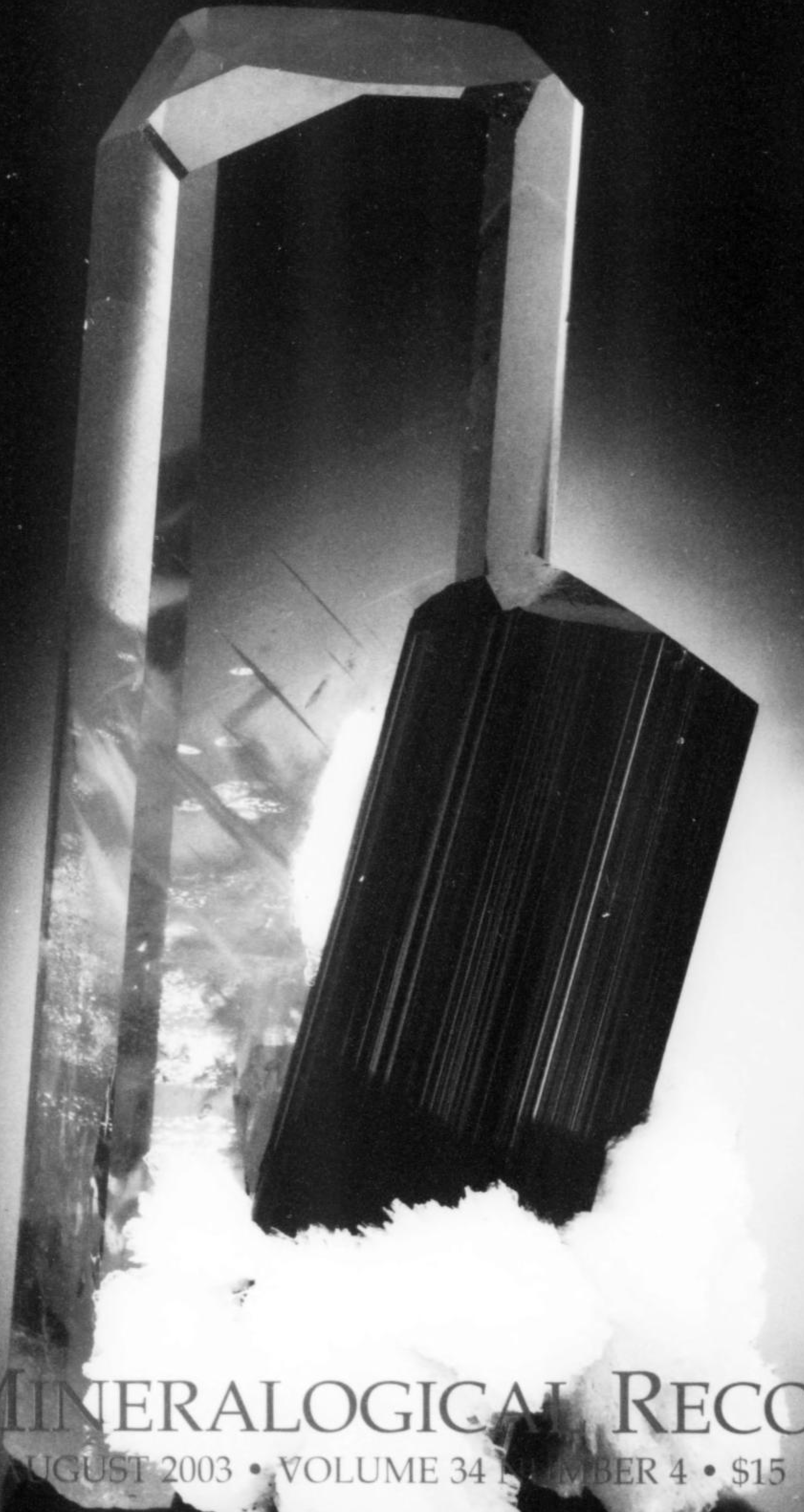
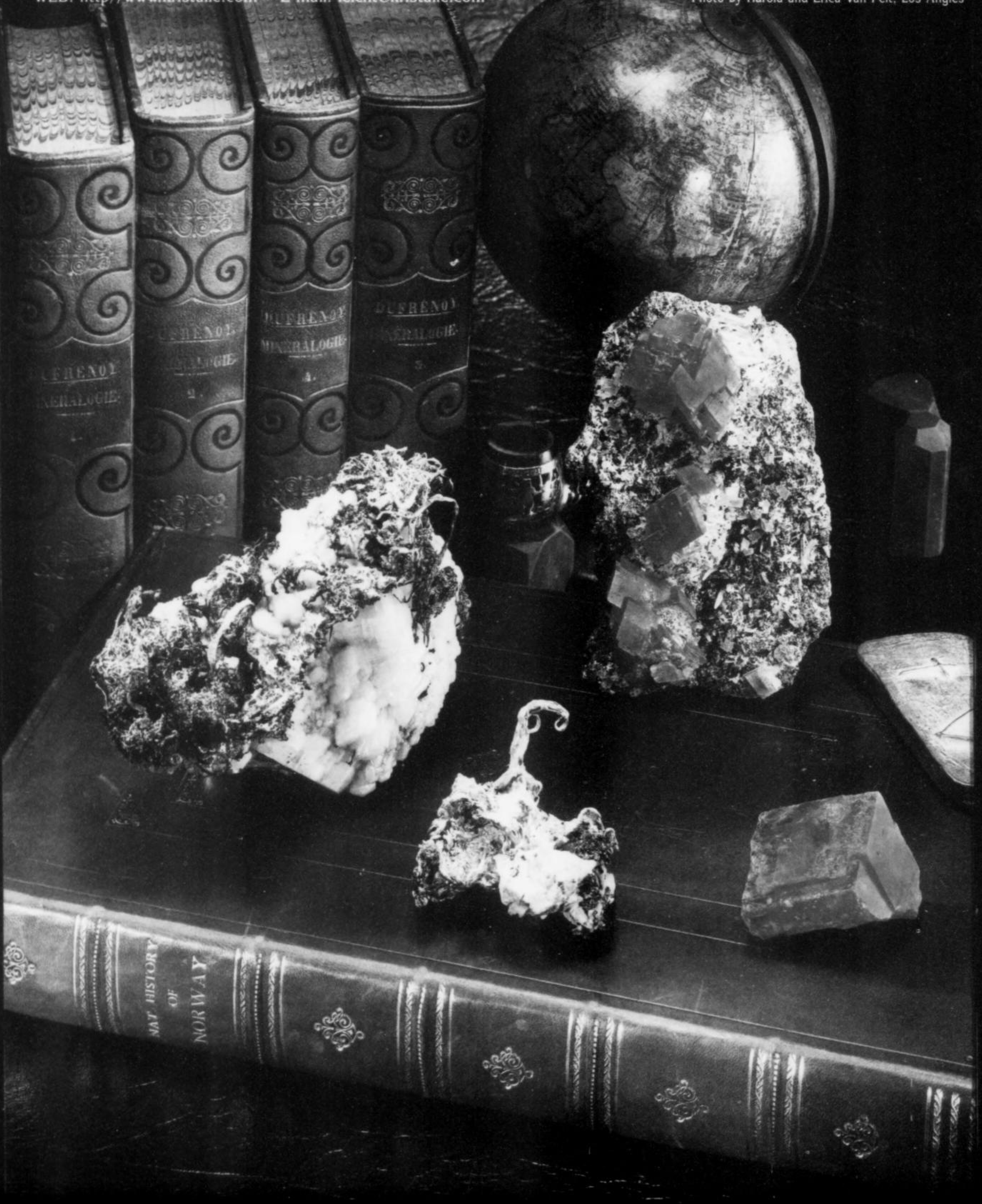


THE MINERALOGICAL RECORD

JULY-AUGUST 2003 • VOLUME 34 NUMBER 4 • $15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notes from the EDITORS

Special Offers for Helping Us Out!

A magazine is only as successful and secure as its subscribers and contributors want it to be. Over the years we've been fortunate to have widespread support among the mineral community, not only from collectors and dealers but also from many professional curators, mineralogists and other earth science professionals, and from the Friends of Mineralogy. That support has kept us going, through good times and bad. It is easy, after a third of a century of publication, for our readers to become complacent and think that their favorite magazine no longer needs their help in order to flourish. Not true! We still need as much support and word-of-mouth advertising as we ever did.

We know that there are many mineral collectors out there who haven't gotten around to subscribing, or who are inclined to hide their head in the sand rather than look around to experience all the mineral world has to offer. Amazingly, in many mineral clubs perhaps only 5% or less of the members will be subscribers. Some may not even have heard of the *Mineralogical Record.* You can help such unknowing collectors, and help the *Record*, by urging them to subscribe. Friends don't let friends collect minerals without the *Mineralogical Record*!

Why do we need your help? During every year since at least 1980, our rate of non-renewals has remained remarkably constant: we lose roughly 250 subscribers per year. That is an exceptionally low non-renewal rate, as magazines go. One year we actually called every one of those 250 just to see why they had dropped. Almost without exception the reasons were that the former subscriber had died, or was liquidating his property preparatory to dying, or had gone blind, or had retired on a very low income and could no longer afford to collect minerals or subscribe to magazines. Low as this number is, it has meant that we have had to find at least 250 new subscribers to take their place each year, and for much of our history we were able to do that. Lately, however, new subscribers have been harder to find.

Why? Perhaps it is due to the aging of the population of mineral collectors (ever notice how many gray heads you see at mineral shows these days?)—the ranks are not being reinforced by many new young collectors. Field collecting opportunities are not as widely available to the younger generation as they were to many of us when we were young, and consequently many would-have-been mineral collectors end up pursuing other interests. That is why many dealers, societies, clubs and the Friends of Mineralogy have evolved special offers and programs to attract younger people into the hobby. And, of course, those young people are not liable to become *Mineralogical Record* subscribers until they first become mineral collectors or mineralogy students, so we wholeheartedly support those efforts.

The unfortunate economic situation that has prevailed for several years now is also making it more difficult for some people to pay for the magazines they want. Of course, if you can't afford the price of a subscription, you probably can't afford to collect minerals either. But if you can scrape up the price, at least you can see and read about minerals until times improve. We know it's a sacrifice on the part of our faithful readers to stick with us during these times, and we appreciate it. We try, in response, to offer as many extra pages and as much extra value as we can, funded as much as possible by donations and other sources so as to keep the subscription price as low as possible.

Are there ways we could improve the magazine to make it more attractive to our subscribers and potential subscribers? We are always open to suggestions, and value such feedback highly. Our readers are the experts in knowing what serves their own needs, and we want to keep in touch with those needs so as to serve them best. If you have helpful ideas, please let us know.

Here's something else you might consider. If you have an older friend who can't afford to subscribe anymore (and perhaps can't even afford to collect), buy him a gift subscription. You know he'll enjoy it, perhaps more than anything else that money could have bought. When a person has a passion for something, it is sad indeed to see him separated from it for lack of a few dollars.

Our you might put a gift subscription to work nurturing a new collector (young or old) who really *needs* the *Record* but just doesn't realize that fact yet. A one-year trial subscription as a gift might be just the thing to help him fully enter the mineral world.

Or you might buy a subscription for a local library, perhaps even a school library, or a club library where students could be exposed to the wonders of mineralogy through the *Record.* In that way you could also contribute to the broadening of the hobby among the younger generation.

Here's the deal. We could spend thousands of dollars on advertising in other magazines (and have in the past), but we think that our own subscribers might be our best ambassadors. Because of that, we're willing to rechannel our advertising money into a **$10 discount** for the first year of a new subscription, that is, a subscription for someone or some library who has never before subscribed. **Whether you buy a gift subscription for a person or a library, you will pay only $45 (U.S.) or $49 (outside the U.S.).** If you convince someone to subscribe, tell him that as a current subscriber you can get him a $10 discount if he will simply mention your name when he subscribes, or, better yet, he can give you the check (made out to the Mineralogical Record) to mail in for him. You have the power to save your friend ten bucks! And while you're at it, **accept a free back issue of your choice** from us for every new subscriber or gift subscription you generate, as our way of saying thanks for your help.

Sit back right now and consider who you know who should have a subscription. Then take some action to make it happen, one way or another. You'll be doing a noble thing. And you'll be helping to guarantee the continued publication of your favorite magazine.

Retired, Abraham (Abe) Rosenzweig

Mineralogist and crystallographer Abe Rosenzweig retired recently from his long-time position on the Editorial Board of the *Mineralogical Record*, a position he held for 27 years; he was also a member of the Board of Directors until 1995, and served his turn as President of the corporation. His acute technical expertise and his wise advice have helped the *Mineralogical Record* to grow and flourish throughout most of its years of publication. He is also the author of more than 50 articles in professional journals, and is a coauthor of *Dana's New Mineralogy* (1997).

Abe earned his B.S. in Chemistry from the University of Pennsylvania in 1946, and his PhD in Geology and Chemistry from Bryn Mawr College in 1950. While in school he served as a chemist during the summers of 1945 and 1946 for the Foote

Kent England

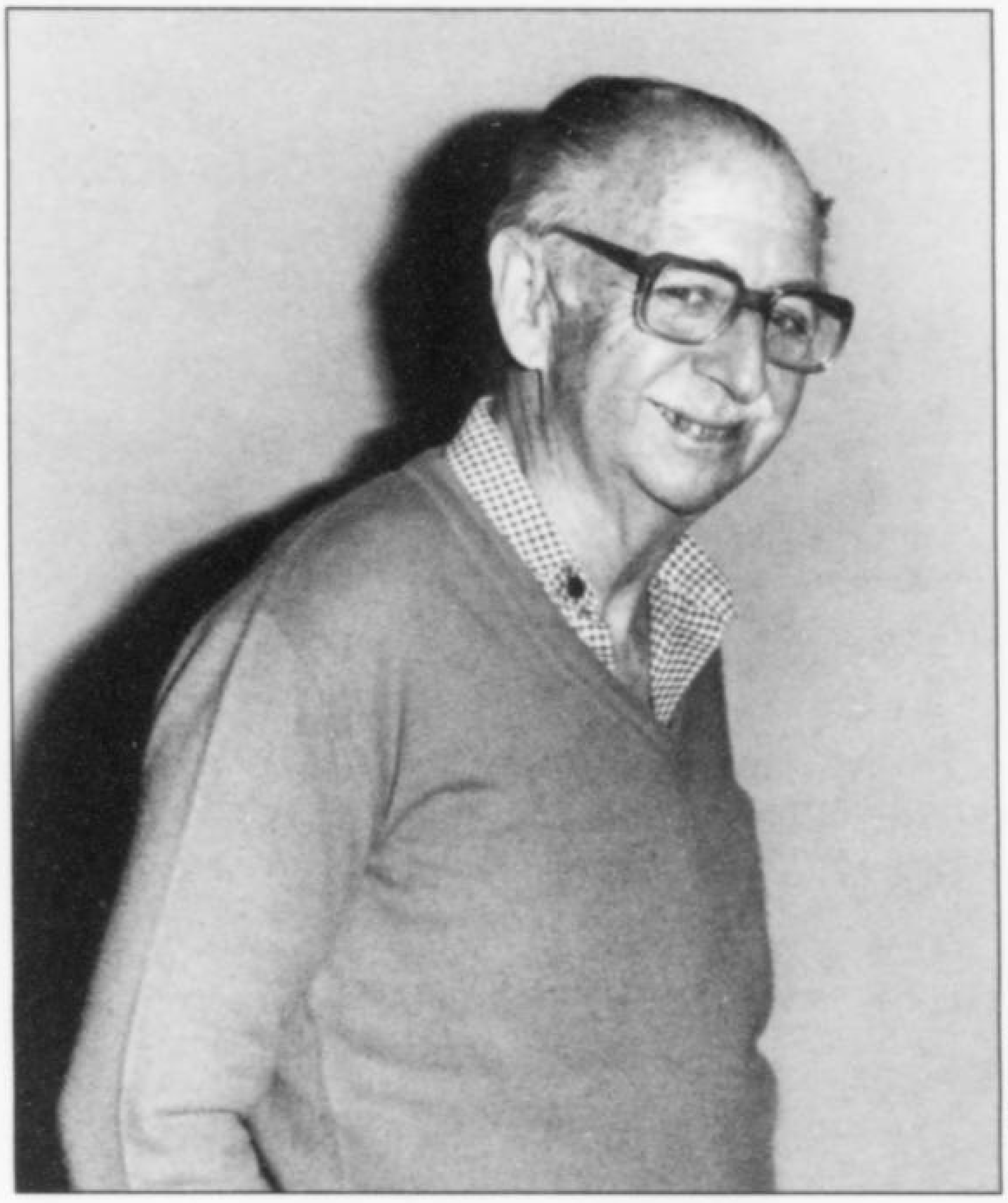
Abe Rosenzweig

Mineral Company, and in 1947 and 1948 spent his summers working for the Pennsylvania Geologic and Topographic Survey. Following his graduation in 1950 he took a position as mineralogist for the U. S. Atomic Energy Commission, and later worked as a consultant for the Sandia Corporation in Albuquerque and for the Special Weapons Center at Kirtland Air Force Base; he was also a visiting staff member at the Los Alamos National Laboratory from 1957–1984, and served as curatorial consultant for the Romero Mineralogical Museum in Tehuacan, Mexico from 1975–1981. He has traveled widely and occasionally dealt in mineral specimens acquired on his many trips, especially those trips which took him to Korea.

Abe has had a long career in academic life, teaching and conducting research in mineralogy and geology at Bryn Mawr (1949–1950), the University of Minnesota (Research Associate in Geology, 1953–1954), the University of New Mexico (Assistant Dean and Dean, 1963–1965; Associate Professor 1961–1968; Professor 1968–1973), the University of South Florida (Professor of Geology, 1977–1984), Oberlin College in Ohio (1973–1974), and as Visiting Professor at National Taiwan University (1954–1961). He has been self-employed as a consultant in crystallography, mineralogy, economic geology, appraisals and custom gem cutting since 1975, and is co-owner (with his wife Daphne) of Rosenzweig Associates. During that time he has also served as Director of Microscopy Services for Thornton Laboratories in Tampa (1988–1993), and as a Technical Expert for the National Institute for Standards and Technology (1988–1995).

We at the *Mineralogical Record*, and indeed all of the many mineral collectors, mineralogists and mineralogy students who have benefitted from his many contributions, owe him a lasting debt of gratitude.

WEW



Kent England

Carlos Barbosa (1917–2003)

Died, Carlos do Prado do Barbosa, 86

Carlos Barbosa, well-known Brazilian mineral dealer, was born in the town of Alfenas, Minas Gerais, Brazil on January 7, 1917. He graduated from the University of Minas Gerais (Belo Horizonte) with a degree in Chemical Engineering in 1939, and went on to post-graduate work, earning a specialized degree in Mineralogy from the National College of Philosophy in Rio de Janeiro in 1943. Throughout his professional career he worked for the National Institute of Technology in Rio de Janeiro, on the recovery of gold; he retired in 1972, after suffering lung damage from the inhalation f toxic gases.

Following his retirement he decided to pursue his love of minerals full-time, both as a mineral dealer and as an independent mineralogical researcher. He attended the Tucson Show for the first time in 1972 or 1973, joining the dealers informally set up at the Desert Inn. Although his English was poor, he endeared himself to the international collecting and dealing community, and quickly became well-known and admired for the fine Brazilian minerals he brought. His kindness, friendliness and generosity transcended the language barrier, and made him many friends among the collectors, curators, dealers, and even among the housekeeping staff—the young women doted on him like a grandfather, which indeed he was (Carlos had four children, the youngest just 14 years old, nine grandchildren and one great-grandchild). He continued to attend the show every year until 2002 when, because of his failing health, he sadly acknowledged that it would probably be his final year there; he bade many of his cherished friends goodbye and worked at selling off the last of his stock.

I first met Carlos in 1980 when he paid me a visit at the Jacupiranga mine; somehow he had learned of my mineralogical researches at that deposit. He told me about the Tucson Show—a revelation to me, which he always claimed jokingly to have been one of his worst mistakes, because it inspired me to attend the show as a competing Brazilian dealer in 1981. Far from being regrettable, however, it was the beginning of a strong and enduring friendship between us.

Though he published relatively little, Carlos conducted extensive research on Brazilian mineralogy over the years. For example, he made in-depth studies of the mineralogy of the now-famous Brumado mine in Bahia, recovering countless superb crystal specimens of uvite, dolomite, hematite, magnesite and Japan-law twinned quartz, as well as rarities such as chernovite, agardite-(Y), florencite-(Ce), woodhouseite and svanbergite among many others. He studied various Minas Gerais pegmatites, including especially those near Linópolis and Galiléia, and also the Golconda mine (from which he recovered the world's finest bertrandite specimens). At the Cauê iron deposit at Itabira, Minas Gerais, Carlos persuaded the independent miners to save important specimens from the iron ore tailings, including palladian gold ("porpezite"), palladseite, arsenopalladinite and native palladium. Many other examples of his recovery work could be cited.

Wherever interesting minerals were being found in Brazil, Carlos had the skill and the intuition to be on the spot and save untold numbers of unique and interesting specimens from the crushers and smelters. And no matter how rare and unusual the minerals might be, Carlos always had the analytical data at hand to back up his identifications. Even in the last years of his life, when his health was declining, he continued to search for new things. Just last January I visited Skip Simmons at the University of New Orleans, and there I saw a black crystal of synchesite-(Nd) from Linópolis which Skip had recently received from Carlos.

Carlos Barbosa died of pneumonia on April 7, 2003, and was buried (in accordance with his wishes) at the tiny cemetery in Linópolis where he can be close to the minerals he loved. He deserves to be honored and remembered as one of the most important Brazilian field mineralogists and mineral dealers of the last century.

Luiz Menezes

Died, Sydney Pieters, 83

Sid Pieters was a true pioneer in the mineral and gem world of what was once known as South West Africa. Sid was born into a mining family on March 8, 1920; his father was mining tin as early as 1920 all along the Erongo Flats, and had established such mines as the Ariakos, the Sydney mine, and Pieters Hill. The tin ore there was in pegmatites, and not infrequently associated with gem minerals such as beryl, topaz and tourmaline. Sid was particularly attracted to the beautifully colored tourmalines, and decided to exploit them commercially. He started his gem and mineral business, the first of its kind in all of southern Africa, in Usakos in 1945, and 18 years later opened his now-famous "House of Gems" store in Windhoek. He was the source of vast treasures for over 40 years, especially from his tourmaline mines at Karibib and Usakos, and from deposits at Spitzkop, Erongo, Onganja, Berg Aukas, Rossing, Arandis, Otavi, Brandberg, and countless other occurrences. By far his most important source of specimens was the legendary Tsumeb mine, from which he handled an amazing quantity of superb specimens over the years; a new thiosulfate-bearing lead mineral from Tsumeb was named *sidpietersite* in 1998, "in recognition of his outstanding contributions to Namibian mineralogy" (see v. 31, n.4, p.371; see also the personality sketch of Sid in the 1977 Tsumeb Issue). He made his first visit to the Tucson Gem & Mineral Show in 1977, and attended the show for many years thereafter.

Sid died on March 23, 2003, and is survived by his wife Val and three daughters, Shelley, Maurine and Gail (all now with families of their own). His business continues to operate under the able management and ownership of Mr. Herbert Naegele.

I will always treasure the many times I spent in his company, in his shop, in his home with his naughty African gray parrot, under the spell of his many tales about Namibian minerals. He was a special and unique person.

Charles L. Key

Randolph S. Rothschild (1909–2003)

Died, Randolph (Randy) S. Rothschild, 93

Randy Rothschild, micromounter, patron of mineralogy and patron of the arts, was a long-time supporter of the *Mineralogical Record*; he made substantial annual donations toward magazine production expenses every year since the mid-1970's, and was thereby responsible for helping to assure the magazine's continued success and quality level.

Randy was born in Baltimore on June 23, 1909. His life-long love, aside from mineralogy, was music; he graduated from the Peabody Institute of Music in 1927. His family preferred that he enter traditional business circles, however, so he attended the Wharton School of Finance and Commerce, where he was awarded his BS degree in Economics in 1932; he also attended the University of Pennsylvania Law School (2 years) and the University of Maryland Law School, graduating with his LLB in 1936. He was admitted to the Maryland Bar that same year, and took a position with Sun Life Insurance Company (a company founded by his father, Solomon Rothschild), where he worked until his retirement in 1972, rising to the position of Vice President and General Counsel. He was financially very successful in his business life, although he was not related to the European Rothschilds of banking fame.

"If he hadn't had rigid German parents," says his daughter Amalie, "he would have been a jazz pianist. He wrote a number of popular songs that were published in the 1930's." He made major contributions to the advance of modern music by commissioning important works from modern composers (which were then premiered by the Baltimore Symphony Orchestra), and was a long-time board member of the Chamber Music Society of Baltimore and the Baltimore Symphony Orchestra Association. In 1992 he was awarded the George Peabody Medal for Outstanding Contributions to Music in America, and has for many years been listed in *Who's Who in American Music* and *The International Who's Who in Music*. His wife of 65 years, Amalie Rosenfeld Rothschild, was an artist in her own right who specialized in geometric abstract sculptures and painting. In 1993 Randy and Amalie were presented jointly with the Maryland Medici Lifetime Achievement Award, given by the Maryland Citizens for the Arts and the Maryland State Arts Council.

Mineralogy was one of his major hobbies (he also enjoyed photography, stamp collecting and coin collecting), and he was a member of the Baltimore Mineralogical Society since 1962; he served that society as editor of *The International Directory of Micromounters* from 1963 to 1993. His micromount collection consisted of thousands of carefully chosen specimens, many of which were bequeathed to important museums.

Randy was a modest, hospitable, intelligent and generous man with a deep passion for mineralogy and the arts; his support in all of these fields will be sorely missed.

WEW

Died, Richard T. Liddicoat, 84

Known affectionately as the "Father of Modern Gemology," and the "Dean of the Jewelry Industry," Richard T. Liddicoat invented the International Diamond Grading System in 1953 and contributed in major ways to gemological education, gem identification technology, and gemological research. He was a former President and lifetime board member of the Gemological Institute of America, the foremost educational and research organization in the gem world.

Richard T. Liddicoat, Jr. was born on March 2, 1918 in Kearsarge, Michigan, the son of an engineering professor at the University of Michigan in Ann Arbor. His grandfathers were immigrant miners in the copper country of Upper Michigan, inspiring him to investigate the local geology and eventually earn a Bachelor's Degree in geology (1939) and a Master's Degree in mineralogy (1940) from the University of Michigan. His mineralogy professor recommended him for an opening as Assistant Director of Education at the Gemological Institute of America, which had been founded in Los Angeles by Robert Shipley in 1931. At that time there was no formal education available in gemology, and professional jewelers had to learn the business on their own or as apprentices. Although the old-timers in the business resisted at first, the GIA eventually convinced the gem world that education was as important in gemology as in any other profession. Liddicoat rose through the ranks, being promoted to instructor and then to Director of Education. During World War II he served as a weather officer on an aircraft carrier in the Pacific, then returned to the institute after the war, where he was named Director of Research, and later Director of Education and Research. In 1952 he succeeded Shipley as Executive Director [later retitled President], and led the institute until 1983 when he retired as President to become Chairman of the Board of Directors. He also served as Editor-in-Chief of the institute's high-quality journal, *Gems & Gemology*, from 1952 until his death. He was also the author of *The Handbook of Gem Identification, The Diamond Dictionary* and *The Jeweler's Manual*. In addition to his work at the GIA, he was a founding member of the board of the Gem and Mineral Council of the Natural History Museum of Los Angeles County, and was instrumental in the growth of the Museum's gem collection. In 1977 he was appropriately honored by the naming of a new and very beautiful gem species of tourmaline, *liddicoatite*. Liddicoat was a giant in his field, a true pioneer whose accomplishments have forever changed the science and profession of gemology.

WEW

Died, Jolene (Jo) Runner, 79

Born Jolene Jensen in 1923, Jo and her husband Bruce were successful mineral dealers for 32 years, attending shows in Tucson, Los Angeles, Denver and Australia. They specialized in California minerals, especially benitoite and native gold. Field collecting was Jo's favorite part of the business, and she was a staunch supporter of children's programs at local clubs, always having free specimens available for kids. She was also actively involved in the Northern California Mineralogical Association. She died following a short illness, in Turlock, California on October 8, 2002, and is survived by Bruce, two children, seven grandchildren and 16 great-grandchildren.

WEW

"New" Old Back Issues

Most of our currently available back issues are listed on pages 310–311. *However,* we recently acquired a substantial stash of old but mint-condition out-of-print back issues of the *Mineralogical Record* from the unused stock of one of our foreign subscription agents (now deceased). These newly found issues, because of the limited quantities, are *not* included on pages 364–365, but are available only through our website, www.minrec.org. Many issues that have been unavailable for years (including all five Arizona Issues, the first Gold Issue, the Mineral Books Issue, and others) are now temporarily available once again. You now have a second chance, for a short while, to acquire some rare and popular "classic" issues of the *Record*.

English ExtraLapis

Christian Weise's excellent series of independent special-topic publications for mineral collectors is currently being translated into English and re-edited for publication in America. We think the new English versions are now even better than the original German-language editions. Thus far the books (as they should be called, despite their magazine format) that have been reissued in English include the ones dealing with *Tourmaline, Emerald*, and *Madagascar*, with another one to come out shortly. We have reviewed each of these in our "Book Reviews" department (vol. 34, no. 2 and vol. 33, no. 2) and recommend them highly.

For the convenience of *Mineralogical Record* subscribers, we are stocking these books for immediate delivery, and will let readers know as each new title is issued. They may be ordered through the Circulation Manager (e-mail minrec@aol.com, or FAX at 520-544-0815); VISA and MC orders accepted. The price is $24 each, plus $2 each shipping (or $6 for Priority Mail) in the U.S. (shipping to non-U.S. countries is $6 for surface mail, and by airmail $12).

THE MUSEUM DIRECTORY

New York State Museum

Curator (Geol.): Dr. William Kelly
Tel: 518-474-7559
Collections Mgr. (Geol.):
Michael Hawkins
Tel: 518-486-2011
Fax: 518-486-3696
3140 Cultural Education Ctr.
Albany, NY 12230-0001
Website: www.nysm.nysed.gov
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Specialty: New York & worldwide minerals
Support Org.: NY State Acad. of Mineralogy (www.nysm.nysed.gov/nysam)

Geology and Meteorite Museums University of New Mexico

Curators: Barry Kues (Geology), Rhian Jones (Meteorites)
Tel: (505) 277-4204
Dept. of Earth & Planetary Sciences
Northrop Hall, Univ. of New Mexico
Albuquerque, NM 87131
Hours: 8–12, 1–4 M–F (closed on school holidays)
Specialties: Worldwide minerals and meteorites, New Mexico fossils, Harding Pegmatite Mine Collection

Colburn Gem & Mineral Museum

Executive Director: Debbie Mowrey
Tel: (828) 254-7162
Fax: (828) 257-4505
Website: www.main.nc.us/colburn
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2 South Pack Square
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Accessible to persons with disabilities

Montana Tech Mineral Museum

Curator: Dr. Richard Berg
Tel: 406-496-4172
Fax: 406-496-4451
e-mail:dberg@mtech.edu
Program Director: Ginette Abdo
Tel: 406-496-4414
e-mail:gabdo@mtech.edu
Website: www.mbmg.mtech.edu/museumm.htm
Montana Bureau of Mines & Geology
Montana Tech of UM,
1300 W. Park Street
Butte, Montana 59701
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Specialties: Butte and Montana minerals, worldwide classics

Harvard Mineralogical Museum

Curators: Dr. Carl A. Francis
William Metropolis
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24 Oxford Street
Cambridge, Mass. 02138
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Specialties: Systematic Mineral Coll'n

Western Museum of Mining & Industry

Curator: Terry A. Girouard
Tel: (719) 495-2182
email: wmmicurator@aol.com
Dir. of Educ.: Scott Wright
Tel: (719) 488-0880
Fax: (719) 488-9261
www.wmmi.org
1025 North Gate Road
Colorado Springs, CO 80921
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The Gillespie Museum of Minerals, Stetson University

Curator: Dr. Bruce Bradford
Tel: (904) 822-7331
E-mail: bbradfor@stetson.edu
Assistant Director: Holli M. Vanater
Tel: (904) 822-7330
E-mail: hvanater@stetson.edu
Fax: (904) 822-7328
234 E. Michigan Avenue
DeLand, Florida
Mailing: 421 N. Woodland Blvd., Unit 8403, DeLand, FL 32720-3757
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A. E. Seaman Mineralogical Museum

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Curator (mineralogy):
George W. Robinson
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
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Fax: (713) 523-4125
1 Herman Circle Drive
Houston, Texas 77030
Hours: 9–6 M–Sat., 12–6 Sun.
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Additional listings welcome!

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

Museums listed alphabetically by city

THE MUSEUM DIRECTORY

Natural History Museum of Los Angeles County

Fax: (213) 749-4107
Website: http://nhm.org/minsci
Curator (Mineral Sciences):
Dr. Anthony R. Kampf
Tel: (213) 763-3328
e-mail: akampf@nhm.org
Collections Manager:
Dorothy L. Ettensohn
Tel: (213) 763-3327
e-mail: dettenso@nhm.org
900 Exposition Blvd.
Los Angeles, CA 90007
Hours: 9:30–5:00 Daily
Specialties: Calif. & worldwide minerals, gold, gem crystals, colored gemstones
Support organization:
The Gem and Mineral Council

California State Mining and Mineral Museum

Website: http//parks.ca.gov/parkpages/park_page.asp?lvl_id=227
Curator: Peggy Ronning
Tel: (209) 742-7625
Fax: (209) 966-3597
e-mail: mineralcurator@sierratel.com
5005 Fairgrounds Rd.
Mariposa, CA 95338
Mailing Address:
P.O. Box 1192
Mariposa, CA 95338
Hours: 10–6 Daily (May–Sept.)
10–4 Wÿ¥.–Mon. (Oct–Apr.)
Specialties: Gold, California minerals, California mining

Arizona Mining & Mineral Museum

Department Director: Doug Sawyer
Curator: Sue Celestian
Tel: (602) 255-3795
1502 W. Washington Avenue
Phoenix, AZ 85007
Hours: 8–5 M–F, 11–4 Sat., closed Sun. & holidays
Specialty: Arizona minerals

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

Museum of Geology

Curator: Thomas J. Campbell
Tel: (605) 718-2288
South Dakota School of Mines & Technology
501 E. St. Joseph St.
Rapid City, SD 57701-3995

New Mexico Bureau of Mines & Mineral Resources—Mineral Museum

Director: Dr. Virgil W. Lueth
Tel: (505) 835-5140
E-Mail: vwlueth@nmt.edu
Fax: (505) 835-6333
Associate Curator: Robert Eveleth
Tel: (505) 835-5325
E-mail: beveleth@gis.nmt.edu
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801 Leroy Place
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The El Desierto Sulfur Mine
Potosí, Bolivia

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In July of 1999, at the instigation of Mr. Rock Currier, who wanted a sea container (8 tons) of crystallized native sulfur for his wholesale mineral business in California, I set off for the remote El Desierto sulfur mine in Bolivia to check on the progress of our specimen-mining project.

VISITING THE SITE

El Desierto is one of about sixty sulfur deposits in Bolivia, all located on the chain of volcanoes that forms the Western Andes cordillera along the border between Bolivia and Chile. At most of these deposits, the native sulfur is massive, occurring as the cementing agent in volcanic ash, but in three deposits, including El Desierto, good crystals of sulfur are found.

El Desierto is two days' drive from civilization (i.e. my home town of Cochabamba) across the southern Altiplano, the dry high-altitude plains (over 13,000 feet) that cover much of southwestern Bolivia. July is winter here and night-time temperatures can drop to –20°C (–4°F). So I loaded my much-abused four-wheel-drive vehicle inside and out with sleeping bags, extra blankets, food, water, cans of gasoline, and a Bolivian friend who is adept at keeping jeeps alive under conditions not anticipated by the manufacturer.

He knew all sorts of useful local tricks, like covering the car engine with blankets at night, and urinating into the brake fluid receptacle to keep the brakes working after we ran out of brake fluid. On the first night we pulled into the dust-blown town of Sevaruyo, which looks remarkably like a trading post in a post-apocalyptic nuclear holocaust film, but it does boast the only hotel for a hundred miles around. Even at $1.50 per bed in the large communal sleeping room it was overpriced: candlelight only, no toilet, and my pillow felt greasy and smelled of hair cream (I don't use hair cream). In the wee hours of the morning we were awakened by a horde of smugglers stomping groggily into "our" room, looking for a place to rest after their freezing overnight drive on rough, unmapped tracks coming from Chile.

On the second day out the scenery became even more desolate. The hundreds of kilometers of volcanic mountains made the landscape appear more and more like Mars the further we drove. We encountered very few human beings, only a handful of farmers who grow *quinoa* (a fine-grained cereal grown locally), and smugglers. We met only one vehicle all day, a truck carrying *yareta* firewood, the only burnable plant which can survive the intense ultraviolet radiation and the temperature extremes in this area.

By late afternoon we reached the northern shores of the Salar de Uyuni, the world's largest salt flat, three million acres of absolutely flat, blinding white salt stretching to the horizon. At only 12,000 feet above sea level, the Salar De Uyuni is the lowest part of the Altiplano. It also happens to be by far the best "highway" in the Republic of Bolivia, made by nature and not by the Servicio Nacional de Caminos. Driving into the Salar is easy—just follow the tracks of previous vehicles across the muddy shores. There the tracks disappear.

Once on the hard salt we drove at high speed, at least as fast as my poor old car would go, for some 50 or 60 miles to the southwestern shore of the salar. On the way we saw islands of stone that rose from the horizon as we approached them. They are the remnants of pyroclastic flows covered in part with collapsing stromatolite deposits. These islands have benches of rounded

Figure 2. **Salar de Uyuni with Mt. Tunupa at the north end of the salar. Rock Currier photo.**

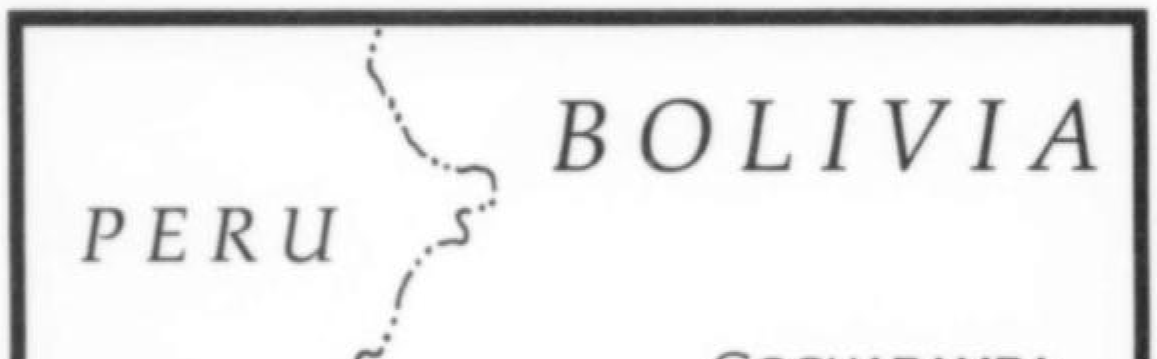


Figure 1. **Location map.**

volcanic pebbles formed by the wave action of the ancient lake, when it had water at higher levels.

That was the easiest part of the trip. Getting *out* of the salar, however, is not as easy as getting into it. Over the hundreds of miles of shoreline there are only about a dozen places where it is possible to drive out. Most of the shore is bordered by soft mud or mushy wet salt where runoff from the surrounding mountains has reached the salar. We got lost and couldn't find the exit. Daylight was failing. We started remembering the local horror stories about cars and buses full of people sinking into brine-filled caves to be lost forever, or perhaps to surface in some future millennium as human pickles. (The good thing about these brine caves is that they may hold very fine crystal groups of halite).

After driving carefully parallel to the soft shoreline for 20 miles, we found some black stones that other travelers had left on the salt to mark the hard-surface way off the salar. In the last light of the long summer day we wound our way westward up into the mountains. We passed a little hot spring where boiling water bubbles out of the ground and crude (mostly abandoned) "hot tubs" have been made by locals for bathing purposes. Finally at 9:00 pm we arrived at the Bolivian Military post on the border with Chile.

We found a few soldiers, a few sulfur miners, five children and one young schoolmistress. They had been without water and fuel for four days. The schoolteacher and some of the miners complained that they had not been paid for months. The soldiers' diet is frugal by American standards, but they can earn a few extra morsels by moonlighting in the sulfur mine. Nightlife in the village is limited. Miners sit around by candlelight drinking pure cane alcohol out of plastic cups after briefly setting it on fire, a process which they believe drives off the impurities responsible for hangovers. The upper classes, i.e. the mine owner and the sergeant, have extensive collections of X-rated videotapes and a 12-volt videocassette player. The only two women in the community, the mine camp cook and the pretty young schoolteacher, wisely stay out of sight at night.

In the morning we went out to inspect the specimen-mining project. The miners were tunneling up fractures in the quarry walls. The fractures opened into crystal-lined pockets every few feet. They had become quite expert at dynamiting out delicate vugs and saving the specimens intact. Five tons of specimens were already boxed or else awaiting the arrival of more wrapping materials. Some of the fissures in the quarry wall were emitting hot stinky gases. The miners, all working for Rock Currier, were being paid about eight times more per week than the average Bolivian miner gets, but they were earning every penny of it the hard way. Their eyes were burned bright red by the acidic sulfate dust. Their clothes

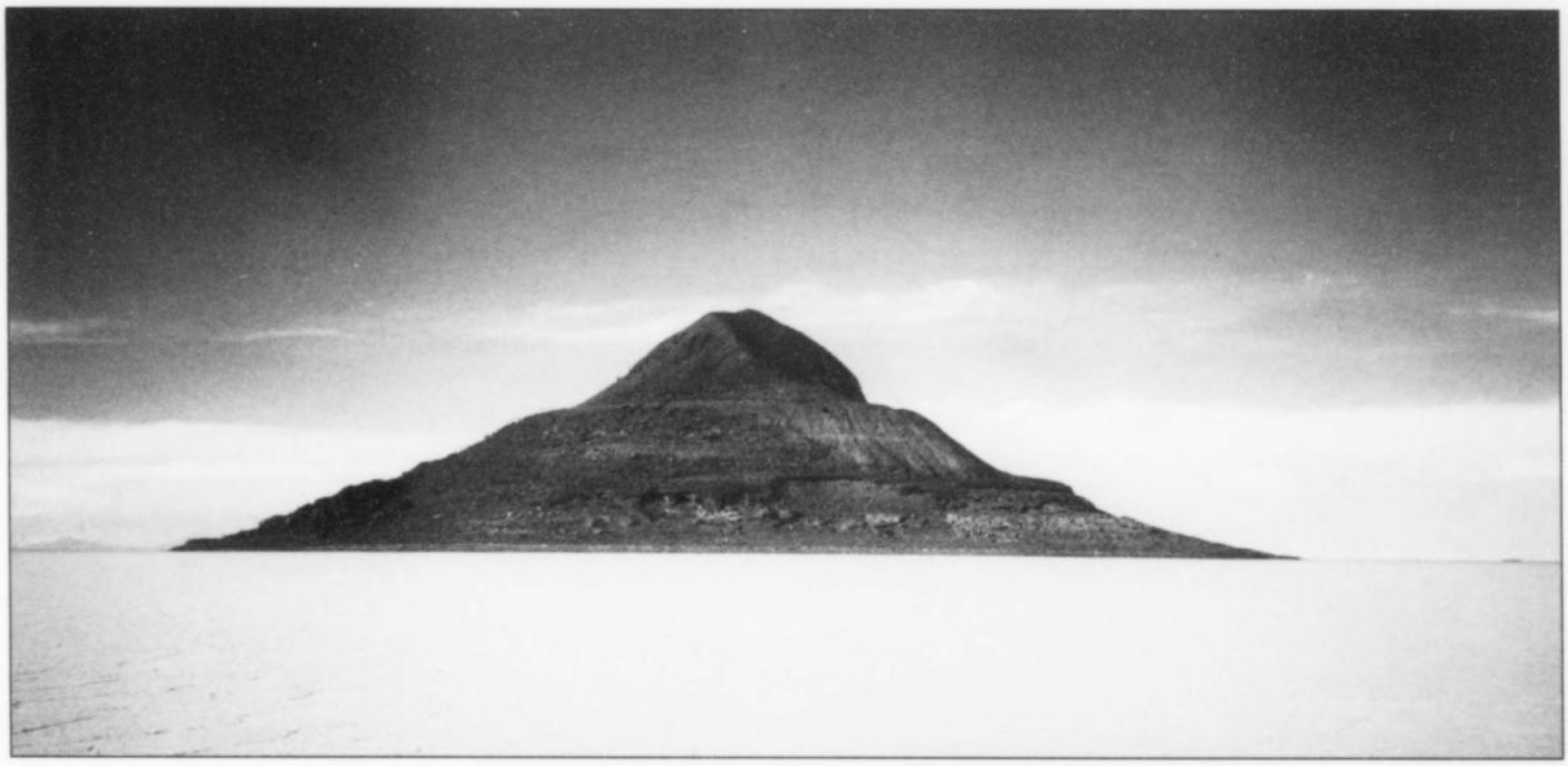


Figure 3. **Isla Comaña, a volcanic hill rising out of the Salar de Uyuni. Rock Currier photo.**

Figure 4. **Halite crystals collected by Alfredo Petrov out of cavities at the base of a small satellite volcanic island near a larger island. Rock Currier photo.**

and shoes were also being destroyed by the acid. No one had had a bath in six weeks. One miner had arrived at the work site with his wife and two small children, and everyone in the family was infested with lice. After two days at the mine, the lice were dropping off dead. (A visit to this mine would probably also be a rapid cure for stubborn fungal infections of the skin!)

On the second night, a tremendous howling wind lifted up the tin roof of the shack I was camping in, and slammed it back down with enough force to break off bits of the adobe wall, which rained down on my head. My hair was a dust-caked uncombable mass, I stank, and my clothes reeked of sulfur. After two days at El Desierto I was most eager to head back home. The schoolteacher, also desperate to escape the place but having no transportation and being unwilling to walk the 60 miles across the salt, begged to come with me. I regretfully refused to save her from her fate; the car was full, and anyway I didn't want to leave the children without a teacher.

The long drive home was uneventful. Not so the complicated transport routes and Byzantine bureaucratic hurdles which had to be overcome to get the sulfur specimens from El Desierto to the port in Arica, Chile and then on to the United States—but that is another long story . . .

Most of the sulfur crystals at El Desierto are found growing on a white sulfate-rich rock, but a few are found on a contrasting black manganese oxide-coated matrix. Colorless crystals of potassium alum are not uncommon. Several other sulfates are also present in small quantities. Botryoidal hyaline opal is the only other common mineral, although it is usually overlooked because it is almost invisible on the white matrix rock.

Figure 5. **The post-apocalyptic-looking town of Sevaruyo. Rock Currier photo.**

Figure 6. **Wild eagle perched on the author's head on Inca Huasi Island, one of the volcanic islands in the Salar de Uyuni. Rock Currier photo.**

LOCATION AND OWNERSHIP

The El Desierto mine and the neighboring Concepción mine are actively worked sulfur quarries associated with the dormant Cayte (also spelled Caite) volcano, located at 20°32′2″ S, 68°31′8″ W, roughly 5 miles south of the abandoned village of San Pablo de Napa, at the southern end of the Salar de Empexa, and only a few hundred meters from the Chilean border, in Daniel Campos Province, Potosí Department, Bolivia. Both mines belong to the Empresa Minera Clavijo (EMICLA), which also owns sodium carbonate and sulfate deposits further south.

PRODUCTION AND RESERVES

When mining commenced in the early 20th century, the sulfur ore at El Desierto was the richest in Bolivia, averaging 80% sulfur! By 1941, between 400 and 500 tons per month were being produced for export to Argentina and Brazil for the production of sulfuric acid. At present the ore averages about 50% sulfur, and yearly production does not exceed 2,000 tons, mostly destined for a sugar refinery in Santa Cruz, Bolivia. Estimated reserves are 320,000 tons at 56% sulfur for the El Desierto mine. Other references give a combined reserve for both mines of 500,000 tons at 50% sulfur, and 3,000,000 tons at 33% to 50% sulfur. A serious hindrance to increasing production is the lack of fuel for the sulfur refining plant. At present the only fuel available is the mostly underground and very slow-growing resinous *yareta* "bush" (it looks like a low growing mound of moss). This plant has already been exterminated across an area of a few tens of kilometers around the mine.

GEOLOGY

Although most Bolivian sulfur mines are located at very high altitudes in the craters of several volcanoes of the Western Andes, the San Pablo de Napa deposits occur at a more tolerable altitude on the lower slopes of the Cayte volcano, hosted in an old debris avalanche. The host rock is a Pliocene volcanic ash bed, from 50 to 100 cm thick, dipping 15 to 20° north. The surface area of the deposit measures about 400 meters by 2.5 km. At its upper elevation, 4,300 meters above sea level, the sulfur is covered by lava. At its lowest elevation, 3,750 meters, almost on the shores of the Salar de Empexa, the sulfur crops out at the surface. Weak fumarolic activity is still evident in several fissures in the sulfur quarries. (Occasionally, parts of the sulfur deposit accidentally catch on fire, resulting in strong "pseudo-fumaroles" that cannot be extinguished by covering them with dirt; they have to be put out

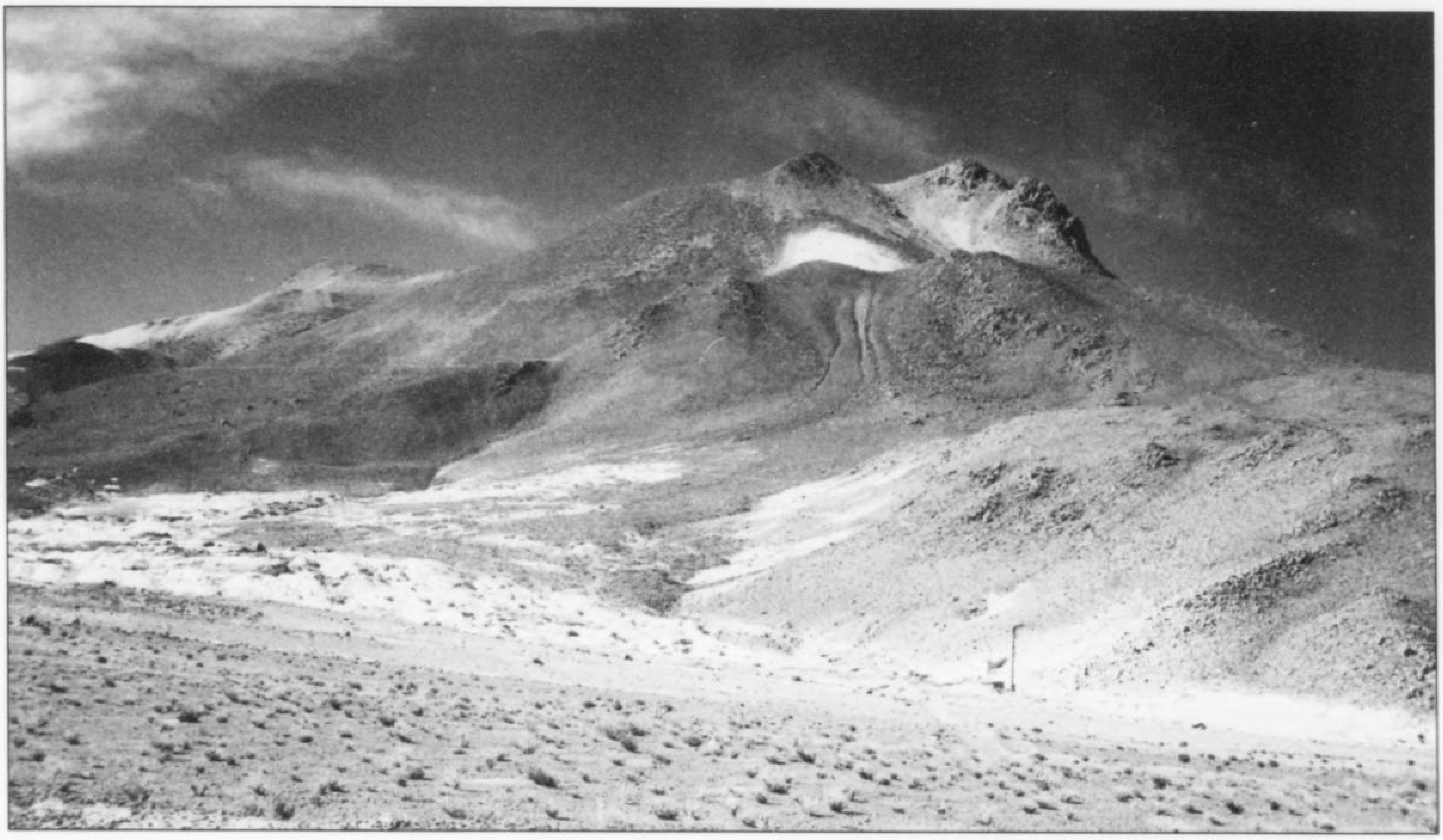


Figure 7. **The El Desierto sulfur mine. Rock Currier photo.**

Figure 8. **The El Desierto sulfur mine, with the Salar de Empexa in the background. Rock Currier photo.**

with water, a scarce resource there!) Very acidic warm springs (31°C) flow at the borders of the Salar de Empexa, near the El Desierto mine, and there is at least one geyser, which tends to erupt once a day, soon after dawn. The greenish-yellow sulfate crust on one area of the Salar might indicate the presence of sub-salar fumaroles. At Quebrada Malpaso, an alkaline (pH 8.3) spring, enriched in lithium and boron, flows into the salar. Although the water temperature is only 78°C, it is boiling because of the low air pressure at such high altitude. Unlike the Salar de Uyuni, which is covered by a halite crust with minor sylvite and gypsum, the Salar De Empexa's crust is composed mainly of gypsum, halite, clay and calcite, with minor sodium sulfate; 210–580 ppm Li, 0.77–2.0% K, 0.85–2.3% Mg. (The Salar de Empexa is the fourth largest salar in Bolivia, although it covers only 191 km^2, compared to over 11,000

Figure 9. **The face of one of the open cast pits at the El Desierto sulfur mine, showing mined-out fissures that were once lined with sulfur crystals. Rock Currier photo.**

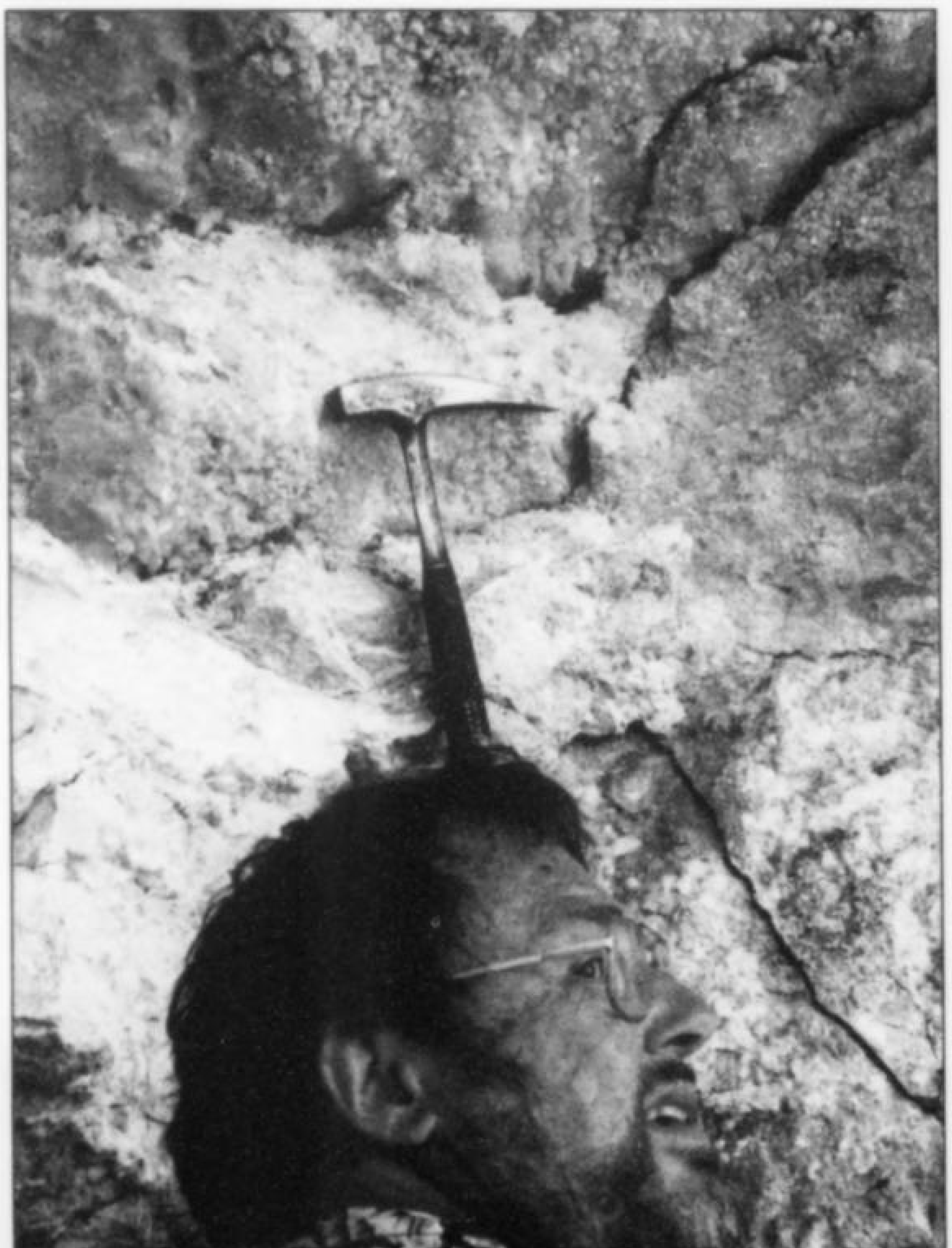


Figure 10. **Sulfur crystal, 8 cm, from the El Desierto mine. Jaroslav Hyrsl photo.**

Figure 11. **Sulfur crystals in place at the El Desierto mine. Rock Currier holding rock hammer for scale.**

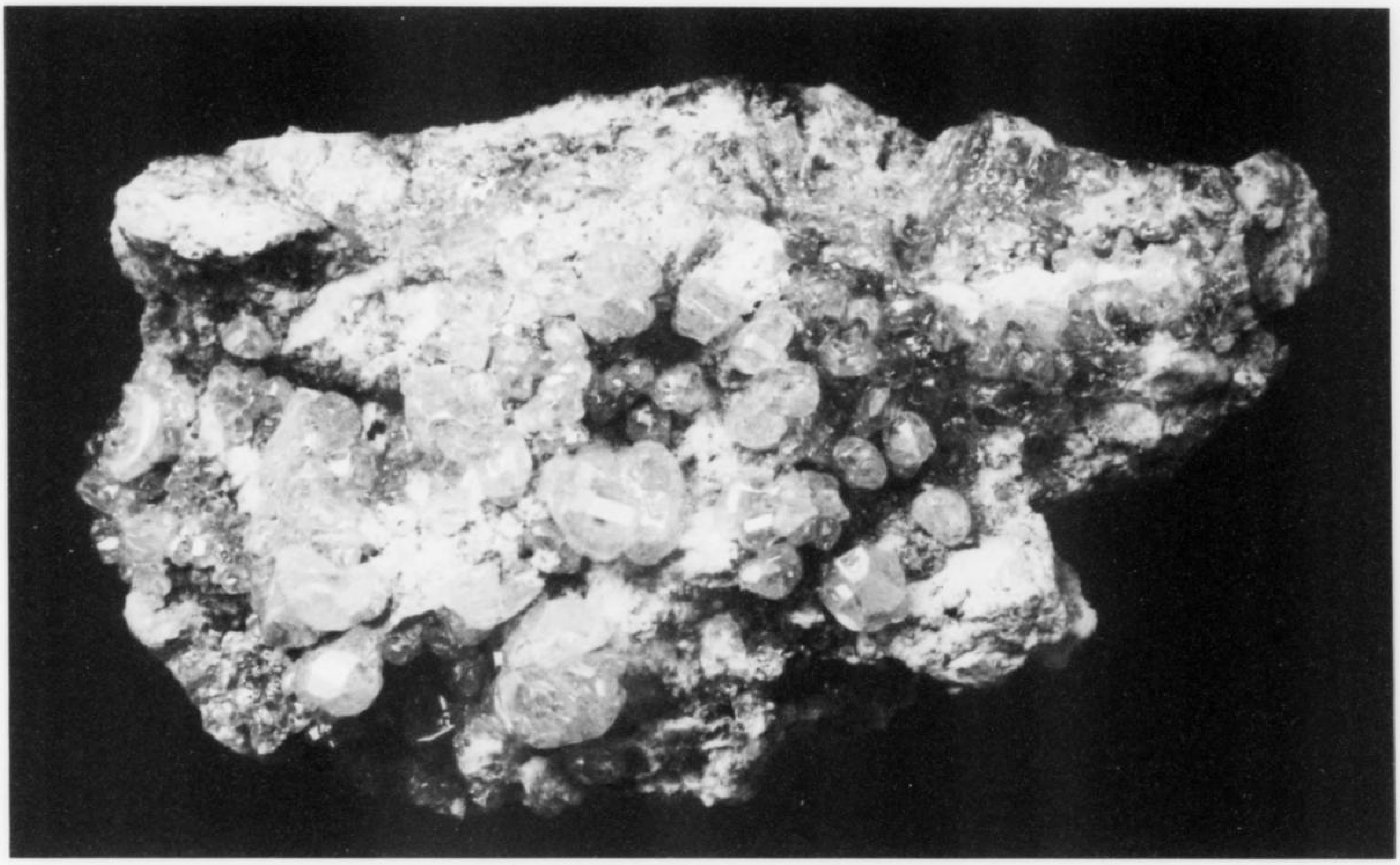


Figure 12. **Sulfur crystals on matrix, 10 cm (the largest crystal measures 1 cm), from the El Desierto mine. Jaroslav Hyrsl photo.**

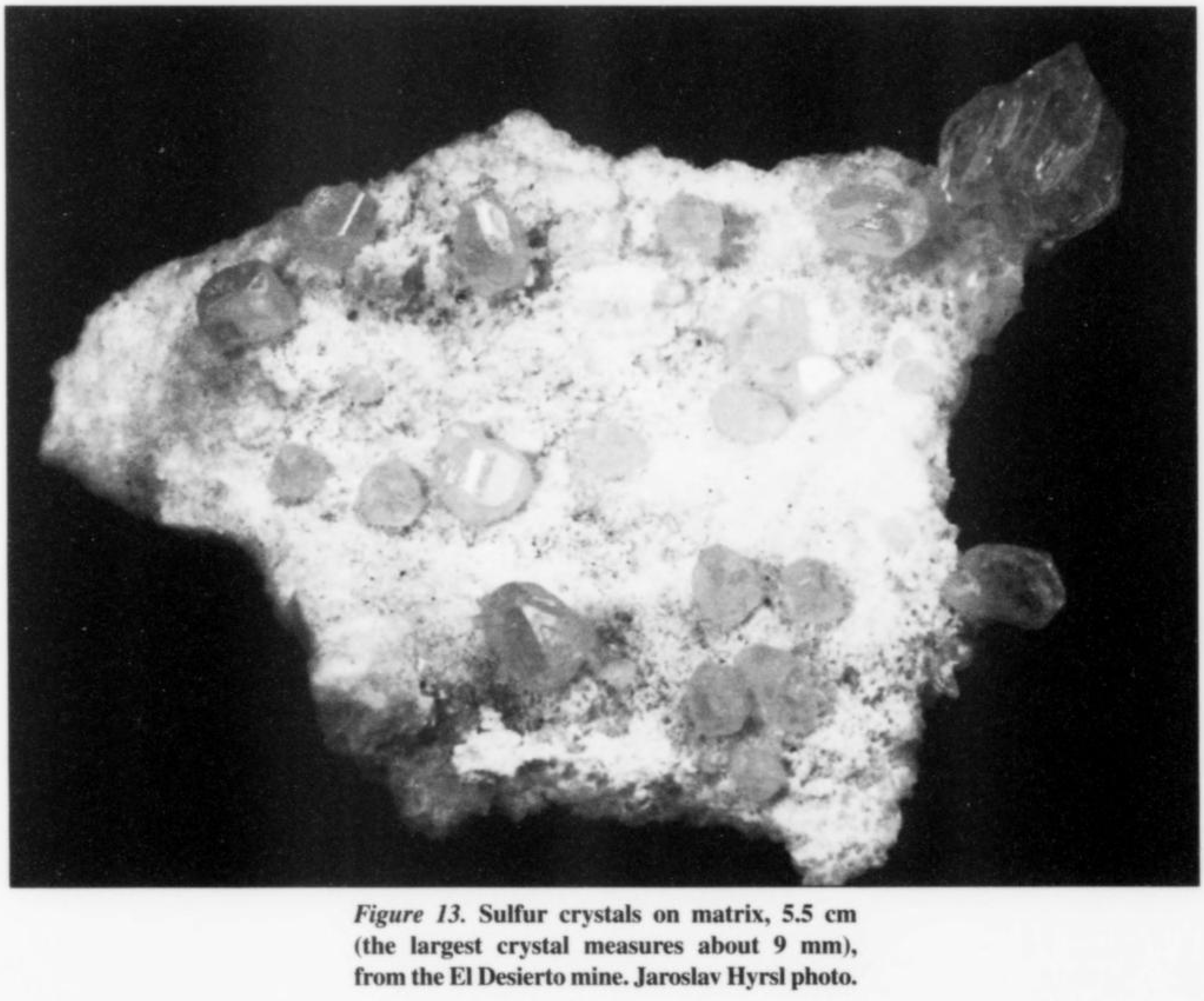


Figure 13. **Sulfur crystals on matrix, 5.5 cm (the largest crystal measures about 9 mm), from the El Desierto mine. Jaroslav Hyrsl photo.**

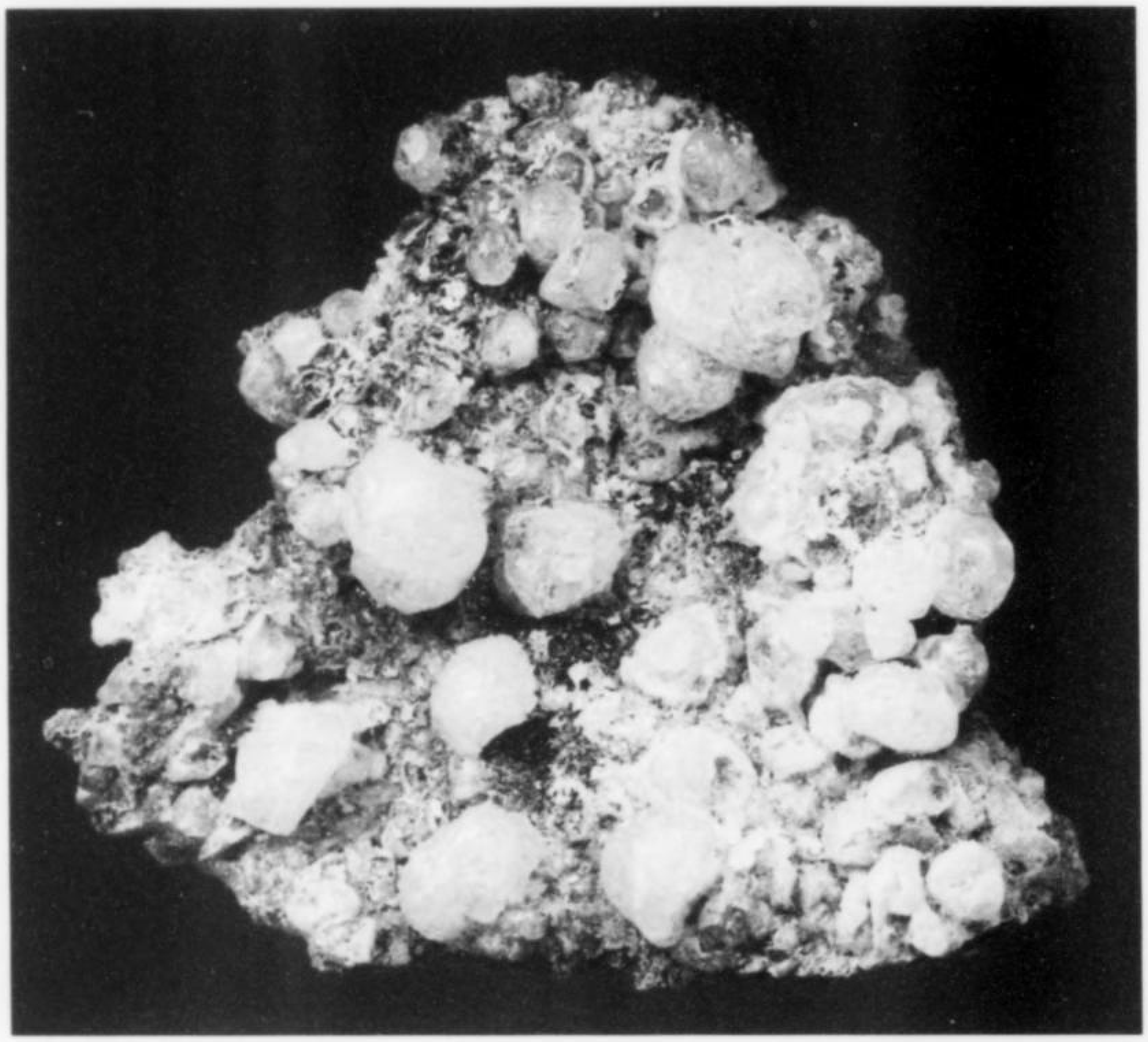


Figure 14. **Sulfur crystals on matrix, 9 cm (the largest crystal measures 1 cm), from the El Desierto mine. Photo by Jaroslav Hyrsl.**

km² for the Salar de Uyuni.) From 1900 until 1941, the Salar de Empexa was the most important ulexite producer in Bolivia, with a 60-cm-thick bed of ulexite, now worked out, at Boratera Laqueca, and a 30-cm to 40-cm bed at Boratera Isma, likewise mined out.

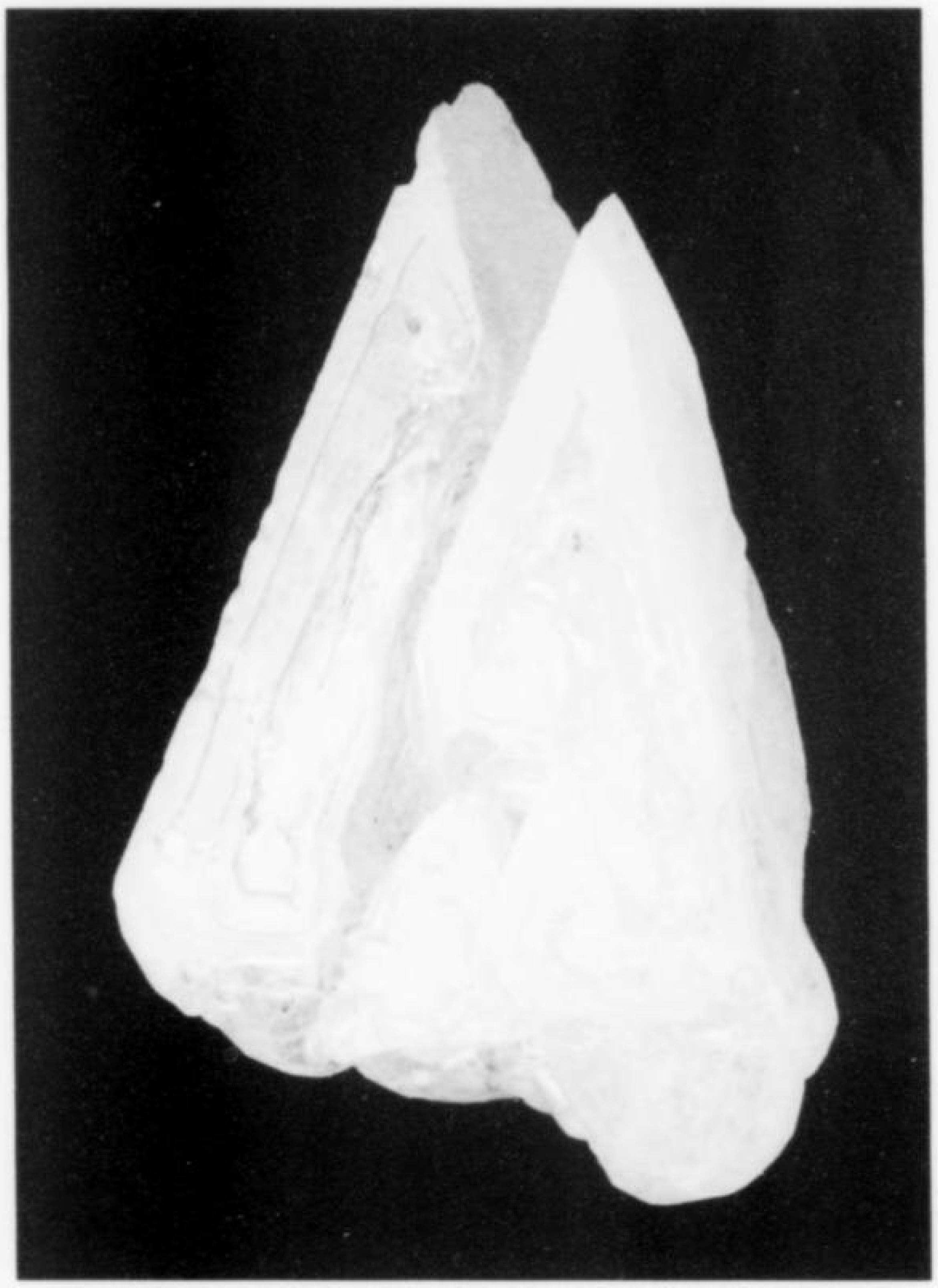
MINERALS

Sulfur, well-crystallized in a wide array of crystal habits ranging from equant to acicular (possibly the habit is dependant on the temperature of deposition) is the most abundant and well-known mineral from these deposits. The sulfur is quite pure, with some of it containing just traces of arsenic and selenium. Crystals average about 1 cm in length, but a few can reach 10 cm. The chemical reaction that probably forms the sulfur is $H_2S + SO_2 = S + H_2O$. The matrix rock for the sulfur crystals is highly-altered volcanic material consisting now mainly of clay minerals, opal (hyalite), alunite, gypsum and minor films of manganese oxides.

Other fumarolic minerals present include **potassium alum**, as sharp, complex colorless crystals and as colorless to white "rams horn" growths, often with millimeter-sized gemmy sulfur crystals sprinkled on them, proving that the sulfur was deposited later (and presumably at an even lower temperature) than the alum.

Coquimbite occurs rarely as pale violet-colored crusts. Other minor associated minerals include **kalinite**, **mirabilite**, **alunogen**, **pickeringite** and **melanterite**. Several blue and orange-colored sulfates have not been positively identified but probably include **romerite**, **voltaite**, **metavoltine** and **chalcanthite**. The **alunogen** and **melanterite** are probably the minerals responsible for the acidic properties of the matrix, which destroys the paper used to wrap the specimens.

Figure 15. **Sulfur crystal, 3.5 cm, from the El Desierto mine. Jaroslav Hyrsl photo.**



CARE AND FEEDING

To prepare the specimens for sale it is necessary to soak them in water to which ammonium hydroxide has been added. This neutralizes the acidic component of the matrix, and thus prevents the specimens from eating up any paper or cardboard that they might come in contact with. A small amount of sodium bifluoride is added in order to complex iron. Without this treatment, the matrix of many specimens would gradually turn a pale brown.

CURRENT COLLECTING STATUS

The owner of the mine is usually happy to give visiting collectors permission to dig. Remember that a bottle of fine liquor, a sack of fruit or vegetables, some foreign tobacco and a raunchy video all make much-appreciated gifts in this luxury-starved landscape of unwilling ascetics. Bring especially lots of drinking water and food for yourself, in case the camp has run short. A face mask with a good dust filter is advisable for those collectors who might feel some discomfort when the tears and mucus in their eyes and nose turn into sulfuric acid.

REFERENCES

AHLFELD, Federico (1941) *Los Yacimientos Minerales de Bolivia.* Dirección General de Minas & Petróleo, La Paz.

AHLFELD, F., and SCHNEIDER-SCHERBINA, A. (1964) Los Yacimientos Minerales & de Hidrocarburos de Bolivia. *Departamento Nacional de Geología, Bolivia, Boletín* **5** (Especial), 338 p.

ANONYMOUS (1992) Geology and mineral resources of the Altiplano and Cordillera Occidental, Bolivia. U.S. Geological Survey and Servicio Geológico de Bolivia. *U.S. Geological Survey Bulletin* **1975**.

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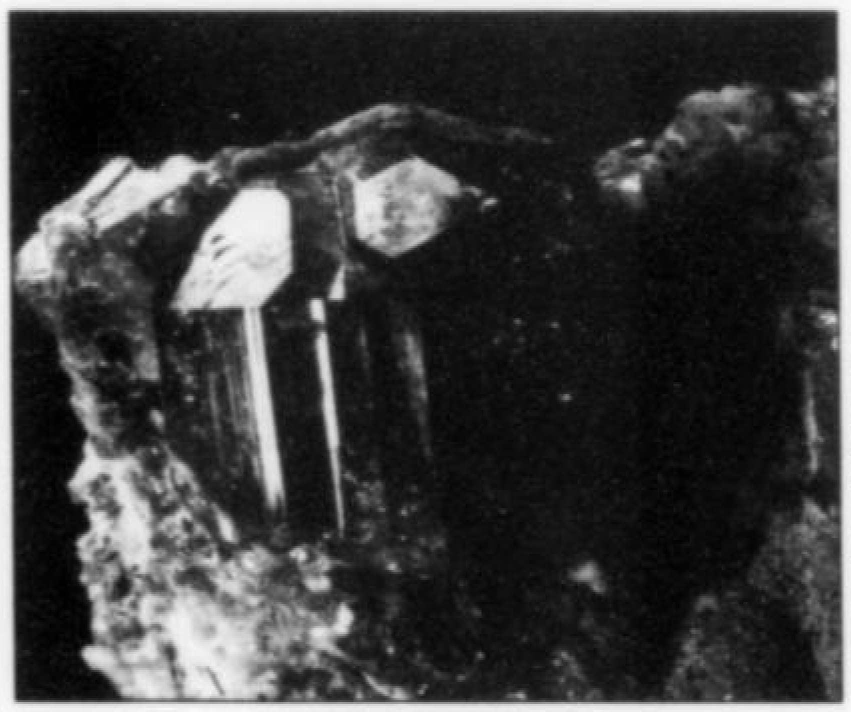

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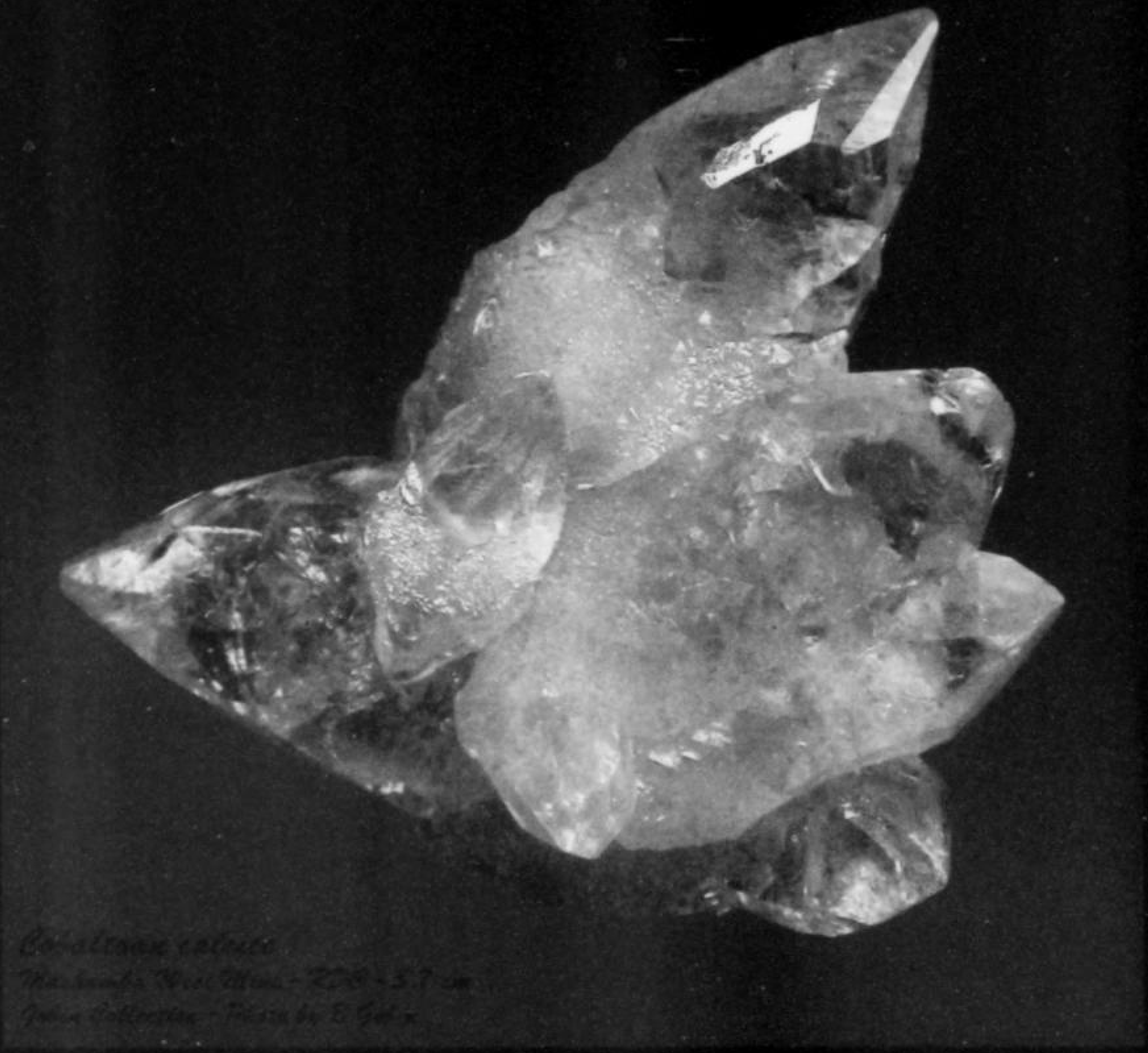

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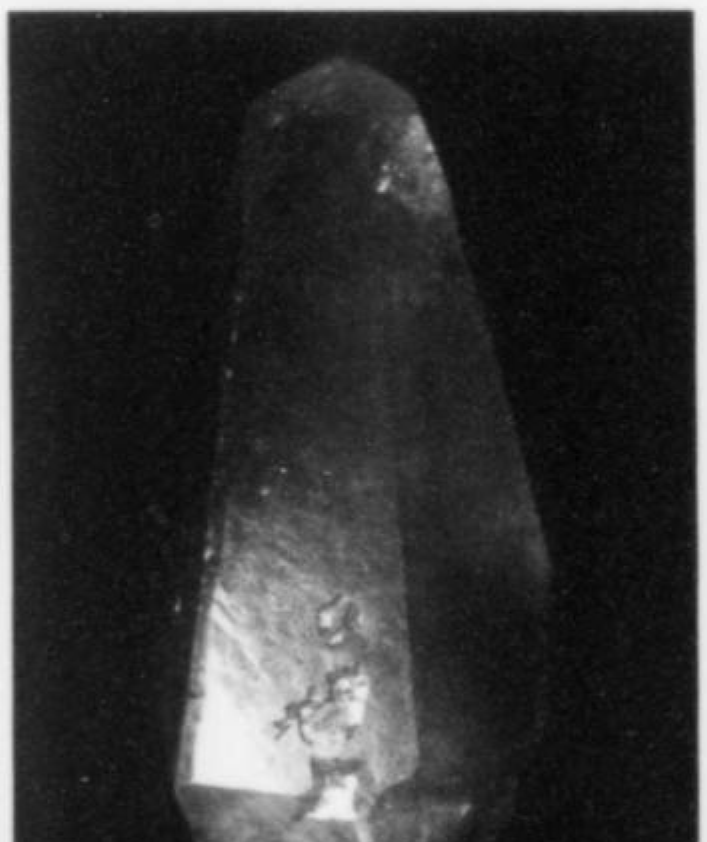

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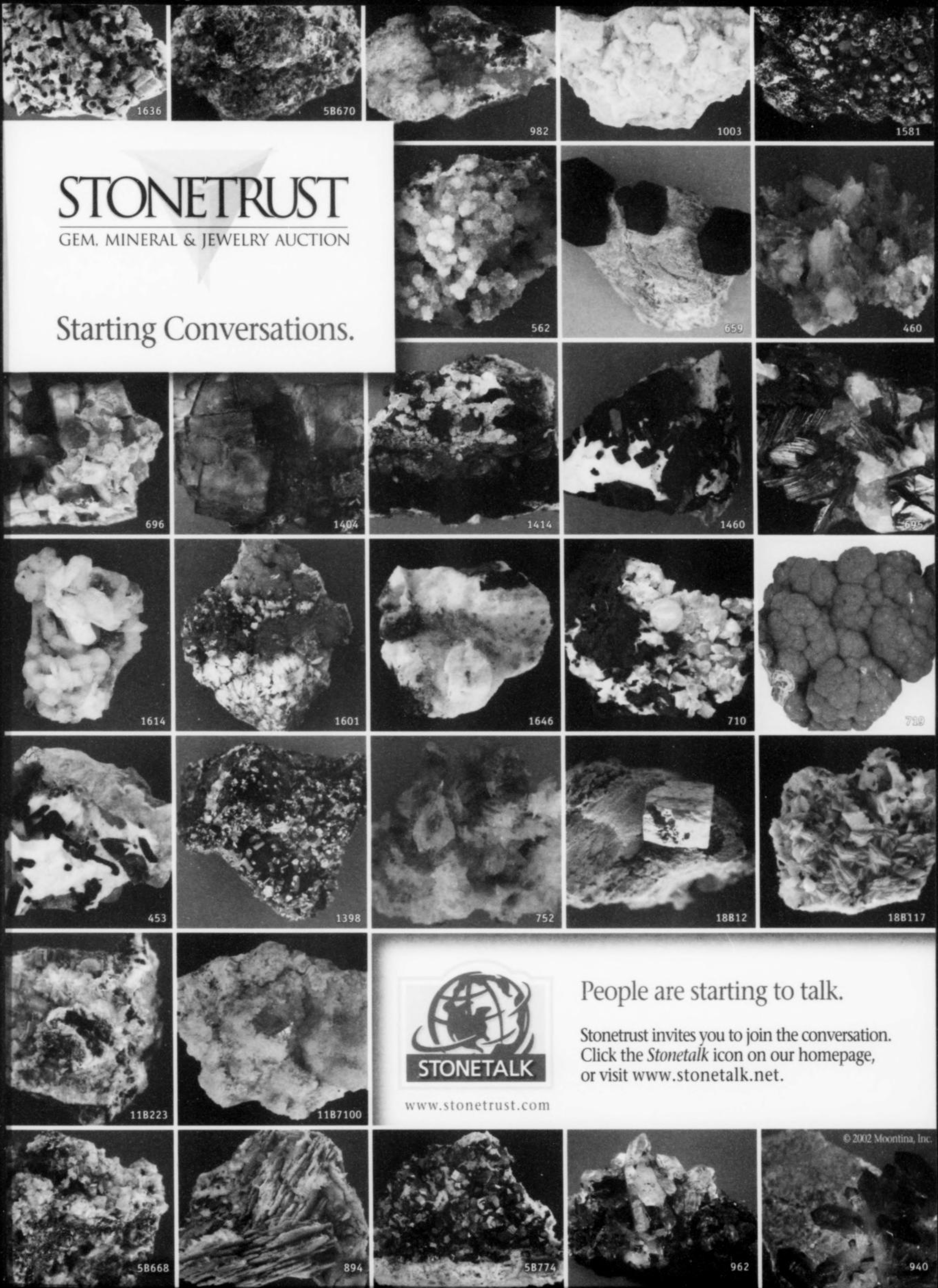

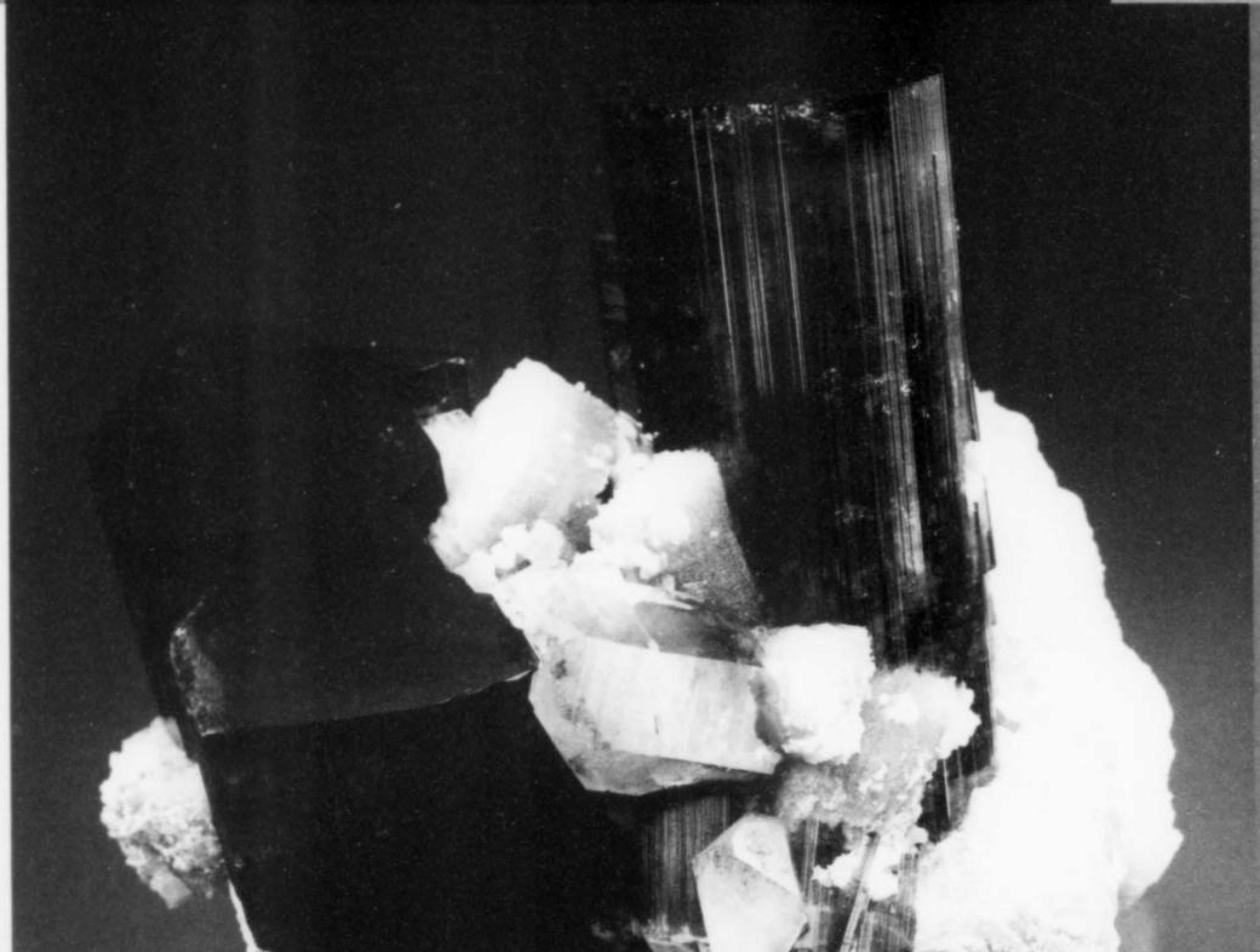

Secondary Minerals of the Mazarrón-Águilas Mining District, Murcia Province, Spain

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Three small prospects in the Mazarrón-Águilas mining district—the Dolores prospect near Pastrana village, the La Atalaya prospect at the La Crisoleja site, and the La Umbría de Ramonete Valley prospect in the Lomo de Bas Mountains (all in Murcia Province, southeastern Spain)—have produced well-crystallized copper arsenates and associated secondary minerals. Outstanding among these are the new mineral cobaltarthurite for which the Dolores prospect is the type locality, world-class specimens of lavendulan, one of the first world occurrences of zálesíite, rare yukonite specimens and, perhaps, some future new mineral species currently under study.

Figure 1. **Umbría de Ramonete prospect in October 2001.**

INTRODUCTION

At the beginning of the 1990's, a specimen labeled as "aurichalcite" from Pastrana (Murcia) was handed to one of the authors (BSB). Its habit, color and association with other copper arsenates suggested that the specimen could be lavendulan, and an EDS qualitative analysis at the Mining School of Madrid in 1992 confirmed the identification.

Subsequent studies at the Dolores prospect showed abundant lavendulan, associated with some copper arsenates and other secondary minerals. Investigations of other copper prospects in the area were conducted, and one small prospect in the Umbría de Ramonete valley was found also to produce lavendulan, as small electric-blue crystals similar to the Dolores specimens. These lavendulan crystals, better formed than the Dolores crystals, were found in a jasperoid rock at the entrance to the portal. In addition, an extensive suite of secondary minerals from the Umbría de Ramonete occurrence has been collected and studied. Investigations have also been conducted at the Atalaya copper mine, where copper arsenates are found, but no lavendulan.

One early description of these copper prospects and their secondary minerals was written for the Grupo Mineralogista de Madrid (1994); further references are found in Muelas *et al.* (1996), but no analytical identifications have thus far been reported. In the present paper a complete description of the secondary mineralogy of these mines is presented.

MINING HISTORY

The southeastern part of Spain is among the most intensely mineralized regions of Europe, with a great variety of ore-forming environments containing primarily Pb-Zn-Ag ores. The most important economic districts from north to south are: Sierra de Cartagena (La Unión), Mazarrón, Águilas and Sierra Almagrera. Mining in some of these Pb-Zn-Ag deposits was economically very important as long ago as the pre-Roman period (Villar and Egea, 1990; Rolandi, 1993; Ramallo and Berrocal, 1994). In the Mazarrón-Águilas district, the first documented mines date from 1587 (González, 1832), when Juan Bautista Genovés got permission from the Government to work several argentiferous *pedreras* (gravel dumps) in Mazarrón village; probably these were ancient Roman dumps of Pb-Ag ores or slags.

In 1688, the King of Spain gave Francisco de Leiva permission to work a silver mine at Mazarrón. However, the major mining activity in this district was developed in the nineteenth century; in 1840 there were more than 200 shafts and galleries at Mazarrón, and in 1843 40,670 *quintales* of lead minerals (one quintal is about 46 kg) and 96,849 marks of silver (one mark is about 230 g) were shipped from Águilas harbor (Madoz, 1842–1850). Silver-lead mining increased between these times and 1860, especially in the Lomo de Bas (Águilas) mines and in the Mazarrón mines. During this period these lead/zinc deposits were the most productive in Spain (Villar and Egea, 1990).

Other mineral deposits in the Mazarrón-Águilas area have also been economically important. Mining of the alum (alunite) deposits of San Cerro de Cristobal began in 1462, when the King of Spain granted a license for working these mines to the *Marqueses* of Villena and Los Velez. The alum mining was intensively developed in the sixteenth century. These mining works led to an increase in population, and King Philip II promoted Mazarrón village to the "Villa" category, naming it *Villa de las Casas de los Alumbres* of Mazarrón (village of the houses of the alum) (Madoz, 1842–1850).

In 1853, rich iron and silver veins were discovered in Lomo de Bas (Águilas), initiating the Carmen and La Cruz mines. Soon other large iron deposits were discovered in the Mazarrón area, sometimes including small masses of lead carbonates, silver halides and antimony oxides (Villar and Egea, 1990).

However, copper mining was never of much importance. In the middle of the nineteenth century some small copper prospects developed in the course of a search for silver-rich copper sulfosalts; several claims of minor importance are registered between 1842

Figure 2. **La Atalaya prospect; view of the dumps and portal, September, 1990. BSB photo.**

and 1860 in this district (Villar and Egea, 1990). But the scarcity of primary mineralization and the dissemination of the ores limited development to small prospects and drifts.

Besides the three copper prospects examined here, a few other small prospects are located between Mazarrón and Águilas; these include Morra Blanca, Sierra de las Moreras (SW of Mazarrón), Sierra de la Carrasquilla and Calnegre. Copper is usually associated with the iron deposits of Sierra de Enmedio and Sierra de la Almenara, northwest to northeast of Águilas. Of interest to collectors are the chrysocolla pseudomorphs after malachite from Morra Blanca, and the very nice short-prismatic malachite crystals, elongated on [001] and twinned on {100}, from Almendricos, Sierra de Enmedio, associated with cuprite, calcite and goethite.

By the beginning of the twentieth century, iron mining had stopped. The alum mines were definitively closed in 1953, the lead-zinc mines of Águilas ceased working in the 1960's, and mining activities in the lead-zinc deposits of Mazarrón stopped in 1969.

GEOLOGY

The Mazarrón-Águilas mining district is situated in southeastern Spain, in the eastern part of the Cordillera Bética (Betic Mountains or Betic Range). Geologically the region is known as the Betic Zone, a complex structural framework created by the relative movements of the African and European plates since the late Mesozoic. The Betic Zone may be divided into two major parts: the external and internal zones. The external zone is composed of folded and faulted rocks generally unaffected by Alpine-age metamorphism; the internal zone is characterized by a nappe structure with a very complex tectonic framework, with superimposed tectonic-stratigraphic terrains ranging from lower Paleozoic to Lower Triassic in age. A carbonate terrain of Middle to Upper Triassic age overlies the basement. Cretaceous to Cenozoic subduction-related compression, an effect of the collision of the African and European plates, was followed by Miocene post-collision extension. In the southeastern Betic Zone, as a consequence of this extension, volcanism produced a calc-alkaline belt of basalt to rhyolite rocks. Finally there was a period of widespread hydrothermal activity and associated polymetallic mineralization (Fontboté and Vera, 1983; Arribas and Tosdal, 1994).

The Betic internal zone consists of three major superimposed, deformed allocthonal tectonostratigraphic complexes: the Nevado-Filábride, the Alpujárride and the Maláguide Complexes (the latter not cropping out in this area).

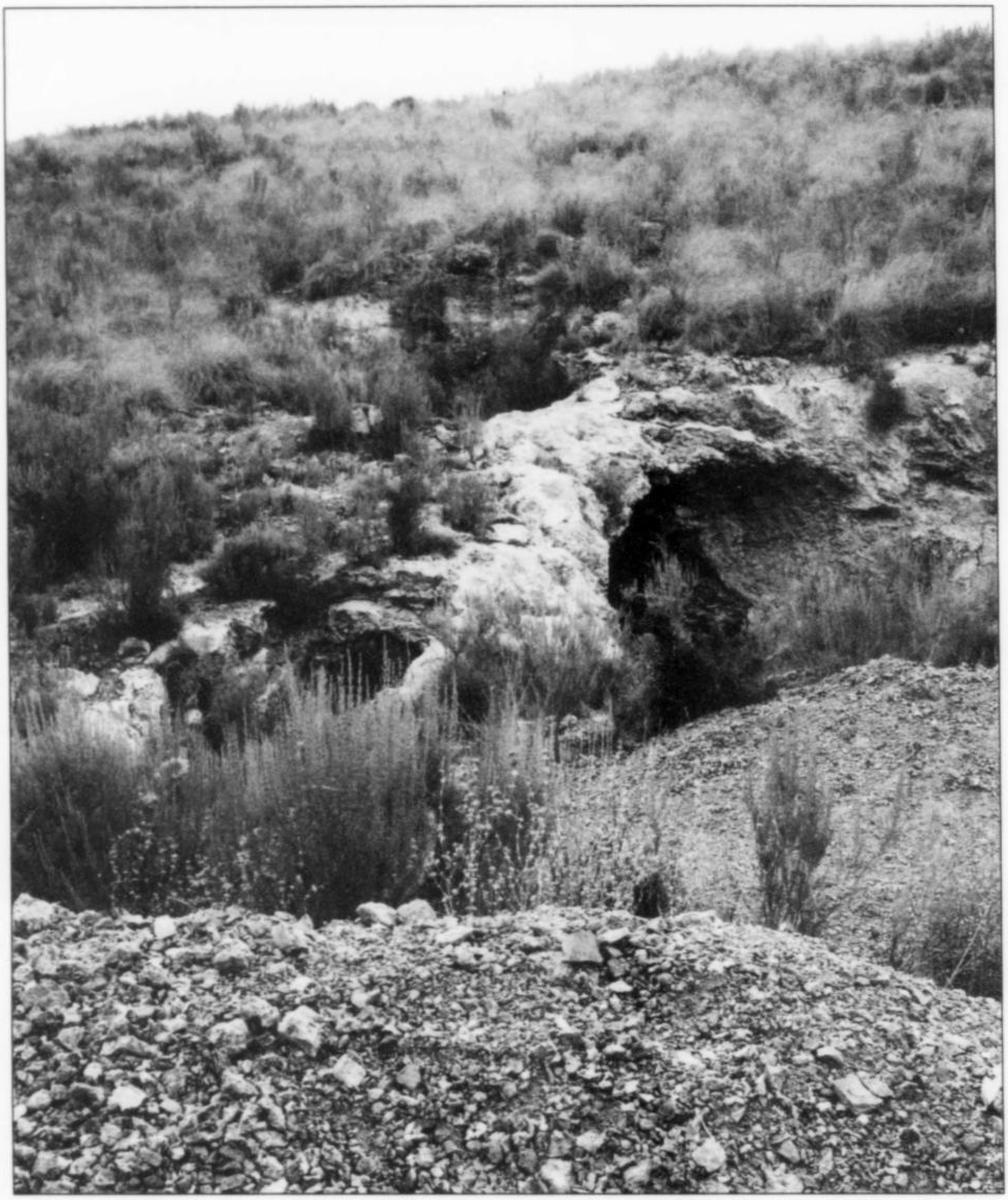


Figure 3. **Dolores prospect in October 2001. Photo by Borja Sainz de Baranda (BSB).**

The Nevado-Filábride Complex represents the core of the Betic Zone, with its oldest rocks; it is a product of multiple metamorphism. A high-pressure, low-temperature metamorphic event erased all evidence of prior alpine metamorphism. The lower part of the Complex is autochtonous, its rocks consisting mainly of quartzites and of graphite-bearing, almandine-bearing and chloritoid-bearing schists. The upper Nevado-Filábride rocks are allochthonous and more lithologically varied; they include mica schists with kyanite and staurolite, interlayered mafic metavolcanic rocks, gneisses formed from felsic volcanic rocks, quartzites, and calcite and dolomite marbles. The Alpujárride Complex has two major units. A thick lower part consists mainly of almandine-bearing mica schists, quartzites and phyllites, and an upper, carbonate part consists of limestones and dolostones, with some interbedded evaporites and mudstones.

According to the study of geological relations and Pb- isotope ranges by Arribas and Tosdal (1994), two main periods of base metal and precious metal mineralization may be distinguished in southeastern Spain. The older period produced F-Pb-Zn-Ba strata-bound deposits in a Triassic carbonate platform of the paleo-Tethys Ocean, these rocks now forming the upper Alpujárride complex. The younger period, related to hydrothermal circulation from the Miocene calc-alkaline volcanic belt, includes some Pb-Zn-(Ag-Cu-Au) and Au-(Cu-Te-Sn) epithermal vein deposits formed in volcanic rocks; it also includes Pb-Zn-Fe-Ag-(Ba-Cu-Sn-Sb) hydrothermal-vein and strata-bound deposits formed in Paleozoic to Triassic clastic and carbonate rocks of the Alpujárride and Nevado-Filábride complexes, in Tertiary sediments, and in volcanic rocks of the calc-alkalic volcanic belt. The last type of deposit is found at Sierra de Cartagena, Mazarrón, Águilas and Sierra Almagrera (the type locality for jarosite and ferberite), along a narrow band parallel to the coast of the Mediterranean Sea.

In the Mazarrón-Águilas district the hydrothermal ores form a stock-work, mainly within intensely altered volcanic and subvolcanic

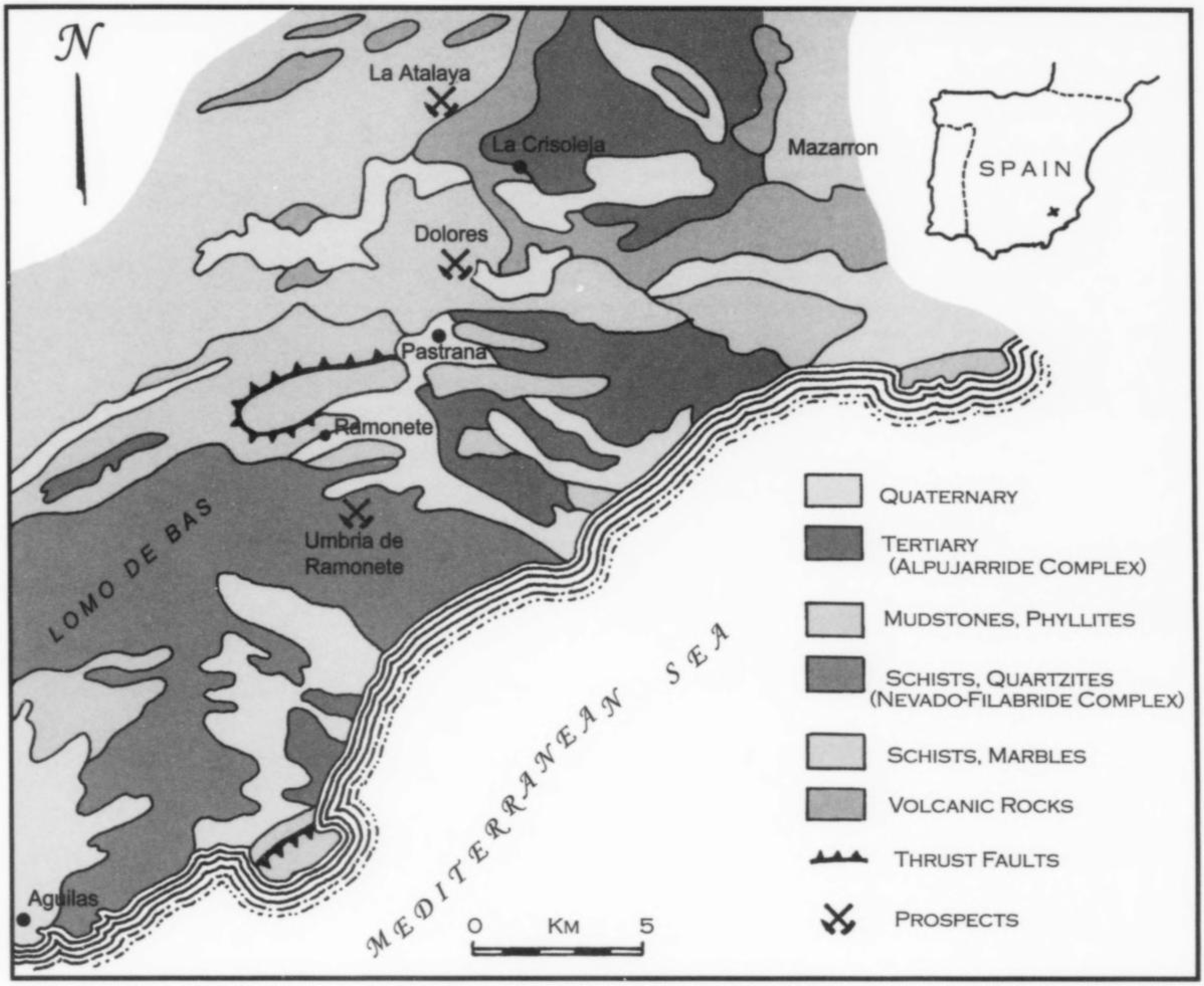


***Figure 4.* Geological map of the Mazarrón-Águilas area, Murcia province, Spain.**

rocks, with abundant alunite and jarosite. The deposits are hosted locally by Paleozoic mica schist and carbonates of the Nevado-Filábride Complex as well as by mica schist of the Alpujárride Complex. The Dolores and La Atalaya prospects are located in the Nevado-Filabride Complex, while the Umbria de Ramonete is located in the Alpujárride Complex.

The Pb-isotope studies of Arribas and Tosdal (1994) have shown the common origin of all the veins and strata-bound polymetallic Pb-Zn-Fe-Ag-(Ba-Cu-Sn-Sb) hydrothermal vein deposits, regardless of the nature of the host rocks. Furthermore, these studies have shown that the Pb source is *not* the remobilization of the Triassic-age F-Pb-Zn-(Ba) deposits of the earlier hydrothermal period; rather, the Pb appears to have originated in larger bodies intruding at depth into Paleozoic-age metasedimentary rocks. Local intrusions, as subvolcanic necks and dikes, would be too small to have produced the Pb-isotope range noted in these polymetallic deposits.

The genetic model, according to these authors, involves pervasive circulation of hydrothermal fluids through the upper crust, enhanced by a good plumbing system created by deep regional faults. Closer to the paleosurface, intensive fracturing, as well as vertical repetition of reactive carbonate levels, provided appropriate structural and lithological sites for mineralization. Finally, the formation of complex hydrothermal ores and metallic deposits may be favored locally by several physiochemical variables, e.g. changes in temperature and pressure conditions, pH and oxidation states, as well as interactions with cool meteoric water, lithological interactions, etc.

For the polymetallic mineralization area of Águilas and Sierra Almagrera, Morales and Fenoll (1992) describe several stages of mineral formation. A first stage with chalcopyrite and sphalerite as the main minerals, and less abundant pyrite and arsenopyrite, was followed by a second stage with pyrrhotite and Bi, Fe, Ni and Co, S-As minerals. Galena and bournonite, in addition to sphalerite II and pyrite II, were the last minerals formed before supergene processes began.

In the small copper prospects that we have examined, the primary mineralogy is poorly known because strong supergene processes have masked it. We have only observed the primary species chalcopyrite and tennantite ($[Cu_{9.48}Fe_{1.50}Ag_{0.92}Zn_{0.32}]$-$[As_{3.56}Sb_{0.25}P_{0.05}]S_{13}$) for a total of 99.48 percent of the weight, in a La Atalaya specimen. Other primary minerals once present are now inferable only from replacement textures, because the oxidation has been complete. The primary mineralization was probably Cu-Fe-rich S-As minerals with very minor Zn, Bi, Co and Ag, much as in the larger polymetallic deposits of Mazarrón, Águilas and Sierra Almagrera. The mineralization in the copper prospects of Mazarrón and Águilas thus closely resembles the earlier stages as described by Morales and Fenoll (1992), but without the later galena stage. Because of the abundance of As and S minerals, we can suppose the presence of arsenopyrite and pyrite in the primary stage of the mineralization, together with chalcopyrite, tennantite and minor Sb, Bi, Ni, Co and Ag-bearing sulfides. However, our principal interest is in the intense supergene mineralization developed in these copper prospects, since it is responsible for the abundant secondary minerals described in this study.

The Dolores, the most representative deposit, shows supergene mineralization in a small, mineralogically zoned lens of only about 10 x 2 x 0.2 meters. Whereas jarosite and iron arsenates are more abundant in the central part of the lens, copper minerals, especially copper carbonates and conichalcite, occur predominantly in the peripheral zone.

The Umbría de Ramonete prospect displays a very similar mineralogy, suggesting a mineralizing process similar to that which operated at the Dolores deposit; however, copper-bearing and silver-bearing minerals have not been found at Ramonete, carbonate minerals are scarce there, and sulfates are more common.

At the La Atalaya mine the ore is disseminated through small faults and fissures. The supergene processes operating here were not as intense as in the other mines, and sometimes lenses of unaltered tennantite, rimmed by chenevixite and other arsenic minerals, remain.

MINERALOGY

Identification of the different mineral phases was accomplished using selected micro-samples, and further examination was done by scanning electron microscopy (SEM). Initial qualitative data were obtained by means of energy-dispersive spectrometry (EDS), and supplementary X-ray diffraction (XRD) patterns were obtained for positive identification where necessary. EPMA (WDS) quantitative analyses were made for micro-samples mounted in epoxy, after a careful polishing, using a Jeol JXA-8900M electron microprobe at the Universidad Complutense (Madrid), operating at 15 Kv and 20 nA, with a beam width of between 2 and 5 microns, and a Cameca electron microprobe at Barcelona University (for the cobaltarthurite and yukonite analyses).

Below are described, in alphabetical order, the most interesting secondary minerals of the Mazarrón-Águilas prospects. Table 1 is a complete list of the secondary minerals found there to date.

Alunite-Jarosite group minerals

According to Jambor (1999), Stoffregen *et al.* (2000) and Dutrizac *et al.* (2000), the alunite supergroup consists of more than 40 mineral species with a general formula $DG_3(TO_4)_2(OH,H_2O)_6$. D sites are occupied by monovalent cations such as K or Na, or divalent cations such as Ca and Sr. G sites are mainly Al or Fe^{3+}, and T are S^{6+}, As^{5+}, P^{5+} and sometimes subordinate Si^{4+}. Because the substitutions K-Na, and Al-Fe^{3+} form a continuous series, we prefer to consider these minerals together.

In the Mazarrón-Águilas district, and especially in the Dolores and Umbría de Ramonete prospects, the alunite-group minerals are very common, forming wide, pale brown to yellowish veins. The vein fillings are composed of loose crystals, from a few micrometers to 1 mm in size, of rhombohedral habit and of a pale to dark brown color. Sometimes the crystals show an idiomorphic habit, and a compositional zoning can be observed by BEI, with an inner zone of Na/K > 1 (natrojarosite) and an outer zone with Na/K < 1 (jarosite). Sometimes a second generation of K-dominant jarosite-alunite has grown on these idiomorphic crystals.

Alunite, natroalunite, jarosite, natrojarosite and perhaps some hydronium jarosite are all present at Mazarrón, and the silver content in these minerals is less than 0.2% by weight.

Table 1. **Distribution of the secondary minerals of the Dolores, Umbría de Ramonete and La Atalaya prospects.**

Mineral	*Dolores*	*Ramonete*	*La Atalaya*
Alunite	—	R	—
Aragonite	C	—	—
Arseniosiderite	C	C	—
Arsenocrandallite	R	—	—
Arsenogoyazite	R	—	—
Arthurite	VR	—	—
Atacamite ?	—	VR	—
Azurite	VC	—	VC
Brochantite	VR	R	—
Chenevixite	—	C	—
Chlorargyrite	R	—	—
Chrysocolla	R	—	C
Cobaltarthurite	R	—	—
Conichalcite	VC	C	C
Cornwallite	C	R	VC
Heterogenite	R	—	—
Hörnesite ?	VR	—	—
Jarosite-natrojarosite	C	VC	—
Lavendulan	C	C	—
Malachite	VC	R	R
Olivenite	VC	VC	C
Parnauite ?	VR	—	—
Pharmacosiderite	VC	C	—
Scorodite-mansfieldite	C	C	—
Sodium pharmacosiderite	C	—	—
Tyrolite	—	—	C
Yukonite	C	C	—
Zálesíite	R	—	—
Unknown #1	VR	—	—
Unknown #2	VR	—	—

VC, very common; C, common; R, rare; VR, very rare;—not found.

Aragonite $CaCO_3$

Crusts of white aragonite, in fibers up to 1 cm, deposited from supergene waters, are common at the Dolores prospect. Prismatic to acicular monocrystals are less common. Often aragonite partially covers large, bright green conichalcite plates, making very nice color-contrasting specimens.

Arseniosiderite $Ca_2Fe^{3+}_3(AsO_4,PO_4)_3O_2\cdot 3H_2O$

Arseniosiderite appears as brown to golden yellow platy crystals forming the matrix for chlorargyrite and several arsenates. Epimorphs/pseudomorphs of arseniosiderite after siderite and overgrowths of arseniosiderite on the edges of pharmacosiderite crystals were also observed at the Dolores prospect. At the Umbría de Ramonete prospect arseniosiderite is found rarely with pharmacosiderite.

Arsenocrandallite $(Ca,Sr)Al_3(AsO_4,PO_4)_2(OH)_5\cdot H_2O$

Arsenocrandallite from the Dolores prospect was identified by EDS and XRD, as fibrous spherules of radiating crystals to 1 mm. The translucent, gray-white to pale blue globules consist of clusters of crystals tabular on {0001}. Frequently it is found with siderite, lavendulan, conichalcite and arseniosiderite.

Figure 5. **Arsenocrandallite (white) with conichalcite (green), 8 x 5 mm, from the Dolores prospect. J. González del Tánago collection and photo.**

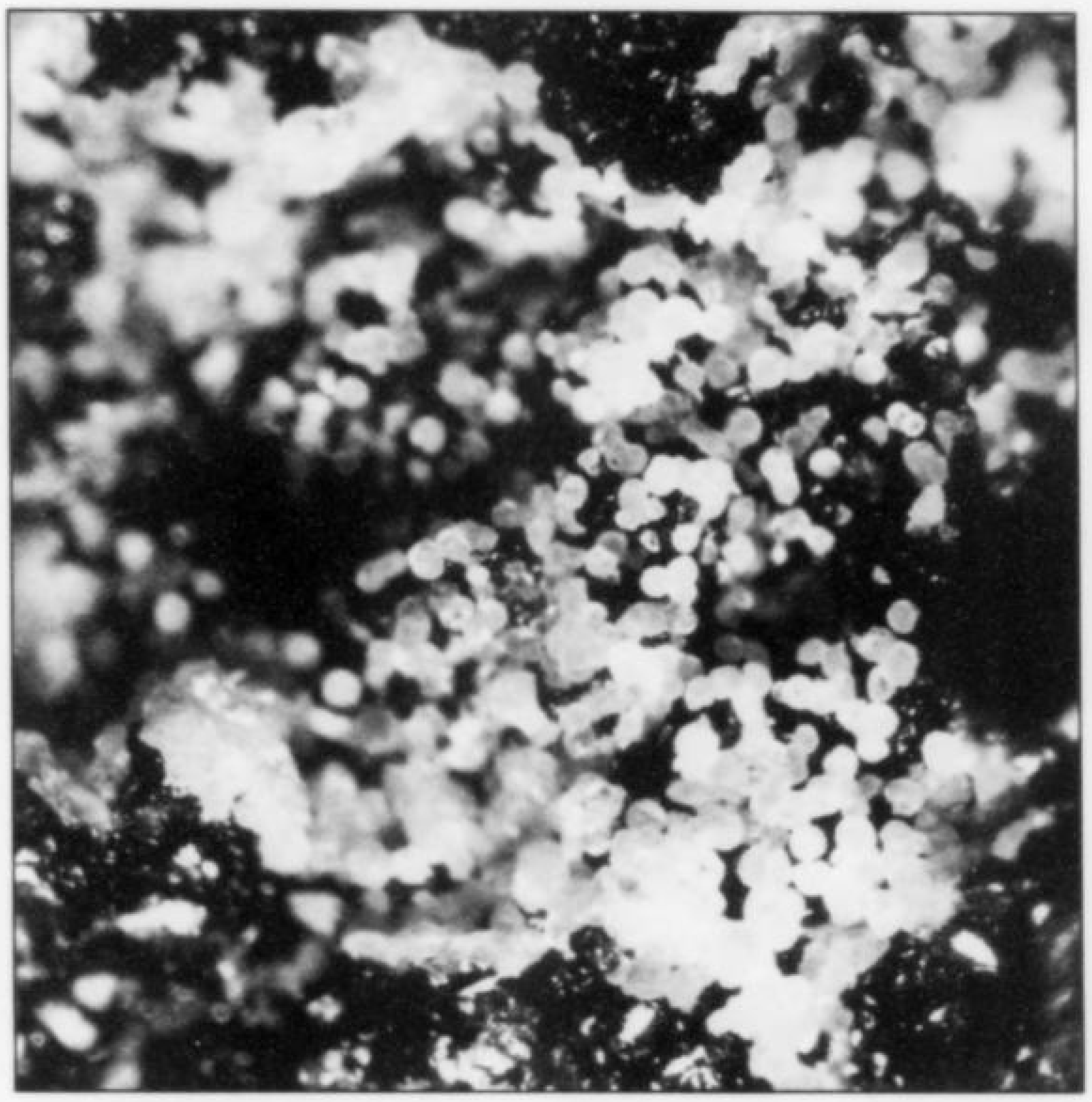


Figure 6. **Arsenocrandallite (49x) from the Dolores prospect. J. Viñals collection and photo.**

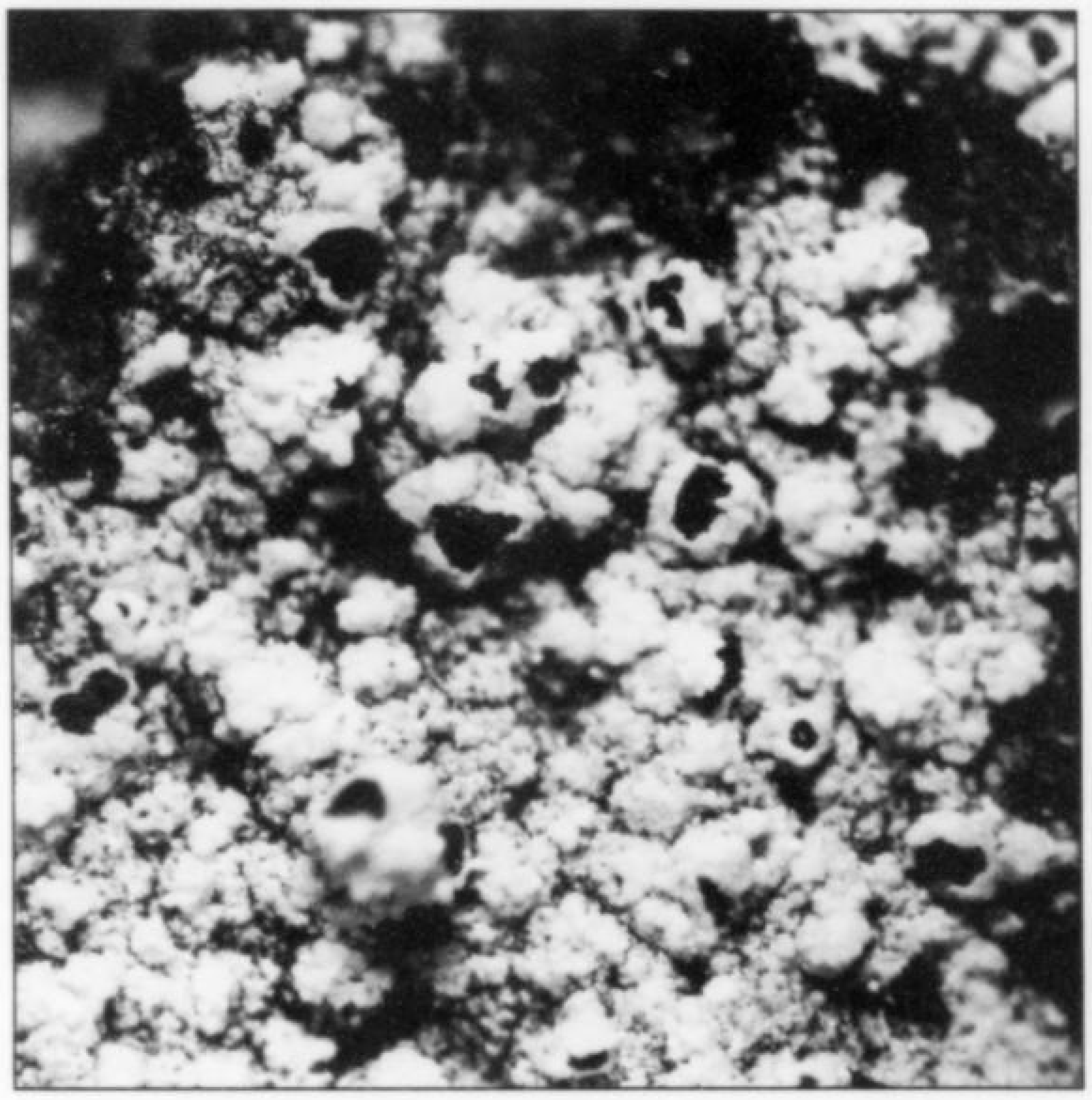


Figure 7. **Arsenogoyazite (48x) from the Dolores prospect. J. Viñals collection and photo.**

Arsenogoyazite $(Sr,Ca,Ba)Al_3(AsO_4,PO_4)_2(OH,F)_5 \cdot H_2O$

Small white globules, up to 0.1 mm, from the Dolores prospect have been identified by EDS and XRD as an Sr > Ca member of the arsenogoyazite-arsenocrandallite series. Arsenogoyazite may be one of the last minerals to form, since it commonly overlies yukonite. It has also been found overlying the larger arsenocrandallite globules.

Arthurite $Cu^{2+}Fe^{3+}_2(AsO_4,PO_4,SO_4)_2(O,OH)_2 \cdot 4H_2O$

Arthurite, as long-prismatic bright green crystals, was found in a single specimen from the Dolores prospect, identified by EDS. The crystals, up to 0.1 mm, occur isolated and in clusters on pharmacosiderite cubes.

Atacamite (?) $Cu^{2+}_2Cl(OH)_3$

A mineral closely approximating atacamite—paratacamite in composition (Table 3) appears in backscattered electron images (BEI) as small inclusions in brochantite aggregates from the Umbría de Ramonete prospect. The very small quantity of the material and its close association with brochantite make confirmation by XRD impossible. The atacamite phase appears to have formed prior to brochantite.

Azurite $Cu^{2+}_3(CO_3)_2(OH)_2$

The copper carbonates malachite and azurite are widespread in the Mazarrón-Águilas district, although azurite has not been found at the Umbría de Ramonete prospect. Usually, azurite forms fine single crystals and crystal clusters covering plates of several square centimeters. Individual crystals can reach 5 mm, with an intense blue color contrasting with the pale brown matrix. Azurite can be replaced by conichalcite.

Brochantite $Cu^{2+}_4(SO_4)(OH)_6$

At the Umbría de Ramonete prospect, brochantite forms rounded, prismatic, emerald-green crystals to 4 mm in size associated with lavendulan. A representative analysis is shown in Table 3. At the Dolores prospect, brochantite was found as veinlets about 1 mm across in malachite, from which it is

Figure 8. **Arthurite crystals to 0.1 mm on pharmacosiderite cubes, from the Dolores prospect. J. Viñals collection and BSE photo.**

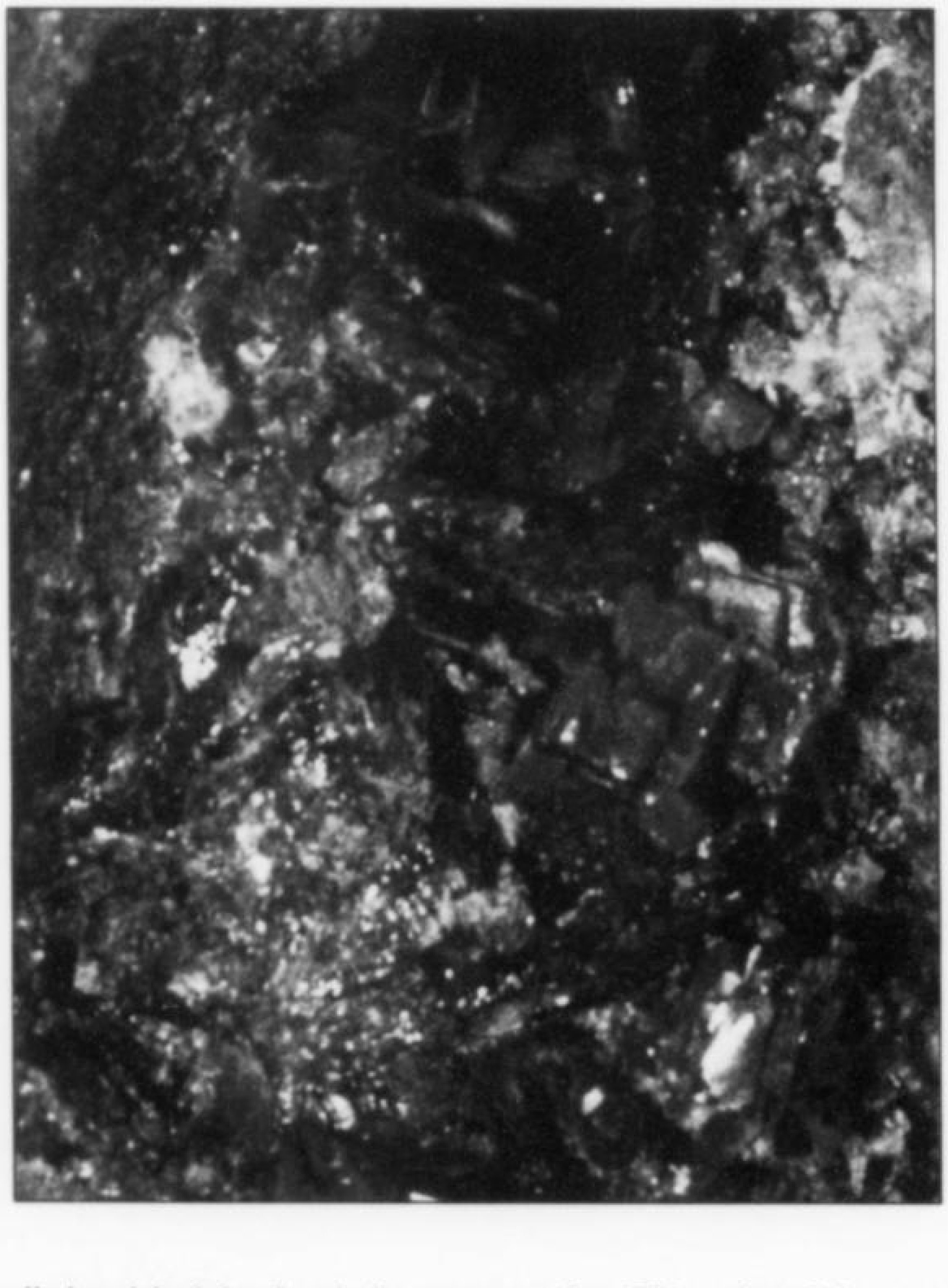


Figure 9. **Brochantite crystals to 2 mm from the Umbría de Ramonete prospect. BSB collection and photo.**

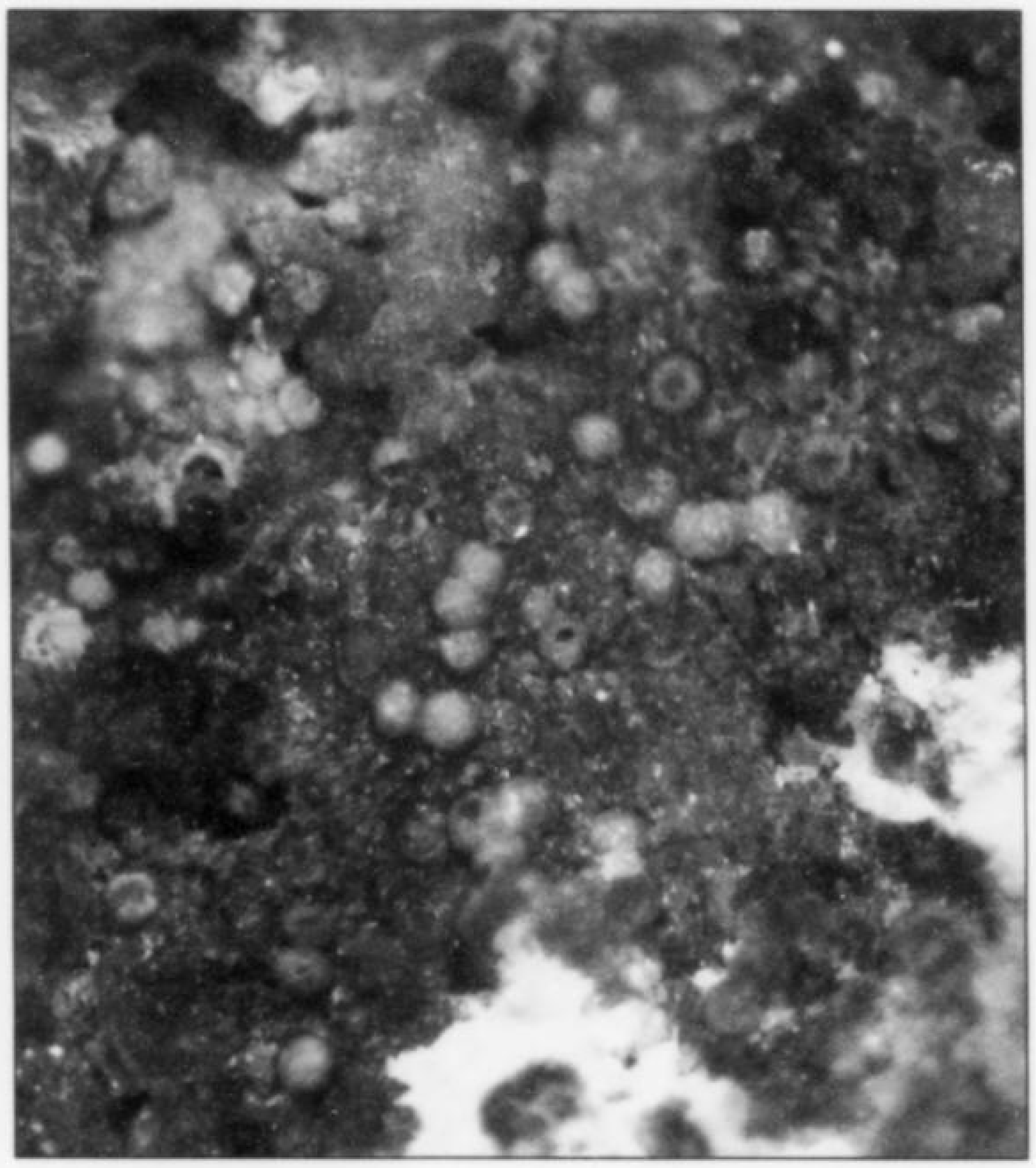


Figure 10. **Chenevixite (57x) from the Umbría de Ramonete prospect. J. Viñals collection and photo.**

distinguished by its darker green color. This mineral is very scarce in both prospects.

Chenevixite $Cu_2^{2+}Fe_2^{3+}(AsO_4)_2(OH)_4 \cdot H_2O$

Chenivixite was identified by Muelas *et al.* (1996), without benefit of analyses, in samples from the Umbría de Ramonete prospect, as microcrystal aggregates shaped like open tulips.

At the La Atalya prospect chenevixite is a direct product of tennantite oxidation, forming as crusts and disseminated areas of alteration in tennantite (see Table 4).

At the Umbría de Ramonete prospect, chenevixite forms yellow-green to grass-green crusts and masses with olivenite, and powdery to nodular precipitates on quartz. Rarely it has been found as very small acicular individual crystals and clusters.

Figure 11. **Chenevixite (yellow-green) with lavendulan, 8 x 5 mm, from the Umbría de Ramonete prospect. BSB collection and photo.**

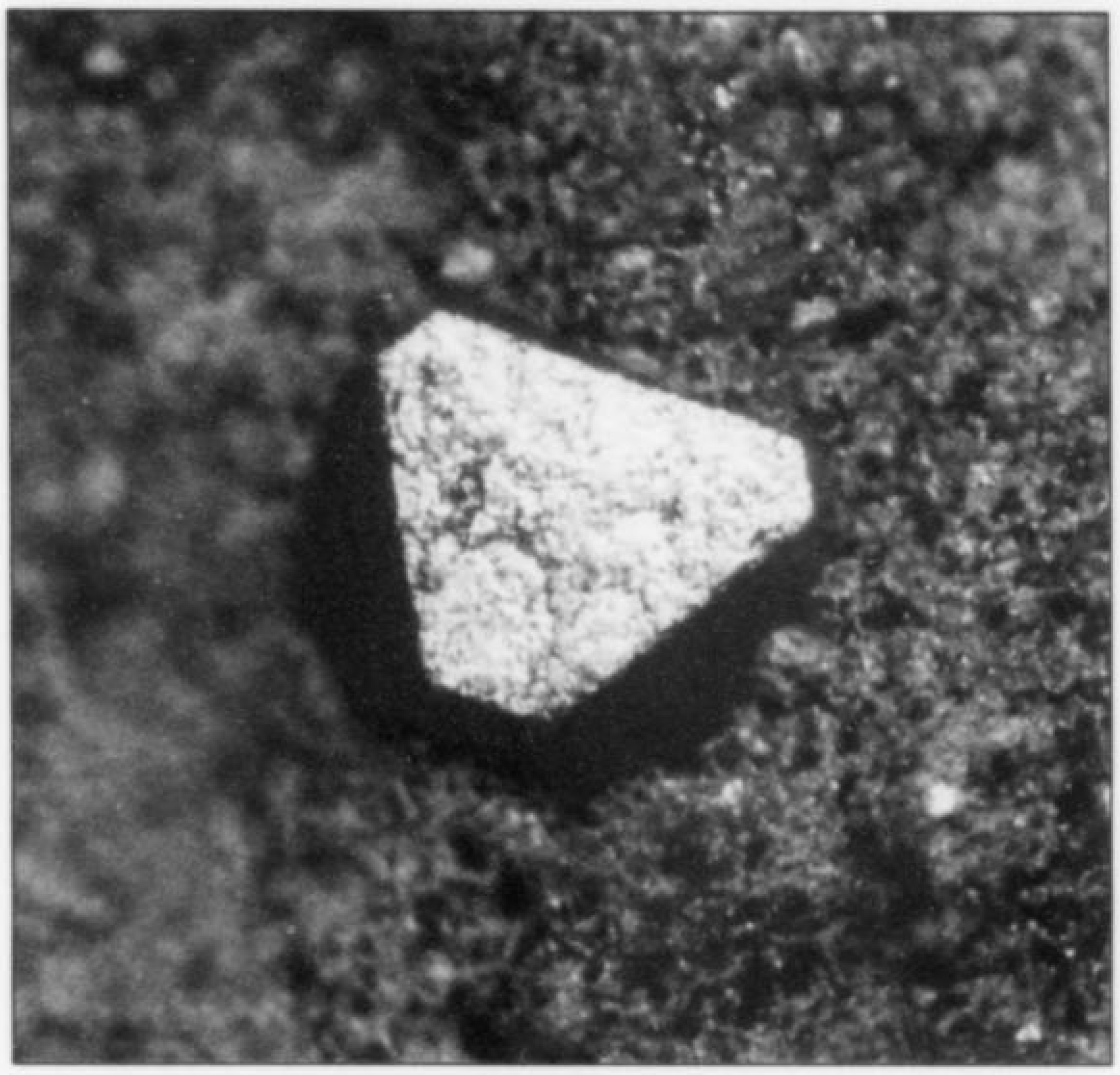


Figure 12. **Chlorargyrite (75x) from the Dolores prospect. J. Viñals collection and photo.**

Figure 13. **Cobaltarthurite (30x) from the Dolores prospect. J. Viñals collection and photo.**

Chlorargyrite AgCl

Small, pale greenish to pale yellowish cuboctahedral crystals of chlorargyrite under 2 mm have sometimes been found in the Dolores prospect, perched on druses of microcrystals of arseniosiderite, jarosite, conichalcite and pharmacosiderite. Common forms are {111} and {100}; rarely, crystals are twinned on {111}. Rounded xenomorphic botryoidal crystalline masses also occur. The chlorargyrite has a low Br content (EDS).

Yellow-green chlorargyrite crystals perched on lavendulan crystal clusters make extremely fine micromount specimens.

Chrysocolla $(Cu^{2+},Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$

Small concretions or pseudomorphs of pale blue chrysocolla after tyrolite were common at the La Atalaya prospect. At the Dolores prospect, chrysocolla was only observed as pseudomorphs after lavendulan.

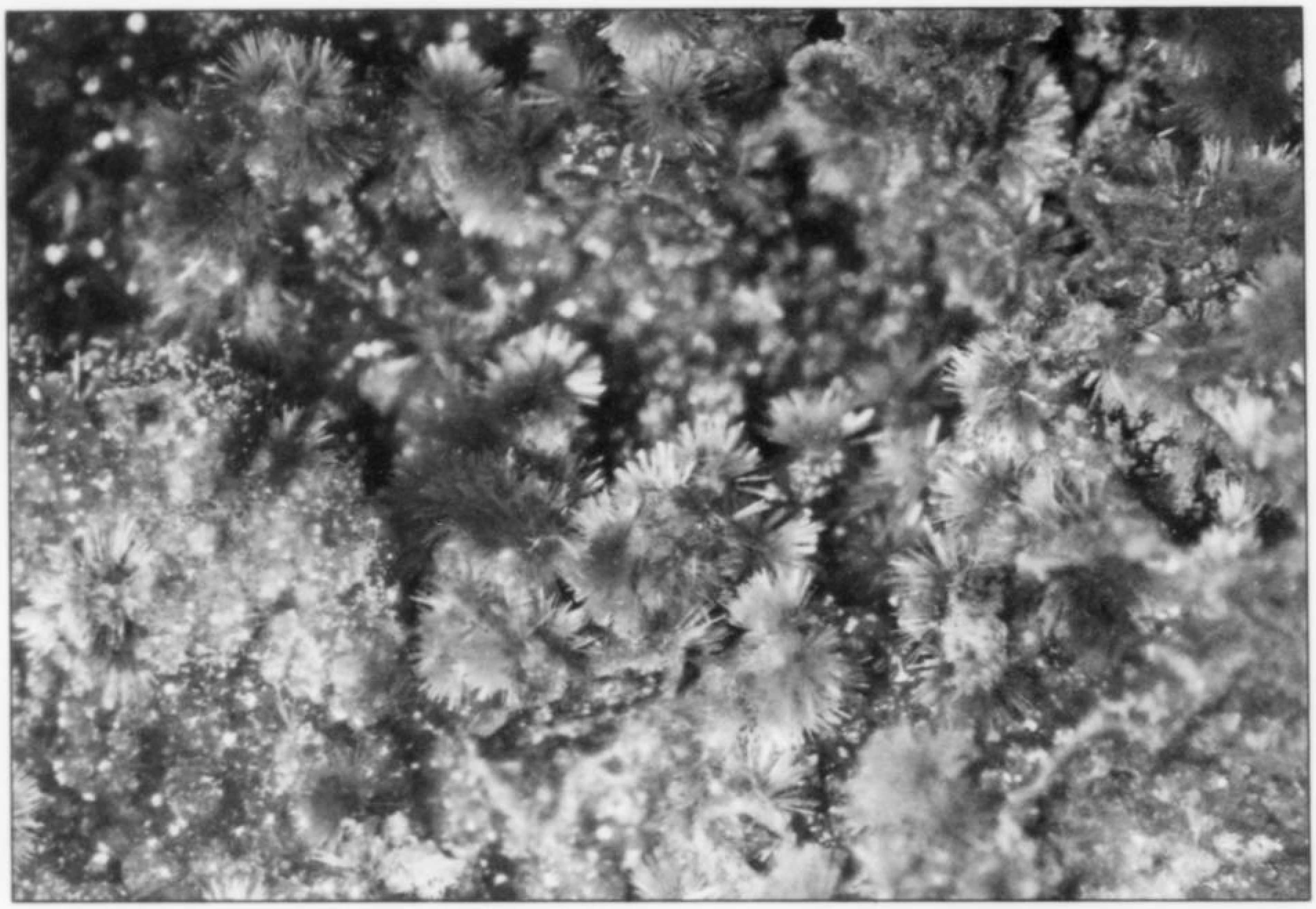


Figure 14. **Cobaltarthurite (37x) from the Dolores prospect. J. Viñals collection and photo.**

Cobaltarthurite $CoFe_2^{3+}(AsO_4)_2(OH)_2 \cdot 4H_2O$

The Dolores prospect is the type locality for cobaltarthurite, a new mineral of the arthurite group (Jambor *et al.*, 2002). Cobaltarthurite occurs predominantly as globular to pellet-like aggregates approximately 1 mm across, consisting of radial fibers. The color grades from straw-yellow to dark brown, although no significant compositional changes were detected within the aggregates. The mineral has also been found as veins up to 2 cm across, filling fractures in the siliceous rock. Exceptionally, cobaltarthurite appears as up to 0.5-mm tufts of divergent prismatic crystals of straw-yellow to golden yellow color. The most consistent association is with pharmacosiderite, on which the pellets or tufts of cobaltarthurite are usually implanted. More rarely, cobaltarthurite is associated with arseniosiderite and heterogenite.

Conichalcite $CaCu^{2+}(AsO_4)(OH)$

Conichalcite is one of the later-forming minerals and the most common secondary mineral in Mazarrón, principally in the Dolores prospect. At this occurrence a spectacular formation was found: a surface of about 10 m^2 completely covered with conichalcite. Some mineralogical and chemical characteristics were determined by Del Valle *et al.* (1995). According to his work and our research by EPMA, Ba and Na substitute weakly for Ca, and Si, P and S for As. Botryoidal conichalcite commonly grows on azurite, malachite, pharmacosiderite, arseniosiderite and lavendulan, and very frequently on olivenite, sometimes completely replacing the latter, as pseudomorphs. The pale green color may distinguish conichalcite from cornwallite (bright green), a commonly associated mineral in the Dolores and Umbría de Ramonete prospects.

Cornwallite $Cu_5^{2+}(AsO_4)_2(OH)_4$

Cornwallite appears as 1-mm spherules and as 2-mm to 3-mm clusters of spherules of a transparent, emerald-green color; at the La Atalaya prospect the spheres cover large surfaces, making this a significant locality for the mineral. Olivenite and tyrolite can be associated. The color contrast of green cornwallite and blue azurite against a brown matrix makes for pretty micromount specimens.

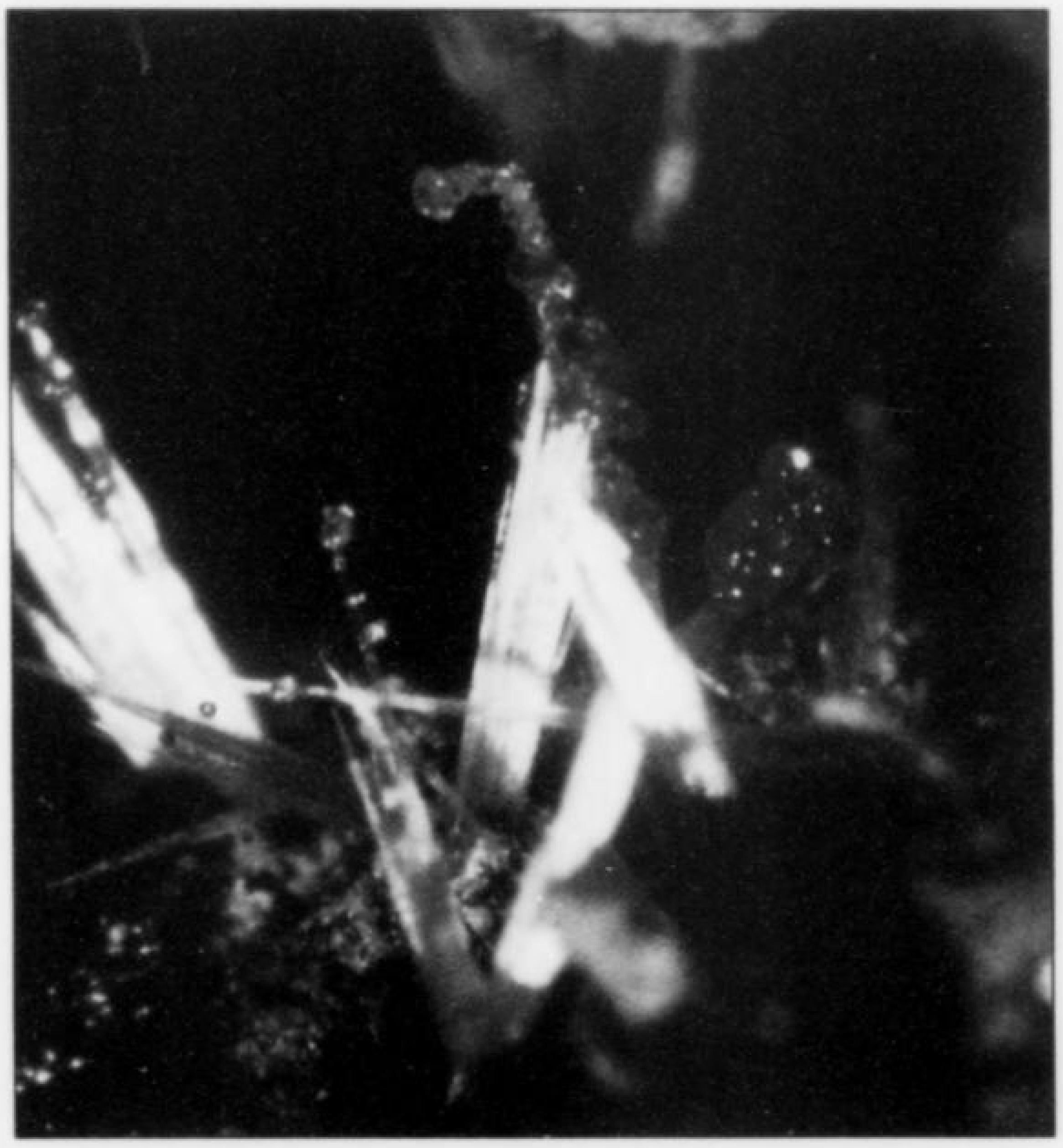
In the Dolores and Umbría de Ramonete prospects, cornwallite is less common, appearing as dark green botryoidal masses and minute crystal clusters.

Figure 15. **Conichalcite globules to 3 mm with hörnessite (?) from the Dolores prospect. BSB collection and photo.**

Figure 16. **Conichalcite (green balls) with olivenite and azurite, 8 x 5 mm, from the Dolores prospect. BSB collection. Photo by J. González del Tánago.**

Figure 17. **Cornwallite (13x) from the La Atalaya prospect. J. Viñals collection and photo.**

Figure 18. **Conichalcite on olivenite crystals to 2 mm from the Dolores prospect. BSB collection. Photo by J. González del Tánago.**



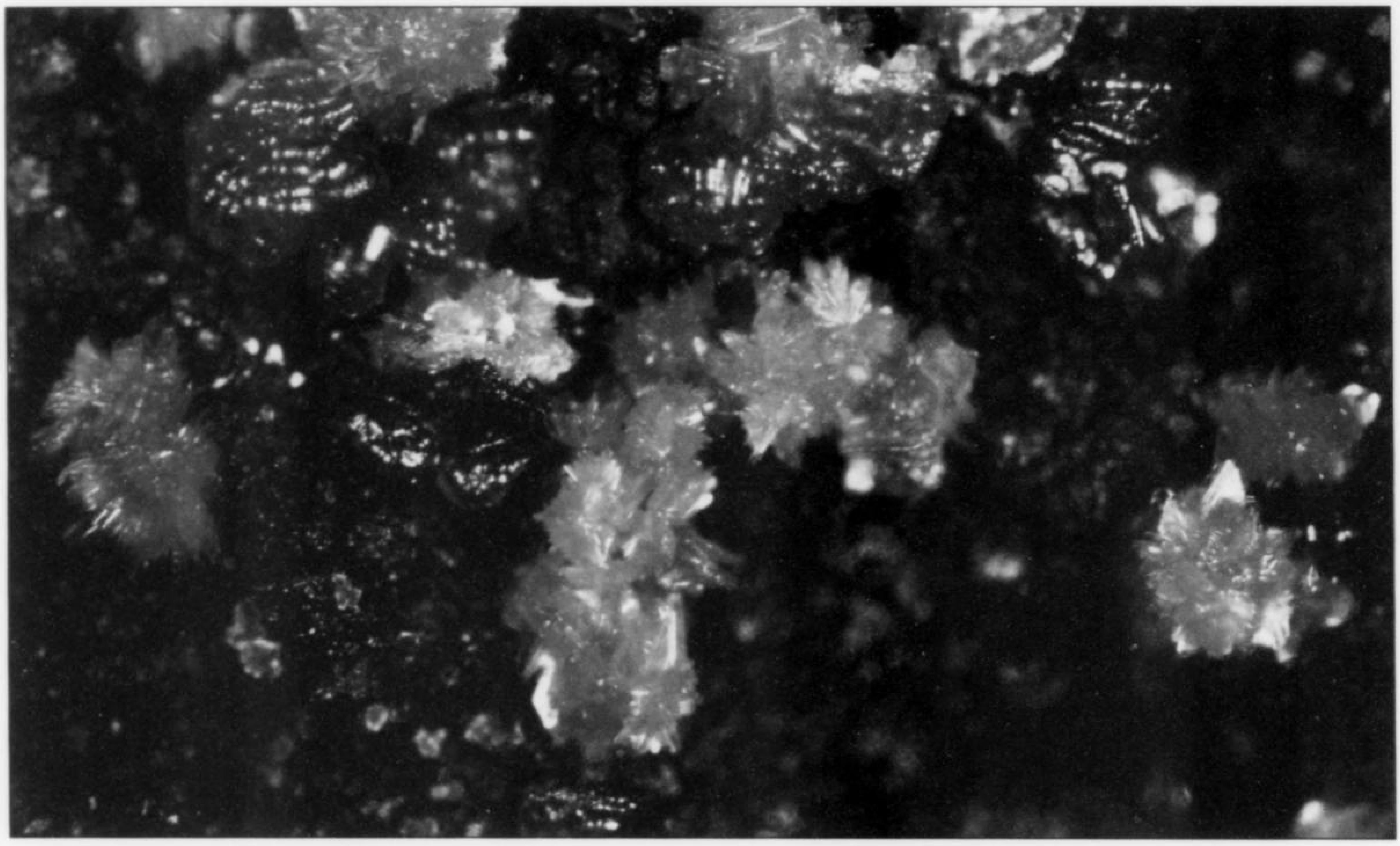


Figure 19. **Lavendulan with conichalcite (36x) from the Dolores prospect. J. Viñals collection and photo.**

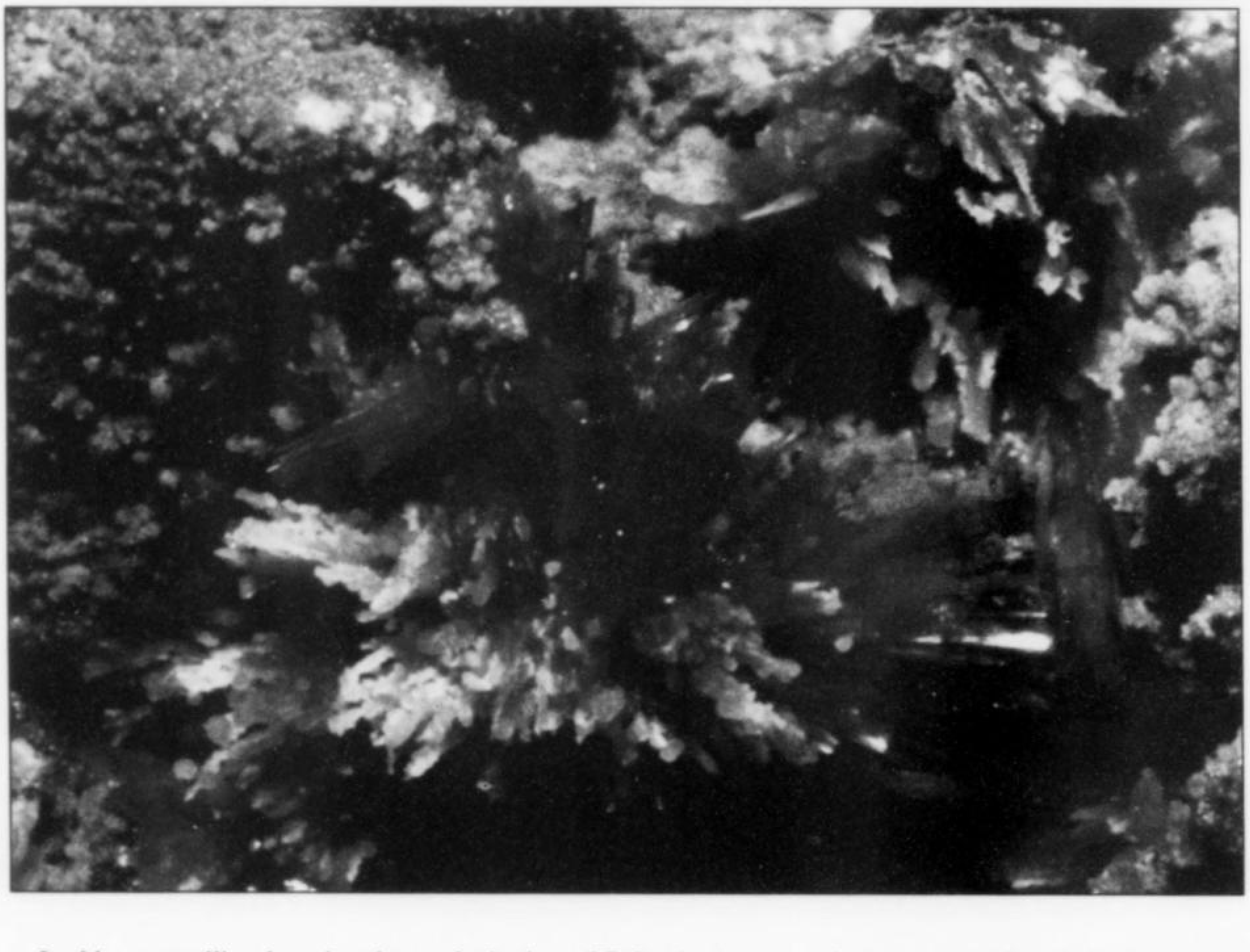


Figure 20. **Lavendulan with conichalcite, 5 mm crystal group, from the Umbría de Ramonete prospect. BSB collection and photo.**

In this cornwallite there is minor substitution of P for As (see Table 4).

Heterogenite CoO(OH)

Botryoidal crusts and spheroids of heterogenite are relatively common at the Dolores prospect, mainly associated with arseniosiderite and less commonly with cobaltarthurite. EDS spectra of most of these samples indicate pure CoO(OH), and its XRD patterns correspond to the Heterogenite-2H polytype. Some samples, however, contain admixed manganese oxides and are shown by XRD to have poor crystallinity.

Hörnesite (?) $Mg_3(AsO_4)_2 \cdot 8H_2O$

Hörnesite was mentioned by Muelas *et al.* (1996) in samples from the Dolores prospect, but analytical data were not provided.

Lavendulan $NaCaCu_5^{2+}(AsO_4)_4Cl \cdot 5H_2O$

Lavendulan is an uncommon mineral that has been found in a

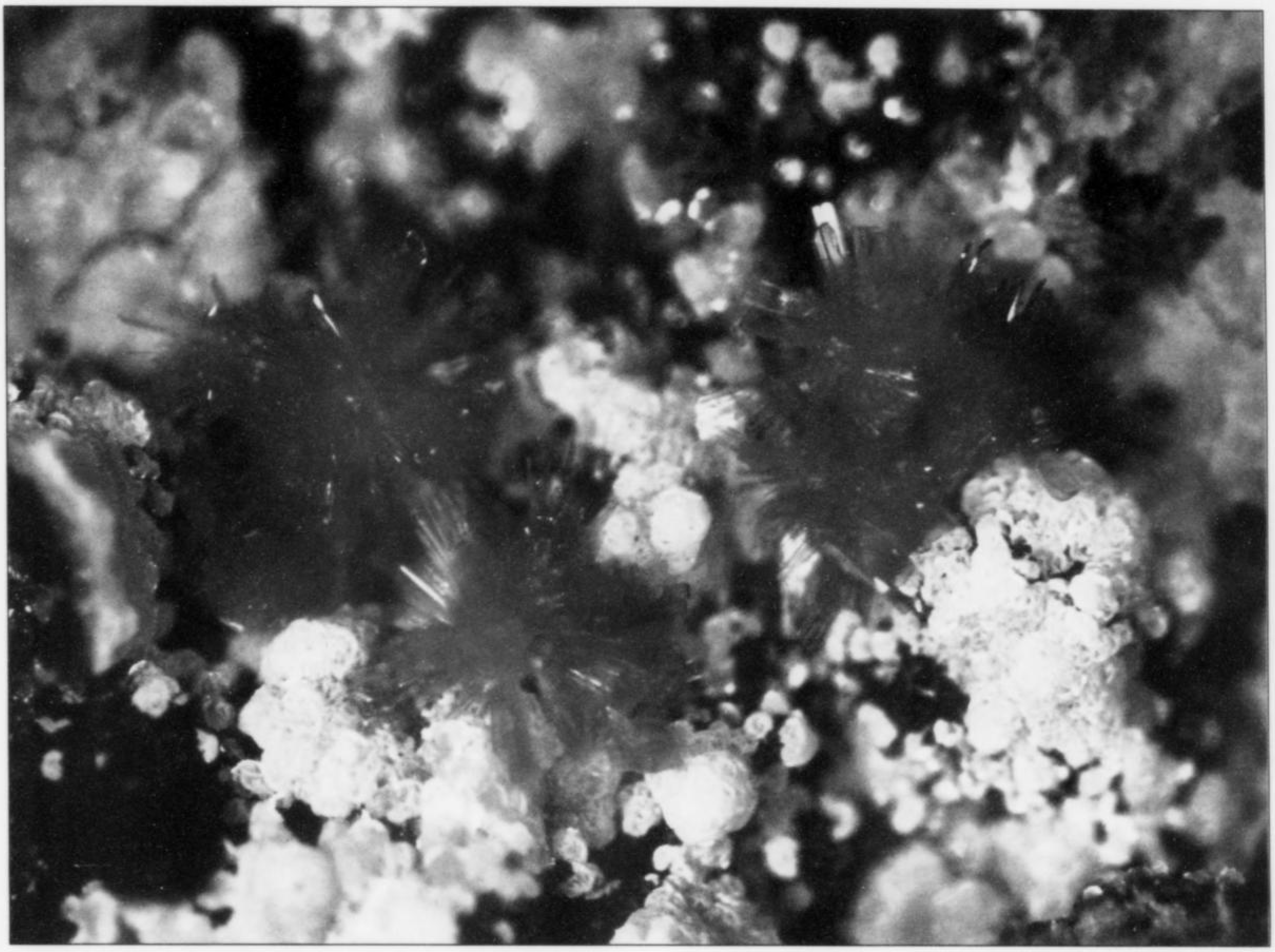


Figure 22. **Lavendulan on arsenocrandallite (62x) from the Dolores prospect. J. Viñals collection and photo.**

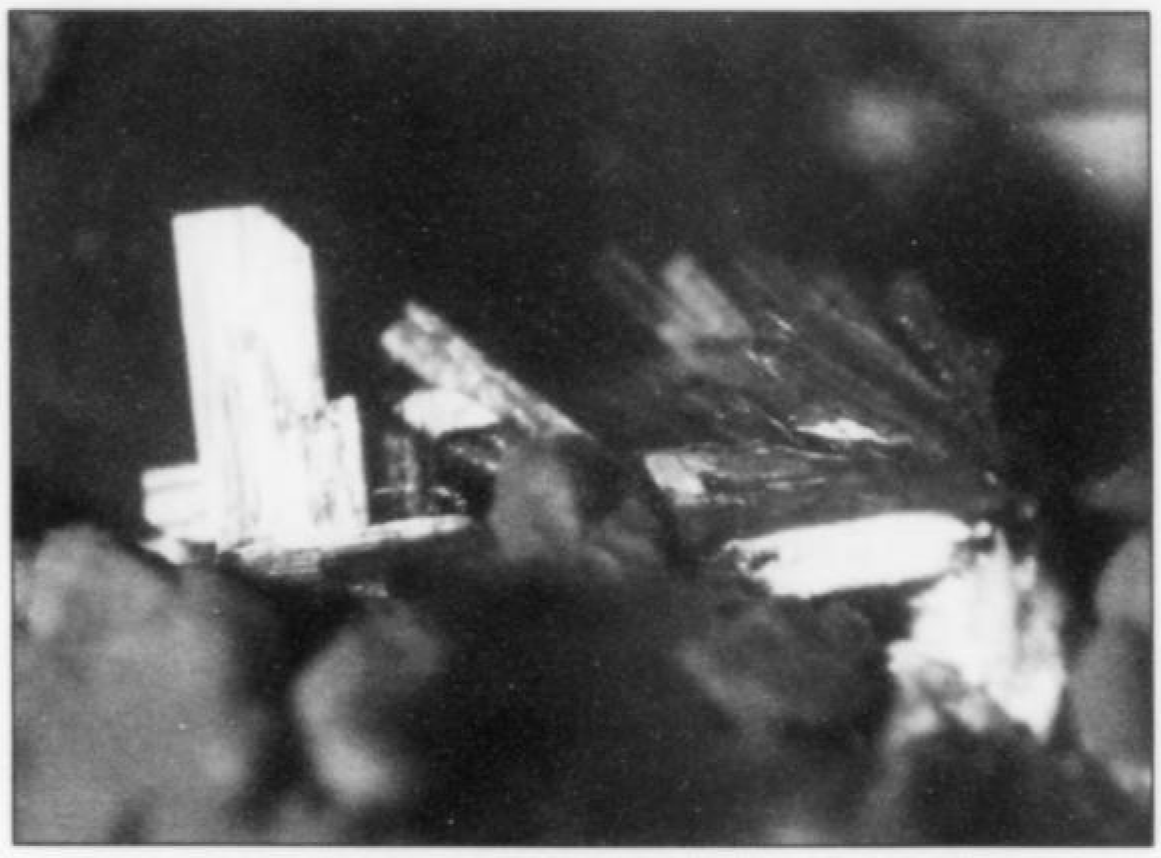


Figure 21. **Lavendulan (50x) from the Umbría de Ramonete prospect. J. Viñals collection and photo.**

few localities worldwide, always as crusts or minute crystals. The superb crystals and clusters recovered at Mazarrón in 1992 must be considered as perhaps the best in the world. Specimens from these localities appear to be far superior to those from other known world localities listed in Clopton and Wilson (1995), and Anthony *et al.* (2000) cite the largest known crystals as 3 mm.

In the Umbría de Ramonete prospect, lavendulan forms bladed to lath-like crystals to 4 mm, and radial groups to 10 mm, covering large matrix plates of jasperoid rock. Individual crystals are flattened on {010} and elongated on {001}. The typical color is electric blue on fresh surfaces and pale blue in altered crystals. Very pretty specimens of bladed, free crystals have been found in quartz cavities, together with pharmacosiderite, yukonite and olivenite needles. Other associated minerals include cornwallite, conichalcite, jarosite-natrojarosite, malachite and pharmacosiderite.

In the Dolores prospect, lavendulan appears as clusters of electric blue laths to 1 mm in druses coating cavities to several centimeters. Here the mineral is most abundant, and hundreds of thumbnail to cabinet-sized specimens have been recovered. Azurite, conichalcite, cornwallite, yukonite and rarely chlorargyrite and arsenocrandallite may be present.

A representative lavendulan analysis is shown in Table 4, showing formulae near the theoretical one without significant substitutions.

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

Acicular and bladed malachite crystals, and radial clusters of prismatic crystals to 1 mm, are frequently found in all Mazarrón-Águilas copper prospects.

Olivenite $Cu_2^{2+}(AsO_4)(OH)$

Olivenite occurs in all Mazarrón prospects as more or less elongated prismatic crystals in different shades of green. There are no significant chemical substitutions, as can be seen in Table 4.

In the Umbría de Ramonete prospect olivenite is very abundant,

***Figure 23.* Lavendulan with azurite and conichalcite, 24 x 15 mm, from the Dolores prospect. J. M. Gordillo collection. Photo by F. Piña.**

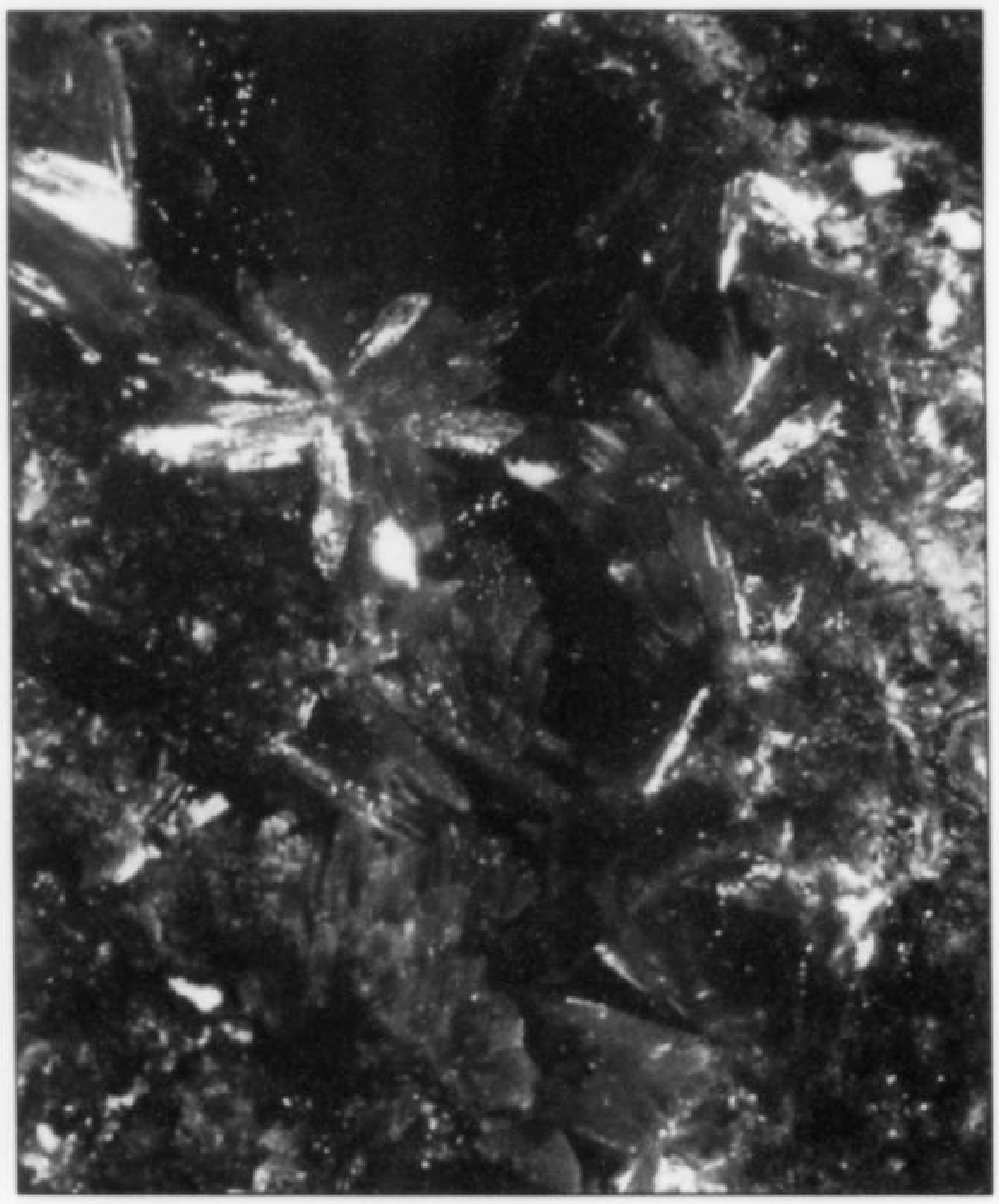


***Figure 24.* Lavendulan with conichalcite, 24 x 15 mm, from the Umbría de Ramonete prospect. BSB collection. Photo by J. González del Tánago.**

usually as dark green prismatic to acicular crystals of less than 3 mm. In the goethite cavities, olivenite is found together with cornwallite and conichalcite; in the quartz cavities, it can be accompanied by pharmacosiderite, lavendulan and chenevixite. Olivenite has also been found in a few specimens on scorodite-mansfieldite and yukonite.

A wider variation in crystal habit is found in the Dolores prospect. Acicular to short prismatic {001} olivenite crystals up to 3 mm and crystal clusters to 10 mm are present in the siderite cavities with azurite, and more rarely with pharmacosiderite. The crystals can be covered by a thin film of conichalcite, or even totally replaced by this mineral, making fine pseudomorphs. Olivenite is also found as radiating fibres with color zoning in shades of gray to green, or as gray to olive-green fibrous crystals of silky luster covering large fracture surfaces.

Rarely, olivenite is found at the La Atalaya prospect, in pale green prismatic crystals on cornwallite.

Parnauite (?) $Cu_9(AsO_4)_2(SO_4)(OH)_{10}\cdot 7H_2O$

A parnauite-like mineral, apple-green to olive-green, occurs at the Dolores prospect as minute (0.1–1 mm) clusters of tabular to platy crystals with square or rectangular outline. The crystals are usually implanted on pharmacosiderite or yukonite, associated with malachite, azurite or lavendulan. The EDS spectra are very close to those obtained, by similar instrumental means, from the parnauite of Majuba Hill (Nevada, USA). The XRD spectra showed the main lines of parnauite but also other lines, which were assigned to quartz and pharmacosiderite. The very small available quantities of this mineral do not permit a definitive characterization.

Pharmacolite (?) $CaHAsO_4\cdot 2H_2O$

According to Muelas *et al.* (1996), small crystals of pharmacolite were found in the Umbría de Ramonete prospect, associated with

Figure 25. **Olivenite crystals to 1.5 mm with conichalcite, from the Dolores prospect. J. M. Gordillo collection. Photo by F. Piña.**

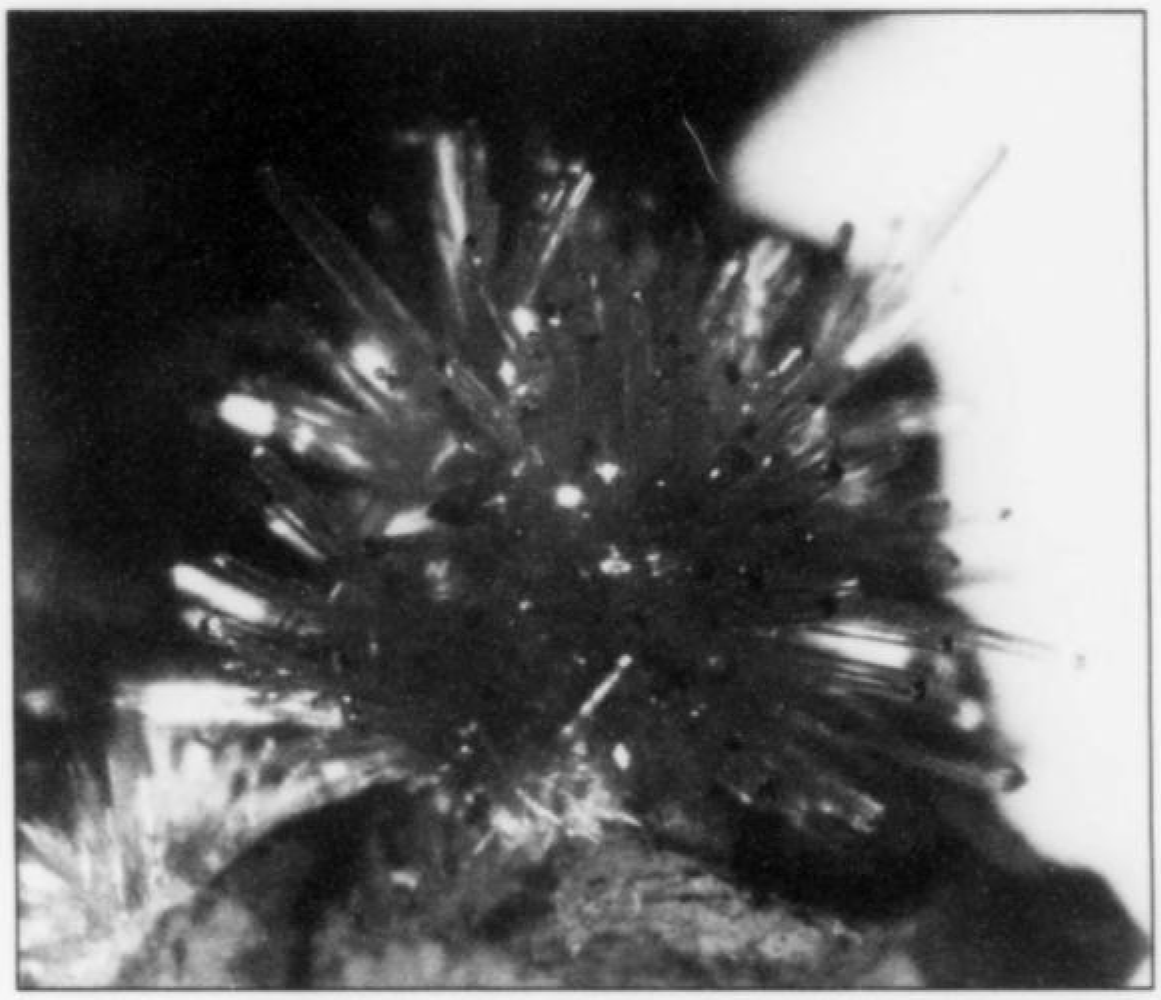


Figure 26. **Olivenite, 2 mm crystal group, from the Dolores prospect. BSB collection. Photo by J. González del Tánago.**

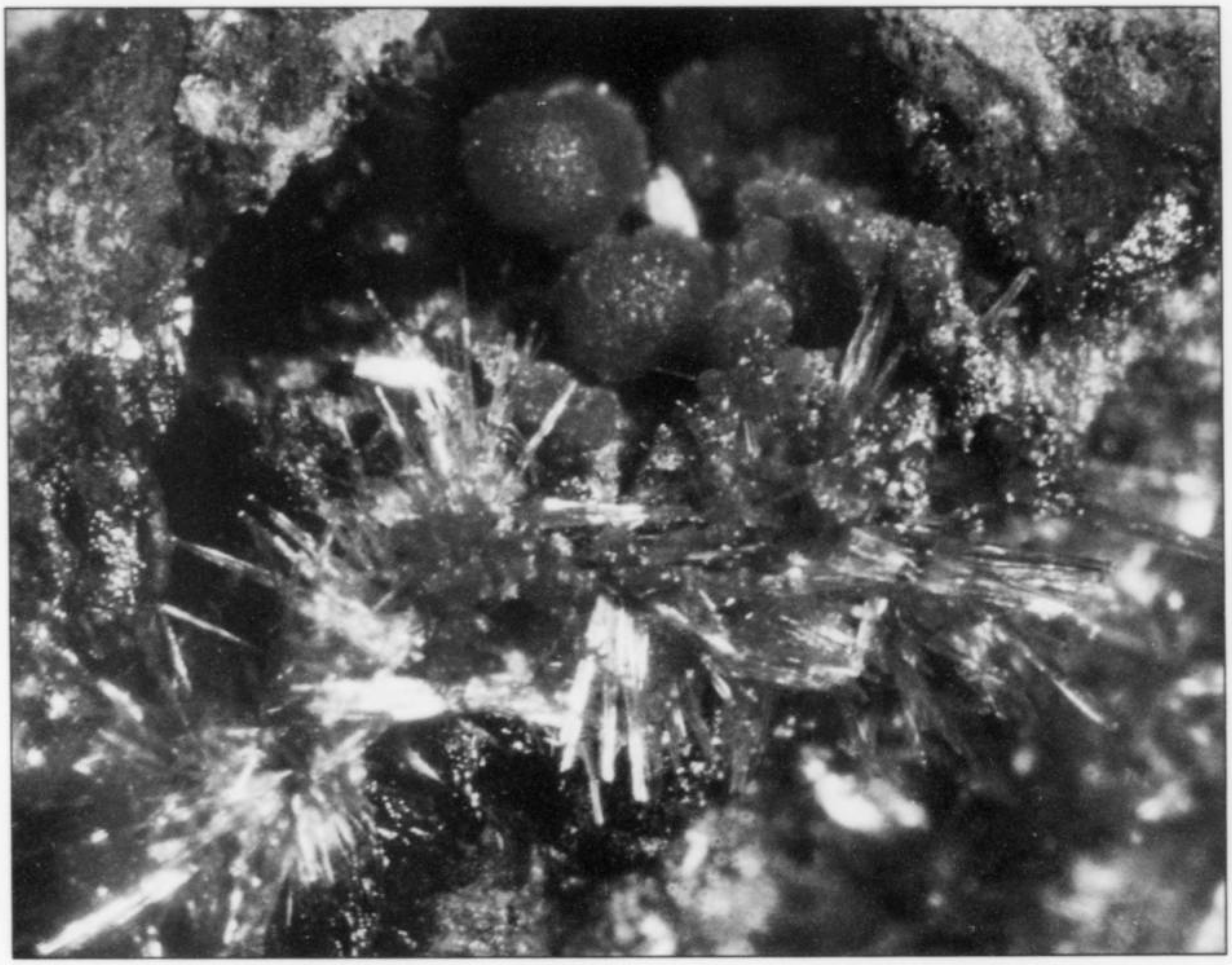


Figure 27. **Olivenite with cornwallite, 12 x 8 mm, from the Dolores prospect. BSB collection. Photo by J. González del Tánago.**

chenevixite, but analytical data have not been provided, and the presence of pharmacolite seems very doubtful.

Pharmacosiderite and sodiumpharmacosiderite

$(K,Na)Fe_4^{3+}(AsO_4)_3(OH)_4 \cdot 6\text{–}7H_2O$

As in the case of the alunite-group minerals, common cation substitutions in pharmacosiderite are Na and Ba for K, Al for Fe^{3+}, and minor P for As, forming several minerals (Gaines *et al.*, 1997). Except for BaK_{-1}, all these substitutions are present in pharmacosiderite from Mazarrón-Águilas. So NaK_{-1} substitution (to Na/K up to 1.2) has been found, together with an important $AlFe^{3}_{-1}$ substitution (Table 4).

These minerals, widespread in the Mazarrón-Águilas copper prospects, form pale green to yellow crusts of idiomorphic cubes to 1 mm. At the Dolores prospect, these minerals sometimes cover the siderite and the fracture surfaces of the host rock. Pharmacosiderite is commonly overlain by arseniosiderite and sometimes replaced by yukonite.

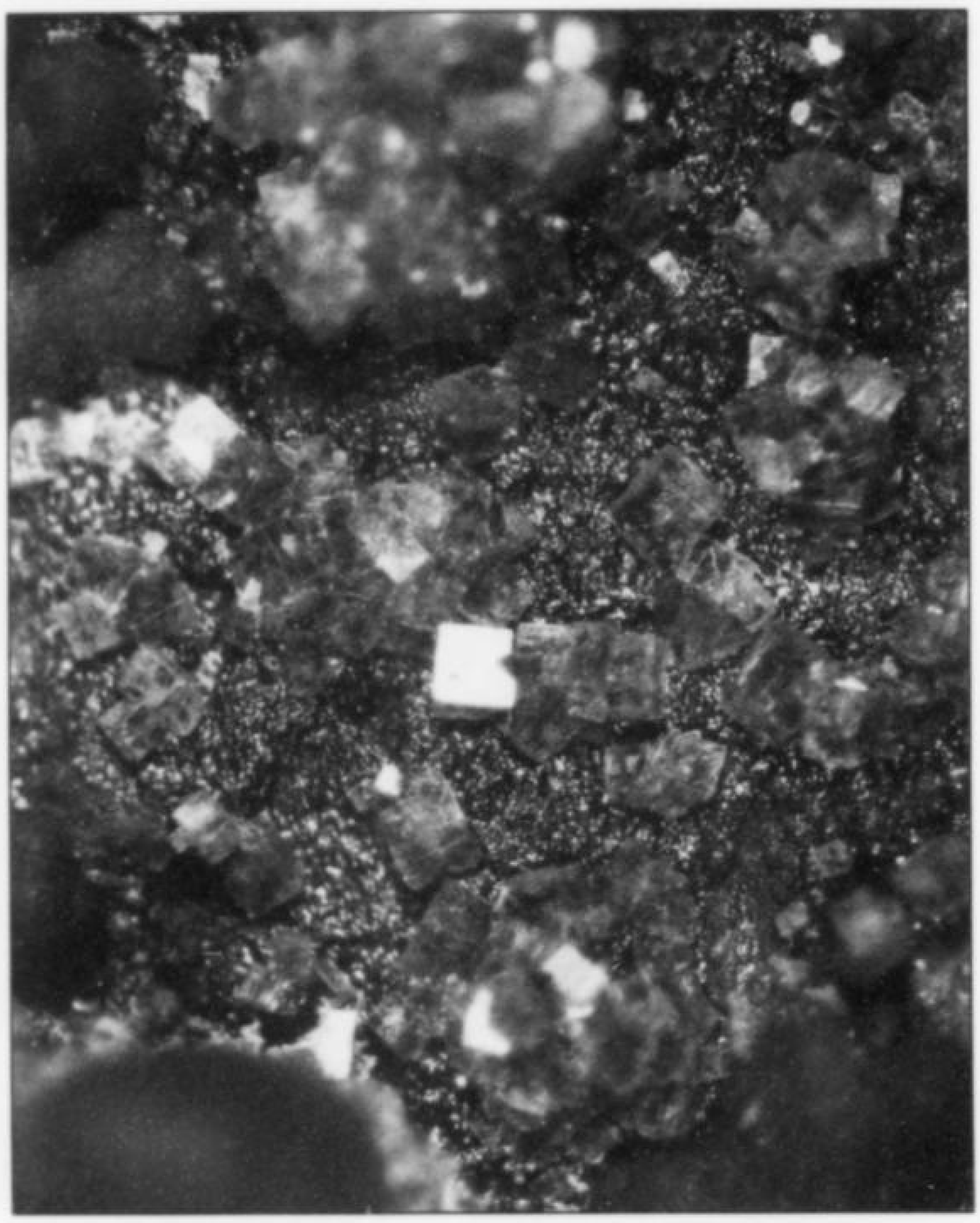


Figure 28. **Pharmacosiderite (49x) from the Dolores prospect. J. Viñals collection and photo.**

Yellowish to greenish crusts composed of very minute (less than 0.1 mm) cubes of sodium pharmacosiderite are also common at the Dolores prospect. This sodium species appears in the late-stage crystallization and is not associated with arseniosiderite

Scorodite-mansfieldite $(Fe^{3+},Al)AsO_4 \cdot 2H_2O$

The scorodite-mansfieldite series, probably as a complete solid solution (Gaines *et al.*, 1997), is abundant in the Dolores and Umbría de Ramonete prospects. The minerals are difficult to recognize because they are often covered or replaced by yukonite. Scorodite-mansfieldite appears as crusts, globules or more rarely as pyramidal {111} microcrystals. The chemical analysis (Table 4) shows monovalent and divalent substitutions for K; Al for Fe^{3+}; and P, S, and minor Si for As. These substitutions are similar to those in alunite-group minerals. At the Dolores prospect mansfieldite the As_6S_{-5} substitution is significant.

Tyrolite $CaCu_5^{2+}(AsO_4)_2(CO_3)(OH) \cdot 6H_2O$

Tabular, emerald-green, pearly crystals and groups of tyrolite to 2 mm have been identified by EDS. The tyrolite is fairly common at the La Atalaya prospect, with cornwallite and, less frequently, azurite.

Yukonite $Ca_7Fe_{11}^{3+}(AsO_4)_9O_{10} \cdot 24 \cdot 3H_2O$ (?)

Yukonite, an amorphous arsenate compound of varying composition, is a rare mineral which has been reported previously from only four localities in the world: Tagish Lake, Yukon, Canada; Sterling Hill, New Jersey, USA; Saalfeld, Thuringia, Germany; and Redziny, Poland (Pieczka *et al.*, 1998; Anthony *et al.*, 2000).

At the Dolores and Umbría de Ramonete prospects, yukonite forms veinlets, spheroids or pseudomorphs, replacing scorodite or, more rarely, pharmacosiderite. Its color is reddish brown to purple-red and its luster is vitreous to resinous.

The chemical composition is shown in Table 2, which also presents this composition in the form of ion contents on the basis of 9 anionic groups, in accordance with the mineral database webmineral.com (2001) and the *New Dana Classification of Hydrated Phosphates* (2001). In the same table, the data reported

Table 2. **Contents of ions on the basis of 9 [$(As,P)O_4^{3-}$, SO_4^{2-}, SiO_4^{4-}] for natural yukonite.**

	1	*2*	*3*	*4*	*5*	*6*	*7*
Ca	5.49	5.07	4.62	5.79	5.84	4.14	4.89
Mg	0.18	0.27	0.36	0.27	0.26	0.86	0.41
Mn	0.14	0.81	0.77	—	0.15	0.03	0.00
Zn	0.17	1.11	1.17	—	0.17	—	—
Cu	—	—	—	—	—	1.29	0.09
-M^{2+}	5.98	7.26	6.92	6.06	6.42	6.32	5.39
Fe^{3+}	11.96	9.86	8.96	10.61	9.63	10.58	8.58
Al	—	0.45	0.50	0.53	—	0.90	0.08
-M^{3+}	11.96	10.31	9.46	11.46	9.63	11.48	8.66
As	8.28	7.91	8.65	9.00	8.78	7.10	6.93
P	0.35	—	—	—	0.09	0.18	0.14
S	0.08	0.08	0.08	—	0.03	0.02	0.05
Si	0.27	1.02	0.27	—	0.09	1.71	1.85

1: Yukon, 2–3: New Jersey, 4: Saalfeld, 5: Redziny, 6: Dolores prospect, 7: Umbría de Ramonete. 1–5 Calculated from data reported by Pieczka et al. (1998).

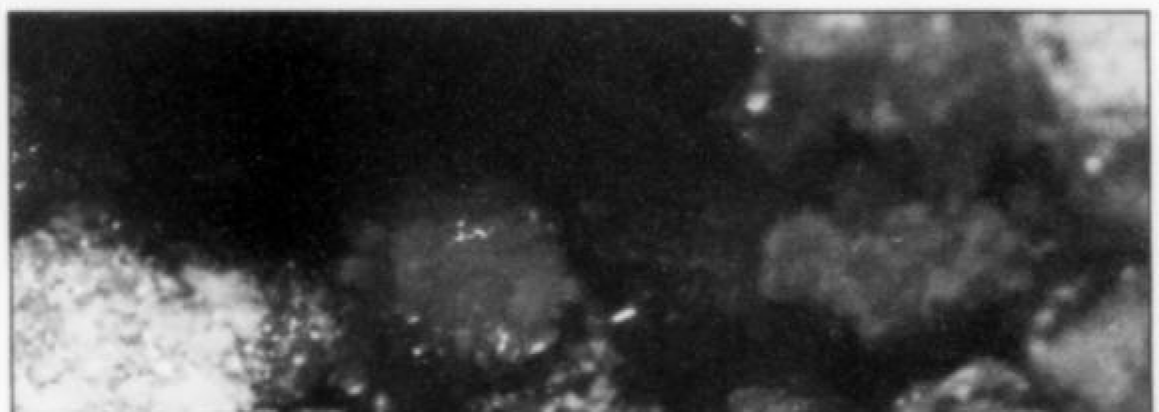


Figure 29. **Yukonite with lavendulan, 24 x 15 mm, from the Umbría de Ramonete prospect. BSB collection. Photo by J. González del Tánago.**

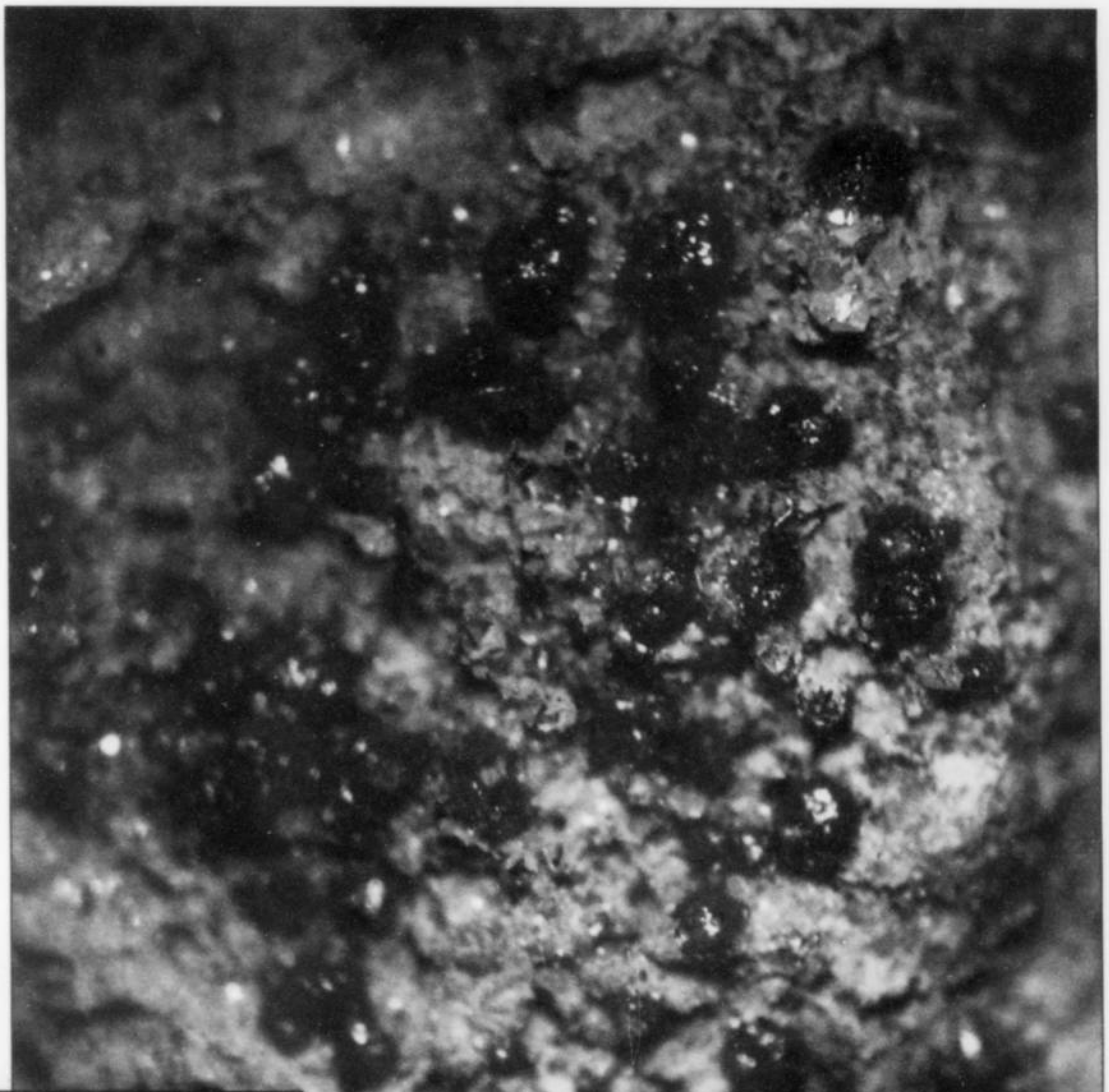
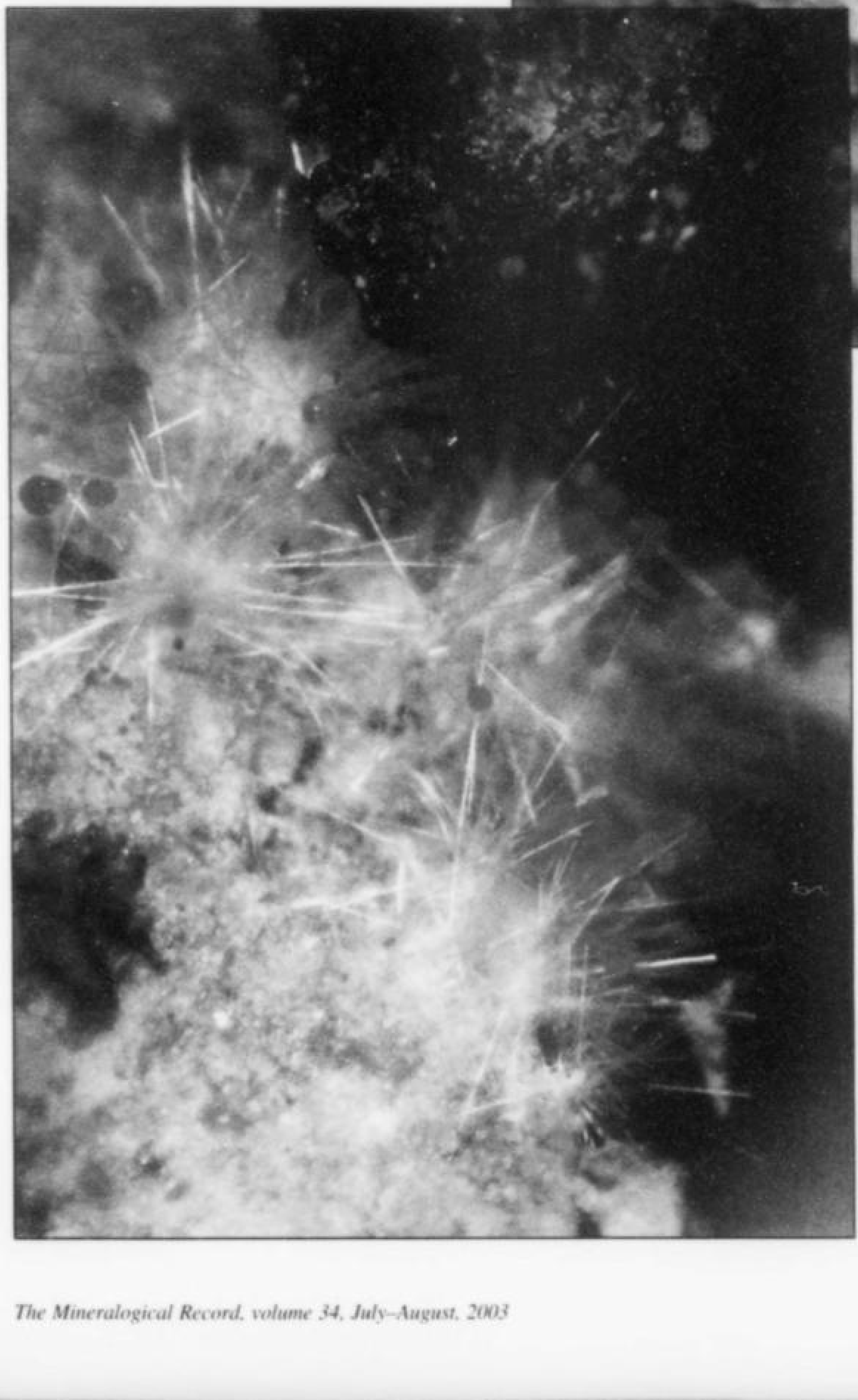


Figure 30. **Yukonite (33x) from the Umbría de Ramonete prospect. J. Viñals collection and photo.**

Figure 31. **Zálesíite with conichalcite (59x) from the Dolores prospect. J. Viñals collection and photo.**



by Pieczka *et al.* (1998) from the other localities were also included. As can be seen, all the natural yukonites fit relatively well for the ratios 9 (XO_4) (6–7) A^{2+} and (9–12) B^{3+}. Other proposed formulas, such as $Ca_6Fe_{16}(AsO_4)_{10}(OH)_{30}\cdot 23H_2O$ (Jambor, 1966), $Ca_3Fe_7(AsO_4)_6(OH)_9\cdot 18H_2O$ (JCPDS, 1982, 1992), and $Ca_2Fe_3(AsO_4)_4(OH)\cdot 12H_2O$ (Mandarino, 1999), deviate more widely from data from some reported localities. Probably the problem is associated with the amorphous nature of this species and the unknown role of potential substitutes for Ca^{2+}, Fe^{3+} and AsO_4^{3-}. A chemical characteristic of the yukonite of this district is the presence of significant copper, especially in the Dolores prospect specimens. A similar zinc content is found, however, in some analyses of Sterling Hill yukonite (Pieczka *et al.*, 1998). Silica content is high in yukonites of this district and, according to Pieczka (*op. cit.*), also in Sterling Hill.

Zálesíite $(Ca,Bi)Cu_6^{2+}(AsO_4)_3(OH)_6\cdot 3H_2O$

During the course of this work, zálesíite was described from Zálesí, Czech Republic, by Sejkora *et al.* (1999). So the Mazarrón zálesíite (found only in the Dolores prospect) is among the first world occurrences.

Zálesíite occurs as green to pale blue sprays of thin acicular

Figure 32. **Zálesíite, 4 mm crystal group., from the Dolores prospect. J. M. Gordillo collection. BSB photo.**

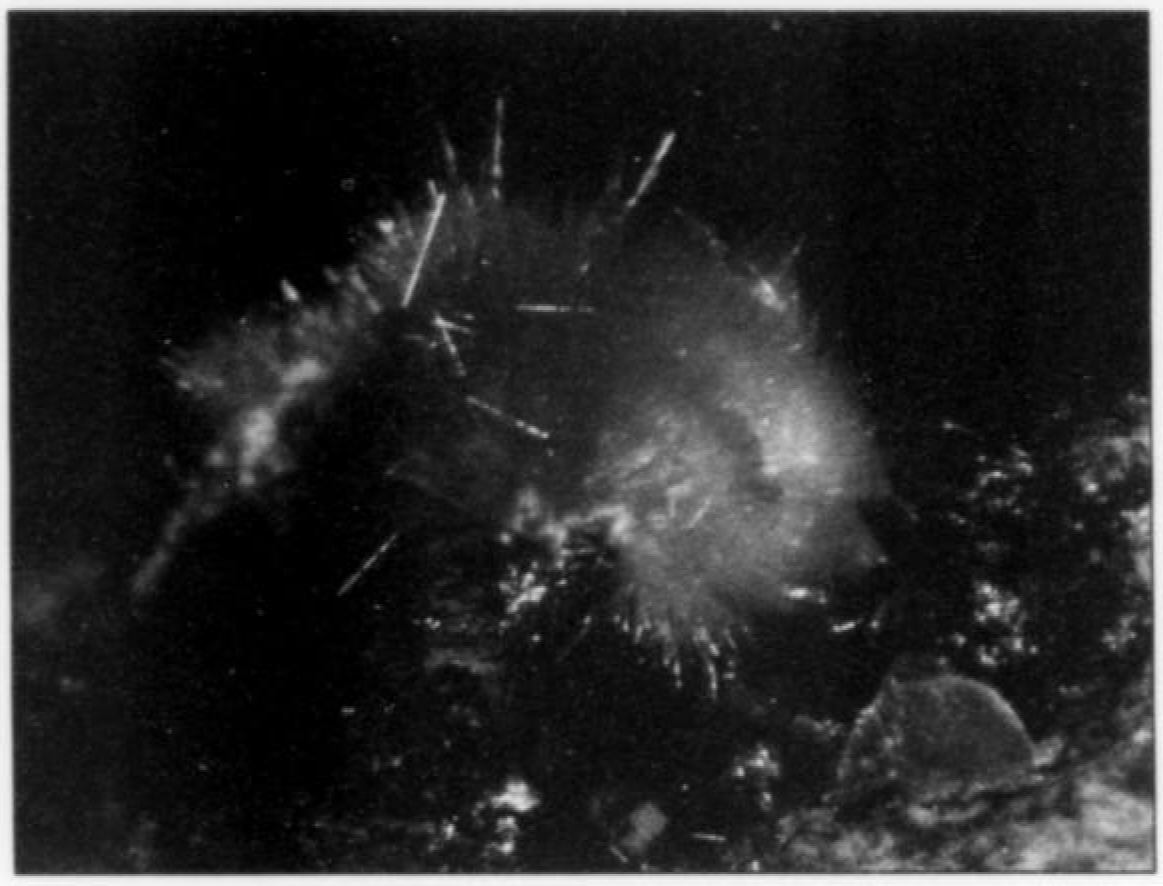


Figure 33. **Zálesíite, 4 mm crystal group, from the Dolores prospect. J. M. Gordillo collection. BSB photo.**

crystals and radial clusters, to 3 mm, with siderite and conichalcite. Very fine specimens were collected in a limonitic gossan.

The chemical composition (Table 4) shows large substitutions in the Ca-Bi site and no REE or Y content such as was seen in the Zálesí material. Mazarrón zálesíite is a solid solution between mixite and zálesíite, but because Ca > Bi it must be classified as zálesíite. A high-Ca mixite has been observed at the Gold Hill mine, Utah (Kokinos and Wise, 1993), suggesting a possible solid solution series also at Gold Hill.

Unknown # 1

This unknown mineral, a Na/Ca/Cu/(Fe/Al)-chloride-arsenate hydrate, was found at the Dolores prospect. It appears as yellow-green (Fe-rich) to pale sky blue (Al-rich) powdery crystalline crusts, which usually overlie jarosite and pharmacosiderite. Under SEM, the powder appears to consist of tabular crystals up to 20 micrometers long and less than one micrometer thick. These characteristics have impeded progress in characterization; further studies of this mineral are under way.

Unknown #2

This mineral occurs in Dolores as minute clusters of tabular to platy crystals of apple-green to olive-green color, similar to the parnauite. Its chemical composition, measured by EPMA for several different points and crystals, is near $Fe^{3+}{}_{0.2}Al_{0.3}Mg_{0.1}Cu_{3.0}Zn_{0.05}$-$(As_{0.8}Si_{0.1}S_{0.1}P_{0.05})O_4$. The simple Cu/As ratio, close to 3, resembles the clinoclase/gilmarite ratio, but the substitutions up to 0.65 cation and the low S content is the problem. The very scarce quantity of this mineral does not permit us to make an XRD determination.

This mineral crystallized before azurite, since idiomorphic azurite crystals are implanted on it.

Table 3. **Representative electron microprobe analyses of Mazarrón-Áquilas jarosite, brochantite and atacamite.**

	Ja-I	*Ja-II*	*Bro*	*Ata*
Al_2O_3	15.39	1.11	0.08	0.13
Fe_2O_3	28.08	46.36	0.23	0.13
FeO	—	—	—	—
MgO	0.20	<0.01	0.01	0.83
CuO	0.81	0.01	73.81	68.35
ZnO	0.02	—	<0.06	<0.06
PbO	0.01	0.16	—	—
BaO	—	0.05	0.28	0.24
CaO	0.09	—	<0.02	0.39
SrO	—	<0.02	0.04	0.02
Na_2O	0.58	0.68	<0.01	0.08
K_2O	4.92	6.71	0.01	0.12
SiO_2	0.19	<0.01	0.03	1.19
P_2O_5	0.02	<0.02	0.02	0.13
As_2O_5	0.59	0.46	0.39	0.18
SO_3	34.12	30.84	18.94	0.38
Cl	<0.01	<0.01	0.01	18.39
Cl_O	—	—	—	4.35
Total	85.52	86.38	93.85	86.21

Ja-I, Al-rich –jarosite (Dolores): $Al_{1.38}Fe^{3+}{}_{1.62}Cu_{0.05}(Na_{0.09}K_{0.48})(S_{0.98}As_{0.01}Si_{0.01}O_4)_2$
Ja-II, jarosite (Dolores): $Al_{0.11}Fe^{3+}{}_{2.49}(Na_{0.11}K_{0.73})(S_{0.99}As_{0.01}O_4)_2$
Bro, brochantite (Umbría de Ramonete): $Fe_{0.01}Cu_{3.92}(S_{0.99}As_{0.01}O_4)$
Ata, atacamite? (Umbría de Ramonete): $Fe_{0.04}Cu_{1.66}Ca_{0.01}Si_{0.04}Cl_1$

DISCUSSION

The Mazarrón-Águilas copper prospects contain a complex suite of K-Na-Ca-Cu-Fe^{3+}-Al, with minor Bi-Co-Ag, secondary arsenate, sulfate and carbonate mineral assemblages.

In the Dolores prospect, the secondary-mineral zoning, where jarosite and iron arsenates are more abundant in the central part of the lens and copper minerals are more abundant in the peripheral zone, suggests a higher mobility of copper than of iron in the first supergene fluids, with a normally decreasing gradient of acidity from the core to the rim of the lens. This decrease in the acidity of the fluids had to be very sharp when the fluids contacted the siderite and the carbonate rocks in the external border of mineralization, producing a decrease in copper solubility and the formation of secondary copper minerals: olivenite and the carbonates azurite and malachite. Contemporaneously, scorodite, pharmacosiderite and jarosite were formed, while the bordering siderite was replaced by goethite.

After this stage an enrichment in calcium resulted from the leaching of rock generated by the acidity produced by alteration of

Table 4. **Representative electron microprobe analyses of Mazarrón-Áquilas arsenates.**

	Lav	*Pha*	*Sco*	*Che*	*Oli*	*Cor*	*Zal*	*Yuk-I*	*Yuk-II*
Al_2O_3	<0.01	16.06	7.30	1.83	0.18	0.22	0.36	1.83	0.14
Fe_2O_3	—	25.50	29.63	23.81	—	—	—	33.51	31.19
FeO	0.01	—	—	—	0.03	<0.04	0.86	—	—
MgO	0.05	0.07	0.23	0.53	<0.01	<0.01	<0.02	1.36	0.74
CuO	40.20	0.27	0.45	27.58	57.79	60.09	45.27	4.04	0.34
ZnO	<0.06	0.12	0.11	<0.06	—	—	—	—	—
PbO		—	—	0.01	—	—	0.04	—	—
Bi_2O_3	—	—	<0.04	—	—	—	10.74	—	—
BaO	0.25	0.04	0.70	—	—	—	0.23	—	—
CaO	5.87	0.67	0.02	0.77	<0.01	0.23	3.59	9.19	12.47
SrO	<0.02	0.10	<0.02	—	—	—	—	—	—
Na_2O	3.48	0.89	0.05	0.07	<0.01	<0.01	<0.01	—	—
K_2O	0.13	6.46	0.02	0.07	<0.01	<0.01	0.08	—	—
SiO_2	0.01	0.02	0.23	0.31	0.06	0.07	0.02	4.10	5.17
P_2O_5	0.23	0.05	0.13	0.24	—	1.74	0.20	0.53	0.44
As_2O_5	45.00	40.81	49.85	33.91	39.63	31.68	33.36	32.30	36.38
SO_3	0.05	5.63	<0.01	0.10	<0.01	0.07	—	0.04	0.13
Cl	3.63	—	—	0.02	<0.01	0.05	<0.01	—	—
Cl-O	0.82	—	—	—	—	0.01	—	—	—
Total	98.0	96.69	88.59	89.55	97.69	94.08	94.73	86.97	87.00

Lav, lavendulan (Umbría de Ramonete): $Mg_{0.01}Cu_{5.12}Ca_{1.06}Ba_{0.01}Na_{1.14}K_{0.02}Cl_{0.96}(P_{0.01}As_{0.99}O_4)_4$
Pha, pharmacosiderite (Dolores): $Al_{2.17}Fe^{3+}_{2.2}Cu_{0.02}Ca_{0.07}Na_{0.19}K_{0.94}(As_{2.45}S_{0.55}O_4)$
Sco, scorodite (Dolores): $Al_{0.33}Fe^{3+}_{0.85}Mg_{0.01}(Si_{0.01}As_{0.99}O_4)$
Che, chenevixite (Umbría de Ramonete): $Al_{0.24}Fe^{3+}_{1.96}Ca_{0.08}Mg_{0.08}Cu_{2.28}Na0_{.02}K_{0.1}(Si_{0.02}P_{0.01}As_{0.97}O_4)$
Oli, olivenite (Dolores): $Cu_{2.11}(AsO_4)$
Cor, cornwallite (La Atalaya): $Al_{0.02}Cu_{5.03}Ca_{0.02}(P_{0.08}As_{0.92}O_4)_2$
Zal, zálesíite (Dolores): $Al_{0.07}Fe^{2+}_{0.12}Cu_{5.82}Bi_{0.47}Ca_{0.65}Ba_{0.02}(P_{0.01}As_{0.99}O_4)_3$
Yuk-I, yukonite (Dolores): For formula see table 4
Yuk-II, yukonite (Umbría de Ramonete): For formula see table 2

sulfides. Arseniosiderite was deposited abundantly, and scorodite was partially replaced by yukonite. In this phase, the increase of Ca activity began to form conichalcite as epimorphs/pseudomorphs over olivenite, azurite and malachite. Zálesíite and arsenocrandallite were also formed.

A final precipitation stage was characterized by the incorporation of Cl, probably from supergene waters, so chlorargyrite, atacamite, lavendulan and an unknown Na-Ca-Cu-Fe chloride-arsenate were formed.

In the Umbría de Ramonete, the mineralogical association suggests a similar geochemical process as in the Dolores deposit, although a different carbon/sulfur ratio must be expected, since carbonate is less abundant than sulfate.

A similar process is observed in La Atalaya, where chenevixite, tyrolite, cornwallite, olivenite and azurite were the first-formed secondary minerals, partially replaced thereafter by conichalcite. A final Si-rich phase, without Cl, formed chrysocolla.

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REFERENCES

ANTHONY, J. W., BIDEAUX, R. A., BLADH, K. W., and NICHOLS, M. C. (2000) *Handbook of Mineralogy, Vol. IV, Arsenates, Phosphates, Vanadates.* Mineral Data Publishing, Tucson, AZ, 680 p.

ARRIBAS, A., and TOSDAL, R. M. (1994) Isotopic Composition of Pb in Ore Deposits of the Betic Cordillera, Spain: Origin and Relationship to Other European Deposits. *Economic Geology,* **89**, 1074–1093.

CLOPTON, E. L., and WILSON, W. E. (1995) *The Mineralogical Record Index. Volumes I–XXV (1970–1994).* Tucson, 312 pp.

Del VALLE, A., NIÑO, M. P., and MARTÍN, J. (1995) Estudio químico de una conicalcita de Pastrana. *Revista Minerales,* **2**, 56–59.

ESPINOSA, J. S., MARTÍN VIVALDI, J. M., HERRERA, J. L., MARTÍN ALAFONT, J. M., PEREDA, M., PÉREZ ROJAS, A., LÓPEZ GARCÍA, M. J., and GONZÁLEZ DONOSO, J. M. (1974) *Mapa Geológico de España, E. 1:50.000, numero 976, Mazarrón, Spain*. Instituto Geologico y Mineralogico de España.

FONTBOTÉ, J. M., and VERA, J. A. (1983) La Cordillera Bética. In COMBA J. A., ed., *Geología de España*, Tomo II, Instituto Geologico y Minero de España p: 205–343.

GAINES R. V., SKINNER, H. C. W., FOORD, E. E., MASON, B., and ROSENZWEIG, A. (1997) *Dana's New Mineralogy*, 8th edition. John Willey & Sons. New York, 1819 pp.

GONZÁLEZ, T. (1832) *Registro y Relación general de las minas de la Corona de Castilla*. Madrid, 2 vol. 718 and 433 pp.

GRUPO MINERALOGISTA DE MADRID (1994) Mazarrón. *Bocamina*, **0**, 23.

JAMBOR, J. L. (1966) Re-examination of yukonite. *Canadian Mineralogist*, **8**, 667.

JAMBOR, J. L. (1999) Nomenclature of the alunite supergroup. *Canadian Mineralogist*, **37**, 1323–1341.

JAMBOR, J .L., VIÑALS, J., GROAT, L. A., and RAUDSEPP, M. (2002) Cobaltarthurite CoFe$_2^{3+}$(AsO$_4$)$_2$(OH)$_2$·4H$_2$O, a new mineral of the arthurite group. *Canadian Mineralogist*, **40**, 725–732.

KOKINOS, M., and WISE, W. S. (1993) Famous mineral localities: The Gold Hill mine, Tooele County, Utah. *Mineralogical Record*, **24**, 11–22.

MADOZ, P. (1842–1850) *Diccionario geográfico-estadístico-histórico de España y sus posesiones de Ultramar.* 16 vol.

MANDARINO, J. A. (1999) *Fleischer's Glossary of Mineral Species 1999*. 8th edition. Mineralogical Record Inc., Tucson. 225 p.

MORALES, S., and FENOLL, P. (1992) Quimismo de las paragénesis asociadas al vulcanismo terciario del sector Águilas-Sierra Almagrera (SE de España). *Boletin de la Sociedad Española Mineralogica*, **15**, 282–286.

MUELAS, M., PÉREZ, P., and GIL, J. (1996) *Minerales de la Región de Murcia*. La Unión 165 p.

PIECZKA, A., GOLEBIOWSKA, B., and FRANUS, W. (1998) Yukonite, a rare Ca-Fe arsenate from Redziny (Sudetes, Poland). *European Journal of Mineralogy*, **10**, 1367–1370.

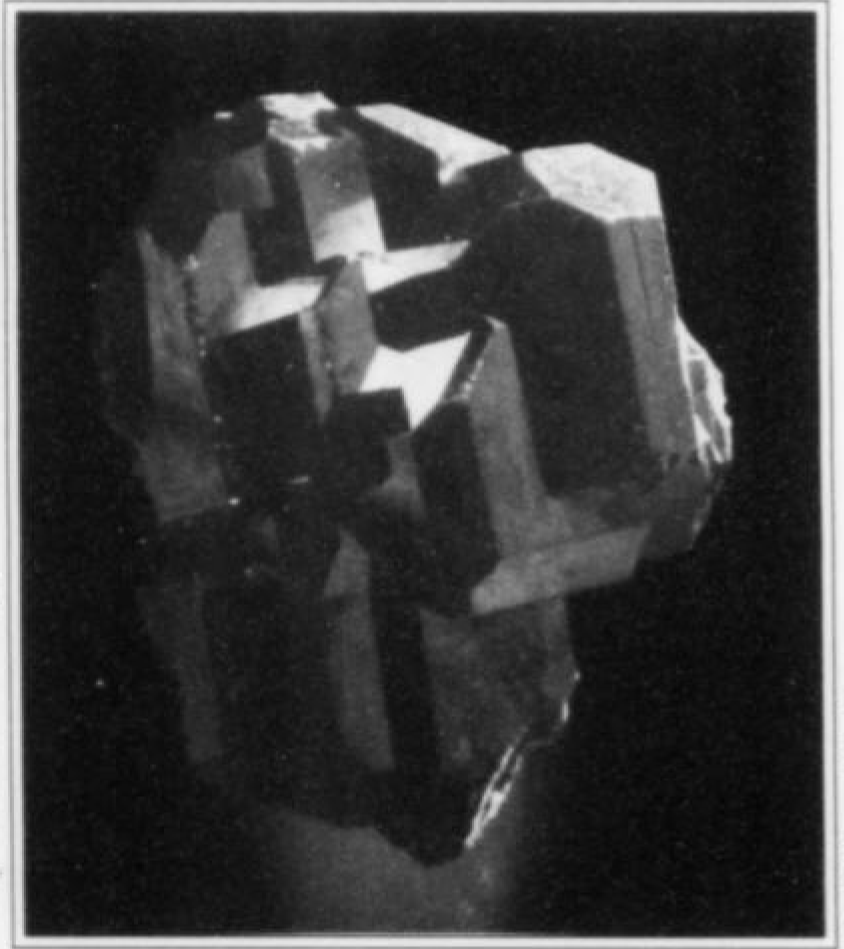
RAMALLO, F., and BERROCAL, M. C. (1994) Minería púnica y romana en el sureste peninsular: el foco de Carthago Nova, in VAQUERIZO, D. (ed.): *Minería y Metalurgia en la España prerromana y romana*, 81–146.

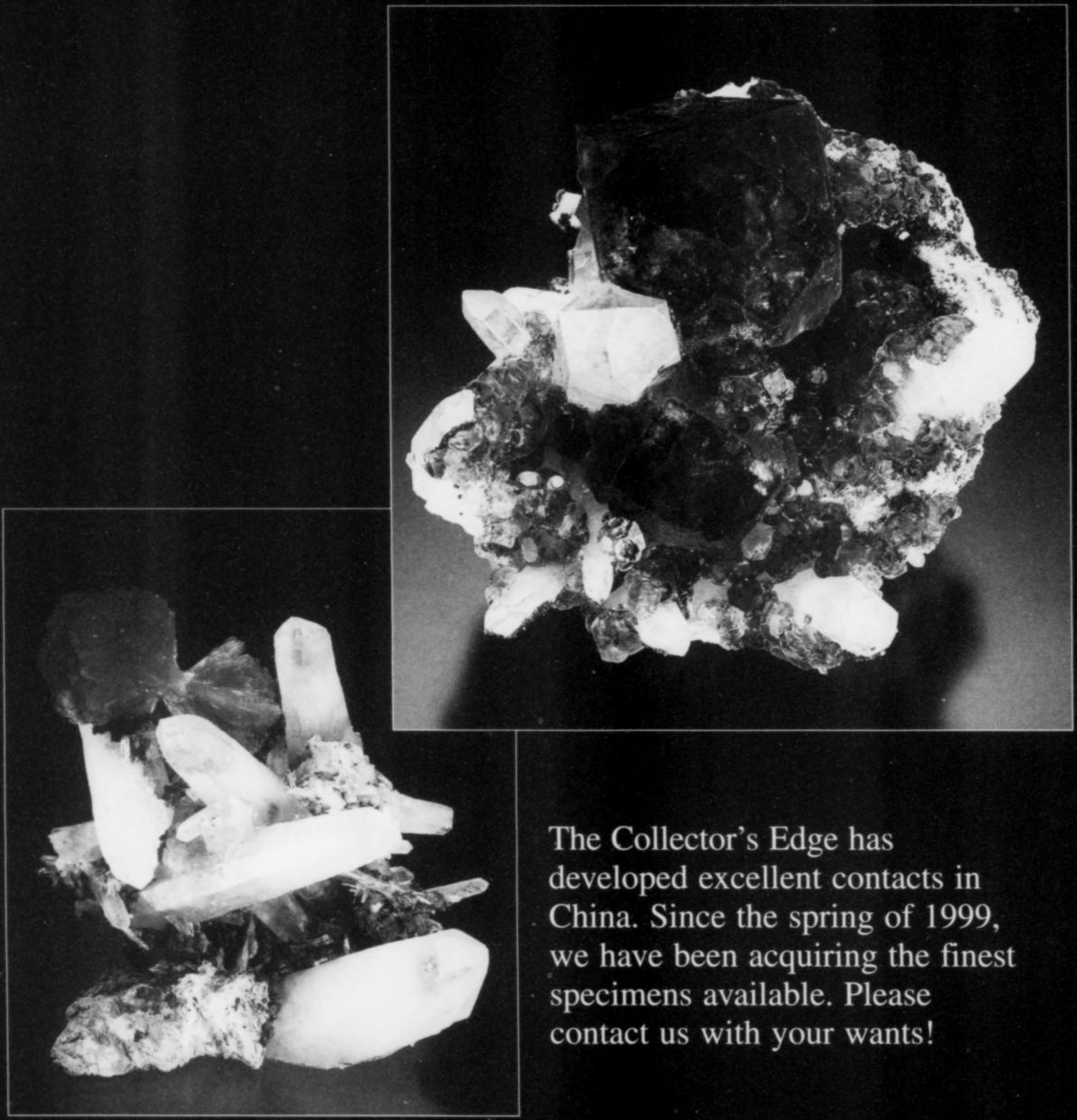
ROLANDI, M. (1993) Apuntes históricos sobre la minería y metalurgia antigua del sureste peninsular. *Tierra y Tecnología*, **5**, 61–73.

SEJKORA, J., RIDKOSIL, T., and SERRÍN, V. (1999) Zálesíite, a new mineral of the mixite group, from Zálesí, Rychlebske hory Mts., Czech Republic. *Neues Jahrbuch für Mineralogie Abhandlungen*, **175**, 105–124.

STOFFREGEN, R. E., ALPERS, C. N., and JAMBOR, J. L. (2000) Alunite-Jarosite Crystallography, Thermodynamics and Geochronology. *In* ALPERS, C. N., JAMBOR, D. K., NORDSTRORM, Eds., *Reviews in Mineralogy & Geochemistry*, **40**, *Sulphate Minerals*, Mineralogical Society of America and the Geochemical Society, 453–479.

VILLAR, J. B., and EGEA, P. M. (1990) *La minería murciana contemporánea, 1840–1930*. 2nd Edition, Murcia University. 362 p.

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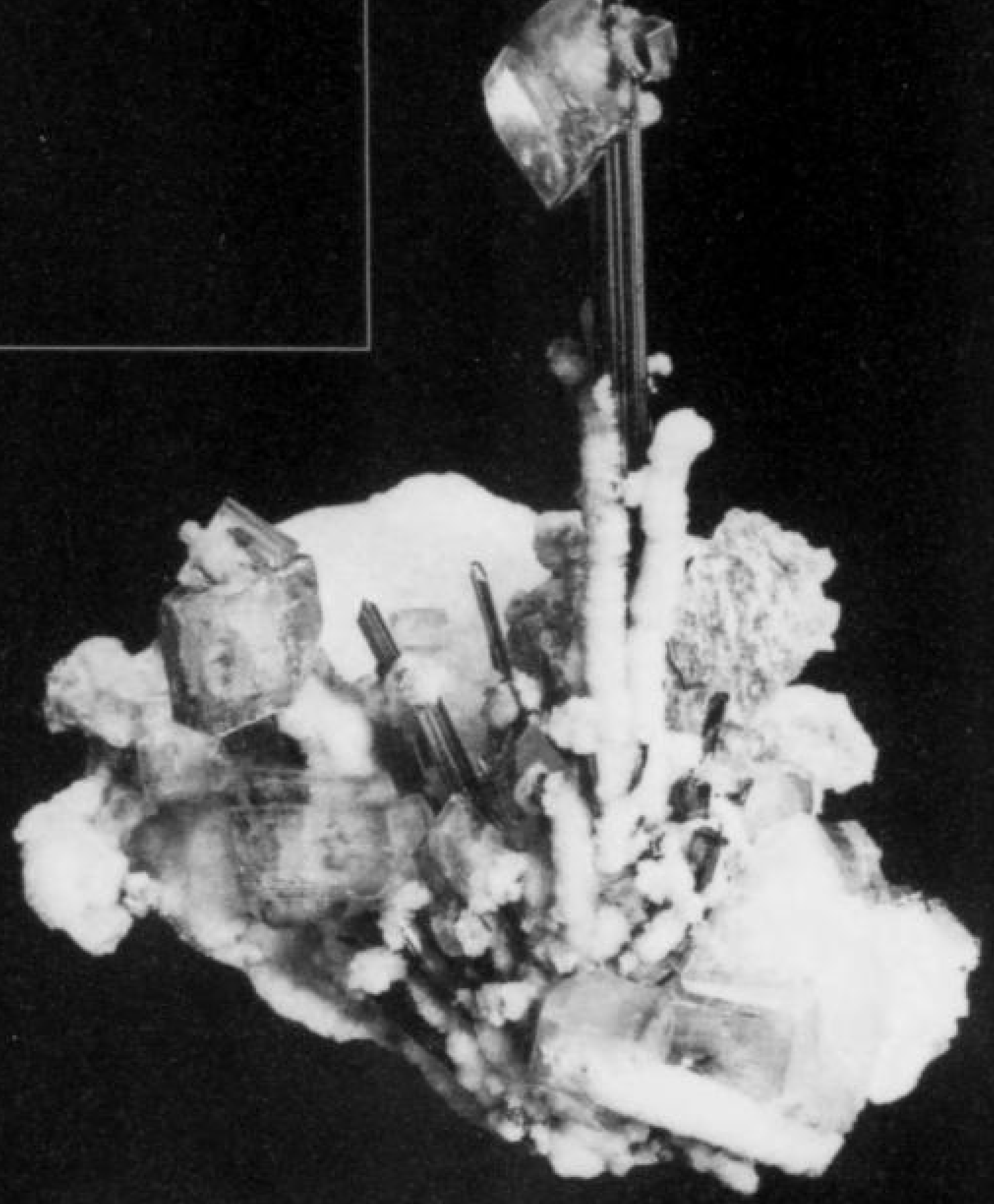

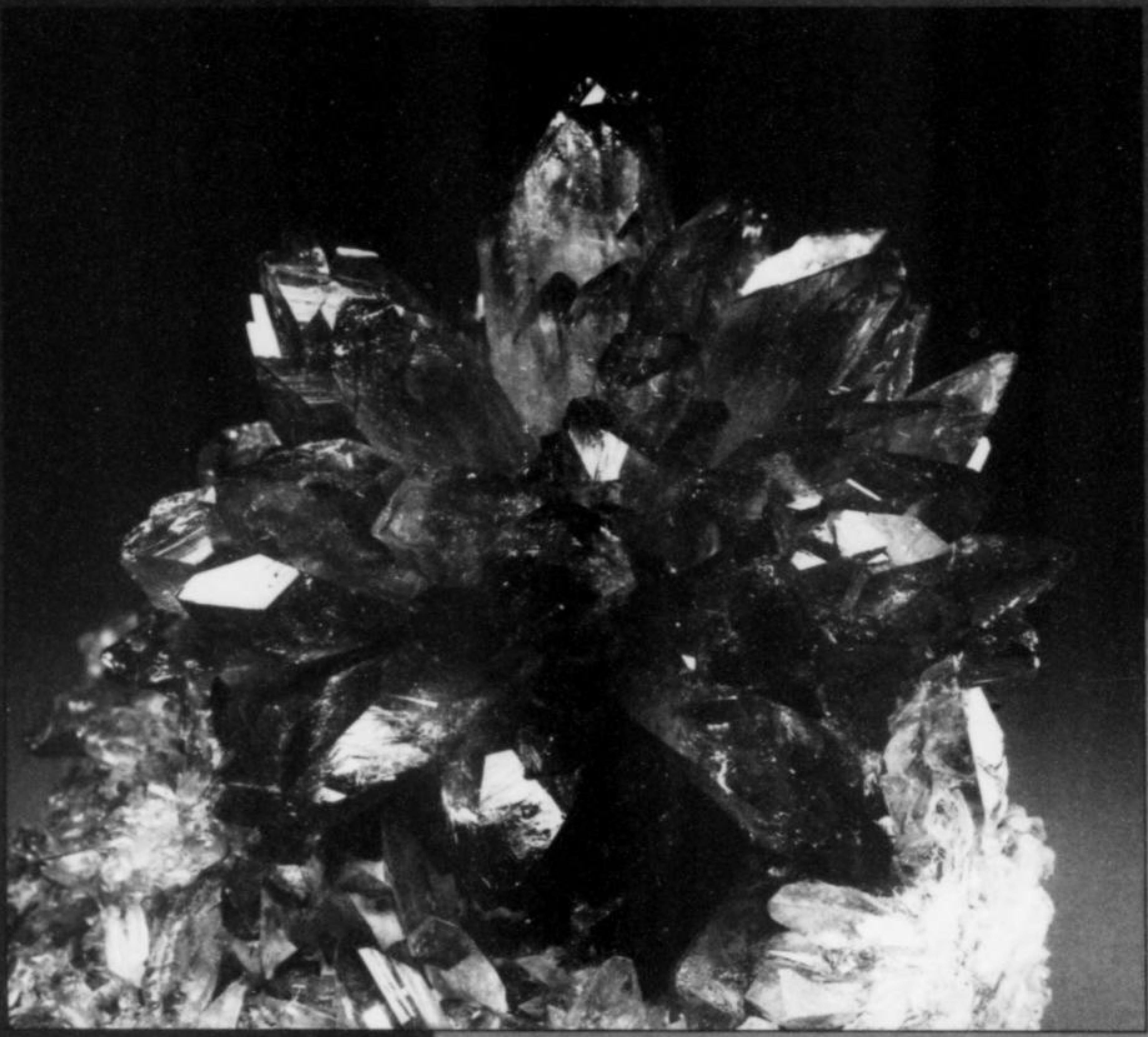

Creedite, 5.2 cm, from Akchatau, Kazakhstan.
Wendell Wilson photo.

Famous Mineral Localities:

The Pacajake Selenium Mine

Potosí, Bolivia

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The Pacajake mine, hidden high in the Cordillera Oriental of the Bolivian Andes, is famous for its rare selenides, selenates and selenites, and is the type locality for penroseite, ahlfeldite, olsacherite and mandarinoite. It was recently rediscovered after having stood abandoned for more than 60 years, and some new specimen material was collected, but the prospects for finding more are now as remote as the locality itself.

INTRODUCTION

Despite its significance with regard to selenium mineralogy, the Pacajake (pronounced Pah-kah-*hah'*-kay) selenium deposit has never been fully described in the mineralogical and geological literature. Previous notes and publications, such as they are, tend to be diverse, obscure and often controversial. The research for the current project, presented here, was conducted during work carried out to rediscover and reopen the mine between 1990 to 1994.

The deposit was mined on a small scale between 1922 and 1925, and from 1935 to 1937. It was originally exploited for silver; the selenides were not identified until 1935, albeit on a sample collected during the first period of mining. Early preliminary descriptions of the geology and mineralogy were published between the mid-1930's and the mid-1940's by Hans Block (a miner at the locality), Friedrich Ahlfeld (the well-known German geologist-mineralogist in Bolivia), Robert Herzenberg (a German chemist) and Paul Ramdohr (the renowned German ore mineralogist). During this period, the German mineralogists began to unravel the unusual mineralogy of the deposit, and several new species were partially described. In the process, a controversy surrounding the naming of the principal selenide mineral arose among the researchers. Some favored *penroseite*, as first proposed by Samuel Gordon of Philadelphia in 1925, based on his description of impure material from a purchased sample of unknown provenance (and later corroborated by the British Museum); others favored the name *blockite*, as proposed for pure material collected at the Pacajake mine by the Germans working in Bolivia. Penroseite is considered today to have priority.

Detailed descriptions of several of the Pacajake minerals were eventually published during the 1950's to the 1980's by various mineralogists working on specimens from museum collections; additional new mineral species were also identified. This cleared up the confusion over many of the earlier unidentified or poorly described species but the mineralogy of the deposit as a whole has remained incompletely described, in part due to a lack of new specimens.

Figure 1. **Location map.**

LOCATION AND ACCESS

The Pacajake mine is located in the Cordillera Oriental (Eastern Cordillera) of the Bolivian Andes, some 340 km southeast of La Paz and 15 km northeast of the famous Colquechaca silver-tin mine at latitude 18°35′52″ S, longitude 65°53′43″ W (UTM grid reference 19K JE 941 406). The terrain consists of deep valleys and sharp ridges with little vegetation due to the high altitude and semi-arid climate. The deposit, on a steep-sided ridge at an altitude of about 3,550 meters, is not shown on modern topographic maps but lies between the Rio Pacayaque and the Rio Castilluma shown on the 1:50,000 scale Chayala sheet (number 6438 III).

Access from La Paz is through Oruro and Uncia to Colquechaca, a distance of 470 km which can be covered in about 8 hours by jeep. Thence over a pass at around 4,700 meters and a further 20 km by road to the village of Estancia Phurqui, then about 2 km must be traversed on foot to reach the deposit. The inhabitants are Quechua Indians, few of whom speak any Spanish; they subsist by grazing sheep, llamas and cattle and by growing potatoes, maize, oats and beans on small plots on the steep slopes.

HISTORY

The Hiaco de Charcas district, in which the Pacajake mine is located, was known for silver and copper in early Spanish Colonial days. It was first mentioned by a Spanish priest, Father Alvaro Alonzo Barba (1637), of Villa de Lepe, Andalucia, Master of Arts and Priest of the Parish of San Bernado, Potosi, in the first treatise on mining in the Americas. *"The province of Charcas possesses,"* wrote Barba, *"in addition to the rich Hill of Potosi (which of itself is sufficient to immortalize its name), and the other mines which have been mentioned, the mines of Yaco, or Cerro del Milagro . . . where, amongst its rich Copper ores, a stringer of native Silver was found in a tawny-colored rock."* The miracle (Milagro) after which the mountain was named is commemorated by the remote shrine of the Virgin of Surumi, located 8 km northeast of the Pacajake mine, where there is a huge dilapidated basilica built halfway down into a deep Andean valley accessible only by foot. The church is built around a tree where the Virgin Mary is said to have appeared to the local farmers; it is still an important annual destination every September 8th for pilgrims from Cochabamba, some 140 km to the north.

The Pacajake deposit itself, however, was not discovered until the 20th century. The name Pacajake means *"Falcon's Rock"* in the Aymara language, after the craggy white ridge formed by the nose of a landslide which is clearly visible in photos taken in 1935 (in Block and Ahlfeld, 1937; Herzenberg, 1945b), but which now no longer exists due to further landslip. A major landslide occurred in 1922, and the resulting dust cloud was seen from the Hiaco (Yaco)[1] mine, 2.5 km away on the ridge to the southwest, where Hans Block was mining lead and silver. Block sent a miner down to investigate the landslide. The miner returned with an unknown mineral that looked like arsenopyrite but assayed 1% silver. Block tried to get the mining concession but was beaten to it by a Syrian named Kunkar, who worked the mine from 1923 to 1925. Kunkar was lucky in finding an ore pocket of 300 kg of silver selenides with a grade of about 40% silver, which must have been pure naumannite. His later attempts were much less successful, and he abandoned the mine in 1926. He is said to have mined a total of 4 to 5 metric tonnes, from which he extracted about 500 kg of concentrates which he sold as silver ore (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937; Block, 1937a, b). The selenium was not recognized, and not paid for. It was during this time, in 1925, that Samuel Gordon obtained the sample of the material which he named *penroseite;* the specimen was in a collection of minerals which he bought in the nearby mining camp of Colquechaca (Gordon, 1925).

Ten years later, in 1935, Ahlfeld was examining Block's collection when he came across the unidentified silver-bearing mineral collected from the landslide at Pacajake. Herzenberg[2] analyzed it by blowpipe and found it to be composed of only nickel and selenium. Intrigued, Block and Ahlfeld visited the mine in April of 1935. They found that a landslide had made most of the workings inaccessible, but fortunately they discovered more of the same mineral in a drift very close to the surface. The new samples were analyzed by Herzenberg, who proposed the name "blockite" for the new mineral, after Hans Block (Herzenberg and Ahlfeld, 1935). Block acquired the mining concessions and began rehabilitating the old adits and opening new ones in August of 1935 (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937). He formed a company called *Empresa Minera Virgen de Surumi* in the name of Block y Compañia (offices headquartered in Colquechaca) to operate the mine.

Analysis of old mine plans shows that most of the workings were developed by Kunkar on the very steep slope—averaging 45°

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[1] Some papers have wrongly described the provenance of the selenium minerals as the Hiaco mine, also spelt Hiaca, or even as the Colquechaca mine. Pacajake is sometimes also known as the Surumi or the Virgen de Surumi mine.

[2] Robert Herzenberg (b. 1885) was the Chief Chemist for Hochschild South American Mines Inc. in Oruro. He was a mine engineer and Doctor in Chemistry, and was later Chief of the Mineralogical Museum in Hamburg. He discovered several other new minerals in Bolivia including ahlfeldite (below), herzenbergite, rooseveltite, hochschildite and souxite, although the latter two are not currently accepted by the IMA as valid species.

Figure 2. **Ore sacks being loaded onto mules at the Surumi Pampa camp at Pacajake in 1935. (Photo courtesy of Hans Block Jr.)**

gradient and reaching 60° in places—below Falcon's Rock at the northwest end of a northwest-trending ridge. The camp was on the flat top of the ridge behind Falcon's Rock at 3730 meters altitude. The workings were on a single vein trending northwest and dipping 60° northeast. Most of the mining was carried out over a strike length of about 90 meters and a vertical range of 40 meters. The main level was Socavon (= "adit" or "tunnel") Kunkar (also called Cable or Sirio), 88 meters long (Level 0, at approximately 3648 meters). Above it were Socavon Felipe (5.5-meter level, 14 meters long), Socavon Vilca (16.5-meter level, 9 meters long), Socavon Coria (23.5-meter level, 7 meters long) and a 1-meter *cateo* (prospect pit). Below the main level was Socavon Calisaya or Nivel [= Level] –20 (16-meter level) with a pique below for a few meters. Levels –16 to +16.5 were connected by piques (raises and winzes), stopes and ore shutes.

Additions to the plans show that Block mined the interval between Socavones Calisaya and Kunkar between 1935 and July 1938, over a distance of about 40 meters, and made various drives and cross-cuts off these levels, with a maximum length of 20 meters. About 170 meters farther east, Block developed Socavon Jarachi, probably at the same level as Calisaya (–16). The cross-cut (61 meters) was made sometime between 1935 and 1937, and the vein appears to have been mined along a drive to the west for some tens of meters probably in 1938 or 1939, with a ventilation raise to the surface. Block says that he mined from the end of 1935 to mid-1936 (Block, 1937c), and that his only production came from the reconnaissance workings (Block, 1937a, b). Ahlfeld reported in September 1936 that the mine was completely exhausted (Aristarain and Hurlbut, 1969).

A number of reconnaissance cross-cuts were made. To the east, Kunkar drove Socavon 6 de Agosto (90 meters at 225°), which failed to cut the vein. Socavon del Prado (25 meters) was made by Kunkar in an uncompleted attempt to join Socavon Kunkar. Three short reconnaissance adits, Socavones Cola (or Chusa), Ojeda, and San Miguel, were driven from the creek to the west of the mine in an attempt to cut the vein at lower levels. The first was made by Kunkar and the latter two by Block in 1935–1937. Socavones Ojeda and San Miguel are still open today, but none of the other adits are open. Further landslides have removed Falcon's Rock and all traces of the mine openings and dumps. Most of the camp has disappeared also, although some ruins remain.

Hand-written instructions by Block dated August 16, 1943 indicate that he had plans to clean out the mine and re-establish production, but this was never done and the mine has remained abandoned to this day.

No road ever existed to the mine, and all transport was by donkey or llama. All mining and concentration were accomplished by hand. Mining was carried out in open stopes where the landslide had left blocks of the vein exposed. Socavones were opened and timbered, and the ore pockets mined by cut and fill stoping. The coarse mineral was hand-sorted. The finer-grained mineral was crushed by *quimbalete*, a rocking boulder, and classified by *maritate* jigs into four sizes, with loss of a lot of fines (Block, 1937a). These old Spanish mining techniques are still used to this day in many small mines in Bolivia.

Hans Block found some areas of "stockwork" deposits, actually breccias cemented by selenides rich in clausthalite. At the beginning of 1937 he reported that the altered dikes near the veins were

relatively high in gold and platinum group metals (PGM) (1.5 to 50 g/t total), although my own analyses of altered dikes did not corroborate this. At the end of 1937 Block explored the river downstream from the vein towards the Río Grande where "*a lot of mineral* [selenide] *was encountered.*" Although he never carried out much development or mining, Block obviously had high hopes for this unusual deposit, and tried to raise capital to mechanize the mine with a 50-tonne/day pilot flotation mill in 1937 and 1939 (Block, 1937b). He had problems finding a market for the polymetallic concentrates, the smelters in Europe only paying for the selenium and not the silver, or the platinum group metals and not the cobalt, for example. World War II then intervened and halted his plans. It is said that he produced a total of 3,000 kg of high-grade selenium concentrates from the mine (Ahlfeld, 1954).

***Figure 3.* The Pacajake deposit looking west in 1993, showing the active landslide area in which the mines were located. Comparison with old photos shows that the prominent white outcrop (Falcon's Rock or Pacajake) has been eroded. S. Redwood photo.**

Figure 4. **Hans Block Jr. (second from right) and the author (second from left) at Colquechaca on the 1990 expedition to Pacajake. S. Redwood photo.**

THE REDISCOVERY OF THE MINE

Between 1992 and 1994 I supervised exploratory work in the Pacajake area hoping to discover a small, underground bonanza deposit having a high-value concentrate, and possible low-grade bulk-tonnage platinum-group metal mineralization (Redwood, 1991, 1993a; Redwood & Garzón, 1993). As part of this investigation I wanted to rediscover the original Pacajake workings.

The first problem was to find the approximate location of the mine. Only one field description of the deposit existed, in Block and Ahlfeld's paper describing their first visit to the site in 1935. Their sketch location map could only be fitted in broad terms with modern topographic maps, and the latitude and longitude given did not match their shown location. To confuse the issue further, modern maps show a valley with the similar name of *Pacayaque* in yet a third location. This conflicting information yielded a large and difficult search area in very steep, high-altitude terrain with no roads. Fortunately I then learned that the son of the original owner, also called Hans Block, was still living in Oruro. He agreed to come along as my guide.

Our preliminary search took place in 1990. Hans and I spent the first night in the near-ghost mining town of Colquechaca. Hans knew the area well and told me a lot of the fascinating history of this old and rich silver mining district. He also proved his worth the next day, for without him I doubt that I would ever have found the Pacajake mine. We took the steep road which climbs out of Colquechaca and over a high pass, then along a new road—hewn out of the rock by hand—which goes part way to the shrine of the Virgin of Surumi. From the road it was a hike of several hours down-hill to reach the site of the mine. After arriving there at last I was disappointed, as there was little to see. The area that Hans showed me was a very steep ridge with a loose bouldery landslide area on one side. Altered and mineralized rock was lying about, and in the sweltering heat of the canyon below we found some short adits.

We started exploration work at the mine in 1992. During the first campaign a rusty water seep was dug out to reveal a very narrow, stone-lined adit. In fact, reported the engineer, it was so small that he could not understand how anybody could have gotten into it, and concluded that it must somehow have become more constricted over time. However, what he had actually found was the *huayra cañon*, the narrow drainage and ventilation adit put in below and to one side of the mine adit (an old Spanish mining technique). Sure enough, our diggers soon encountered the mine adit above and to one side. It was cleaned out for 54 meters but no vein was cut along its length so the work was stopped.

Figure 5. **The remains of the mine camp at Pacajake on the top of the landslide in 1993. S. Redwood photo.**

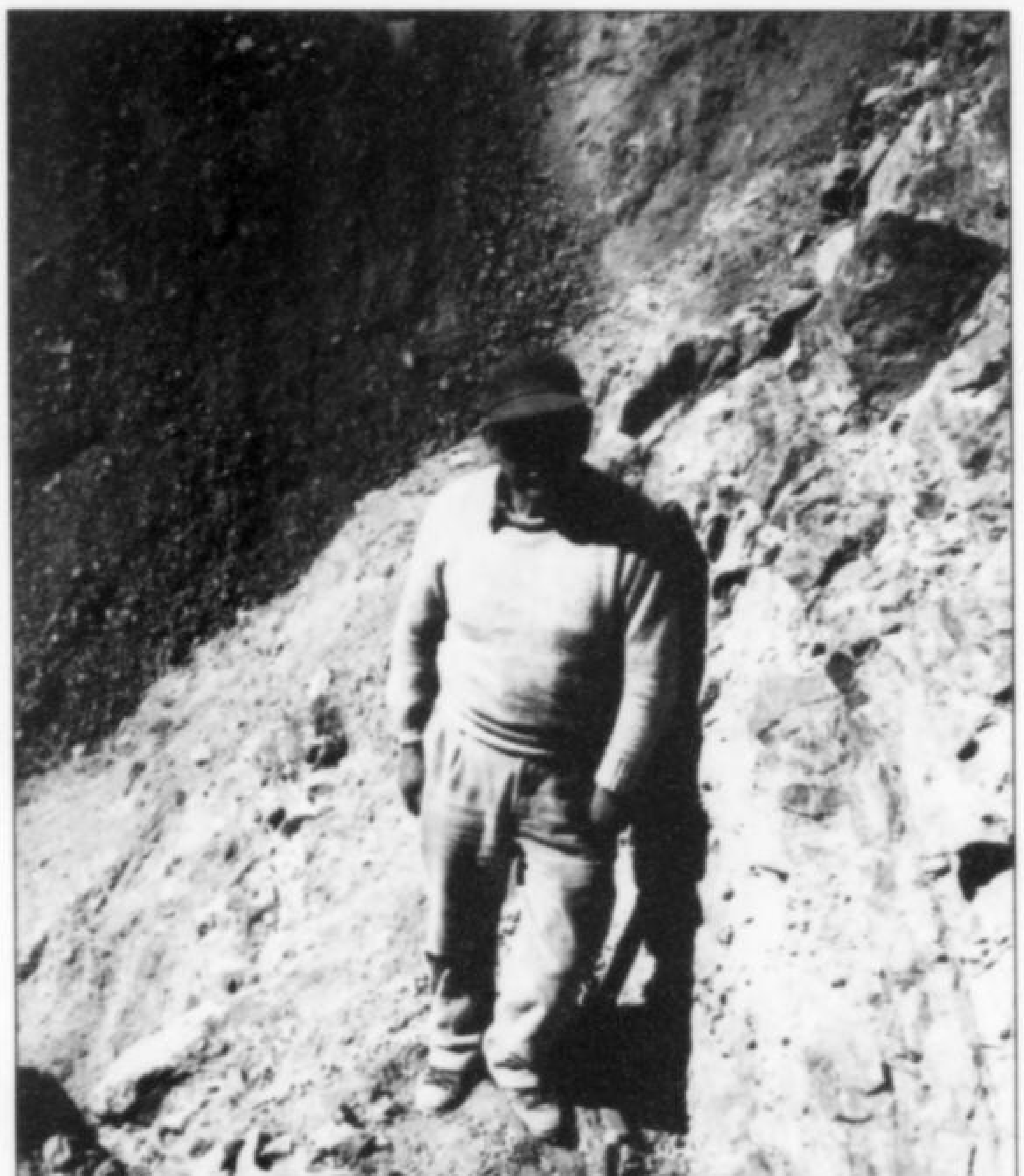


Figure 6. **Macario Zurita on the Discovery Outcrop of the West Vein, 1993. S. Redwood photo.**

The last 11 meters of this old adit was in a fault zone; it was stone-lined and had constricted over the years. This was thought to be Socavon Jarachi, but underground surveying and analysis of old mine plans that later came to light indicated that this was actually Socavon 6 de Agosto, shown on old plans with a length of 94 meters.

Several days were also spent excavating in the area of the old mine workings, but none were found, and the work was halted because heavy rain was causing collapses on the steep slope. The most important result of the first campaign was the discovery of a float sample in the Viluyo River which assayed several grams/tonne of platinum, palladium and gold.

When we returned the following year we quickly found the source of the mineralized sample—a narrow, partly oxidized vein in a fault in a very steep gully. We assigned two miners to excavate the outcrop, and by the next day they had three or four selenide nodules (which they called *plomo*—lead) to show me. We drifted by hand on this structure for 28.5 meters at an altitude of 3570 meters (equivalent to level –78 of the old workings). It proved to contain very little selenide material but it was indeed the selenide vein. The most significant fact was that it is on the west side of the creek where there were no old mines, so we had discovered the continuation of the vein, referred to below as the "West Vein."

We surveyed a polygon on the steep slopes of the old mine area

Figure 7. **The newly discovered West Vein can be seen as a faint fracture above the people in the center who are standing at the new adit. The vein cuts a well-bedded sequence of Ordovician dirty white sandstones and siltstones. S. Redwood photo.**

and found that it matched pretty well with the old plans drawn by Hans Block. This, and old photographs, confirmed my suspicion that the main area containing the original mine adits had been completely lost in a landslide, together with Falcon's Rock and most of the camp. We did find a few remaining stone ruins of the camp and some leveled areas; and there were two small winzes in the vicinity, but with no mineralization.

The other objective of our survey was to locate the old crosscut to the vein. We were able to narrow its location down to an area of about 10 by 10 meters. After some unsuccessful exploratory excavating at a point indicated on the steep colluvium-covered slope by one of the old-time miners, I decided to start a new crosscut. We drove about 56 meters at an elevation of 3659 meters, all by hand steel, but no vein could be found. Further work in 1994 extended the adit by hand through very hard rock to 135 meters, but still no vein was cut.

As an aside, we often used hand underground driving and drifting for exploration in the inaccessible parts of the Andes such as Pacajake, the cost being far lower than for mechanized drilling. The only piece of machinery we had at the site was a small ventilator used when the adit had gone deep enough that dust and fumes became a problem.

The conclusion we finally came to was that the original selenide vein had been very restricted in both the lateral and vertical extent, and that what little there had been was entirely mined out or removed by erosion, except for the western extension, which was not as intensely mineralized.

GEOLOGY

Pacajake is located in the Cordillera Oriental which consists of a thick sequence of Ordovician to Devonian marine siliciclastic

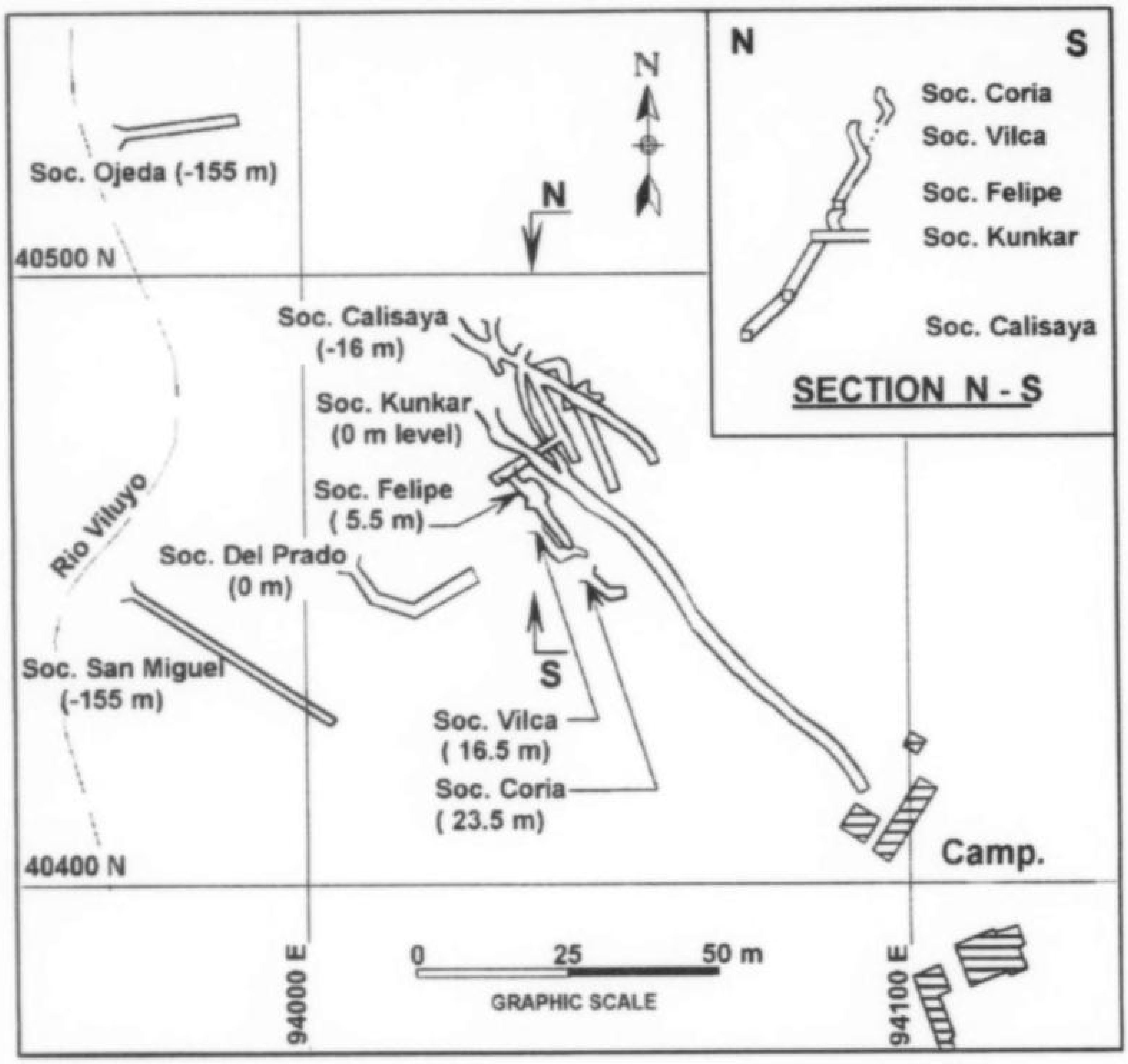


Figure 8. **Plan of the old mine workings at Pacajake in 1935.**

sediments, overlain by Late Jurassic to Tertiary continental sediments (Redwood, 1993b).

The Pacajake vein is hosted by dirty white sandstones with an outcrop thickness of about 225 meters and a dip of 30 to 77 degrees to the southwest. These rocks are part of a sequence of white sandstones and black shales which alternate on a scale of tens to hundreds of meters. They have not been assigned a formation name and are shown on the regional geological map only as undifferentiated Ordovician sediments. The white sandstone is medium-grained, fine to thickly bedded (1 to 160 cm thick) with rootlets, ripple marks and cross-bedding. It is dirty due to an admixture of black shale, and it has rhythmic, thin black micaceous shale to siltstone interbeds with strong bioturbation. The black shale, well bedded and highly fissile, has thin, fine-grained, rippled white sandstone laminae. The depositional environment involved cycles of deposition of deltaic sands prograding into a deeper-water marine black shale basin.

Altered felsic dikes, commonly with wall-rock xenoliths and in some cases with plagioclase phenocrysts, occur in the mine area and cut across black shales in the Rio Castilluma section to the north. The dikes trend northwest and dip at 35 to 60 degrees northeast.

The strata strike northwesterly at 150° and dip at a moderate to steep angle to the southwest on the western flank of a major anticline. There is strong faulting, with both high-angle and low-angle faults. In the Pacajake deposit the dip of the strata and the selenide vein have been rotated by approximately 40 degrees across the north-northeast-trending (015 to 035°) Viluyo Fault after formation of the vein. The strata on the northwestern side dip on average 30° southwest, which is 40° shallower that the beds on the southeastern side which dip about 70° to the southwest. Likewise the vein has been rotated by 40 degrees from a dip of 80° southwest on the northwestern side of the fault (West Vein) to 60° northeast on the southeastern side (Pacajake Vein).

The Paleozoic sediments have undergone very low-grade regional metamorphism with induration of the sandstone to quartzite, and the black shales are locally phyllitic with lenticular shear fractures and spaced cleavage. The Pacajake vein occurs in a zone of regional alteration of the sediments, with widespread milky quartz veinlets, silicification, hematitization, limonitization and bleaching. Numerous veins and veinlets with quartz, specular hematite, calcite, dolomite, barite, pyrite, galena, sphalerite, minor chalcopyrite, bornite, and other sulfides occur in the Pacajake area, but only a single vein containing selenides is known. The dikes are propylitically altered with carbonate (dolomite and siderite) veinlets and minor sulfides (pyrite, sphalerite). To the southeast, in the Guadalupe Valley, there are antimony vein deposits and a very hot thermal spring. The Hiaco mine, to the west of Pacajake, consists of Pb-Ba-Ag in tetrahedrite-bearing veins. Further west lies the major Colquechaca silver-tin mine, now closed, with Ag-Sn-Pb-Zn-Bi mineralization hosted by a dacitic stock of Lower Miocene age.

Old plans and descriptions indicate that the Pacajake vein trended northwesterly and dipped 60° to the northeast. It was known to extend over a length of 250 meters with a width of up to 60 cm. Block and Ahlfeld (1937) described the mined area as a landslipped block, and observed that the host rock was crushed. Falcon's Rock was a quartzite ridge formed by the nose of the landslide, and the flat area behind it was once the site of Block's mine camp. These features were the result of the backward rotation of the slipped block. The landslide is still active and the prominent quartzite ridge no longer exists. However, many of the crush features that Ahlfeld described are the result of mineralization in fault zones. The landslide probably displaced the vein downslope by only a small amount on the end of the ridge and caused additional breakage of the rocks, resulting in dangerous mining conditions.

The vein wall rock was described as a light-colored quartzite in dark-colored shale or slate. The vein was described as having a gangue of siderite with specular hematite, limonite and small

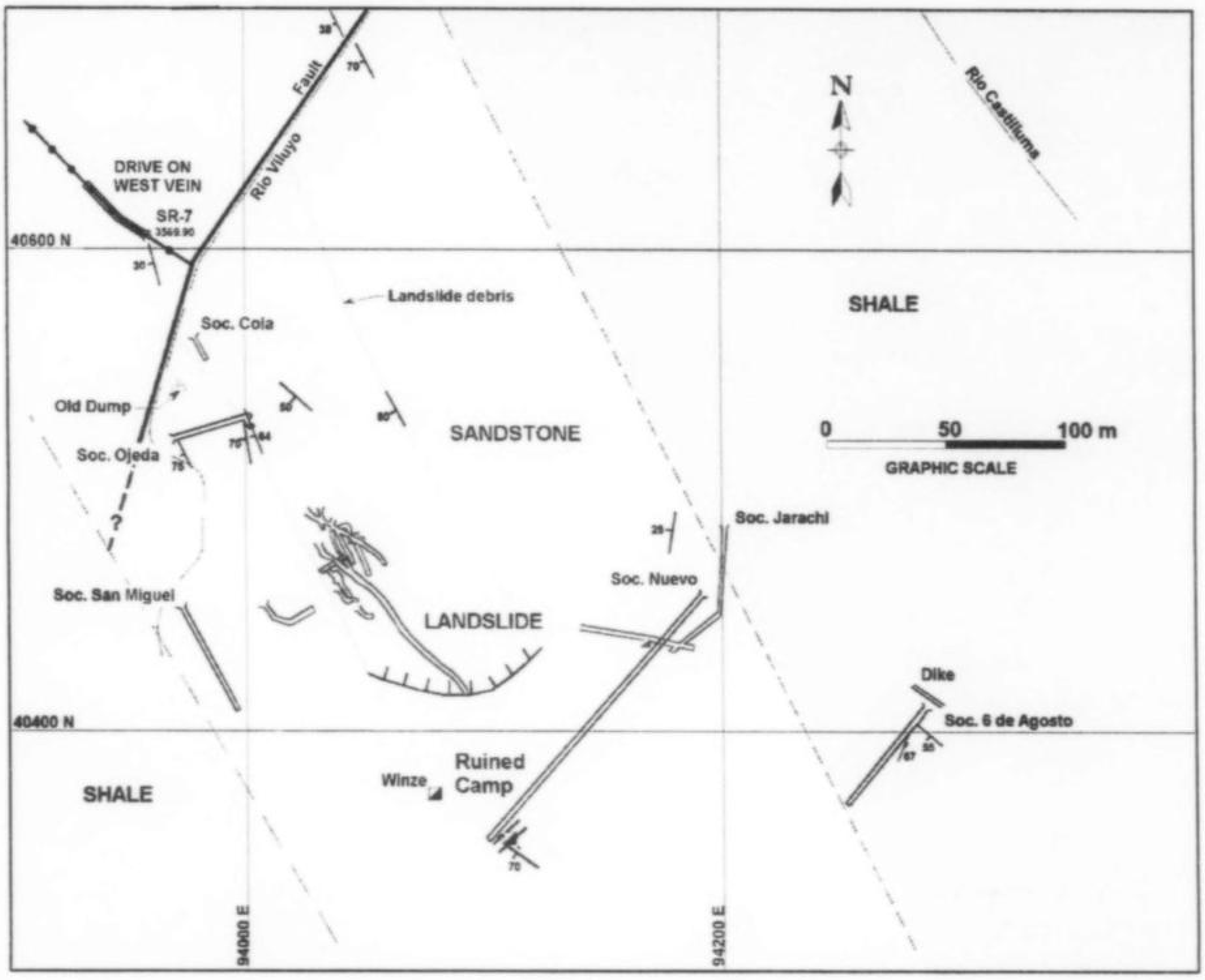


Figure 9. **Geology and mine workings at Pacajake.**

amounts of barite, calcite, pyrite and chalcopyrite. Selenides occurred as pockets and eyes in the vein, up to 2 meters long and 25 cm wide, each of which gave 20 to 400 kg of selenides when mined. The selenides included mainly the nickel selenide penroseite, intimately mixed with selenides of lead (clausthalite), silver (naumannite) and mercury (tiemannite). A variety of minor secondary selenates and selenites were also found in the oxide zone. Limonite occurred on all levels, but the selenides were always fresh and unaltered in appearance (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937). Block (1937c) reported that 10 tonnes of vein material grading 6 to 7% Se were needed to give 1 tonne of concentrates grading 50% Se, 0.05% (500 g/t) platinum-group metals, 0.01% (100 g/t) Au, 15.00% Ni, 5.00% Co and 1.20% Ag. This indicates an average vein grade of 6 to 7% Se, 50 g/t PGM, 10 g/t Au, 1.5% Ni, 0.5% Co and 1,200 g/t Ag.

The newly discovered West Vein strikes northwest (296 to 315 degrees) and dips to the southwest at 78 to 85 degrees. It is a mineralized fault in quartzite and white-gray sandstone interbedded with thin siltstones. The vein has an average width of 40 cm and a brecciated texture. Wall-rock clasts vary from unrotated to subrounded and are cemented by earthy limonite with finely disseminated pyrite and chalcopyrite locally. Selenides form ovoid clots in this gangue up to 2 x 4 x 5 cm. There is no wall rock alteration but it is stained with tan, maroon and yellow-colored limonite, and has limonite veins. The selenides are gray with a metallic luster and a hardness of 4 to 5, and form poor to moderately well-developed, broad curved laths up to 1.5 cm long by 4 mm wide in a sub-radial habit with a hackly to poor cleavage. In places they have an iridescent coating.

Assays have shown the selenides from the West Vein to be dominated by penroseite and to include clausthalite, tiemannite and naumannite with possible krutaite (although the Cu may be chalcopyrite). The clots are usually pure selenides with no gangue. Some selenide clots up to 1.1 cm wide are coated by botryoidal-radial marcasite which disintegrates rapidly. Other clots of creamy white barite and brown siderite contain interstitial selenide particles up to 5 mm. The barite and siderite occur together and have a similar habit, as massive, coarsely cleavable blades up to 1 cm, with coatings of hematite and limonite. The selenide clots commonly have an irregular boxwork texture developed around the outer zone. Various secondary minerals occur in boxworks and vugs.

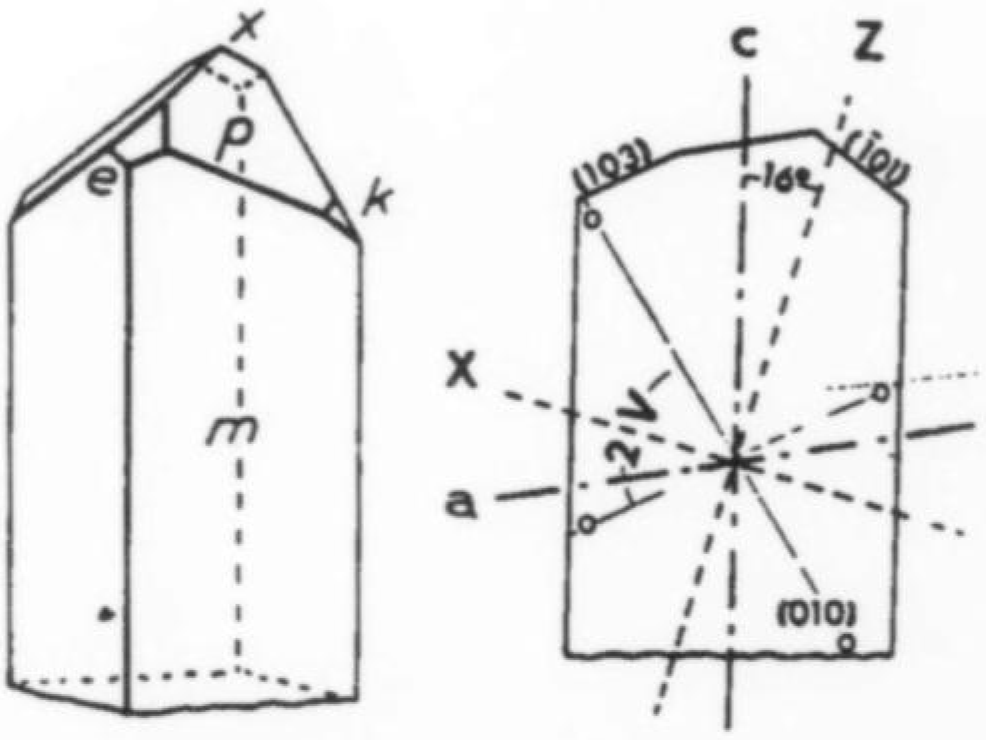


Figure 10. **Ahlfeldite from Pacajake, elongated on the *c* axis (left) and showing the optical orientation (right) (Aristarain and Hurlbut, 1969).**

MINERALOGY

Ahlfeldite $NiSeO_3 \cdot 2H_2O$

Ahlfeldite, a hydrated nickel selenite, was described as a new mineral species from Pacajake by Herzenberg and Ahlfeld (1935). The discovery was first reported by Ramdohr (1935), and the

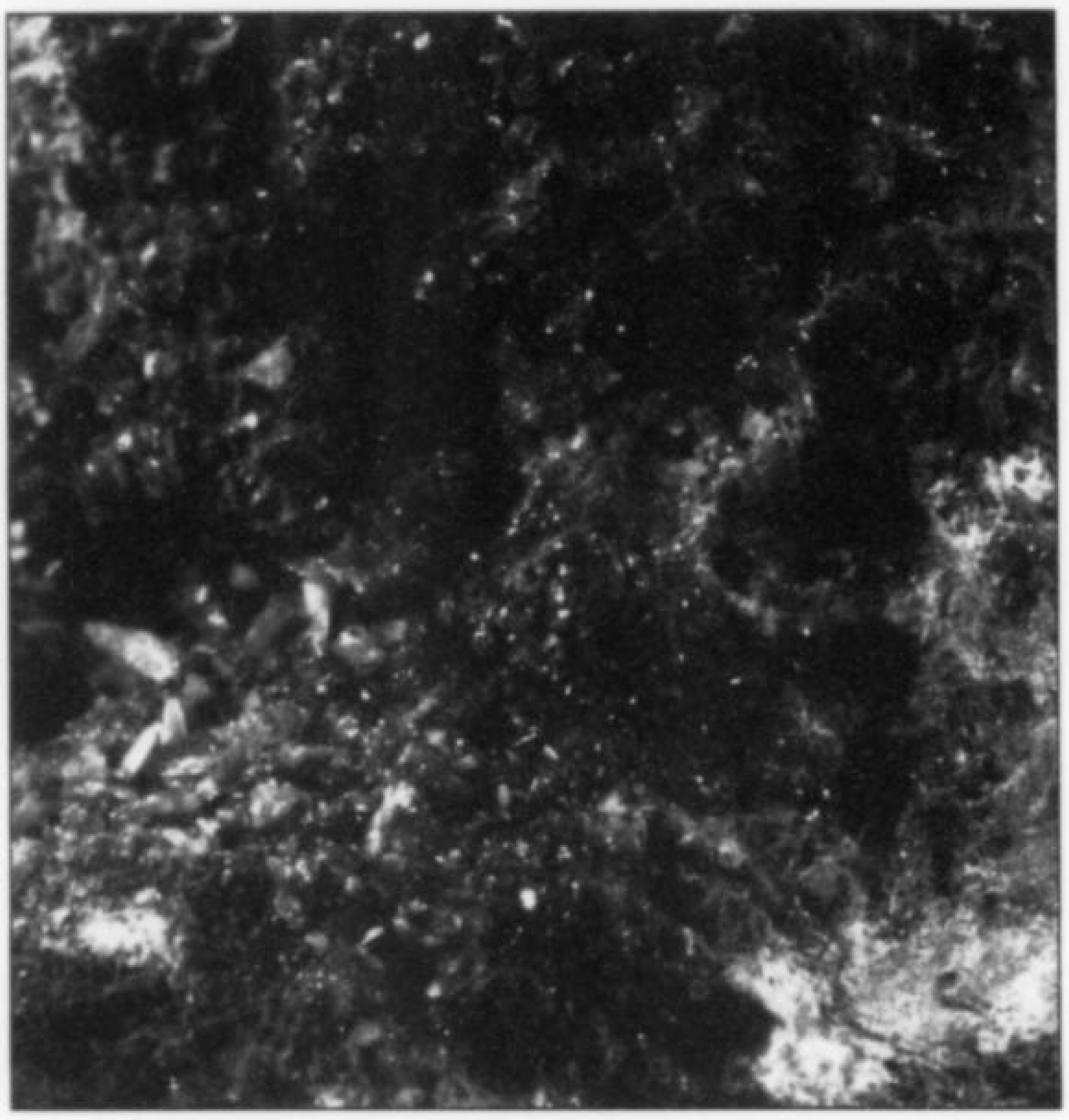


Figure 11. **Pink ahlfeldite druse (3 mm across) with blue chalcomenite. Ahlfeld specimen, Harvard Mineralogical Museum no. 135662.**

mineral was briefly described by Herzenberg (1944, 1945d, 1947) and Fleischer (1946).

Herzenberg named the new mineral in honor of Friedrich (Federico) Ahlfeld (1892–1982), respected as "The Father of Bolivian Geology." Ahlfeld served from 1935 to 1936 as Chief Geologist to the Bolivian Government; it was during this time that he discovered the true nature of the Pacajake samples in Block's collection, and (along with Block) rediscovered the Pacajake mine.

There was considerable confusion and debate in the early descriptions and in correspondence between Ahlfeld and Professor Charles Palache of Harvard University in 1935 over the true identity of this already named yet poorly characterized mineral (Aristarain and Hurlbut, 1969). Herzenberg and Ahlfeld (1935) described it as occurring on specimens of penroseite as a transparent red-brown mineral, with a strong luster, in a lobe form in fractures in penroseite. Herzenberg analyzed it as a nickel selenate.

Ahlfeldite is rare, occurring on only a few samples as an alteration product of penroseite in crystalline crusts 1 to 1.5 mm thick covering areas of only a few square millimeters or filling small cavities. It also occurs rarely as well-formed individual crystals of up to 1 mm in length. Associated species include cerussite, chalcomenite and olsacherite. The color varies from brown through brownish pink to red as the cobalt content increases (Aristarain and Hurlbut, 1969). Herzenberg (1944) analyzed pale green to yellowish crystals coated with a red-brown film. Because of its color, Ahlfeld originally thought it was identical to the cobaltomenite from Cacheuta, described by Bertrand (1882), but Herzenberg determined that the red color was superficial only, and disappeared in nitric acid. The coating was thought to be amorphous selenium formed by oxidation.

Ahlfeldite is monoclinic and the crystals are elongated along the *c*-axis or flattened on {110}. It has no cleavage, is brittle with a conchoidal fracture and is transparent with strong pleochroism. The hardness is 2.5 and the density 3.4. (Ahlfeld and Muñoz Reyes, 1955; Aristarain and Hurlbut, 1969). Ahlfedite was observed in the West Vein as pink, thin (< 1 mm) botryoidal crusts coating vugs in selenide clots.

The first adequate description of ahlfeldite from Pacajake was given by Goni and Guillemin (1953) of the Sorbonne. X-ray studies of ahlfeldite and cobaltomenite from Pacajake were published by Gattow and Lieder (1963). They found a Ni:Co ratio of 1:1 for cobaltomenite and 4:1 for ahlfeldite, and concluded that ahlfeldite is merely a nickel-rich variety of cobaltomenite. Aristarain and Hurlbut (1969) at Harvard University reviewed the history of the ahlfeldite-cobaltomenite series and presented a new mineralogical study of material from Pacajake. They concurred with Fleischer (1963) that cobaltite should be used for cobalt-rich members of the series and ahlfeldite for nickel-rich members. Sturman and Mandarino (1974) of the Royal Ontario Museum made a study of the synthetic end-members of the series to compare with the natural data from Pacajake.

Anglesite $PbSO_4$

Anglesite is listed among the secondary minerals by Hurlbut and Aristarain (1969), but it is not mentioned in any of the primary descriptions of the deposit, so its occurrence remains unsubstantiated.

Arsenic As

Native arsenic is listed as occurring at Pacajake by Ahlfeld and Schneider-Scherbina (1964). However, there is no mention of it in any of the primary descriptions of the deposit, and so its occurrence remains unconfirmed.

Barite $BaSO_4$

White barite is described as occurring in small amounts in nests or eyes in the siderite with calcite (Herzenberg and Ahlfeld, 1935). Creamy white barite occurs in the West Vein forming clots with siderite, occasionally with interstitial selenides. At both locations it is massive with coarse cleavage blades up to 1 cm.

Calcite $CaCO_3$

Calcite is described as occurring with barite in small amounts in eyes in the siderite (Herzenberg and Ahlfeld, 1935). Scalenohedral calcite crystals were observed in vugs on top of penroseite and with clausthalite and chalcopyrite associated with overgrowths of tellurates (?) (C. Stanley, personal communication).

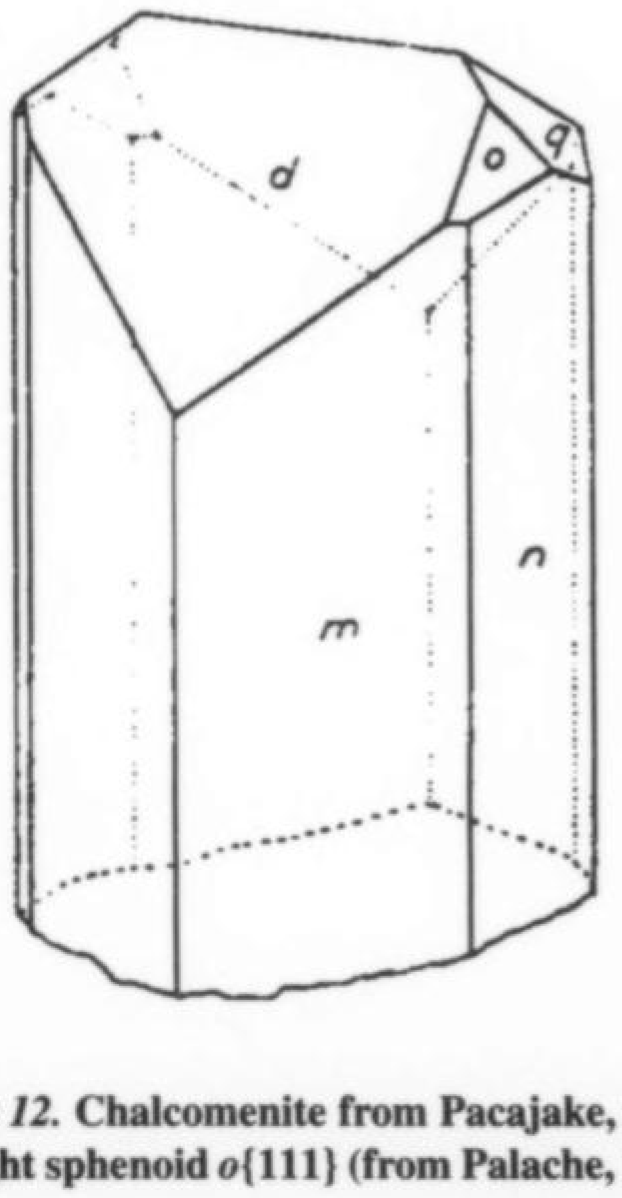


Figure 12. **Chalcomenite from Pacajake, showing right sphenoid *o*{111} (from Palache, 1937).**

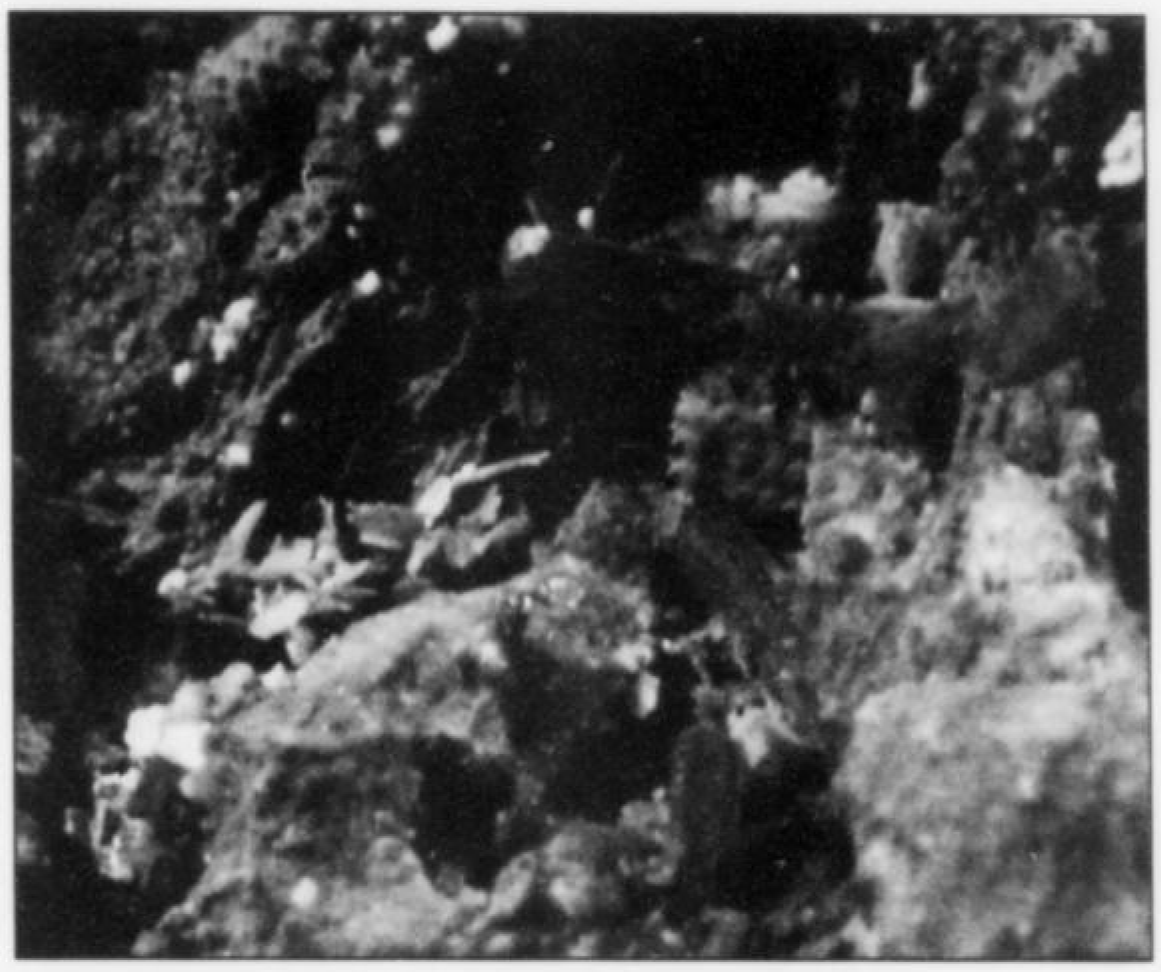
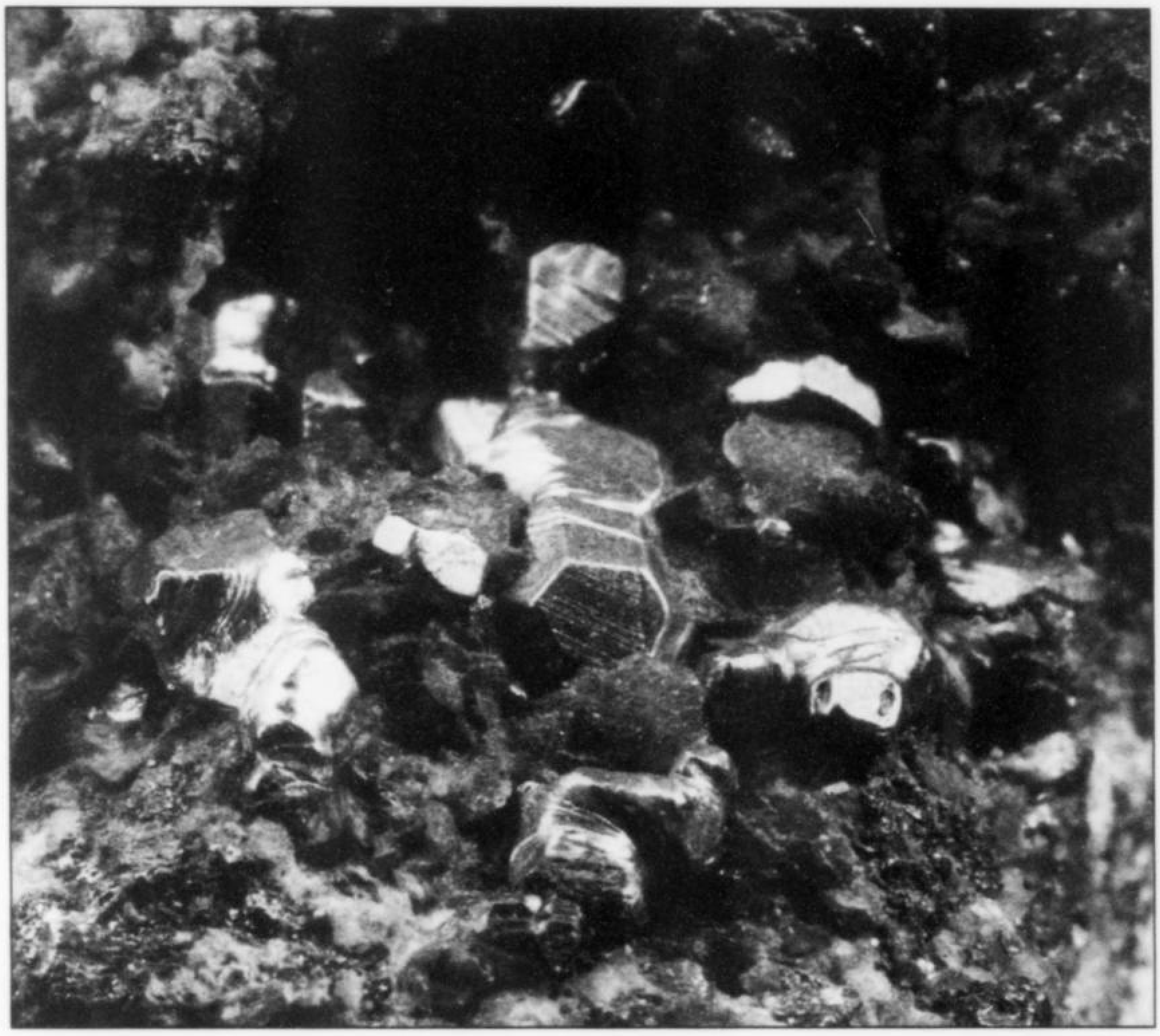


Figure 14. **Blue chalcomenite crystals to 0.5 mm from Pacajake. S. Redwood collection; Wendell Wilson photo.**

Figure 13. **(above) Blue chalcomenite crystals to 0.1 mm from Pacajake; Ahlfeld specimen described by Charles Palache (1937). Harvard Mineralogical Museum specimen no. 92725; Wendell Wilson photo.**

Figure 15. **Clausthalite crystals to 1 mm from Pacajake. Ahlfeld specimen in the Harvard Mineralogical Museum, no. 94984; Wendell Wilson photo.**



Cerussite $PbCO_3$

Cerussite was noted by Gordon (1925) in cavities in penroseite. It was described by Palache (1937) as an acicular, white oxidation product of penroseite, and by Ahlfeld and Muñoz Reyes (1955) as occurring with ahlfeldite, chalcomenite and olsacherite in cavities in decomposed penroseite.

Chalcomenite $CuSeO_3{\cdot}2H_2O$

Chalcomenite is a hydrated copper selenite formed as an oxidation product of penroseite. It was first noted by Block and Ahlfeld (1937) and was described by Palache (1937). It was at the time a rare mineral, the only other then-known locality being Cerro de Cacheuta in Argentina (Ahlfeld and Muñoz Reyes, 1955).

Chalcomenite occurs as acicular crystals up to 3 mm long which are transparent with a blue color and a green tint, on penroseite and cavernous limonite. It occurs alone, in cavities lined with limonite, or with other secondary minerals (cerussite, molybdomenite, cobaltomenite). Crystals are orthorhombic with an acicular habit. It is pleochroic with a glassy luster, has no cleavage, a hardness of just over 2.0 and a specific gravity of 3.35 (Palache, 1937; Ahlfeld and Muñoz Reyes, 1955). It was observed in the West Vein as oblong laths of about 1 mm in length and having a translucent copper sulfate-blue color. It occurs in boxworks and vugs in selenide clots, intergrown with other secondary minerals.

Chalcopyrite $CuFeS_2$

Chalcopyrite was mentioned by Herzenberg and Ahlfeld (1935) as accompanying the selenides. In polished section it is seen to grow on top of clausthalite (C. Stanley, personal communication).

Clausthalite PbSe

Clausthalite was first identified from Pacajake by Block and Ahlfeld (1937). It is the most common selenide after penroseite, and occurs intimately mixed with it. It also occurs rarely as almost pure, coarse-grained masses, and extremely rarely as small, euhedral, cuboctahedral crystals. It is cubic and ductile and looks like galena, with a density of 2.5 to 3 and a specific gravity of 7.6 to 7.8. It gives a strong selenium smell with the blowpipe (Ahlfeld and Muñoz Reyes, 1955). Polished sections show that clausthalite and naumannite cut across earlier-formed penroseite along brittle fractures (C. Stanley, personal communication).

Cobaltomenite $CoSeO_3 \cdot 2H_2O$

Cobaltomenite occurs at Pacajake in solid solution with ahlfeldite; the name cobaltomenite is used when the cobalt content is greater than or equal to the nickel content. The redder color of the mineral indicates higher cobalt. In the early descriptions there was considerable confusion and debate over whether the newly named ahlfeldite (Herzenberg and Ahlfeld, 1935) was, in fact, cobaltomenite, as described from Cacheuta by Bertrand (1882); Block and Ahlfeld (1937) and Ahlfeld and Muñoz-Reyes (1955) both described ahlfeldite as cobaltomenite. Ahlfeld (1941) described cobaltomenite as forming small triclinic crystals with a "*pink the color of peach flower*" on decomposed penroseite, and described it as a selenite of cobalt and nickel which had not yet been studied. This description actually sounds like ahlfeldite, which he does not mention in that paper. Palache (1937) described the presence of cobaltomenite in several druses on samples of penroseite. The ahlfeldite–cobaltomenite series was fully characterized in later studies as described above for ahlfeldite (Goni and Guillemin, 1953; Gattow and Lieder, 1963; Aristarain and Hurlbut, 1969; and Sturman and Mandarino, 1974).

Goethite FeO(OH)

"Limonite," a general term for iron oxides which are mainly goethite and hematite, is described as occurring at all levels of the mine with fresh siderite and fresh penroseite (Block and Ahlfeld, 1937). Goethite pseudomorphs after siderite, forming brown rhombohedral crystals up to 3 mm, were observed lining cavities in penroseite by Gordon (1925). Goethite is described by Dunn *et al.* (1978) as present on many specimens, both as cellular aggregates and as pseudomorphs after siderite.

Gold Au

Gold was reported in concentrates from Pacajake but not in any of the original penroseite-"blockite" analyses, in which it was presumably not assayed (Table 2). Block (1937b) reported 0.01% (100 g/t) Au in selenide vein concentrates (an implied ore grade 10 g/t), and Herzenberg (1945a, b, c) reported 0.1% (1000 ppm) Au in smelted silver from the mine. Selenide samples from the West Vein gave up to 9.7 g/t Au (Table 2). Microscopic native gold inclusions up to 17 microns in penroseite were identified in samples from the West Vein (C. Stanley, personal communication).

Grimaldiite CrO(OH)

Grimaldiite was identified by Livingstone *et al.* (1984) of the Royal Scottish Museum, Edinburgh, on a small purchased specimen of penroseite and barite. The penroseite is coated with a pinkish brown mineral on small cracks and cavities which was identified by X-ray diffraction analysis as grimaldiite. This was only the second discovery ever reported for the species. Within it were minute inclusions of an unidentified lead selenide (Pb 69.4, Bi 0.3, Se 27.9, total 97.6%) and a mercury selenide (Hg 69.8, Se 26.4, Si 0.1, total 96.3%). The authors' description of the locality as the Hiaca mine suggests that it is an old specimen. The grimaldiite is a secondary mineral, and its presence is unusual inasmuch as there is no known precursor.

Hematite Fe_2O_3

Specular hematite is fairly common at Pakajake, occurring with the siderite gangue as small scales having a radial structure (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937). Secondary earthy hematite also forms a coating on the barite-siderite clots and stains the wall-rocks.

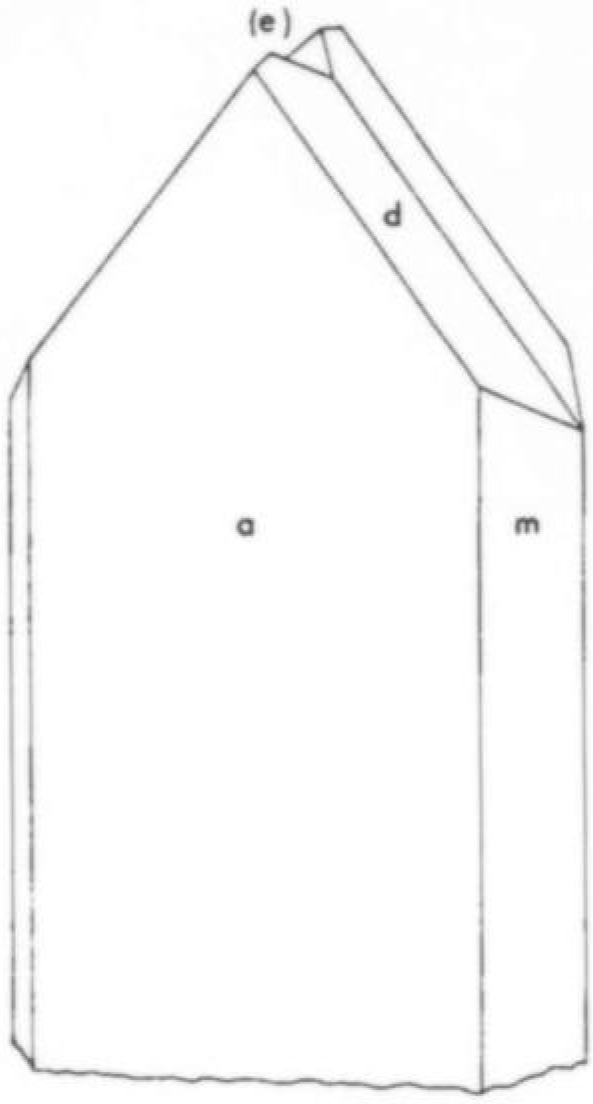


***Figure 16.* Mandarinoite crystal from Pacajake; *a*{100}, *m*{110}, *d*{001}, *e*{011} (from Dunn *et al.*, 1978).**

Mandarinoite $Fe_2(SeO_3)_3 \cdot 6H_2O$

Mandarinoite, a ferric-iron selenite, was identified and named from penroseite specimens in U.S. museum collections by Dunn *et al.* (1978), who gave a full mineralogical description of it. It is named after Dr. Joseph A. Mandarino of the Royal Ontario Museum, in recognition of his work on selenites. This mineral was described by Ahlfeld and Muñoz Reyes (1955, p. 133) as a new, unnamed "hydrated iron selenite" mineral. They described it as rare and occurring in very small amounts, forming thin coatings on sandstone and limonite, sometimes with native selenium. It is colloidal with a reniform to stalactitic habit and a pale apple-green color. In some cases it shows a radial structure with a silky luster on the fibers, which are said to resemble wavellite. There was insufficient material for chemical analysis, but a blowpipe test by Herzenberg indicated that it contained only iron, selenium and water.

Dunn *et al.* (1978) considered mandarinoite to be a probable result of the simultaneous oxidation of penroseite, which contains no iron, and siderite or pyrite. Goethite is present on all of the mandarinoite specimens which they had seen.

Marcasite FeS_2

Marcasite occurs as fine-grained botryoidal masses with a radial

Figure 17. **Olsacherite needles to 0.5 mm, from Pacajake (type specimen). Ahlfeld specimen in the Harvard Mineralogical Museum no. 110966; Wendell Wilson photo.**

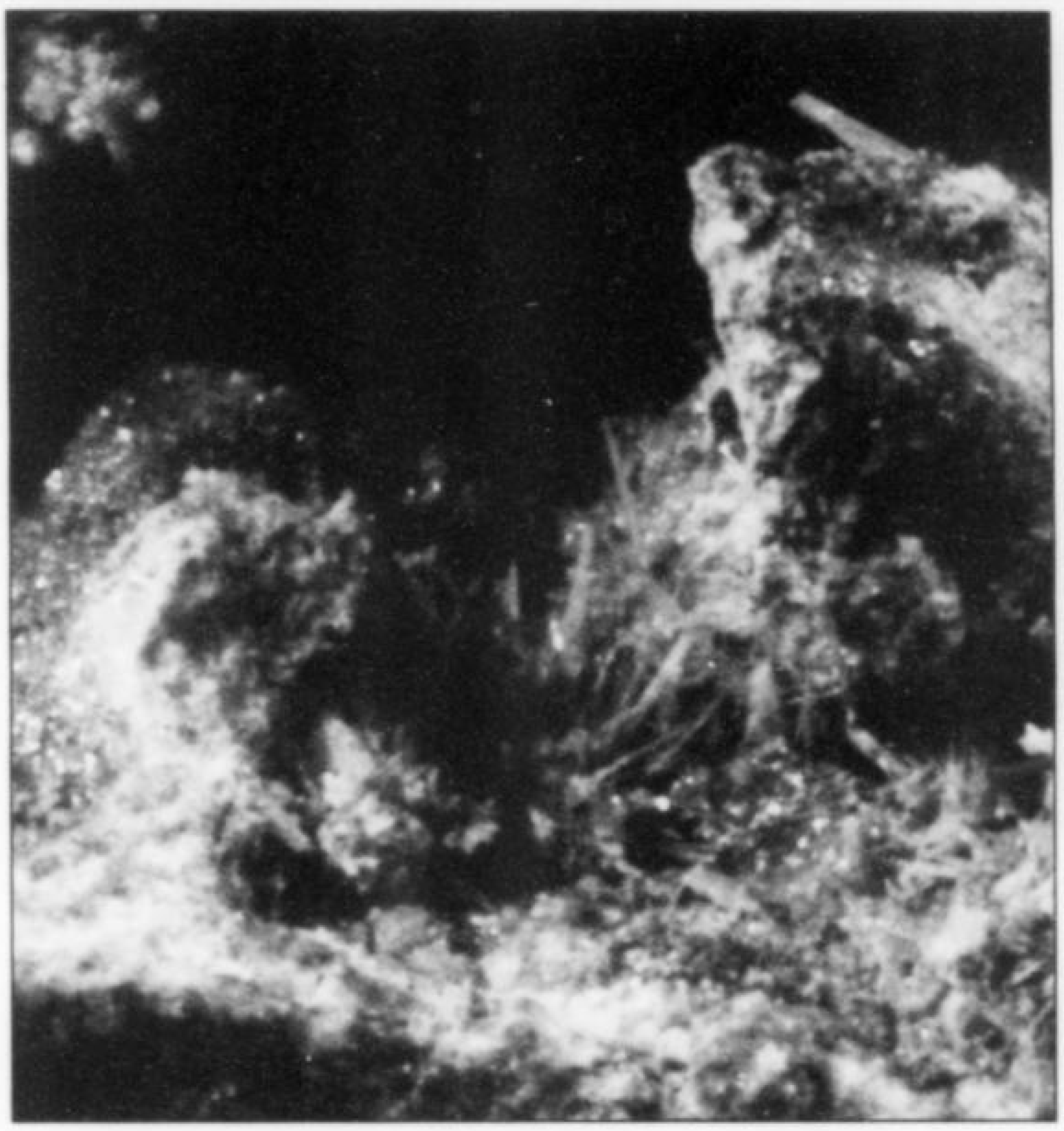


Figure 18. **Olsacherite needles to 0.5 mm, from Pacajake (type specimen). Ahlfeld specimen in the Harvard Mineralogical Museum no. 110966; Wendell Wilson photo.**

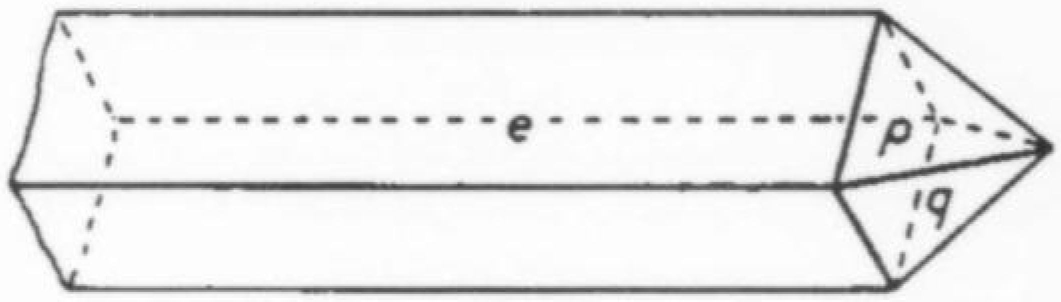


Figure 19. **Olsacherite crystal from Pacajake (Hurlbut and Aristarain, 1969).**

texture which disintegrate rapidly. It is found as coatings up to 1.1 cm thick on some selenide nodules.

Molybdomenite $PbSeO_3$

Originally described from Cacheuta in Argentina by Bertrand (1882), molybdomenite is very rare at Pakajake, where it occurs as an oxidation product of clausthalite. It was identified at Pacajake by Herzenberg, who described it as occurring in white tabular crystals which gave lead and selenium by the blowpipe test, and which could be the same as the molybdomenite from Cacheuta (Block and Ahlfeld, 1937). Palache (1937) also tentatively identified molybdomenite as one of the secondary minerals on penroseite specimens, occurring as white, acicular crystals. A sample from Herzenberg's collection was described as white with a silky luster and a fibrous habit, in thin laminae on limonite and decomposed clausthalite. There was insufficient material for analysis. It is colorless to yellow-white, has a pearly-silky luster and a density of 3.5.

Naumannite Ag_2Se

Naumannite occurs intimately mixed with penroseite and is responsible for the high silver content of the penroseite analyses. It also occurs rarely as small orthorhombic crystals with convex faces in siderite vugs. It has an iron-black color, is ductile and opaque with a metallic luster and is very fragile. It has a hardness of 2 and a specific gravity of 8 (Ahlfeld & Muñoz Reyes, 1955).

The presence of naumannite at Pacajake was first noticed by Herzenberg and Ahlfeld (1935). Gordon (1925) noted the presence of 2 to 3% of an unknown silver selenide. Block and Ahlfeld (1937) reported that it is found in a few samples, coating siderite crystals. They did not consider naumannite to be the most important silver mineral, but rather another unidentified selenide which they could not study thoroughly because it occurred highly disseminated in penroseite. They state that Ramdohr had observed another three unidentified selenides in polished sections. In polished section naumannite occurs intergrown with penroseite and in cross-cutting fractures (C. Stanley, personal communication).

Olsacherite ("selenolite," "kerstenite") $Pb_2(SO_4)(SeO_4)$

Olsacherite is a new mineral described in detail from material from Pacajake in the Ahlfeld Collection at Harvard University by Hurlbut and Aristarain (1969). It was named after Juan A. Olsacher (1903–1964), former Professor of Mineralogy at Córdoba University in Argentina, who studied the selenium minerals of Argentina. Olsacherite is an oxidation product of penroseite and is rare, occurring as well-formed crystals coating the walls of small cracks and cavities. Hurlbut and Aristarain (1969) described it as forming colorless, sharp, fine orthorhombic needles of 0.1 to 1.5 mm length elongated on [010]. It was observed in the West Vein as white acicular crystals up to 1 mm long in boxworks and vugs in selenide clots.

Table 1. **Minerals reported from the Pacajake Deposit.**

Those in bold type are new species first identified from Pacajake. Formulae from Dana's New Mineralogy 8th Edition (Gaines et al., *1997).? indicates uncertainty whether present.*

Primary Minerals	
Native elements	
Arsenic (?)	As
Gold	Au
Selenides	
Clausthalite	PbSe
Naumannite	Ag_2Se
Penroseite (blockite)	$NiSe_2$
Tiemannite	HgSe
Sulfides	
Chalcopyrite	$CuFeS_2$
Marcasite	FeS_2
Pyrite	FeS_2
Carbonates	
Calcite	$CaCO_3$
Siderite	$FeCO_3$
Sulfates	
Barite	$BaSO_4$
Oxides	
Hematite (specularite)	Fe_2O_3
Secondary Minerals	
Native elements	
Selenium	Se
Selenites	
Ahlfeldite	$NiSeO_3 \cdot 2H_2O$
Chalcomenite	$CuSeO_3 \cdot 2H_2O$
Cobaltomenite	$CoSeO_3 \cdot 2H_2O$
Mandarinoite	$Fe_2(SeO_3)_3 \cdot 6H_2O$
Molybdomenite	$PbSeO_3$
Selenates	
Olsacherite	$Pb_2(SO_4)(SeO_4)$
Carbonates	
Cerussite	$PbCO_3$
Hydroxides	
Goethite	FeO(OH)
Grimaldiite	CrO(OH)
Oxides	
Hematite	Fe_2O_3
Molybdates	
Wulfenite (?)	PbMoO

The mineral was first observed at Pacajake by Herzenberg and Ahlfeld (1935) coating ahlfeldite which fills fractures in penroseite. They described it as small white needles, 0.5 to 2 mm long, forming velvety masses, which sublimed with the blowpipe leaving no ash. They thought it could be an oxide of selenium that was first described as minute acicular white crystals from Cacheuta, Argentina by Bertrand (1882), and was subsequently named "selenolite," with the formula SeO_2 by Dana (1892, p. 201). Block and Ahlfeld (1937) repeated this description, and Ahlfeld (1941) described it as small, colorless crystals with a brilliant luster in small geodes coating clausthalite and limonite.

Ahlfeld and Muñoz Reyes (1955) also described the Pakajake material as "selenolite," calling it a hydrated selenium oxide. They observed that it occurs in only a few samples as small, colorless acicular crystals on ahlfeldite and limonite in cavities formed by the weathering of penroseite. They also stated that qualitative analyses by Herzenberg showed only selenium and water, and cited a communication with Professor Palache of Harvard University which indicated that the optical properties differed from those of synthetic selenium oxide. Ahlfeld and Muñoz Reyes (1955) concluded that the Pacajake and Cacheuta minerals are probably identical and that they are a hydrated compound of selenium and not SeO_2. The name "selenolite" was finally rejected for the Bolivian material by Finkelman and Mrose (1977) when they described and named downeyite, the first verified natural occurrence of SeO_2, which had formed from gases given off by burning coal and which had demonstrably different characteristics.

Goni and Guillemin (1953) described a mineral from Pacajake and Cacheuta which they referred to only as an orthorhombic lead selenate and stated that it was impossible to give the mineral a name until the exact nature of "kerstenite," a very poorly described lead selenium mineral, was known. They suggested that this was the same as Ahlfeld's "selenolite." Ahlfeld and Muñoz Reyes (1955) repeated Goni and Guillemin (1953)'s description of the unnamed lead selenite $PbSeO_4$ which they stated *may* be "kerstenite," in addition to a separate description of "selenolite" as mentioned above. Hurlbut and Aristarain (1969) argued that "kerstenite" is an invalid term, and described and named the mineral from Pacajake as olsacherite. They made no reference to the name "selenolite." Finkelman and Mrose (1977) concluded in their excellent review of the name that the olsacherite of Hurlbut and Aristarain (1969), the lead selenate of Goni and Guillemin (1953) and the "selenolite" of Herzenberg and Ahlfeld (1935) appear to be the same mineral (now known as olsacherite), and that the mineral from Cacheuta (Bertrand, 1882) is also olsacherite.

Penroseite $NiSe_2$

Penroseite, the main selenium mineral at Pacajake, occurs as small eyes and pockets in the vein, usually intimately mixed with other selenides. Polished sections show that it is heavily fractured and cemented by clausthalite and naumannite (C. Stanley, personal communication). Pure penroseite has a spherical habit with a radial interior. It is cubic, with a structure analogous to that of pyrite, and a white color similar to that of arsenopyrite. The hardness is 3 and the specific gravity 6.6 to 6.7. Penroseite observed in the West Vein occurs in clots up to 5 cm, has a gray color, hardness of 4 to 5, and a metallic luster. It forms poor to moderately well-developed broad laths up to 1.5 cm long by 4 mm wide arranged in a sub-radial habit, with a hackly to poor planar fracture or cleavage. In some cases it shows an iridescent coating.

There is still some lingering controversy over the priority of the names penroseite and "blockite." In 1925 Samuel Gordon of the Academy of Natural Sciences of Philadelphia described a new mineral which he named "penroseite" in honor of Dr. Richard Alexander Fullerton Penrose Jr. (1863–1931), the well-known Philadelphia mining geologist and benefactor of American geology and mineralogy. He gave it the formula $2PbSe_2 \cdot 3CuSe \cdot 5(Ni,Co)Se_2$ or $PbSe \cdot Cu_2Se \cdot 3(Ni,Co)Se_3$. The specimen was a slightly rounded metallic mass weighing about 1 kilogram which Gordon bought as part of a collection from a merchant in Colquechaca. The collection had been assembled by a local miner named Castellana and had been sold to the merchant by his widow. Gordon wrote that the sample was from the Colquechaca area but that he was uncertain of its exact source; it was probably not from the Colquechaca mine (Gordon, 1925). He believed it to be float from "*some unworked prospect, or undiscovered vein*" (Gordon, 1925). Gordon was in

***Table 2.* Analyses of penroseite, given in percent except for Pt, Pd, Au in ppm.**

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Pb	17.13	0.35	13.72	8.27	10.88	6.35	1.20	8.90	1.56	0.496
Hg		1.95	1.45	1.41	4.12	3.8	1.00	0.57		
Ag	2.04	1.73	2.13	7.78	5.00	0.59	1.10	0.276	0.076	0.0208
Cu	7.84	6.70	4.50	3.55	3.72	6.05	4.80	1.80	0.32	0.034
Fe	1.08	1.29	tr	0.72	0.72	0.35	14.0	14.50		
Co	1.34	2.45	1.10	0.52	0.71	2.1	1.90	0.50	0.1	
Ni	11.14	14.09	8.89	10.30	9.88	14.5	10.00	3.10	0.6	
Se	59.80	69.72	67.01	67.31	66.59	64.6	56.00	17.68	>0.1	
S			0.39	tr	0.52	0.25	2.06			
Pt		220*				1380	450*	8.23	3.287	1.113
Pd						70		11.21	4.282	1.452
Au								3.40	9.737	1.600
Vol						0.15				
Insol		1.28				0.22	2.50			
TOTAL	100.37	99.58	99.19	99.86	102.14	99.10	100.045	47.326		

Blank = not determined. * = total PGM. Vol: = volatiles. Insol. = insoluble.

1. Penroseite, Gordon (1925). Fe as Fe_2O_3. Analyzed by Dr. J. Edward Whitfield.
2. Blockite, Herzenberg & Ahlfeld (1935). Analyzed by Herzenberg. Sample insufficient to determine which PGM. Herzenberg (1945) lists this as platinum in quoting this analysis. Ahlfeld & Schneider Scherbina (1964) wrongly quote this analysis as 0.22% PGE.
3. Penroseite, Bannister & Hey (1937). Sample in British Museum, London, broken from the type specimen, labeled Colquechaca.
4. Blockite, Bannister & Hey (1937). British Museum specimen, labeled Hiaco Mine.
5. Blockite, Bannister & Hey (1937). British Museum specimen, labeled Hiaco Mine.
6. Impure blockite, Herzenberg (1945a, b, c).
7. Hand picked vein concentrate (Block, 1937a, b, c) analyzed by Herzenberg. Total includes 5.50% barite. PGM described as mainly Pd. Quoted as 0.05% (500 ppm) by Block & Ahlfeld (1937).
8. Selenide clot, outcrop of West Vein, sample 29157, Redwood (1993a, Redwood & Garzón 1993). Assayed by Bondar Clegg Ltd. Oruro and Toronto labs.
9. Split of hand sorted concentrate from West Vein (0 to 28.5 m), sample 29196, Redwood (1993a, Redwood & Garzón 1993). Assayed by Bondar Clegg Ltd. Oruro and Toronto labs.
10. Chip sample 0.60 m wide across outcrop of West Vein, sample 52528, Redwood (1993a; Redwood & Garzón 1993). Assayed by Bondar Clegg Ltd. Oruro and Toronto labs. Assay includes 0.176% Zn.

Bolivia on the Third Philadelphia Academy Mineralogical Expedition to Bolivia and Peru of 1925, which is described by Montgomery (1974).

In 1935 Ahlfeld observed an unidentified mineral in specimens of silver ore collected from the landslide at Pacajake by Hans Block's miner in 1922. It was subjected to blowpipe analysis by Herzenberg in Oruro, who identified only nickel and selenium. Block and Ahlfeld visited the mine in April of 1935 and brought back more of the mineral. The new specimens were analyzed by Herzenberg, who proposed the name "blockite" for the new mineral, after the mine owner, in a paper dated May 16, 1935 (Herzenberg and Ahlfeld, 1935).[3] The samples were from a drift very close to the surface; the vein was described as containing 50 to 70% selenides with limonite, in a light colored quartzite. The selenides were very fresh, with a metallic luster, but rapidly turned black on contact with air and water. It was most common in masses with a radial texture. Spherical sections 2 to 10 mm in diameter were common, and showed a concentric structure, very similar to that of native arsenic. They fell to bits easily. The color was very dark gray with some bluish reflections, similar to arsenopyrite, and the streak was black. The hardness was given as 2.5 and the specific gravity as 6.03 to 6.06. They concluded that the general

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[3] Hans Block (1881–1953) was born in Stassfurt (Saxony-Anhalt), Germany on 31 March 1881, the son of Julio Block and Lina Burhaus. Like Ahlfeld, he studied at the University of Clausthal and graduated as an Engineer in Mines and Geology. He emigrated to Bolivia in 1904 at the age of 23, when he was contracted by the Compañia Huanchaca de Bolivia as the Plant Administrator at Huanchaca, the plant for the Pulacayo mine. Thus began his long career in Bolivian mining. He was later Administrator of the Compañia Minera Oruro, General Manager for the Patiño companies in Catavi (1907–1912), Manager of the Empresa Minera y Agrícola Oploca de Bolivia (1914–1917), and Manager of the Compañia Minera Gallofa Consolidada de Colquechaca (1918–1922). During this period of employment at Colquechaca he discovered the unknown mineral at Pacajake. He was also President of the Municipality of Colquechaca in 1921. Subsequently he was Administrator of the Machacamarca plant (1923) and Manager of the Empresa Minera Huanuni. In 1928 he supervised the construction of the Villamontes to Tarija highway, and was later a consultant to the Compañia Minera Mauricio Hochschild. From 1933 he started exploration on his own account, and reopened the Pacajake mine in 1935. His other mines included Lipez Huayco, Amayapampa, Pacopampa, Chaco and Ocuri. In 1945 he became a Professor of the Facultad Nacional de Ingenieria in Oruro, and Dean in 1951. In 1952 he was appointed to the Commission for the Nationalization of the Mines, representing the workers rather than the mine-owners. His final post was as manager of the Corocoro copper mine. He died on 9 August 1953, having built many mines, plants, hospitals, roads, hydroelectric plants, water supplies and other social services in his adopted home country of Bolivia. His son, Hans Block, still resides in Oruro.

formula is RSe_2 where R can be Ag, Hg, Cu, Co, or Ni, but that the mineral is mostly $(Ni, Cu)Se_2$. They also emphasized the high PGE content.

Ramdohr made a detailed structural and microscopic study of the mineral and concluded that copper and cobalt substitute for nickel in the atomic lattice of "blockite." The lead is in clausthalite, the mercury in tiemannite and the PGE in unidentified platinum and palladium selenides. Ramdohr concluded that "blockite" was a new mineral and that "penroseite" was a mixture of "blockite" and other selenides (Herzenberg, 1945; Ramdohr, 1937, 1969, p. 806–807).

Bannister and Hey (1937) of the British Museum in London examined both the original penroseite type material and "blockite" by X-ray and microchemical analyses and concluded that they were the same mineral, and that the name "blockite" could be discarded, for up until then they had been regarded as different minerals. They considered that inclusions of naumannite, recognized optically and by X-ray, caused part of the variation in the silver and lead content, but that penroseite contained combined lead and silver and that "*the true composition of penroseite still remains uncertain*" (Bannister and Hey, 1937).

In 1945 Herzenberg published an impassioned defense of the priority of the name "blockite" (Herzenberg, 1945a, b, c). He was obviously piqued by the description of "his" mineral as "penroseite," with the incorrect formula of $(Ni, Cu, Pb)Se_2$, in the just published seventh edition of *Dana's System of Mineralogy* (Palache *et al.*, 1944). This book was funded, he pointed out, by the Penrose Fund of the Geological Society of America and by the Penrose Fund of the American Philosophical Society, and dedicated, moreover, to Penrose. Gordon and also Bannister and Hey had analyzed impure material, whereas Herzenberg, by luck, had analyzed pure material. Hence Gordon got 17.25% Pb, Bannister and Hey got 8.27% to 13.27% Pb and Herzenberg got 0.36% Pb (Table 2). Herzenberg therefore asserted that the name "penroseite" should not be considered valid because it applied to a mixture, and that the name "blockite" should instead take precedence.

Herzenberg (1945a, b, c) also criticized Bannister and Hey's microanalytical wet chemical method using a 20-mg sample and claiming precision to a few hundredths of a percent. Their analyses, he said, was obviously defective because it showed 20% more selenium than required to combine with all the other metals in their analyses. Herzenberg's two analyses have an excess of 3.45% and a deficit of 0.31% selenium, while Gordon's original analysis had a deficit of only 2.23% selenium.

Despite these arguments, "penroseite" was ultimately the name accepted by the International Mineralogical Association (IMA) and consequently also by most mineralogy treatises, whereas some Bolivian (Ahlfeld and Muñoz Reyes, 1955; Rivas and Ahlfeld, 1998) and German (Ramdohr, 1950, 1969) mineralogists have continued to use the name "blockite." And there the matter rests. My own conclusion is that the "blockite" description was scientifically more accurate and precise, and should clearly have been given precedence by the IMA. It was described and named from a study of pure material by Herzenberg and Ahlfeld (1935). The original analysis and naming of "penroseite" (Gordon, 1925), and the subsequent analyses of "penroseite" and "blockite" (Bannister and Hey, 1937; Herzenberg, 1945a, b) were unquestionably based on impure material which was recognized as such. In the original description of "penroseite" the locality was not known, the crystal system given was wrong (orthorhombic), and the chemical formula was also wrong. The original "blockite" sample was actually collected from the source before the "penroseite" sample of unknown provenance was purchased. Nevertheless, mineralogists worldwide should comply with the decisions of the IMA for the sake of international consistency, and should submit formal proposals for changes in nomenclature to the IMA Commission on New Minerals and Mineral Names whenever they believe a past error such as this needs correcting. Perhaps that will be done some day with regard to "penroseite," and "blockite" will officially be granted the status it deserves.

Platinum-Group Metals

Platinum-group metals (PGM) occur in high amounts in analyses of penroseite and selenides (Table 2), with values of 0.022% (220 g/t) PGM in pure penroseite; 0.045% (450 g/t) PGM in concentrate; and 0.138% (1,380 g/t) platinum with 0.007% (70 g/t) palladium in impure penroseite. In addition an assay of smelted silver reported 0.4% (4,000 g/t) Pd, 0.2% (2,000 g/t) Pt and 0.1% (1,000 g/t) Au (Herzenberg, 1945a, b, c). Platinum-group metals were not assayed for in the other samples. The PGM content of selenide samples from the West Vein is up to 8.23 g/t Pt and 11.21 g/t Pd (Table 2).

Block and Ahlfeld (1937) ascribe the PGM assay of 450 g/t in concentrate to a hypothetical a palladium selenide "*whose microscopic grains are disseminated in all the minerals.*" A search of PGM-rich samples from the West Vein by microscope and electron microprobe failed to detect any PGM-bearing minerals. The platinum-group metals are suspected to occur dissolved in penroseite or naumannite in quantities too low to be detected by microprobe (C. Stanley, personal communication).

Pyrite FeS_2

Most of the pyrite in early descriptions is actually marcasite. Pyrite also occurs in small amounts in fractures in the wall rock (Block and Ahlfeld, 1937).

Quartz SiO_2

The presence of quartz is mentioned only by Dunn *et al.* (1978). It is not described in any other papers on Pacajake nor was it observed associated with selenide veins in the present study. Quartz veinlets are present in the area of the deposit and may belong to a separate mineralizing event. Socavon San Miguel is driven along a quartz veinlet.

Selenium Se

Herzenberg (1944) thought the red-brown coating on ahlfeldite, which was removed by nitric acid, to be amorphous selenium formed by oxidation of ahlfeldite on exposure to air, however, there is no evidence to support this speculation. Pacajake was described as the only known locality in the world for native selenium by Ahlfeld and Muñoz Reyes (1955, p. 20); they seem to have been unaware of the 1934 description by Palache of native selenium crystals to 2 cm from the United Verde mine in Jerome, Arizona, or Ahlfeld and Muñoz Reyes may not have considered the Jerome mine fire minerals to be valid natural species. They stated that selenium is an oxidation product of penroseite and that it was studied by Ramdohr (1950). It is only visible in polished section and is easily identified by its strong anisotropy. It forms striated crystals and colloidal structures in limonite. Ramdohr (1969) described the optical properties of native selenium and mentions Pacajake. He stated that the paragenesis of native selenium is most widespread as a weathering product of natural selenides, especially clausthalite, where it is associated with cerussite and others (Ramdohr, 1937). Ahlfeld (1941) and Ahlfeld and Muñoz Reyes (1955) quoted Ramdohr's studies of native selenium and said that it had formed at Pacajake by the oxidation of clausthalite and occurs as dark gray needles and colloidal masses in limonite, visible only under the microscope.

Siderite $FeCO_3$

Siderite is the main gangue mineral at Pacajake. It is coarse-grained, sometimes forming crystals in vugs; selenides sometimes occur in pockets in the siderite (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937.) In the West Vein, siderite and barite form clots with interstitial selenides. The siderite is brown and massive with cleavage blades up to 1 cm.

Tiemannite HgSe

Tiemannite, identified at Pacajake by Herzenberg, occurs intimately mixed with penroseite and is responsible for the high mercury content of the penroseite. It occurs in rare compact masses of a dark gray color, sometimes associated with clausthalite. Crystals are very rare. It has an irregular fracture, a hardness of 2.5 and a specific gravity of 8.3, with a metallic luster (Ahlfeld and Muñoz Reyes, 1955).

Wulfenite $PbMoO_4$

Block and Ahlfeld (1937) noted pale yellow tabular crystals from Pacajake, which they described as being similar in appearance to wulfenite, but which were not studied.

Zinc Minerals

Zinc is strongly anomalous in some assays of selenide clots, with grades up to 0.176% (Table 2), although it has generally not been assayed. Surface samples of mineralized float from old dumps and outcrops with iron staining and limonitic fractures assay up to 0.150% and 0.046% Zn respectively. No zinc minerals have been recognized at Pacajake and it may occur as a selenide (e.g. stilleite) or sulfide (sphalerite); zinc oxide minerals may also be expected.

PARAGENESIS

The Pacajake deposit has a three-stage paragenesis. The selenides formed first and are dominated by penroseite (Ni-Co), which is fractured and cut by veinlets of clausthalite (Pb), naumannite (Ag) and tiemannite (Hg). Native gold occurs as inclusions in penroseite. The selenides contain high amounts of platinum-group metals but no PGM-bearing minerals have been identified and the PGM are presumed to substitute in the penroseite and naumannite crystal structures.

The gangue minerals, formed after the selenides, include sulfides (minor chalcopyrite, marcasite), carbonates (siderite, calcite), sulfates (barite) and oxides (specular hematite).

The final stage of paragenesis was supergene oxidation which formed a variety of secondary minerals lining boxworks and vugs in the selenide clots. Goethite and hematite formed by oxidation of siderite and sulfides, and occur with fresh penroseite which is evidently more resistant to weathering. Oxidation of penroseite gave rise to ahlfeldite (Ni), cobaltomenite (Co) and chalcomenite (Cu), while clausthalite gave the secondary lead minerals cerussite, molybdomenite, olsacherite and perhaps also wulfenite. Mandarinoite formed with iron from sulfides or siderite and selenium from the selenides, and native selenium also formed from the selenides. Elements which have no known hypogene precursor mineral are the chromium in grimaldiite and the molybdenum in wulfenite. No secondary silver and mercury minerals have been identified, although their existence may be expected.

The hypogene paragenesis shows a trend from selenides with native Au and PGM, to later sulfides, carbonates, sulfates and oxides. The Pacajake deposit is epigenetic and fault-controlled and was formed by a low temperature, acidic, hydrothermal fluid with high oxygen and selenium fugacities and a low sulfur fugacity. There are no intrusions or volcanic rocks nearby; the ore-forming fluid is considered to have been of meteoric or basinal brine origin. Pacajake has a geochemical association of Se, Ni, Co, Cu, Pb, Ag, Fe, Ca, Ba, Cr, Bi, Hg, Zn, Mo(?), Au, Pt and Pd. It is probable that the metals were derived from the Lower Paleozoic black shales. Pacajake belongs to the epithermal gold-selenide category of Lindgren (1928), and has been classified as a telethermal selenide vein by Simon *et al*. (1997), with the temperature of formation of this group constrained by phase stability relations to below the interval 133 to 112°C.

The Pacajake deposit has similarities to various deposits in South America, England, Germany and Australia. Similar deposits in South America include El Dragón, which is 135 km to the south of Pacajake (Grundmann *et al*., 1990), and the Cerro Cachito, Sañogasta, Tinogasta, Cerro Chusco–Los Llantenes and Cerro Cacheuta selenide occurrences in the Frontal Cordillera of Argentina (Catamarca, La Rioja and Mendoza Provinces) some 1,000 km further south (Ahlfeld and Angelelli, 1948). These deposits differ from Pacajake in being dominated by copper selenides. Pacajake is also similar to the Hope's Nose (Devon, England) selenide occurrence (Stanley *et al*., 1990) and to the classic selenide veins of the Harz Mountains (Germany), such as Tilkerode, Charlotte (Clausthal), Trogtal, Zorge, Corbach and Lerbach, in which clausthalite dominates (Ramdohr, 1969, p. 649–650; Tischendorf, 1959). As a historical connection, both Federico Ahlfeld and Hans Block studied at the mining school in Clausthal in the heart of this well-known mining region.

Palladian gold associated with selenide minerals in veins in Devon (Stanley *et al*., 1990) and in widespread alluvial gold grains in Devon (Leake *et al*., 1991) and Scotland (Leake *et al*., 1998) is modeled to have originated by downward movement of oxidizing solutions circulating in the Permian red-bed basins and the reaction of these with more reduced solutions below the unconformity. A similar model has been proposed for the Coronation Hill Au-Pt-Pd-(Se-Sb±U) deposit in the Paleoproterozoic Pine Creek inlier of the Northern Territory of Australia (Mernagh *et al*., 1994). The deposit is similar to unconformity-related uranium deposits elsewhere in the region where the precious metal (±U) mineralization occurs below a major unconformity. Mineralization occurred by reaction of highly oxidized, acidic basin brines with feldspathic and reducing rocks in the crystalline basement at a temperature of around 140°C.

The mineralization at Pacajake is believed to be of Mesozoic age but is not well constrained. The host Ordovician sediments were folded in the Late Devonian to Early Carboniferous Hercynian Orogeny, and the low-temperature, near-surface style of mineralization indicates that it formed after erosion and exhumation of the fold belt. The mineralizing fluids may have been basinal brines and hence related to Late Jurassic to lower Tertiary continental red-bed sediments in the region.

CONCLUSION

The Pacajake selenide deposit has a three-stage paragenesis of selenides with platinum group metals and native gold, followed by sulfides, carbonates, sulfates and oxides. The third stage was supergene oxidation which formed a variety of selenites, selenates and other secondary minerals.

The mineralization is fault-controlled and is hosted by Ordovician sandstones and quartzites. It is epithermal and formed at low temperature from an acidic fluid with high oxygen and selenium fugacities. The fluid is interpreted to have been a basinal brine related to Mesozoic continental red-bed sediments, with transport of the metals by oxidizing solutions in the red-beds and deposition by reduction with the underlying Lower Paleozoic sediments and fluids. Hence the age of mineralization is believed to be Mesozoic. Widespread hematitization and local silicification and quartz veining of the sediments support an unconformity model. The unusual metal association of Se, Ni, Co, Cu, Pb, Ag, Fe, Ca, Ba, Cr, Bi, Hg, Zn, Au, Pt, Pd and Mo(?) was probably derived from the Lower Paleozoic metalliferous black shales.

Our work in the field strongly suggests that only one vein at Pacajake contained significant selenium, that all accessible portions of the vein are essentially worked out, and that some areas of the mine and vein system no longer exist because of landslides in the Pacajake area. Consequently the Pacajake mine should probably be considered an extinct locality, and it is extremely unlikely that anyone will ever again visit this remote site in the high Andes with the intent of searching or mining for more selenide minerals. Existing specimens in museums and private collections should be valued accordingly.

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REFERENCES

AHLFELD, F. (1941) El Yacimiento de selenio de Pacajake. *Ministerio de la Economía Nacional Boletín Informativo*, La Paz, Bolivia, **1**, (2), 23–28.

AHLFELD, F. (1954) *Los Yacimientos Minerales de Bolivia*. Imprenta Industrial, Bilbao, Spain, for Banco Minera de Bolivia and Corporación Minera de Bolivia, 277 p.

AHLFELD, F., and ANGELELLI, V. (1948) *Las Especies Minerales de la Republica de Argentina*. Universidad del Tucumán, Argentina, Instituto de Mineralogia y Geologia Yacimientos Minerales, Publicación No. **458**, 304 p.

AHLFELD, F., and MUÑOZ REYES, J. (1955) *Las Especies Minerales de Bolivia*. La Paz, Bolivia, Banco Minero de Bolivia, 3rd edition, 180 p.

AHLFELD, F., and SCHNEIDER-SCHERBINA, A. (1964) Los yacimientos minerales y de hidrocarburos de Bolivia. La Paz, Bolivia. *Departamento Nacional de Geología, Boletín No.* **5** (Especial), 388 p.

ARISTARAIN, L. F., and HURLBUT, C. S., Jr. (1969) Ahlfeldite from Pacajake, Bolivia; a restudy. *American Mineralogist*, **54**, 448–456.

AVILA SALINAS, W. A. (1982) Homenaje Postuma a Federico Ahlfeld (1892–1982). La Paz, Servicio Nacional de Geologia y Mineria (SERGEOMIN), unpublished report, 5 p.

BANNISTER, F. A., and HEY, M. H. (1937) The identity of penroseite and blockite. American Mineralogist, **22**, 319–324.

BARBA, A. A. (1637) *Arte de los Metalos*. Madrid, 1640. English translation by DOUGLASS, R. E., and MATHEWSON, E. P. (1923) John Wiley & Sons Inc., New York, Chapman & Hall Ltd., London.

BARTH, W. (1983) Nachruf Friedrich Ahlfeld 6.10.1982–9.1.1982. *Zentralblatt für Geologie und Paläeontologie, Teil I: Allgemeine, Angewandte, Regionale und Historische Geologie*, **3–4**, 187–189.

BERTRAND, E. (1882) Sur la molybdoménite (sélénite de plomb), la cobaltoménite (sélénite de cobalt) et l'acide sélénieux de Cacheuta (La Plata). *Bulletin de la Société minéralogique de France*, **5**, 90–92.

BLOCK, H. (1937a) Los Yacimientos de Selenio de Pacajake, Bolivia. Unpublished report, Oruro, 8 April 1937, 4 p.

BLOCK, H. (1937b) Das Selenvorkommen von Pacajake in Bolivien. *Metall und Erz*, **34**, 237–238.

BLOCK, H. (1937c) Brief report on discovery of platinum-selenium ore at Pacajake, Bolivia. Unpublished report, Santiago 11 August 1937, and Oruro 21 February 1939, 7 p.

BLOCK, H., and AHLFELD, F. (1937) Die Selenerzlagerstätte Pacajake, Bolivia. *Zeitschrift für praktische Geologie*, **45**, 9–14.

DANA, E. S. (1892) *A System of Mineralogy*. 6th edition.

DANIELI, C. (1986) Dr. Federico Ahlfeld, 1892–1982. *Revista del Instituto de Geologia y Mineria*. Instituto de Geologia y Mineria, Universidad Nacional de Jujuy, San Salvador de Jujuy, Argentina, **6**, 261–264.

DUNN, P. J., PEACOR, D. R., and STURMAN, B. D. (1978) Mandarinoite, a new ferric-iron selenite from Bolivia. *Canadian Mineralogist*, **16**, 605–609.

FINKELMAN, R. B., and MROSE, M. E. (1977) Downeyite, the first verified natural occurrence of SeO_2. *American Mineralogist*, **62**, 316–320.

FLEISCHER, M. (1946) New data, Ahlfeldite. *American Mineralogist*, **31**, 86 (Abs. of Herzenberg, 1945d).

FLEISCHER, M. (1963) New data, ahlfeldite, cobaltomenite. *American Mineralogist*, **48**, 1183 (Abs. of Gattow and Leider, 1963).

GAINES, R. V., SKINNER, H. C. W., FOORD, E. E., MASON, B., and ROSENZWEIG, A. (1997) *Dana's New Mineralogy. The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana*. Eighth Edition. New York, etc., John Wiley & Sons, 1819 pp.

GATTOW, G., and LIEDER, O. J. (1963) Über Ahlfeldit und Cobaltomenit. *Naturwissenschaften*, **50**, 333–334.

GONI, J., and GUILLEMIN, C. (1953) Données nouvelles sur les sélénites et séléniates naturels. *Bulletin de la Société française de minéralogie et de cristallographie*, **76**, 422–429.

GORDON, S. G. (1925) Penroseite and trudellite: two new minerals. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **77**, 317–324.

GRUNDMANN, G., LEHRBERGER, G., and SCHNORRER-KÖHLER, G. (1990) The El Dragón Mine, Potosí, Bolivia. *Mineralogical Record*, **21**, 133–146.

HERZENBERG, R. (1944) Ahlfeldita, un nuevo mineral de Bolivia. Notas sobre la cobaltomenita. *Boletín de la Facultad de Ciencias Exactas, Físicas y Naturales, Universidad de Cordoba*, Argentina, **7** (4), 1–4.

HERZENBERG, R. (1945a) Blockita versus Penroseita en el nuevo "Dana's System." *Mineria Boliviana*, **2** (24), 11–14.

HERZENBERG, R. (1945b) Blockita versus Penroseita en el nuevo "Dana's System." *Boletín de la Sociedad Geografica de La Paz*, **68**, 180–189.

HERZENBERG, R. (1945c) Blockita versus Penroseita en el nuevo "Dana's System." *Mineraçao e Metalurgia*, **10** (57), 1945, 141–143.

HERZENBERG, R. (1945d) Ahlfeldita un nuevo mineral de Bolivia. *Mineria Boliviana*, **3** (25), 11–12.

HERZENBERG, R. (1947) Ahlfeldita un nuevo mineral de Bolivia. *Mineraçao e Metalurgia*, **12** (67), 27.

HERZENBERG, R., and AHLFELD, F. (1935) Blockit, ein neues Selenerz aus Bolivien. *Zentralblatt für Mineralogie, Geologie und Paläontologie, Abteilung A, Mineralogie and Petrographie*, 277–279.

HURLBUT, C. S., Jr., and ARISTARAIN, L. F. (1969) Olsacherite, $Pb_2(SO_4)(SeO_4)$, a new mineral from Bolivia. *American Mineralogist*, **54**, 1519–1527.

LEAKE, R. C., BLAND, D. J., STYLES, M. T., and CAMERON, D. G. (1991) Internal structure of Au-Pd-Pt grains from South Devon, England, in relation to low temperature transport and deposition. *Transactions of the Institute for Mining and Metallurgy, Section B, Applied Earth Sciences*, **100**, 159–178.

LEAKE, R. C., CHAPMAN, R. J., BLAND, D. J., STONE, P., CAMERON, D. G., and STYLES, M. T. (1998) The origin of alluvial gold in the Leadhills area of Scotland: evidence from interpretation of internal chemical characteristics. *Journal of Geochemical Exploration*, **63**, 7–36.

LINDGREN, W. (1928) *Mineral Deposits*. 3rd edition, New York, McGraw-Hill, 1049 p.

LIVINGSTON, A., JACKSON, B., and DAVIDSON, P. J. (1984) Grimaldiite, CrOOH, a second occurrence, from the Hiaca mine, Colquechaca, Bolivia. *Mineralogical Magazine*, **48**, 560–562.

MERNAGH, T. P., HEINRICH, C. A., LECKIE, J. F., CARVILLE, D. P., GILBERT, D. J., VALENTA, R. K., and WYBORN, L. A. I. (1994) Chemistry of Low-Temperature Hydrothermal Gold, Platinum, and Palladium (±Uranium) Mineralization at Coronation Hill, Northern Territory, Australia. *Economic Geology*, **89**, 1053–1073.

MONTGOMERY, A. (1974) An American Mineralogist Part V. *Mineralogical Record*, **5**, 160–166.

OLSACHER, J. A. (1939) Achavalita, seleniuro de hierro. Nueva especie mineral. *Boletín de la Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Cordoba*, Argentina, **2** (3–4), 73–78.

PALACHE, C. (1934) Contributions to crystallography: claudetite, minasragrite, samsonite, native selenium, iridium. *American Mineralogist*, **19,** 194–205.

PALACHE, C. (1937) Chalcomenite from Bolivia. *American Mineralogist*, **22**, 790-795.

PALACHE, C., BERMAN, H., and FRONDEL, C. (1944) *Dana's System of Mineralogy*. Seventh Edition, New York, John Wiley & Sons, Inc.

RAMDOHR, P. (1935) Zwei neue Mineralien. *Zentralblatt für Mineralogie, Geologie und Paläontologie, Abteilung A, Mineralogie und Petrographie*, 189.

RAMDOHR, P. (1937) Erzmikroskopische Untersuchungen an einigen seltenen oder bisher wenig beachteten Erzmineralen. Teil 1–3, *Zentralblatt für Mineralogie* A, 193–211, 289–303.

RAMDOHR, P. (1950) *Die Erzmineralien und ihre Verwachsungen*. Berlin.

RAMDOHR, P. (1969) *The Ore Minerals and their Intergrowths* Oxford etc., Pergamon Press, 1174 p.

REDWOOD, S. D. (1991) The Virgen de Surumi (Pacajakes) Selenium—Precious Metals Deposit, Bolivia. La Paz, unpublished report for Mintec, 6 p.

REDWOOD, S. D. (1993a) The Pacajake Selenium—Precious Metals Deposit, Potosi, Bolivia: Progress Report as of April 1993. La Paz, unpublished report for Mintec, 10 p.

REDWOOD, S. D. (1993b) The Metallogeny of the Bolivian Andes, 120 p. *In:* SILLITOE, R., CAMUS, F., MPODOZIS, C., and REDWOOD, S. D., *Metallogeny of the Central Andes*. Vancouver, Canada, Mineral Deposit Research Unit, University of British Columbia, Short Course No. **15**.

REDWOOD, S. D. (2002) Dr. Federico Ahlfeld (1892–1982), The Father of Bolivian Geology. *Mineralogical Record*, **34**, 225–233.

REDWOOD, S. D., and GARZON, D. (1993) The Pacajake Selenium—Precious Metals Deposit, Potosi, Bolivia: Progress Report, July–September 1993. La Paz, unpublished report for Mintec, 12 p.

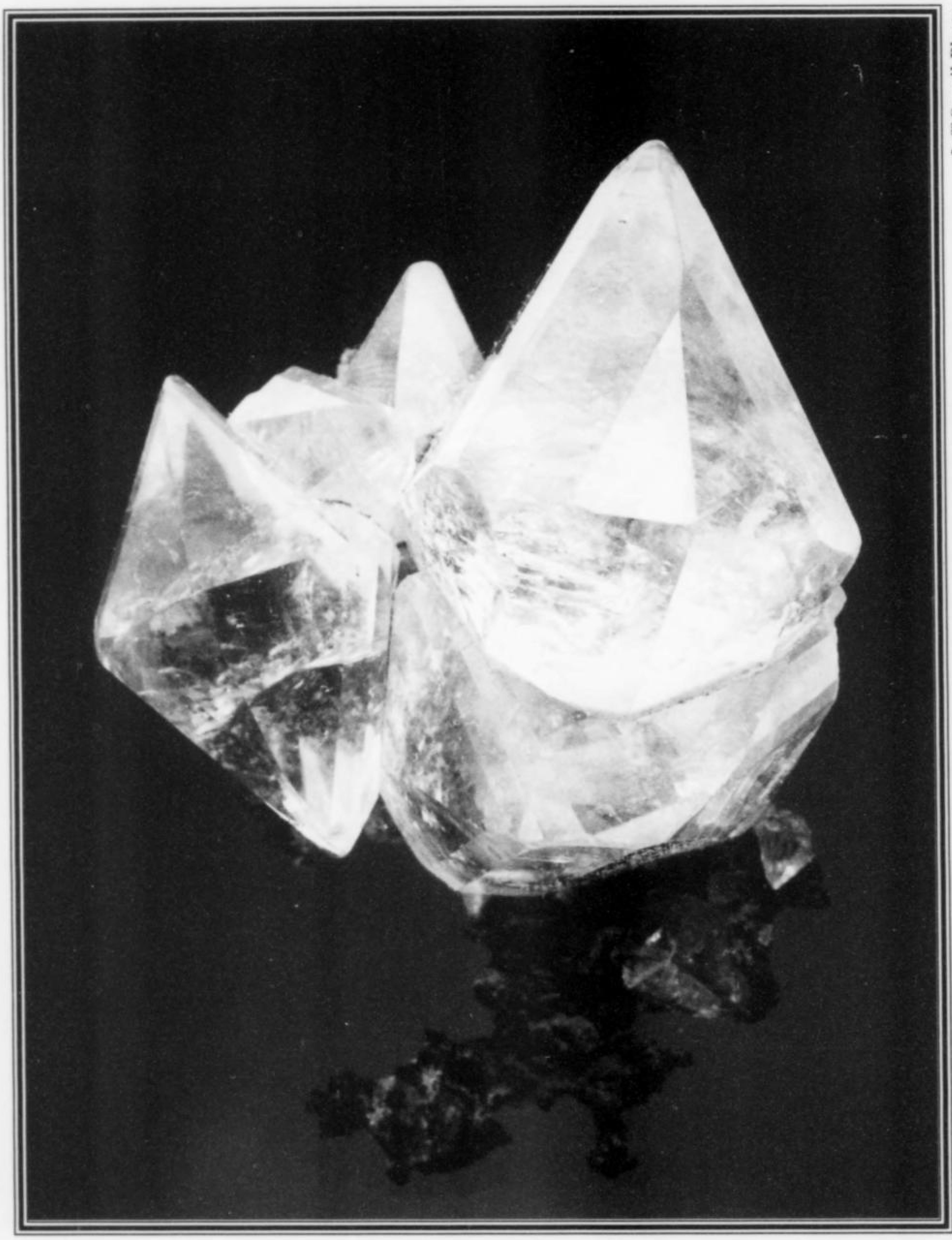
RIVAS, S., and AHLFELD, F. (1998) *Los Minerales de Bolivia y sus Parajes*. Bolivia, Santa Cruz de la Sierra, 2 vols, 629 p.

SIMON, G., KESLER, S. E., and ESSENE, E. J. (1997) Phase relations among selenides, sulfides, tellurides, and oxides: II. Applications to selenide-bearing ore deposits. *Economic Geology*, **92**, 468–484.

STANLEY, C. J., CRIDDLE, A. J., and LLOYD, D. (1990) Precious and base metal selenide mineralization at Hope's Nose, Torquay, Devon. *Mineralogical Magazine*, **54**, 485–493.

STURMAN, B. D., and MANDARINO, J. A. (1974) The ahlfeldite-cobaltomenite series. *Canadian Mineralogist*, **12**, 304–307.

TISCHENDORF, G. (1959) Zur Genesis einiger Selenidvorkommen insbesondere von Tilkerode im Harz. *Freiberger Forschungshefte*, **C 69**, 1–168.



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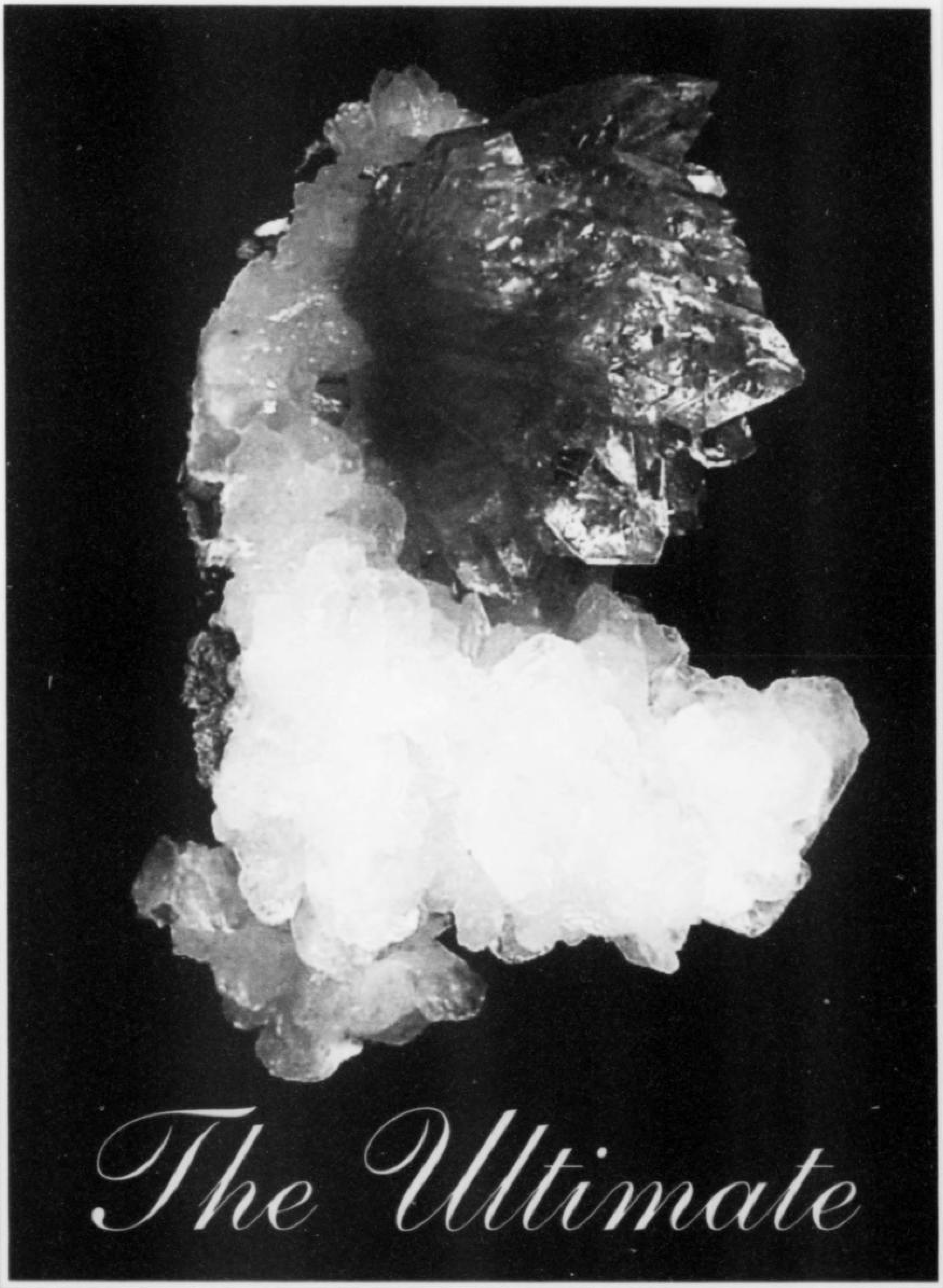
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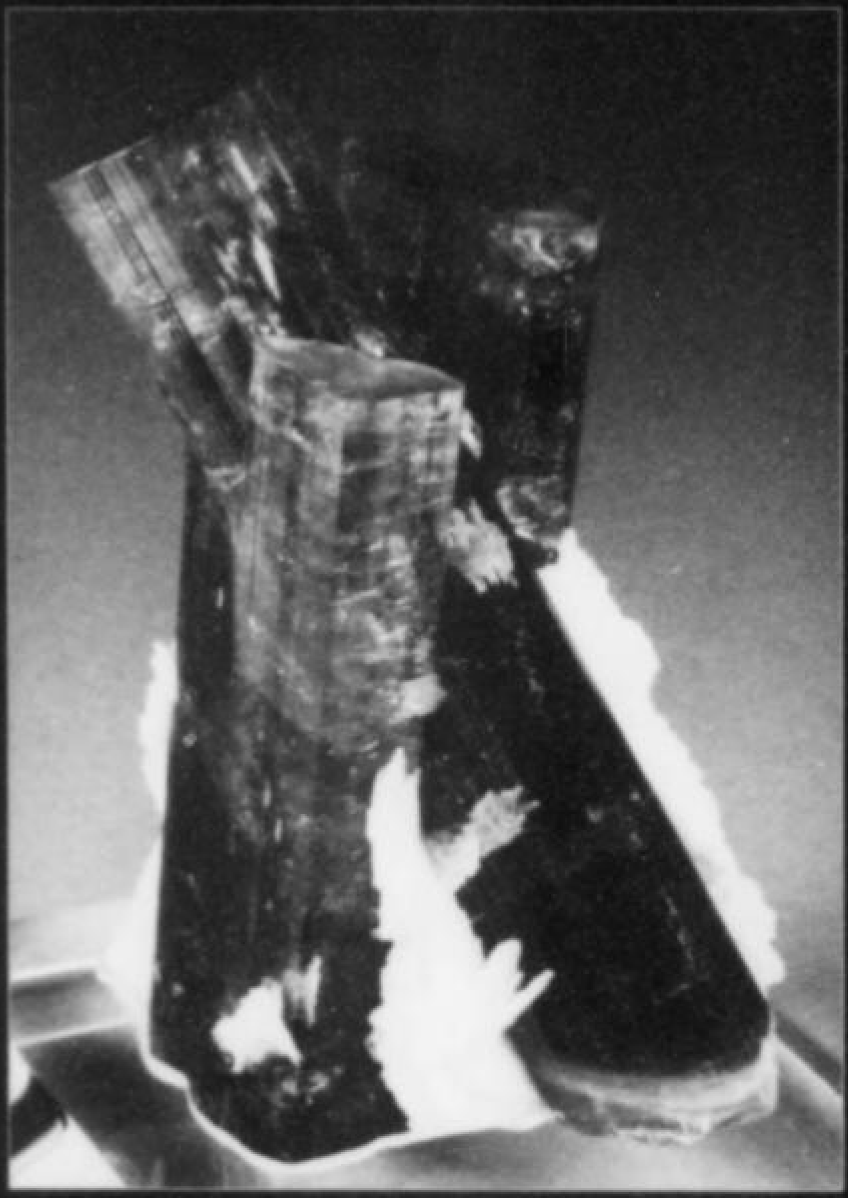

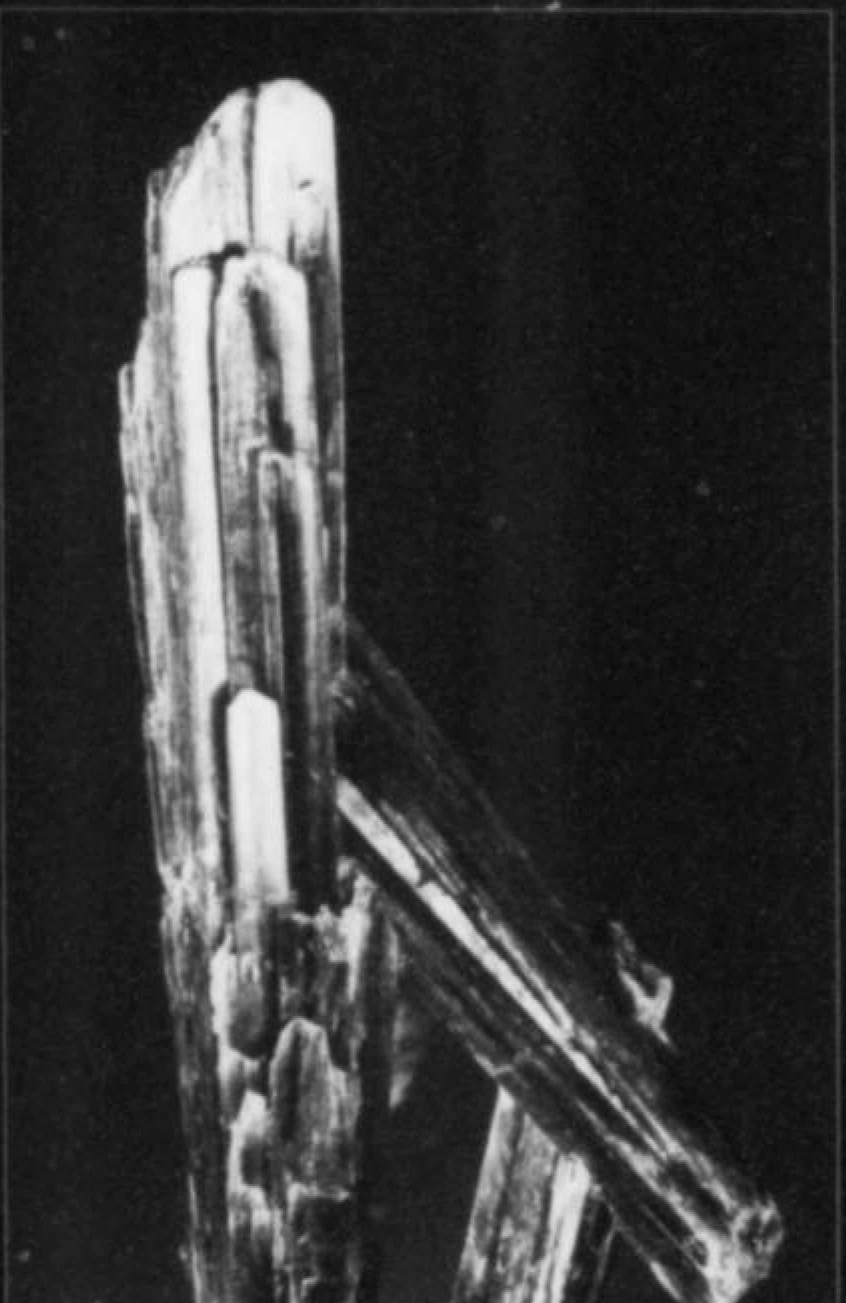

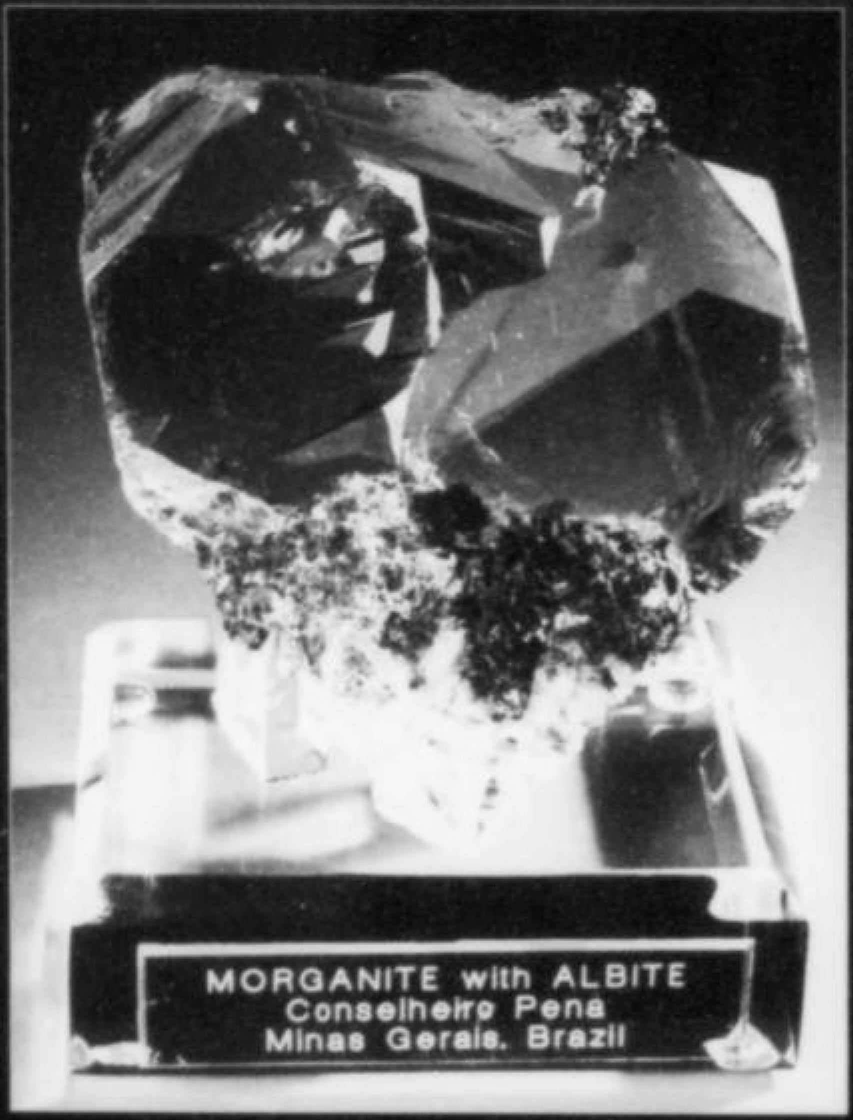
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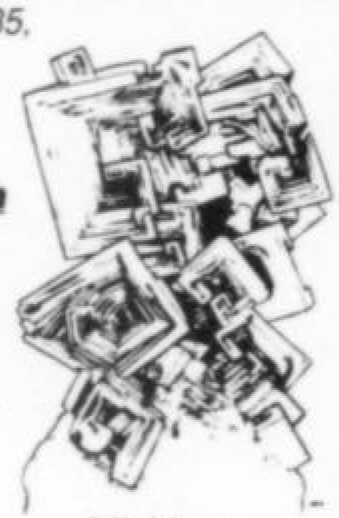
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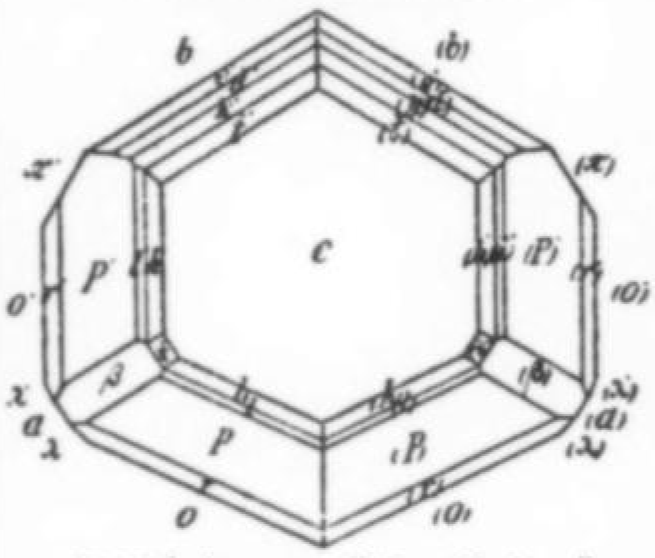
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- Compiling and publishing information on mineral localities, and important mineral collections.
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- Support a semi-professional journal of high excellence and interest designed to appeal to mineral amateurs and professionals, through which *FM* activities may be circulated.
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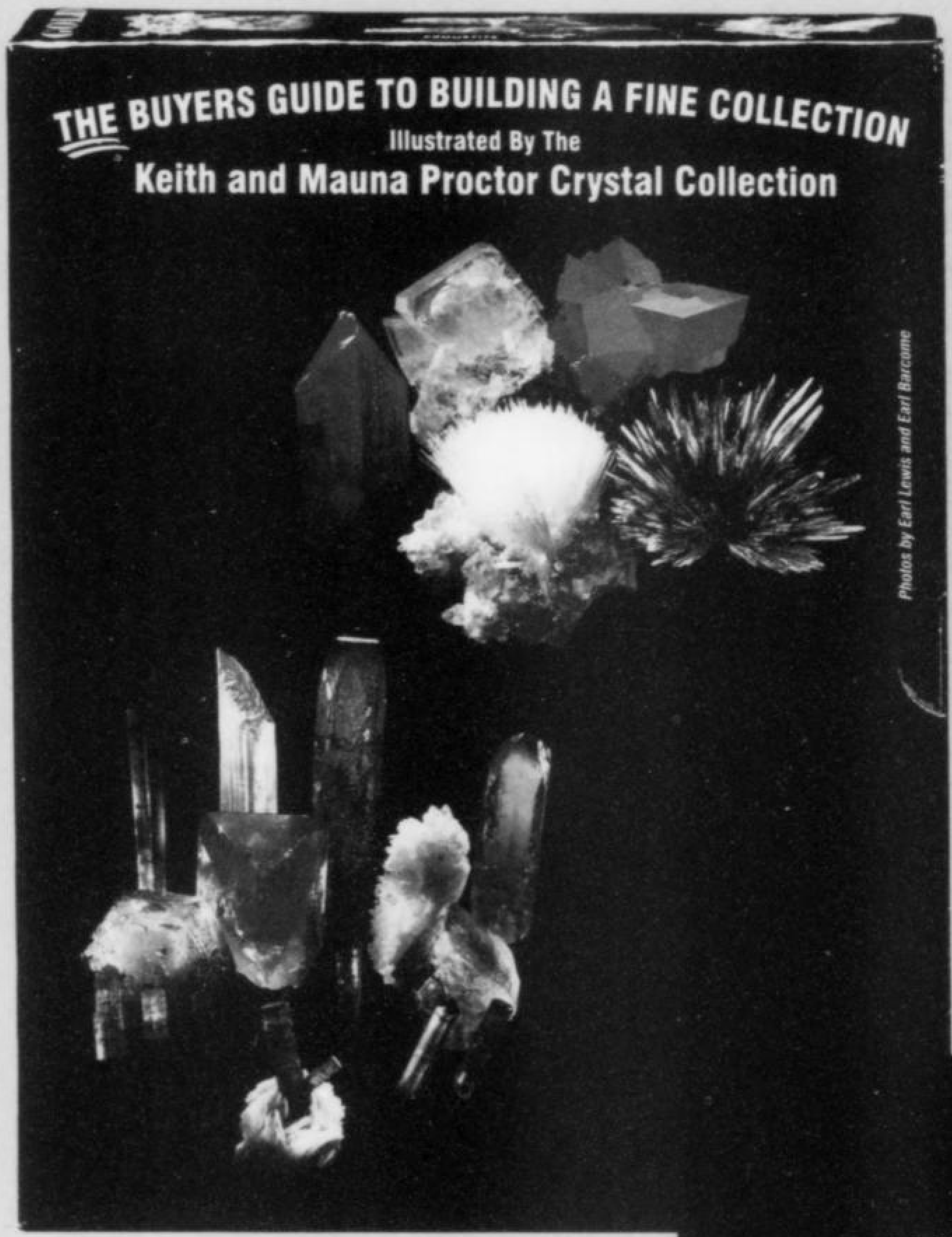

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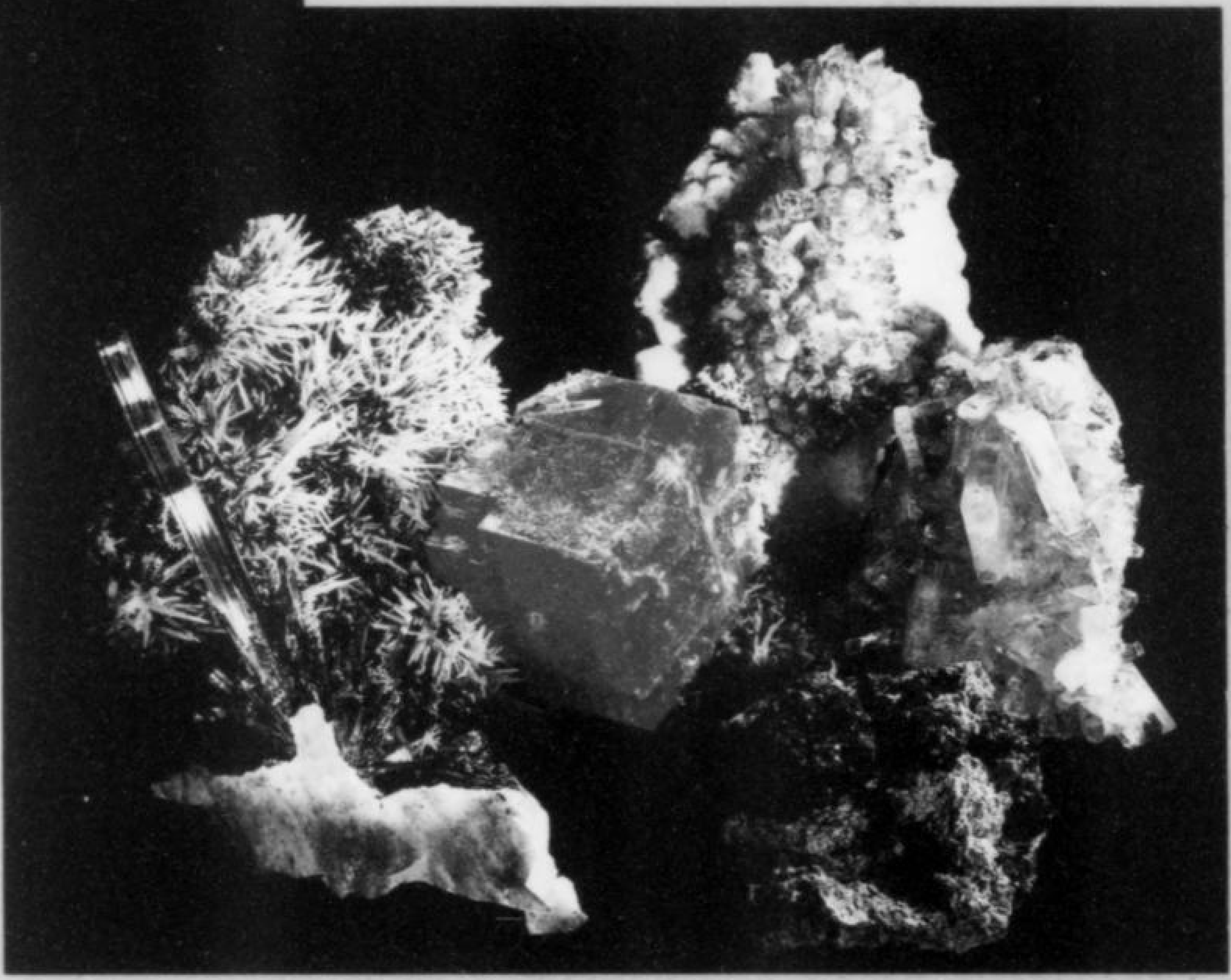

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