stanley, 1986), as a rare intergrowth in sulfides and associated with other tellurides (Alan Criddle, personal communication, 1992).

Ktenasite $(Cu^{2+},Zn)_5(SO_4)_2(OH)_6 \cdot 6H_2O$

Campbell shaft, as a thin crystalline crust on pyrite-chalcopyrite ore (Sid Williams, personal communication, 1992).

Kuramite Cu_3SnS_4

Campbell shaft, as extremely small gray grains intergrown in sphalerite; also associated with pyrite, quartz, altaite and melonite (Sid Williams, personal communication, 1987).

Luzonite Cu_3AsS_4

Junction shaft, as massive, fine-grained material from the lower levels.

Malachite $Cu_2^{+2}(CO_3)(OH)_2$

Junction shaft, as massive material, in many cases as a replacement of cuprite or azurite with the latter showing partial to complete replacement (Mitchell, 1920).

Shattuck shaft*—200 level,* as bright crystals to 1 cm in and on shattuckite. *500 level,* as acicular replacement overgrowths on irregular cuprite nodules with minor calcite. This occurrence is in a cave, where the nodules are found in collapse breccia at the bottom.

Southwest mine*—4th level,* as complete replacement of cuprite nodules by bright, compact acicular crystals. *5th level,* as pseudomorphs after atacamite crystals to 6 mm in length.

Matildite $AgBiS_2$

Campbell shaft*—1600 level,* recognized in this part of the Campbell orebody by Criddle and Stanley as a minor accessory mineral associated with other bismuth and silver minerals (Alan Criddle, personal communication, 1992).

Mawsonite $Cu_6^{+1}Fe_2^{+3}Sn^{4+}S_8$

Campbell shaft*—2300 level—125 stope,* as one of the several tin-bearing species recognized from this part of the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Melonite $NiTe_2$

Campbell shaft (noted from this locality by Criddle and Stanley, 1986), from the Campbell orebody as reddish gray to brown grains (in reflected light) with altaite and pyrite in quartz. (Specimen and identification provided by Sid Williams.)

Miersite (Ag,Cu)I

Southwest mine*—5th level,* as small, lemon-yellow crystals that range from simple tetrahedrons to complex forms, or as patchy films of a waxy yellow material. Associated with atacamite, malachite and cuprite as well as very minor chlorargyrite or bromargyrite.

Murdochite $PbCu_3^{+3}O_{8-x}(Cl,Br)_{2x}$, $x \leqslant 0.5$

Examination of early specimens and recent field work have indicated that this mineral is much more common at Bisbee than previously realized.

Shattuck shaft*—200 level,* found in small amounts with plattnerite and minor bromargyrite on siliceous fragments which are partially coated with specular hematite.

Southwest mine*—4th level, near the Uncle Sam shaft,* as drusy films on altered Martin Limestone at the edge of an orebody.

5th level, as brilliant, sharp 1 to 2-mm crystals associated with malachite and calcite on stalactitic goethite as well as goethite boxwork.

Muscovite $KAl_2(Si_3Al)O_{10}(OH,F)_2$

Campbell shaft*—1600 level,* the chromian variety, as deep green folia with quartz in crystalline limestone associated with visible gold and bismutite (Sid Williams, personal communication, 1987).

Nantokite CuCl

Southwest mine*—5th level,* as a colorless, massive filling of pockets in cuprite, less commonly as complex crystals to 6 mm in vugs of cuprite crystals. On exposure to a moist environment, this material readily alters to pulverulent paratacamite.

Nekrasovite $Cu_{26}V_2(Sn,As,Sb)_6S_{32}$

Campbell shaft (a zincian variety was noted from here by Criddle and Stanley, 1986), as brownish to bronze-colored (in reflected light) granular blebs to 0.7 mm in quartz with pyrite and minor calcite (Sid Williams, personal communication, 1987).

Neltnerite $CaMn_6^{+3}SiO_{12}$

White Tailed Deer shaft *(a nearby surface outcrop),* as small crystals at the interface between braunite overgrowths on crystals of braunite II (Sid Williams, personal communication, 1987).

Nolanite $(V^{3+},Fe^{2+},Fe^{3+},Ti)_{10}O_{14}(OH)_2$

Campbell shaft*—2566 level,* as one of the more abundant vanadium minerals from this part of the Campbell orebody (Alan Criddle, personal communication, 1992).

Paratacamite $Cu_2^{+2}(OH)_3Cl$

Southwest mine*—5th level;* what may well be the finest examples of this species are from this locality. It is found as sharp, complex crystals to 1.5 cm on cuprite, also as simple 3-mm crystals on cuprite that is coated with a film of paratacamite.

Atacamite, claringbullite and spangolite may be associated with paratacamite from this locality.

Pulverulent paratacamite was produced during collecting this and other species as the result of nantokite reacting with moisture in the damp mine atmosphere.

Paratellurite TeO_2

Campbell shaft, recognized by Williams in his work on the minerals from the Campbell orebody (Sid Williams, personal communication, 1987).

Pearceite $Ag_{16}As_2S_{11}$

Campbell shaft*—1700 level, 113 stope.* As clusters of black, anhedral grains to 0.05 mm in a mixture of massive chalcocite and bornite. (USNM Natural History specimen number 100455).

Petzite Ag_3AuTe_2

Campbell shaft (noted from here by Criddle and Stanley, 1986), as a minor part of the compound inclusions in the sulfides from the mid-portion of the Campbell orebody (Alan Criddle, personal communication, 1992).

Plattnerite PbO_2

A more common mineral in the district than previously recognized. The more significant additional occurrences are described below.

Shattuck shaft*—200 level,* as scattered microcrystals on siliceous fragments with bromargyrite, murdochite and specular hematite.

Southwest mine*—6th level,* as thin veneers along cracks in cerussite ores, often coated by later calcite.

Pyromorphite $Pb_5(PO_4)_3Cl$

Shattuck shaft, as apple-green crust and 2-mm cavernous growth crystals on malachite with later malachite pseudomorphs after azurite (Gene Wright specimen).

Ralstonite $Na_xMg_xAl_{2-x}(F,OH)_6 \cdot H_2O$

Southwest mine*—5th level,* as colorless to white aggregates of microcrystals on cuprite and atacamite.

Rhodostannite $Cu_2FeSn_3S_8$

Campbell shaft*—2200 level,* as microcrystals associated with altaite, melonite and volynskite in a pyrite-rich sphalerite ore (Sid Williams, personal communication, 1987).

Rickardite Cu_7Te_5

Campbell shaft, as minute patches of compound grains with sylvanite included in henryite grains (Criddle *et al.*, 1983).

Rosasite $(Cu^{2+},Zn)_2(CO_3)(OH)_2$

Uncle Sam shaft*—"A" level,* as sharp pseudomorphs after azurite up to 1.5 cm, with later hemimorphite and aurichalcite. The larger pseudomorphs appear to be only surficial, partial rosasite replacements of malachite pseudomorphs after azurite, the rosasite layer seldom being more than 5 mm thick; smaller crystals are complete replacements.

"B" level, as botryoidal linings of pockets with aurichalcite in boulders in the bottom of a small natural cave.

Roscoelite $K(V^{3+},Al,Mg)_2(AlSi_3)O_{10}(OH)_2$

Campbell shaft*—2566 level,* noted during their work on the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Rucklidgeite $(Bi,Pb)_3Te_4$

Campbell shaft (noted from this mine by Criddle and Stanley, 1986)*—2300 level—125 stope,* one of several minerals occurring as a minor inclusion in and replacement of granular pyrite (Alan Criddle, personal communication, 1992).

Scheelite $CaWO_4$

Campbell shaft*—2566 level,* recognized by Criddle and Stanley in their study of the Campbell orebody (Alan Criddle, personal communication, 1992).

Silver Ag

Campbell shaft, widely distributed in minor amounts through the Campbell orebody (Alan Criddle, personal communication, 1992).

Czar shaft, as an unusual specimen that was sent to the 1884 New Orleans Exhibition for display. It was described as "a cuplike mass 8 inches in diameter with a 3-inch mushroom growing from the center" (Anonymous, 1884).

Spangolite $Cu_6^{+2}Al(SO_4)(OH)_{12}Cl \cdot 3H_2O$

Southwest mine*—5th level,* as several specimens with crystals to 4 mm associated with claringbullite, atacamite and paratacamite.

Spertiniite $Cu^{2+}(OH)_2$

From the district as pale blue-green encrustations on and associated with atacamite (Sid Williams, personal communication, 1992).

Spessartine $Mn_3^{+2}Al_2(SiO_4)_3$

As red-brown euhedral crystals to almost a centimeter, in massive chalcopyrite, exact mine unrecorded (U.S.N.M., Natural History specimen number 119229).

Cole shaft*—700 level,* as 5-mm crystals with azurite in vugs in massive material.

Spionkopite $Cu_{39}S_{28}$

Campbell shaft (noted from here by Criddle and Stanley, 1986), associated with other copper sulfides in the upper part of the Campbell orebody (Alan Criddle, personal communication, 1992).

Stannite Cu_2FeSnS_4

Campbell shaft*—2100 level,* as one of several minerals forming compound inclusions in pyrite (Alan Criddle, personal communication, 1992).

Stutzite $Ag_{5-x}Te_3$

Campbell shaft (noted from this mine by Criddle and Stanley, 1986), from the Campbell orebody as lead-gray coatings on small pyrite crystals with minor kesterite (specimen and identification provided by Sid Williams).

Sylvanite $(AuAg)_2Te_4$

Campbell shaft, noted from several locations within the Campbell orebody by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Teineite $Cu^{2+}Te^{4+}O_3 \cdot 2H_2O$

Shattuck shaft. As bright blue, oriented, partial overgrowths on graemite pseudomorphs after teineite.

Tellurite TeO_2

Campbell shaft, recognized by Criddle and Stanley during their work on the Campbell orebody (Alan Criddle, personal communication, 1992).

Tellurium Te

Campbell shaft, one of the minerals recognized by Criddle and Stanley in their work with the Campbell ores (Alan Criddle, personal communication, 1992). As bright, tin-white (in reflected light) grains with pyrite, quartz, chalcopyrite and minor altaite (specimen and identification provided by Sid Williams).

Table 1. **Minerals found at Bisbee.**

Acanthite
Actinolite
Aikinite
Alabandite
Albite
Allanite
Allophane
Altaite
Alunite
Anatase
Andesine
Andradite
Anglesite
Anhydrite
Anthonyite
Antigorite
Antlerite
Apatite
Aragonite
Arsenosulvanite
Atacamite
Augite
Aurichalcite
Azurite
Barite
Basaluminite
Bayldonite
Bayleyite
Beaverite
Beudatite
Bianchite
Bilinite
Bindheimite
Biotite
Bisbeeite
Bismite
Bismuth
Bismuthinite
Bismutite
Bixbyite
Bogdanovite
Bohmite
Bornite
Botallackite
Botryogen
Braunite
Braunite II
Brochantite
Bromargyrite
Brucite
Calaverite
Calcite
Canfieldite
Carbonate-Cyanotrichite
Cassiterite
Celadonite
Cerussite
Cesarolite
Chalcanthite
Chalcoaulumite
Chalcocite
Chalcophanite
Chalcophyllite
Chalcopyrite
Chalcosiderite
Chamosite
Chlorargyrite
Chromite
Chrysocolla
Chrysotilep
Cinnabar
Claringbullite
Clinochlore
Clinochrysotile
Clinozoisite
Colusite
Conichalcite
Connellite
Copiapite
Copper
Coquimbite
Coronadite
Cosalite
Covellite
Crednerite
Cryptomelane
Cuprite
Cupropavonite
Cyanotrichite
Delafossite
Descloizite
Devillie
Diaspore
Dickite
Digenite
Diopside
Dioptase
Djurleite
Dolomite
Edenite
Embolite
Emplectite
Enargite
Enstatite
Epidote
Epsomite
Eugenite
Famatinite
Fericopiapite
Ferrimolybdite
Fibroferrite
Fluorite
Forncite
Forsterite
Freibergite
Galena
Gibbsite
Goethite
Gold
Goldfieldite
Goslarite
Graemite
Grapite
Greenockite
Grossular
Groutite
Gypsum
Halloysite
Halotrichite
Hausmannite
Hematite
Hemimorphite
Henryite
Hessite
Hetaerolite
Hexahydrite
Hisingerite
Hocarite
Hodrushite
Hubnerite
Hydrobasaluminite
Hydrocerussite
Hydrohetaerolite
Hydrozincite
Illite
Ilsemannite
Iodargyrite
Jalpaite
Jarosite
Kaolinite
Kesterite
Kettnerite
Kiddcreekite
Kornelite
Kostovite
Krennerite
Ktenasite
Kuramite
Labradorite
Langite
Laumontite
Leadhillite
Lepidocrocite
Lime
Linarite
Luzonite
Magnesite
Magnetite
Malachite
Manganite
Marcasite
Matildite
Mawsonite
Melanterite
Melonite
Metavoltine
Microclie
Miersite
Mimetite
Minium
Molybdenite
Mottramite
Murdochite
Muscovite
Nantokite
Natrolite
Nekrasovite
Neltnerite
Nolanite
Oligoclase
Olivine
Orthoclase
Osarizawaite
Paramelaconite
Paratacamite
Paratellurite
Pearceite
Petzite
Pharmacosiderite
Pickeringite
Plancheite
Plumbojarosite
Polybasite
Powellite
Prehnite
Pseudomalachite
Pumpellyite
Pyrite
Pyrolusite
Pyromorphite
Pyrophyllite
Pyrrhotite
Quartz
Ralstonite
Ransomite
Rhodochrosite
Rhodostannite
Rhomboclase
Rickardite
Romerite
Rosasite
Roscoelite
Rozenite
Rucklidgeite
Rutile
Sanidine
Scapolite
Scheelite
Sengierite
Sepiolite
Shattuckite
Siderite
Siderotil
Silver
Smithsonite
Spangolite
Spertiniite
Spessartine
Sphalerite
Spionkopite
Stannite
Stannoidite
Stevensite
Stibiconite
Stolzite
Sulfur
Sylvanite
Szomolnokite
Talc
Teineite
Tellurite
Tellurium
Tellurobismuthite
Tennanite
Tenorite
Tetradymite
Tetrahedrite
Thomsonite
Tilasite
Titanite
Tolbachite
Tourmaline
Tremolite
Turquoise
Tyuyamunite
Uraninite
Vanadinite
Variscite
Velikite
Vesuvianite
Volkonskoite
Voltaite
Volynskite
Willemite
Wittichenite
Wolframite
Wollastonite
Wulfenite
Yarrowite
Zincootryogen
Zircon
Zoisite

Tellurobismuthite $Bi_{12}Te_3$

Campbell shaft (noted from this mine by Criddle and Stanley, 1986)—*2100 level*, one of the more abundant intergrowths in the various sulfides found in this part of the Campbell orebody (Alan Criddle, personal communication, 1992).

Tetradymite Bi_2Te_2S

Campbell shaft—2300 level—125 stope, one of several minerals included within, and replacing granular pyrite in the ores studied by Criddle and Stanley (Alan Criddle, personal communication, 1992).

Tolbachite $Cu^{2+}Cl_2$

Southwest mine*—5th level,* as yellow-brown, filmy patches on cuprite associated with atacamite, paratacamite and tenorite.

Velikite $(Cu,Hg)_{11}Sn_4S_{16}$

Campbell shaft, noted by Williams as one of the many microcrystalline minerals in the complex ores of the Campbell orebody (Sid Williams, personal communication, 1992).

Volkonskoite $Ca_{0.3}(Cr^{3+},Mg,Fe^{3+})_2(Si,Al)_4O_{10}(OH)_2\cdot 4H_2O$

Campbell shaft, as waxy green masses with pyrite and quartz from the Campbell orebody.

Volynskite $AgBiTe_2$

Campbell shaft (noted from this mine by Criddle and Stanley, 1986)*—2200 level,* as a microcrystalline mineral associated with altaite, melonite and rhodostannite in a pyrite-rich sphalerite ore (Sid Williams, personal communication, 1987).

Wittichenite Cu_3BiS_3

Campbell shaft, recognized by Sid Williams as well as Criddle and Stanley in their independent studies, as one of the more abundant bismuth minerals from the Campbell orebody (Sid Williams, personal communication, 1987; Alan Criddle, personal communication, 1992). Criddle reports the material from the 1600 level to contain up to 7 weight % silver (Alan Criddle, personal communication, 1992).

Wolframite $(Fe,Mn)WO_4$

Campbell shaft, noted in their studies of the Campbell orebody by Williams as well as Criddle and Stanley (Sid Williams, personal communication, 1987; Alan Criddle, personal communication, 1992).

Wulfenite $PbMoO_4$

Cole shaft*—700 level,* as colorless, water-clear crystals to 8 mm on goethite and partially decomposed galena.

Yarrowite Cu_9S_8

Campbell shaft, noted by Williams as one of the many microcrystalline minerals in the complex ores of the Campbell orebody (Sid Williams, personal communication, 1992).

Zincobotryogen $(Zn,Mg,Mn^{2+})Fe^{3+}(SO_4)_2(OH)\cdot 7H_2O$

Occurrence in the district represented by specimen number 97,317 in the collection of the American Museum of Natural History (J. Peters, personal communication, 1992).

ACKNOWLEDGMENTS

The effort, assistance and frequent counsel of Sid Williams played a most vital part in developing this work, as was the kind and generous sharing of information by Alan Criddle. My sons, Richard and Douglass, were important contributors of time and energies during the many many hours of field work, library research and identification efforts that this work required. Also, I am indebted to Monica, my wife, for her insistence that an update such as this was in order. She also provided all of the specimen photos except Figure 17.

Sid Williams, Alan Criddle, Richard C. Erd, Steven Morehead and Wendell Wilson have been kind enough to review the manuscript and provide comments that have greatly enhanced its quality.

BIBLIOGRAPHY

One unstated goal of the bibliography in the original Bisbee paper was to not only document the sources used but to also note other important references. This approach is continued here. Below are those sources used in the development of this article, as well as significant additional references that may add to the readers understanding of Bisbee and its minerals.

ANONYMOUS (1881) Cave struck. *The Engineering and Mining Journal,* **31**, 215.

ANONYMOUS (1882) The Denver Exhibition. *The Engineering and Mining Journal,* **34**, 107.

ANONYMOUS (1883) Cave with large volumes of copper ore is found. *The Engineering and Mining Journal,* **36**, 69.

ANONYMOUS (1884) Unique specimen of Silver ore. *The Engineering and Mining Journal,* **38**, 270.

ANONYMOUS (1888) Pay day and gambling. *The Engineering and Mining Journal,* **45**, 310.

ANONYMOUS (1921) Calumet & Arizona finds new body of high-grade Carbonate ore. *The Engineering and Mining Journal,* **111**, 406.

ANONYMOUS (1981) *Phelps Dodge—A Copper Centennial, 1881–1981.* Pay Dirt, Bisbee, Arizona, 192 p.

ANONYMOUS (1985) Phelps Dodge Corporation will stop pumping water at some mines. *The Wall Street Journal,* **120**, May 22.

BAILEY, L. R. (1983) *Bisbee, Queen of the Copper Camps.* Westernlore Press, Tucson, Arizona, 159 p.

BALDRIDGE, B. (1929) Future of district assured as Campbell orebody proves to be largest in history of Bisbee. *Bisbee Daily Review,* **32**, March 17.

BATEMAN, A. M., and MURDOCH, J. (1914) Secondary enrichment investigation; notes on Bisbee, Arizona. Unpublished notes. Harvard University Mineralogical Museum files, 240 p.

BONILLAS, Y. S., TENNEY, J. B., and FEUCHERE, L. (1916) Geology of the Warren mining district. *A.I.M.E. Transactions,* **55**, 285–355.

BRYANT, D. G., and METZ, H. E. (1966) Geology and ore deposits of the Warren mining district; in *Geology of the Porphyry Copper Deposits, Southwestern North America,* edited by S. Titley and C. Hicks. The University of Arizona Press, Tucson, Arizona, 189–204.

BYRKIT, J. W. (1982) *Forging the Copper Collar.* The University of Arizona Press, Tucson, Arizona, 435 p.

CRAWFORD, W. P. (1930) Notes on rickardite, a new occurrence. *American Mineralogist,* **15**, 272–273.

CRIDDLE, A. J., STANLEY, C. J., CHISHOLM, J. E., and FEYER, E. E. (1983) Henryite, a new copper-silver telluride from Bisbee, Arizona. *Bulletin de Mineralogie,* **106**, 511–517.

CRIDDLE, A. J., and STANLEY, C. J., editors (1986) *Quantitative Data File for Ore Minerals.* 2nd edition. The Commission on Ore Microscopy of the International Mineralogical Association. British Museum (Natural History), London, 420 p.

FATHOUER, I. S. (1991) *Lemuel C. Shattuck.* Westernlore Press, Tucson, Arizona, 337 p.

FLEISCHER, M., and MANDARINO, J. A. (1991) *Glossary of Mineral Species 1991.* The Mineralogical Record Inc., Tucson, Arizona, 267 p.

GRAEME, R. W. (1981) Famous Mineral Localities: Bisbee, Arizona. *Mineralogical Record,* **12**, 258–319.

GRAEME, R. W. (1987) Bisbee, Arizona's dowager queen of mining camps: A look at her first 50 years; in *History of Arizona Mining,* edited by J. M. Canty and M. Greeley, Mining Club of the Southwest Foundation, Tucson, Arizona, 51–76.

HARRIS, D. C., ROBERTS, A. C., THORPE, R. I., CRIDDLE, A. J., and STANLEY, C. J. (1984) Kiddcreekite, a new mineral species from the Kidd Creek Mine, Timmins, Ontario and from the Campbell orebody, Bisbee, Arizona. *Canadian Mineralogist,* **22**, 227–232.

HODGSON, J. P. (1914) Mining methods used in the Copper Queen mine. *The Mining and Engineering World,* **49**, 991–996.

HOGUE, W. G., and WILSON, E. D. (1950) Bisbee or Warren district, Arizona. *Arizona Bureau of Mines Bulletin,* **156**, 17–29.

HUTTON, C. O. (1957) Sengierite from Bisbee, Arizona. *American Mineralogist,* **42**, 408–411.

JUNCTION MINING COMPANY (1906) *Junction Mining Company Annual Report for 1905*. Calumet, 19–22.

MITCHELL, G. J. (1920) Vertical extent of copper ore minerals in the Junction mine, Warren district, Arizona. *Engineering and Mining Journal,* **109**, 1411–1412.

NAVIAS, R. A. (1952) The mineralogy of the Campbell mine. Pennsylvania State College, unpublished M.S. thesis, 61 p.

PHELPS DODGE CORPORATION (1919) *The Copper Queen Practical Mining Course*. Bisbee Publishing Company, Bisbee, Arizona, 385 p.

PHELPS DODGE (1992) *Phelps Dodge Corporation 1991 Annual Report*. Phoenix, Arizona, 60 p.

SCHWANTES, C. A., editor (1992) *Bisbee, Urban Outpost on the Frontier*. The University of Arizona Press, Tucson, Arizona, 145 p.

TABER, S., and SCHALLER, W. T. (1930) Psittacinite from the Higgins mine, Bisbee, Arizona. *American Mineralogist,* **15**, 575–579.

TRISCHKA, C. (1938) Bisbee district. *Arizona Bureau of Mines Bulletin,* **145**, 32–41.

TRISCHKA, C. (1926) New cave found in Copper Queen. *Engineering and Mining Journal,* **121**, 328.

TUPPER, C. A. (1915) The Bisbee-Warren district–Copper Queen mine. *Mining and Engineering World,* **43**, 515–522.

WILLIAMS, S. A., and MATTER, P. III (1975) Graemite, a new Bisbee mineral. *Mineralogical Record,* **6**, 32.

ALLCHAR, MACEDONIA

Branko Rieck
Institut für Mineralogie und Kristallographie
Universität Wien
Dr.-Karl-Lueger-Ring 1
A-1010 Vienna, Austria

The deposit at Allchar is unique in the world because of its high thallium content. It is the type locality for the thallium minerals bernardite, lorandite, parapierrotite, picotpaulite, raguinite, rebulite, simonite, vrbaite and the source of three as yet unnamed species.

INTRODUCTION

Allchar, Macedonia, is situated near the town of Majdan, 32 km south of Kavadarci and 6 km north of the Greek border. The mines are located in the hills east of the Majdanska Valley, on the slopes of the "Crven Dol" ("Red Valley"). The Allchar deposits are unique in the world because of the economic concentrations of thallium there, and the consequent assemblage of thallium minerals; it is the type locality for no less than eleven thallium species, many found nowhere else. The deposits are distributed over a faulted and brecciated area 200 meters wide and 2.5 km long.

The Crven Dol thallium mine at Allchar has been the subject of renewed interest in recent years. Freedman *et al.* (1976) and Freedman (1979) proposed that lorandite from Allchar could be used as a solar neutrino detector, but this idea had to be set aside at that time due to a lack of sufficient analytical accuracy. In 1983 the project was promoted again by Morinaga (1983), who supported Freedman's idea in view of the fact that now sufficient accuracy could be obtained and that new achievements in accelerator mass spectrometry could solve other problems (Ernst *et al.*, 1984). This led to the formation of the International Project on Solar Neutrino Detection by Thallium Minerals, which includes numerous scientific institutions from Austria, Croatia, Germany, Macedonia, Slovenia, the former Yugoslavia and some other countries. This project is also known as "LOREX," which is an acronym for LORandite EXperiment (Pavicevic, 1986).

The idea behind this experiment is to prove higher concentrations of ^{205}Pb in lorandite than would be expected as a result of natural radioactivity and cosmic radiation alone. The excess can be related to the formation of ^{205}Pb by solar neutrino capture in ^{205}Tl. It is important to keep in mind the expected quantity of ^{205}Pb, namely 35 to 75 atoms per gram of lorandite (Freedman *et al.*, 1976; Pavicevic, 1988) (1 gram of lorandite contains about $7 \cdot 10^{21}$ atoms). These figures show the immense analytical difficulties to be overcome by this experiment. Another problem is the possible contamination of lorandite by trace elements introduced through geochemical processes, influencing the formation of ^{205}Pb. Therefore the deposit is now being studied in detail to characterize its mineralogical, geochemical and geological features (Jankovic, 1988; Palme *et al.*, 1988; Pavicevic, 1988; Pavicevic and El Goresy, 1988).

HISTORY

Remains of early mining works bear witness to the exploitation of the area in ancient times. Antimony, realgar and orpiment were mined, especially during the 12th and 13th centuries, for paint pigments and for their presumed medicinal value.

Mining peaked during a short but intense period in the years from 1881 to 1908 (Jankovic, 1960). It was at this time that the locality (previously known as Kozuf) was renamed Allchar. The name Allchar itself is an acronym consisting of the first syllables of the names ALLatini (brothers from Salonica who owned the mining concessions at Kozuf at the time) and CHARteaux (a French engineer who carried out substantial investigations at the deposit). Commercial exploitation of the Allchar mines ended in 1913.

After World War II intensive geological surveying was carried out in and around the deposit from 1953 to 1957, as well as from 1962 to 1964 and from 1970 to 1974. In the 1960's mineable reserves were estimated at several tens of thousands of tons of ore containing in average 0.1% thallium in the central zone. In the 1970's investigations concentrated on the northern zone, and delineated ore reserves of several thousand tons with an average thallium content of 0.3%.

In 1983 another period of small-scale mining started with the goal of producing several hundred kilograms of lorandite concentrate for the LOREX program (Pavicevic, 1988).

GEOLOGY

The Allchar deposit is part of the Serbo-Macedonian (Kozuf) me-

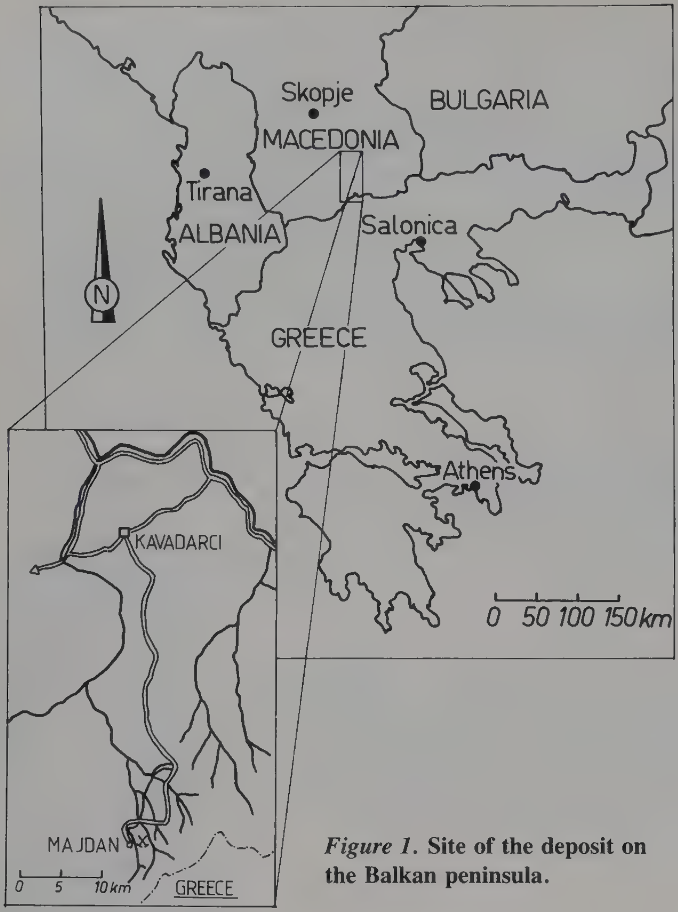


Figure 1. **Site of the deposit on the Balkan peninsula.**

tallogenic province. This province is located in a major fault zone between the Pelagonian block to the west and the tectonically unstable Vadar zone to the east. The Allchar tectonic body has a west-southwest-trending anticlinal structure. The oldest rocks—Paleozoic metasediments such as chlorite schists and marbles—are situated in the core of the anticline. They are surrounded by Triassic dolomites, Jurassic ophiolitic ultramafic rocks with prevailing gabbro-peridotites, and young (5 million years, biotite age; Pavicevic, 1988) volcanic rocks consisting of andesite, quartz latite, latite, rhyolite and trachytic tuffs. Some radially structured ring complexes can be observed in the area.

Allchar is among the deposits now commonly referred to as "Carlin type deposits." Hydrothermal fluid introduction and interaction with receptive host rocks is facilitated by faulting, fracturing and brecciation associated with structural intersections in all such deposits. The lithology of the host rocks is of no importance as long as permeability is sufficient. Hydrothermal alteration typically includes decarbonatization, silicification, argillization and baritization. The mineralized and altered rocks show a characteristic geochemical zoning pattern of enrichment in gold, arsenic, antimony, mercury, and thallium.

The formation of the Allchar orebody is closely related to the emplacement of the andesitic rocks. This event mobilized hydrothermal solutions which resulted in the formation of the ore lenses along the contact between andesite and dolomites, introducing Sb, As, Tl, Fe, Au and Hg as well as traces of Pb, Zn, Cu and Ag. The solutions followed steeply dipping shear zones filled with breccia and characterized by high porosity and permeability.

Hydrothermal alteration of the wallrock began at 500° C (Pavicevic, 1988) in a weakly acidic environment. In the first phase carbonate minerals were partially removed within the main path of the solutions. This led to a general increase in porosity and thus to a decrease in density.

The next phase of mineralization is characterized by the silicification of the wallrock (reducing its porosity again) and the precipitation of

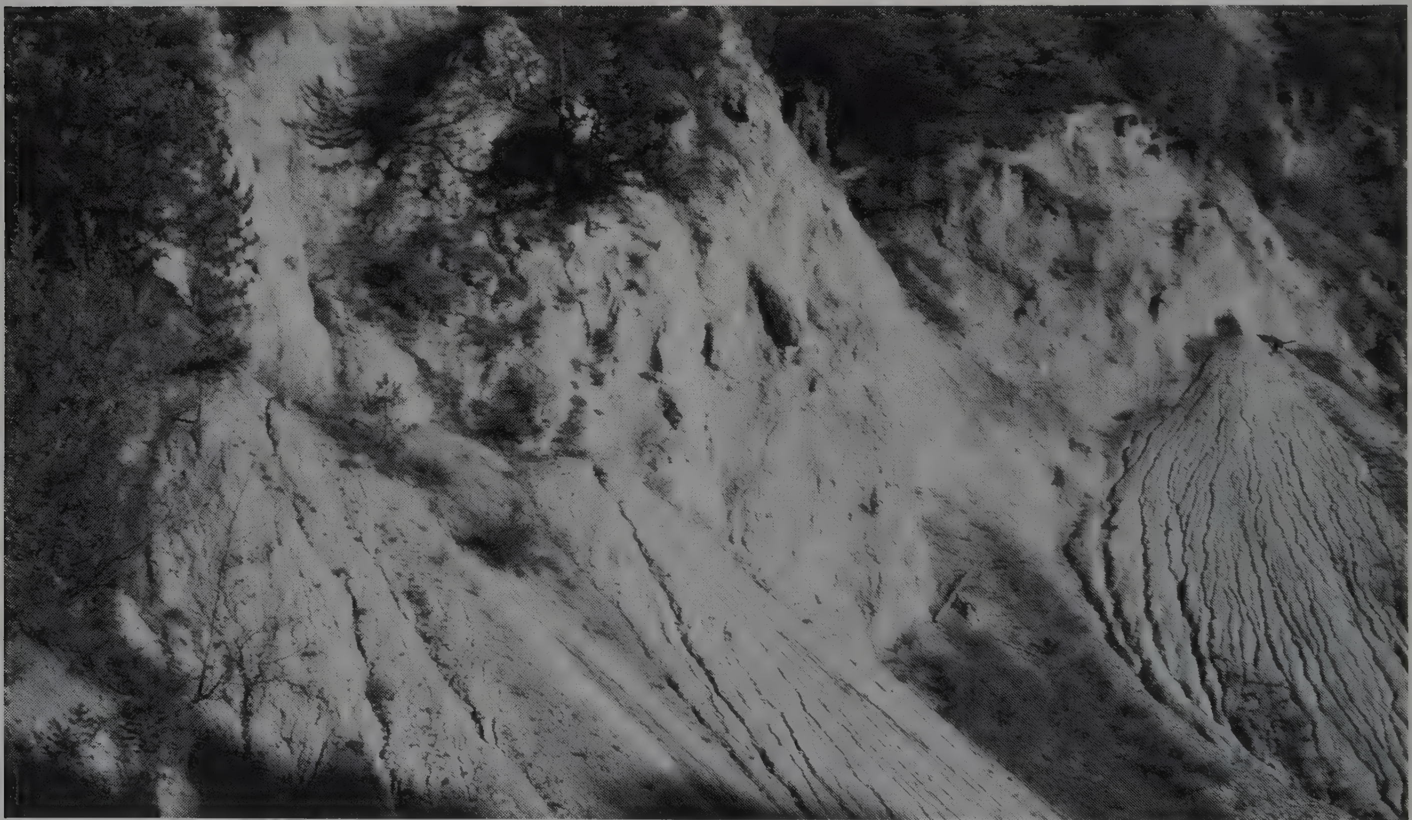


Figure 2. **The dumps of P28. The photo was taken from the Majdanska Valley looking east. Eva Franz photo.**

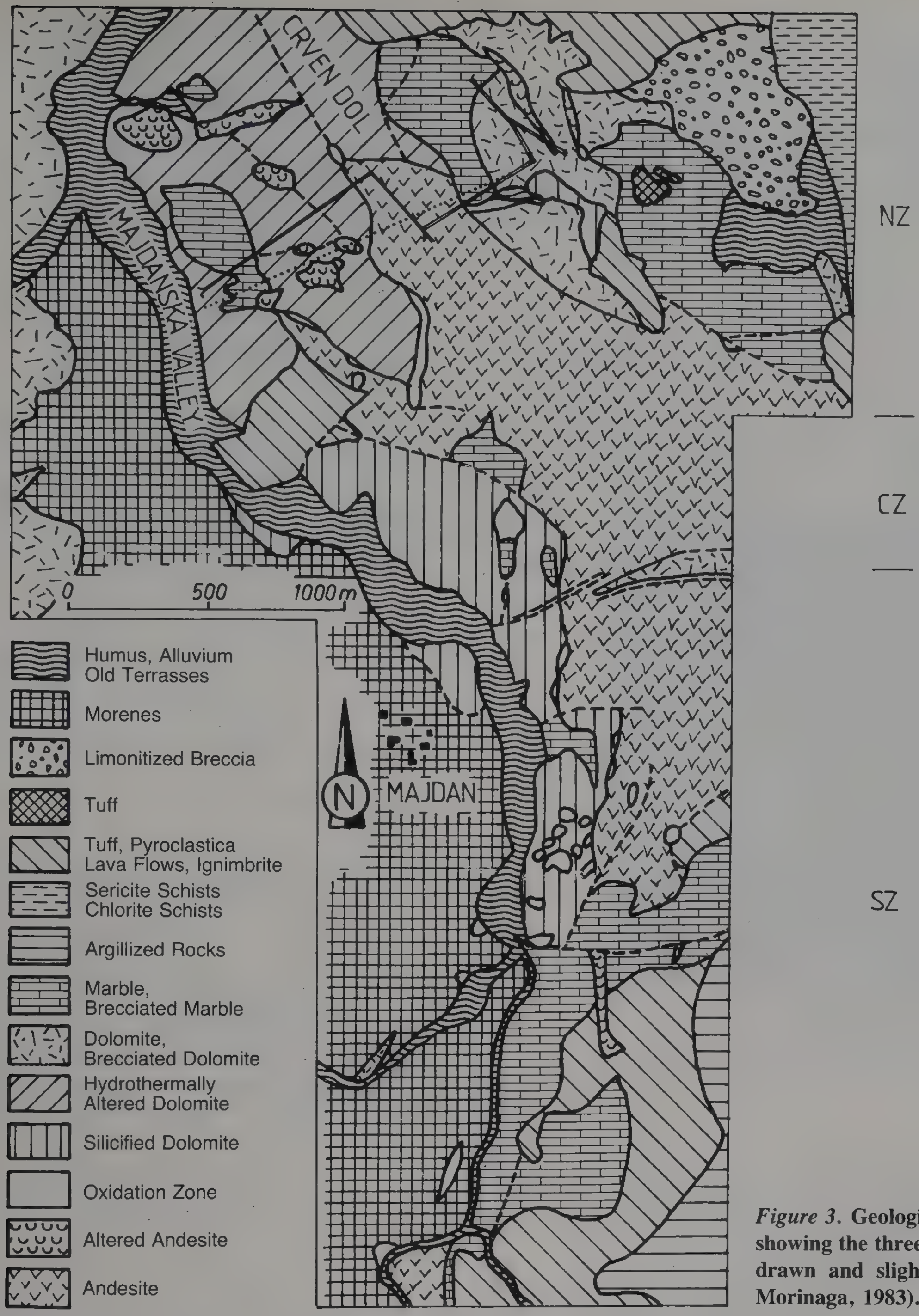


Figure 3. **Geological map of the Allchar area, showing the three zones of mineralization. Redrawn and slightly altered from Ivanov (in Morinaga, 1983).**

the sulfide minerals. (The silicification at Allchar is not as extensive as usually observed in the other Carlin type deposits.)

During the third stage the hydrothermal solutions mingled with oxygenated descending waters. This resulted in the formation of fluids which were enriched with sulfuric acid. These fluids were responsible for wallrock alteration, causing deposition of alunite and kaolinite along open fractures.

The final phase of hypogene mineralization was the argillization of the andesite. The clay minerals formed were illite and kaolinite with subordinate amounts of montmorillionite. Finally, supergene alteration led to the formation of the sulfate and arsenate minerals described below.

The ores are zoned. The northern zone (NZ in Fig. 3) is dominated by As and Tl, with an average content of 6% As, 0.3% Tl, 0.08% Sb and 0.2 ppm Au. In the southern zone (SZ) Sb and Au prevail. The orebodies here contain an average of 3% Sb, 2% As, 0.06% Tl and 3.5 ppm Au. In the central zone (CZ) the two types overlap. This area is characterized by an abundance of Sb and a decreasing As and Tl content.

The thallium source is assumed to be the quartz-latitic and latitic rocks, which occur near the deposit. Thallium is generally known for having a great geochemical affinity for these types of rock. A further confirmation is given by the small variation of the δ^{34}S parameter, which is typical for magmatically induced hydrothermal solutions. These solutions leached Sb, As and Tl from the parent rocks and transported them in a low acidic to low alkaline environment in the form of S-complexes. The ore minerals were deposited in the course of a metasomatic process within carbonaceous rocks, with the Tl minerals crystallizing in the latest stage of mineralization. In the northern zone this can be subdivided into five events (Pavicevic and El Goresy, 1988):

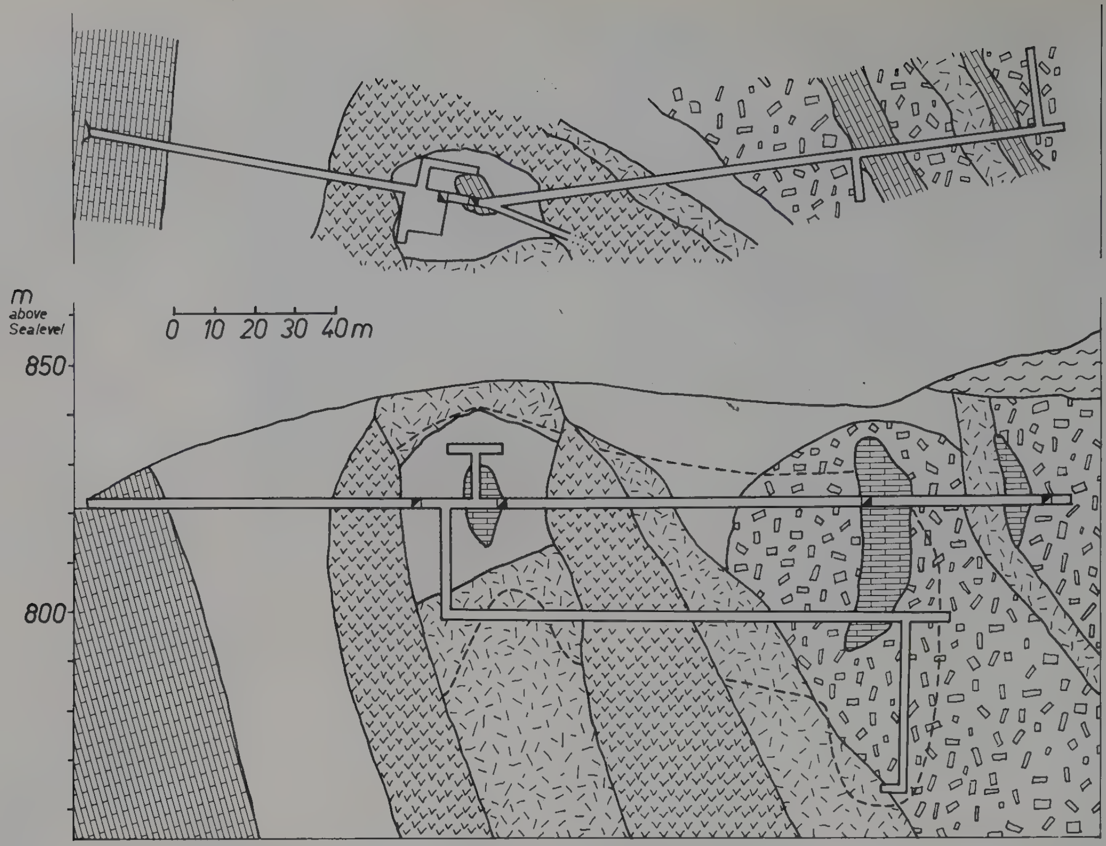


Figure 4. **Idealized cross-section of the Crven Dol mine along adit P21.**

(1) Precipitation of pyrite globules with a low As content.

(2) First As enrichment, leading to the formation of As-rich pyrite and marcasite.

(3) Second As enrichment, leading to the formation of large realgar-orpiment orebodies.

(4) First Tl spike, crystallization of lorandite.

(5) Last stage with a second Tl spike.

This type of ore-forming process is typical of all Carlin type deposits.

MINERALS

Because the number of specimens available for this study was limited and the sampling did not cover the entire deposit but concentrated on the northern and central zones, it is very likely that with further sampling more species will be added to this list.

Following are all those which have previously been reported in the literature, or which have been identified for the first time during the course of the study. Minerals from wallrock, and clay minerals are not included.

Aragonite $CaCO_3$

Aragonite has been reported at Allchar to form white crusts consisting of crystal fibers between stibnite or realgar crystals.

Arsenolite/Senarmontite As_2O_3

Small veinlets between realgar grains have been identified by Frantz *et al.* (1993) as a mineral with the chemical composition As_2O_3. It is as yet unknown which of the two minerals with this composition is present. It is even possible that both occur, but due to the small quantities that have been found to date it has been impossible to answer this question.

Arsenopyrite FeAsS

Only one occurrence of arsenopyrite in small lustrous crystals embedded in massive orpiment, has been reported (Foullon, 1882). In the northern zone of the deposit, grains are found in small quantities with As-rich marcasite and pyrite.

Barite $BaSO_4$

The occurrence of barite has until now been mentioned in only two papers (Baric, 1958; Stieglitz, 1990). I have identified barite on a single specimen of brownish orpiment. It appears as platy, lustrous, clear to milky crystals to a maximum size of 6 mm. Barium is commonly enriched in Carlin type deposits. Some of these deposits have yielded economically important quantities of barite. It is still unknown why this is not the case at Allchar.

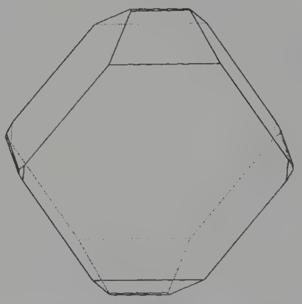


Figure 5. **Idealized crystal drawing of bernardite. Drawn from the accounts of Prof. Dr. F. Pertlik, co-author of the original description of the species (Pasava *et al.*, 1989). {100}, {001}, {012}, {210}, {201}, $\{\bar{2}01\}$, {010}.**

Bernardite $TlAs_5S_8$

Bernardite is the latest of a series of new minerals that have been described from Allchar (Pasava *et al.*, 1989). It forms thick tabular crystals. The crystal faces are commonly corroded or striated and dull.

Figure 6. **The type specimen of bernardite. In the right half of the picture the mark can be seen where one fragment of the crystal was broken from the specimen for the determination of the crystal structure (Pasava *et al.*, 1989). University of Vienna collection; photo by Fritz Schreiber.**

The dominant forms are {100}, {012} and {210}, occasionally the subordinate forms {201}, {$\bar{2}$01} and {010} are exhibited. The crystals are usually smaller than 1 mm, the largest reported being 4 mm. It is black with occasional dark red internal reflections, and has a red streak. No cleavage has been observed. Associated minerals are orpiment and realgar.

Calcite $CaCO_3$

Calcite is found in grains and veinlets in dolomite as well as in the form of marble as part of the host rock. Additionally it appears as fine-grained masses of minute scalenohedral crystals. On these masses the most attractive stibnite sprays are found.

Cervantite $Sb^{3+}Sb^{5+}O_4$

Glassy yellow coatings on stibnite crystals have already been reported by many authors (Stieglitz, 1990). Previously these coatings have always been called "antimon ochre." This study has revealed that their major component in most cases is cervantite with subordinate amounts of roméite and stibiconite.

Cinnabar HgS

Cinnabar is found as microscopic grains up to 150 µm in realgar from the southern zone. It is very rare, detectable only in polished sections.

Dolomite $CaMg(CO_3)_2$

Massive dolomite is the major host rock of the deposit. Idiomorphic crystals have been found in cavities in massive dolomite, but they usually do not exceed 1 mm in size. Iron-bearing weathering solutions have colored most of it brownish. In many parts of the deposit the dolomite is partly or wholly replaced by silica.

Fibroferrite $FeSO_4(OH)\cdot 5H_2O$

Fibroferrite forms hemispheres of yellow fibers. It is associated with hörnesite, rozenite and gypsum on altered host rock in the vicinity of realgar veins. It was identified during the course of this study by powder diffraction and EDX analysis, and is reported here for the first time.

Goethite FeO(OH)

Earthy light to dark brown masses and minute crystals of goethite appear to be ubiquitous in the deposit. In the past these crystals have been considered to be a new mineral and were consequently described as "allcharite" (Jezek, 1913b; Cech and Johann, 1967). Pseudomorphs after pyrite crystals consist almost entirely of goethite.

Gold Au

Gold has been reported to occur as flakes around pyrite grains with maximum dimension of 1.0 µm. It is extremely sparse.

Gypsum $CaSO_4\cdot 2H_2O$

Gypsum appears as an efflorescense on wall rock and timbering. Stalactitic masses have been observed with a length exceeding 25 cm. Single crystals are usually small and very flat on {010}, but well developed and lustrous. Gypsum is found on all types of ore and host rock.

Hörnesite $Mg_3(AsO_4)_2\cdot 8H_2O$

This arsenate is associated with most of the other efflorescent minerals. Its identity can only be confirmed by means of chemical or X-ray analysis. It is sometimes intimately intergrown with gypsum. Its white crystals (which do not exceed a size of 50 µm) are prismatic elongated along the *c*-axis, and are aggregated to crusts and stalactites. It is reported here for the first time.

Figure 7. **Lorandite crystal, 4 mm, on realgar, from adit P21. Author's specimen and photo.**

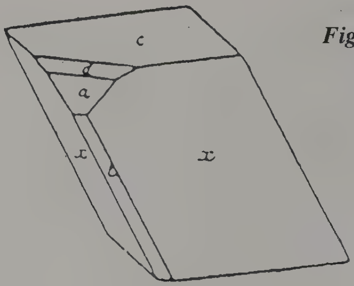


Figure 8. **Lorandite; {100}, {$\bar{1}$01}, {001}, {$\bar{1}$21}. (Goldschmidt, 1899).**

Lorandite $TlAsS_2$

Lorandite was the first thallium-bearing mineral to be described. Since its first discovery in Allchar in 1884 (Krenner, 1884, 1885, 1889) it has been found in only a few other localities worldwide. Its chemical composition has been well established (Jannasch, 1904). Lorandite can easily be distinguished from realgar by its darker red color, its semimetallic luster and its perfect cleavage on {001}, {201} and {110}. The monoclinic tabular aggregates of lorandite are typically dispersed throughout realgar and orpiment hosts. Well developed crystals in cavities are very rare and show many different forms. Goldschmidt (1899) described 32 forms. Recent investigations in connection with the LOREX program have revealed two interesting features. First, that the Allchar lorandite is very pure, containing only traces

Table 1. **Minerals identified from Allchar, arranged according to the Ramdohr and Strunz (1978) classification, as updated by Weiss (1991a, 1991b). (Wallrock and clay minerals not included.)**

Elements	
Gold	Au
Sulfur	S
Sulfides & Sulfosalts	
Raguinite	$TlFeS_2$
Picotpaulite	$TlFe_2S_3$
Cinnabar	HgS
Stibnite	Sb_2S_3
Pyrite	FeS_2
Marcasite	FeS_2
Arsenopyrite	$FeAsS$
Simonite	$TlHgAs_3S_6$
Vrbaite	$Tl_4Hg_3As_8Sb_2S_{20}$
Lorandite	$TlAsS_2$
Weissbergite*+	$TlSbS_2$
Rebulite	$Tl_5Sb_5As_8S_{22}$
Bernardite	$TlAs_5S_8$
Parapierrotite	$Tl(Sb,As)_5S_8$
Realgar	As_4S_4
Pararealgar	AsS
Orpiment	As_2S_3
Unnamed	Tl_3AsS_4
Unnamed	$Tl_5Sb_9As_4S_{22}$
Oxides	
Valentinite	Sb_2O_3
Arsenolite/Senarmontite	As_2O_3
Roméite*	$(Ca,Fe^{2+},Mn,Na)_2(Sb,Ti)_2O_6(O,OH,F)$
Stibiconite*	$Sb^{3+}Sb_2^{5+}O_6(OH)$
Quartz	SiO_2
Cervantite*	$Sb^{3+}Sb^{5+}O_4$
Goethite	$FeO(OH)$
Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Aragonite	$CaCO_3$
Sulfates	
Barite	$BaSO_4$
Rozenite	$FeSO_4 \cdot 4H_2O$
Melanterite	$FeSO_4 \cdot 7H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
Starkeyite*	$MgSO_4 \cdot 4H_2O$
Fibroferrite*	$FeSO_4(OH) \cdot 5H_2O$
Arsenates	
Hörnesite*	$Mg_3(AsO_4)_2 \cdot 8H_2O$
Picropharmacolite*	$H_2Ca_4Mg(AsO_4)_4 \cdot 11H_2O$
Pharmacolite*	$CaHAsO_4 \cdot 2H_2O$
Unnamed	$Fe_2Tl[(As_{0.85}S_{0.15})O_4]_3 \cdot 4H_2O$

Names **in bold** are species for which Allchar is the type locality
*Species reported here from Allchar for the first time
+ Second known occurrence

of K, Cr, Fe, Cu and Zn (Palme *et al.*, 1988). Second, it was discovered that ore-grade lorandite is restricted to four zones within the deposit, two of which are accessible through gallery P21, the others through gallery P28. The zone richest in thallium, which is now the target of mining for the LOREX program, was encountered in gallery P21, from 79 to 110 meters from the adit (see Fig. 3). This orebody contains about 18,000 cubic meters of ore with an average Tl content of 0.35%. Lorandite crystals here typically reach sizes of 1 cm, exceptionally up to 5 cm. Some crystals are coated by a brownish yellow crust. Lorandite is named after the Hungarian physician Lorand Eötvös (1848–1919).

Marcasite FeS_2

Marcasite appears as dull black botryoidal nodules with relatively high arsenic content. It is associated with realgar and stibnite. Marcasite is very crumbly, altering to fibroferrite, melanterite and rozenite in the presence of moisture or humidity.

Melanterite $FeSO_4 \cdot 7H_2O$

This mineral is, like rozenite, a post mining product. It fills small clefts forming veins up to 7 cm wide, traversing the highly altered parts of the host rock. Melanterite decomposes easily and changes from greenish blue to an off-white color. Like rozenite, it is readily water-soluble. Chemical analyses have shown that Mg is replacing Fe by up to 15%.

Orpiment As_2S_3

Like realgar, orpiment is a stoichiometrically rather "pure" mineral at Allchar, although it does contain traces of K, Cl, Cr, Mn, Fe and Cu (Palme *et al.*, 1988). It occurs mainly as compact masses of foliated crystals. Idiomorphic crystals are rare, mainly having brownish yellow color and dull luster. Usually these crystals form fan-shaped aggregates or hemispheres, whereas thin, elongated, bright yellow crystals with adamantine luster are restricted to the highest parts of the deposit, where they occur with realgar. The crystal size of both types usually does not exceed 2 mm, whereas compact masses weighing several hundred kilograms have been found. Recent mining activities have revealed that its abundance in comparison to realgar increased significantly with depth (E. Frantz, personal communication, 1991). Near the contact between the realgar-dominated orebody and the orpiment-dominated zone, lorandite has been found in large quantities intergrown with orpiment.

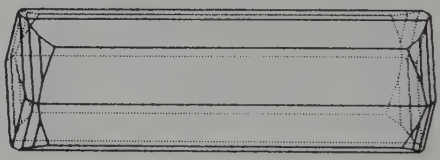


Figure 9. **Idealized crystal drawing of a parapierrotite crystal from adit P21. {100}, {010}, {001}, {101}, {111}, {121}, {141}. Drawn after measurements on a two cycle reflecting goniometer.**

Parapierrotite $Tl(Sb,As)_5S_8$

This mineral occurs as monoclinic needles in massive realgar, and as well-terminated crystals in cavities in realgar. They are black with a semimetallic luster. The crystals commonly reach a length of 3 mm, but sizes have been reported up to 1 cm as rare exceptions. Parapierrotite usually appears as single crystals, groups and aggregates seem to be rare (Johann *et al.*, 1975).

Pararealgar AsS

Pararealgar occurs as a decomposition product of realgar. It is found predominantly on the small dumps where realgar has been exposed to sunlight.

Pharmacolite $CaHAsO_4 \cdot 2H_2O$

Pharmacolite has been found as radiating acicular coatings on realgar, orpiment and host rock. Rarely can single crystals be observed.

It is usually intimately intergrown with gypsum and picropharmacolite, and was identified during the course of this study by powder diffraction and EDX analysis. It is reported here for the first time.

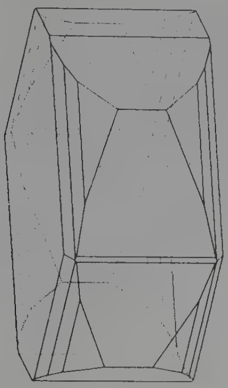


Figure 10. **Idealized crystal drawing of picotpaulite. The values of the cell parameters and the Miller indices were taken from Johann *et al.* (1970). The faces were sized to match a crystal from adit P28 (University of Vienna specimen #23679). {001}, {110}, {140}, {232}, {234}, {236}.**

Picotpaulite $TlFe_2S_3$
Picotpaulite was found as inclusions up to 2 mm in realgar in the lorandite bearing zone of the deposit. It is bronze colored; in polished section under reflected light it appears creamy white. Often it is at least partly replaced pseudomorphically by raguinite. Picotpaulite is rhombic, but because penetration twinning on (120) is common with this mineral, the crystals are usually pseudohexagonal (Johann *et al.*, 1970). The most prominent forms exhibited are {001}, {110}, {010}, and {140}. Rarely the forms {232}, {234} and {236} are also observed. It is named after the French mineralogist Paul Picot.

Picropharmacolite $H_2Ca_4Mg(AsO_4)_4 \cdot 11H_2O$
Picropharmacolite occurs as dense coatings with a maximum thickness of 0.5 mm along fracture surfaces. The appearance varies from clear to milky white; the crystals are bladed and give the specimen a silky sheen. The maximum crystal size is 50 μm. It was identified during the course of this study by powder diffraction and EDX analysis; it is reported here for the first time.

Pyrite FeS_2
Pyrite was the first of all sulfide minerals to crystallize at Allchar. It is found as corroded grains and in the core of marcasite nodules. The pyrite itself is very unattractive, but it is interesting because of its importance to the formation of some of the extremely rare iron-bearing thallium sulfosalts. As in the other Carlin type deposits, pyrite is responsible for the precipitation of invisible gold and thus for a high percentage of the gold content of the deposit.

Quartz SiO_2
Quartz is found as microscopic grains in silicified dolomite. Well-developed clear to milky crystals are restricted to the central zone, where they are found on realgar which in turn is associated with stibnite. The crystals size usually does not exceed 2 mm, but they are sometimes found as aggregates reaching up to 2.5 cm. Quartz is also found in the form of chalcedony and jasper in most parts of the deposit.

Raguinite $TlFeS_2$
Raguinite was first discovered in 1965 and reported in 1966 by Ivanov at the 4th Congress of Jugoslav geologists which took place in Ochrid. It was initially named *soferthallite,* derived from the first letters of the French names for its constituent elements (*soufre* for sulfur, *fer* for iron, and thallium). The authors who later submitted this mineral to the IMA Commission on New Minerals and Mineral Names (Laurent *et al.*, 1969) proposed the name *raguinite* instead, to honor the French scholar Eugène Raguin. Raguinite is found as pseudomorphs after an unknown species later described and named picotpaulite. The pseudohexagonal pyramidal grains consist of brilliant bronze-colored bundles of raguinite fibers. It is associated with orpiment, realgar and lorandite. Usually it is intimately intergrown with pyrite. Like picotpaulite it is found in the central zone, but only small quantities of this mineral have been recovered to date.

Realgar As_4S_4
The bright red color of realgar was one of the main reasons for the exploitation of the deposit in ancient times. Unfortunately when exposed to light it makes a transition to yellow pararealgar. Realgar appears as crystalline lenticular masses up to 1 cubic meter in size, and as crystals up to 1.5 cm. They are generally elongated prismatic along [010] and of a bright red color, but color varies greatly due to inclusions of iron hydroxides. Chemical analysis shows that realgar contains traces of K, Cu, Ga, Na, Cr and Fe (Palme *et al.*, 1988). Recent studies have revealed that realgar was formed at a temperature range between 144° C and 170° C (Beran *et al.*, 1993). Realgar occurs together with stibnite and orpiment and is the host for lorandite and the other Tl-bearing sulfosalts.

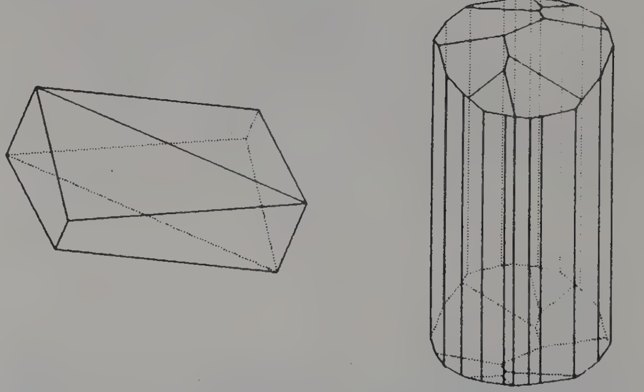


Figure 11. **Rebulite (a); {100}, {001}, {111}; redrawn from Balic-Zunic and Engel (1982). (b); {100}, {001}, {111}, {101}, {102}, {103}, $\{\bar{1}01\}$, $\{\bar{1}02\}$, $\{\bar{1}03\}$, $\{10\bar{1}\}$, $\{10\bar{2}\}$, $\{10\bar{3}\}$; drawn after measurements on a two-cycle reflecting goniometer.**

Rebulite $Tl_5Sb_5As_8S_{22}$
Rebulite is among the new minerals that have been found at Allchar during the last decade. The crystals are dark gray with a metallic luster and a brownish red streak. They are monoclinic, up to 2 mm in size, and exhibit the dominant forms {100}, {001} and {111}. The faces of the zone [010] are striated. It has in one case been found as elongated prismatic crystals which were at first considered to be parapierrotite because of their morphology. Rebulite is associated with realgar, simonite and other Tl-Hg-sulfosalt (probably christite) (Balic-Zunic and Engel, 1982).

In the course of this study it has been necessary to identify some of the samples by means of powder diffraction. In two cases (rebulite and simonite) patterns were obtained which are not in the JCPDS Data Files, nor are they published anywhere else. The identity of these

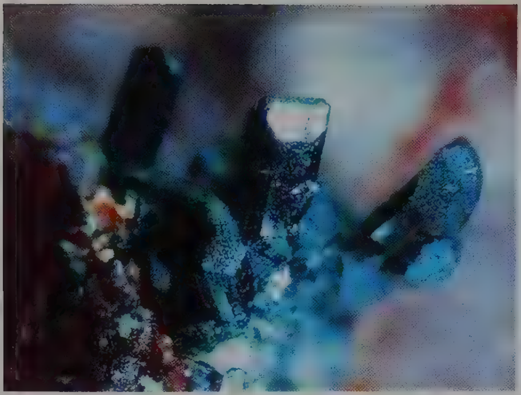


Figure 12. **Parapierrotite, a group of 1 mm crystals on realgar from adit P21. Author's specimen and photo.**

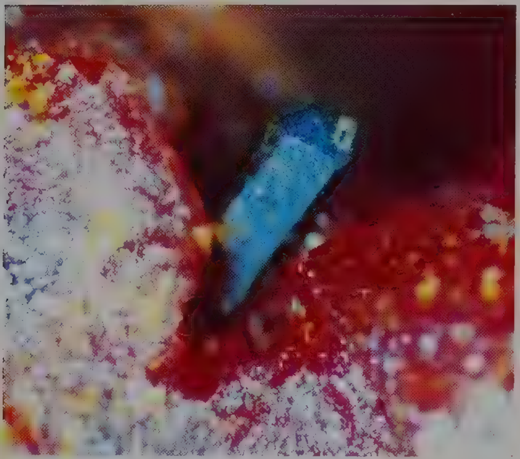


Figure 13. **A 1 mm crystal of rebulite on realgar. This crystal was initially thought to be parapierrotite because of its morphology. Otto Thiele collection; photo by the author.**

Figure 14. **Orpiment with calcite. This specimen was found in the uppermost part of the deposit in P21. The average size of the crystals is 3 mm. Author's specimen and photo.**

samples was established by means of EDX analysis, and powder patterns were calculated according to the crystal structures (Balic-Zunic and Engel, 1982; Engel *et al.*, 1982). These calculated patterns were then compared with the observed ones. As can be seen in Tables 2 and 3, there is good conformity in both cases.

Figure 15. **SEM photograph of a type "B" rebulite crystal on parapierrotite. University of Vienna collection; photo by the author.**

Roméite $(Ca,Fe^{2+},Mn,Na)_2(Sb,Ti)_2O_6(O,OH,F)$

Roméite is an alteration product of stibnite. It forms part of glassy coatings on stibnite which consist predominantly of cervantite. Additionally it forms yellow powdery coatings. At Allchar, roméite is virtually free of Mn, Ti and F.

Rozenite $FeSO_4 \cdot 4H_2O$

Rozenite is a decomposition product of marcasite, pyrite and melanterite. It forms white crusts of prismatic crystals or stalactitic aggregates that are bent in most cases. At Allchar "rams horn" aggregates are generally rozenite and not gypsum. Usually associated with melanterite, hörnesite, gypsum and fibroferrite, it is found throughout the deposit on altered host rock and ore.

Simonite $TlHgAs_3S_6$

Crystals of simonite have so far been found only as inclusions in rebulite, which in turn is associated with realgar. They are orange-red and therefore can easily be confused with realgar (Engel *et al.*, 1982). Allchar is the type locality.

Starkeyite $MgSO_4 \cdot 4H_2O$

Starkeyite was identified during the course of this study on a single specimen consisting entirely of realgar and starkeyite. The latter forms fibrous aggregates partly filling the space between the realgar crystals. It is white with a silky sheen. (Identified by powder diffraction and EDX analysis; reported here for the first time.)

Stibiconite $Sb^{3+}Sb_2^{5+}O_6(OH)$

In rare cases stibiconite forms pseudomorphs after stibnite at Allchar. Usually it is found as earthy yellow to brown coatings and powdery masses in vugs within massive stibnite.

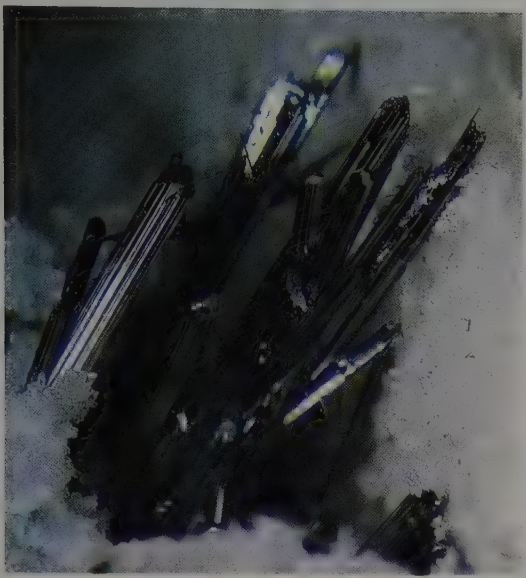


Figure 16. **A spray of stibnite crystals on calcite from the central zone. The crystals are about 2.5 cm long. Author's specimen and photo.**

Stibnite Sb_2S_3

Stibnite is a very common mineral in the central and the southern zone of the deposit. It was mined especially at the turn of the century. The entire production of manually upgraded ore (with an antimony content of 60%; the Sb content of pure stibnite is 71.68%) was sold to England to use in the hardening of lead and tin alloys. Stibnite occurs in veinlets both as compact masses of fibrous crystals and as groups of radiating, well-developed crystals. These groups are found in cavities in massive stibnite and on druses of tiny white calcite crystals. The latter provides a strong contrast, making very attractive specimens. Crystals of stibnite are elongated prismatic, with mostly high luster. They reach a length of 10 cm and a diameter of up to 1 cm. They are often accompanied by small realgar crystals which are sprinkled on the stibnites, adding to the attractiveness of the specimens. Sometimes multifaceted sulfur crystals are found on the stibnites, in place of realgar.

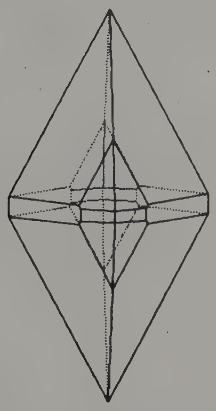


Figure 17. **Idealized crystal drawing of a sulfur crystal from adit P28. {111}, {110}, {210}, {211}. Drawn after measurements on a two cycle reflecting goniometer.**

Sulfur S

Native sulfur usually occurs with pyrite, marcasite and stibnite. It forms small bright yellow crystals up to 1 mm with the forms {111}, {110}, {210} and {211} predominating. More than 20 forms have been observed up to now. It is also found as earthy yellow masses which can easily be confused with earthy pararealgar. Crystals seem to be very unstable, tending to become milky on exposure to sunlight.

Unnamed $Fe_2Tl[(As_{0.85}S_{0.15})O_4]_3 \cdot 4H_2O$

In the course of reflected light investigations Frantz *et al.* (1993) discovered a phase with a radial structure. Microprobe analysis yielded the tentative stoichiometric composition that is given above. Often this mineral is found near pyrite globules which are altered and partly or completely replaced by this new mineral,* suggesting that it was formed through the alteration of pyrite by thallium-bearing weathering solutions. The sizes of the grains encountered varied from 30 μm to over 100 μm.

Unnamed Tl_3AsS_4

This new mineral* was first reported by El Goresy and Pavicevic in 1988. It forms rims around lorandite and has so far only been identified using reflected light microscopy and microprobe analysis. Recent studies by Frantz *et al.* (1993) have reconfirmed the existence and chemical composition of this unnamed mineral.

Unnamed $Tl_5Sb_9As_4S_{22}$

The mineralogical investigations of the deposit have revealed another Tl sulphosalt. It closely resembles rebulite, but investigations carried out at the Universities of Belgrade and Vienna suggest that the mineral in question is new* (L. Cvetkovic, M. K. Pavicevic, and E. Tillmanns, personal communication, 1993).

Valentinite Sb_2O_3

The occurrence of this antimony oxide was predicted by Foullon (1882) and finally found by him on material he received from an engineer for his studies (Foullon, 1890). No further description of Allchar valentinite has been given by him, nor by any other author.

Vrbait $Tl_4Hg_3As_8Sb_2S_{20}$

Small cavities in realgar from the thallium-rich part of the central zone of the deposit have been found to contain vrbaite which was noticed for the first time in 1903 in a shipment of ore to Freiberg,

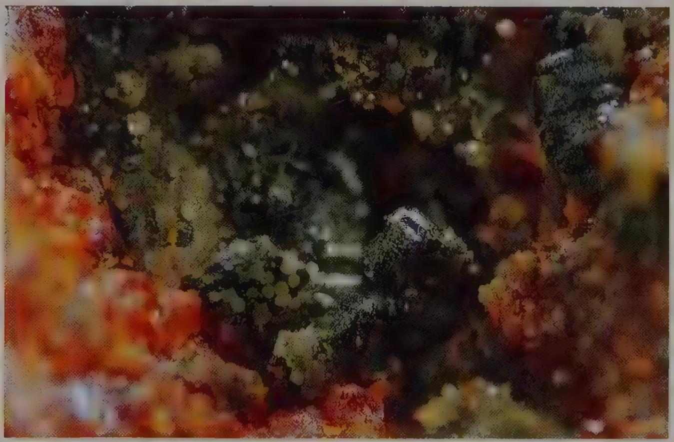


Figure 18. **A group of vrbaite crystals to 1.5 mm with calcite, realgar and orpiment. Author's collection; photo by Fritz Schreiber.**

---

*Formally it is incorrect to use the term "new mineral" as long as the species has not been accepted by the IMA Commission on New Minerals and Mineral Names, but considering the great efforts being made in all three cases, there is little doubt that this will soon be the case.

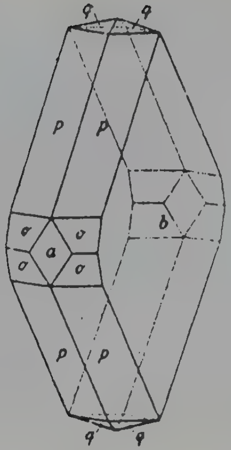


Figure 19. **Vrbaite; {100}, {010}, {111}, {112}, {331}. (Krehlik, 1913).**

Saxony, by the metallurgical chemist Wilhem Maucher (1879–1930). He identified thallium, arsenic, antimony and sulfur as the major constituents of these samples suggesting the existence of a new, as yet undescribed mineral. He showed the material to Karl Vrba (1845–1922), professor at the University of Prague, during his visit to the smelter in 1912. Vrba took samples to Prague and handed them over to his student B. Jezek for further investigations; Jezek (1912, 1913a) described it as a new mineral and named it in honor of his teacher.

Vrbaite occurs as minute crystals and groups up to 3 mm in size. They are dark gray with a bluish sheen and semimetallic luster. Usually they are tabular or flat bipyramidal. Although rhombic the mineral appears strongly pseudohexagonal (Caye *et al.*, 1967; Ohmasa and Nowacki, 1971). Vrbaite is dark red translucent in thinnest sections and has a pale yellowish streak. Its good cleavage in {010} is usually observable and can be used for identification.

Krehlik investigated the chemistry of vrbaite in 1912. Based on his results (Tl 29.52, Fe 1.85, Sb 18.34, As 24.06, and S 25.20 weight %) he propounded a chemical formula, $TlAs_2SbS_5$ or $Tl(As,Sb)_3S_5$, omitting Fe as an impurity of his samples. More than 50 years later this composition was found to be incomplete. The results of microprobe work by Giraud (Caye *et al.*, 1967) and Rudolf (Nowacki, 1968) were published almost simultaneously. Both found Hg to be a major constituent of the composition leading to the now commonly accepted chemical formula: $Tl_4Hg_3As_8Sb_2S_{20}$.

Weissbergite $TlSbS_2$

I have identified weissbergite, in the form of elongated prismatic crystals with a maximum size of 0.5 mm, on a single specimen of realgar. It is steel gray, and has a metallic luster, with deeply striated faces. This is the first time weissbergite has been reported from Allchar, which is now the second known location for this mineral. Its well developed cleavage in four different directions helps to distinguish it from the other thallium sulfosalts that are similar in appearance. (Weissbergite was first described from the Carlin mine by Dickson and Radke in 1978.)

CONCLUSION

In addition to the political unrest afflicting Macedonia, specimen acquisition has been hampered by three principal factors:

(1) The mines have been closed for a long time.

(2) Many species were unknown at the time when the mines were active, and thus were not collected.

(3) Mining operations close to the deposit did not permit collector access to the location.

The scientific activities have inspired renewed interest in Allchar, not only by other scientists, but also among the great community of collectors. Unfortunately there is little chance that new specimens will be available to collectors in the near future, although there have recently been some exceptions to this rule. The LOREX program is doing much to restore and preserve this classic mineral locality; perhaps in future times the mines of Allchar will be opened to the public, and specimens will once again be available.

Table 2. **X-ray diffraction powder pattern of rebulite, 57.3 mm camera, Cu Ka radiation.**

$2\theta_{calc.}$	$d_{calc.}$	$I(100)_{calc.}$	h	k	l	$2\theta_{obs.}$	$I(100)_{obs.}$
16.92	5.2368	30	3	0	$\bar{4}$	17.00	20
17.45	5.0775	25	2	0	4	n.o.	
21.41	4.1466	45	2	1	$\bar{6}$	21.50	40
22.18	4.0045	65	1	0	$\bar{8}$	22.25	60
22.75	3.9061	25	1	1	6	n.o.	
22.97	3.8687	40	0	0	8	23.00	35
23.70	3.7515	35	4	1	$\bar{2}$	n.o.	
25.67	3.4673	40	0	2	3	25.75	35
25.75	3.4563	35	1	2	$\bar{3}$	n.o.	
26.44	3.3682	90	5	0	0	26.50	90
26.49	3.3615	35	4	1	$\bar{6}$	n.o.	
26.86	3.3163	30	2	2	1	n.o.	
27.97	3.1876	30	1	2	$\bar{5}$	28.25	20
28.71	3.1074	45	3	2	$\bar{1}$	n.o.	
29.01	3.0756	100	3	1	6	29.25	100
30.18	2.9586	35	5	1	$\bar{6}$	n.o.	
30.29	2.9482	75	5	0	$\bar{8}$	30.50	70
30.51	2.9279	40	3	2	$\bar{5}$	n.o.	
31.41	2.8455	30	4	1	$\bar{9}$	n.o.	
31.47	2,8403	35	2	2	5	31.50	30
34.22	2.6184	40	6	0	$\bar{8}$	34.25	35
35.32	2.5388	40	4	0	8	35.25	35
38.84	2.3169	30	5	2	3	38.75	20
39.47	2.2813	25	6	2	$\bar{3}$	n.o.	
39.48	2.2807	35	2	2	$\overline{11}$	39.50	30
41.26	2.1862	75	2	1	$\overline{14}$	41.25	70
46.54	1.9497	15	1	3	9	46.75	5
49.56	1.8379	15	7	2	$\overline{11}$	n.o.	
49.61	1.8359	15	3	1	14	n.o.	
49.74	1.8317	20	7	1	$\overline{14}$	50.00	10
52.49	1.7419	20	8	1	6	52.75	10
54.44	1.6841	20	10	0	0	54.50	10

Table 3. **X-ray diffraction powder pattern of simonite, 57.3 mm camera, Cu Ka radiation.**

$2\theta_{calc.}$	$d_{calc.}$	$I(100)_{calc.}$	h	k	l	$2\theta_{obs.}$	$I(100)_{obs.}$
9.53	9.2824	20	0	1	1	9.50	15
16.49	5.3703	15	0	2	1	16.50	10
20.18	4.3967	20	1	1	2	20.25	15
23.58	3.7701	10	0	1	4	n.o.	
23.75	3.7432	15	1	1	3	n.o.	
24.29	3.6618	100	1	2	$\bar{2}$	24.50	100
28.99	3.0772	10	0	1	5	29.25	5
31.05	2.8777	20	2	1	0	n.o.	
31.35	2.8510	45	0	4	0	31.50	45
31.58	2.8309	30	2	1	1	n.o.	
32.08	2.7878	15	0	2	5	32.25	10
32.49	2.7538	10	0	3	4	n.o.	
32.61	2.7432	20	1	3	3	32.75	15
34.56	2.5934	10	0	1	6	34.75	5
37.63	2.3885	10	2	0	$\bar{4}$	n.o.	
38.40	2.3423	10	2	3	0	38.50	5
51.72	1.7660	10	1	6	$\bar{2}$	51.75	5

ACKNOWLEDGMENTS

I am deeply indebted to Prof. Dr. A. Beran and Dr. M. A. Götzinger for their guidance and unfailing help and patience. I gratefully appreciate the interest of Prof. Dr. E. Tillmanns, Prof. Dr. J. Zemann and Dr. M. K. Pavicevic in the preparation of this paper. Dr. E. Frantz is thanked for many useful suggestions and the locality photo; Doz. Dr. H. Effenberger, P. Hubert, K. Schebesta and F. Schreiber for their assistance in microphotography; Prof. Dr. F. Pertlik, Dr. K. Becherer and Dr. O. Thiele for their loans of specimens for photography. Ing. W. Zirbs is thanked for the drawings of Figures 1, 3 and 4. Dr. B. Birch and Dr. W. E. Wilson who reviewed the manuscript are thanked for their comments, which led to a great improvement of this paper. S. and H. Kaiser are thanked for friendship and their substantial contribution to the acquisition of specimens for study, as well as for photography. Fluid inclusion studies in realgar for this paper were sponsored by the *Fonds zur Förderung der wissenschaftlichen Forschung, project #6072-GEO.*

REFERENCES

BALIC-ZUNIC, T., and ENGEL, P. (1982) The crystal structure of rebulite, $Tl_5Sb_5As_8S_{22}$. *Zeitschrift für Kristallographie*, **160**, 109–125.

BARIC, L. (1958) Neuuntersuchungen des Loranditvorkommens von Mazedonien und Vergleich der Mineralvergesellschaftungen in den beiden bisher unbekannten Fundorten des Lorandits. *Schweizer Mineralogische und Petrographische Mitteilungen*, **38**, 247–253.

BERAN. A., GÖTZINGER, M. A., and RIECK, B. (1993) A fluid inclusion study of realgar from the Allchar deposit, Yugoslavia. *Neues Jahrbuch für Mineralogie; Abhandlungen* (in press).

CAYE, R., PICOT, P., PIERROT, R., and PERMINGEAT, F. (1967) Nouvelles donnees sur la vrbaite, sa tenuer en mercure. *Bulltein de la Societe francaise de Mineralogie et Cristallographie*, **90**, 185–191.

CECH, F., and JOHANN, Z. (1967) Identite de l'allcharite et de la goethite. *Bulltein de la Societe francaise de Mineralogie et Cristallographie*, **92**, 99–100.

DICKSON, F. W., and RADKE, A. S. (1978) Weissbergite, $TlSbS_2$, a new mineral from the Carlin gold deposit, Nevada. *American Mineralogist*, **63**, 720–724.

ENGEL, P., NOWACKI, W., BALIC-ZUNIC, T., and SCAVNICAR, S. (1982) The crystal structure of simonite, $TlHgAs_3S_6$. *Zeitschrift für Kristallographie*, **161**, 159–166.

ERNST, H., KORSCHINEK, G., KUBIK, P., MAYER, W., MORINAGA, H., NOLTE, E. RATZINGER, U., HENNING, W., KUTSCHERA, W., MÜLLER, M., and SCHULL, D. (1984) ^{205}Pb: Accelerator mass spectrometry of a very heavy radioisotope and the Solar neutrino problem. *Nuclear Instruments and Methods in Physics Research*, **B5**, 426–429.

FOULLON, H. von (1882) Schwefel und Realgar aus Allchar. *Verhandlungen der K.u.K. Reichsanstalt*.

FOULLON, H. von (1890) Über Antimonit und Schwefel aus Macedonien. *Verhandlungen der K.u.K. Reichsanstalt*.

FRANTZ, E., TODT, W., PALME, H., EL GORESY, A., PAVICEVIC, M. K., JANKOVIC, S., and BOEV, B. (1993) Geochemistry of Tl and As minerals and basement rocks of Allchar (Yugoslavia). *Neues Jahrbuch für Mineralogie; Abhandlungen* (in press).

FREEDMAN, M. S., STEVENS, C. M., HORWITH, E. D., FUCHS, H., LERNER, J. S., GOODMAN, L. S., CHILDS, W. J., and HESSLER, J. (1976) Solar Neutrinos: proposal for a new test. *Science*, **193**, 1117–1118.

FREEDMAN, M. S. (1979) ^{205}Tl as a low energy neutrino detector, Proceedings of the Informal Conference on the Status and Future of Solar Neutrino Research, Editor: G. Frielander, **1**, *RNL Report* **50879**, 313–360.

GOLDSCHMIDT, V. (1899) Über Lorandit von Allchar in Mazedonien. *Zeitschrift für Krystallographie und Mineralogie*, **30**, 272–294.

JANKOVIC, S. (1960) Allgemeine Charakteristika der Antimon-Erzlagerstätten Jugoslawiens. *Neues Jahrbuch für Mineralogie; Abhandlungen*, **94**, 506–538.

JANKOVIC, S. (1988) The Allchar Tl-As-Sb Deposit, Yugoslavia and its specific metallogenic features. *Nuclear Instruments and Methods in Physics Research*, **A271**, 286.

JANNASCH, P. (1904) Analyse des Lorandit von Allchar. *Zeitschrift für Krystallographie*, **39**, 122–124.

JEZEK, B. (1912) Vrbait, novi thallnaty mineral z Allcharu v Macedonii. *Rozpravy cecke akademie*, **21/2** cislo 26, 1–11.

JEZEK, B. (1913a) Vrbait, ein neues Thalliummineral von Allchar in Macedonien. *Zeitschrift für Krystallographie und Mineralogie*, **51**, 365–378.

JEZEK, B. (1913b) Allchait, ein wahrscheinlich neues Mineral. *Zeitschrift für Krystallographie und Mineralogie*, **51**, 275–278.

JOHANN, Z., PIERROT, R., SCHUBNEL, H.-J., and PERMINGEAT, F. (1970) La Picotpaulite $TlFe_2S_3$, une nouvelle espiece minerale. *Bulletin de la Societe francaise de Mineralogie et Cristallographie*, **93**, 545–549.

JOHANN, Z., PICOT, P., HAK, J., and KVACEK, M. (1975) La parapierrotite, un nouveau mineral thallifere d'Allchar. *Tschermaks Mineralogische und Petrographische Mitteilungen*, **22**, 200–210.

KREHLIK, F. (1912) Analysa vrbaitu. *Rozpravy ceske akademie*, **21/2** cislo 27, 38–39.

KREHLIK, F. (1913) Chemische Untersuchungen des Vrbait. *Zeitschrift für Krystallographie*, **51**, 379–383.

KRENNER, J. A. (1884) Lorandit, ein neues Thalliummineral von Allchar in Macedonien. *Mat es Term Tud Ertesitö*, **12**, 473.

KRENNER, J. A. (1885) Lorandit, ein neues Thalliummineral von Allchar in Macedonien. *Mat es Term Tud Ertesitö*, **13**, 258–265.

KRENNER, J. A. (1889) Lorandit, ein Thalliummineral von Allchar in Macedonien. *Zeitschrift für Krystallographie und Mineralogie*, **27**, 107–109.

LAURENT, Y., PICOT, P. PIERROT, R., PERMINGEAT, F., and IVANOV, T. (1969) La Raguinite, $TlFeS_2$, une nouvelle minerale et le probleme de l'allcharite. *Bulletin de la Societe francaise de Mineralogie et Cristallographie*, **92**, 38–48.

MORINAGA, H. (1983) Workshop on the Feasibility of Solar Neutrino Detection with ^{205}Pb by Geochemical and AMS Methods, Editor: E. Nolte, *GSI Report*, **86-9**, Darmstadt.

NOWACKI, W. (1968) Über Hatchit, Lengenbachit und Vrbait. *Neues Jahrbuch für Mineralogie; Monatshefte*, **102**, 69–75.

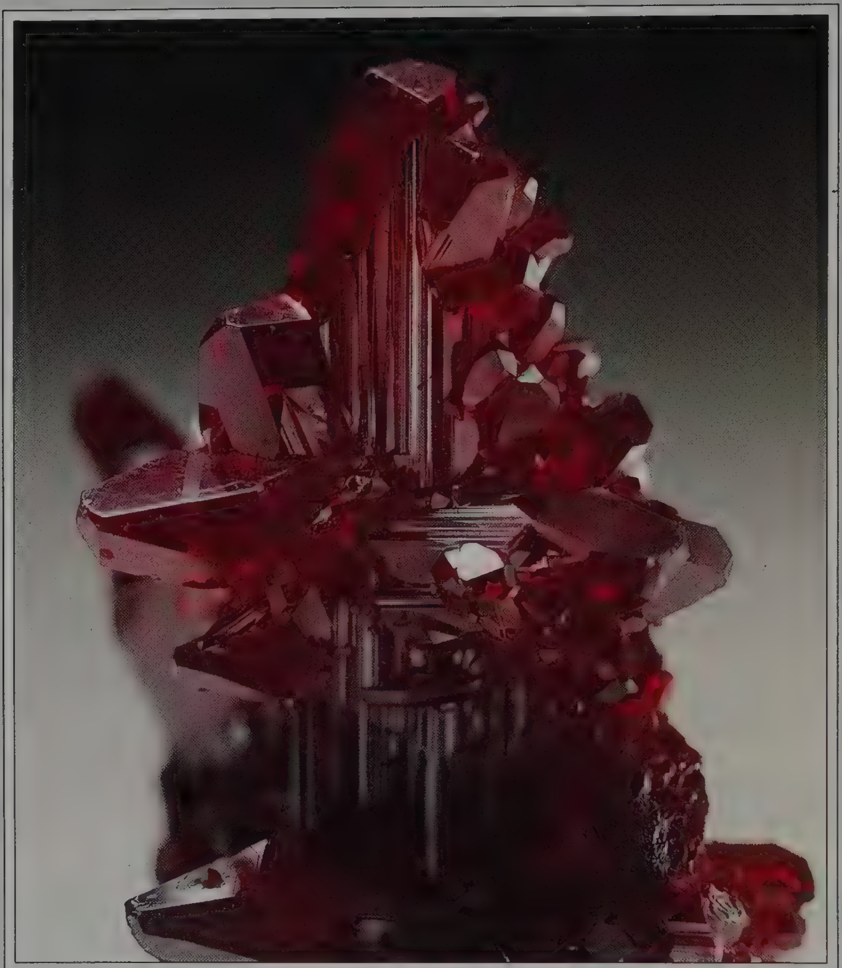
OHMASA, M., and NOWACKI, W. (1971) The crystal structure of vrbaite $Tl_4Hg_3As_8Sb_2S_{20}$. *Zeitschrift für Krystallographie*, **134**, 360–380.

PALME, H., PAVICEVIC, M. K., and SPETTEL, B. (1988) Major and trace elements in some minerals and ore from Crven Dol, Allchar. *Nuclear Instruments and Methods in Physics Research*, **A271**, 314–319.

PASAVA, J., PERTLIK, F., STUMPFL, E. F., and ZEMANN, J. (1989) Bernardite, a new thallium arsenic sulphosalt from Allchar, Macedonia, with a determination of the crystal structure. *Mineralogical Magazine*, **53**, 531–583.

PAVICEVIC, M. K. (1986) International Conference on Solar Neutrino Detection with ^{205}Tl. *Program and Abstract Book*, Dubrovnik.

(Continued on p. 449)



PAVICEVIC, M. K. (1988) Lorandite from Allchar—A low energy solar neutrino dosimeter. *Nuclear Instruments and Methods in Physics Research,* **A271**, 287–296.

PAVICEVIC, M. K., and EL GORESY, A. (1988) Crven Dol Tl deposit in Allchar: Mineralogical investigations, chemical composition of Tl minerals and genetic implications. *Nuclear Instruments and Methods in Physics Research,* **A271**, 297–300.

RAMDOHR, P., and STRUNZ, H. (1978) *Klockmanns Lehrbuch der Mineralogie,* 389–800.

STIEGLITZ, H. (1990) Abenteuer Allchar. *Lapis,* **15(2)**, 11–20.

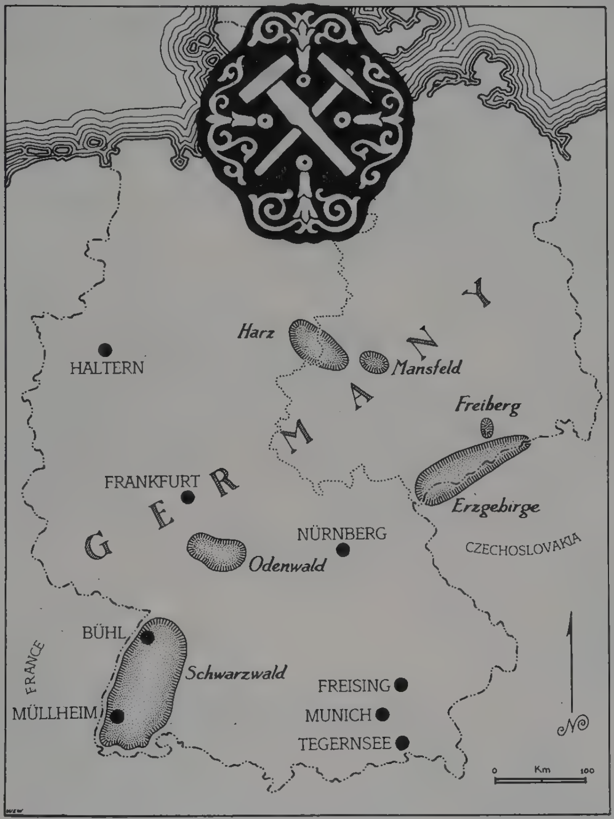
WEISS, S. (1991a) Systematik der Minerale. *Lapis,* **16(2)**, 25–36.

WEISS, S. (1991b) Systematik der Minerale. *Lapis,* **16(3)**, 27–34.

German Dealers

The next time you're traveling in Germany, visit us for some German hospitality & see some exceptional specimens!

Old classics & recent discoveries, display specimens & rare species, fossils, meteorites, books & other collectibles.



Baumstark Mineralien & Edelsteine
Dipl. Min. M. Baumstark
Geppertstr. 20
D-7580 Bühl/Baden
Tel: 07223-1503
Fine Worldwide Minerals—esp. Bulgaria & USSR

Kristallkeller–Nürnberg
Ulrike Buchner-Endres
Stralsunder Str. 50
D-8500 Nürnberg 90
Tel: 0911-383680
Aesthetic Minerals for Collectors and Museums—By Appt. Only

Bode-Verlag GmbH
Rainer Bode
Dürnberg 2
D-4358 Haltern 4
Tel: 0049-2364-16107
Emser Hefte, Mineralien-Welt, Fine Books

Exclusive Mineralien Brückner
G. Brückner
Box 1342
D-79373 Müllheim 16
Tel: 07631-12801
Fine Classic Minerals, By Appt. Only

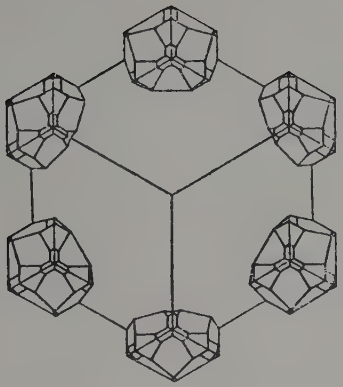
Kristalldruse GmbH
Christian Weise
Oberanger 6
D-80331 Munich 2
Tel: 089-260-4018
FAX: 089-260-3499
Over 1,000 species; Rarities Bought & Sold; All German Books on Minerals, etc. [List]; M-F, 9:30-6, Sat., 9:30-1
Publisher of **Lapis,** number one mineral magazine in Europe

Mineral Exquisit
Karin & Uli Burchard
Schlosstrasse 6
D-8050 Haindlfing-Freising
Tel: 08167-8567
Top-quality minerals, antique mineralogical instruments

Wilke Mineralien
Dr. H. J. Wilke & Else A. Wilke
Händelstr. 5
D-6116 Eppertshausen
Tel: 06071-31394
Exclusive Minerals, Classic Localities, Rare Species

The Mine with the Iron Door

Wendell E. Wilson ©1983



THE CRYSTAL FORMS OF CALCITE

Kenneth J. Brock
Department of Geosciences
Indiana University Northwest
3400 Broadway
Gary, Indiana 46408

Calcite is among the most widely collectible and the most morphologically varied of all mineral species. Appreciating its vast array of crystal forms, recognizing its form-families and understanding the mechanics of calcite crystal form notation are well within the capabilities of the geometrically minded collector.

INTRODUCTION

An often repeated story recounts that René Haüy's most important scientific contribution was facilitated by an accident involving calcite. According to the tale, Haüy accidently dropped a fine prismatic crystal only to have it break into several cleavage fragments. Puzzled that the rhombohedral cleavages were shaped so differently from the parent crystal, Haüy reportedly reduced the entire museum-quality specimen to dust in an unsuccessful effort to obtain a cleavage fragment of other than rhombohedral shape. This failure ultimately led Haüy to conclude that the external form of calcite crystals was created by stacking minute rhombohedra in various ways. From this event arose a fundamental tenet of crystallography: the Law of Rational Indices.

Haüy's fascination with calcite is not unique; virtually every student of minerals has marveled at the morphological variety displayed by calcite. One need only browse through the 2,544 calcite drawings contained in Victor Goldschmidt's *Atlas der Krystallformen,* volume 2, to obtain a sense of the seemingly infinite number of geometric patterns this mineral displays. Goldschmidt illustrates thin scalenohedron icicles, flat sand-dollar shaped rhombohedra, round golfball-like composites, and a montage of intermediate morphologies. Clearly the diversity of form and variation in habit of calcite is unmatched in the mineral world.

Nineteenth century crystallographers were equally intrigued by "calc spar," as it was formerly known; indeed, the search for new calcite forms constituted the "cutting edge" of crystallographic research during that era. That these investigators met with considerable success was documented in 1943, when Charles Palache surveyed the literature on calcite morphology and compiled a comprehensive list of calcite forms. Palache's final tabulation included a remarkable total of 630 different calcite forms.

Based on calcite's abundance and diverse morphology, "calc spar" would seem to constitute the ideal mineral for serious crystal collectors; however, collections specializing in calcite crystal forms are rare. Although everyone enjoys the beauty of a well-formed calcite crystal, many collectors have found calcite morphology difficult to interpret. In view of the complexity of calcite crystals, this confusion is not surprising. Difficulty in understanding calcite crystals is compounded by several factors, including: the technical nature of the subject; the hexagonal crystallographic axes (our minds seem more comfortable with three mutually perpendicular axes); and the current usage of three different types of crystallographic indices to describe calcite crystals.

This paper is intended to aid serious collectors who wish to understand the morphology of these crystals. Within the text, subtleties of calcite form indices are clarified and each form-type is illustrated with drawings. A few tips for identifying calcite forms are also included. The intent here is to generate a greater interest and a deeper appreciation for calcite crystals by rendering them more easily understood. In writing this paper I have drawn heavily upon the previously cited works of Goldschmidt and Palache.

CALCITE SYMMETRY

Calcite belongs to the rhombohedral division of the hexagonal crystal system (known as the trigonal crystal system by European crystallographers), and to crystal class $\bar{3}\,{}^{2}/m$. This symmetry is characterized by a single 3-fold inversion axis (indicated by the "$\bar{3}$" in the crystal class code) parallel to the *c* crystallographic axis, and three 2-fold axes each parallel to an *a* crystallographic axis (Fig. 1a). A mirror plane (m) is oriented perpendicular to each of the 2-fold axes (indicated as "${}^{2}/m$" in the class code).

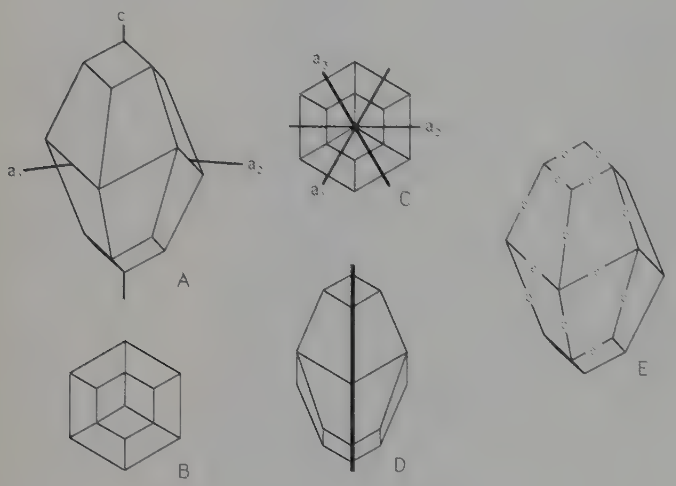


Figure 1. **The anatomy of calcite crystals. (a) Orthographic projection of a calcite crystal showing *c*, a_1, and a_2 crystallographic axes. A 3-fold inversion axis is parallel to *c*, and 2-fold axes are parallel to the *a* axes. (b) View down the *c* axis showing the 3-fold crystal symmetry. (c) View down the *c* axis with *a* axes illustrated. (d) View down the edge of one of the three mirror planes (thick line). (e) Crystal edge nomenclature. Polar edges are labeled p; these edges, extended if necessary, intersect the *c* axis. Equatorial edges, labeled e, never intersect the *c* axis.**

As illustrated in Figure 1b, the 3-fold symmetry is readily apparent on most well-formed calcite crystals when viewed down the *c* axis (a few crystals may show pseudo-hexagonal symmetry). Locating the 2-fold axes is a bit more challenging, but can usually be accomplished by finding a mirror plane; a 2-fold axis will be located perpendicular to each mirror plane (Figs. 1c and 1d).

Figure 1e illustrates the use of "equatorial" and "polar" edges as employed in the following discussion. Polar edges, labeled p in Figure 1e, are edges that, extended if necessary, intersect the *c* axis. Equatorial edges, labeled e, are edges that do not intersect the *c* axis. The latter were aptly described by Phillips (1963) as ". . . edges forming the zigzag 'waist-line' of the crystal."

CRYSTAL FORM NOTATIONS

A crystal form is a set of faces that are mutually identical in their relationship to crystal symmetry. That is, given one face, the crystal's symmetry "generates" all remaining faces in the set. On perfectly formed crystals all faces belonging to the same form are identical. Forms often occur in familiar geometric shapes such as the cube, the octahedron, or the prism; indeed forms are named for their distinctive geometric shapes. Crystal forms can be identified specifically by giving the Miller indices* of a face within the form, or more generally by geometric name (e.g., prism, rhombohedron or dipyramid).

The $\bar{3}\,{}^{2}/m$ symmetry limits the number of calcite forms to six types: pinacoid, hexagonal prism, dihexagonal prism, rhombohedron, hexagonal dipyramid, and scalenohedron. The pinacoid is unique and only two hexagonal prisms can occur on calcite; each of the other forms on the above list is actually a form-family (a set of forms). For example, a family of different dipyramids, each with different steepness of the faces, occurs on calcite crystals. In theory the number of possible dipyramids is limited only by the Law of Rational Indices. It is this multiplicity of dipyramids along with an even greater number of rhombohedra and scalenohedra that generate the myriad of forms observed on calcite crystals.

Clearly if a variety of hexagonal dipyramids occurs on calcite the name hexagonal dipyramid is inadequate to distinguish among them. Thus, in calcite the names hexagonal prism, dihexagonal prism, rhombohedron, hexagonal dipyramid, and scalenohedron are generally used to specify form-families and Miller indices must be employed to identify specific forms.

In view of the importance of indices for identifying calcite forms it is worthwhile to review their usage. This is especially important because three different sets of crystallographic indices are used to describe calcite forms.

Indices are a set of integers that define the orientation of a crystal face relative to the crystallographic axes; $(10\bar{1}1)$ constitutes a typical example. Each index corresponds to a specific axis, dictating that the number of integers within a symbol exactly equals the number of crystallographic axes. Thus, the above example contains four axes. In general terms indices are traditionally written (*hkl*), where *h*, *k* and *l* represent positive or negative integers or zero. Forms are identified by recording the indices of a face within the form; any face will suffice, but the face with positive values for *h*, *k* and *l* is normally chosen. Index notations are distinguished by enclosing the form indices in braces {111}; braces can also signify a cleavage plane. Indices enclosed in parentheses (111) refer to a specific face, a general plane, or a twinning composition plane. Indices in square brackets [111] refer to axes rather than planes.

For calcite the most widely used index system in North America is the four-integer system known as Miller indices. An entirely different three-index system, based on rhombohedral axes, is used by some crystallographers, especially in Europe. And finally, a third system of indices is based on X-ray diffraction studies of calcite. X-ray indices are of the four-digit Miller type, but differ in the value of the fourth index.

Miller Indices

The standard crystallographic axis system used for calcite consists of four axes; accordingly, the indices consist of four numbers {*hkil*}, known as the Miller indices. Historically these four numbers were referred to as Miller-Bravais (or Bravais-Miller) indices, but most contemporary textbook refer to them simply as Miller indices.

Geometry of the hexagonal crystallographic axes dictates that the first three Miller indices are not independent; in fact the requirement $h + k = -i$ must be met for every crystal face. The value of *i* is

---

*Miller indexing is a shorthand notation for the way a plane intersects with crystallographic axes. For example, if a plane intersects the vertical axis at a point 2 units from the center, and the other two axes at 1 unit from the center, the number 112 is then taken as reciprocals 1/1 1/1 1/2 and the fractions cleared to give the Miller indices of (221). (This is read as "two, two, one.") By tradition, the last of the three numbers always refers to the vertical, or "c," axis. An intercept on a negative side of an axis yields a negative index, indicated by a bar on top, e.g. $(2\bar{2}1)$ (read as "two, bar-two, one").

therefore redundant and can be omitted from the symbol. Authors often write the symbol $\{hk.l\}$ or $\{hk{*}l\}$ to remind the readers they are dealing with a four-axis, rather than three-axis, system and occasionally the *i* index is entirely omitted. The abbreviated form $\{hk.l\}$, which is far less cumbersome than the complete symbol, is employed throughout this paper. Using this abbreviated notation the $\{10\bar{1}1\}$ indices of the calcite unit rhombohedron (parallel to the cleavage rhomb) shorten to {10.1}.

Rhombohedral Indices

It is possible to index trigonal crystals using only three axes; unfortunately, these axes, known as rhombohedral axes, are neither mutually perpendicular not located parallel to symmetry axes. In calcite the rhombohedral axes are oriented parallel to the three polar edges of the cleavage rhombohedron. This arrangement results in indices entirely defined by three digits. Readers of the older literature should exercise caution; 19th century mineralogists often referred to rhombohedral indices as Miller indices and to the above four-digit system as Miller-Bravais, or Bravais, indices. Rhombohedral indices are rarely encountered in North American literature; consequently they are probably most conveniently dealt with by converting them to Miller indices as described here in the Appendix. Readers interested in more information about rhombohedral indices are urged to consult any European crystallography textbook; Phillips (1963) contains an excellent summary.

X-ray Indices

Much of our knowledge about calcite morphology was determined in the 19th century by goniometry (the physical measurement of the angles between crystal faces). In systematically indexing calcite crystals crystallographers implicitly assumed that the cleavage rhomb had indices {10.1}. That is, identical minute blocks of atoms, known as unit cells, were stacked one to one, in stair-step fashion, along the a_1 and *c* axes to create the (10.1) face. Morphological crystallographers calculated that the relative dimensions of the unit cell's edges had to be 1.0 and .8543 respectively along the a_1 and *c* axes. This ratio was required to produce the observed interfacial angle of 44.63° between the (10.1) and (00.1) faces.

Subsequent X-ray diffraction studies revealed that the calcite unit cell is actually four-times greater along the *c* axis than assumed by the morphologists. Consequently, the relative *a* and *c* dimensions of the calcite unit cell are in the proportion 1.0 to 3.4199 (X-ray studies give the absolute unit cell dimensions of a = 4.9896 and c = 17.061Å). These taller unit cells must be stacked in the ratio of 4:1 along the a_1 and *c* axes to produce the 44.63° angle between the (10.1) and (00.1) faces. Therefore, the *true* indices of the cleavage rhomb, based on X-ray studies, are {10.4} (i.e., *l* for X-ray indices is four-times *l* for morphological indices).

Although X-ray diffraction has shown that indices based on calcite morphology are thus incorrect, morphological indices are still used to describe calcite crystals. It is worth noting, however, that the use of morphological indices produces no error in describing external morphology; they are incorrect only in their implications about calcite's internal structure. Indeed, collectors are likely to encounter X-ray indices only in articles dealing with the internal structure of calcite. X-ray indices can be converted to morphological indices by simply dividing the fourth index by four and clearing any resulting fractions. Thus, the X-ray indices {21.4} transform into the morphological indices {21.1} and {01.1} into {04.1}.

Examples of Miller, rhombohedral and X-ray indices for common forms are given in Table 1.

Form Symbols

Nineteenth century authors found it cumbersome to identify calcite forms with Miller indices; instead they labeled illustrated forms with single characters. Thus, a tradition was established for identifying forms by Greek, Roman and German letters (often followed by a period, a colon, or three vertical dots), and occasionally by even more arcane symbols. Every author tended to generate his own set of symbols resulting in a multitude of different symbols for each form. For example, the symbols: g, t, 4, d, δ, δ., and e have all been used to represent the common negative rhombohedron {01.2}. Consequently, a uniform system of symbol usage does not exist and readers must pay close attention to the symbol definitions employed by each author. The symbols used in this paper generally follow those of Palache (1943); and are in some cases different from the form-symbols used in current mineralogy textbooks.

***Table 1.* A comparison of crystallographic indices used for calcite.**

Form	Miller (complete)	Miller (abbreviated)	X-ray (abbreviated)	Rhombohedral
Pinacoid	{0001}	{00.1}	{00.1}	{111}
Prism hexagonal)	$\{10\bar{1}0\}$	{10.0}	{10.0}	$\{2\bar{1}\bar{1}\}$
Rhomdohedra	$\{10\bar{1}1\}$	{10.1}	{10.4}	{100}
	$\{01\bar{1}2\}$	{01.2}	{01.8}	{110}
	$\{02\bar{2}1\}$	{02.1}	{01.2}	$\{11\bar{1}\}$
Scalenohedron	$\{21\bar{3}1\}$	{21.1}	{21.4}	$\{20\bar{1}\}$

CALCITE FORMS

As previously noted, numerous forms within each family combine to produce the incredible number of forms observed on calcite crystals. The magnitude of this number was clearly demonstrated in 1943 when Palache tabulated 328 confirmed, plus an additional 302 probable or uncertain calcite forms. The distribution of Palache's confirmed forms among the form-families is shown in Table 2.

***Table 2.* Distribution of the 328 confirmed calcite forms among the form families (from Palache, 1943).**

Form Family	Indices	Number
Pinacoid	{00.1}	*1
Prisms	{10.0} & {11.0}	*2
Dihexagonal Prisms	$\{hk.0\}\ h \neq k$	5
Dipyramids	$\{hh.l\}$	12
Rhomdohedra		
Positive	$\{h0.l\}$	28
Negative	$\{0k.l\}$	56
Scalenohedra		
Positive	$\{hk.l\}\ h>k$	128
Negative	$\{hk.l\}\ h<k$	96
		328

*These are the only forms possible.

The particular form-family to which a specific calcite form belongs can be easily identified by its Miller indices. The pinacoid for example is simply {00.1}. Prisms always have "0" for the "*l*" index (e.g., {10.0} or {21.0}). Rhombohedra have either $h = 0$ or $k = 0$; examples include {10.1}, {02.1} and {04.5}. Dipyramids have no indices = 0, and the value of *h* equals the value of *k*; {22.1}, {11.3} and {88.3} are dipyramids. And finally scalenohedra have no indices = 0 with $h \neq k$; examples include {21.1} and {28.3}.

Miller indices also provide a simple means for distinguishing positive and negative forms, which are extremely common on calcite crystals. The positive position is defined by the cleavage rhombohedron. Positive rhombohedra have indices of the form $\{h0.l\}$ with "0" in the second position; whereas, indices of negative rhombohedra have "0" in the first position, $\{0k.l\}$. The forms {10.1} and {01.1}

Calcite, Bigrigg mine, Egremont, Cumberland, England; 9 cm; Canfield Collection, Smithsonian Institution

provide simple examples of positive and negative calcite rhombohedra. Positive scalenohedra have $h > k$, and negative scalenohedra have $h < k$. Thus, {21.1}, {32.1} and {41.3} are positive, whereas, {12.1}, {23.1} and {14.3} are negative.

Although faces on positive and negative calcite forms may *appear* identical to the eye in hand specimens, the atomic arrangement beneath the faces of each form is slightly different. As a result, positive and negative forms with corresponding indices do not occur with equal frequency. The positive unit rhombohedron {10.1}, for example, is very common on calcite crystals, but its corresponding negative {01.1} is rare. Morphological crystallographers recognized the contrasting importance of positive and negative forms on calcite and formulated the Rhombohedral Rule to describe it. This empirical rule proposes that the Miller indices of important calcite forms will adhere to the equation $2h + k + l = 3n$. This equation states that the indices of common forms, when combined as prescribed by the Rhombohedral Rule, will sum to a number evenly divisible by three. A remarkable percentage of the common calcite forms do indeed satisfy the Rhombohedral Rule. Note that {10.1} adheres to the Rhombohedral Rule whereas {01.1} does not.

An intriguing aspect of calcite crystals is their propensity to develop faces with unusually large Miller indices. A fundamental tenet of crystallography states that indices of crystal faces are typically small whole numbers, usually less than five. In contrast, numerous calcite forms have indices far above this "limiting" value. Palache, for example, confirmed the existence of a positive scalenohedron with indices {37,19.21} and faces with even larger indices have been reported. Note that multiple digit indices are separated by a comma to avoid ambiguity.

Although it is generally impossible to positively identify specific calcite forms without measuring interfacial angles, on most crystals it is not difficult to assign forms to their appropriate form-family by visual inspection. That is, one can recognize that a form is a positive scalenohedron, without being able to actually determine indices of the form. Interfacial angles were traditionally measured with reflecting goniometers; however, on large, well-formed crystals a simple contact goniometer often provides sufficient accuracy to identify forms. Additionally, in some cases the "tricks" described in the following discussion will allow the determination of specific forms by visual inspection.

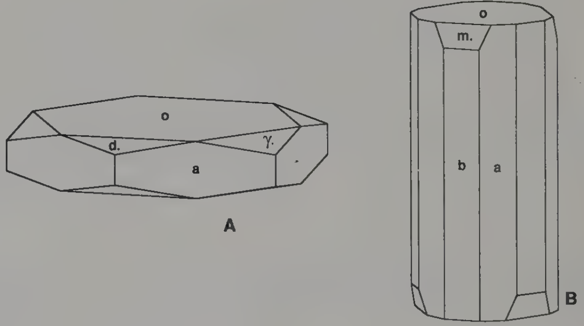


Figure 2. **Calcite crystals showing the pinacoid o{00.1}. (a) Tabular crystal with prism a{11.0}; positive rhombohedron d.{10.4}; and negative rhombohedron γ.{02.5} (Goldschmidt, 1913, Figure 113, from the Harz Mountains, Germany). (b) Prismatic crystal with prisms a{11.0} and b{10.0}; and positive rhombohedron m.{40.1} (Goldschmidt, 1913, Figure 825, from Andreasburg, Germany).**

Pinacoid {00.1}

Among calcite forms the pinacoid is unique, as it consists of just two faces, both oriented parallel to each other and perpendicular to

Calcite with duftite inclusions, from Tsumeb, Namibia; 3.2-cm crystals; Miller collection

the *c* axis. All other calcite forms contain either six or twelve faces. The pinacoid is an "open" form, in that it alone cannot entirely enclose space; thus the pinacoid must accompany some other form on calcite crystals. The pinacoid is among the most common calcite forms. Crystals with well-developed pinacoid faces are shown in Figure 2.

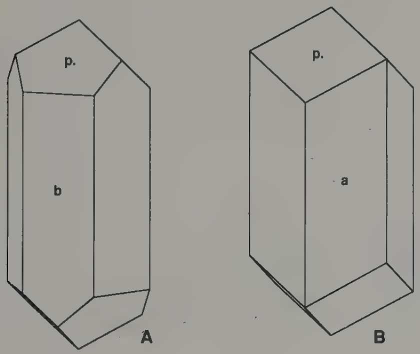


Figure 3. **The hexagonal prisms b{10.0} and a{11.0} and the unit rhombohedron p.{10.1}. (a) b{10.0} and p.{10.1} (Goldschmidt 1913, Figure 60). (b) a{11.0} and p.{10.1} (Goldschmidt 1913, Figure 58). Both crystals are from Dauphiné, France.**

Hexagonal Prisms {10.0} and {11.0}

Two different hexagonal prisms occur on calcite; both are quite common. Indeed, {10.0} is without doubt the most widespread and extensively developed single form on calcite crystals. On crystals containing the rhombohedron, the two prisms can readily be separated by the manner in which they cut the rhombohedron face. The {10.0} prism intersects the lower edge of a rhombohedron face forming a single horizontal line as shown in Figure 3a, whereas {11.0} truncates the rhombohedron face along two lines, each of which is parallel to an equatorial edge of the rhombohedron face (see Fig. 3b).

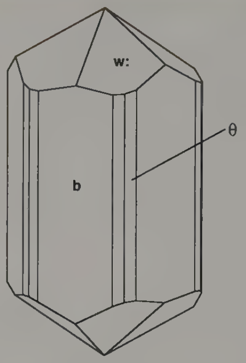


Figure 4. **The dihexagonal prism θ{21.0}. Also present: the hexagonal prism b{10.0} and positive scalenohedron w:{31.5}. (Goldschmidt 1913, Figure 723; from Cumberland, England).**

Dihexagonal Prisms {*hk*.0}

In contrast to the very common hexagonal prisms, the twelve-faced dihexagonal prism is quite rare. Palache included only five dihexagonal prisms on his list of confirmed calcite forms: {53.0), {21.0}, {31.0}, {71.0} and {10,1.0}. Of these only {31.0} was considered common. Additionally, when present, this form typically occupies only a small fraction of the total crystal area (see Figs. 4 and 7b).

Hexagonal Dipyramids {*hh.l*}

Among the twelve confirmed dipyramids {88.3} is most common, {11.3} and {22.3} are reasonably common, and the others are rare. The $h = k$ characteristic gives dipyramids symmetry with respect to a horizontal plane (upper faces are mirror images of lower faces). On well-developed dipyramids this symmetry produces horizontal, equatorial edges (see Fig. 5). The equatorial edges of rhombohedra and scalenohedra are not horizontal; consequently, this feature aids in detecting the presence of dipyramids.

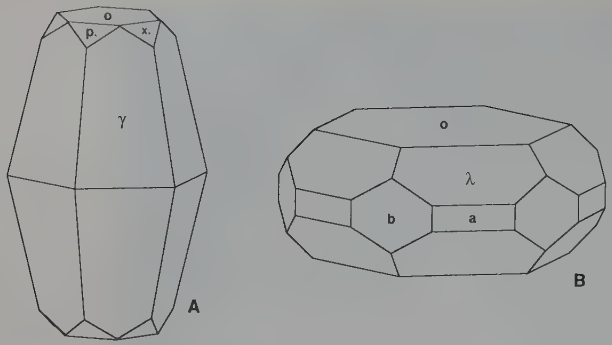


Figure 5. **Hexagonal dipyramids γ{88.3} and λ{22.3}. (a) γ{88.3} with rhombohedra p.{10.1}, x.{01.1}, and o{00.1} (Goldschmidt, 1913, Figure 1666, from Belgium). (b) λ{22.3} with pinacoid o{00.1} and the prisms b{10.0} and a{11.0} (Goldschmidt, 1913, Figure 1082, from St. Andreasburg, Germany).**

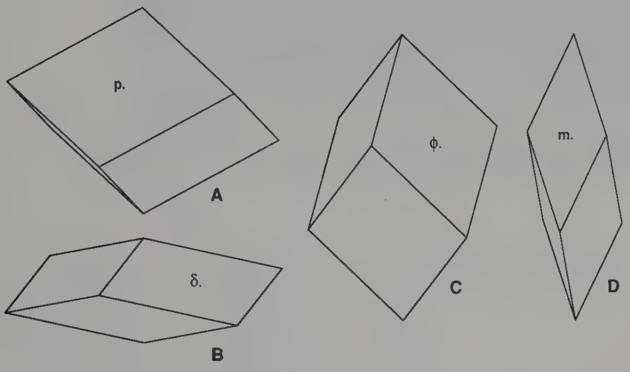


Figure 6. **The common rhombohedra, each shown alone. (a) The unit rhombohedron p.{10.1} (Goldschmidt, 1913, Figure 1279, from the Ural Mountains, Russia). (b) The flat negative rhombohedron δ{01.2} (Goldschmidt, 1913, Figure 77, from many locations). (c) The negative rhombohedron φ{02.1} (Goldschmidt, 1913, Figure 205, from Derbyshire, England). (d) The steep positive rhombohedron m.{40.1} (Goldschmidt, 1913, Figure 6, from Lockport, New York).**

Rhombohedra {*h*0.*l*} and {0*k*.*l*}

Rhombohedra are among the most frequently observed calcite forms and of course the perfect calcite cleavage splits along planes parallel to the unit rhombohedron {10.1}. Among the 84 confirmed calcite rhombohedra, four are especially common: {01.2}, {02.1}, {10.1} and {40.1} (in order of decreasing importance). All four are illustrated in Figure 6. It turns out that negative rhombohedra exceed the positive varieties by a ratio of two to one (see Table 2).

Steepness of the faces and the angle between equatorial edges differ for each rhombohedron. Miller indices also provide information about the shape of a rhombohedron. Rhombohedra with *h* or $k > l$ have steep faces (Figs. 6c and 6d) and those with *h* or $k < l$ are flat (Fig. 6b).

Of the 28 positive rhombohedra confirmed by Palache, the flattest is {10.4} and the steepest is {28,0.1}; the former is illustrated in Figure 2. Though unconfirmed, Palache deemed the report of the extremely flat form {10.7} as probably correct. The flattest negative rhombohedron is {01.5} and the steepest {0,28.1}; both are shown in Figure 7. Additionally, a crystal showing the even steeper negative rhombohedron {0,36.1} was found in Norberg, Sweden; Palache also believed that this report was probably accurate.

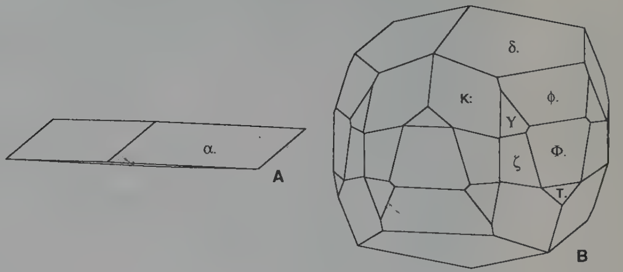


Figure 7. **Extreme examples of negative rhombohedra. (a) The flattest confirmed form α.{01.5} shown alone (Goldschmidt, 1913, Figure 997, from Offenbanya, Romania). (b) The steepest negative form T.{0,28.1}, with the negative rhombohedra δ.{01.2}, φ.{02.1} and Φ.{0,14.1} plus the scalenohedra K:{21.1}, and Y{12,32.13} and the dihexagonal prism ζ{31.0} (Goldschmidt, 1913, Figure 2495, from Rondout, New York).**

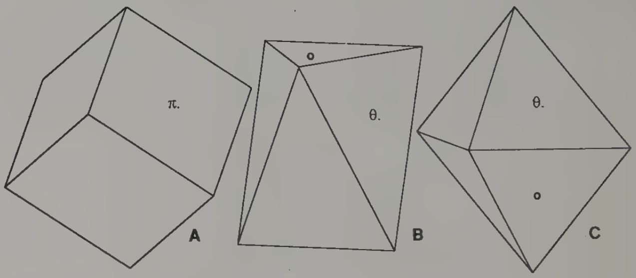


Figure 8. **Pseudo-cubic calcite crystals. (a) The negative rhombohedron π.{07.5} has faces within one degree of a perfect cube (Goldschmidt, 1913, Figure 2349, from Jersey City, New Jersey). (b) Pseudo-octahedron: combined θ.{04.1} and o{00.1} in standard orientation (Schaller, 1942), from the Magdalena district, New Mexico. (c) Crystal (b) rotated to enhance the octahedral appearance.**

Calcite rhombohedra can also occur in habits that simulate cubic symmetry. Rhombohedron faces with indices {70.5} or {07.5} have interfacial angles near 89.1° and look very much like cubes (the true cube might be thought of as a rhombohedron in which the interfacial angle is exactly 90°). Figure 8a shows a pseudo-cubic calcite crystal. Schaller (1942) described octahedral-appearing calcite crystals from the Magdalena district, New Mexico. Upon examination, these interesting crystals proved to consist of a combination of the negative rhombohedron {04.1} and the pinacoid {00.1} (see Figs. 8b and 8c).

Scalenohedra {*hk*.*l*}

More varieties of scalenohedra occur than any other calcite form; indeed Table 2 shows that a full 68% of all confirmed forms are scalenohedra. The name scalenohedra is derived from the twelve

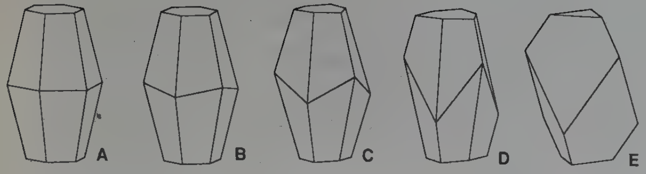


***Figure 9.* Changes in scalenohedra shape as the *h/k* ratio varies from 1 to ∞, while *l* remains constant. Note that the greater the difference between *h* and *k*, the more acute the angle between equatorial edges. (a) The dipyramid {88.3}; (b) {87.3}; (c) {85.3}; (d) {82.3}; and (e) rhombohedron {80.3}. All drawings are of hypothetical crystals modified by {00.1}.**

scalene triangles that bound this form when it occurs alone. Proportions of the bounding scalene triangles, and the resulting appearance of the scalenohedron, vary with Miller indices. The steepness of scalenohedron faces varies with *h* and *l* as described for the rhombohedron. Variations in *h* and *k*, with *l* fixed, produce a continuum of shapes ranging from the dipyramid (which may be thought of as a special scalenohedron with $h = k$) to the rhombohedron. Figure 9 illustrates systematic changes in scalenohedra between the dipyramid {88.3} and rhombohedron {80.3}. Note that the angle between equatorial edges becomes progressively more acute from the dipyramid where $h \div k = 1$ to the rhombohedron in which $h \div k = \infty$.

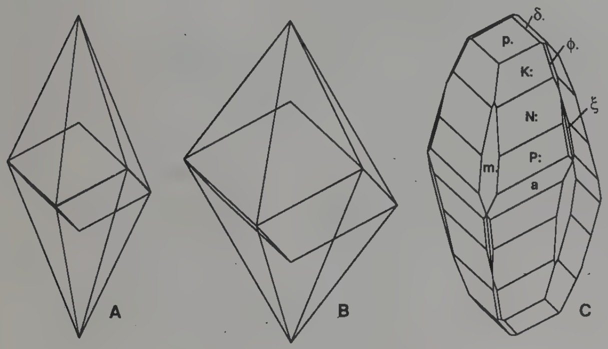


***Figure 10.* Scalenohedra with {10.1} as the base-rhomb. (a) Hypothetical crystal showing {21.1} and a {10.1} phantom. (b) Hypothetical crystal showing {31.2} and a {10.1} phantom. Note that the scalenohedra in both (a) and (b) share equatorial edges with their base-rhombs. (c) A real crystal showing three scalenohedra with {10.1} as their base-rhomb: K:{21.1}, N:{53.2} and P:{32.1}. Observe that mutual edges between K:, N:, and P: are all parallel to edges of the base-rhomb p. and the prism a. Also present on (c) are: m.{40.1}, ϕ.{02.1}, δ.{01.2} and ζ{13.1} (Goldschmidt, 1913, Figure 2102, from Renfrewshire, England).**

By far the most common scalenohedron is the positive form {21.1}, shown in Figure 10a. This scalenohedron, often referred to as “dog-tooth spar,” is second only to the prism {10.0} in worldwide abundance. Interestingly, {12.1} the negative counterpart of {21.1} is rare, usually occurring only as minor faces on crystals dominated by other forms. Other common positive scalenohedra include {32.1}, {54.1}, {74.3}, {31.5} and {21.4}; several of these are illustrated in Figure 11. The steepest confirmed positive scalenohedron is {21,19.2} and the flattest is {43.10}; see Figure 12.

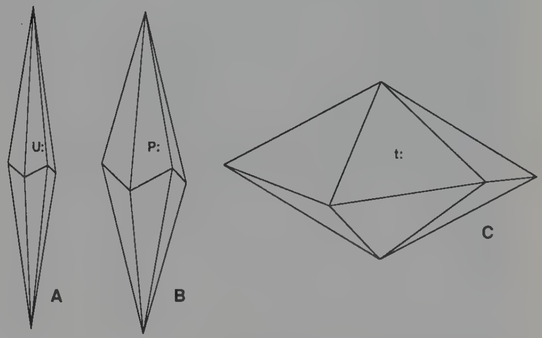


***Figure 11.* The most common positive scalenohedra (excluding {21.1}), each shown alone. (a) The steep scalenohedron U:{54.1} (Goldschmidt, 1913, Figure 1762, from Framont, Vosges, France). (b) The intermediate form P:{32.1} (Goldschmidt, 1913, Figure 552, from Hungary). (c) The flat form t:{21.4} (Goldschmidt, 1913, Figure 348, from Derbyshire, England).**

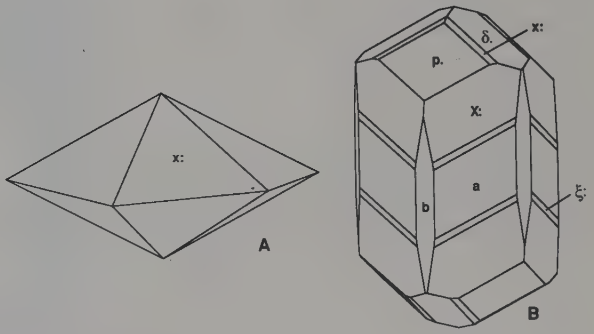
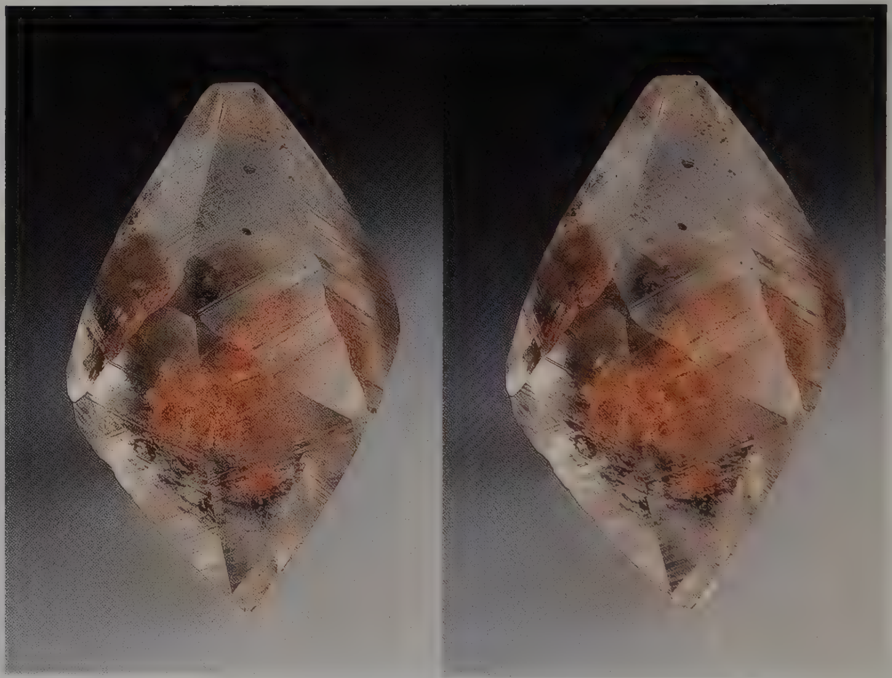


***Figure 12.* Extreme examples of positive scalenohedra. (a) The flattest confirmed positive scalenohedron x:{43.10} shown alone (Goldschmidt, 1913, Figure 341, from Derbyshire, England). (b) An amazing crystal that shows both the flattest x:{43.10} and the steepest ζ{21,19.2} confirmed positive scalenohedra. Also present are the positive scalenohedron X:{76.1}; the positive rhombohedron p.{10.1}; the prisms a{11.0} and b{10.0}; and the negative rhombohedron δ{01.2} (Goldschmidt, 1913, Figure 1704, from Arendal, Norway).**

The variety of negative scalenohedra is considerably smaller than that of the positive types. The most common negative scalenohedron is {13.1}, followed by {28.3} and {48.5}; these forms are shown in Figure 13. Among confirmed negative scalenohedra, the flattest is {16.13} and the steepest is {12,20.1}.

Calcite crystals to 6.1 cm Linwood mine, Iowa; Paul Garvin collection



Calcite with copper inclusions, 3.7 cm, from the Quincy mine, Michigan. Seaman Mineralogical Museum collection. (stereopair)

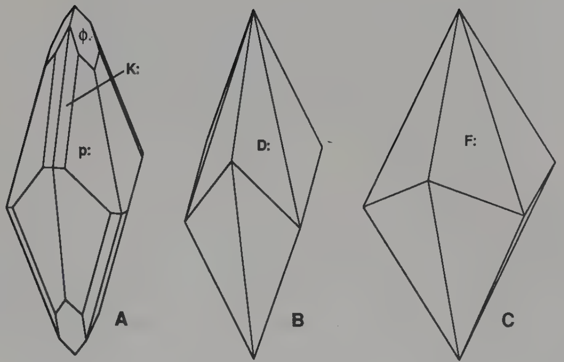


Figure 13. **Common negative scalenohedra. (a) p:{13.1} with the common positive scalenohedron K:{211} and negative rhombohedron ϕ.{02.1} (Goldschmidt, 1913, Figure 727, from St. Julien du Sault). (b) D:{28.3} shown alone (Goldschmidt, 1913, Figure 632, from Cumberland, England).(c) F:{48.5} shown alone (Goldschmidt, 1913, Figure 611, from Derbyshire, England).**

Calcite crystal group, 5 cm, from Chihuahua, Mexico; Zweibel collection

Oil painting by Wendell Wilson; Victor Yount collection.

Scalenohedron geometry is generally complex, and crystals bearing this form may be quite difficult to orient, especially when several forms appear in combination. Accordingly, a geometric aid termed the base-rhombohedron or simply "base-rhomb" proves helpful in many cases. This concept, introduced by Whitlock in 1910, who termed it the "rhombohedron of the middle edges," works as follows: for every scalenohedron there exists a base-rhomb that possesses precisely the same angle between equatorial edges as the parent scalenohedron. Thus, a base-rhomb phantom would share equatorial edges with its host scalenohedron as shown in Figures 10a and 10b.

Readers should keep in mind that the base-rhomb concept is artificial, because every scalenohedron is entirely independent of all rhombohedra, including its base-rhomb. In fact, base-rhomb faces need not appear at all; however, when the base-rhomb is present the shared scalenohedron/base-rhomb edges exactly parallel the equatorial edges of the parent scalenohedron. This parallelism provides a distinctive geometric pattern easily recognized on calcite crystals. In addition, the shared scalenohedron/base-rhomb edge is also parallel to the common edge between the scalenohedron and the prism {11.0}, see Figure 10c.

Moreover, every base-rhomb forms the foundation for an entire set of scalenohedra, each with different face steepness; thus, scalenohedra could actually be classified according to the indices of their base-rhombs. Figure 10c shows three scalenohedra each with {10.1} as the base-rhomb; note that in each case scalenohedron edges are parallel to the edges of both the {10.1} rhombohedron and the {11.0} prism.

The utility of the base-rhomb approach arises from the fact that most scalenohedra have common rhombohedra as their base-rhombs. Accordingly, many scalenohedra actually do appear in nature with their base-rhombs. Consider, for example, scalenohedra with {10.1} as the base-rhomb. Geometric constraints require that scalenohedra must have $h = k + l$ in order to share equatorial edges with {10.1} (e.g., {21.1}, {31.2} and {53.2}). Remarkably, 49 different scalenohedra with {10.1} as the base-rhomb have been reported; these range from the relatively flat {11,1.10} to the stiletto-like {21,19.2}. Nineteenth century crystallographers recognized that a large number of positive scalenohedra possess {10.1} as their base-rhomb; however, they expressed this point in more formal crystallographic terms by proclaiming the importance of the crystallographic zone defined by the combination of (11.0) and (10.1).

The second most important base-rhomb for positive scalenohedra is {40.1}. For negative scalenohedra the most common base-rhombs are {01.1}, {01.2}, {02.1}, {05.4} and {08.7}, though none of these serve more than ten confirmed scalenohedra. The Miller indices of any scalenohedron's base-rhomb can be mathematically determined from the scalenohedron's indices (see Appendix).

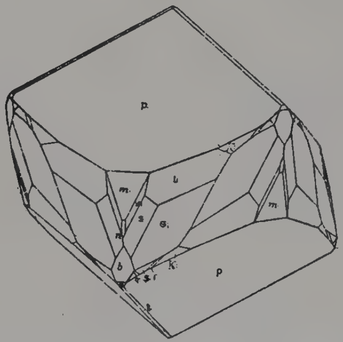


Figure 14. **Calcite crystal showing a combination of 14 different crystal forms (Goldschmidt, 1913, Figure 2410, from Rossie, New York).**

Combinations of Forms

Most calcite crystals contain several forms; crystals displaying more than a dozen forms have been reported. Goldschmidt's Figure 2410 (from Rossie, New York), which is comprised of 14 forms, provides a grand example of form-combination; if fully developed on all sides this crystal would possess 132 faces (Fig. 14). The identification of forms, or even form-families, on crystals of this complexity can be extremely difficult. Fortunately, most crystals show incipient cleavages and/or display one or more of the common calcite forms. The identification of a cleavage plane or a form allows the crystal to be properly oriented, thereby greatly simplifying the task of assigning the remaining faces to their appropriate form-families.

Thus the starting point in calcite form identification, is to locate the cleavage planes (which determine the positive position) and then search for one or more of the seven most common forms. These seven forms include: the pinacoid {00.1}; the two hexagonal prisms {10.0} and {11.0}; the positive rhombohedron {10.1}; the negative rhombohedra {01.2} and {02.1}; and the scalenohedron {21.1}. Among these the rhombohedron {10.1} is perhaps easiest to identify as its faces parallel the cleavage planes.

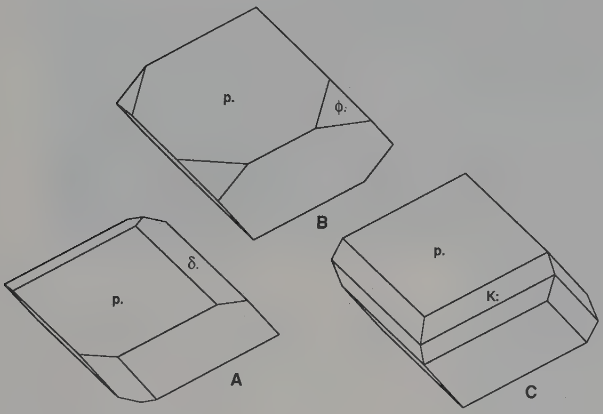


Figure 15. **Very common calcite forms combined with the positive rhombohedron p.{10.1}: (a) with minor δ.{01.2}, the latter bevels the {10.1} faces (Goldschmidt, 1913, Figure 72, from Derbyshire, England); (b) with minor ϕ.{02.1} (Goldschmidt, 1913, Figure 201, from Couson, France); and (c) with minor K:{21.1}; note that {10.1} is the base rhomb for {21.1} (Goldschmidt, 1913, Figure 406, from many locations).**

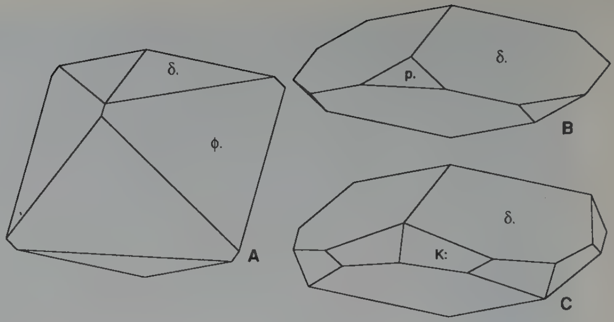


Figure 16. **Very common calcite forms combined with the flat negative rhombohedron δ.{01.2}: (a) with ϕ.{02.1} (Goldschmidt, 1913, Figure 2282, from Torocko, Hungary); (b) with minor p.{10.1} (Goldschmidt, 1913, Figure 75, from Derbyshire, England); and (c) with minor K:{21.1} (Goldschmidt, 1913, Figure 441, from Derbyshire, England).**

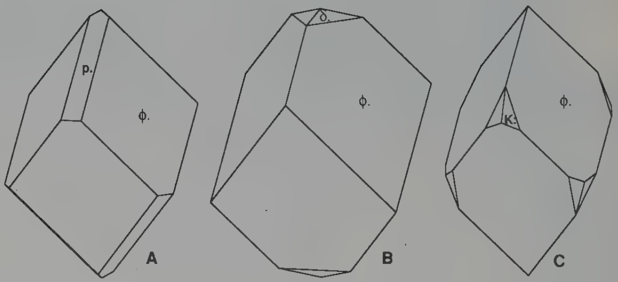


Figure 17. **Very common calcite forms combined with the steep negative rhombohedron ϕ.{02.1}: (a) with p.{10.1}, which bevels the {02.1} faces (Goldschmidt, 1913, Figure 10, from Couson, France); (b) with minor δ.{01.2} (Goldschmidt, 1913, Figure 212, from Couson, France); and (c) with minor K:{21.1} (Goldschmidt, 1913, Figure 235, from Bath, England).**

The morphology of many calcite crystals is dominated by one or more of these common forms; a few examples of their combinations are shown in Figures 15, 16, 17 and 18. The pinacoid and hexagonal prisms are excluded from the drawings because their faces occupy positions that usually allow detection with a cursory examination.

Figure 15 shows the minor development of {01.2}, {02.1} and {21.1} in combination with the positive rhombohedron {10.1}. In Figure 15a the (01.2) indices of the beveling face δ. can be calculated by adding indices of the host rhombohedron faces (10.1) and $(\bar{1}1.1)$ as described in the Appendix. Note the distinctive pattern of parallel edges shown in Figure 15c; this results from the fact that {10.1} is the base-rhomb of {21.1}.

Figure 16 shows {10.1}, {02.1} and {21.1} combined with {01.2} as the dominant form. Of all the drawings contained in Goldschmidt's compendium, Figure 16a illustrates the crystal with greatest development of {01.2} in combination with {02.1}. Oddly, combinations of these two forms in which {01.2} is dominant have not been published, though R. Peter Richards (personal communication) reports this habit from Pleasant Ridge, Indiana. Figures 16b and 16c illustrate crystals commonly referred to as the "nailhead" habit.

The steep negative rhombohedron {02.1} is shown as the dominant form in Figure 17. Note that in Figure 17a the positive rhombohedron {10.1} perfectly bevels the edge between {02.1} faces.

The dominant form in Figure 18 is the positive scalenohedron {21.1} (dogtooth spar), shown with the minor development of {10.1}, {01.2} and {02.1}. Note once again that p. is the base rhombohedron in Figure 18a and that ϕ. is the beveling face in Figure 18c.

One final relationship might prove helpful for a few form combinations. When two forms with identical *h:k* ratios share an edge, the joint edge will be horizontal. Note, for example, that the {10.1}/{10.0} edge in Figure 3a is in fact horizontal. Further, consider {21.1}, the most common scalenohedron; if {21.1} faces on a crystal show a horizontal edge, the adjoining form must also have a two-to-one *h:k* ratio. An example is shown in Figure 19.

Computer Drawings

The advent of personal computer software that can generate accurate crystal drawings offers an excellent method for confirming form iden-

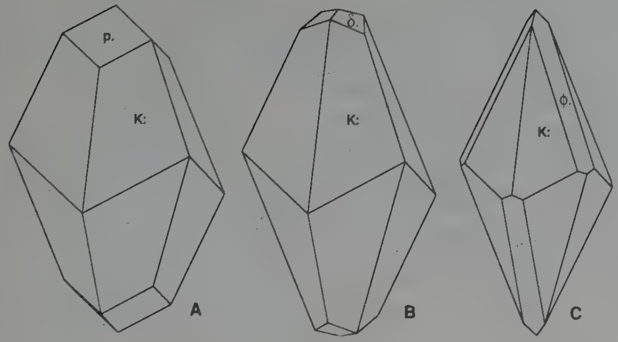


***Figure 18.* Very common calcite forms combined with the positive scalenohedron K:{21.1}: (a) with minor p.{10.1}, which is the base-rhomb for {21.1} (Goldschmidt, 1913, Figure 12); (b) with minor δ.{01.2} (Goldschmidt, 1913, Figure 421); and (c) with minor φ.{02.1}; note that {02.1} bevels one set of polar edges on {21.1} (Goldschmidt, 1913, Figure 472). All are from Derbyshire, England.**

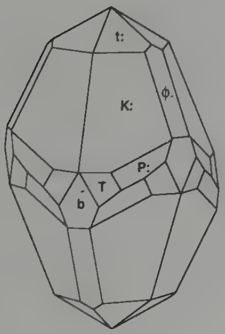


***Figure 19.* Crystal illustrating that edges between scalenohedra with identical *h:k* ratios are horizontal. Note that both the K:{21.1}–t:{21.4} edge and the K:{21.1}–T{42.1} edge are horizontal. In each case the *h:k* ratio is 2:1. Other forms present include: the prism b{10.0}, the steep negative rhombohedron φ.{02.1}, and the positive scalenohedron P:{32.1}. (Goldschmidt, 1913, Figure 1704, from Derbyshire, England).**

tifications on calcite crystals. Although computer drawings cannot positively identify forms (the difference between {21.1} and {19,9.9} for example, would not be apparent), they provide a powerful (and rapid) method for checking to see if proposed indices create a crystal similar to the one under investigation. These programs are also capable of calculating interfacial angles, allowing collectors to compare theoretical values with angles measured using a contact goniometer.

All drawings in this article except Figure 14 were made with the Macintosh version of SHAPE; a computer program written for the IBM-PC and Apple II by Eric Dowty and adapted for the Macintosh by R. Peter Richards. This software provides an extremely powerful tool and is highly recommended for use in the study of crystal morphology. In my experience, an individual familiar with the common calcite forms (as previously described) can completely index most calcite crystals using SHAPE and a simple contact goniometer.

ACKNOWLEDGMENTS

Groundwork for this paper was conducted while I was on sabbatical leave from Indiana University Northwest; I wish to express gratitude to the University for providing this opportunity. Special thanks go to Jean Segal who generously made available her personal copy of Whitlock's memoir on long-term loan. I am especially indebted to Vaughn E. Fitzgerald and R. Peter Richards, both of whom critically reviewed early drafts of the manuscript; their suggestions greatly improved the paper.

REFERENCES

GOLDSCHMIDT, V. (1913) *Atlas der Krystallformen,* vol. 2, Carl Winters Universitätsbuchhandlung, Heidelberg. Reprinted by the Rochester Academy of Science, 1986.

PALACHE, C. (1943) *Calcite, an Angle Table and Critical List.* Harvard University Department of Mineralogy and Petrology publication number 259.

PHILLIPS, F. C. (1963) *An Introduction to Crystallography.* Third edition, John Wiley & Sons, New York, N.Y., 340 p.

SCHALLER, W. T. (1942) Calcitkrystalle mit neuen Formen. *Zeitschrift für Krystallographie,* **44**, 321–331.

WHITLOCK, H. P. (1910) Calcites of New York. *N.Y. State Museum Memoir* **13**, 190 p.

Appendix

RHOMBOHEDRAL INDICES

The three-digit rhombohedral indices $\{h_r k_r l_r\}$ can be converted to Miller indices by the following relationships:

$$h = h_r - k_r$$
$$k = k_r - l_r$$
$$l = h_r + k_r + l_r$$

where rhombohedral indices are indicated by the "r" subscript. Sample calculation: convert the rhombohedral indices {771} to Miller indices.

The h Miller index is given by: $h = 7 - 7 = 0$
The k Miller index is given by: $k = 7 - 1 = 6$
The l Miller index is given by: $l = 7 + 7 + 1 = 15$

Giving abbreviated Miller indices of {06.15} which reduce to {02.5}. Miller indices can also be converted into rhombohedral indices by the equations:

$$h_r = 2h/3 + k/3 + l/3$$
$$k_r = -h/3 + k/3 + l/3$$
$$l_r = -h/3 - k/3 + l/3$$

IDENTIFYING BEVELING RHOMBOHEDRA

The rhombohedron face that bevels the edge of a form can easily be identified, providing indices of the adjacent parent faces are known. Such a beveling face parallels the common edge of the host form; its indices are found by simply adding corresponding indices of the two adjacent faces of the host form; that is

$$h_b = h_1 + h_2$$
$$k_b = k_1 + k_2$$
$$l_b = l_1 + l_2$$

(Continued on p. 470)

SEELITE

A NEW URANIUM MINERAL FROM THE TALMESSI MINE, IRAN, AND RABEJAC, FRANCE

P. Bariand, B. Bachet, C. Brassy
Laboratoire de Minéralogie et Cristallographie
associé au C.N.R.S.
Université Pierre et Marie Curie
4, Place Jussieu
75252 Paris Cedex 05, France

O. Medenbach
Ruhr Universität
Postfach 102148
D-4630 Bochum 1, Germany

M. Deliens
Institut Royal des
Sciences Naturelles de Belgique
Rue Vautier 29
B-1040 Brusselles, Belgium

P. Piret
Laboratoire de Chimie-Physique
et de Cristallographie de l'Université
1 Place Pasteur
B-1348 Louvain-La-Neuve, Belgium

INTRODUCTION

A new arsenic-magnesium-uranium mineral has been discovered on specimens collected from the oxidation zone of two deposits: the Talmessi mine in central Iran, and Rabejac in Herault, France. The first specimens were found in 1955 during the course of a systematic study of the metalliferous deposits of Iran; P. Bariand collected millimeter-size yellow needles at the Talmessi mine. A microchemical analysis showed As, U and Mg; and Debye-Scherrer and Weissenberg photographs revealed monoclinic symmetry, thereby confirming the mineral to be a new species. However, insufficient material was present to allow a full characterization at that time. The preliminary results were published by Bariand (1963), and repeated in the second appendix (1963), to Hey's *Chemical Index*.

In 1991 the material was restudied by electron probe microanalysis, and its structure was investigated and solved (Bachet *et al.*, 1991). Following that, Bariand, Bachet and Brassy proposed to the International Mineralogical Association that the species be validated and given the name *seelite*. At about the same time, Deliens and Piret had been studying an arsenate of magnesium and uranium from the uranium deposit at Rabejac, Lodeve, Department of Herault, France, and also submitted a proposal to the I.M.A.

In comparing the physical properties, crystallography and chemical composition of the two proposed minerals, Joseph Mandarino, president of the Commission on New Minerals and Mineral Names of the I.M.A., noted the close similarity. He proposed to the authors that they collaborate on a joint description of the new species, giving the name *seelite* (which had chronological priority by several weeks). Seelite was subsequently accepted by the I.M.A. as a new species in April of 1992, and its formal description is the object of this paper.

NOMENCLATURE

With the naming of this mineral after Paul and Hilde Seel (whom many readers will remember fondly), we commemorate a husband-and-wife team of American mineralogists who left their mark on the affections of many of us. Paul Seel, "gentleman, scholar and mineral

Figure 1. **Hildegard Schumann Seel (1902–1987) and Paul Seel (1904–1982).**

collector," was written up by Paul Desautels in the very first issue of the *Mineralogical Record* (1970) and it seems fitting for this new mineral to be first announced in the *Mineralogical Record*.

Paul was born in Germany in 1904 and came to America in 1926 with an engineering degree. He worked for the Pennsylvania Railroad as a transportation expert, devoting most of his spare time to the Philadelphia and Pennsylvania Mineralogical Societies, the AFMS, and to the Wagner Free Institute of Science in Philadelphia. Hilde, whom Paul had met in Germany many years before, returned to America as Paul's wife in 1933 and joined him throughout his career. "Like twin crystals, each complemented the other" is the way Russel MacFall put it in a memorial note in the *San Diego Pegmatite* upon her death in 1987, five years after Paul had died.

It is a pleasure to honor Paul and Hilde Seel by naming this new mineral after them.

THE OCCURRENCES

Talmessi

The Talmessi deposit is situated 35 km west of the village of Anarak in central Iran. Native copper has been mined there since ancient times; the discovery of nickel and cobalt in the deposit in 1930 revitalized the mine. Uranium was subsequently discovered there as well (Bariand, 1955), in the form of uranospinite. The site was prospected in 1960–1961 with the aim of recovering uranium, but the discontinuous nature of the mineralization made exploitation impractical.

The Anarak region is characterized structurally by a major northwest-trending syncline flanked by two parallel mountain chains following the emergent stratigraphic layers. Within these outcrops a fractured porphyritic olivine diorite is the host rock for metalliferous mineralization extending from Talmessi on the north to Meskani in the south.

An extraordinary assemblage of primary and secondary minerals has been identified at the Talmessi mine, including primary copper, nickel and cobalt arsenides (algodonite, domeykite, nickeline, rammelsbergite, safflorite, skutterudite), native copper, chalcocite, and concretionary pitchblende. In more or less intimate association are the less abundant sulfides (pyrite, galena, sphalerite, bornite, covellite, chalcopyrite) and cuprite. Secondary minerals are particularly diversified, including lavendulan, conichalcite, tyrolite, lindackerite, mixite, annabergite, cabrerite, erythrite, roselite, uranospinite, metazeunerite, pharmacolite and talmessite (type locality), with rare connellite, atacamite, malachite, azurite, garnierite, zaratite and others. Unfortunately, the closing of the Talmessi mine in 1960 has made further specimen recovery very difficult.

The nearby Meskani mine has a similar mineralization. Numerous other sites of copper mineralization in the area remain to be investigated.

Rabejac

The Rabejac uranium deposit is located 7 km south-southeast of Lodeve in the French Department of Herault. The oxidation zone was exploited via open pit mining in several successive phases from 1989 to 1991. Mineralization is concentrated in a reopened fault in the local Saxonian (uppermost Permian) silts and red pelites.

The geology and metallogeny of the uranium deposits of the Lodeve Basin have been described in detail by Mathis *et al.* (1990). A summary of their work is included by Deliens and Piret (1992) in their description of fontanite, a new calcium uranyl carbonate hydrate from Rabejac. Deliens and Piret also describe the paragenesis of the supergene alteration zone at Rabejac, remarkable for their presence of rare uranium molybdates (e.g. umohoite, iriginite, calcurmolite) and the diverse assemblage of uranium minerals (including arsenuranosphathite, becquerelite, billietite, cuprosklodowskite, fontanite, ianthinite, novacekite, rutherfordine, schoepite, sklodowskite, alpha- and beta-uranophane, vandenbrandeite, vandendriesscheite and zeunerite). Seelite occurs on a micaceous, apple-green veneer on zeunerite, on a brownish siltstone.

DESCRIPTION and PHYSICAL PROPERTIES

The seelite from Talmessi occurs in transparent canary-yellow tabular crystals, flattened on (100), attaining a maximum length of 1 mm. They commonly form tufted spherules and rosettes of divergent hair-like needles. The morphological characteristics (Fig. 5) are identical to those of the seelite from Rabejac. At Talmessi the seelite has been found only at the 30-meter level in the mine, in a uraniferous horizon. It occurs in cracks and vugs in arsenides (nickeline) and is associated with annabergite, talmessite, zaratite and uranospinite.

The seelite from Rabejac occurs in radial aggregates of transparent, bright yellow tablets (Fig. 4). Individual crystals have a maximum length of 0.5 mm, a width of 0.1 mm, and a thickness of several dozen microns. The luster is vitreous, the fracture irregular and the powder colorless. The isolated platelets are elongated along [010], flattened most often on (100), more rarely on (001). The prism faces {100} and {001} are terminated by {010} or by {011} and {01$\bar{1}$}. The angle between the latter can be measured under the microscope to be 86.7°.

Seelite is optically biaxial negative. The optic axial plane is (010), the orientation of the indicatrix is $Z \Lambda c = 5(1)^{\circ}$. Thus the flattened crystals show a typical nearly centered interference figure with a marked monoclinic inclined dispersion on (100), the most preferential orientation in grain mounts.

A crystal mounted with n_m parallel to the spindle of a spindle stage and immersed in an appropriate liquid (with $n = n_\beta$) allows very exact measurements of the optical axial angle 2V (compare: Medenbach, 1985). Such measurements have been carried out for seelite from Talmessi at eight different wavelengths. The results are shown graphically in Figure 6. Seelite has an extreme dispersion of the optical axial angle 2V with $r \gg v$, the value for 589 nm is 41 ± 0.5°. The

Figure 2. Headframe and dumps at the Talmessi mine, Iran, in 1964. Photo by P. Bariand.

Figure 3. Seelite crystal spray, 1 mm, from the Talmessi mine. Collection of the Sorbonne (University of Paris); photo by Nelly Bariand.

Figure 4. Seelite crystal sprays to 0.6 mm, from Rabejac, France. Collection of F. Durand; photo by R. Vernet.

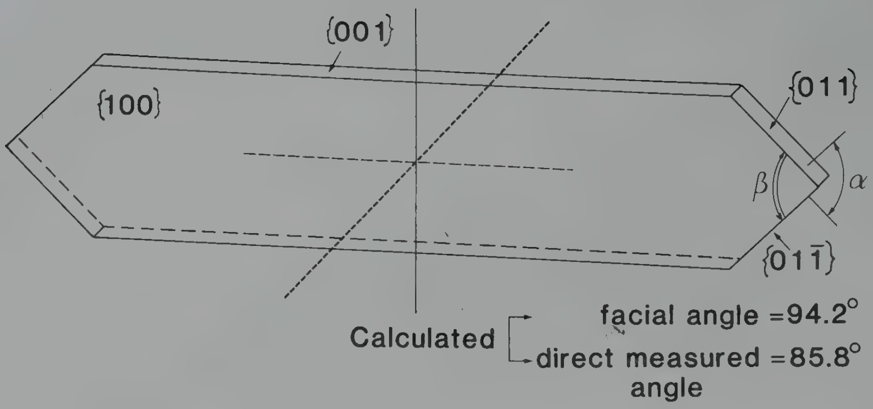


Figure 5. **Seelite morphology.**

monoclinic inclined dispersion of the bisectrix between 680 and 450 nm is 3°.

Pleochroism is strong with n_γ = colorless, n_β = yellow, n_α = yellow. No fluorescence in either shortwave or longwave ultraviolet radiation has been observed.

Hardness on the Mohs scale is about 3, and the density measured by immersion in Clerici solution is 3.70 g/cm^3. These data in comparison with those for Talmessi seelite are assembled in the first part of Table 1.

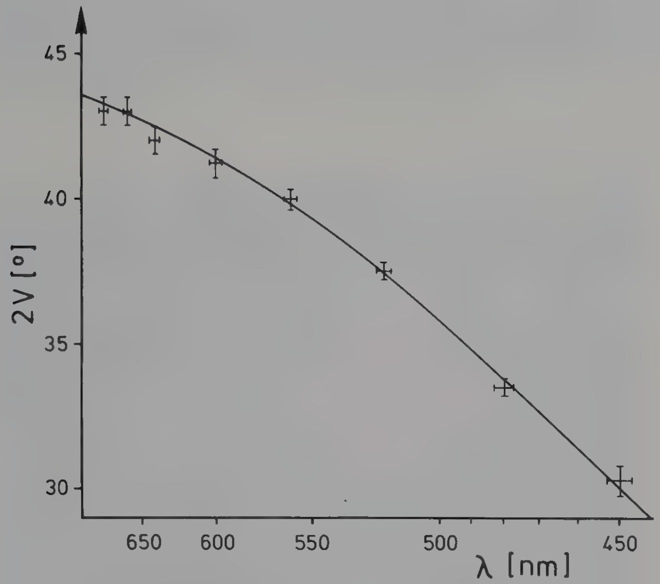


Figure 6. **Relationship between seelite 2V and the wavelength of light used in the measurement.**

X-RAY DIFFRACTION

The X-ray study of single crystal patterns with the 4-circle diffractometer confirmed the monoclinic symmetry. The space group is *C2/m* if we consider systematic absences (hkl for h + k = 2n + l) and the determination of the structure (Bachet *et al.*, 1991; Piret and Piret-Meunier, in preparation). The lattice parameters calculated by least-squares are given in the second part of Table 1.

The X-ray powder pattern (Table 2) is indexed by intensities measured by diffractometer for the single crystal. It is very close to that attributed by Walenta (1972) to a natural arsenate of barium and uranium (card n° 29-209 of J.C.P.D.S.) but it does not resemble in any way those of novacekite or metanovacekite, $Mg(UO_2)_2(AsO_4)_2 \cdot 8\text{–}12H_2O$ (Walenta, 1964).

Table 1. **Optical data and crystallography for seelite from Talmessi (T) and Rabejac (R).**

Optical data

	n_α	n_β	n_γ	$2V_{mes.}$	$2V_{calc.}$
T	1.602(1)	1.737(3)	1.753(3)	41.0(5)°	37.5°
R	1.610(2)	1.730(4)	1.740(4)	30(3)°	34°
T + R	//a* colorless	//b yellow	//c yellow		

Crystallography

	a(Å)	b(Å)	c(Å)	β	V(Å)^3	D_x	Z
T	18.207(5)	7.062(3)	6.661(3)	99.65(5)	844.3(9)	3.60	2
R	18.194(3)	7.071(1)	6.670(1)	99.70(1)	845.8(2)	3.71	2

CHEMICAL COMPOSITION

Qualitative chemical analysis shows the presence of arsenic, magnesium and uranium for the seelite of both localities. The seelite of Rabejac has been quantitatively analyzed by microprobe in the Mineralogy Laboratory of Paul Sabatier University, Toulouse, France (Camebax apparatus; F. Fontan analyst). The following standards have been used: olivine for Mg, synthetic UO_2 for uranium, and arsenopyrite for arsenic (5 measurements). The quantity of water has been measured by the CHN (carbon-hydrogen-nitrogen) method with gas chromatography (2 measurements; P. Van Ransbeke, analyst). The average of the results with the maximum deviation are given in Table 3. For the chemical composition of seelite from Rabejac, the arsenic has been divided into 0.7 As^{3+} and 0.3 As^{5+}, obtained by the determination of the structure (Piret and Piret-Meunier, in preparation).

The rough totals (Table 3, column 1) are too high because of the dehydration of the specimens in the chamber of the microprobe. The oxide percentages are corrected in column 2 in order to get a total of 100%. The third column gives the molecular percentages for a total of 17.6 oxygens. The ideal formula for the seelite of Rabejac is:

1 MgO, 2 UO_3, 0.7 As_2O_3, 0,3 As_2O_5, 7 H_2O equivalent to:
$Mg[UO_2(AsO_3)_x(AsO_4)_{1-x}]_2 \cdot 7H_2O$ with X about 0.7

From this formula, the calculated theoretical percentage of column 4 has been derived. For the seelite from Talmessi, only the proportions

Table 2. **Powder diagram of seelite (camera diameter 114.6 mm) CuKa radiation, Ni filter.**

	Rabejac			Talmessi		
hkl	d_{calc}	d_{obs}	I_{vis}	d_{calc}	d_{obs}	I_{vis}
200	8.97	9.02	100	8.97	9.05	100
001	6.57	6.61	10	6.57	6.48	30
$\bar{2}01$	5.79	5.80	10	5.78	5.72	30
201	4.92	4.90	40	4.92	4.85	50
$\bar{1}11$	4.80			4.79		
400	4.48	4.48	80	4.49	4.44	80
$\bar{3}11$	4.00	4.00	40	3.99	3.99	50
020	3.54	3.53	40	3.53	3.52	60
401	3.44	3.44	10	3.45	3.48	30
220	3.29	3.28	50	3.29	3.30	30
$\bar{1}12$	3.02	3.01	60	3.01	3.03	30
600	2.99			2.99		
221	2.871			2.869		
112	2.871	2.849	60	2.868	2.86	5
$\bar{3}12$	2.847			2.843		
420	2.776	2.776	10	2.775	2.77	30
601	2.563	2.550	5	2.565	2.57	30
$\bar{5}12$	2.487	2.478	15	2.485	2.47	30
421	2.467			2.466		
$\bar{7}11$	2.387	2.383	8	2.388	2.38	30
800	2.242			2.244		
$\bar{1}31$	2.217	—	—	2.215	2.22	30
$\bar{2}03$	2.217			2.214		
$\bar{3}31$	2.120			2.117		
$\bar{4}03$	2.114	2.110	15	2.112	2.11	30
$\bar{7}12$	2.109			2.108		
621	2.075	2.065	5	2.075	—	—
801	2.020	2.025	5	2.022	—	—
$\bar{6}03$	1.929			1.927		
$\bar{9}11$	1.927	1.922	25	1.928	1.92	80
$\bar{1}32$	1.925			1.922		
132	1.885			1.883		
313	1.883	1.875	25	1.882	1.88	30
$\bar{3}32$	1.879			1.876		
040	1.768			1.766		
$\bar{5}32$	1.763	1.762	10	1.761	1.76	30
821	1.754			1.755		

of cations and anions have been measured. The same relationship is found as for the Rabejac material: 1 Mg, 2 UO_3 and 2,03 As. The following formula where all the arsenic is As^{5+} can be deduced from the structure (Bachet *et al.*, 1991): $Mg[(UO_2)(AsO_4)]_2 \cdot 4H_2O$. The arsenic is pentavalent, which corresponds to the $X = 0$ in the formula of the Rabejac material.

PRESERVATION OF TYPE MATERIAL

The Rabejac type material is registered under the No. R.C. 4191 in the Mineralogical Collection of the Royal Institute of Natural Sciences of Belgium in Brussels. The Talmessi type specimen is kept in the Mineralogical Collection of the Pierre and Marie Curie University in Paris.

ACKNOWLEDGMENTS

Thanks to Allan Basset who prepared the English translation of the manuscript, and to Olivier Henriot from COGEMA (the French mining company controlling the type locality) who collected the specimens from the Rabejac mine.

Table 3. **Chemical composition of seelite from Rabejac.**

	1		2	3	4
MgO	4.28	(4.09–4.60)	4.09	0.97	4.26
UO_3	65.37	(63.41–66.68)	62.43	2.08	60.50
As_2O_3	14.00	(13.75–14.59)	13.41	0.65	14.64
As_2O_5	6.98	(6.83–7.25)	6.67	0.28	7.26
H_2O	13.40		13.40	7.08	13.34
	104.03		100.00		

1. Experimental mean percentage and maximum range
2. Experimental percentage (100%)
3. Molecular proportions for 17.6 oxygens
4. Theoretical percentage for the formula $Mg(UO_2)(AsO_3)_{0.7}(AsO_4)_{0.3} \cdot 7H_2O$

Table 4. **Chemical composition of seelite from Talmessi.**

	1		2	3
MgO	4.39	(4.36–4.43)	0.996	4.41
UO_3	62.75	(62.35–64.10)	2.006	62.57
As_2O_5	25.52	(24.19–27.03)	1.015	25.14
H_2O	7.34			7.88
	100.00			100.00

1. Mean experimental percentage in weight and maximal range (H_2O was calculated by difference)
2. Molecular proportions for 16 oxygens
3. Theoretical percentage for the formula $Mg[(UO_2)(AsO_4)]_2 \cdot 4H_2O$

BIBLIOGRAPHY

BACHET, G., BRASSY, C., and COUSSON, A. (1991) Structure de $Mg[(UO_2)(AsO_4)]_2 \cdot 4H_2O$. *Acta Crystallographica*, **C47**, 2013–2015.

BARIAND, P. (1963) Contribution à la minéralogie de l'Iran. *Bulletin de la societe francaise de Minéralogie et Cristallographie*, **86**, 17–64.

DELIENS, M., and PIRET, P. (1992) La fontanite, carbonate hydraté d'uranyle et de calcium, nouvelle espèce minérale de Rabejac, Hérault, France. *European Journal of Mineralogy*, **4**, 1271–1274.

DESAUTELS, P. (1970) Paul Seel, a gentleman, scholar and mineral collector. *Mineralogical Record*, **1**, 11–31.

HEY, M. H. (1963) *Appendix to the Second Edition of an Index of Mineral Species and Varieties Arranged Chemically*. London, Trustees of the British Museum (Natural History), p. 71.

MATHIS, V. ROBERT, J. P., and SAINT MARTIN, J. (1990) Géologie et métallogénie des gisements d'uranium du basin permien de Lodève (Sud du Massif Central français) *Chron. Rech. Min.*, **499**, 31–41.

MEDENBACH, O. (1985) A new microrefractometer spindle-stage and its application. *Fortschr. Miner.*, **63**, 111–133.

WALENTA, K. (1964) Beiträge zur Kenntnis seltener Arsenatmineralien unter besonderer Berücksichtigung von Vorkommen des Schwarzwaldes. Teil 1. Uranglimmer. *Tschermaks Miner. Petrogr. Mitt.*, **9**, 111–174.

WALENTA, K. (1972) The secondary minerals of the Co-Ni-Ag-Bi-U-ore veins in the Wittichen Aufschluss, **23**, 279–329.

FOR SALE! THE PROCTOR CRYSTAL COLLECTION

Hundreds of specimens priced under $1,000. Write for List.

Order your 96-minute Video.

One of the World's Premier Crystal Collections —

Featuring gem crystals, gold specimens and hundreds of classic examples from world-wide locations.

You can preview this collection with a 96-minute, professionally prepared video. This live-action presentation features 180 specimens, individually filmed, and 35 mine location photos to illustrate the history and workings of many great mines and their crystal treasures. This unique, educational video graphically illustrates the 12 criteria used to assemble this world-class collection. To order your video send $29.50 plus $2.50 postage.

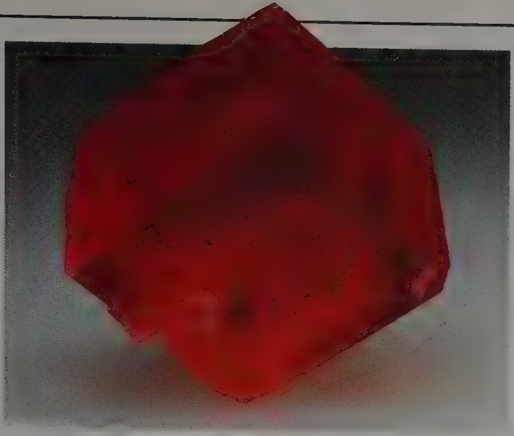
"This video offers an opportunity to see and study Proctor's exquisite specimens at leisure. Many are pictured on slowly revolving turntables, allowing all sides of the specimens to be seen, and their three-dimensional shapes to be fully realized, as reflections play across crystal faces and gemmy interiors . . . this really is one of the best private collections ever assembled. . . ." W.E.W. Video Review: Nov/Dec '92

Wendell Wilson in his video review in M.R., Nov/Dec 1992, p. 504, says "The collector of aesthetic mineral specimens will find much to savor in Keith Proctor's video catalog of his collection. . . . It really delivers in terms of extraordinary mineral images and specimen information and will stand for many years to come as a historically valuable documentation of one of the great private collections of our time."

Keith Proctor

88 Raven Hills Court, Colorado Springs, CO 80919-1316
Telephone: (719) 598-1233

Photo by Earl Lewis, Los Angeles



The Collector's Edge

Bryan & Kathryn Lees
Spectacular Rhodochrosites
Call and ask about recent mining discoveries
Dave Wilber, Sales
554 Orchard St., Unit 4, Golden, CO 80401
303-278-9724

Above: TN Alma rhodochrosite; WEW photo

By Appointment Only

DELTA BRAVO
G·E·M·S·T·O·N·E

SPECIALIZING IN EMERALDS
AND OTHER MINERALS
FROM COLOMBIA

P.O. BOX 1858 BOULDER, CO 80306-1858
303-447-9686 Fax 447-9687

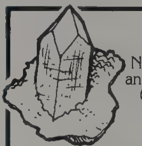
FINE & RARE MINERALS

FABRE MINERALS
Jordi Fabre

C/Arc de Sant Martí 79 Local
08032-BARCELONA (SPAIN)
☎ (3) 4333022 · Fax (3) 4504745
By Appt. only

See you at St-Marie-aux-Mines Show (Théâtre)
●
Munich Show (stand 2505)
●
Tucson Show

Monteregian Minerals
microminerals & rare species
Specializing in Mont Saint-Hilaire and
other Canadian localities. List $1.
P.O. Box 53077, Dorval, Québec
H9S 5W4 CANADA



Affordable Green
APOPHYLLITES
Nice green pieces with wonderful termination and in association with other minerals. 10 Kgs, US $375; 50 Kgs, US $1750; 100 Kgs, US $3200; 250 Kgs, US $7500. CIF by sea.
Make sure you don't miss this offer.
Send your checks/drafts today to:

NATIONAL MINERALS, G3/7-A Sunder Nagar,
Malad (W), Bombay-400064, INDIA.
Tel: 873-6161, 872-6874. Fax: 91-22-8827457.

Mineral Kingdom

Canvassing the world for fine Mineral Specimens!
See us at the TUCSON SHOW!
We'll have a New Group of Indian
Specimens at Attractive Prices

MIRIAM & JULIUS ZWEIBEL
20686 N.W. 27th Avenue
Boca Raton, FL 33434
Phone or FAX: (305) 781-9860

Kongsberg Silver, 12.1 cm

Continued from p. 461

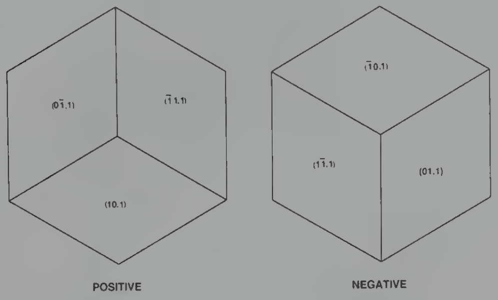


***Figure 20. C*-axis views of positive and negative rhombohedra {10.1} and {01.1}. In each case face indices are given.**

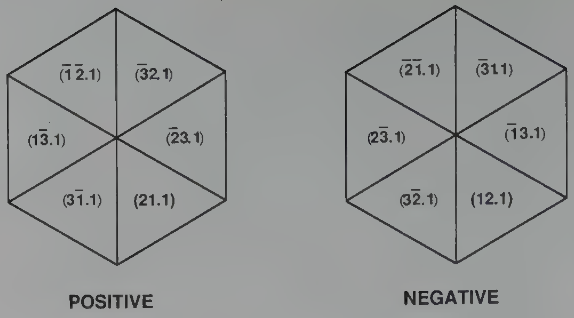


***Figure 21. C*-axis views of positive and negative scalenohedra {21.1} and {12.1}. In each case face indices are given.**

where the subscripts $_{b}$, $_{1}$ and $_{2}$ respectively refer to the beveling face and faces 1 and 2 of the host form. This procedure is best illustrated by an example. Figure 20 shows views down the *c* axis of positive and negative rhombohedra {10.1} and {01.1}. The Miller indices of upper hemisphere faces are identified on the drawing. On each rhombohedron, Miller indices of beveling faces are found by adding corresponding indices of the adjacent faces. Consider the four o'clock edge on the {10.1} rhombohedron (between the (10.1) and $(\bar{1}1.1)$ faces). Indices of the rhombohedron that bevels this edge are:

$$h = 1 + -1 = 0$$
$$k = 0 + 1 = 1$$
$$l = 1 + 1 = 2$$

Thus the beveling rhombohedron is {01.2}.

Figure 21 shows the equivalent orientations of the positive and negative scalenohedra {21.1} and {12.1}. Beveling rhombohedra can be identified as before. Consider the six o'clock edge on the {21.1} scalenohedron between the $(3\bar{1}.1)$ and (21.1) faces. Indices of the rhombohedron that bevels this edge are:

$$h = 3 + 2 = 5$$
$$k = -1 + 1 = 0$$
$$l = 1 + 1 = 2$$

Thus the beveling rhombohedron is {50.2}. Similarly, the rhombohedron beveling the four o'clock edge of the negative scalenohedron is {05.2}, calculated as follows:

$$h = 1 - 1 = 0$$
$$k = 2 + 3 = 5$$
$$l = 1 + 1 = 2$$

The above procedure can also be applied to faces that bevel adjacent faces of different forms. In that case, however, the beveling face is generally a scalenohedron, and the resulting indices are not unique. That is, many different scalenohedra bevel the same edge; the indices derived by the above procedure simply produce one scalenohedron of the set.

BASE-RHOMB OF ANY SCALENOHEDRON

For any positive scalenohedron of indices $\{h_s k_s l_s\}$, the corresponding base-rhomb indices $\{h0l\}$ are given by:

$$h = h_s - k_s$$
$$k = 0$$
$$l = l_s$$

Sample calculation: Find the base-rhomb for {62.5}.

$$h = h_s - k_s = 6 - 2 = 4$$
$$k = 0$$
$$l = l_s = 5$$

Thus indices for the base-rhomb are {40.5}. The base-rhomb for any negative scalenohedron is given by the similar equations:

$$h = 0$$
$$k = k_s - h_s$$
$$l = l_s$$

EDOYLERITE

$Hg_3^{2+}Cr^{6+}O_4S_2$
A NEW MINERAL FROM THE CLEAR CREEK CLAIM SAN BENITO COUNTY, CALIFORNIA

Richard C. Erd
United States Geological Survey
345 Middlefield Road
Menlo Park, California 94025

Andrew C. Roberts[1] and **Maurizio Bonardi***
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario, Canada K1A 0E8

Alan J. Criddle
Department of Mineralogy
The Natural History Museum
Cromwell Road
London, England SW7 5BD

Yvon Le Page and **Eric J. Gabe**
Solid State Chemistry
National Research Council of Canada
Montreal Road
Ottawa, Ontario, Canada K1A 0R9

ABSTRACT

Edoylerite, idealized as $Hg_3^{2+}Cr^{6+}O_4S_2$, is monoclinic, space group $P2_1/a$, with refined unit-cell parameters a = 7.524(7), b = 14.819(8), c = 7.443(5) Å, β = 118.72(5)°, V = 728(3)Å^3, $a:b:c$ = 0.5077:1:0.5023, Z = 4. The strongest six reflections in the X-ray powder pattern are [dÅ$(I)(hkl)$]: 5.94(40) (011, $\bar{1}11$); 4.88(50) (120, 021, $\bar{1}21$); 3.212(100) (210, $\bar{2}02$, $\bar{1}41$, 012); 3.012(60) (131); 2.307(40) ($\bar{1}61$); 2.185(40) ($\bar{1}33$, $\bar{2}52$). The mineral is a rare constituent of a small prospect near the long-abandoned Clear Creek mercury mine, New Idria district, San Benito County, California. It is most closely associated with cinnabar, from which it is a primary alteration product, in a host rock composed predominantly of quartz, chalcedony and ferroan magnesite. Edoylerite typically occurs as acicular to stellate crystal groupings on and around corroded masses of cinnabar. Individual crystals are acicular to prismatic, elongate [101], do not exceed 0.5 mm in length, and have a maximum length to width ratio of 60:1. The average crystal length is 0.2 mm. Forms observed are: {010}, {$\bar{1}11$}, {001} and {101}. The mineral is canary yellow to orangish yellow, and possesses a yellow streak and an adamantine luster. Physical properties include: opaque (masses) to transparent or translucent (individual crystals); nonfluorescent; brittle and inflexible; subconchoidal fracture; weakly photosensitive to X-radiation; good cleavage {010} and fair cleavage {101}; calculated density 7.64 g/cm^3 (for empirical formula), 7.13 g/cm^3 (for idealized formula). The mineral is optically biaxial with all refractive indices greater than 1.78; it has weak pleochroism and strong bireflectance and absorption. In polished section, edoylerite is weakly bireflectant and weakly pleochroic and is light gray in color. In plane-polarized light it is bluish gray to gray with brilliant pale yellow internal reflections. Measured

---

* Present address: Consiglio Nazionale delle Ricerche (ISDGM), S Polo 1364, 30125, Venezia, Italy.

[1] Geological Survey of Canada contribution number 14593.

Figure 1. **Stellate and acicular crystal groupings of edoylerite on holotype specimen NMC 65026.**

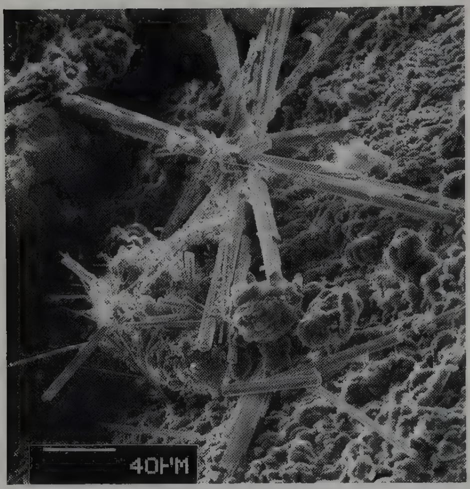


Figure 2. **Scanning electron photomicrograph of a stellate group of edoylerite crystals.**

reflectance values, in air and in oil, are tabulated. The crystal structure shows that mercury exists in two different coordination environments, therefore mercury was partitioned to Hg and to HgO. Averaged electron microprobe analyses yielded Hg = 51.6, HgO = 27.9, CrO_3 = 11.5, S = 8.2, total = 99.2 weight %, corresponding to $Hg^{2+}_{3.26}Cr^{6+}_{0.97}O_4S_{2.16}$, based on O = 4. The mineral is named for Mr. Edward H. Oyler (1915–), a well-known California mineral collector, who first discovered and collected the mineral.

INTRODUCTION

The new mineral edoylerite, described herein, was first discovered by Mr. Edward H. Oyler, a talented collector and specialist in the minerals of mercury, in late 1961. He brought the material to the late Edgar H. Bailey and one of us (RCE) who, after X-ray powder and single-crystal study and a preliminary electron microprobe analysis (by E. D. Ghent), recognized it to be a new mineral species. Unfortunately, the nature of the material then precluded further investigation. The study was renewed in 1986 with the finding of crystals sufficiently large for a crystal-structure determination and in sufficient quantity for a full mineralogical characterization.

The new mineral species is named in honor of Mr. Oyler, not only for its discovery, but, for his long service in providing many materials for mineralogical research. He was born February 4, 1915, in Fresno County, California, and has collected minerals since 1927. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, I.M.A. Holotype material has been deposited within the Systematic Reference Series of the National Mineral Collection at the Geological Survey of Canada under catalogue number NMC 65026. This is also one of the holotype specimens for deanesmithite (Roberts *et al.,* 1993).

OCCURRENCE

The new mineral was first discovered in a large meter-sized boulder (Fig. 4), near a small prospect area known informally as the Clear Creek claim. It was later found in an outcrop of the silica-carbonate rock on the west side of the claim. The Clear Creek claim is situated near the long-abandoned Clear Creek (also Boston; Morning Star) mercury mine, one of the Flint Group of mines in the New Idria district, San Benito County, California. Sparse details regarding the Clear Creek mine are given by Eckel and Myers (1946). The mine is correctly located in R. 11 E. on Plate 8, but is erroneously reported in R. 12 E. (p. 106) of their report. The exact location of the Clear Creek claim is at the coordinates 36°22′59″ N. and 120°43′58″ W., or in the NW1/4 NE1/4 sec. 11, T. 18 S., R. 11 E., Mount Diablo meridian, found on the Idria 7½-minute Quadrangle of the U.S. Geological Survey. Both the Clear Creek claim and the Clear Creek mine are in a large, elongate, tectonically emplaced serpentinite body which is completely surrounded by parts of the Panoche Formation (Upper Cretaceous) and the Franciscan Complex (late Mesozoic to early Tertiary) (Eckel and Myers, 1946; Millage, 1981; Fox, 1983; Boctor *et al.*, 1987). Portions of the serpentinite mass have been hydrothermally altered to a rock composed principally of quartz, chalcedony and ferroan magnesite which is the chief host rock for mercury deposits in the Coast Ranges of California. An extensive discussion of the silica-carbonate rock is provided by Bailey and Everhart (1964, pp. 58–64). The Clear Creek mine and the Clear Creek claim are situated in small bodies of the silica-carbonate rock that were mineralized by cinnabar following the hydrothermal alteration of the serpentinite.

At the edoylerite locality, the host rock is composed of quartz, chalcedony, opal, ferroan magnesite, dolomite, goethite, and minor chlorite. Severely altered to relatively fresh ferroan magnesiochromite occurs as a minor accessory mineral. Magnesiochromite is a ubiquitous mineral in the Coast Range serpentinites, often in deposits of commercial size (Walker and Griggs, 1953; Rice, 1957). Minerals formed during the mercury mineralization, in rough order of abundance, are cinnabar, elemental mercury, edgarbaileyite (Roberts *et al.*, 1990a), metacinnabar, montroydite, eglestonite, calomel, an unidentified yellow massive cryptocrystalline mercury mineral, edoylerite, wattersite (Roberts *et al.*, 1991), giannellaite, mosesite, deanesmithite (Roberts *et al.*, 1993), and a single occurrence of szymańskiite (Roberts *et al.*, 1990b). Despite extensive search, only microgram quantities of edoylerite have been found since 1961. Edoylerite is a primary alteration product of cinnabar.

X-RAY DIFFRACTION

Precession single-crystal studies, employing Zr-filtered Mo radiation, showed that edoylerite is monoclinic with space group $P2_1/a$. The following levels were photographed: *h0l* ➧ *h4l*, *0kl* ➧ *4kl*, and *hk0* ➧ *hk2*. The refined unit-cell parameters: a = 7.524(7), b = 14.819(8), c = 7.443(5) Å, β = 118.72(5)°, V = 728(3) Å³, $a{:}b{:}c$ = 0.5077:1:0.5023 are based on 18 powder reflections representing *d*-values between 3.012 and 1.755 Å for which unambiguous indexing was possible, based on visual inspection of precession single-crystal films. Details regarding the crystal structure will be published elsewhere, but it should be noted that the structure refinement clearly shows three Hg^{2+} atoms in octahedral coordination, two S^{2-} atoms in tetrahedral coordination, and one Cr^{6+} atom in tetrahedral coordination.

The powder data (Table 1) are unique and bear no resemblance to any other inorganic phase in the Powder Diffraction File up to and including Set 42. Edoylerite is the second reported mercury chromate sulfide (the first was deanesmithite).

***Table 1.* X-ray powder diffraction data for edoylerite.**

$I_{est.}$	$d_{Åmeas.}$	$d_{Åcalc.}$	*hkl*	$I_{est.}$	$d_{Åmeas.}$	$d_{Åcalc.}$	*hkl*
10	7.42	7.41	020	5	2.627	2.625	$\bar{1}42$
5	6.54	6.53	001	25	2.468	2.470	060
40	5.94	5.97	011	3	2.431	2.430	$\bar{2}42$
		5.91	$\bar{1}11$	25	2.351	2.348	$\bar{3}21$
		4.93	120	40	2.307	2.306	$\bar{1}61$
50	4.88	4.90	021	35	2.208	2.213	$\bar{3}31$
		4.86	$\bar{1}21$	40	2.185	2.191	$\bar{1}33$
		3.95	130			2.180	$\bar{2}52$
20	3.94	3.94	031	3	2.152	2.153	013
		3.92	$\bar{1}31$	20	2.121	2.124	$\bar{3}13$
25	3.71	3.71	040	10	2.066	2.064	$\bar{2}61$
5	3.66	3.65	$\bar{2}11$	5	2.038	2.041	$\bar{1}43$
10	3.339	3.353	$\bar{2}21$			2.032	$\bar{2}43$
		3.325	$\bar{1}22$	5	2.011	2.016	170
		3.220	210			2.014	071
100	3.212	3.219	$\bar{2}02$	10	1.967	1.968	$\bar{3}33$
		3.211	$\bar{1}41$	30	1.908	1.907	202
		3.187	012	5	1.882	1.880	$\bar{4}02$
60	3.012	3.019	131	30	1.852	1.851	171
3	2.964	2.972	$\bar{1}32$	10	1.822	1.822	$\bar{4}22$
		2.952	$\bar{2}22$	3	1.806	1.804	$\bar{2}24$
25	2.738	2.744	230	30	1.779	1.782	270
		2.723	032			1.776	072
20	2.704	2.704	150	15	1.755	1.757	261

—114.6 mm Debye-Scherrer powder camera
—Ni-filtered Cu radiation (λ Cu Kα = 1.54178 Å)
—intensities estimated visually
—indexed on $a = 7.524$, $b = 14.819$, $c = 7.443$ Å, $\beta = 118.72°$

PHYSICAL and MORPHOLOGICAL PROPERTIES

Edoylerite occurs as acicular to stellate crystal groupings (Fig. 1) on and around corroded masses of cinnabar. Most crystals do not exceed 0.5 mm in length with a maximum length to width ratio of 60:1 (Fig. 2). The average crystal length is 0.2 mm. Individual crystals are acicular to prismatic, are elongate [101], and are pseudo-orthorhombic to almost pseudo-hexagonal in morphology. Crystals suitable for goniometric measurement are rare and measurable faces give multiple signals. Forms, measured with a two-circle goniometer, and arranged in decreasing order of importance, are {010}, {$\bar{1}11$}, {001} and {101}. The mineral is canary yellow to orangish yellow, has a yellow streak and an adamantine luster. Crystals of edoylerite are transparent to translucent, but massive material appears opaque. There is a very good cleavage on {010} and a fair cleavage on {101}; fracture is subconchoidal and no parting has been detected. Neither hardness nor density could be measured due to size limitations and paucity of material. The mineral is brittle and inflexible. Edoylerite is photosensitive, but a few months time is required to turn the crystals olive-green; Zr-filtered Mo X-radiation produces a dark orange color. No differences are apparent in the X-ray powder diffraction patterns of fresh and exposed edoylerite. The mineral is both nonfluorescent and nonmagnetic.

OPTICAL PROPERTIES

Edoylerite is biaxial with positive elongation (Z = [101]) and is slightly pleochroic with X = Y lemon yellow, Z = slightly darker lemon yellow, and Z > X = Y. We are unable to determine other optical properties due to the high indices of refraction, strong birefringence (estimated at 0.2 ± 0.02), and strong absorption. The indices of refraction greatly exceed 1.78, but the mineral reacts rapidly with high-index immersion media above this value.

In reflected, plane-polarized light (in polished section), edoylerite is light gray, weakly bireflectant and weakly pleochroic. Individual grains, or crystals, have no discernible internal reflections, but, when clustered together in the polished section, a diffuse yellow color is apparent. Between crossed polars, brilliant pale yellow internal reflections are readily apparent and mask the anisotropy of the mineral. When immersed in oil (N_D = 1.515), the reflectance pleochroism—from bluish gray to gray—is seen in a few small grains, but is generally masked by the bright canary yellow internal reflections.

Reflectance measurements (using the equipment and procedures outlined by Criddle *et al.*, 1983) were made relative to a Zeiss SiC reflectance standard (no. 472) with X40 objectives, the effective numerical apertures of which had been adjusted to 0.26. Immersion measurements were made using Zeiss oil, N_D = 1.515, at an ambient temperature of 20° C. The samples, which had been polished with diamond abrasives, were lightly buffed with MgO immediately before measurement.

Edoylerite presented some difficulty for measurement: in plane section, its prismatic to acicular habit and small grain size meant that the largest areas of crystals exposed by polishing were 60 x 10 μm and 40 x 20 μm, and the abundance of internal reflections effectively reduced sample selection to one area of one crystal of less than 10 μm diameter, which further dictated that the measured area was less than 4 μm. Inevitably, given the much reduced light flux, the *R* data are less reliable than could have been hoped for. In addition, the orientation for measurement had to be made photometrically. For all of these misgivings, the reflectance spectra (Fig. 3) obtained were reproducible, and are consistent with the qualitative observations. This is more readily understood by reference to Table 2 where, in addition to the *R* data, the color values are tabulated. Here, it can be seen that R_1 is not only lower reflecting than R_2, but is more saturated and blue, thus accounting for the reflectance pleochroism.

Application of the Koenigsberger equations to the *R* and ^{im}R data

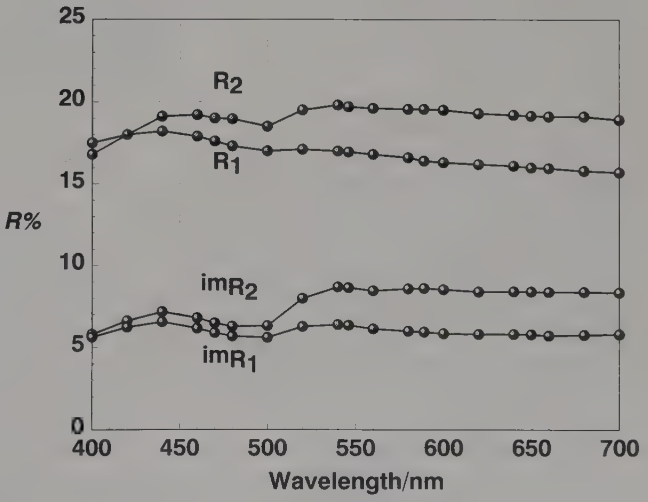


***Figure 3.* Reflectance spectra measured in air and in oil (N_D = 1.515) for edoylerite.**

Figure 4. **The area of the Clear Creek claim with Ed Oyler posed by the discovery boulder for edoylerite.**

gives results which are at variance with the observed transparency of the mineral, i.e., absorption coefficients (at 590 *nm*) of 0.9 and 0.7 respectively for R_1 and R_2, with the corresponding refractive indices of 2.08 and 2.06. These data are clearly erroneous, and the errors are almost certainly the product of unequal increments from internal reflections added during air and oil reflectance measurement, *cf.*, Dunn *et al.* (1988). Recalculation of the measured data at 590 *nm* using the Fresnel relation (for transparent media) immediately proves the incompatibility of the air and oil reflectances; for $R_1/^{im}R_1$, the corresponding n_1 values are 2.37 and 2.49; for $R_2/^{im}R_2$, they are 2.58 and 2.77. In this instance, the best *approximations* to the real values for n_1 and n_2 are the mean values, 2.43 and 2.67 (Embrey and Criddle, 1978).

CHEMISTRY

Edoylerite was analyzed chemically by means of a Cameca CAMEBAX electron microprobe, using a 20-kV operating voltage, a 30-nA beam current, a 5-second count rate, and a 6- to 8- micron beam diameter. The standards employed were natural cinnabar (for Hg, S) and synthetic Cr metal (for Cr). A wavelength-dispersive microprobe scan indicated the absence of any other elements with atomic number greater than 9 except those reported here. The structure was known prior to the interpretation of the analytical data. Because mercury exists in two different coordination environments, it was partitioned to Hg and to HgO based on the results of the crystal structure. The Hg and S values were processed using Love and Scott (1981) matrix correction procedures. The average of five analyses gave: Hg = 51.6, HgO = 27.9, CrO_3 = 11.5, S = 8.2, total = 99.2 weight %. The

Table 2. **Reflectance values for edoylerite: for ^{im}R, N_D = 1.515.**

λ*nm*	R_1	R_2	$^{im}R_1$	$^{im}R_2$
400	17.5	16.8	5.61	5.79
420	18.0	18.0	6.22	6.61
440	18.2	19.1	6.55	7.17
460	17.9	19.2	6.15	6.79
470	*17.6*	*19.0*	*5.88*	*6.48*
480	17.3	18.95	5.68	6.28
500	17.0	18.5	5.60	6.32
520	17.1	19.5	6.26	7.99
540	17.0	19.8	6.38	8.69
546	*16.95*	*19.7*	*6.34*	*8.64*
560	16.8	19.6	6.13	8.46
580	16.6	19.55	6.00	8.58
589	*16.4*	*19.55*	*5.94*	*8.61*
600	16.3	19.5	5.85	8.54
620	16.2	19.3	5.81	8.41
640	16.1	19.2	5.81	8.42
650	*16.0*	*19.15*	*5.78*	*8.40*
660	15.95	19.1	5.71	8.38
680	15.8	19.1	5.75	8.38
700	15.7	18.9	5.80	8.34
COLOR VALUES (Illuminant C):				
x	.303	.312	.306	.330
y	.309	.320	.315	.339
Y%	16.8	19.4	6.06	8.21
λ_d	478	570	487	576
P_e%	3.6	1.6	1.6	11.4

empirical formula, on the basis of O = 4, is $Hg^{2+}_{3.26}Cr^{6+}_{0.97}O_4S_{2.16}$ or, ideally, $Hg^{2+}_3Cr^{6+}O_4S_2$. The density, calculated for the empirical formula with Z = 4, is 7.64 g/cm³ and the calculated density for the idealized formula is 7.13 g/cm³. The ideal formula requires: Hg = 51.31, HgO = 27.70, CrO_3 = 12.79, S = 8.20, total = 100.00 weight %.

Edoylerite is insoluble or only slightly soluble in cold mineral acids, but dissolves slowly in aqua regia. The mineral turns greenish yellow after 24 hours at 115° C under infrared radiation but shows no change in its X-ray powder diffraction pattern after this treatment. At higher temperatures (red heat) in a closed tube, the mineral loses Hg and S, turns yellowish black, and then dark green upon cooling. The green residue gives the X-ray powder pattern of Cr_2O_3 (the synthetic equivalent of eskolaite).

ACKNOWLEDGMENTS

The authors thank D. E. Appleman (Smithsonian Institution) for help and advice during the initial stages of this project, E. D. Ghent (University of Calgary) for preliminary probe analyses, R. L. Oscarson (U.S. Geological Survey) for the scanning electron photomicrograph reproduced in Figure 2, R. D. Lancaster (Geological Society of Canada) for the photographs reproduced in Figure 1, and J. J. Rytuba (U.S. Geological Survey) for helpful discussions concerning mine locations. The authors also wish to thank A. Rosenzweig and an anonymous referee for excellent reviews of the manuscript.

REFERENCES

BAILEY, E. H., and EVERHART, D. L. (1964) Geology and quicksilver deposits of the New Almaden district, Santa Clara County, California. *U.S. Geological Survey Professional Paper,* **360**, 1–206.

BOCTOR, N. Z., SHIEH, Y. N., and KULLERUD, G. (1987) Mercury ores from the New Idria mining district, California: Geochemical and stable isotope studies. *Geochimica et Cosmochimica Acta,* **51**, 1705–1715.

CRIDDLE, A. J., STANLEY, C. J., CHISHOLM, J. E., and FEJER, E. E. (1983) Henryite, a new copper-silver-telluride from Bisbee, Arizona. *Bulletin de Minéralogie,* **106**, 511–517.

DUNN, P. J., PEACOR, D. R., CRIDDLE, A. J., and STANLEY, C. J. (1988) Ingersonite, a new calcium-manganese antimonate related to pyrochlore, from Långban, Sweden. *American Mineralogist,* **73**, 405–412.

ECKEL, E. B., and MYERS, W. B. (1946) Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California. *California Journal of Mines and Geology,* **42**, 81–124.

EMBREY, P. G., and CRIDDLE, A. J. (1978) Error problems in the two-media method of deriving the optical constants *n* and *k* from measured reflectances. *American Mineralogist,* **63**, 854–862.

FOX, K. E. (1983) Melanges and their bearing on late Mesozoic and Tertiary subduction and interplate translation at the west edge of the North American plate. *U.S. Geological Survey Professional Paper,* **1198**, 1–40.

LOVE, G., and SCOTT, V. D. (1981) Updating correction procedures in quantitative electron-probe microanalysis. *Scanning,* **4**, 111–130.

MILLAGE, A. H. (1981) Mineralogy of the Victor Claim, New Idria district, San Benito County, California. *M.S. Thesis, Stanford University, Stanford, California,* 1–172.

RICE, S. J. (1957) Chromite *in* Mineral commodities of California. *California Division of Mines and Geology Bulletin,* **176**, 121–130.

ROBERTS, A. C., BONARDI, M., ERD, R. C., CRIDDLE, A. J., and LE PAGE, Y. (1991) Wattersite, $Hg^{1+}_4Hg^{2+}Cr^{6+}O_6$, a new mineral from the Clear Creek claim, San Benito County, California. *Mineralogical Record,* **22**, 269–272.

ROBERTS, A. C., BONARDI, M., ERD, R. C., CRIDDLE, A. J., STANLEY, C. J., CRESSEY, G., ANGEL, R. J., and LAFLAMME, J. H. G. (1990a) Edgarbaileyite—the first known silicate of mercury, from California and Texas. *Mineralogical Record,* **21**, 215–220.

ROBERTS, A. C., ERCIT, T. S., ERD, R. C., and OSCARSON, R. L. (1990b) Szymańskiite, $Hg^{1+}_{16}(Ni,Mg)_6(CO_3)_{12}(OH)_{12}(H_3O)^{1+}_8 \cdot 3H_2O$, a new mineral species from the Clear Creek claim, San Benito County, California. *Canadian Mineralogist,* **28**, 703–707.

ROBERTS, A. C., SZYMAŃSKI, J. T., ERD, R. C., CRIDDLE, A. J., and BONARDI, M. (1993) Deanesmithite, $Hg^{1+}_2Hg^{2+}_3Cr^{6+}O_5S_2$, a new mineral from the Clear Creek claim, San Benito County, California. *Canadian Mineralogist,* **31**.

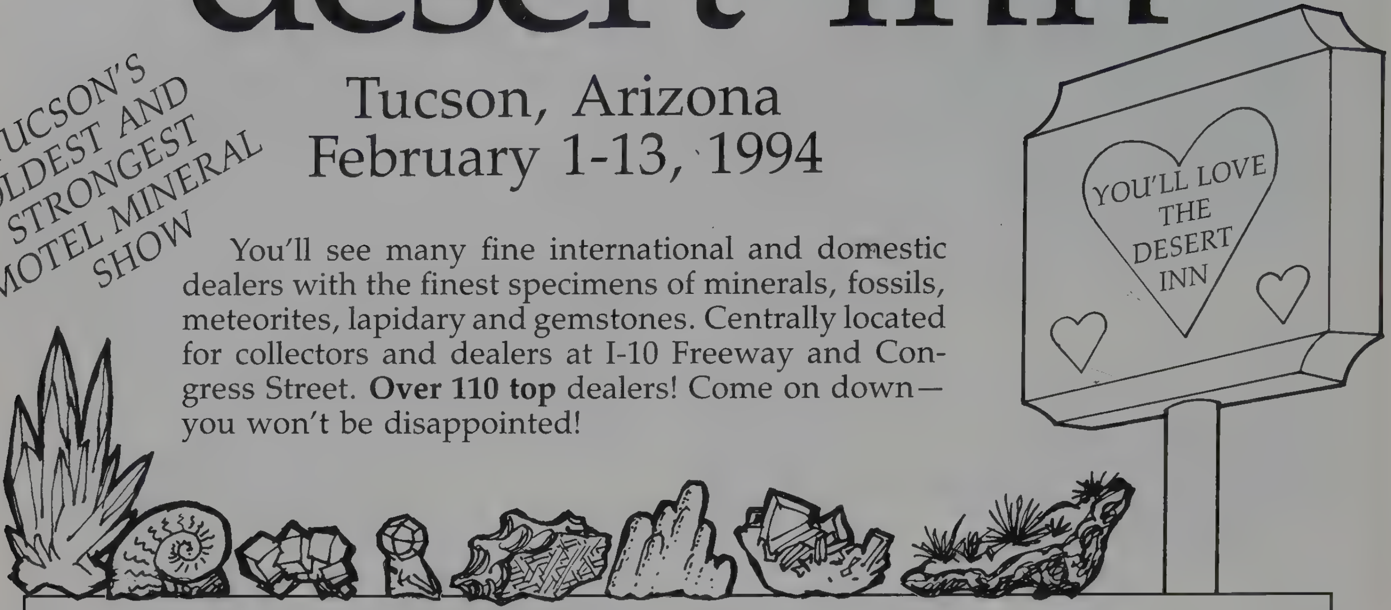
WALKER, G. W., and GRIGGS, A. B. (1953) Chromite deposits of the southern Coast Ranges of California. Chapter 2 *in* Pt. 2 of Geological investigations of chromite in California. *California Division of Mines and Geology Bulletin,* **134**, 39–88.

desert inn

TUCSON'S OLDEST AND STRONGEST MOTEL MINERAL SHOW

Tucson, Arizona
February 1-13, 1994

You'll see many fine international and domestic dealers with the finest specimens of minerals, fossils, meteorites, lapidary and gemstones. Centrally located for collectors and dealers at I-10 Freeway and Congress Street. **Over 110 top** dealers! Come on down—you won't be disappointed!



SOME DESERT INN MINERAL DEALERS:

Antero Minerals & Jewelry—Lake Havasu City, AZ—Bill & Lisa Gagne—**Room 101**—*Arkansas Quartz, Fine Brazilian Amethyst, Silver Jewelry*

Zaire Minerals—Lubumbashi, Zaire—Henry Vandormael—**Room 105**—*Cuprite, Malachite, Chrysocolla, and other fine Zaire Minerals*

Rupalee Gems & Minerals—Bombay, India—Rupesh Zaveri—**Suite 102–104**—*Green Apophyllite, Heulandite and many other fine Indian Zeolites*

Saint-Roy—Paris, France—Paul Obeniche—**Room 111–113**—*Celestine, polished Spheres and Eggs from Madagascar, Worldwide Minerals*

Rocks of Ages—Tustin, CA—John and Linda Stimson—**Room 126**—*Fine Minerals, Rare Books, Mining Artifacts*

Geological Specimens Int'l.—Tucson, AZ—Maudine & Bob Sullivan—**Room 117**—*Worldwide Classic Minerals, Meteorites, Tektites, Decorator Specimens*

Aurora Minerals West—Sealrock, OR—Mike & Susie Siegel—**Room 118–120**—*Brazilian Amethyst, Quartz, Calcite, and other Worldwide Minerals*

I Sassi di Alfredo Ferri—Milan, Italy—Alfredo Ferri—**Room 123**—*Ruby in Zoisite (Tanzania) specimens and carvings; Deep-Cleaning Gun*

Colorado Gem & Mineral Co.—Tempe, AZ—Jack Lowell—**Room 128**—*Brazilian, Russian, Afghan, Pakistani Minerals and Morenci Azurite*

Minéraux du Claridge—Paris, France—Jean-Pierre Agesilas—**Room 131**—*Fine Australian Minerals, French and European Specimens*

Mono International—Bombay, India—Dinesh Zaveri—**Room 134**—*Indian Zeolites, Apophyllite, Heulandite, etc., plus Lapidary items*

Donald K. Olson & Associates—Bonsall, CA—Don and Gloria Olson—**Suite 202–204**—*Mineral Specimens, fine faceted Gemstones, and Custom Cabochons*

African Gems & Minerals—Johannesburg, SA—Rob Smith—**Room 150**—*Fine Specimens from South Africa & Namibia; also Lapidary items*

Freedom Valley Minerals & Gems—Fremont, CA—Ali Baigzad—**Room 224**—*Minerals direct from Afghanistan & Pakistan: Topaz, Aquamarine, Lapis, etc.*

Now in 2 Hotels!

ARIZONA MINERAL and FOSSIL SHOW

FEB. 4 - 12, 1994

10 :00 A.M. to 7:00 P.M. Daily

PART I

EXECUTIVE INN
333 W. Drachman ● Tucson
across Oracle from the Quality Inn

PART II — *New in 1994*

QUALITY INN - University
1601 N. Oracle ● Tucson
across Oracle from the Executive Inn

EXECUTIVE INN DEALERS

AESTHETICS UNDERGROUND - Canada
ALVARO LUCIO MINERALS - Brazil
ANA ARRUDA - Azores
ARIZONA MINERALS
ARTIFACTUAL IMPORT
ATELIER DRAPELA - Austria
AUSROX - Australia
BITNER'S INC. MINERALS
BOB JACKSON MINERALS
BOTTOMLESS PIT MINERALS
BRAZIL MINERALAND - Brazil
BRAZILIAN MINERALS - Brazil
BRUCE & JO RUNNER
BURKARD, HORST - Germany
C D MINERALS - South Africa
C S QUEIT - South Africa
C T MINERALS
CAMERON OWLS
CARROL & C ENTERPRISES INC.
CARTER RICH FINE MINERALS
CHRISTIAN GORNIK - Germany
CLAUDE BEN DAVID - Canada
COLLECTION HEINEAULT - Canada
COLLECTOR'S STOPE
CONTINENTAL DRIFTER
COOGAN GOLD CO
CRYSTAL SPRING MINING & JEWELRY CO., INC.
CRYSTAL SYSTEMS
D J MINERALS INC.
DAN WEINRICH MINERALS
DAVID M CRAWFORD
DAVID SHANNON MINERALS
DELTA BRAVO
DENVER BOX CO.
DIDONI FRANCESCO - Italy
DIVERSIFIED MINERALS
DJ "DOUG" PARSONS
DONALD K OLSON AND ASSOC.
DRY CREEK MINERALS
DUTCH RUSSIAN MIN. SOC. - Holland
E & R CRYSTALS
ENRIQUE KUCERA MINERALS - Spain
ERASIA STONE COOPERATION - Holland/Russia
ERICH'S MINERALS - Austria
ERNIE SCHLICHTER MINERALS
ESMERALDA - France
EXCALIBUR-CURETON CO.
FABRE MINERALS - Spain
FALCO BAATZ MINERALIEN-FOSSILIEN-Germany
FENN'S GEMS & MINERALS
FERSMAN MINERALOGICAL MUSEUM - Russia
FLEDGELING MINERALS
FOSSILSOURCE
FOSTER RICHARDS
FRANKFURTER MIN. KONTOR - Germany
FROM THE ADIT
FTS ENTERPRISES
GALLERY OF GEMS
GEBRUDER HENN - Germany
GEM & MINERAL OF DALLAS
GEM CITY LAPIDARY INC.
GEM TECHNOLOGY INDUSTRIES
GEMINI MINERALS
GEO-ARGENTINA MINERALS - Argentina
GEOCOMMERCE-Bulgaria
GEOFIL - Portugal
GEORGE HESLEP FOSSILS
GEORGE STEVENS MINERALS
GOOD ENOUGH, INC.
H. OBODDA - Z BOOKS
HORIZON MINERALS
INKA CUZCO TRADING S.A. - Peru
IRISH ROVERS
JACK & ELAINE GREENSPAN
JAMES & DUANE TYNSKY FOSSILS
JEFFREY MINING CO., INC.
JENDON MINERALS
JEWEL TUNNEL IMPORTS
JOHN C. MEDICI
JOUTY MICHEL MINERALS - France
K A R P - Czech. Republic
KING DRAGON
KRISTALLKELLER - Germany
L & T CREATIONS
LANG'S FOSSILS & METEORITES
LAPIDARY JOURNAL MAGAZINE
LAWRENCE CONKLIN
LE MINERAL BRUT - France
LELKES - Hungary
LUIS LEITE - Portugal
LUIS MIGUEL FERNANDEZ - Spain
LUIZ MENEZES MINERALS - Brazil
MALACHITE STONE
MANFRED SCHWARZ - Germany
MARTIN ROSSER MINERALS - Australia
MERCER MINERALS
MESOLIET MINERALS - Holland
METRO MINERALS
MIKE BERGMANN MINERALS
MINAS VICTORIA - Spain
MINERAL CABINET
MINERAL MINER
MINERLIEN ZENTRUM - Germany
MORGAN MARCUE
MOUSSA MINERALS - England
MYRDDIN EMRYS LTD.
NATURAL CONNECTION
NORTH STAR MINERALS
ORDWAY'S MINERALS
PACKAGING STORE
PALA INTERNATIONAL'S THE COLLECTOR
PALEO FACTS
PAT HENDRICKS GEMS & MINERALS
PAUL A. LOWE - England
PEQUA MINERALS
PETER LYCKBERG - Sweden
PETER MEGAW MINERALS
PLUMBAGO MINING
PRECIOUS EARTH CO.
PRIMARY GEMS
PRISMA MINERALS - Spain
RAGING MOLE MINERALS
RED BERYL COMPANY
RED METAL MINERALS
ROCK & MINERAL MAGAZINE
ROCK ART - England
ROCK BOTTOM MINING
RUSSELL - ZUHL, INC.
SANDOR P. FUSS
SCOTT WILLIAMS MINERAL CO.
SILVERHORN
SMITH SPECIALTIES
ST. PETERSBURG MINING INST. - Russia
STD MINERAL CO.
STONE FLOWER - Russia
SUNSHINE MINERALS
SYNTAXIS
THE SUNNYWOOD COLLECTION
TIDESWELL DALE ROCK SHOP - England
TINTIC & TIGER TRADING CO.
TOM WOLFE MINERALS
TOP MINERALS INTERNATIONAL - Austria
TRADEWELL
TRAP HILLS MINING & MINERALS
TYSON'S FINE MINERALS INC. - Canada
VALADARES MINERALS - Brazil
VAN SCRIVER'S MINERALS - Bulgaria
VASCONCELOS - Brazil
WAYNE A. THOMPSON MINERALS
WHOLE EARTH MINERALS
WHOLESALE TENNESSEE MINERALS
WILKE MINERALIEN - Germany
WILLIS' EARTH TREASURES
WRIGHT'S ROCK SHOP, INC.
XTAL - Dennis Beals

QUALITY INN DEALERS

ART OF GOD
B.C. FOSSILS
BARBERA COMPANY
BILL HAWES FOSSILS
BLACK HAWK FOSSILS
BLACK HILLS INSTITUTE
BLAINE REED METEORITES
BUG HOUSE
BURKARD, HORST - Germany
BURNETT PETRIFIED WOOD, INC.
C & C FORRESTER
CANADA FOSSILS LTD. - Canada
CARROL ORIGINALS
CAVEMAN LAPIDARY
CINCINNATI APPLIED PALEO
COELODUS - Italy
COPPER CITY ROCK SHOP
CRISTA-GALLI
CRYSTAL SPRINGS MINING CO.
CUSTOM PALEO
D & M ROCK & GEM
DAKOTA FOSSILS
DEN'S PETRIFIED CRITTERS
EARTH ENTERPRISES
ELK CREEK FOSSILS
EXTINCTIONSFACOP'S = Spain
FOOTHILLS WHOLESALE BOXES
FOX HILLS FOSSILS
FRONTIER FOSSILS
GALERIE FOSSILE - Germany
GEO-EXPERT - Germany
GEOLINEA - Italy
GEORGE & PAT FULLER
GEOSCIENCE ENTERPRISES
GREEN RIVER GEOLOGICAL LABS
HALLELUJAH MINES
HILLTOP MINERALS
HOUSE OF PHACOPS
INGEBORGS STENAR AB - Sweden
INLAND DIAMOND
J & S FOSSILS
JEANNE'S ROCK & JEWELRY
L & J FOSSILS - Austria
LAMP-TOPPERS LTD.
LARRY WILLIAMS PALEO SCULPTURE
LEONHARDT & PARTNER - Germany
LOVELACE
MAXILLA & MANDIBLE LTD.
McCARTHY'S FOSSILS
MID IOWA MINERALS
MILLENNIUM, INC.
MINERALIEN ZENTRUM GMBH - Germany
MINERALIEN-FOSSILIEN-GALERIE - Germany
MONTANA FOSSILS
MT. BLANCO FOSSIL CASTS
MURPH'S
NORD FOSSIL - Germany
OJEIL LEBANESE FOSSILS - IItaly
ORIUS GROUP
PALEO IMPRESSIONS
PALEO-ART - Germany
PALEOSEARCH
PETER GRISS - Germany
PHOENIX FOSSILS
PITTMAN FOSSILS - Germany
PLANEY CO. LTD. - Japan
POOR RICHARD'S
POTOMAC MUSEUM GROUP
PRIMIGENICES FOSSILS - Netherlands
R.J.B. ROCK SHOP
RED BERYL MINE
SCHEELE FINE ARTS
SIMON COHEN FOSSILS - England
STEVEN WOLFE FOSSILS
TESOROS NATURALES - Spain
TOM WITHERSPOON FOSSILS
TRIEBOLD PALEONTOLOGY
TYNSKY FOSSIL FISH
ULRICH DERNBACH - Germany
WAPPO GEMS
WARFIELD FOSSILS
WEST COAST MINING
WESTERN PALEO
WHOLESALE PALEO
WIESNER MINERALS
WORLD FOSSILS

***250 TOP QUALITY** Mineral & Fossil Dealers in One Location!*

*Open to the Public ● **Free** Shuttle Bus ● **Free** Parking ● Wholesale and Retail Dealers*

Tucson's Center For Fossil & Mineral Enthusiasts

Information/Rooms: MARTIN ZINN EXPOSITIONS, P.O. BOX 999, EVERGREEN, CO 80439-0999

THE MUSEUM DIRECTORY

Geology and Meteorite Museums University of New Mexico

Curators:
Gary Smith (Geology)
Adrian Brearley (Meteorites)
Tel: (505) 277-4204
Dept. of Earth & Planetary Sciences
Northrop Hall
Univ. of New Mexico
Albuquerque, NM 87131
Hours: 9–4 M–F (closed on school holidays)
Specialties: Worldwide minerals and meteorites, New Mexico fossils, Harding Pegmatite Mine Collection

Museum of Geological Sciences, V.P.I.

Curator:
Dr. Susan C. Eriksson
Tel: (703) 231-6029
2062 Derring Hall
Virginia Polytechnic Inst. & State University
Blacksburg, VA 24061-0420
Hours: 8–4 M–F, 10–2 Sat.
Specialty: Virginia and worldwide minerals & fossils

Montana Tech Mineral Museum

Curator:
Richard Berg
Adjunct Curator:
Lester G. Zeihen
Tel: (406) 496-4414
c/o Montana Tech
Butte, MT 59701-9981
Hours: 8–5 daily June–Labor Day; M–F & Sun afternoons Labor Day–May
Specialties: Montana & Idaho minerals; systematics

Harvard Mineralogical Museum

Curators:
Dr. Carl A. Francis
William Metropolis
Tel: (617) 495-4758
24 Oxford Street
Cambridge, Mass. 02138
Hours: 9–4:30 M–Sat; 1–4:30 Sun
Specialties: Systematic Mineral Collection

William Weinman Mineral Museum

Curator: Kim B. Cochran
Tel: (404) 386-0576
P.O. Box 1255
Cartersville, GA 30120
Hours: 10–4:30 Tue–Sat, 2–4:30 Sun.
Specialty: Georgia & worldwide minerals & fossils

Denver Museum of Natural History

Curator of Geology:
Jack A. Murphy
Tel: (303) 370-6445
Dept. of Earth Sciences
20001 Colorado Blvd.
Denver, CO 80205
Hours: 9–5 daily
Specialties: Colorado minerals

Geology Museum Colorado School of Mines

Curator: Virginia A. Mast
Tel: (303) 273-3823
Golden, Colorado
Hours: 9–4 M–Sat, 1–4 Sun. (closed on school holidays & Sundays in the summer)
Specialties: Worldwide minerals; Colorado mining & minerals

A. E. Seaman Mineralogical Museum

Curator (mineralogy):
Stanley J. Dyl II
Adjunct Curator:
Dr. John A. Jaszczak
Tel: (906) 487-2572
Michigan Technological Univ.
Houghton, Michigan 49931
Hours: 9–4:30 M–F
Specialty: Michigan minerals, copper minerals & worldwide minerals

Houston Museum of Natural Science

Curator (mineralogy):
Joel Bartsch
Tel: (713) 639-4673
Fax: (713) 523-4125
1 Hermann Circle Drive
Houston, Texas 77030
Hours: 9–6 M–Sat; 12–6 Sun
Specialty: Finest or near-finest known specimens

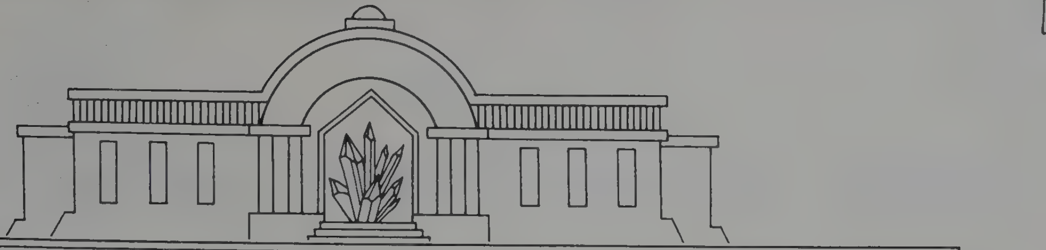
Natural History Museum of Los Angeles County

Curator (mineralogy):
Dr. Anthony R. Kampf
Tel: (213) 744-3328
900 Exposition Blvd.
Los Angeles, CA 90007
Hours: 10–4:45 Tu–Sun.
Specialties: Calif. & worldwide minerals, gold, gem crystals, colored gemstones
Support organization:
The Gem and Mineral Council

Sterling Hill Mining Museum

Curators:
Robert Hauck
Richard Hauck
Tel: (201) 209-7212
30 Plant Street
Ogdensburg, NJ 07439
Hours: 10–5 M–Sun, Mar.–Dec.
Specialty: Local mining & minerals

Museums listed alphabetically by city



THE MUSEUM DIRECTORY

Carnegie Museum of Natural History
Collection Manager:
Marc L. Wilson
Tel: (412) 622-3391
4400 Forbes Avenue
Pittsburgh, PA 15213
Hours: 10–5 Tues–Sat,
10–9 F, 1–5 Sun,
closed Mon. & holidays
Specialty: Worldwide
minerals & gems

Musée de géologie de l'Universite Laval
Curator:
André Lévesque
Tel: (418) 656-2193
Geology Dept., 4th floor
Adrien-Pouliot Building
Québec, Que., Canada G1K 7P4
Hours: 8:30–5 M–F
Specialties: Quebec and
worldwide minerals and
fossils; Miguasha fishes

Museum of Geology
Director:
Philip R. Bjork
Tel: (605) 394-2467
South Dakota School of
Mines & Technology
501 E. St. Joseph Street
Rapid City, SD 57701-3995
Hours: 8–5 M–F, 9–4 Sat., 1–4 Sun.
Specialty: Black Hills minerals,
esp. pegmatites

Jurupa Earth Science Museum
Curators:
Dr. Jack Nieburger
William Hudson
Tel: (714) 685-5818
7621 Granite Hill Dr. (Hwy 60)
Riverside, CA 92509
Hours: 1–4 Tues–F, 10–5 Sat.
Specialty: Crestmore &
worldwide minerals & fossils

Penn State Earth & Mineral Sciences Museum
Curator:
Andrew Sicree
Tel: (814) 865-6427
Steidle Building
University Park
State College, PA 16802
Hours: 9–5 M–F & by Appt.
(closed holidays)
Specialties: Mineral properties
exhibits; "velvet" malachite; old
Penna. minerals; mining art

M.Y. Williams Geological Museum
Curator: Joe Nagel
Tel: (604) 822-5586
University of British Columbia
6339 Stores Road
Vancouver, B.C.,
Canada V6T 1Z4
Hours: 8:30–4:30 M–F
1:30–4:30 W (Collector Shop)
Specialty: B.C., Pacific NW,
Canada; Exhibit Quality

Private Museums

Hampel Mineralogical Museum
Curator:
Lance T. Hampel
Tel: (414) 255-4540
P.O. Box 39
Germantown, WI 53022
Hours: by Appt.
Specialty: Midwest minerals

Museo Mineralógico M. Romero
Curator: Jorge Díaz de León
Tel: (238) 3-00-07
7 Norte #356
Tehuacán Puebla, México 75700
Hours: 10–12 noon M–Sat
4–6 p.m. M–F & by Appt.
Specialty: Mexican Minerals

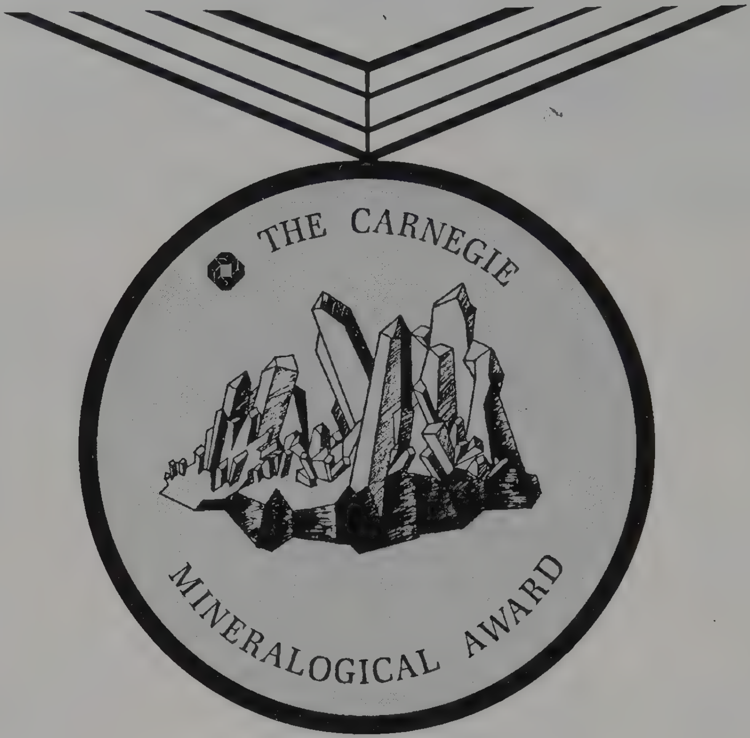
Europe

Museu de Geologia "Valentí Masachs"
Curator (Mineralogy):
Joaquim Sanz i Balagué
Tel: 34-3-877-2088
Polytechnical University
of Catalonia
Av. de Les Bases de Manresa, 61-73
08240 **Manresa** (Catalonia)
Spain
Hours: 11–2 p.m. Sundays,
and by Appointment
Specialties: Catalonia,
Spain & worldwide minerals &
Fossils

Sorbonne Mineral Collection
Curator of Mineralogy:
Pierre Bariand
Tel: (33) 144-275288
Univ. Pierre et Marie Curie
(entrance: 34 Rue Jussieu)
Lab. de Minéralogie
4 Place Jussieu
75252 **Paris** Cedex 05, France
Hours: 1–6 W–M
Specialty: Worldwide minerals

Additional listings welcome!
Send vital information, as shown, to the editor. There is a modest annual fee (lower than our regular advertising rates).

the
1993 Carnegie Mineralogical Award!



LAST CALL FOR NOMINATIONS

The Carnegie Mineralogical Award was established in 1987 to recognize outstanding contributions which promote mineralogical preservation, conservation and education, ideals embodied in the Carnegie Museum's **Hillman Hall of Minerals & Gems.** The award is open to individuals, groups, organizations and institutions. Private mineral enthusiasts, collectors, educators, curators, and mineral clubs and societies, as well as museums and universities, are all eligible. The award, consisting of a certificate of recognition, a cast bronze medallion, and a $1500 cash prize, is presented each February during the Tucson Gem and Mineral Show. Past recipients are the Tucson Gem & Mineral Society, John Sinkankas, Frederick H. Pough, Paul E. Desautels, Miguel Romero and Carl A. Francis.

The Mineral Museums Advisory Council administers the award and oversees the selection process. Nominations for the **1993 Carnegie Mineralogical Award** may be submitted, until December 31, to the following address.

Marc L. Wilson
Director, Carnegie Museum of Natural History
4400 Forbes Avenue
Pittsburgh, PA 15213

A Gourmet's Guide to Russia

by **Rock H. Currier**

Do you dream of cupped double-handfuls of flawless natural diamond crystals, hundreds of pounds of big gold and platinum nuggets, emeralds and sapphires as big as door knobs? Giant open pit mines with waterfalls cascading over 40-foot benches of apatite? If so, read on and I will tell you of my recent trip to Russia, the once-feared home of communists and the KGB.

I was too wise and chicken to take the trip on my own, so I hounded a real mineralogist, Dr. Eugene Foord of the U.S.G.S., into going with me. All activities that offer adventure, good times and the prospect of getting good rocks seem to grow, and before we left we were joined by Dr. Michael Brownfield of the U.S.G.S. and my good friend, Gary Moss. We had invitations from various scientific groups in Russia and were able to obtain academic visas. This enabled us to escape the heavy hand of the Russian Intourist organization. Gene and Mick had purchased a 386 computer that we were to deliver to Irkutsk.

MOSCOW

We arrived in Moscow at about 3 p.m., August 23, 1992. After a struggle with our grossly overweight, gift-laden luggage we arrived at the Academic Hotel, not far from the old walled enclosure of the Kremlin. We immediately took a kilometer hike down the street to the Fersman Museum. Here, in a park-like setting, an old brick building houses the best mineral collection in Russia. For most of the 20th century Russia has been isolated from the West. During this period they have created the biggest mining industry and the largest cadre of earth science professionals in the world. With this in mind, it is not surprising that their national museum, the Fersman, contains many fine and interesting specimens seldom seen in the West.

A guard told us that the Museum was closed, but invoking the name of the director, Dr. Godovikov, got us into the building. There we were eyed suspiciously by another guard and one of the ubiquitous older ladies who patrol each floor of every hotel and each room of every museum. They keep a vigilant eye on everything, ready to scold at the least infraction, but often willing to help as well. Finally we were rescued by senior staff members Gene and Mick knew from a previous visit and I knew from their presence at some mineral shows where they had sold specimens to help pay for museum activities.

The Fersman Museum is renovating some of their displays, and about half the exhibition is closed. The specimens are housed in glass display cases in a large open room and scattered among them are some spectacular items. One pedestal holds a big white crystal that measures about 10 cm thick and 25 cm high with a nice termination. The crystal encloses a sizable transparent area that would grab the attention of any gem cutter. After laboriously translating its label, we discovered that it was a huge *natrolite* crystal! On another pedestal there was a meter-high fluted malachite vase. In a corner, still crated up, was a vase of solid, fine-quality rhodonite of about the same size. Everywhere we looked we saw specimens that were entirely new to us. With grinding envy we gathered around the display case containing their atacamite pseudomorph after mouse.

Gary and I got square eyeballs looking at the displays while Gene and Mick consulted with their professional colleagues. The museum usually has some specimens for sale, and I bought a stillwellite crystal about an inch in diameter, plus a number of terrible looking rare minerals.

All of our hotels had small "lunchrooms" which were usually open for breakfast, lunch and dinner. Often it seemed that the lunchroom was closed for no apparent reason, and we quickly learned to buy extra food whenever we could. Many nights we were forced to make do with whatever food we had in our rooms. Gary said we were becoming like our plains Indians who ate well only when the buffalo ran. Often, when we were treated to an exceptionally good meal, one of us would look at another and mutter, "Buffalo runnem good." The food was very cheap. A typical breakfast would cost the four of us less than two dollars. Hotels were also inexpensive, and I don't believe we ever paid more than $12 a night. In contrast to the $80 to $200 per night of the Intourist hotels, our lodgings were bargains by Western standards. Inflation of the ruble was running at about 20% a month. Entering the country, we officially got 160 rubles per dollar and, on leaving, about 230. The black market rate was only about 10% better, so we stayed away from changing money on the street.

The subways in Moscow are fabulous. Each station has a different design and lighting system. The interiors are finished with different kinds of natural polished stone. It cost only a ruble (half a cent) to ride the subway and only half of that to ride the buses and street cars. It was obvious that public transport in Russia was run at a great loss to the state. Food is also heavily subsidized, as are many of the industries, and the terrifying problem for Russia is that the people can't pay more for things because they are paid so little. The government is faced with keeping prices artificially low and letting inflation spiral out of control, or raising prices till people literally can't afford the essentials of life. It is a terrible dilemma and many governments throughout history, rather than face such hard realities, have started wars to divert the attention of their populations away from such dreadful problems.

We went to check out the flea market in Izmailovsky Park near the soccer stadium where we were told that a number of mineral dealers hung out. We were astonished at the size of the thing. There were miles of small tables of every possible kind of tourist goodie and collectible. In this multitude were at least 50 people selling mineral specimens, fossils, lapidary items, gemstones and jewelry. I made some useful contacts and even bought a few specimens. Gary bought a big red velvet communist banner with a picture of Lenin on one side. Soon I had to have one, and finally Gene caved in and bought one too. We all bought one of the classic Russian fur hats. There were thousands of painted lacquered (*Palekh*) boxes and *matrushka* dolls for sale. *Matrushka* (Russian for "little mother") dolls are pear-shaped and cleverly come apart in the middle to reveal another smaller doll

Figure 1. **Exhibit room in the Fersman Museum, Moscow.**

inside, and so on for up to 24 dolls, each smaller than the last. They are made from wood and are painted with all manner of clever, colorful designs.

When we returned to our car we found that the right rear window had been smashed, and the coats in the back seat had been stolen. Crime in Moscow is not uncommon, and it was unsettling to be confronted with it so blatantly. I now had to face our visit to the Russian Arctic in short sleeves.

We ran around Moscow looking at what specimens various individuals had for sale. Everyone seemed to live on the top floor of big blocky five to ten-story walk-up apartment houses that frequently contained urine-scented stair wells. We found more good specimens to buy than we expected but no large quantity of anything. Another guy, let us call him Alexi, had a place of business in an old building that had been designated as a historical landmark; he had it stuffed full, in wild disarray, of specimens from all over Russia. He had a large quantity of dioptase specimens from the classical locality of Kazakhstan. He also had substantial quantities of vivianite from Kerch and some fine small balls of thomsonite crystals from the Yakutia region. I bought something over a thousand specimens of dioptase and smaller quantities of the vivianite and thomsonite.

We spent some time visiting Red Square and the churches, but the highlight of our Kremlin visit was the Diamond Fund ($16 per ticket) and the Armory. It is located in a big vault-like series of rooms with as much security as the Crown Jewels of England. We were given a closely supervised and guided 45 minute tour. There must be over 1000 pounds of gold nuggets ranging in size from over a foot across down to little tiny ones as big as your fist. In addition there are about 200 pounds of platinum nuggets from almost double fist size down to the size of a hen's egg. There are hundreds of rough diamond crystals, all gem quality. The crystals are predominantly octahedrons and macles (flattened spinel-law twins) from 1 to 2 cm in size. The cut diamonds are magnificent and the Royal crowns are even more impressive. There is an unforgettable, nearly flawless emerald easily 5 cm across, and an even bigger dark blue sapphire. After that, the cases of modern jewelry seemed almost pedestrian. The Armory contains a room of Imperial Russian carriages (one with mica windows) and in other rooms clothing, arms, thrones, crowns and other palace knickknacks that would practically poleax your average antique dealer.

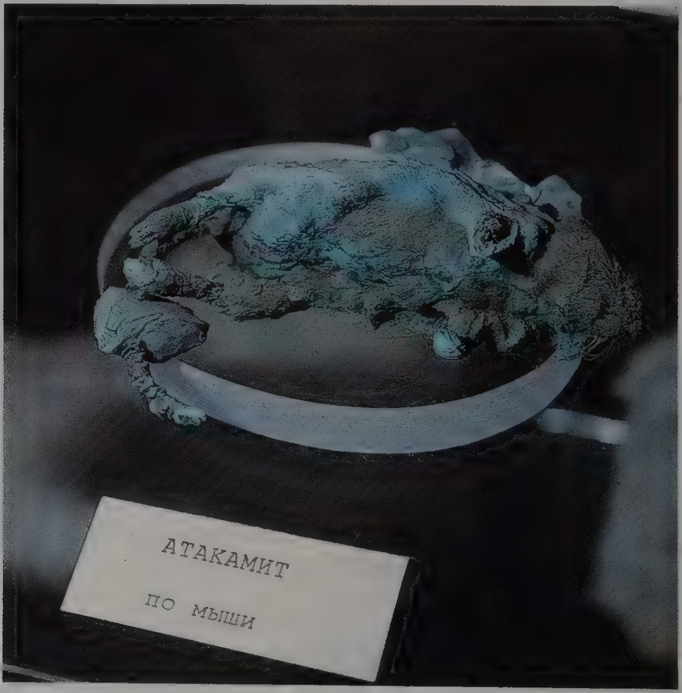


Figure 2. **Atacamite replacing a mouse; Fersman Museum, Moscow.**

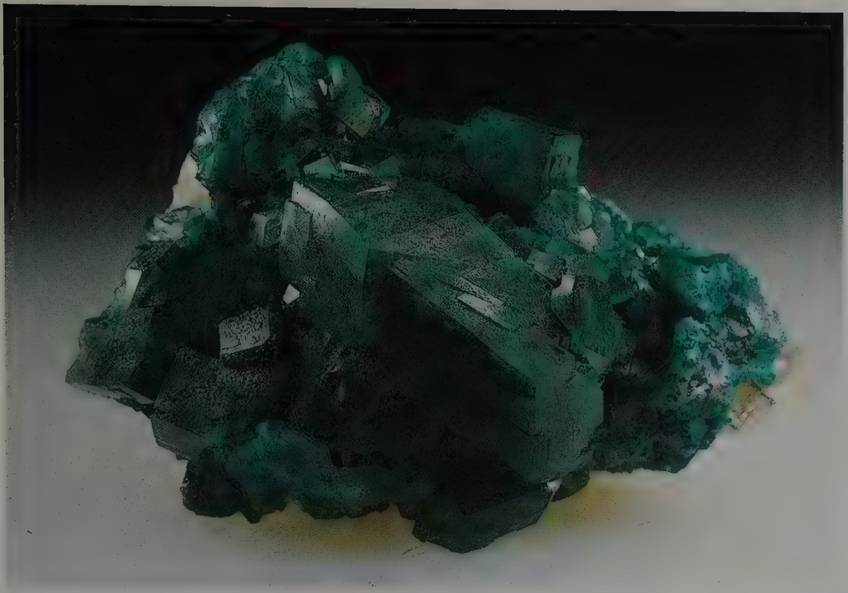


Figure 3. **Dioptase crystals to 2.7 cm, from the Altyn Tyube mine, Kazakhstan. Rock Currier collection.**

IRKUTSK

Our flight for Irkutsk left from the domestic airport, which was in total chaos. It reminded me of the train station in Bombay with seething humanity and families camping out on the floors. Fortunately, we had paid for our tickets in dollars (at about twenty times what the Russians pay) and were allowed access to Intourist facilities which were much less crowded and better organized. We were told not to check the computer boxes but to carry them directly onto the Aeroflot plane because of almost certain damage or theft. Aeroflot is a leading contender for the worst airline in the world, and the appellation "Aeroflop" springs irresistibly to the tongue of its English-speaking clients.

Figure 5. **Tourmaline crystal, 5 cm, from Transbaikalia. Rock Currier collection.**

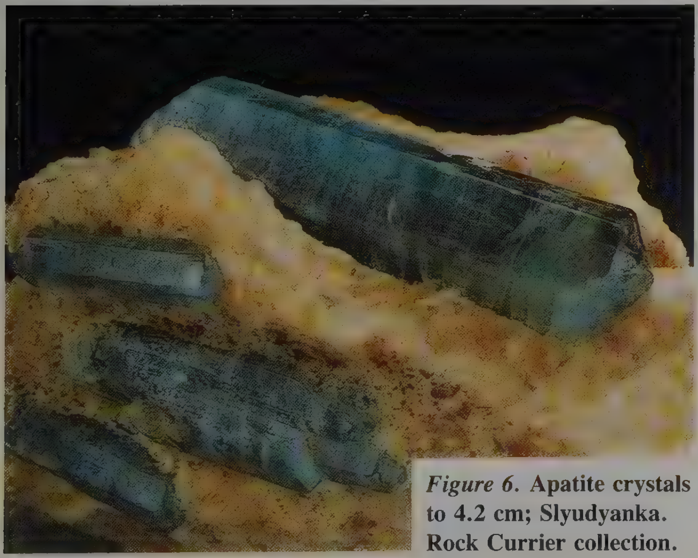
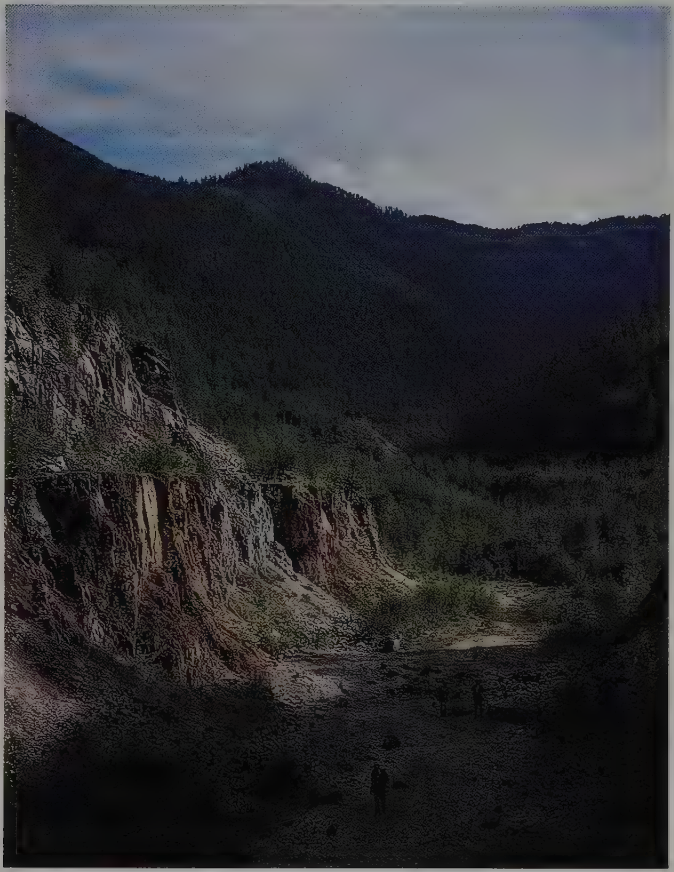


Figure 6. **Apatite crystals to 4.2 cm; Slyudyanka. Rock Currier collection.**

Figure 4. **Mica mine at Slyudyanka near Lake Baikal, source of blue apatite crystals in orange calcite. Rock Currier collection.**



We wrestled the big computer boxes up the ramp and down the aisle and found a little room in the rear of the airplane between the bathrooms where we could stash them. No one said a word or even looked at us funny. The seats were cruelly small even for an average-sized person. Leg room was nonexistent, and for me the trip was painful. There was a small dog on our flight that was carried in a canvas bag and even put through the X-ray machines. On another flight we had a full-size poodle and a German shepherd. Because of fog, our flight was diverted without notice to Ulan Ude on the Mongolian border. Again we struggled with the computer off and back on the plane before finally arriving in Irkutsk several hours late. We were effusively greeted by Dr. Boris Shmakin and others from the Geochemical Institute.

We were at last able to divest ourselves of the great albatross of the computer. They housed us in a spacious, ground-floor apartment in the academic city near the Institute. The first order of business was to visit the Geochemical Institute and their mineral museum. It was a good museum of modest size, and they even had a small gift shop that sold miscellaneous small specimens and jewelry made from local stones. In a nearby laboratory, cubic zirconia was first synthesized, and we were later shown some unattractive brown nephrite jade that they had changed into an attractive green color. The Russians are very advanced in their production of synthetic minerals. I bought a beautiful, flawless crystal of synthetic amethyst that measures about 3 by 8 by 15 cm to keep as a reference specimen. At the recent Denver gem and mineral show I put it in my back pocket with some of the shiny, almost black-looking termination sticking out and pretended it was the world's best azurite. It took more than just a casual look to tell that it wasn't, and I managed to hoax any number of my friends.

The next morning a small bus showed up and took us on a two-hour ride through pine-covered mountains to the small town of Slyudyanka, which means "Mica Town." It is located at the south end of Lake Baikal, which holds approximately one-sixth of all the fresh water (excluding ice) in the world. The town was named after the mica found nearby. Originally the mica was used for windows in homes, carriages and stoves. Eventually this material became known as muscovite because it was first noticed in Muscovy (the old name for Russia). We visited a big magnesite mine, hoping to find some red spinels, but had no luck and moved on to an abandoned mica quarry. We were able to collect cleavage sections of phlogopite crystals up to 15 cm in diameter, and saw evidence of well-formed blue apatite crystals frozen in pale orange calcite. We didn't have time to do more than pick around a little, but it was obvious that many good specimens could be collected. We also visited a small private museum and hotel complex aimed at the collector. They wanted $35 a night, but there was no hot water in the rooms and only one outside Asian-style toilet available for guests. They sold specimens as well, and we all got a few apatite specimens. I asked if I could buy 500 specimens to be sent to the United States. They had absolutely no interest in exporting mineral specimens and were convinced that it would be nearly impossible to do so.

We had lunch in a worker's-style cafeteria with cabbage soup, bread, pasta and cheese to eat. It was good, filling and very cheap (about $3 for seven people). Gary wanted to go swimming in Lake Baikal in spite of its frigid reputation. He even made me go in with him, but I soon got out, practically running on top of the water to get back to shore. While in the region we drank the water that was drawn from the lake. It is reputed to be some of the cleanest water in the world. In other Russian cities we were reluctant to drink tap water and found we could seldom buy non-carbonated drinking water in bottles. At airport hard-currency shops we would buy six or eight bottles to carry with us.

The next day we visited the Baikal Quartz Gemstone Company in the Irkutsk suburb of Smolenshina. I particularly wanted to buy some of the rubellite tourmaline crystals they had from the Transbaikalia region. They initially showed us some lots that Gene and Mick said they had been offered on a previous trip; with this as a starting point, bargaining proceeded. Eventually I cut a deal for a hundred or so rubellite crystals from less than an inch to two inches. Matrix pieces were noticeably absent.

Next we visited their cutting factory, and I was astonished to see the abundant use of modern diamond tools in their various lapidary operations. They had one big diamond saw with a blade almost two meters in diameter. It was being used to cut a boulder of charoite the size of a sofa into twelve-inch-thick slabs. They were using diamond core drills to make cylinders of nephrite jade for beautiful, small round boxes. At first, a clerk quoted very attractive prices in rubles, but as soon as the factory manager arrived the prices changed to dollars and were bumped up about four times. Even offering to buy large quantities of various items and initiate a long-term relationship would not budge him on prices. Later I was able to buy the same lapidary items at the flea market in Moscow at a fraction of the factory price. It was just another of the many examples of the general Russian policy where foreigners are charged many times the "Russian" price.

We were treated royally by our friends in the Institute and invited into their homes for dinners that were frequently punctuated by toasts of vodka, served in small shot glasses. These were tossed back with one gulp into cast iron stomachs. Had I fully participated in these toasts I would have ended up under the table. We enjoyed sliced fresh tomatoes and found particularly delectable their homemade preserves made from local berries. After dinner some specimens for sale were trotted out. Most were rare species with a sprinkling of more common specimens like almandine garnets and blue apatites. We all bought a few things, but there was no large quantity of anything available. Discussions followed about potential business we might do, and they said they would do their best to get quantities of various items for me, including the blue apatite specimens. They felt that exporting the specimens would be a problem, but we all felt that in the future regulations would be relaxed.

On one of the flights on our way back to St. Petersburg, four people who had no seats ran a black-market business in the rear of the airplane in what we thought were small bottles of perfume. Dinner consisted of a cracker that might have been a stale dog biscuit and a small piece of greasy chicken which had obviously not been plucked too well. By this time even the pin feathers tasted good. If anything complimentary can be said about Aeroflot, it is that the pilots landed the planes so smoothly that it was sometimes difficult to tell exactly when the plane had actually touched down.

ST. PETERSBURG

Our hotel was one that catered to athletes and was located in a park-like area on one of St. Petersburg's many canals. Although we had to make do one night with the food in our luggage, generous tips in dollars, to the dining room staff provided us with breakfasts and dinners that were almost lavish by Russian standards.

A visit to the Gorni Mining Institute was the first order of business. It is located on the Neva River. Upon our arrival at the Institute we were taken in hand by two delightful ladies: Elena Popova, the curator of the mineral museum, and her able assistant, Natalia Pitomtseva. This museum was established by Catherine the Great, who decreed that any exceptional specimens encountered in Russian mines should be sent to this museum for preservation. The big gold and platinum nuggets originally here had been taken to Moscow to form the foundation of the collection in the Diamond Fund. In addition, the museum suffered a major robbery many years ago. They lost many valuable items, including their important emeralds. Recently the museum has been undergoing restoration and much of it is not open to the public. The exhibits are of antique style in big vertical wall cases with gold trim. More standard, horizontal, glass-topped, display cases fill the rest of the floor space in the midst of classical surroundings. The director of the Mining Museum, Dr. Vladimir Kolomensky, took the time to show us some of the Institute's treasures. There is a 5-kg platinum nugget that seemed heavier than the shot put I used to try to throw in school. He also let us hold a wonderful, shiny, neon-green aquamarine crystal of great transparency, about the size of your forearm.

The next morning, after much effort, we managed to find a taxi to the Hermitage. Taxies in Russia are not common, and at times it is impossible to find them. Their meters are no longer usable because of the rapid inflation, and when we asked a taxi driver how much it would cost to go to a particular place it was always $5, $10 or $20 dollars. We quickly learned to offer only what we wanted to pay. We kept lowering what we offered till we reached 200 rubles, or about a dollar. At this point even though we knew the Russians were paying less, we quit bargaining because we didn't want to waste time arguing

Figure 7. **Cathedral in St. Petersburg.**

over a few cents. One evening we even took a water taxi back across the Neva River and through the canals to our hotel.

Catherine the Great was responsible for accumulating the foundation of the great collections now on exhibit at the Hermitage. This collection absolutely sucks the doors off any decorative arts museum I have ever seen. Perhaps the Louvre and Prado can match or even surpass it for paintings, but for furniture, lapidary works, silver work, porcelain, Greek vases, etc., this museum makes many of our museums look downright frumpy. For an extra five dollars you can buy a special ticket that permits photography. In some rooms the old ladies would scold you if you took pictures, especially with a flash, but in others they hardly blinked. On two different days we spent a total of about eight hours trying to see the exhibits in over 300 rooms. With time running out we finally made it to the third floor with the French impressionist paintings and managed to glance around at the contents of a few of the rooms before closing time. Particularly impressive were the lapidary works. Malachite was used with abandon for everything from columns, fireplaces, clocks and vases that ranged from a mere two or three feet to one monster big enough to take a bath in. Often a particular room would specialize in some particular thing like French porcelain or cameos. The room with the Scythian gold, which I had been told was a "must see," was closed. Each room's floor was unique and made from different inlaid woods. We wondered why the very substantial crowds were permitted to walk around on them in their regular shoes, when it was forbidden in the Summer Palace across the bay.

We devoted one day to a hydrofoil excursion across the bay to the fabulous Summer Palace. Begun by Peter the Great, it was wantonly destroyed by the Germans before their retreat from Russia. The Russians have almost finished a meticulous reconstruction of the buildings and grounds. I found particularly delightful the scores of wonderful fountains, each different from the others and all running without the aid of pumps.

During our trip back across the Little Neva River, we saw the most amazing boat. It was a hovercraft that must have been over 100 feet long. It was low and sleek, and the conning tower, bridge and gun turrets were streamlined. The craft was powered by three giant turboprop engines (with 15 foot? diameter propellers) mounted high in a line across the rear of the boat. It looked like something out of Star Wars. We speculated that it was an invasion craft designed to carry everything the size of tanks on down. We guessed it was capable of speeds approaching 100 miles an hour, and could travel on top of an ice pack as easily as the open ocean.

The balance of our time in St. Petersburg was spent chasing minerals. At the Mining Institute we were introduced to several professors who happened to have a few specimens to sell. Although I bought a few things it was obvious that, for these men and others, I was their first contact with a foreign specimen dealer. We found another mineral specimen company working out of three tiny cramped rooms near the top of a building by the railway station. They had a much larger and better inventory. We were able to buy some nice murmanites and several small lots of other specimens.

For lapidary enthusiasts as well as mineral persons a visit to St. Issac's Cathedral in St. Petersburg is necessary to gain a proper perspective of what is possible in the lapidary arts. On four sides the entrance porticos are held up with giant red granite pillars about 5 feet in diameter and 30 feet high that are made from single pieces of red granite. The interior of this huge structure is finished with many different kinds of polished stone from all over Russia. Flanking each side of what used to be the altar (all the altars had been removed from the churches we visited), are a number of 15-foot columns of malachite and two somewhat smaller columns of fine quality lapis. As in all old, large Russian lapidary works, the malachite and lapis are veneered over other materials, but the craftsmanship is superb. Adorning the walls are large, colorful religious pictures made from closely fitted small blocks of stone. I usually do not wax poetic over churches, but this church rivals the Taj Mahal in India in its decorative use of stone. It is one thing to pour concrete and nail wood together, but such careful work with stone represents an effort an order of magnitude greater than your average big cathedral.

KOLA PENINSULA and APATITY

Summer was coming to a close, and one morning found us at 7 a.m. in front of our hotel, waiting for a taxi to take us to the airport for our 9 a.m. flight to Murmansk and our visit to the Kola Peninsula. No taxi! An hour later, after phone calls, cajoling, raised voices and much brain storming—still no taxi. Finally a police captain who was staying in our hotel surprisingly volunteered to take us in his tiny jeep with a driver all the way across town to the airport. The poor little jeep had a motor that couldn't have been more than 20 horsepower, which severely limited its speed, but the siren and flashing light on the roof worked just fine. We arrived at the airport with ten minutes to spare, and to see us pouring from that jeep would have reminded you of the little circus car that miraculously spills forth ten to 20 clowns. Amid a welter of thanks we dashed into the terminal to find that our flight had departed an hour earlier.

A young counter agent found us space on a plane that had just landed from a resort on the Black Sea on its way to Murmansk. After the passing of a gratuity, we found ourselves escorted onto the plane. What the young counter agent didn't tell us was that the airport at Murmansk was closed for repairs. From the air we could see the myriad of small lakes created by the glaciers of the last Ice Age as we landed, and we knew we were far north. We landed at what appeared to be a military air base with a large contingent of bombers and MiG fighters. Gene knew we were not at Murmansk, and asked

Figure 8. **Browsing through drawers of specimens in the Gorni Institute, St. Petersburg.**

Figure 9. **Rock Currier (left), Mick Brownfield, Gene Foord and Gary Moss in front of a giant malachite vase at the Hermitage.**

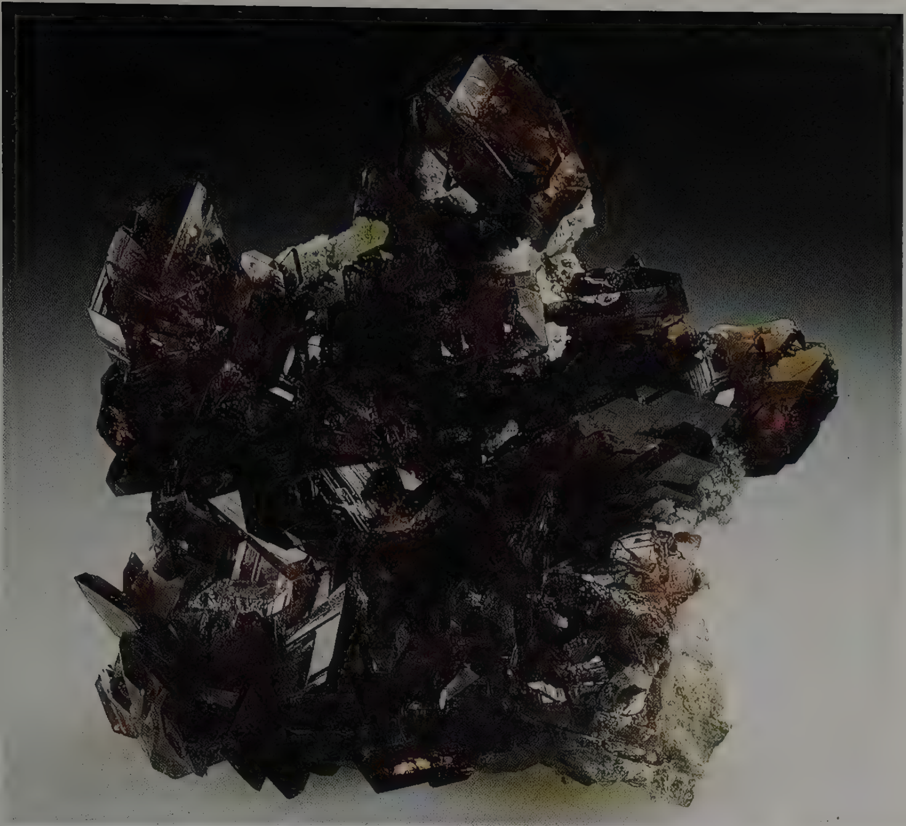
in his modest Russian where we were but they wouldn't tell him. We followed our fellow passengers across the tarmac in a cold drizzling rain and through a gate in a security fence. Some of the passengers got into a line by a wooden shack, and some were milling around a tarpaper shed waiting for luggage. Others greeted friends and got into waiting cars, and yet others just started walking across the tundra and disappearing into the low second-growth forest.

The bus by the shed quickly left, and we were left abandoned, standing around in the freezing rain, with visions of the KGB finding our bodies in the spring. Eventually a man approached us and said the most amazing word, "Taxi?" He was greeted with four of the biggest grins seen that day in all of northern Russia. Forty dollars bought us a three-hour ride south, on good paved roads, to our destination, the Geological Institute of Apatity. The whole way we were treated to the autumn beauty of Karelian birch trees amongst the green pines. Most of the trees were smallish and second growth. Stalin had a lot of gulags in the Kola Peninsula, and among other things, the inmates cut down most of the trees. That far north the trees grow slowly, and it will take many years for the trees to regain the size of the monsters which were cut down.

Apatity is named after the mineral apatite that is mined locally, along with nepheline from giant open pit and underground mines. The apatite is converted to a phosphate suitable for fertilizer, and the nepheline is mined, amazingly enough, for its aluminum content. Russia does not have any suitable bauxite from which to produce its aluminum, but in their drive for economic self-sufficiency the Russians have built a large aluminum industry around this not very convenient raw material. Both apatite and nepheline are noncompetitive as raw materials in world markets and, as there is currently not much market for apatite in Russia, some of the mines have been closed. The future of the very substantial communities which support the mining and refining of these minerals is now in doubt.

We found lodgings waiting for us in Apatity at the Amethyst Hotel. No one was very sure why the hotel had that name, but some said that there had been a modest deposit of amethyst nearby. It was located on Fersman Street, which was named, like the mineral museum in Moscow, after perhaps the most famous Russian mineralogist, A. E. Fersman. The Geological Institute has a modest museum of minerals and rocks, as well as the personal library of Fersman himself. The museum is short on specimens of well-formed crystals but long on the rare minerals found in the big alkaline massifs of the region. These massifs are the remains of mountains that have been ground down by glaciation. The geochemistry of alkaline massifs is such that they produce commercially mineable quantities of some minerals, and many rare and unusual minerals as well.

Our hosts treated us well and took us to visit several of the local mines. One huge apatite mine near Kirovsk had 40-feet benches of greenish apatite punctuated with occasional watermelon-size masses of eudialyte. Streams were cascading into this huge open pit mine, creating numerous waterfalls. We also went looking for perovskite at the Dana locality of Afrikanda, but found only a few small crystals. A foreign mining company may help reopen this mine for the rare elements contained in the perovskite. If this happens, we all felt the mine would produce a lot of specimens. The weather was uniformly miserable during our collecting endeavors, and we had only one sunny day during our entire stay. On that day, one of our hosts said, "Yes,



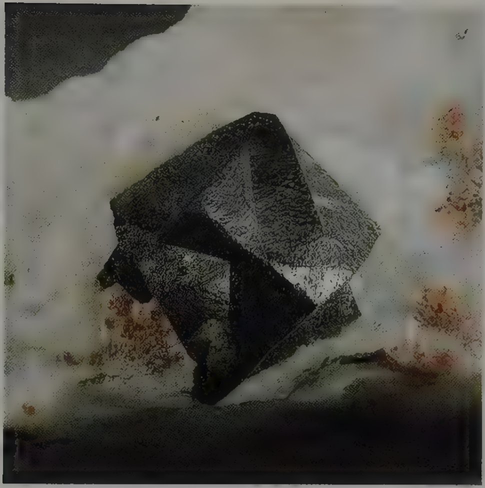


Figure 10. Loparite twin, 1.4 cm, from the Khibina Tundra, Kola Peninsula. Rock Currier collection.

Figure 11. Axinite crystal group, 7.2 cm, from Saranpaul in the Polar Urals. Rock Currier collection.

Figure 12. Anapaite crystals in an internal clam shell cast section, 4 cm across; Kerch mine, Kerch, Keren Peninsula. Rock Currier collection.

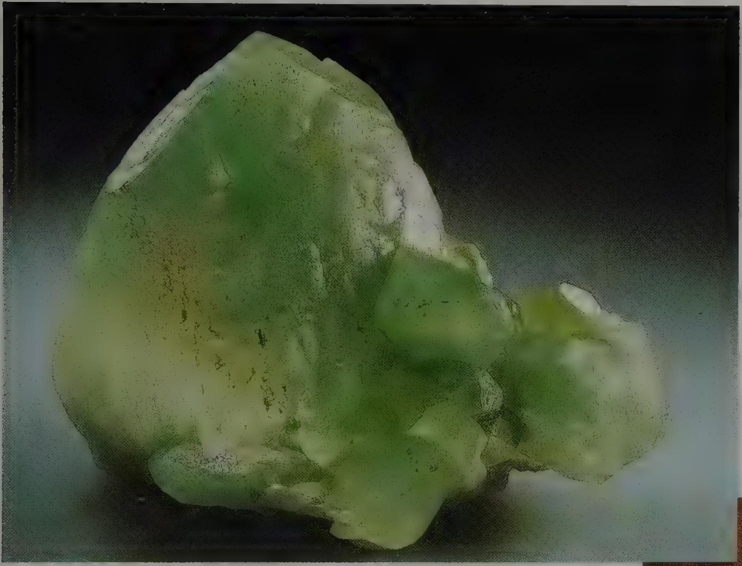


Figure 13. Large datolite crystal group, 15.4 cm across, from Dalnegorsk, Siberia. Rock Currier collection.

Figure 14. Kovdorskite crystal group with bobierrite on matrix, 6 cm across, from the Kola Peninsula. Britvin collection.

it is a beautiful day. We had a whole week of weather like this about two weeks ago." That week may have been their entire summer.

We enquired about the possibility of purchasing mineral specimens, and learned that some were available, but the prices were high. It turned out that two of the main mineral collectors of the area had already been three times to the Frankfurt gem and mineral show where they quickly learned to put generous retail prices on the things they had for sale. Some specimens already wrapped for the Frankfurt show were unwrapped for us complete with prices attached on little square pieces of papers. We were told the prices represented dollars, but soon surmised that they really represented German marks. Our purchases were accordingly rather modest, although I did spring for a nice pale blue thumbnail size terminated kovdorskite crystal for my collection. I had brought some thousands of dollars north to buy specimens, but was rather turned off by being shown retail prices in Deutschemarks and asked to pay dollars for them. It would have been cheaper just to go and buy them in Frankfurt. It certainly left no incentive to return and buy more.

Many people in Russia grow vegetables and potatoes during the brief summer. In addition, during the summer months, many people in the Apatity region gather berries and mushrooms in the local woods to preserve for winter use. We spent time waiting in lines to buy bread and cheese. We learned to jump in lines that led to fresh tomatoes, various sweet bakery goods and cabbage fritters which were often sold, still warm, out of buckets or baskets by local ladies. One afternoon Gary came back to our rooms triumphantly brandishing five one-liter plastic bags of milk. Like any successful hunter he regaled us with the details of his successful hunt, and how he had survived an aggressively shoving mob of local ladies to buy the five-liter limit right off the tailgate of the delivery truck before it even unloaded into the store. We drank them all on the spot.

Our farewell celebration was a dinner at the local hot spot, a dark and not-too-fresh-smelling dining room with a way-too-loud rock and roll band. We had two bottles of Moldavian wine that were redolent of turpentine and other vaguely remembered aldehydes and ketones from long-ago chemistry classes. We drank it all anyway. Gene said his meat was spoiled and managed to eat only one of his two silver dollar sized portions. I grabbed the other off his plate and bounced it off the head of a scrawny dog that had obviously marked us the easiest touch in the room. The dog took one sniff and walked away. Many toasts were made and although I did not throw back the vodka like our Russian hosts, I did come to appreciate the warmth and comfort it provided. I am sure that were I to survive a Russian winter I would be tossing the vodka back with the best of them.

We managed to buy return tickets to St. Petersburg from the local airport. The weather mercifully relented, and we got off on schedule. For the two-hour flight our fellow passengers paid about $5 each for their tickets. Our price, the non-Russian price, was a little over a hundred dollars each, and we calculated that we paid more for our four tickets than all the other passengers combined paid for theirs. Strangely enough, there was always plenty of space in the smallish luggage racks on Russian planes. Most Russians travel light.

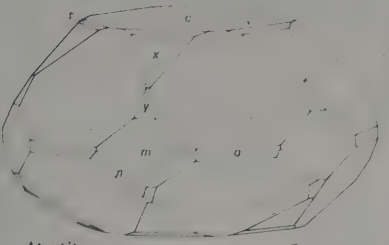
One of the taxies that took us to the St. Petersburg international airport had a flat tire, but we still made our flight on time. We lamented that, if anything, our luggage had grown even heavier and were thankful that we were flying with KLM which allowed 40 kg of luggage rather than the strict 20 kg limit of Aeroflot. Ahead of us, Russian customs officials were thoroughly searching the luggage of a large party of Japanese tourists. They found a large quantity of black market caviar in small tin cans (about 50 kg) which they immediately confiscated. We began to worry about the specimens in our bags. We had all kinds of receipts and documents from various companies and government agencies and were passed quickly through without delay.

The Russians are educated people, capable of huge enterprise. They have trouble understanding Americans because we are much too ready to smile, laugh and make friends. They know life is not easy and do not quickly trust people who pretend it is. You have to work much harder to earn the right to call a Russian a friend than you do an American. When all is said and done I have to admit that we live in a fool's paradise here in the United States, and that the Russians have a much better understanding of how hard life really is for most of the people in our world.

That evening in Amsterdam we had dinner in an Argentine steak house. I ordered two of their largest steaks much to the amusement of the manager and waiters who were surprised that I could talk with them in Spanish. The manager told us how difficult things were in Argentina. We laughed and regaled him instead with stories about our experiences in Russia. We pigged out totally and got moderately zonked on several liters of a good house wine. Gary said, "Do you realize we have eaten more this evening than we ate during entire days in Russia?" I said, "Yeah right, please pass the French fries and the rest of those vegetables." Buffalo runnem good. ⊠

G. Carlo Fiöravanti

mineralogist



Apatite Carrara

19/20 Via Pie di Marmo
Rome, Italy

Located between Piazza
Venezia and the Pantheon

Mon. 5-8 pm; Thurs. & Fri.,
11-1 pm, 5-8 pm; Sat. 11-1 pm

Phone: 06-6786067

MINERIVE

fine & classic worldwide minerals
Pakistan • Eastern Europe
North & South Africa
•

François LIETARD
Au Bourg, 42800 TARTARAS, France
Tel. (33) 7783-9869
FAX: (33) 7483-9837

Tucson Show
at the Community Center

Looking for
Meteorites?
Swiss Museum offers free sales list.
Swiss Meteorite Lab.
Museum Bally-Prior
P.O. Box 126
CH-8750 Glarus
Switzerland
FAX: 41-58-618638
TEL: 41-77-572601
We also buy meteorites!

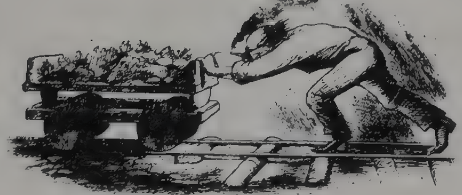
WASHINGTON, DC AREA
- BUYING & SELLING GREAT PIECES
- CLASSIC MINERALS & LOCALITIES
- ESTATE APPRAISALS AVAILABLE
- PROMPT RESPONSE TO INQUIRIES

C. CARTER RICH
—FINE MINERALS—

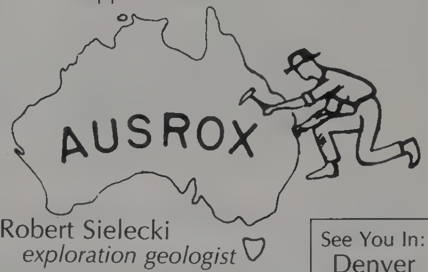
- TUCSON, EXECUTIVE INN, ROOM 233
- CLIFTON, ROCHESTER, HOUSTON, MORRIS, EFMS (SYRACUSE), S'FIELD, DENVER, ROGAMS, OTHERS IN 1944

PO BOX 69
ALDIE, VA 22001
(703) 327-6373

WILLIS' EARTH TREASURES
Fine Mineral Specimens
Wholesale & Retail
Rock Trimmers & Hardwood
Thumbnail Cabinets
Send want list or by appointment
116 Prospect St., Stewartsville, N.J. 08886
908-859-0643



Fine Australian & Worldwide
Minerals, Fossils, Rare
Australian Species, Meteorites
& Tektites. Retail & Wholesale
supplier since 1984.



Robert Sielecki
exploration geologist
Janine Rea
mine geologist
42 Hex St., Tottenham
Melbourne, Victoria 3012
Australia (phone (61-3)314-9612)
FAX: (61-3)315-1819

See You In:
Denver
Munich
Paris
Tucson
Tokyo
1993

ZEOLITES INDIA

Specializing in GREEN APOPHYLLITE, MESOLITE sprays and sunbursts, NATROLITE in vugs, CALCITE varieties, CAVANSITE, STILBITE bow ties, OKENITE geodes, PREHNITE statactites, colorful GYROLITE balls, HEULANDITE, SCOLECITE, MORDENITE, THOMSONITE, EPI-STILBITE, AMETHYST, QUARTZ, RUBY in matrix.

Rarities: POWELLITE, YUGAWARALITE, GOOSECREEKITE, ILVAITE, LEVYNE.

Zeolites India • D-311 Manju Mahal,
35 Nargis Dutt Rd., Bandra (West)
BOMBAY 400 050, INDIA.
FAX/PHONE: 91-22-6462284 & 6271102.

Schooler's
Minerals & Fossils

Choice Specimens for the
Collector and Museum
Shows Only

Please Write with Specific Wants
Buying Single Specimens &
Collections
P.O. BOX 1032, BLUE SPRINGS, MO 64015
(816) 931-1576

fine minerals & gems
Direct from Brazil
OCEANSIDE GEM IMPORTS, INC.
P.O. Box 222
Oceanside, N.Y. 11572
Phone (516) 678-3473
Hours by Appointment

Understanding Crystallography
by Jennie R. Smith
Written Expressly for the Amateur Mineral Collector and Student of Mineralogy
Includes Detailed Explanations of:
The Six Crystal Systems • Twinning
Miller Indices • Stereographs
$20.00 Postpaid
overseas add: $3.00 surface, $5.00 airmail
Send check or money order to:
Crystallography Dept. C
Box 12 • Fairfax, VA 22030

JENDON MINERALS
P.O. Box 6214
Rome, Georgia 30162-6214
Tel: 706-291-4618
No List. Please write for specific requests.

THE ROCKSMITHS INC.

Oct. 23-24	Pikesville, MD
Oct. 30-31	Warwick, RI
Nov. 6-7	Stamford, CT
Nov. 12-14	Olivette, MO (St. Louis area)
Nov. 13-14	Plano, TX
Nov. 19-20	Phoenix, AZ
Nov. 19-20	Marietta, GA (Atlanta area)
Nov. 19-21	Austin, TX
Nov. 27-28	W. Palm Beach, FL
Dec. 10-12	Nashville, TN

Thanks to All for a Great Year!

SHOWS

5th & Toughnut, Box 157, Tombstone, Arizona 85638

P. O. Box 816, Redondo Beach, CA 90277

(213) 372-6149

(213) 372-5969
(Ans & Fax)

Old & Rare Books

The Gemmary

Antique Scientific Instruments

* *Book Catalog #1: $2.00* *
Mining, mineralogy, gemology & jewelry
* *Book Catalog # 2: $2.00* *
Early science, technology & scientific instruments
* *Scientific Instruments Catalog #3: $5.00* *
18th & 19th century mathematical, philosophical and optical instruments of all kinds

Carousel
GEMS AND MINERALS

1202 Perion Drive
Belen, New Mexico 87002
505-864-2145
1-year subscription to our mineral listings: $1

W.A.

WESTAUS
Mineral Museum
Rare Species
Mainly from Western Australia

The **NEW MINERAL** *Widgiemoolthalite* is now available in limited quantities. It is the Ni analogue of Hydromagnesite. This deposit has yielded the best Kambaldaite, Hydrohonessite, Carrboydite, Gaspeite, Lavendulan, Nepouite, Nickelhexahydrite, Nullaginite and Otwayite found to date and are now available. Wanted for our type loc. coll. are Kimrobinsonite, Holtite, Moolooite, Cassidyite, Krinovite, Majorite and Suessite.

Send for list

P.O. Box 116, Beverley,
Western Australia, Australia 6304

FROM THE ADIT

Rare & Out of Print Books
Extensive catalog on mineralogy, geology, mining & exploration.
See us at the Executive Inn during the Tucson Show.
Contact Ed Rogers, PO Box 455
Poncha Springs, CO 81242 USA
(719) 539-4113 Fax 539-3690

MOUNTAIN MINERALS INTERNATIONAL

We provide exact locale information for mineral occurrences in Pakistan, India & Sri Lanka.

See us at the Tucson Convention Center in February.

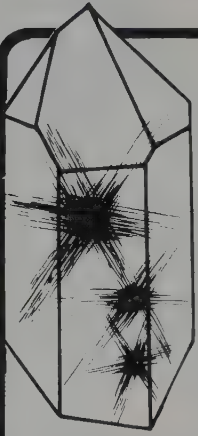
Mountain Minerals International
P.O. Box 302 • Louisville, Colorado 80027-0302
Tel./FAX: (303) 665-0672

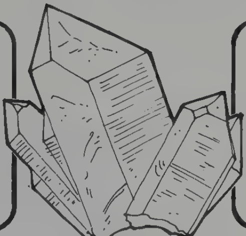
FREE CATALOG

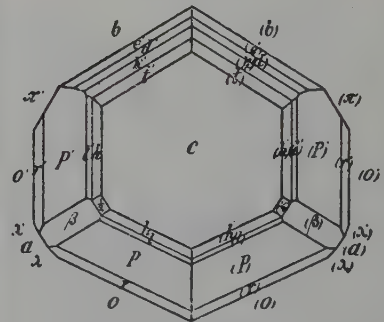
Over 800 sizes of plastic boxes.
- Hinged
- Non-hinged
- Micromount
- Perky and magnifier boxes

ALTHOR PRODUCTS

496 Danbury Road, Dept. MR • Wilton, CT 06897
(203) 762-0796 • FAX (203) 762-3180






b
(b)
x
(x)
c
p'
(P)
o'
(o)
x
a
λ
β
(β)
p
(P)
(a)
(λ)
o
(o)

Colorado Dealers

David Bunk Minerals
David Bunk
9240 W. 49th Street, #317
Wheat Ridge, CO 80033
303-421-3646 (by appointment)
Colorado & Worldwide Specimens

Caviano Mineral Gallery
5910 South University
Littleton, CO 80121
303-798-6696
Mon-Sat 10-5:30, Sun call first
Quality Minerals from the
Ray Thompson Collection

Collector's Stope
Jim & Patti McGlasson
7387 S. Flower Street
Littleton, CO 80123
303-972-0376
Fine Minerals, Species, Micromounts

Columbine Mineral Shop
Benjy & Liz Kuehling
633 Main Street, Ouray, CO 81427
303-325-4345, 9 a.m. to 9 p.m.
Open 7 days, May 1-Oct. 31
Off-season by Appointment
Fine Minerals for Collectors

Genesis Epoch
Mel & Pam Bersch
2417 Sandridge Court
Grand Junction, CO 81503
303-242-3134 (call for appt.)
Fine Minerals & Fossils

Glacier Peak Gems & Minerals
Joseph & Susan Dorris
P.O. Box 413
Manitou Springs, CO 80829-0413
719-685-4479 (by appointment)
Top Minerals—Colo., Pakistan, Mex.

Golden Minerals
Don E. Knowles
13030 West 6th Place
Golden, CO 80401
303-233-4188
Largest Comprehensive Stock in Colorado

Green Mountain Minerals
Stanley Korzeb
13812 W. Dakota Avenue
Lakewood, CO 80228
303-988-2642 (Call for Appt.)
Species, Fine Minerals, write for List

**COLORADO
MINERAL
AND FOSSIL
SHOW**

WED.–SUN.
SEPT. 14-18, 1994
Holiday Inn Denver North
(where I-25 meets I-70, exit 214C)

10 a.m. to 8 p.m. Daily
Be sure to attend the
Museum Benefit Auction, Wed. 5 pm

**Shuttle Bus
to Other Shows**

NEW! Sunday Sidewalk Show
INFO: P.O. Box 999 • Evergreen, CO 80439

Bill Hayward Minerals
Bill & Christopher Hayward
3286 Quitman Street
Denver, CO 80212
303-455-1977 (Call for Appt.)
Colorado & Pikes Peak Minerals

Irish Rovers
John & Gerry Shannon
7319 W. Cedar Circle
Lakewood, CO 80226
By Appt. Only: 303-232-1534
Items unique and antique for
the mining & mineral collector

L & T Creations
Lee A. McKinney
1800 Winfield Drive
Lakewood, CO 80215
By Appt. Only 303-232-6451
Colorado Amazonite

LJP—Colorado
Larry & Carmen Piekenbrock
P.O. Box 1758
Boulder, CO 80306
303-666-6926 (by Appt. only)
Colorado & Western Minerals

Mountain Minerals International
Dudley Blauwet
P.O. Box 302
Louisville, CO 80027-0302
303-665-0672, Buy/Sell/Trade
Minerals, Gems, Gem Rough

Red & Green Minerals, Inc.
Denzil Wiggins
7595 W. Florida Avenue
Lakewood, CO 80227
303-985-5559
Custom Jewelry, fine mineral
specimens, lapidary & jewelers'
tools & supplies

The Sunnywood Collection
Bill & Elsie Stone
12068 E. Amherst Place
Aurora, CO 80014
303-368-7497 (by Appt. only)
Fine Minerals & Fossils,
Mounted on Exotic Hardwoods
Custom mounting available

INDEX TO VOLUME TWENTY-FOUR (1993)

[The pages preceded by the letter "G" are in the independently paginated Greenland Issue, March–April 1993.]

Localities

Minerals

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION

(Required by 39 U.S.C. 3685)

1. *Title of publication:* Mineralogical Record
2. *Date of filing:* September 30, 1993
3. *Frequency of issue:* Bimonthly
   a. *Number of issues published annually:* Six.
   b. *Annual subscription price:* $33 (FGN $36).
4. *Location of known office of publication:* 7413 N. Mowry Place, Tucson, Arizona 85741.
5. *Location of the headquarters or general business offices of the publishers:* 7413 N. Mowry Place, Tucson, Arizona 85741.
6. *Names and complete addresses of publisher, editor, and managing editor: Publisher:* Wendell Wilson, 4631 Paseo Tubutama, Tucson, AZ 85715. *Editor:* Wendell E. Wilson, 4631 Paseo Tubutama, Tucson, Arizona 85715. *Managing editor:* none.
7. *Owner:* The Mineralogical Record Incorporated, 7413 N. Mowry Place, Tucson, Arizona 85741. No stockholders.
8. *Known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other security:* none.
9. *For completion by nonprofit organizations authorized to mail at special rates (Section 132.122, PSM).* The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes have not changed during the preceding 12 months.
10. *Extent and nature of circulation:*

	Average no. copies each issue during preceding 12 months	Actual no. copies of single issue published nearest to filing date
A. Total no. copies printed	7818	7820
B. Paid circulation		
1. Sales through dealers and carriers, street vendors and counter sales	400	413
2. Mail subscriptions	6075	6161
C. Total paid circulation	6475	6574
D. Free distribution by mail, carrier or other means, samples, complimentary and other free copies	256	258
E. Total distribution	6731	6832
F. Copies not distributed		
1. Office use, left over, unaccounted, spoiled after printing	1087	988
2. Returns from news agents	0	0
G. Total	7818	7820

11. I certify that the statements made by me above are correct and complete. Mary Lynn Michela, treasurer.
12. In accordance with the provisions of this statute, I hereby request permission to mail the publication named in item 1 at the phased postage rates presently authorized by 39 U.S.C. 3626. Mary Lynn Michela, Circulation Manager.

Mineralogical Record Inc.
Board of Directors
Abraham Rosenzweig (Pres.)
P.O. Box 16187
Temple Terrace, FL 33617
Terry C. Wallace
(Vice Pres.)
Dept. of Geosciences
Univ. of Arizona
Tucson, AZ 85721
Patricia A. Carlon (Secr.)
1110 E. Emerson
Bloomington, IL 61701
Thomas M. Gressman (Treas.)
7753 Emerald Peak
Littleton, CO 80127
Ronald E. Bentley
30 Filley St.
Bloomfield, CT 06002
Anthony R. Kampf
Mineral. Section,
Natural History Museum
900 Exposition Blvd.
Los Angeles, CA 90007
Mary Lynn Michela
7413 N. Mowry Place
Tucson, AZ 85741
George W. Robinson
Mineral Sciences Div., NMC
1926 Merivale Rd.
Ottawa, Ontario K1A 0M8
Marshall Sussman
618 Hartrey
Evanston, IL 60202
Wendell E. Wilson
4631 Paseo Tubutama
Tucson, AZ 85715

Volunteer Coordinators
Eastern U.S.
Charles & Marcelle Weber
1172 West Lake Ave.
Guilford, CT 06437

Advertising Information
All advertising in the Mineralogical Record must be paid in advance of the closing date. Telephone orders not accepted. Write to the editor for rates.

Closing dates:
Jan.-Feb. issue .... Oct. 15
March-April issue ...... Dec. 15
May-June issue .... Feb. 15
July-Aug. issue .... April 15
Sept.-Oct. issue .... June 15
Nov.-Dec. issue .... Aug. 15

An additional 20 days past the closing date are allowed in which advertisers may make changes (excluding size changes) in ads already paid for.

Design
Wendell E. Wilson

Graphic Production
Capitol Communications
Crofton, MD

Printing
Waverly Press, Easton, MD

Color Separations
Hollis Phototechnics
Tucson, AZ

Circulation
P.O. Box 35565
Tucson, AZ 85740
602-297-6709

Editing, advertising
4631 Paseo Tubutama
Tucson, AZ 85715
602-299-5274

Foreign Payments
Remittance may be made in local currency, at *prevailing exchange rates,* without surcharge, to the following people:

Belgium
Paul Van Hee
Marialei 43
B-2900 Schoten

Canada
Mrs. J. W. Peat
36 Deepwood Crescent
Don Mills, Ontario M3C 1N8

Great Britain
Paul Lowe
"Endsleigh"
50 Daniell Road
Truro, Cornwall TR1 2DA

Italy
Renato & Adriana Pagano
P.O. Box 37
I-20092 Cinisello Balsamo MI

Japan
Tsukasa Kikuchi
P.O. Box 18, Hongo
Tokyo 113-91

Netherlands
W. J. R. Kwak
Kabeljauwallee 23
6865 BL Doorwerth (Gld)

Norway & Sweden
Geir Wiik
N-2740 Roa
Norway

South Africa
Horst Windisch
30 Van Wouw Street
Groenkloof, Pretoria

West Germany
Christian Weise Verlag
Oberanger 6
D-8000 München 2

Affiliated with the Friends of Mineralogy, an independent, non-profit organization devoted to furthering amateur and professional interests in mineralogy. For membership information contact Richard Thomssen, Treasurer, P.O. Box 1656, Carson City, NV 89702

Searching the world

*. . . to bring you the finest in mineral specimens
at competitive prices*

- *Fine Display-Quality Specimens and Rare Species:*

Send for our bimonthly *mineral lists* of thumbnail, miniature, and cabinet specimens. First quality mineral specimens for collection and display, plus rare species for systematic collection, reference, and research. Send large SASE for lists. Non-USA, send two International Reply Coupons.

- *Micromount and Specimen Boxes of All Kinds:*

A separate listing is available detailing prices and sizes of micromount, Perky Boxes, plastic magnifier boxes, white cotton-lined specimen boxes, display stands, etc. Send large SASE for lists. Non-USA, send two International Reply Coupons.

- *Books—Mineralogical Subjects:*

Send for our separate price list with information covering new books on mineralogical subjects, as well as older, out of print mineralogical books. Send large SASE for lists.
Non-USA, send two International Reply Coupons.

- *Back Issues of the Mineralogical Record:*

Ask for our listing of out-of-print issues currently in stock. Send us your want list, if you need back issues to complete your set. Send us your offers, if you have back issues available for sale.

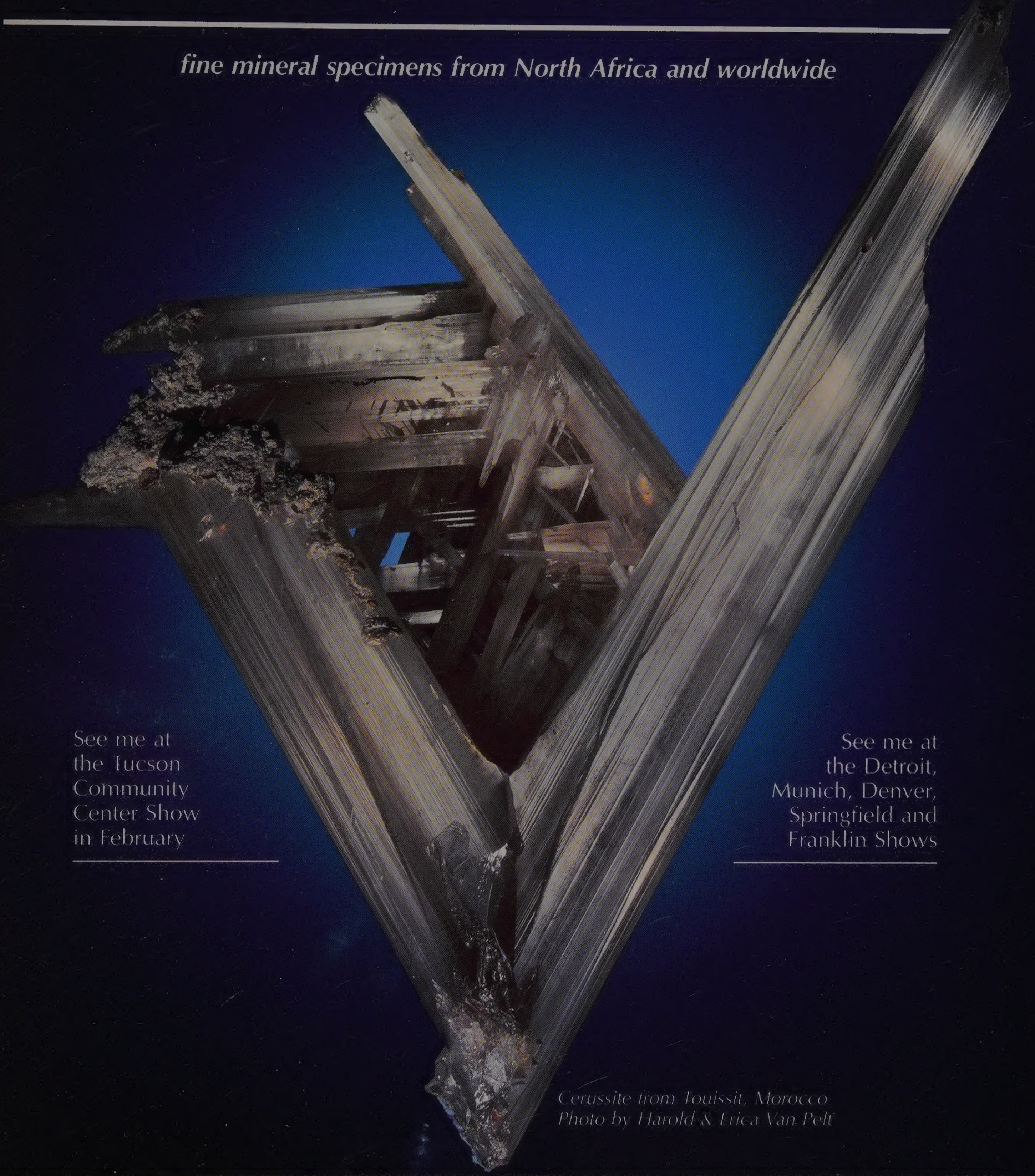
Mineralogical Research Co.

Eugene & Sharon Cisneros
15840 East Alta Vista Way, San Jose, California 95127-1737
Look for our booth at major Western U.S. Shows • A Division of the Nazca Corporation
PHONE: 408-923-6800 • FAX: 408-926-6015

Advertisers Index

VICTOR YOUNT

fine mineral specimens from North Africa and worldwide



See me at
the Tucson
Community
Center Show
in February

See me at
the Detroit,
Munich, Denver,
Springfield and
Franklin Shows

Cerussite from Touissit, Morocco
Photo by Harold & Erica Van Pelt

ROUTE 3, BOX 250, WARRENTON, VIRGINIA 22186 • (703) 347-5599 • BY APPT. ONLY
45 miles from Downtown Washington