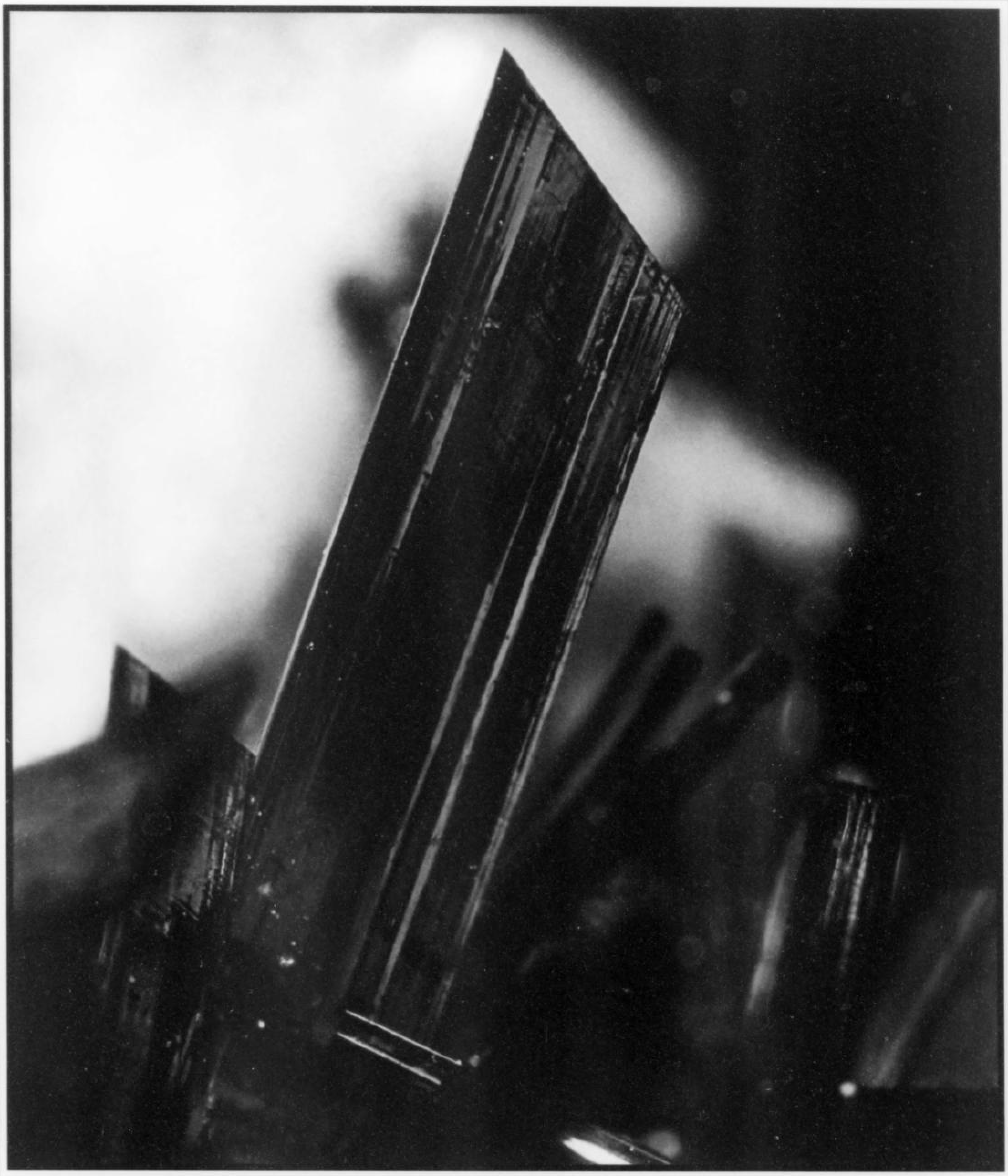
Bou Azzer, Morocco



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THE MINERALOGICAL RECORD

September–October 2007 Volume Thirty-eight, Number Five

Famous mineral localities:

Bou Azzer, Morocco

by

G. Favreau, J. E. Dietrich, N. Meisser, J. Brugger, L. Ait Haddouch & L. Maacha

COVER: ERYTHRITE crystal, 3 mm, from Bou Azzer, Morocco. G. Favreau collection; Robert Vernet photo.

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notes from the EDITORS

Philadelphia Academy to Keep Vaux Collection

As readers may recall, the Philadelphia Academy of Natural Sciences, after letting its historic mineral collection languish uncurated for decades, decided last year to divest itself of the collection and invest the money generated by the sale in its library. To that end the Academy signed a contract to sell the entire collection, including the portion donated by William S. Vaux in 1882, to a consortium of dealers composed of Bryan Lees (Collector's Edge Minerals), Wayne Leight (Kristalle) and Ian Bruce (Crystal Classics). We editorialized on this tragedy (in vol. 37, no. 6) but concluded that, given the Academy's longstanding history of neglecting the collection, it was the best thing to do from the standpoint of preserving the specimens. The only catch was that when the Academy agreed to accept the original donation of the Vaux collection in 1882, they also agreed to keep it "in perpetuity." Selling that portion would violate the original terms of the bequest, and thus the matter had to be put before the so-called "Orphan's Court" judge where such issues are dealt with under Pennsylvania law.

While that matter was pending, the sale of the rest of the collection (including, as it turned out, many specimens donated by William S. Vaux prior to his death and not covered by the terms of the bequest) to the consortium was completed, and work was begun to find new homes for the important regional suites. Thus far, around 8,000 specimens have been relocated to other museums where they will be better appreciated and cared for. The Pennsylvania specimens were acquired by the Carnegie Museum of Natural History, augmenting that institution's extensive Pennsylvania collection; in fact, some of the Academy specimens have already been placed on exhibit there in the Hillman Hall of Minerals and Gems. The Franklin Mineral Museum and the Sterling Hill Mining Museum have taken the New Jersey suite, the New York State Museum at Albany now has the New York suite, and the Museo di Storia Naturale in Milan has acquired the Italian suite. Efforts to place other suites with other museums are continuing, and many specimens not part of historically important suites are being sold individually.

But what of the superb specimens in the 1882 Vaux bequest? The Academy, under new management since the contract was signed for the sale of the specimens, apparently decided that it did not want to sell the specimens after all. A staff member testified at the court hearing (I was there) that the Academy did not really need the money from the sale anyway, and proposed that the Academy's paleontology curators could take good care of the Vaux collection very well, thank you. This removed any incentive the judge might have had to approve the sale, and so he denied the motion to fulfill the sales contract.

Curation by paleontologists? This is clearly an unfortunate development. They might as well assign it to the botanists or the ethnographers. Fine mineral specimens are generally best curated, cleaned, preserved and protected by people who have specialized in mineralogy, who have a passion for minerals and a lifetime of experience at handling minerals. In our formative years as mineral collectors we all have made mistakes that have resulted in unintended damage, deterioration, information loss and even theft of our personal specimens. We practiced our cleaning and trimming techniques on the cheap stuff, and accidentally ruined not a few pieces. We learned from our mistakes on the $10 specimens long before we graduated to $100 specimens or $1,000 specimens. It is unconscionable to put a fine and historic mineral collection into the untrained and dispassionate hands of rank novices. It appears that the famous Vaux collection, which has already suffered such unfortunate neglect and deterioration at the hands of the Academy, is sadly not destined for anything much better in the foreseeable future.

Prof. J. F. Kirkaldy's Tennant Medal (1928)

Tennant Medal

David Greenwood of the Kirkaldy Society in Hertfordshire, England kindly sent us the accompanying photo of a medal commemmorating James Tennant (1808–1881), British mineralogist, mineral dealer, and Professor of Mineralogy at Kings College, London. (The late Professor J. F. Kirkaldy was a recipient of the medal in 1928.) The Tennant Prizes were founded by means of a legacy bequeathed to the College by James Tennant himself; the first one was presented in 1883. The financial awards accompanying the medals—one given each year in Geology and one in Mineralogy—were of the annual value of about £15 altogether, and were generally given in the form of books or instruments. The prizes were presented at the Annual Examination, based on the results of the year's work. Both prizes were open to all students of the Faculties of Science and Engineering who had completed a year's work, and who were 22 years old or younger.

The entire Geology Department of Kings College was transferred to Royal Holloway University of London in 1985, and the Tennant Medal went with it. It is still being awarded there each year.

A brief biography of Tennant may be found in the Mineralogical Record's online *Biographical Archive*, and a much lengthier one (eight pages, illustrated) appears in Mick Cooper's wonderful book *Robbing the Sparry Garniture; A 200-Year History of British Mineral Dealers* (available from the Mineralogical Record's online bookstore).

How Times Have Changed

Half a century ago the mineral world was a very different place compared to what it is today. There were a few elite collectors and hard-core amateur mineralogists, to be sure, but there were also huge numbers of rockhounds—people who enjoyed minerals and often field-collected minerals, but didn't often spend a great deal of money on minerals. As a national hobby, minerals were very popular. People formed active clubs all over, held well-attended meetings and shows, and involved whole families in the fun. They enjoyed learning about minerals at a very basic level, and wrote about their collecting experiences. The popular mineral magazines of the day (Peter Zodac's *Rocks & Minerals* and Henry Dake's *The Mineralogist*) were far from technical and emphasized the people involved as much as the minerals.

Take the 1953 Arizona State Fair in Phoenix, for example. The Fair had a "Mineral Building" with permanent mineral exhibits, and plenty of extra space for exhibits by individuals and schools. Yes, the schools from around the state didn't just bring students to *see* exhibits, they put in their own competitive exhibits! The Lower Miami public school won First Prize and the Phelps Dodge Trophy. Yes, Phelps Dodge awarded a trophy for the best exhibit put together by the students of a school. Fifteen individual students won cash prizes and ribbons in five divisions. Other exhibits included a case showing early mining methods, a case of antique mine lamps, worldwide uranium and rare earth ores, gold specimens, fluorescent minerals, malachite pseudomorphs, Richard Bideaux's case of dioptase, wulfenite, cerussite and descloizite, numerous cases of "rare and beautiful thumbnails," and so on. Sounds like quite a nice show, although the Mineral Building wasn't nearly as large as today's Tucson Convention Center Exhibition Hall.

How many people would you guess visited the Mineral Building during the Fair? (Remember that in 1950, the Phoenix area had a population of around 200,000.) Answer: the total attendance in the Mineral Building alone from November 6–15 was 57,000 people. That is more than attended the 2007 Tucson Show, the greatest mineral show in the world today. On Armistice Day it was estimated that nearly 1,000 people *per hour* passed through the Mineral Building.

Today Phoenix proper has a population of about 1.5 million, and the "Phoenix Metropolitan Statistical Area," as they call it, has a population exceeding 4 million. What would a *proportional* attendance level be for a major mineral show there today? Around *1.1 million* people. (Let's see . . . if the show charged 5 bucks a head for admission . . . Oh my! And think of the hot dog concession!)

Mineralogical Record Receives Printing Award

The 20th annual Gold Ink Awards ceremony and banquet was held September 10, 2007 at McCormick Place in Chicago. The prestigious Gold Ink Awards competition, sponsored by two prominent trade journals (*Publishing Executive* and *Printing Impressions* magazines), has earned a reputation for attracting the highest quality of work from printing professionals throughout North America. It recognizes excellence in pre-press and printing quality in several publication categories. This year the *Mineralogical Record*'s *Ikons* special supplement *and* the March–April issue won awards in the scientific & technical journals category. We would like to thank our new printer, Allen Press in Lawrence, Kansas, for working with us at every stage of production and doing such a fine job on our challenging subject matter. The staff at Allen Press, from John Aamot (Director of Business Development) and Justin Roberts (our Account Manager) right down to the keen-eyed pressmen, have been consistently quality-oriented and highly competent.

Chinese Cinnabar Wendell E. Wilson©2004

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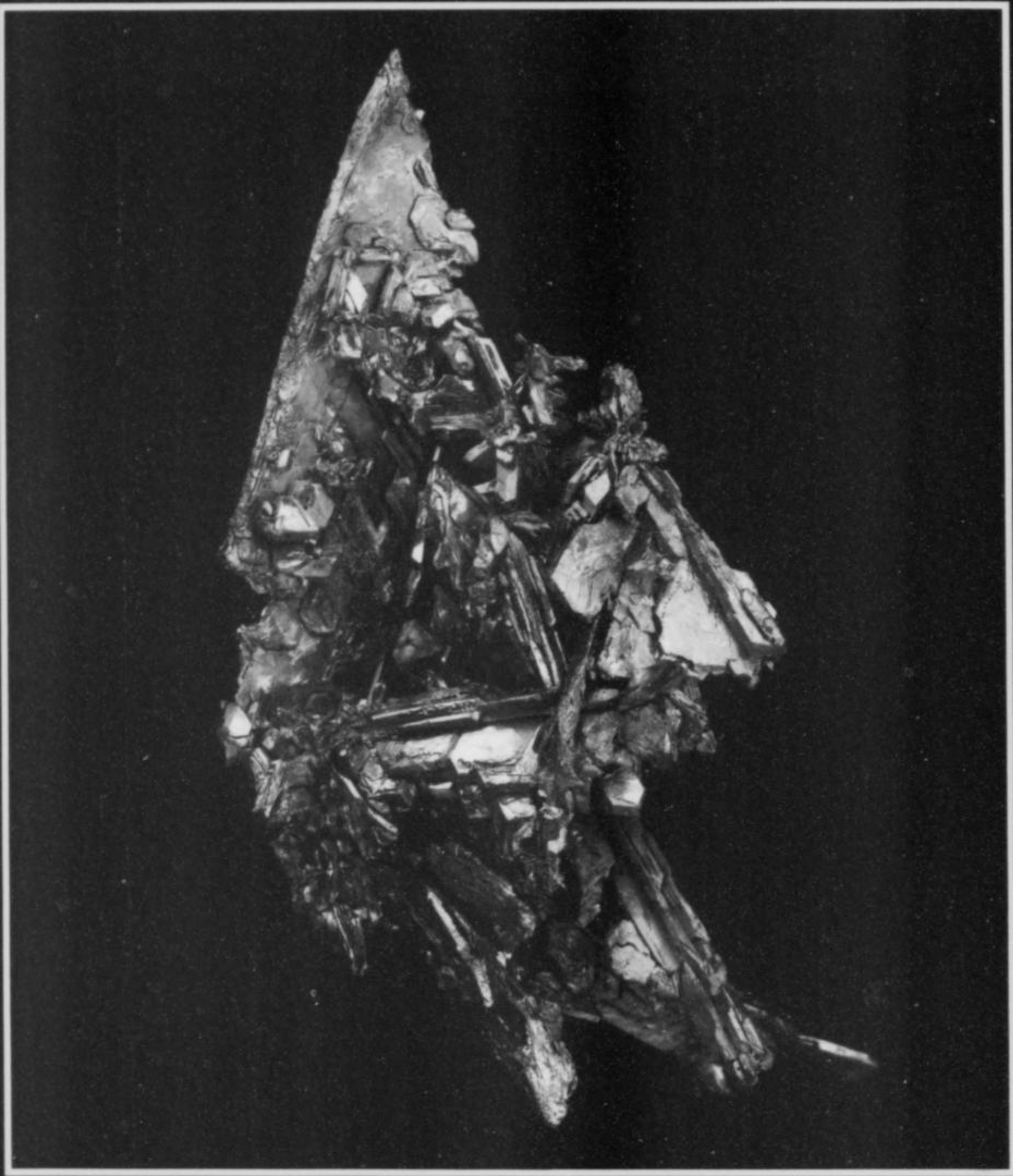

Famous mineral localities:

Bou Azzer, Morocco

Georges Favreau[1]
Jacques Emile Dietrich[2]
Nicolas Meisser[3]
Joël Brugger[4]
Lahcen Ait Haddouch[5]
and
Lhou Maacha[6]

with scientific support from
Anthony Kampf[7], Bertrand Devouard[8], Halil Sarp[9],
Gian Carlo Parodi[10] and Stefan Weiß[11]

Bou Azzer has produced the world's finest specimens of erythrite, roselite, roselite-beta, talmessite, wendwilsonite, skutterudite and gersdorffite. About 215 mineral species have been identified from the district, of which six were new to science: irhtemite, arhbarite, nickelaustinite, wendwilsonite, bouazzerite and maghrebite. Bou Azzer is also considered to be the world's best (or at least second best) locality for the very rare species cobaltarthurite, cobaltaustinite, cobaltlotharmeyerite, karibibite and guanacoite.

This article has been translated (by Thomas Moore) from* Lapis *magazine; we wish to acknowledge with thanks the kind permission of Publisher Christian Weise and the authors. It appeared originally as a group of separate articles in volume 31, no. 7/8 (2006), which we have combined into one. The authors are listed here in order of the amount of corresponding text in the original publications, which are cited individually in the Bibliography as Bartoli and Favreau (2006), Favreau and Dietrich (2006a), Favreau and Dietrich (2006b), Ait Haddouch* et al. *(2006), and Meisser and Brugger (2006).

INTRODUCTION

Bou Azzer might be translated as "where the fig tree stands." In a little gorge to the left of the road out of Tazenahkt a tiny garden lies hidden, not far from a spring inhabited by many frogs—a rare thing in the barren Anti-Atlas Mountains. An old, stunted fig tree seems to watch over the garden, and it is this diminutive tree which has given a name to the whole, very well-mineralized region thereabouts.

The Bou Azzer mining district encompasses many distinct mines, of which the most famous—from west to east—are Bou

Figure 1. **Snow in North Africa: the way to Bou Azzer leads south over the High Atlas Mountains. Georges Favreau photo.**

Azzer proper, Aghbar (Arhbar),[12] Ightem (Irhtem), Tamdrost and Aït Ahmane. These classic localities have produced the world's finest specimens of erythrite, roselite, roselite-beta, talmessite, wendwilsonite, skutterudite and gersdorffite. As of the end of 2006 the Bou Azzer district had produced about 215 mineral species altogether, and was the type locality for four of them: **irhtemite** (Pierrot and Schubnel, 1972), **arhbarite** (Schmetzer *et al.*, 1982), **nickelaustinite** (Cesbron *et al.*, 1987), and **wendwilsonite** (Dunn *et al.*, 1987). Two more new species have just been described from the district: **bouazzerite** and **maghrebite** (Meisser and Brugger, 2006). Bou Azzer is also considered to be the world's best (or second best) locality for the rare minerals cobaltarthurite, cobaltaustinite, cobaltlotharmeyerite, karibibite and guanacoite.

Since the early 1930's there have been numerous publications about the Bou Azzer mining district—chiefly geological and economic studies concerning extraction of cobalt and nickel arsenide ores. By contrast, descriptions of the district's other minerals, especially the secondary mineralogy, are dispersed among various specialized treatises. Most published works on the descriptive mineralogy of Bou Azzer are products of the *Service Géologique du Maroc*: windows to a "golden age" in the time of French geolo-

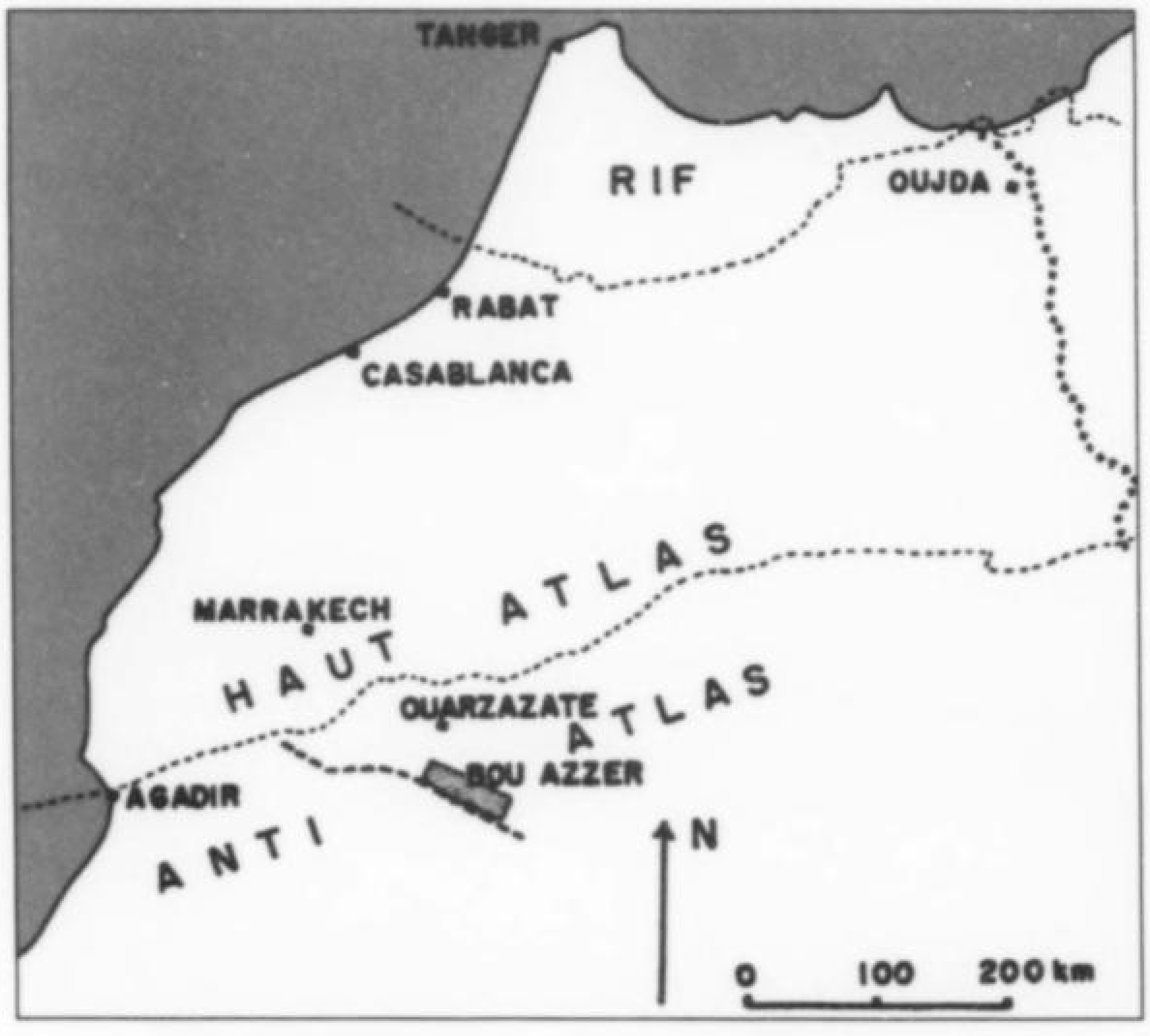

Figure 2. **Sketch map showing the location of the Bou Azzer mining district (modified from Leblanc, 1975).**

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[6] Former Director of Exploration, Bou Azzer

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[9] Musée d'Histoire Naturelle, Geneva, Switzerland

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[11] *Lapis* magazine, Christian Weise Verlag, Orleansstrasse 69, D-81667 München, Germany

[12] "**Aghbar**" is the literal transcription of the Arabic name; nevertheless, Western mineralogists write "Arhbar," as in the mineral species name "*arhbarite*." The same situation applies to "Ightem" and "Irhtem," and the corresponding mineral name "*irhtemite*." We use the spellings with **gh**, conforming with usage by modern Moroccan authors. By the same principle we use Aït Ahmane in the singular.

Figure 3. **A snow-white mosque behind the palm trees at Aït Ahmane (December 2002). Georges Favreau photo.**

rakech and the Aït-Hammou tribe, and they are said to have been sold in the Marakech "souks" (markets) as rat poison.

The economic potential of the cobalt ore occurrences was first recognized near the end of the First World War. The area in which the veins appeared was fairly small, difficult of access, and—during the first years of the French protectorate—politically unsettled. The

Figure 4. **Caution is always advised for mineral collectors in the open country. A 7-cm spider (with a painful bite!) on a dolomite dump in Aghbar. Georges Favreau photo.**

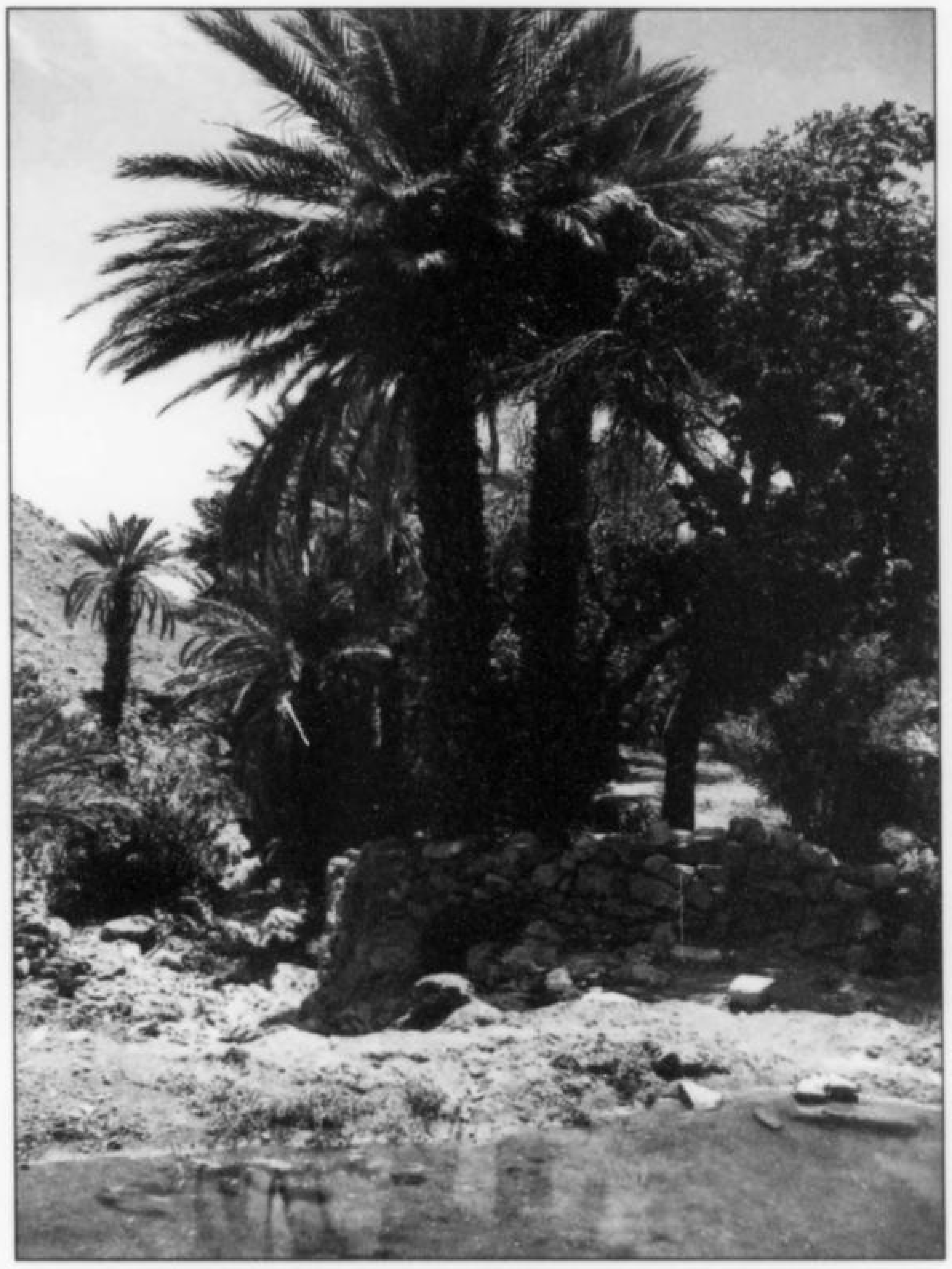


Figure 5. **The humble namesake of a world-famous place name: the original ancient fig tree stood in this palm grove by the spring at Bou Azzer ("Where the fig tree stands"). The tree (since cut down) is behind the photographer in this photo, April 2004. Georges Favreau photo.**

gists like Christophe Gaudefroy (1888–1971), Georges Jouravsky (1896–1964) and François Permingeat (1917–1988). These original works are highly interesting, and remain pertinent even now. The same remarks apply to the excellent works on arhbarite, schneiderhöhnite and karibibite by German scientists.

Although the region's deposits are world-famous and although two of us (GF and JED) have visited them many times, we have had to recognize that the extant listings of Bou Azzer's known secondary minerals and their varieties are radically incomplete. The fact has moved us to conduct many new investigations, particularly for the microcrystalline minerals. The result has been the identification of 46 Bou Azzer mineral species not previously known from there. These include arseniosiderite, bromargyrite, cabalzarite, chalcophyllite, clinoclase, clinotyrolite, cobaltkoritnigite, cornubite, fornacite, geminite, litharge, mottramite, nickellotharmeyerite, nováčekite, parnauite, powellite, uvarovite, walentaite, wulfenite, yukonite and zálesíite.

HISTORY

For a long time the tribal Berbers of the region around Bou Azzer had known of the outcropping arsenic-rich ore veins and of their cobalt arsenate minerals, especially erythrite, whose beautiful violet-red color seized their attention. The local populations knew of the toxic properties of these substances, and used them to fight insects. Contracts for their use existed between the Pasha of Mar-

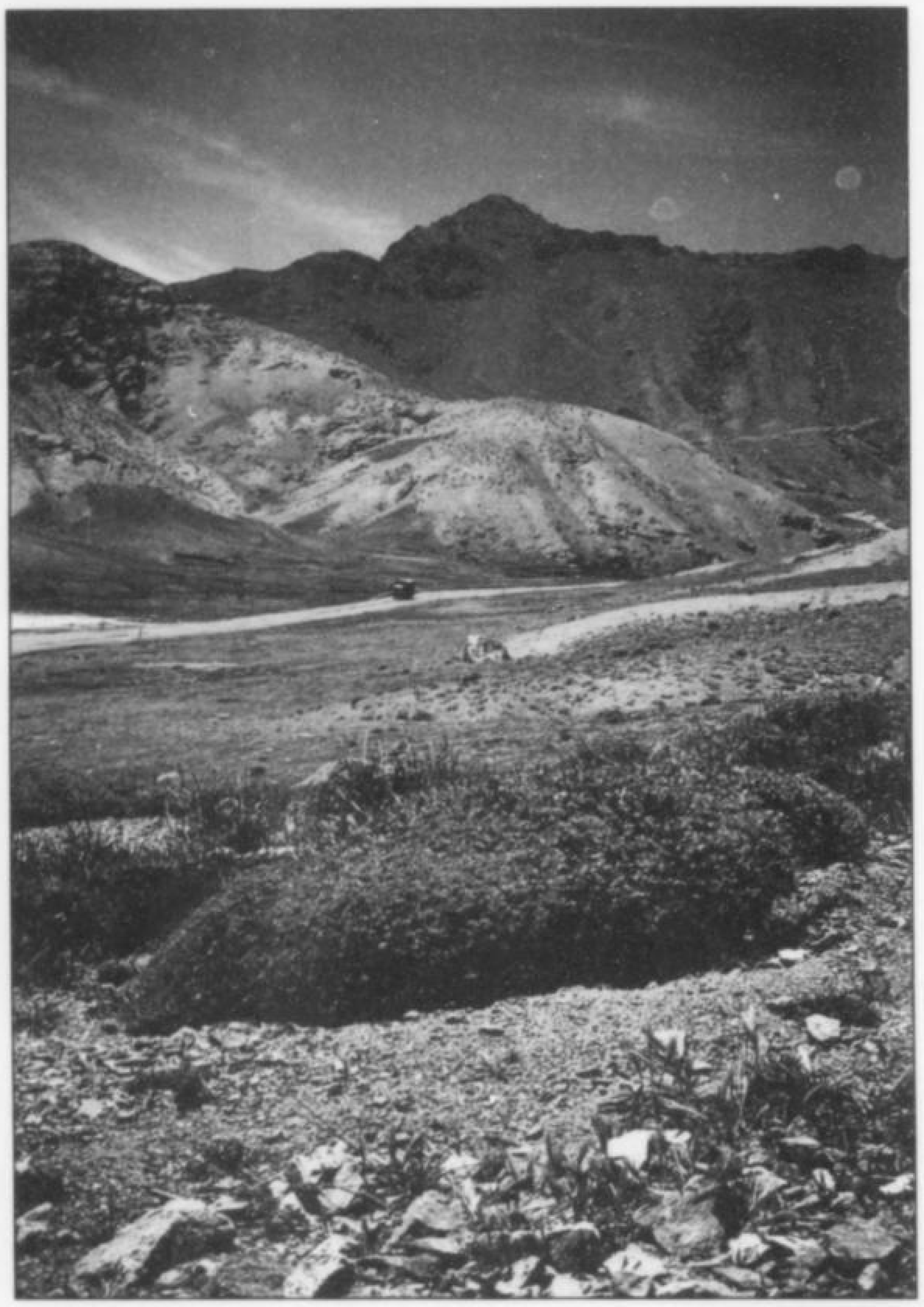


Figure 6. A blooming "stone garden" at Tizi-n-Tichka, May 2003. Georges Favreau photo.

Graara Mining Company began industrial mining of Veins 7, 5 and 2, all in the mining center of Bou Azzer, and of the deposits at Ightem.

Until 1950 the ore was processed through simple sorting and washing in basins—*bacs sardes*. During the Second World War production ceased for four years (1940–1944). In 1944 the installation of pneumatic tables and a hydraulic ore-washing system for ore concentration was completed. At that time, development of the deposits at Aghbar was also initiated.

In the period 1953–1958, mining activity was reinvigorated by the *Penarroya* mining company. A new ore-concentration facility was constructed, and in May of 1957 a flotation plant came on line. Thanks to these new facilities, 8,000 tons of raw ore from Bou Azzer and 4,000 tons from Aghbar were processed into 700–900 tons of ore concentrate each month. During this time about 2,000 people, of whom 800 to 900 were Moroccan workers and 120 were Europeans, lived in the mining district.

Because the hydrothermal cobalt-nickel mineralization is linked to serpentinite bodies (at the intersections between southwest-striking faults and the main fault zone of the Anti-Atlas Mountains), geophysical investigations (magnetometry and electrical conductivity measurements) were undertaken in 1956, in order to determine the size and shape of the serpentinite bodies beneath the sedimentary cover.

During the 1960's the cobalt ore concentrates were shipped to Europe out of the harbors of Casablanca and Agadir. The transport of the material over 520 km to Casablanca made for an arduous expedition: 15-ton trucks had to surmount the 2,270 meter-high Tichka Pass over the High Atlas Mountains, and then, in Marrakech, the ore concentrate had to be transferred to railroad cars

Figure 7. "Snakestone": after a winter rain, a horned viper rests on serpentinite rubble, December 2002. Georges Favreau photo.

first mining facilities (still visible today) took the form of small fortresses—"*Bordj*," in Arabic.

1928: BOU AZZER IS "DISCOVERED"

In 1927, His Excellency Si Hadj Thami el Glaoui, Pasha of Marrakech, concluded contracts with the local tribes who controlled the ore deposits. These contracts permitted exploration work by French prospectors which led, in 1928, to the true "discovery" of the deposits. With the intensification of prospecting after 1929, the most important occurrences—Veins 7, 5 and 2, Aghbar and Ightem—were located. Mining began in 1932, and several hundred tons of hand-sorted ore were produced. In 1934 the Bou Azzer-El

to be taken to Casablanca. The route to Agadir was somewhat less perilous: the concentrate was carried by trucks with capacities of up to 20 tons.

Since 1958 the mining rights have belonged to the Moroccan holding company *Omnium Nord-Africain* (ONA), headquartered in Casablanca. This company is represented by the *Compagnie de Tifnout-Tiranimine* (CTT), which currently conducts mining operations.

1967: WAS BOU AZZER "EXHAUSTED"?

In September 1967, the workings on Veins 7 and 5 were closed, the ore zone there having been declared exhausted. A little mining

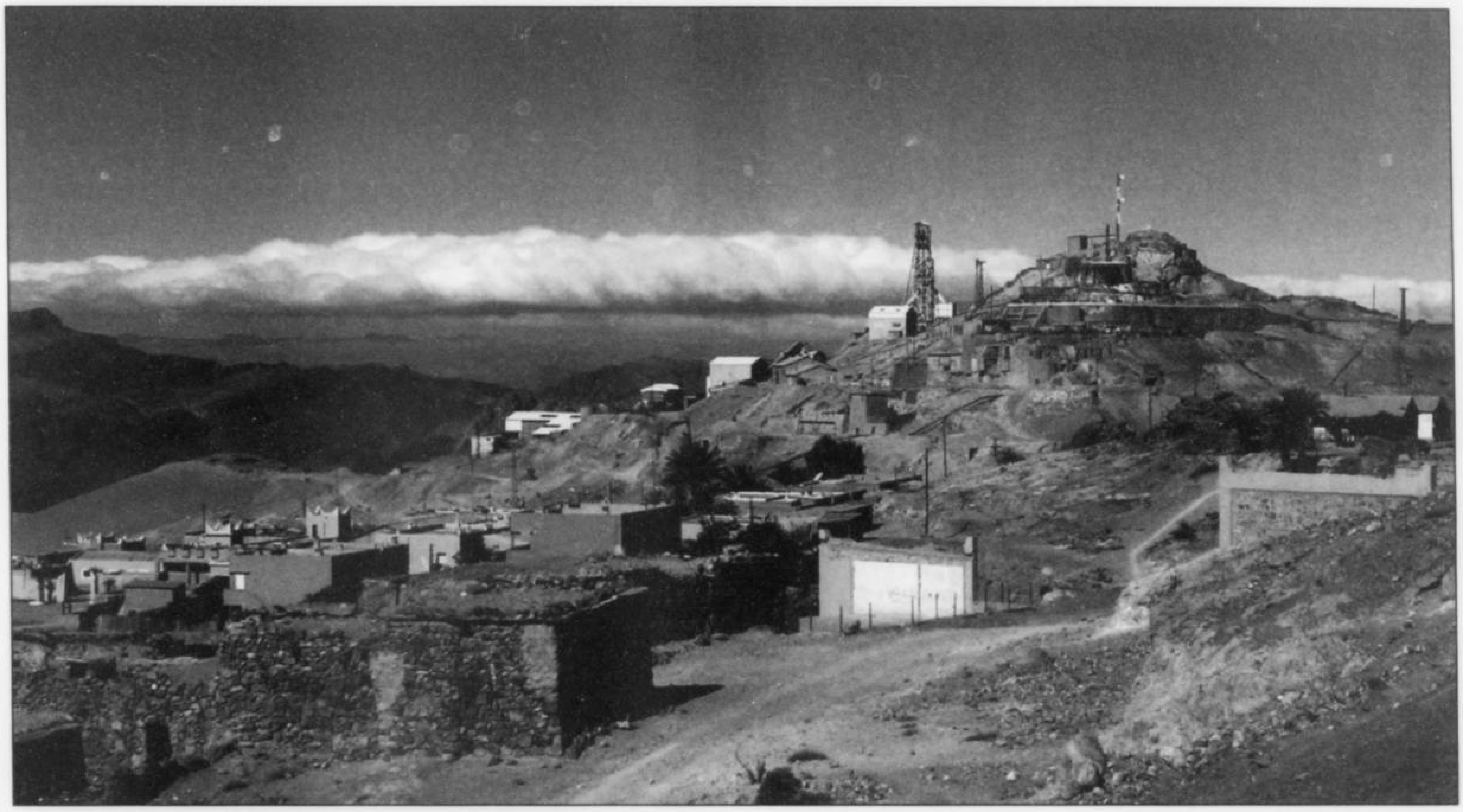


Figure 8. Bou Azzer mining center in April 2004. Georges Favreau photo.

Figure 9. Shaft 1, Bou Azzer, on the day in May 2001 when bouazzerite was discovered. The miners are unloading an ore car from Vein 7. Photo: Robert Pecorini.

Figure 10. Landmark: Shaft 3 at Bou Azzer. Behind it, mud tanks for ore preparation. May 2001. Georges Favreau photo.

Figure 11. **The Bordj in 2002. Located near the headquarters, it serves now as guest house and restaurant for CTT staff. Georges Favreau photo.**

Figure 12. **Workers hauling ore from the shaft at Bou Azzer-East, May 2001. Georges Favreau photo.**

in the Aghbar deposits continued, but by 1970 the reserves there were also thought to be exhausted. Accordingly the ONA hired a team of Soviet experts who specialized in exploring for ore mineralization in greenstones. Between 1969 and 1971 this team investigated the area's geochemistry and geophysics through mapping, drilling, and prospecting; the team found evidence of a large Co-As-Bi-Ag-Ni-Cu-Zn-Mo anomaly, with rich ore occurrences in Taghouni, Tamdrost and Bou Azzer-East.

CTT began mining for ore in **Bou Azzer-East** in 1971, and in **Tamdrost** (with estimated reserves of 350,000 tons of ungraded cobalt ore) in 1974. After 1976 there was ore production also from a series of small to medium-size deposits including **Taghouni** (or Tarouni, 1976), **Oumlil Centre** (1977), **Aït Ahmane** (Vein 61, 1980) and **Bouismas** (1981), as well as from the small **ST1** and **ST2 Veins** in the mining center of Bou Azzer. However, mining ceased again in 1983.

In 1987, geologists employed by CTT discovered the cobalt deposits of **Méchoui**, and mining there was begun in the same year, followed in 1990 by **Vein 53**, **Aït Ahmane**. Work stopped at Méchoui in 1994 after a short period of operation.

At this time the deposit at Aghbar, from which have come the most beautiful minerals of the region, was still slumbering, its specimen riches only partially known. Revival of mining there began with the dewatering of the shafts in 1997–1998. In 1999–2000, new workings were initiated in the oxidation zone near the top of the deposit, where exceptionally rich areas were found. New open-cut diggings there intersected old workings, and a few spectacular secondary mineral specimens were found.

By the end of 2002 short-lived mining had brought to light some very interesting, rare secondary minerals (iron and arsenic-bearing minerals like karibibite and schneiderhöhnite), both from the small

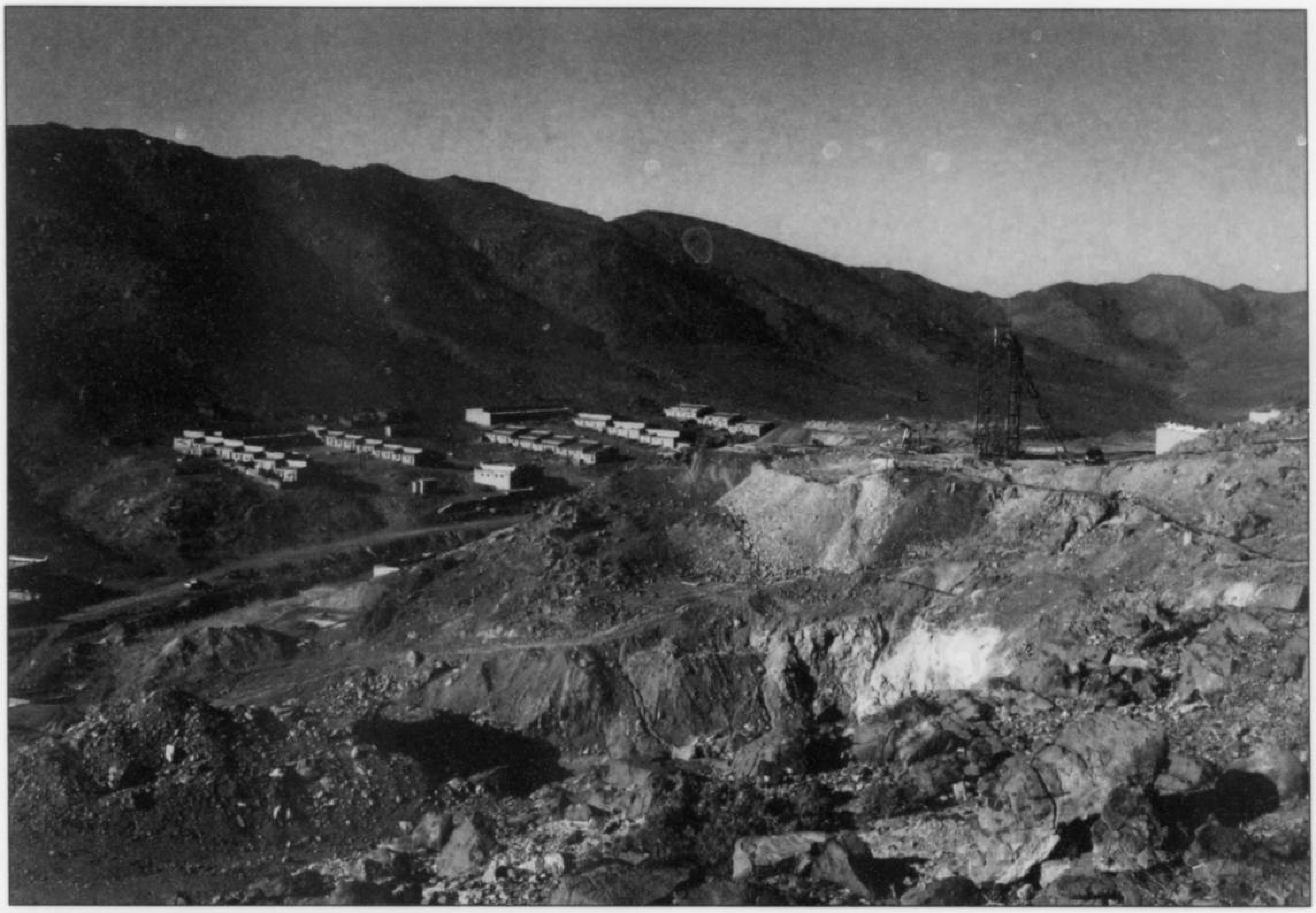


Figure 13. Type locality for maghrebite: the opencast Aghbar mine in November 2005. The miners' settlement is seen in the middle distance; on the right is the new haulage shaft. Georges Favreau photo.

Figure 14. An excellent collecting site for cobalt-rich calcite and erythrite: a zone of mineralized veins in Agoudal, December 2002. Georges Favreau photo.

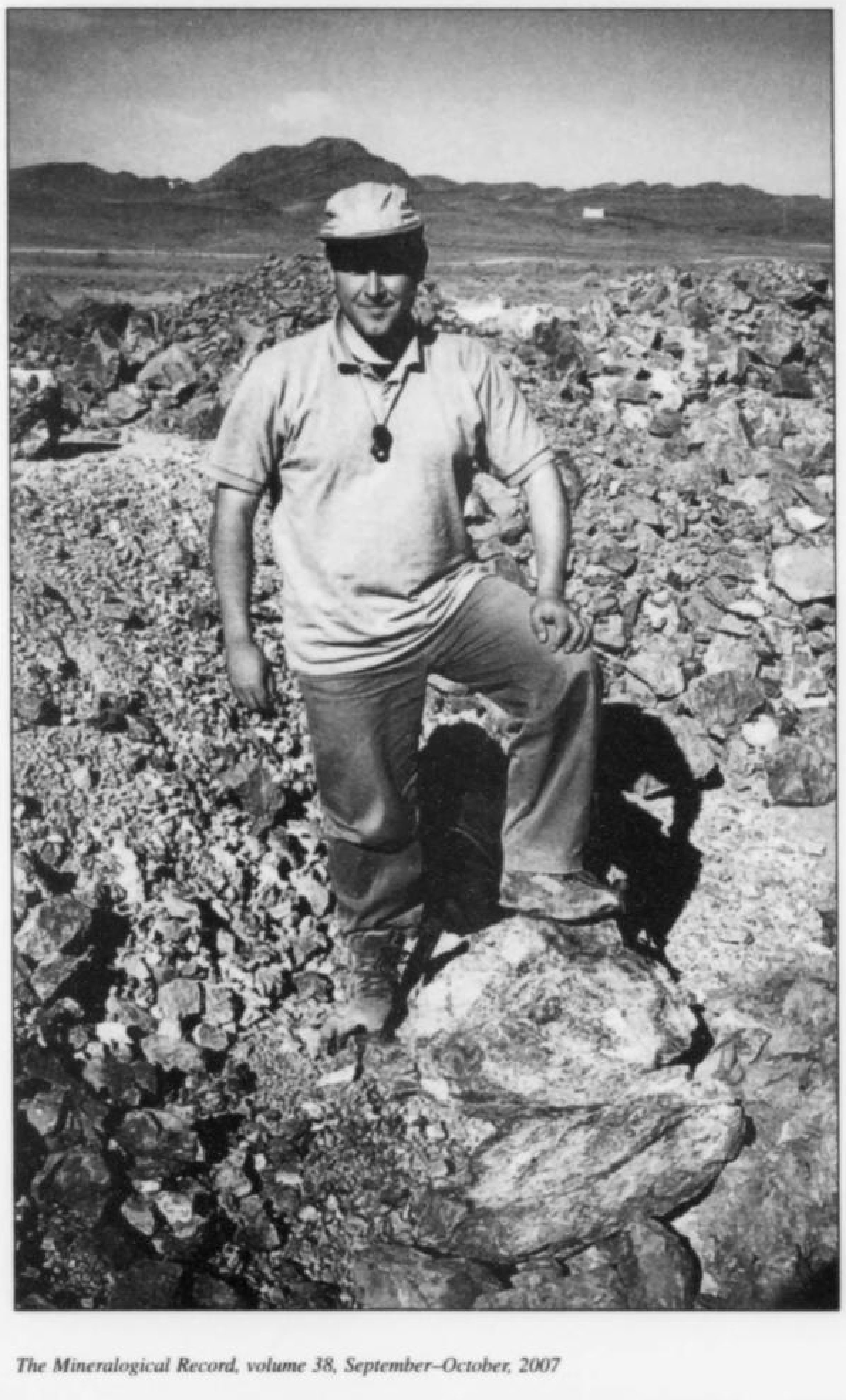


Figure 15. Author Georges Favreau and a large block of löllingite ore with golden yellow karibibite and pharmacosiderite, Oumlil-East.

Figure 16. **A fortress-like old Berber town: the settlement at Aït Ahmane in May 2001. Georges Favreau photo.**

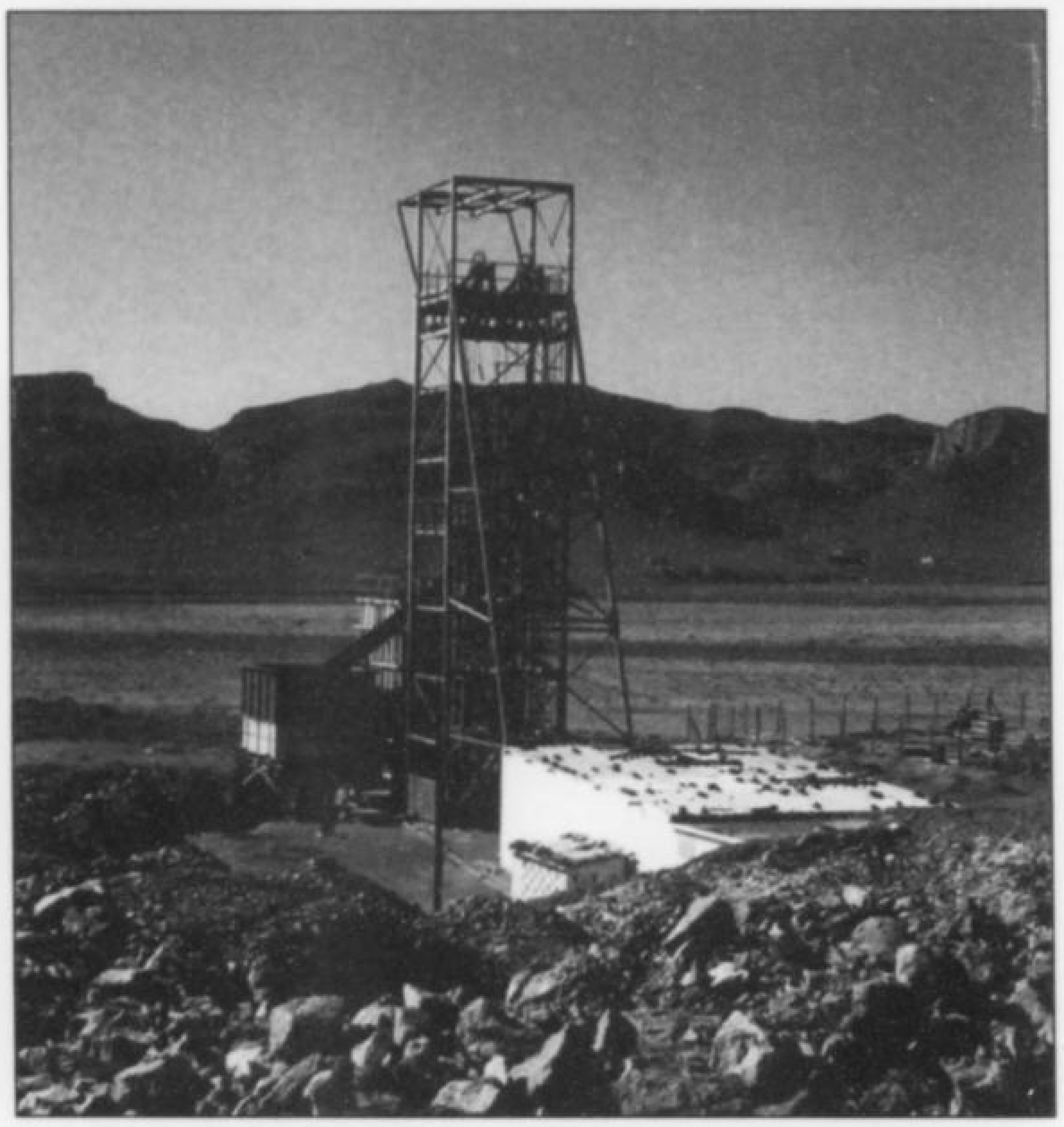


Figure 17. **Headframe of the Bouismas mine, re-opened in 2003 and known for recent discoveries of native silver and proustite. Georges Favreau photo.**

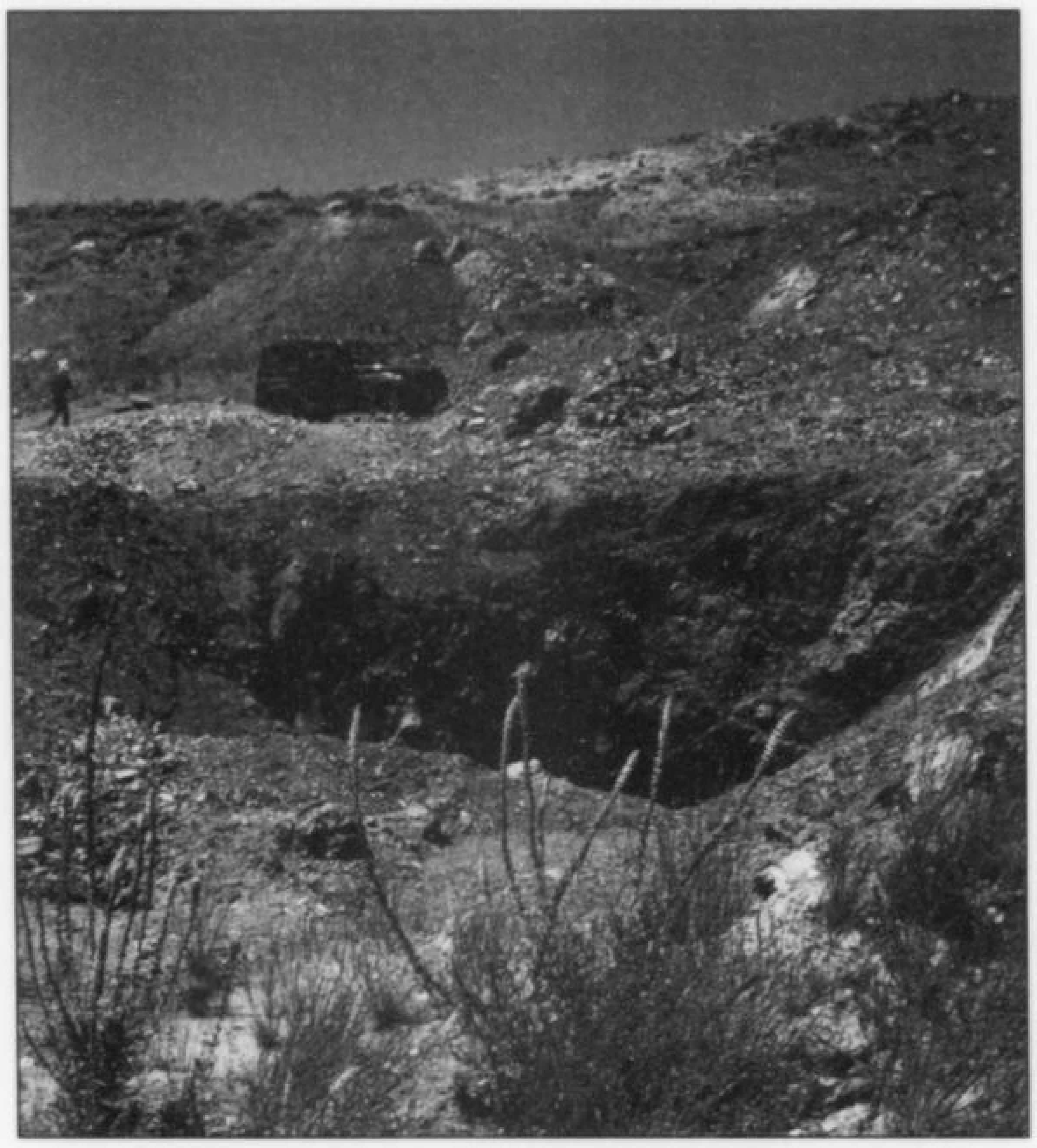


Figure 18. **A new collecting site for rare iron and copper arsenates: the Khder open pit, April 2004. Georges Favreau photo.**

Méchoui I and **Khder** mines and from large mines at **Oumlil-East** and **Tamdrost**.

As of November 2005, of the 20 deposits mentioned above and about 60 prospect pits, five mines remain in operation; since 2002–2003, all serious mining activity has taken place underground in these mines. The westernmost of these mines is **Taghouni.** At the mining center of Bou Azzer, Shaft 3, with Veins 7 and 5, is temporarily dormant, as is Bou Azzer East. The other currently active mines, from west to east, are **Aghbar, Bouismas, Oumlil-Centre** and **Agoudal**. Currently the workings exploit primary arsenide ores. The mining of oxide ores is not considered economically feasible.

Figure 19. **Weathered, brown-black serpentinite ridges in the Tamdrost mining area, May 2003. Georges Favreau photo.**

Figure 20. **Shaft at Oumlil Center, April 2004. Georges Favreau photo.**

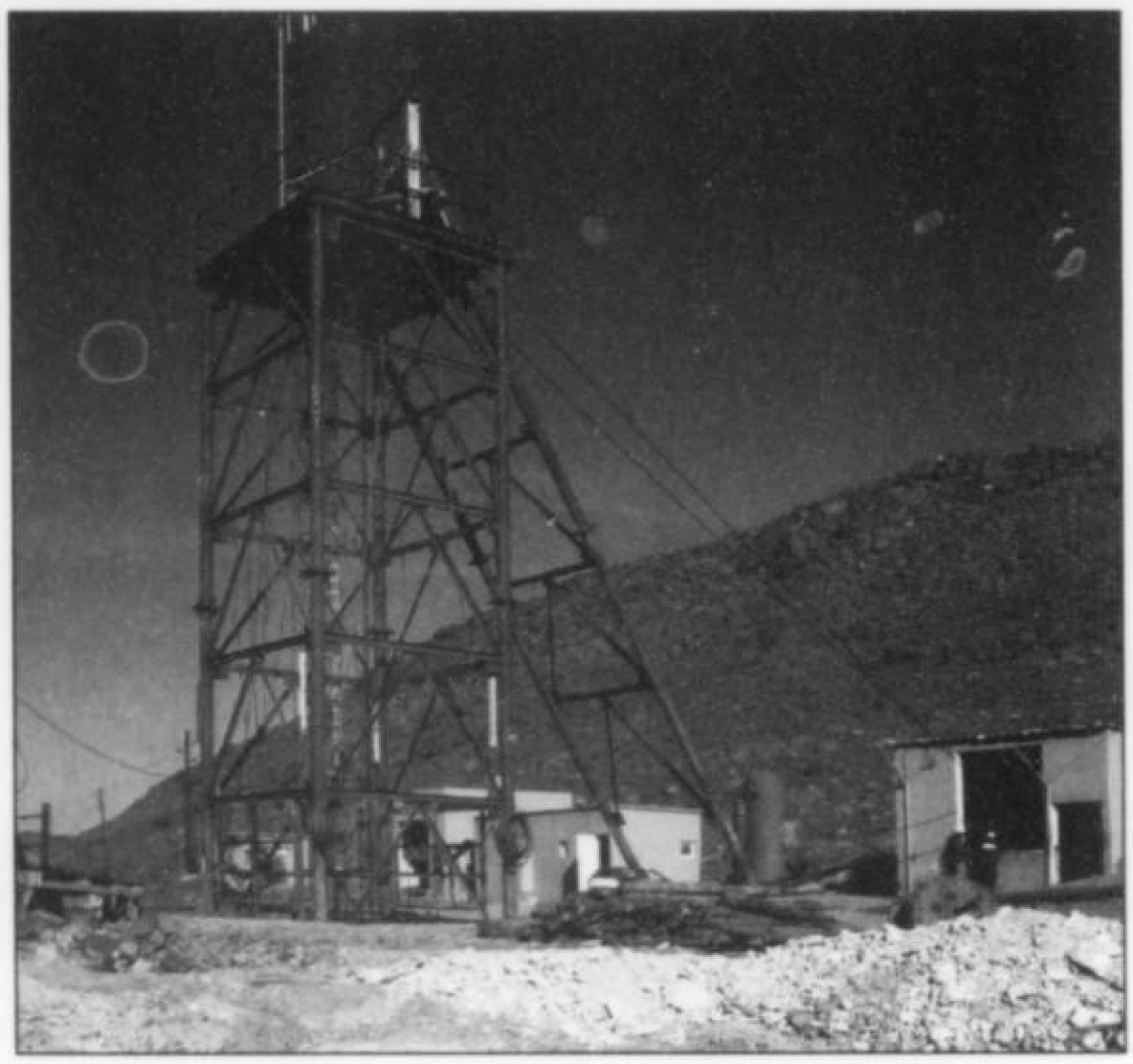


Figure 21. **Main shaft for the underground workings at Aghbar, November 2005. Georges Favreau photo.**

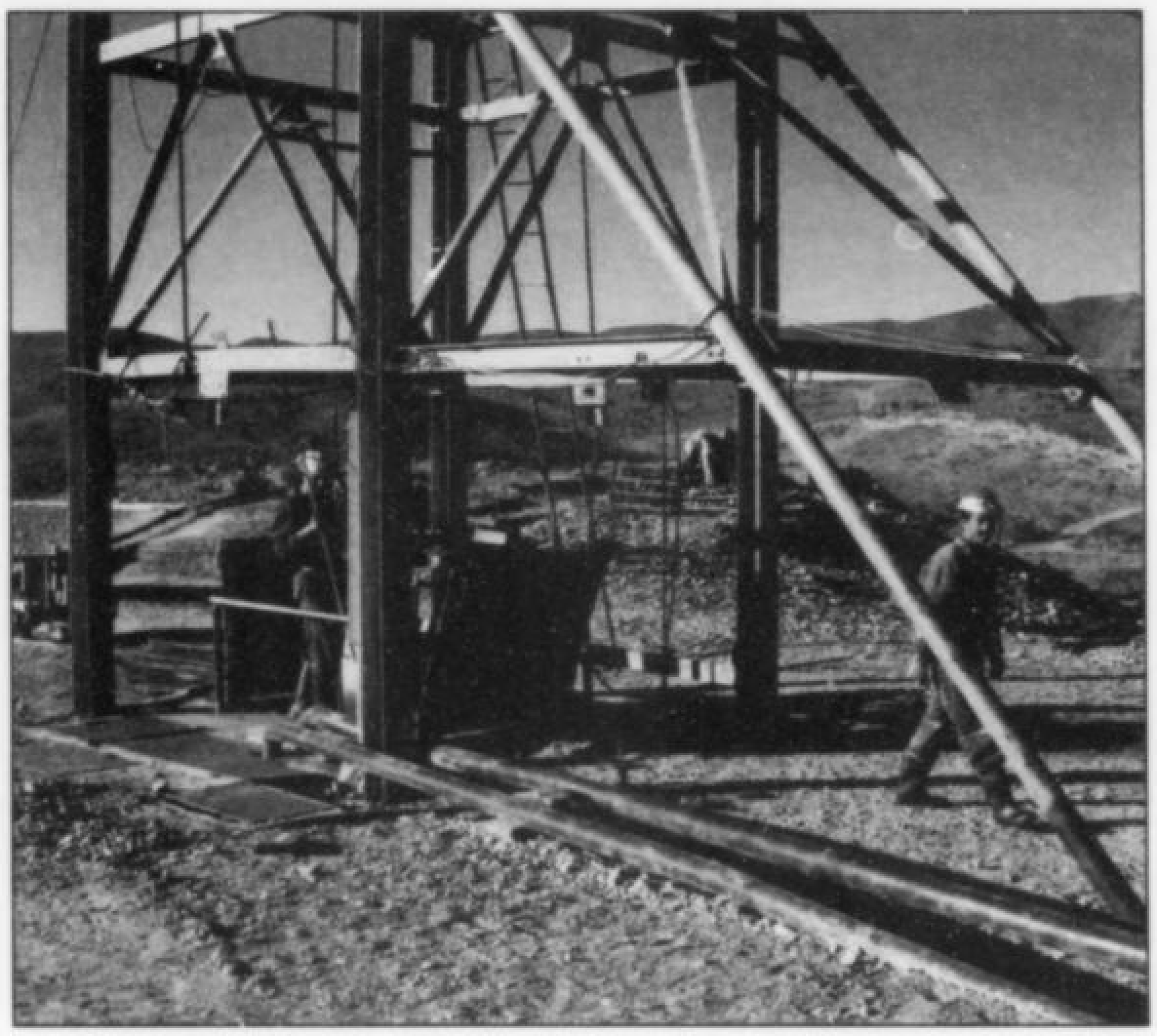


Figure 22. **A shift change at the Agoudal mine, November 2005. This mine has been known since 2002 for excellent cobalt-rich calcite and erythrite specimens. Robert Pecorini photo.**

GEOLOGY

Setting and Landscape

Bou Azzer lies in the central part of the Anti-Atlas Mountains of southern Morocco and within a distinctive geological feature, the saddle-shaped ridge of Bou Azzer-El Graara. This *boutonnière*[13] stretches in an east-southeast direction for about 50 km; its western edge lies about 60 air-kilometers southwest of Ouarzazate and about 30 km east of Tazenahkt.

The landscape resembles that of the southwestern United States; American Westerns have been filmed in the vicinity of Ouarzazate. The dominant prospect is one of brown steppelands where innumerable gray-green St. John's wort bushes (*Izri* in the Berber language) flourish. Small life forms, mostly concealed, are everywhere. Immediately after sunset, or in shaded hollows where water collects, one can observe the region's fauna, including some dangerous species such as biting spiders and horned vipers.

On a large-scale geological map the Bou Azzer-El Graara boutonnière is easy to see: in the midst of a homogenous geological prospect the ridge of the boutonnière is entirely distinctive. Its surroundings consist of a series of Precambrian volcanic rocks, including a carbonaceous unit (the Adoudounian Formation), resting on a still older basement. These basement rocks, about 2 billion years old, consist predominantly of leucocratic (felsic) granites, noticeable as paler rocks cropping out among the green (brown, when weathered) serpentinites which stretch between Aghbar and Tamdrost.

IN THE PRECAMBRIAN HIGHLANDS

The geology of the region is extremely complex; the Precambrian rocks have undergone multiple episodes of deformation since their formation, resulting in overthrusts, horizontal and vertical fracturing, brecciation, and the creation of cavity-rich permeable zones in which hydrothermal solutions could circulate. Profound chemical transformations resulted, including the serpentinization of rocks and the deposition of metallic vein deposits.

The Anti-Atlas Mountains consist of two clearly distinct structural blocks separated by a prominent fault zone running west-southwest to east-northeast, called the "AMAA," or "Accident Majeur de l'Anti-Atlas." This fault zone, which runs through the middle of the Bou Azzer-El Graara ore district, lies on the northern margin of an Achean-age craton which is the West African part of the earth's primordial crust. The stable craton is ringed by major tectonic boundary zones characterized by thick, weakly deformed sedimentary sequences (e.g. the Tindouf Basin and the Taoudemni Depression).

The Bou Azzer-El Graara ore district is elongated, stretching along the strike of the "AMAA" fault zone within the Precambrian boutonniére. The central ore-rich region is demarcated in the west by Bou Azzer (veins 7 and 5) and in the east by El Graara, with Aghbar, Ightem and Ambed among the intermediate mining areas.

In general the most important orebodies seem to lie in the vicinity of Middle Precambrian serpentinites. These orebodies are elongated east-northeast to west-southwest along the fault zone and are displaced to varying degrees by northeast-southwest transverse faulting.

Probably the cobalt-nickel ores were already being formed during the Precambrian by serpentinization and by weathering processes (leading in part to a layering of the deposits), then later by hydrothermal mobilization related to volcanic emplacement of alkaline andesite-trachytes (600 to 565 million years ago). Thus, deposition of primary ores in the Bou Azzer-El Graara region began in the Precambrian (more than 800 million years ago) in ophiolitic greenschists; ore vein formation reached its maximum during the late phases of a pan-African mountain-building orogeny (about 550 million years ago), and the process finally ended during the so-called "Saalian phase" of the Hercynian orogeny (250 to 240 million years ago).

ORES CONTACTING SERPENTINITES

A general rule for the Bou Azzer district is that all Co-Ni-Fe arsenide ore mineralization occurs at contacts with serpentinite.

[13]**Boutonnière**: An eroded anticline with an oval-shaped surface expression; the term is derived from the French word for "buttonhole."

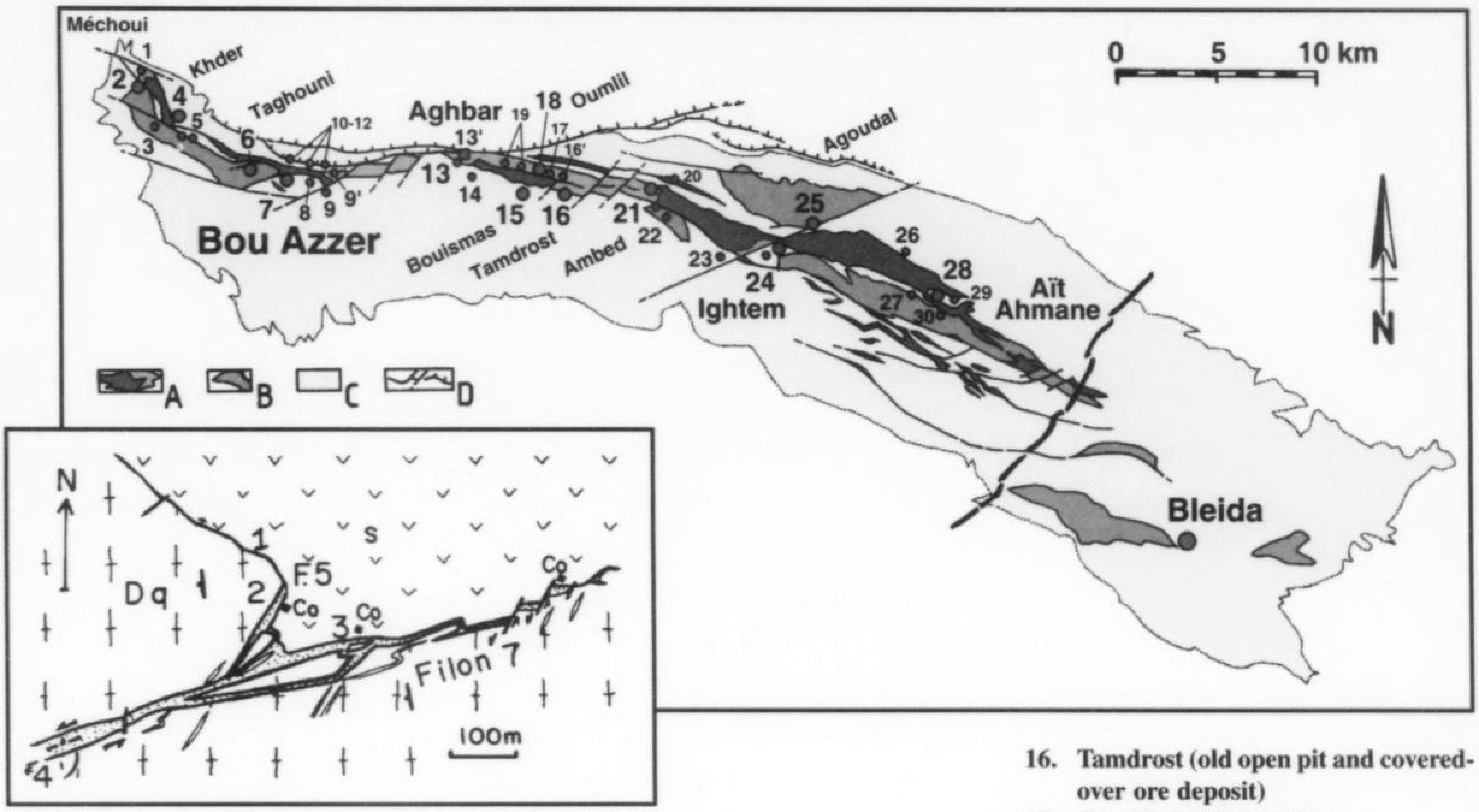


Figure 23. **Ore deposits in the Bou Azzer-El Graara *boutonnière* (after Leblanc, 1975). Drawing: Stefan Weiß, with additional data from Leblanc and Fischer (1990). Red dots indicate the deposits; those presently being worked are shown in all-capital letters in the list below. Bleida was opened as a new gold/copper mine in 2006. Legend: A = basic rocks (dark green = serpentinite; lighter green = rhyolitic tuffs and gabbros); B = quartz diorite; C = Precambrian volcanics and dolomites; D = fault zones (thrust faults and overturned strata). Black: dolerite sills (Jura). (*Inset*): Plan view at the surface, showing the 5 to 10-meter-thick Veins 5 and 7 of cobalt ore at Bou Azzer (Filon 5, Filon 7), at the brecciated contact between serpentine (s) and quartz diorite (Dq). Original sketch from Leblanc (1975).**

MINES:

1. **El Gir**
2. **Méchoui**
3. **Moghazni**
4. **Khder**
5. **Nickéline, ore veins**
6. **TAGHOUNI (Tarouni)**
7. **BOU AZZER, Veins 5 and 7**
8. **Baron Reservoir (south)**
9. **Bou Azzer-East**

9'. **Bou Azzer-East (northern part)**

10. **Bou Azzer (Vein 2)**
11. **Serpentinite E Bou Azzer**
12. **Baron Reservoir (east)**
13. **AGHBAR**

13'. **Aghbar, open pit (1999-2003)**

14. **Aghbar-East**
15. **BOUISMAS**
16. **Tamdrost (old open pit and covered-over ore deposit)**
17. **Oumlil, northern edge**
18. **OUMLIL (main vein)**
19. **Oumlil-North (löllingite lenses)**
20. **Ambed I**
21. **Ambed II**
22. **Ambed III+III-East**
23. **Ightem SW**
24. **Ightem**
25. **AGOUDAL**
26. **Vein 60**
27. **Aït Ahmane/SW, löllingite vein**
28. **Aït Ahmane, Veins 54-57**
29. **Aït Ahmane, Vein 51**
30. **Aït Ahmane, Vein 52**

Three broad types of ore mineralization are distinguishable:

[1] Strata-bound mineralization of the Ambed type. The Upper Precambrian Ambed Formation (El Graara) is a result of the serpentinization of ophiolitic greenstones and the later weathering effects of meteoric (surface) water. It was later deformed and eventually covered over by felsic volcanic rocks (rhyolite). This sedimentary formation seems to have served as an essential source of the Co-Ni-Fe in the ore deposits.

[2] Complex capping mineralization of the Aghbar type. The rather strongly weathered Aghbar serpentinite body was covered over by chloritized rhyolite, and the mostly flat-lying contact zones between the two rock types were brecciated by tectonic movements. Parts of the underlying serpentinite were pushed up as horst-like tongues or "pseudoplutons" into the rhyolite layers above, creating structures resembling salt diapirs. Carbonate rock layers, especially on the northern side of the boutonnière, were heavily faulted, with local overthrusting. The mineralization is probably related to a late Variscan tectonic phase during which elements already present in the weathered serpentinite were remobilized and concentrated.

[3] Vein mineralization of the Bou Azzer type. In the area of the Bou Azzer (proper) deposit an extensive, steeply dipping fault running east-northeast/west-southwest separates serpentinite from Precambrian quartz diorite. In this fault zone the #7 ore vein is found at a depth of more than 300 meters; it is, however, mineralized only at the point where it contacts serpentinite. The strongly brecciated Vein #7 carries quartz and carbonate gangue in which the minable ore occurs as lenses dipping about 60° to the west. Probably this indicates either a boudin-like structure formed when tension pressure tore the vein into discrete elliptical pieces, or a large-scale pattern of thin fissures in the vein.

Farther to the north, Vein #7 crosses Vein #5 in the region of quartz diorite. Here the presence of erythrite gives the first sign of cobalt mineralization. Probably these veins, with their accompanying systems of smaller veins, were emplaced during the earlier formation phases (about 600 million years ago).

As Leblanc (1980) has suggested, it seems clear that the "Bou

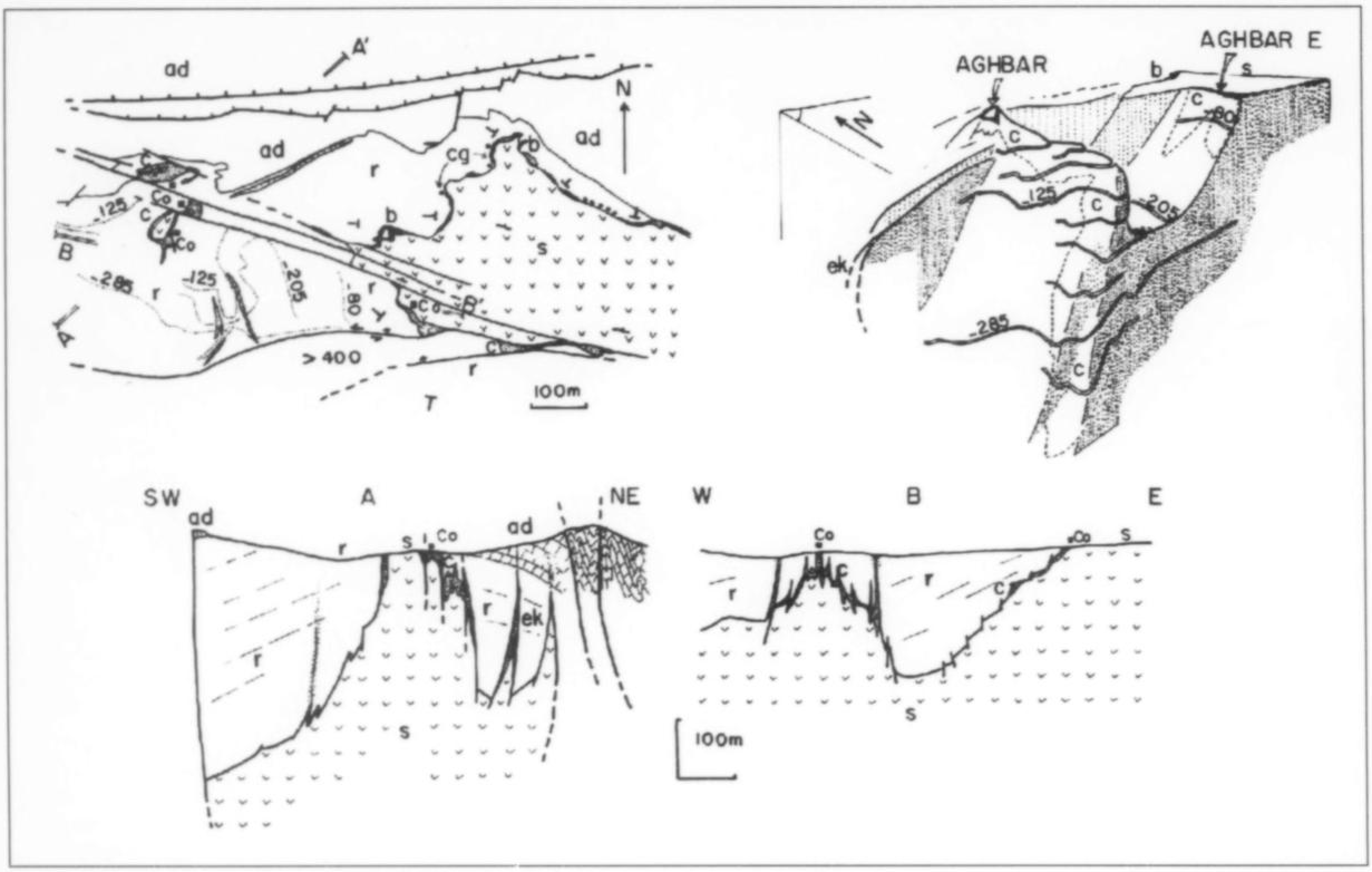


Figure 24. **Cobalt ore is emplaced along steep fault zones and as horizontal bands between "flame-like" structures of sheared serpentinite (s) and the overlying rhyolite (r). Top view, block diagram and vertical section of the Aghbar deposit (from Leblanc, 1975).**

Azzer" type of deposit can be defined as: "Cobalt arsenide deposits in serpentinite with overlying silicate-carbonate sedimentary rocks, the ore concentration resulting from tectonic remobilization and surficial weathering." Of all the rocks of the region, the serpentinites are the richest in cobalt and nickel content which could be leached out and concentrated (Jouravsky, 1952). Serpentinites are not found at the surface in other parts of the Anti-Atlas Mountains or the Tafilalt. Thus the Bou Azzer district is quite remarkable, because of its great age and because of the practically uninterrupted period of formation from the middle Precambrian to the Permian/Triassic boundary (about 240 million years ago).

The physical form of the orebodies is highly variable—veins, seams, chimneys, lenses and stockworks in breccia. The form of the deposits depends on the intensity of fracturing in the rock and on the properties of the rock, since these two factors affect the circulation of mineralizing fluids and therefore the deposition of minerals. In general we distinguish two types of ore deposits:

[1] Ore masses with strong ore enrichment ("*amas*"-type) are concentrated along irregular contacts between serpentinites and Precambrian volcanics (Tamdrost) or quartz diorites (Bou Azzer-east, Bouismas). The ore masses, with thicknesses measured in meters, run extensively *along* the irregular contacts with serpentinite.

[2] Ore veins which are aligned obliquely ("*transverse*" type) to serpentinite contacts. The rock units on the other side of the contacts may be quartz diorites (Veins 5 and 7), greenstones (Vein 2) or Precambrian volcanics (Tamdrost).

Ore Mineralogy

Most of the ore deposits are bound either in Precambrian structures or in the younger fault zones of the Variscan Orogeny (late Paleozoic). The richest orebodies are always found where deformation was most intense (a fact which often poses problems in mining), particularly in the west-northwest/east-southeast striking zone of contact between quartz diorite and serpentinite, cut in turn by faults striking northeast-southwest.

Co-Ni-Fe arsenides are found ubiquitously in such structures in both the western and eastern parts of the boutonnière; the most common species are skutterudite, löllingite and nickeline. Nickel is more common in the central part of the boutonnière and to the east, at Aït Ahmane. The sulfides linneite, millerite and pyrite seem merely subordinate, and sphalerite and galena can be considered rare. Chalcocite and molybdenite have been noted at both Bou Azzer and Aghbar. Chalcopyrite and bornite are found in most of the deposits, in some cases in considerable quantity. Co-Ni-Fe sulfarsenides such as gersdorffite, glaucodot, arsenopyrite and cobaltite are found generally in the eastern part of the district, around Aït Ahmane.

Gold and silver are the predominant native elements (Ennaciri, 1995). In the western part of the boutonnière (Veins 5, 7, II, ST2, ST1), the average gold content of the ore—more than 8 grams per ton—is higher than in the eastern part. On the other hand, the distribution of silver throughout the district is fairly homogenous at 13–37 grams per ton. The gold-poor sectors in particular (Bouismas, Oumlil, Tamdrost) tend to carry a higher silver content.

Chromite and magnetite, typical minerals in ophiolites, occur throughout the boutonnière and are regarded as relict products of serpentinization. There is a possibly mineable chromite body in the eastern part of the boutonnière. The chromite ore carries 0.2 grams per ton of platinum-group metals, occurring as microscopic inclusions of laurite, native osmium, native iridium, kashinite and heazlewoodite (Ghorfi *et al*., 2005).

The gangue minerals in the veins are quartz, various carbonates, asbestiform and talcose silicates, and much more rarely pyrophyllite and the finely acicular borate szaibelyite.

MINING AND ORE PRODUCTION

In the Bou Azzer mines the ore is extracted by overhead stoping in the veins, then backfilling the mined-out areas with waste rock. In the Bouismas mine and in Veins 7 and 5, chamber-mining has been employed experimentally. The method of reinforcing the floor of the mine with concrete platforms, as used in other places (for instance, in mining the rich ore of Tamdrost) was given up as too costly and risky. Mining proceeds by following an overhead vein upward, letting the ore fall to the floor to be scooped up by a diesel loader or an electric-powered excavator. The ore is then crushed and concentrated by gravimetric separation of the minerals based on the differing densities of ore, gangue and country rock.

To increase production in the future, extraction of ore in Veins 7 and 5 will be further mechanized, with mining activity focused on the most productive areas, including **Taghouni** and **Bou Azzer-East** (Veins 7 and 5), **Bouismas/Oumlil** and **Agoudal**.

Ennacri (1995) and Ghorfi *et al.* (2005) estimate the minimum production of the Bou Azzer district between 1933 and 1995 as follows:

50,000 to 60,000 tons of cobalt
5,000 tons of nickel
150,000 tons of arsenic
3,500 tons of chromite
9–10 tons of silver
2–5 tons of gold

To have obtained these quantities of metals, a total of 1,150,000 tons of raw ore (with 2–2.4% Co) must have been mined in Aghbar and 1,350,000 tons must have been mined from Veins 7, 5 and 2 in the center of the Bou Azzer district. Since 2001 the yearly production has increased to 140,000 tons of cobalt ore, with 1.2% Co (Barakate, 2005) and showing a gold content between 1 gram and 49 grams (!) per ton (Ghorfi *et al.*, 2005).

Here are a few final statistics from the years 1992–1995: the raw ore extracted contained *at least* 0.6% metallic cobalt. The gravimetric-hydraulic beneficiation method permitted a yield of 92% (corresponding to about 7% by weight), to produce in the end an ore concentrate with an average of 10.5–12% Co, 2.5% Ni, 7.4% Fe, 2% S, 59% As and 6% SiO_2, we well as 124 grams Ag and 11.7 grams Au per ton.

During the years 1998–1999, for political reasons, cobalt production from the Congo—another important producing area—came almost to a standstill. Consequently, cobalt production from Bou Azzer has continuously increased, from 40,000 tons of ore (with an average 1.4% Co content) in 1999 to 170,000 tons (with 1.1% Co) in 2004 and 2005; currently there is a yield of more than 1,800 tons of metallic cobalt per year. In addition to considerable ore reserves in old mine dumps (1.1 million tons with 0.32% Co), there are now proven reserves of about 1.7 million tons of ore containing 0.76–1.27% Co, about 45% As and about 6 grams per ton Au, ensuring the future of mining at Bou Azzer for at least another 10 or 11 years (M. Barakate, Internet report by the management of CTT, Nov. 23, 2005). Five mines are now operating, five are idle, two will soon be closed, and four new workings are being planned.

MINERALS

General Remarks

The mineralogical fame of the Bou Azzer district is founded on its extensive suite of rare and colorful arsenates, and especially on its superlative macro-specimens of erythrite, roselite, roselite-beta and wendwilsonite. In many respects the arsenates of Bou Azzer recall other occurrences (e.g. Wittichen and Richelsdorf in Germany or Sainte-Marie-aux-Mines in Alsace, France), and they are especially reminiscent of the classic cobalt ore occurrences of Schneeberg, Saxony, which indeed is the type locality for several minerals found commonly at Bou Azzer, among them erythrite, roselite, roselite-beta and cobaltlotharmeyerite. In general, arsenates from Bou Azzer have only three essential metals—cobalt, calcium and magnesium—whose compounds can sometimes form "mixed" crystals. Zinc, nickel and iron also sometimes contribute to the formation of interesting arsenates.

The primary ore minerals in the Bou Azzer district are chiefly cobalt, nickel and iron arsenides, copper sulfides, and native gold and molybdenite—Bou Azzer is also known to mineral collectors as the source of the world's finest crystal specimens of the ore species skutterudite and gersdorffite. The major gangue minerals of the district are quartz, dolomite, calcite, chlorite, talc and magnetite/chromite, as well as products of the alteration of serpentinite.

As of early summer 2006, about 215 distinct mineral species had been identified from Bou Azzer, counting the rock-forming minerals in the surrounding country rock, and about 60 species recognizable only with an ore microscope. The count places Bou Azzer among the 12 most mineralogically diverse localities in the world. Of course, it is still a long way from the classic Schneeberg district in Saxony (with more than 290 species), but intensive mineralogical investigation of Bou Azzer began only 40 years ago!

Figure 25. **"Cobalt colors": dolomite boulders shot through with secondary cobalt minerals at the Aghbar mining area, December 2002. Georges Favreau photo.**

In our mineral descriptions we highlight specimens collected since 1992, and minerals collected and studied by the second author during his 8-year sojourn in Morocco; in doing so we are reporting many Bou Azzer species for the first time.

The correct identification of many Bou Azzer minerals is possible only by X-ray diffractometry, EDX-spectrometry and wavelength-dispersive X-ray spectroscopy. These methods have facilitated the identification of several species previously unknown from Bou Azzer, e.g. powellite, cobaltlotharmeyerite, cobaltaustinite, cobaltarthurite and guanacoite, as well as interesting varieties of cobaltaustinite and zinc-rich roselite-beta.

The reader will notice that many of the Bou Azzer minerals described here occur commonly in very small crystals suitable for micromounts; however, the district is also known for unusually large crystals of several minerals. Below are listed a few examples of remarkable discoveries of world-class minerals made in recent years at Bou Azzer:

Roselite/Wendwilsonite from Aghbar (after 1999): lustrous red crystals to 1.5 cm on dolomite druses to 10 cm across.

Roselite-beta/Talmessite from Aghbar (after 1999): red-brown to orange crystal clusters to 1 cm.

Erythrite from Veins 7/5, Bou Azzer (2000–2001): deep red tabular crystals to more than 3.5 cm.

Goethite from Aghbar (after 2000): crystal crusts to several centimeters across, with gold-brown acicular crystals displaying adamantine luster.

Scorodite from "Tamdrost" (probably Oumlil, since 2001): highly lustrous, dark blue-green crystals to more than 2 cm.

Karibibite from Oumlil (2001): thick druses over areas more than 5 cm across.

Cobaltlotharmeyerite from Vein 2, Bou Azzer (2002): crystal clusters to 3 mm and druses to several centimeters across, with individual crystals around 1 mm.

Powellite from Vein 2, Bou Azzer (2002): honey-colored pseudo-octahedral crystals to 5 mm.

Vladimirite from Aït Ahmane (2002): colorless acicular crystals as matrix coatings to 10 cm across.

Cobalt-rich calcite from Agoudal (2002–2003): crystal crusts on matrix to a meter across, with deep pink crystals from 1 to 2 cm.

Erythrite from Oumlil and Agoudal (2005): metallic-violet-red tabular and acicular crystals, some more than 2 cm, associated with sphaerocobaltite, the latter as carmine-red rhombohedral crystals to 1 mm.

Skutterudite from Aghbar and Tamdrost (2005): highly lustrous, mirror-faced crystals to more than 3 cm, in some cases as crystal clusters to more than 6 cm across in a matrix of coarsely cleavable calcite.

MINERAL DESCRIPTIONS

Adamite $Zn_2(AsO_4)(OH)$

Adamite is the most common member of Bou Azzer's modest suite of zinc arsenates. In Méchoui, adamite forms bottle-green, lens-shaped crystals, resembling zinc-rich olivenite, to 0.2 mm in dolomite cavities. X-ray analysis first identified the species from this occurrence, where it is associated with chalcocite, lavendulan and conichalcite.

On the old dumps of the Ightem mine, well-crystallized adamite occurs commonly in a gray-white dolomite—despite the carbonate milieu it is overwhelmingly arsenates (annabergite, conichalcite, adamite . . .) which are present in this dolomite. Zinc carbonates such as smithsonite and hydrozincite have not yet been identified, and aurichalcite has been found sporadically. Blue-green, copper-rich adamite forms rounded groups of crystals to 1.5 mm which

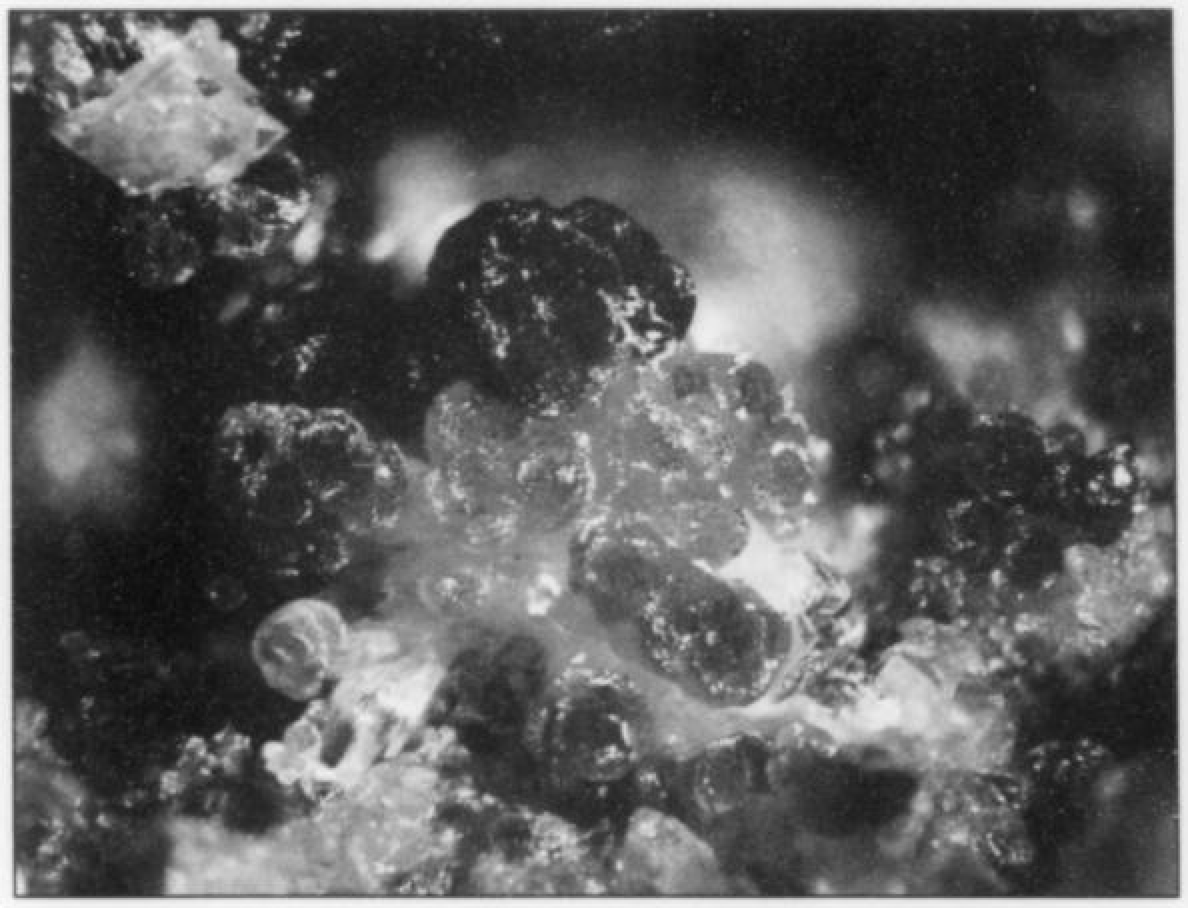


***Figure 26.* Lustrous green botryoidal adamite on annabergite from Ightem; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

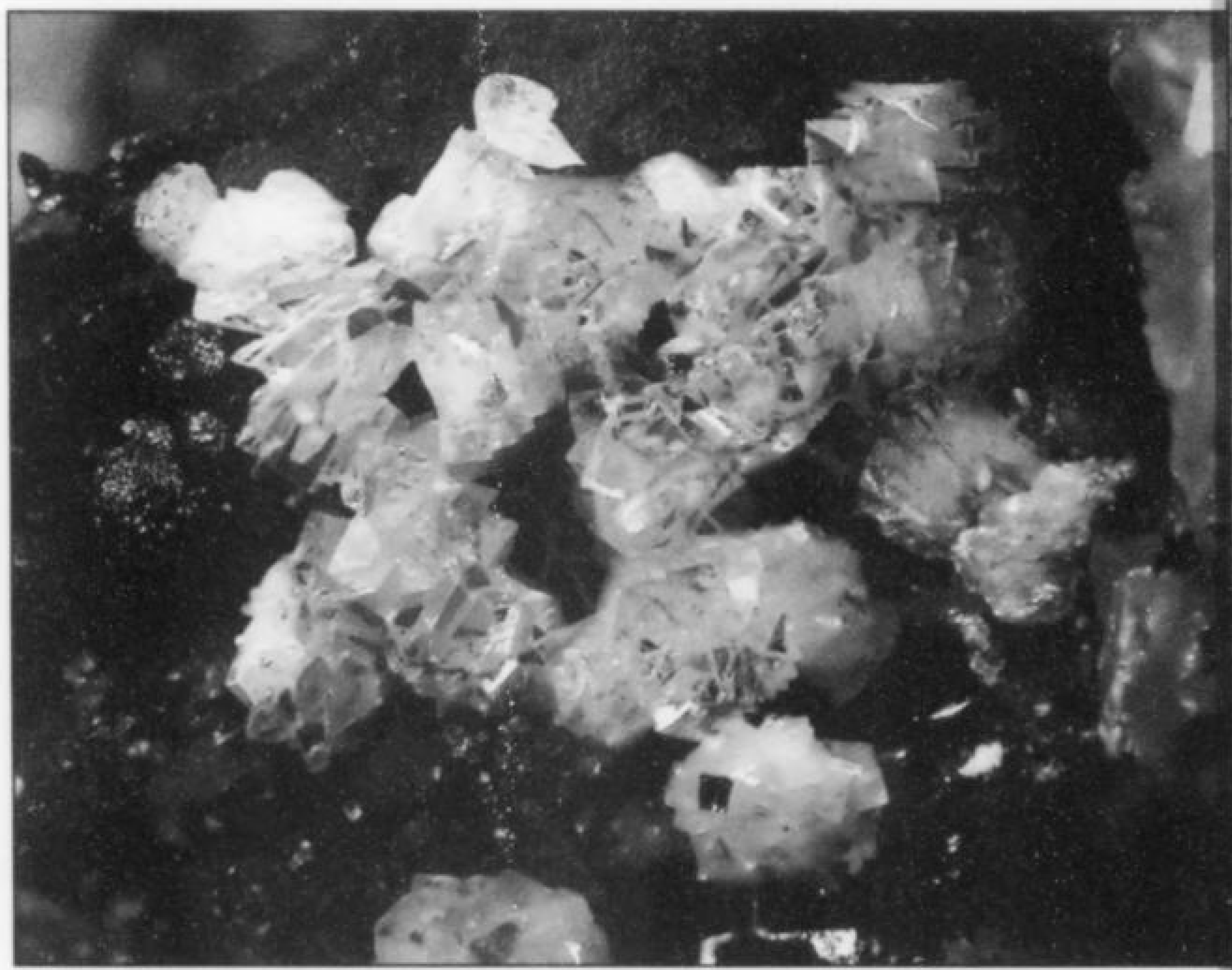


***Figure 27.* Adamite crystals from Ightem; field of view 3 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

occasionally rest directly on annabergite; with their pointed crystal tips these adamite aggregates recall those from Laurium, Greece and from the Ojuela mine, Mapimí, Mexico. Free-standing pseudo-octahedral adamite crystals are rare and microscopically small; their typical associations are annabergite, conichalcite, powellite and talmessite. Rarely the adamite is sky-blue, resembling the aluminum-rich adamite of Laurium (kaolinite, common on the Ightem dumps, is an aluminum-rich mineral).

Adamite forms small spherical crystal groups, together with glassy green austinite (?) crystals, in the conichalcite-rich quartz units of the Ambed 2 mine.

Agardite-(Ce)

(See under Zálesíite and Agardite-(Ce).)

Alumopharmacosiderite $KAl_4(AsO_4)_3(OH)_4 \cdot 6.5H_2O$

Alumopharmacosiderite forms countless tiny cubic crystals associated with nováčekite and zeunerite in a body of uranium ore at Tamdrost-West. The lustrous, pale greenish crystals are unusually

Figure 28. **New from Aghbar: strongly zoned, pink, cubic crystals of alumopharmacosiderite with lustrous, colorless crystals of maghrebite, the new aluminum arsenate, from Aghbar; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

tened crystals and stout face-rich crystals of anglesite, never larger than 0.5 mm, occur in small cavities.

Annabergite $Ni_3(AsO_4)_2 \cdot 8H_2O$

The best reported Bou Azzer annabergite specimens (Clavel and Elmaleh-Levy, 1978) are those found in an ore vein (designated as the *Filon Nickéline*—"Nickeline Vein") in the western part of the district, 6 km west-northwest of Bou Azzer. Specimens showing apple-green annabergite crystals to 5 mm, as beautiful fan-shaped groups, were recovered in 1965; the specimens were found in a dolomitic cavity zone with nickeline, rammelsbergite and gersdorffite, at a depth of about 30 meters. This is a magnesium-rich annabergite, like that found at Laurium, with Mg replacing Ni to about 30%—not sufficient to form hörnesite.

In Vein 51, Aït Ahmane, annabergite formed by the hydrothermal alteration of gersdorffite has been found as beautiful green leafy crystals in quartz, with massive "garnierite" and pale green, microcrystalline, nickel-rich talmessite. Vein 52 has produced color-zoned mixed crystals of annabergite-erythrite which form very pale, elongated parallel groups and fan-shaped aggregates to 1 mm. Vein 59 has yielded gray-green, thick-tabular crystals of annabergite, some with a yellowish patina, in fan-shaped and spherical groups in a quartz-rich rock with metallic gray nickel arsenides. These assemblages also contain nickelaustinite. At Ightem, small, pale green spheres of annabergite have been found, with green spheres of adamite and yellow rosettes of powellite. Other collecting sites for the species include Tamdrost and Ambed I (tiny leafy crystals and lamellae).

Figure 29. **Pale greenish yellow annabergite from Vein 59, Aït Ahmane; field of view 5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

aluminum-rich. Associations include erythrite, annabergite, talmessite, powellite, galena and native gold.

At Aghbar, tiny (<0.2 mm), white to pale pink, cubic alumopharmacosiderite crystals, some showing phantoms, are associated with roselite-beta, mansfieldite and the new aluminum arsenate maghrebite. At Oumlil, similar crystals containing some strontium are associated with scorodite and mansfieldite.

Anglesite $PbSO_4$

In Oumlil, anglesite formed with mimetite from the weathering of galena; it is found chiefly as gray masses to 1 cm. Lustrous flat-

Aragonite

(See under Calcite, Dolomite and Aragonite.)

Arhbarite $Cu_2Mg(AsO_4)(OH)_3$

The rare hydrated copper and magnesium arsenate arhbarite was described from Aghbar by Schmetzer *et al.* (1982), as vivid blue spherules composed of crystals measuring less than 0.01 mm, associated with erythrite, pharmacolite, löllingite, bluish green mcguinessite, talc and hematite on coarsely cleavable dolomite. As of 1998, when much better arhbarite from El Guanaco in Chile became known, the mineral had not been found again at the type locality

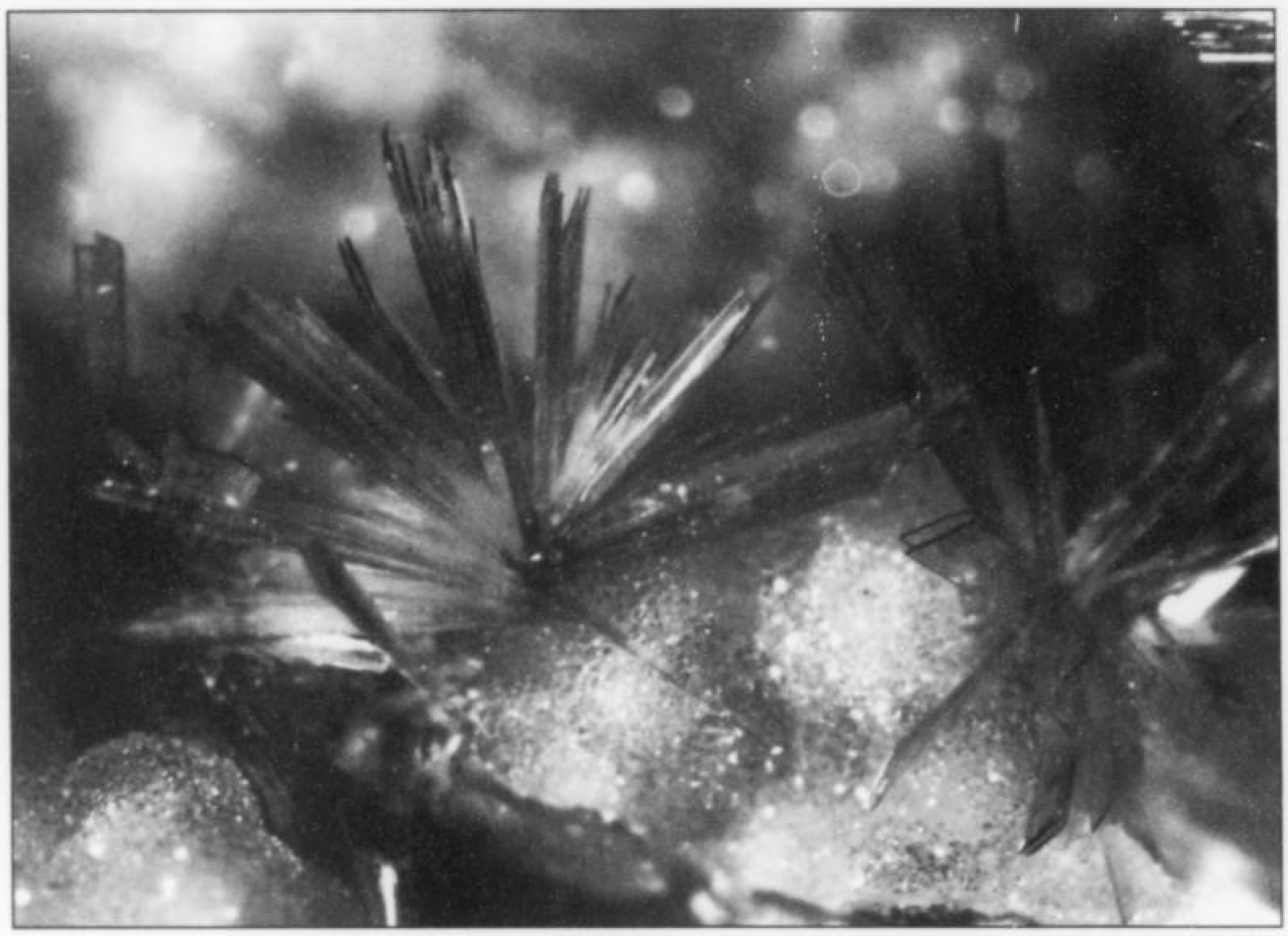


Figure 30. **Annabergite-erythrite, color-zoned mixed crystals from Vein 52, Aït Ahmane; field of view 3 mm. J. R. Legris specimen; Robert Vernet photo.**

of Arhbar; today it is one of the greatest rarities of the Bou Azzer district, known in only three specimens. Dark blue material newly formed in old mine workings has been shown to be lavendulan.

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

In the district, secondary iron arsenates generally form at the expense of löllingite, arsenopyrite, safflorite and skutterudite. Of these iron arsenates, arseniosiderite is the most common, although it has not been previously reported. Arseniosiderite typically forms pearly scales of various colors: from pale orange through dark red-brown and cream-colored. The scales commonly form rosette-shaped aggregates, or pile up in thick layers. Certainly the mineral is very common in the Bou Azzer district, but its usual rust-red color often causes it to be mistaken for an iron oxide (e.g. goethite).

In the quartz veins of Vein 2, arseniosiderite forms layers of thin orange lamellae, with chalcopyrite, late-formed zeunerite and barite. A dark variety appears in Vein 52, Aït Ahmane, with löllingite and fibrous erythrite. Rosettes of arseniosiderite perch on the faces of some large pyritohedral crystals of skutterudite from Vein 59, Aït Ahmane.

The best and richest specimens of this species—from Méchoui—show red-brown rosettes and spherules resting directly on crystals of safflorite. In weathered ores at Tamdrost, arseniosiderite forms thin, cream-colored lamellae, and at Aghbar the species is associated with cabalzarite.

Arsenolite As_2O_3

Arsenolite, as an alteration product in strongly weathered ores, occurs very commonly in fissures. In many cases the fissures are coated by newly formed erythrite and by countless octahedral crystals of arsenolite in colorless, white, or pale violet colors with a diamond-like brilliance. Arsenolite occurs with cobaltkoritnigite at Aghbar, in Veins 2 and 7 at Bou Azzer, and at Ightem. Like picropharmacolite, arsenolite is found in general in the vicinity of Ca and Mg arsenates.

Arsenopyrite FeAsS

Arsenopyrite is especially common at Tamdrost, occurring there as lustrous prismatic crystals to 1 mm, in some cases resting on matte-gray crests of safflorite. At Méchoui, Ightem, and in Vein 2, Bou Azzer, arsenopyrite occurs as thin columnar crystals, associated at Bou Azzer with cobaltlotharmeyerite and roselite.

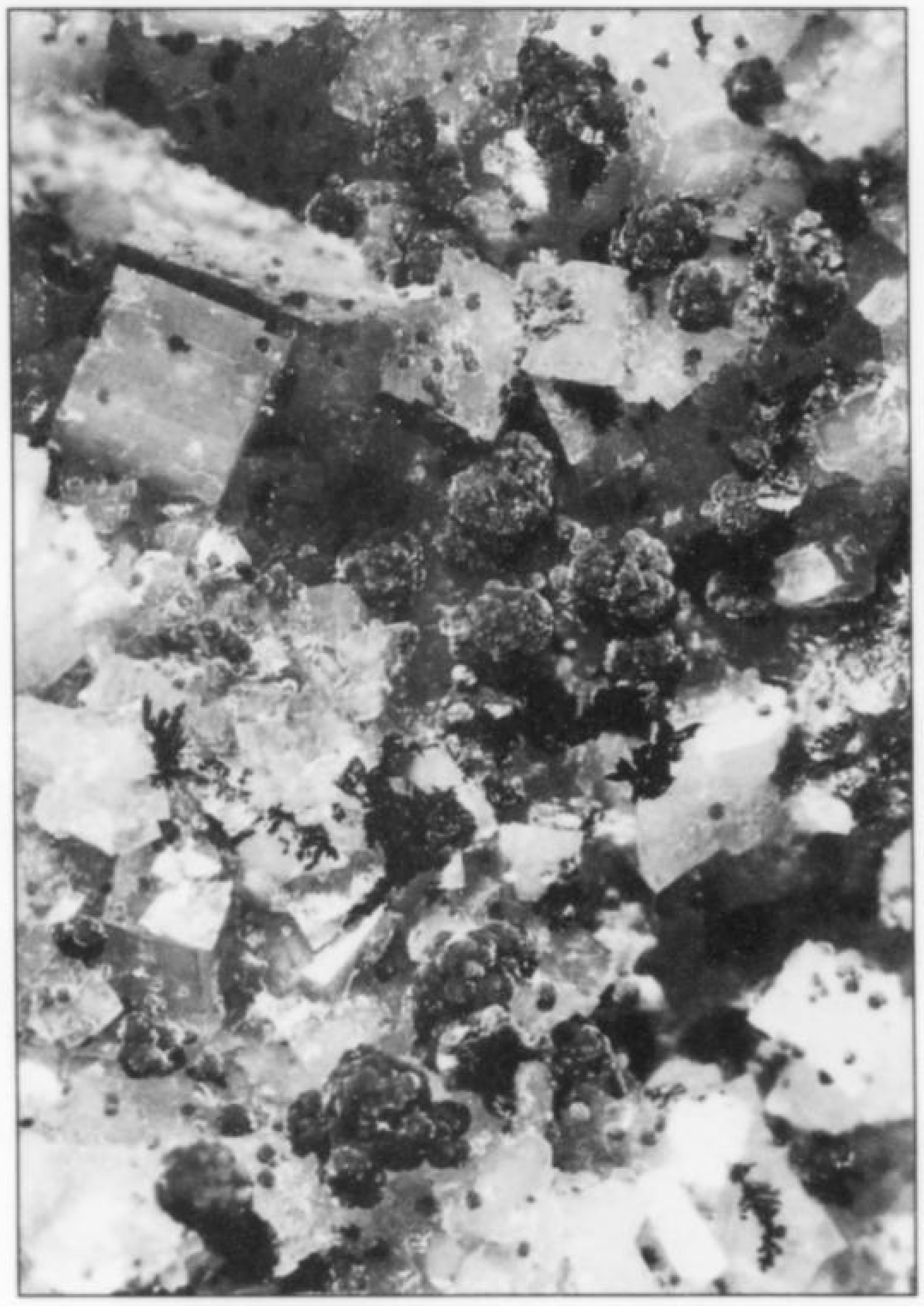


Figure 31. **Arseniosiderite on dolomite, from Ightem; field of view 4.8 mm. G. Favreau specimen; Robert Vernet photo.**

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

In early 2002, at Aghbar, a dolomite boulder enriched in sulfides and shot through with erythrite was found. There, for the first time, turquoise-blue aggregates, less than 0.5 mm wide, of sharp, elongated platy crystals of aurichalcite were discovered. The crystals are soluble with effervescence in hydrochloric acid, and distinguishable in that way from the similar-looking devilline and clinotyrolite. A strong pearly luster and the association with erythrite create an

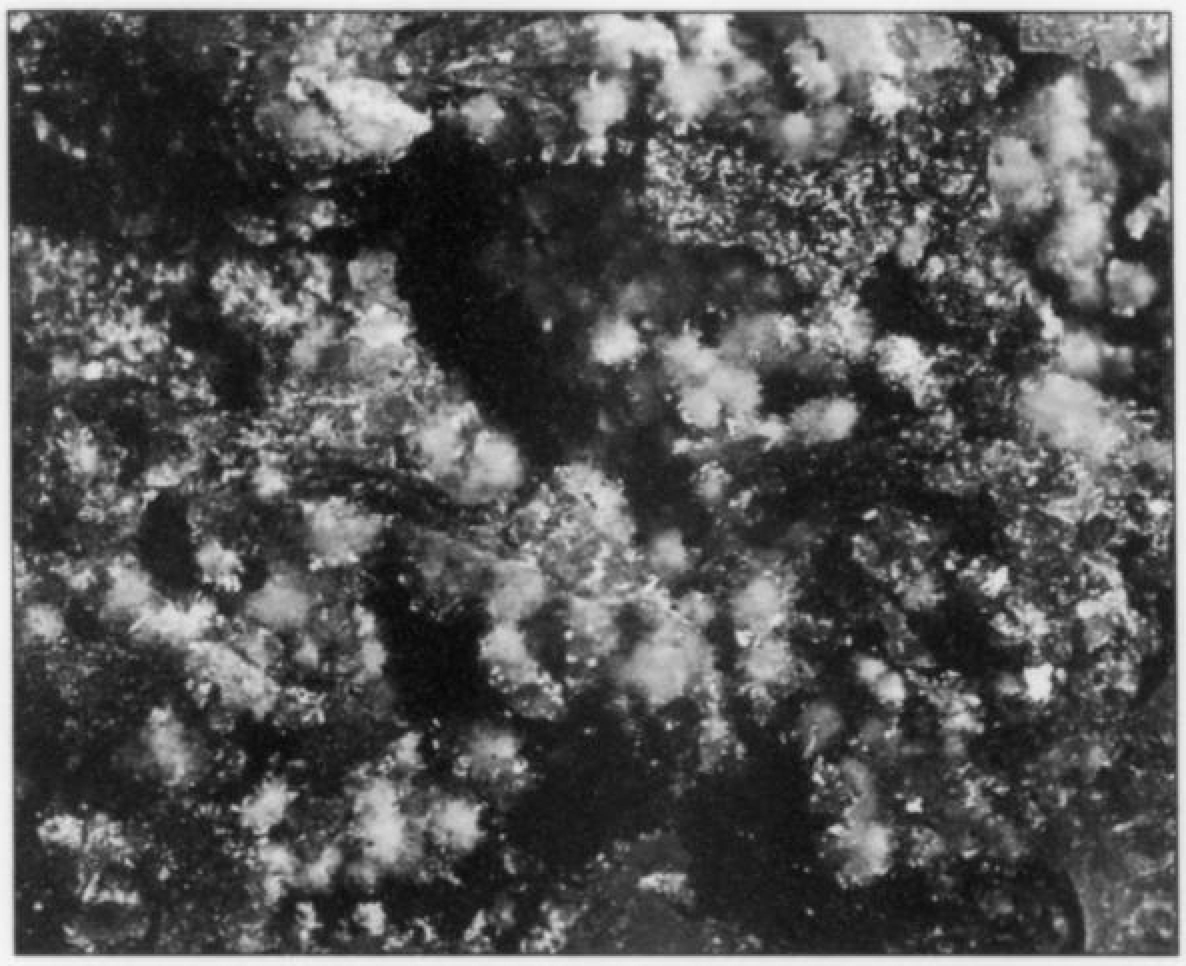


Figure 32. **Aurichalcite from Ightem; field of view 4 mm. J. P. Barral specimen; Robert Vernet photo.**

Figure 33. **Transparent blue azurite crystals, Vein 2, Bou Azzer; field of view 1 cm. G. Favreau specimen; Heinz Dieter Müller photo.**

attractive contrast of colors. Similar rosette-shaped aggregates of aurichalcite have also been found on the dumps at Ightem, from which also come sphalerite, adamite and clinotyrolite.

Austinite $CaZn(AsO_4)(OH)$

Austinite seems to be fairly rare in the Bou Azzer district. Johan *et al.* (1972) described the zinc arsenate from Aghbar as dark yellow-green crusts and pale yellow spherules in quartz and dolomite cavities. Austinite shows four-cornered prisms, some with chisel-shaped terminations, measuring less than 0.3 mm. Associations include roselite, cobalt-rich talmessite and calcite.

Johan *et al.* (1972) also mention a tiny substitution of copper for zinc; however, the substitution of cobalt for zinc is much more significant (mixed crystals of austinite-cobaltaustinite exist). A conichalcite-rich quartzite in Ambed contains bottle-green prisms of possible austinite measuring less than 0.5 mm, with copper-rich adamite.

Azurite $Cu_3^{2+}(CO_3)_2(OH)_2$ and
Malachite $Cu_2^{2+}(CO_3)(OH)_2$

The copper carbonates azurite and malachite are known chiefly in tiny amounts from the Bou Azzer district. The effervescence of malachite in hydrochloric acid distinguishes it easily from the associated copper minerals brochantite and conichalcite. In Vein 2 at Bou Azzer, azurite and malachite accompany chalcopyrite and chalcocite, respectively as elongated blue crystals (with partial pseudomorphing to malachite) and as green, millimeter-size globules with radial structure. In the dolomite of Ightem, azurite (as radial spherules measuring less than 3 mm) and malachite (as spherules measuring less than 1 mm) accompany conichalcite, chrysocolla and especially powellite. Crusts of massive azurite to 10 cm wide on pale sandstone have been found at Oumlil. Discoveries at Aghbar in 2003 yielded malachite specimens to 30 cm, with stout crystals to 5 mm long.

Beudantite $PbFe_3[(As,S)O_4]_2(OH,H_2O)_6$

Beudantite, a secondary lead mineral new to the district, was found with the bromargyrite discovered in brochantite-rich rocks at Ambed 2 (see entry below). This beudantite forms minute brown-green rhombohedral crystals which clearly contain copper.

Bismuth Bi

The re-opening of the Bouismas mine in May 2003 enabled us to take ore samples in the vicinity of the winding shaft. The fresh ore

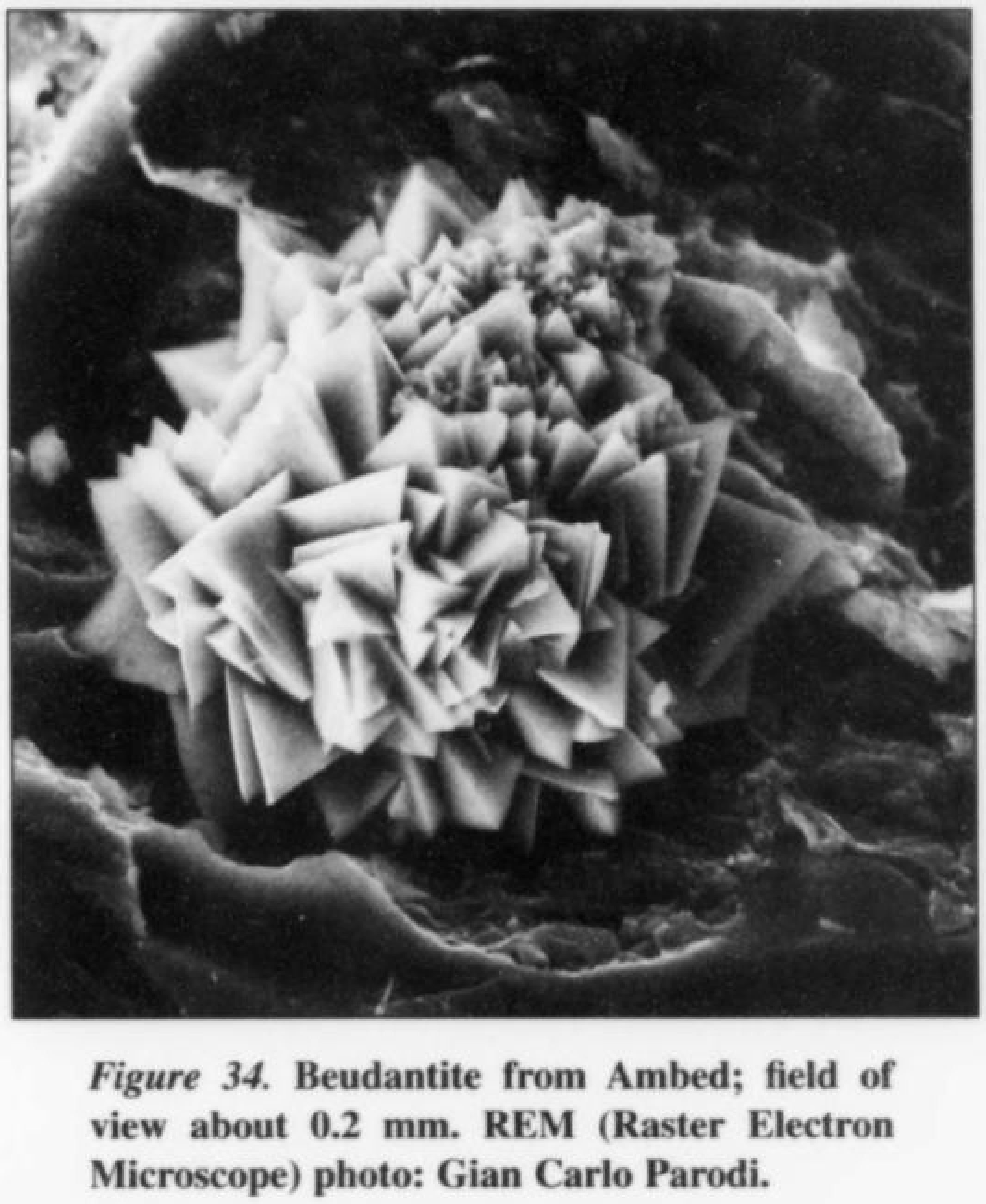


Figure 34. **Beudantite from Ambed; field of view about 0.2 mm. REM (Raster Electron Microscope) photo: Gian Carlo Parodi.**

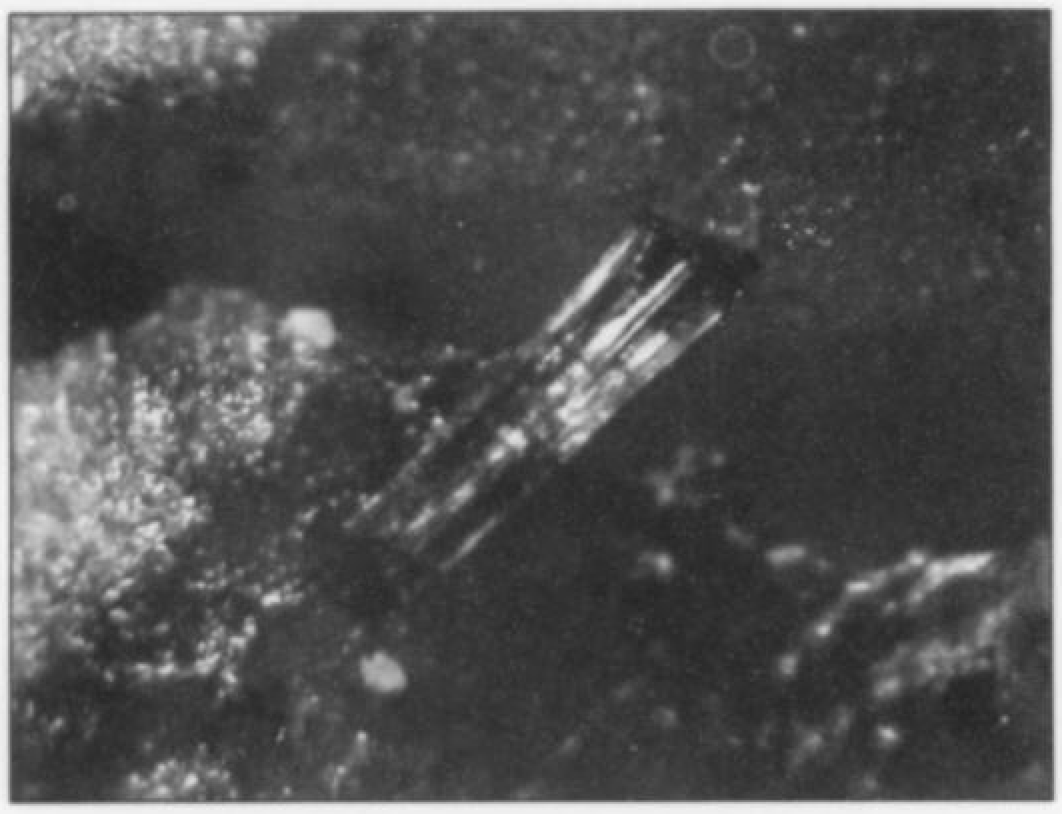


Figure 35. **The best known crystal of bouazzerite, 0.8 mm, from Vein 7, Bou Azzer. G. Favreau specimen and photo.**

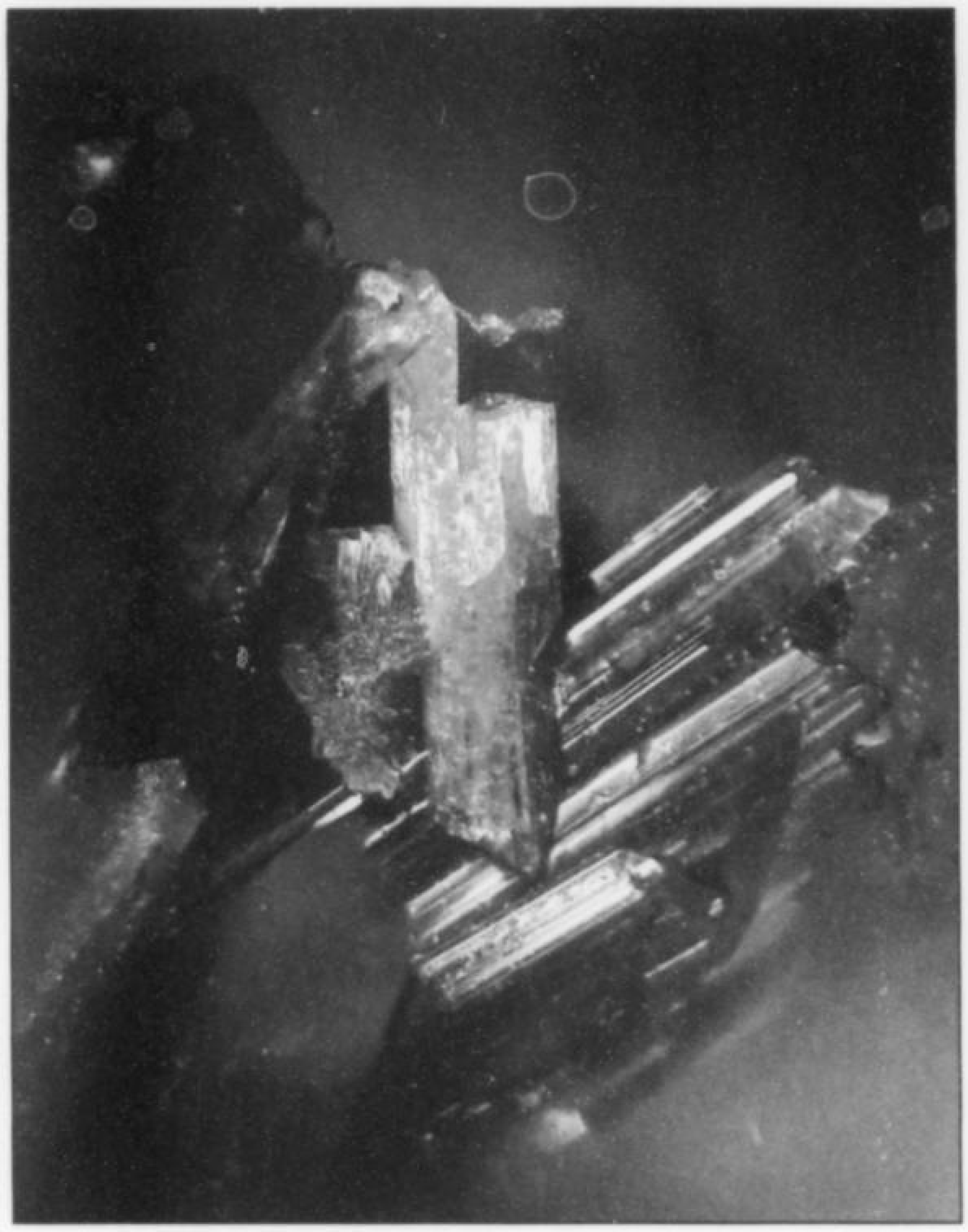


Figure 36. **Green prismatic crystal of bouazzerite on erythrite from Vein 7, Bou Azzer; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

consists predominantly of white calcite and gray arsenides, clearly löllingite or safflorite, shot through with pinkish metallic, cleavable grains of native bismuth. Permingeat (1991) described microscopic bismuth from the district, without giving a specific sublocality.

Bouazzerite

$Mg_{4-5}Bi_3(Fe^{3+},Cr^{3+})_7[O_{12}(OH)_2(AsO_3)_2(AsO_4,CrO_4)_7]\cdot 45H_2O$

A few of the tiny specimens of interesting rare minerals collected during the past decade at Bou Azzer could not at first be identified; these were turned over to the Geological Museum of Lausanne for rigorous testing. Earlier X-ray and EDX analyses permitted the isolation of two unknown species from specimens collected by one of us (GF). With the help of Professors Sergei Krivovichev (University of Innsbruck) and Thomas Armbruster (University of Bern), who determined the crystal structures, we were able to write full descriptions of the two new species. Thus, in autumn 2004, the species bouazzerite and maghrebite, from the Bou Azzer district, were officially approved by the Commission of New Minerals and Mineral Names of the IMA.

Bouazzerite comes from Vein 7 in the Bou Azzer mine—the thick vein of ore which has produced the world's finest erythrite crystals (to 25 cm long!). All known specimens of bouazzerite were taken in May 2001 from an ore car which had just been loaded at Vein 7 and brought to the surface through Shaft Number One. The ore was unusually rich in native gold (according to the mine geologist, it contained up to 100 grams of gold per ton). Erythrite and talmessite/roselite-beta were recognizable in hand specimens of the ore. On the type specimen, on a surface of about 1 square centimeter, bouazzerite is intimately associated with quartz, chalcopyrite, erythrite, chromium-rich yukonite, alumopharmacosiderite, powellite, and an earthy blue-green copper arsenate related to geminite. At the University of Clermont-Ferrand, B. Devouard performed EDX-analyses of a few of these associated minerals and found significant amounts of tellurium; this possibly is attributable to primary bismuth tellurides such as tetradymite or tsumoite having once been present in this gold-rich ore.

Bouazzerite is a product of the oxidation of As-Ni-Fe-Co-Bi ores in quartz/carbonate veins which neighbor serpentinite containing finely divided chromite. The new species forms extremely brittle monoclinic prisms to 0.8 mm; the prism form {021} dominates, with the {110} form appearing at the terminations. Bouazzerite is pale apple-green to bottle-green, transparent, and has an adamantine luster.

Chemically, bouazzerite is an extremely complex, chromium-bearing Mg-Bi-Fe arsenate with arsenite groups and some empty sites in place of magnesium in the crystal structure: $(Mg\square)_{11}Bi_6$-$(Fe^{3+},Cr^{3+})_{14}(AsO_4,CrO_4)_{14}[AsO_3(H_2O)]_4O_{12}(OH)_4(H_2O)_{86}$—this is the formula corresponding to the refined crystal structure. A unique feature of the structure of bouazzerite is the presence of Fe^{3+} in trigonal-prismatic coordination, here noted for the first time in any mineral species.

The name comes from the type locality and particularly from the Bou Azzer mine proper, in recognition of that mine's extraordinary importance to mineralogical science, and the importance of the whole district to mineral collectors. The term "bouazzerite" had earlier been used by the local miners for an iron-rich variety of stichtite, but as a species name it was discredited by Caillère (1942) and again by Paclt (1953). [*Ed. Note:* under International Mineralogical Association rules, a discredited name can be reintroduced for a different new species after 50 years.]

The type material is stored at the Musée Géologique Cantonal in Lausanne, Switzerland (sample MGL #79798 is the holotype and sample MGL #79803 is the co-type).

Brannerite $(U,Ca,Y,Ce)(Ti,Fe)_2O_6$

Brannerite, a highly radioactive oxide, is common in some minor veins in the mining center at Bou Azzer, where it is associated with native gold. It is seen as small, pitch-black grains (showing

Figure 39. **Brochantite from Khder; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

***Figure 37. (above)* A brannerite crystal, 1.1 mm, in quartz from Aghbar. This brannerite is commonly associated with gold. G. Favreau specimen and photo.**

***Figure 38.* Transparent brochantite crystals from Ambed; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

conchoidal fracture) in quartz and as black columnar crystals to 2 mm in massive calcite. Secondary uranospinite and nováčekite occasionally are associated (Bültemann, 1957).

Brochantite $Cu_4^{2+}(SO_4)(OH)_6$

Compact masses of "limonite" with millimeter-size grains of chalcopyrite come from the gossan zone of the Ambed 2 mine; these show tiny druses of acicular, blue-green crystals of brochantite associated with massive azurite and cuprite.

Bromargyrite AgBr

Essaraj (1999) mentioned chlorargyrite in the course of her studies of silver-bearing minerals from the Anti-Atlas Mountains. In the course of our own systematic investigations at Bou Azzer we found another silver halide species—bromargyrite. Among the material from the gossan zone of the Ambed 2 mine are thick masses of "limonite" intergrown with quartz, rich in brochantite and conichalcite and also containing adamite and austinite. Together with these species, bromargyrite occurs as brightly lustrous yellow-orange interstitial fillings which analyses have shown to be poor in Cl and I.

Cabalzarite $Ca(Mg,Al,Fe)_2(AsO_4)_2(H_2O,OH)_2$

Earlier known only from Falotta, Switzerland, the rare Ca-Mg arsenate cabalzarite occurs at Aghbar as minute yellowish grains mixed with arseniosiderite in the matrix of erythrite/talmessite specimens which host crystals of the new species maghrebite.

Calcite $CaCO_3$
Dolomite $CaMg(CO_3)_2$ and
Aragonite $CaCO_3$

Massive beige-colored dolomite is one of the most common gangue species in the district, but dolomite occurs also as distorted, saddle-shaped rhombohedral crystals to 2 cm in cavities in the ore veins. The crystals are pearly white or pink (some of the latter are colored by manganese, not by cobalt), and are commonly associated with colorless calcite.

Calcite appears as rhombohedral cleavages to 20 cm in Vein 52, Aït Ahmane, and in a limestone quarry north of Ightem. Plates to a meter wide covered with short-prismatic, deep pink crystals of cobalt-rich calcite, with individual crystals between 1 and 3 cm, have come from Agoudal since 2001.

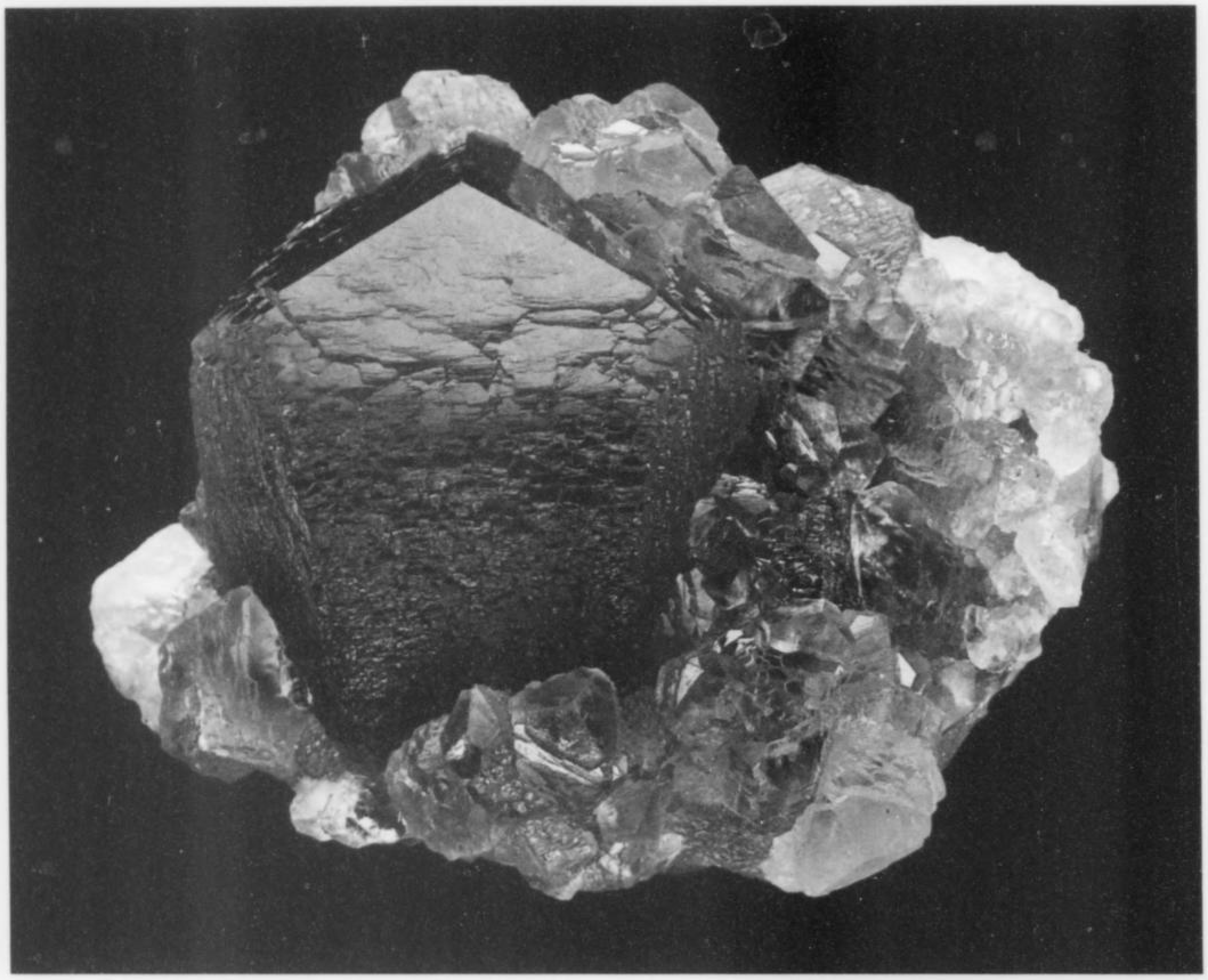


Figure 40. Cobalt-rich calcite, 4.4 cm, from Agoudal; collected in 2003. Astier Minéraux specimen; Jeff Scovil photo.

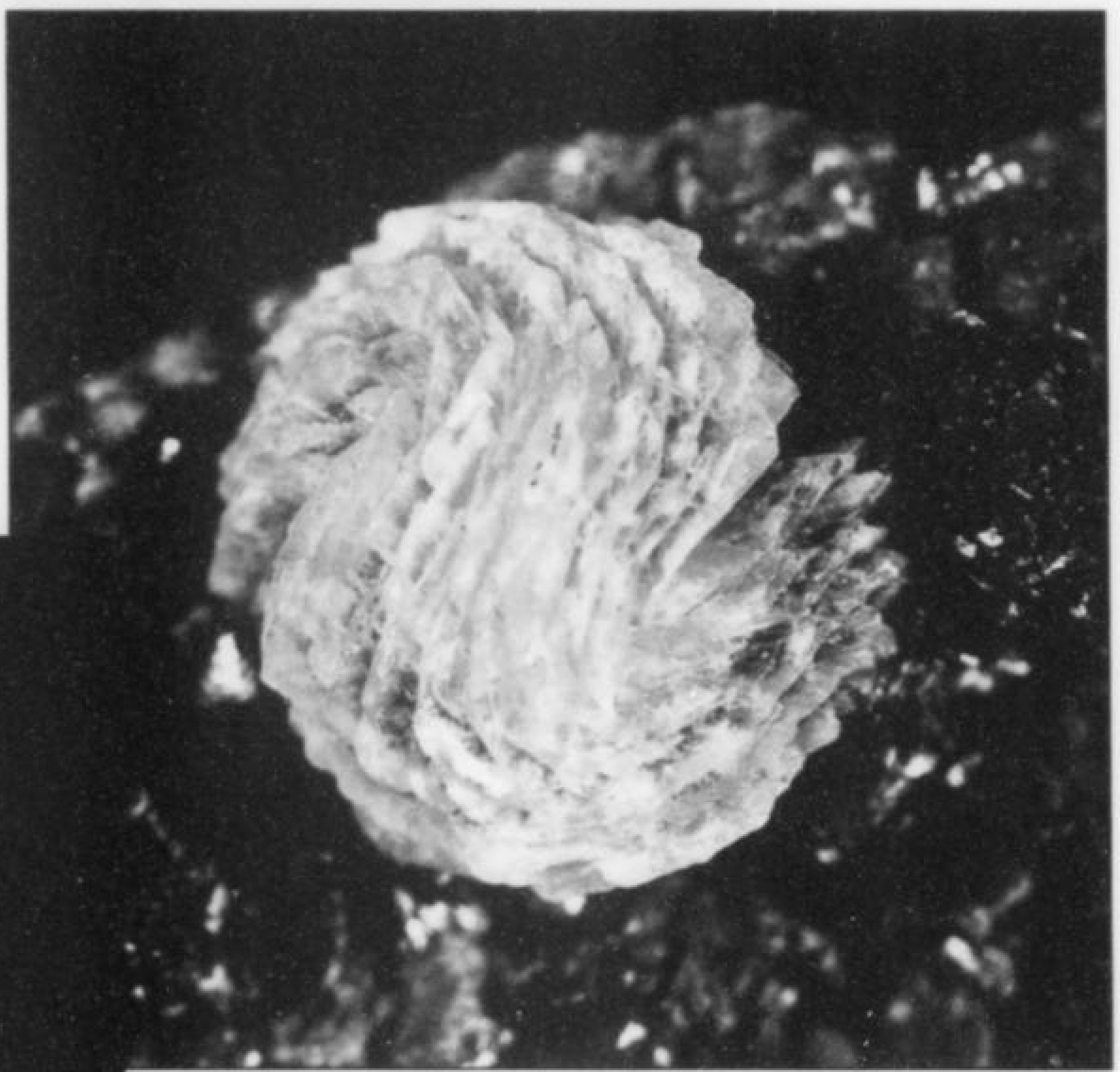


Figure 41. Horsetail-shaped rosette of cobalt-rich calcite, 4 mm, on deep red sphaerocobaltite, from Bou Azzer. G. Favreau specimen; Robert Vernet photo.

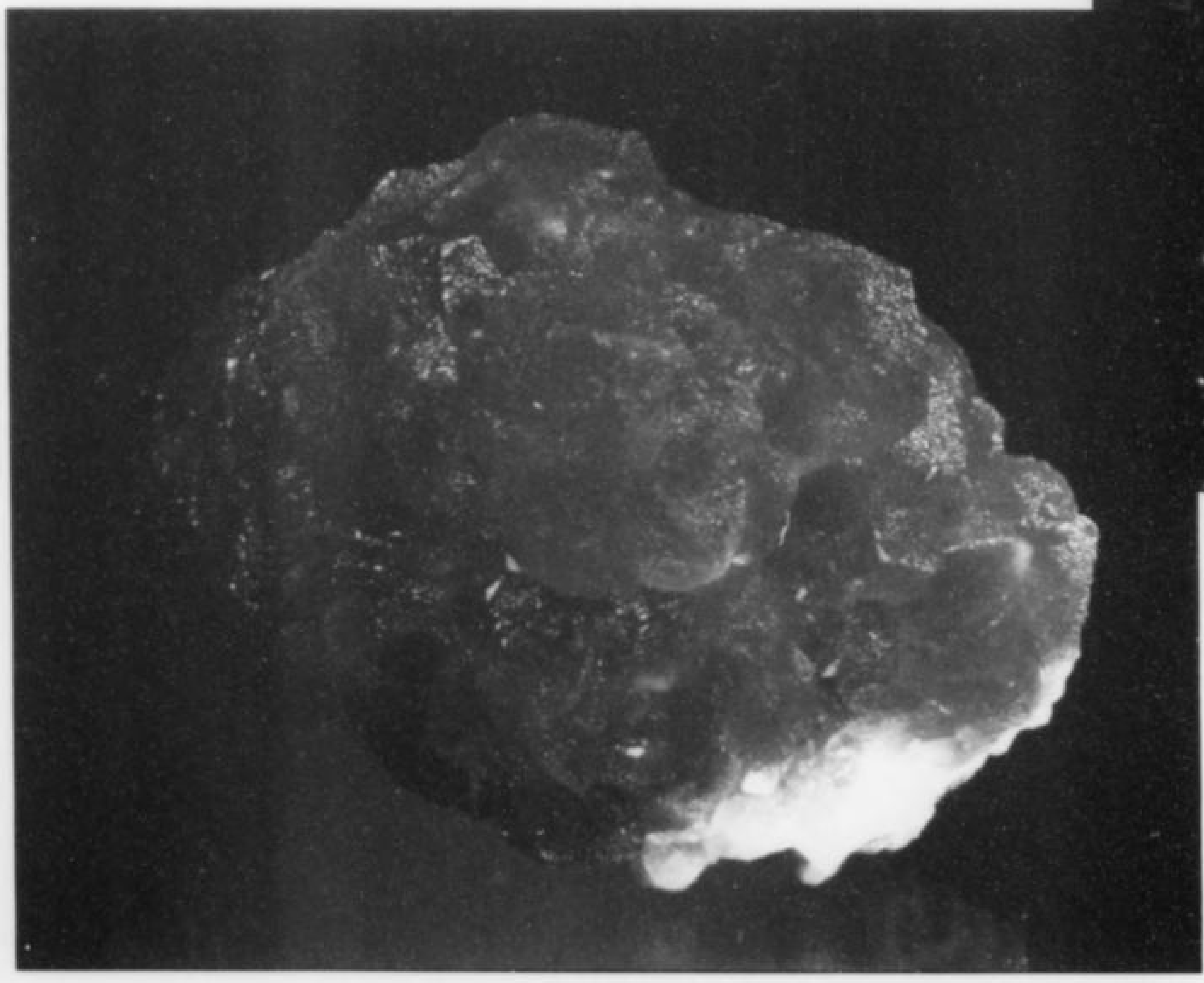


Figure 42. Cobalt-rich calcite, 5.6 cm, from the Aghbar(?) mine, Bou Azzer, Morocco. Jordi Fabre specimen; Jeff Scovil photo.

Figure 43. **In 2002–2003 the Agoudal mine yielded superb specimens of lilac to violet-red cobalt-rich calcite. This is the offering of a dealer near Ouarzazate. Field of view: 40 cm. Georges Favreau photo.**

Figure 44. Cobalt-rich calcite, 8 cm, from the Aghbar(?) mine, Bou Azzer; collected in 2004. Heliodor Minerals specimen; Wendell Wilson photo.

Aragonite is found as encrustations of beautiful, colorless and transparent crystals to 2 cm long in Vein 7, Bou Azzer. In an open pit mine east of Agoudal, veins in chromite ore are entirely composed of small white rods of aragonite; in 2001 a pocket zone there produced brownish yellow, skewer-shaped aragonite crystals to 9 cm long. In Aghbar, small tufts of aragonite crystals rest on druses of roselite-beta and talmessite. Specimens of karibibite from Oumlil may show colorless lamellar crystals of aragonite.

Celestine $SrSO_4$

Celestine from Ightem was described by Leblanc and Levy (1969). The strontium sulfate forms pale yellow to amber-brown, platy crystals in dolomite cavities; most of these crystals measure between 1 and 3 mm, but exceptionally they reach 1 cm. The well-developed {100} faces are matte, but the side faces are lustrous. Commonly associated are hematite in rhombohedral crystals, as well as magnetite, skutterudite and powdery kaolinite in aggregates reaching 3 cm.

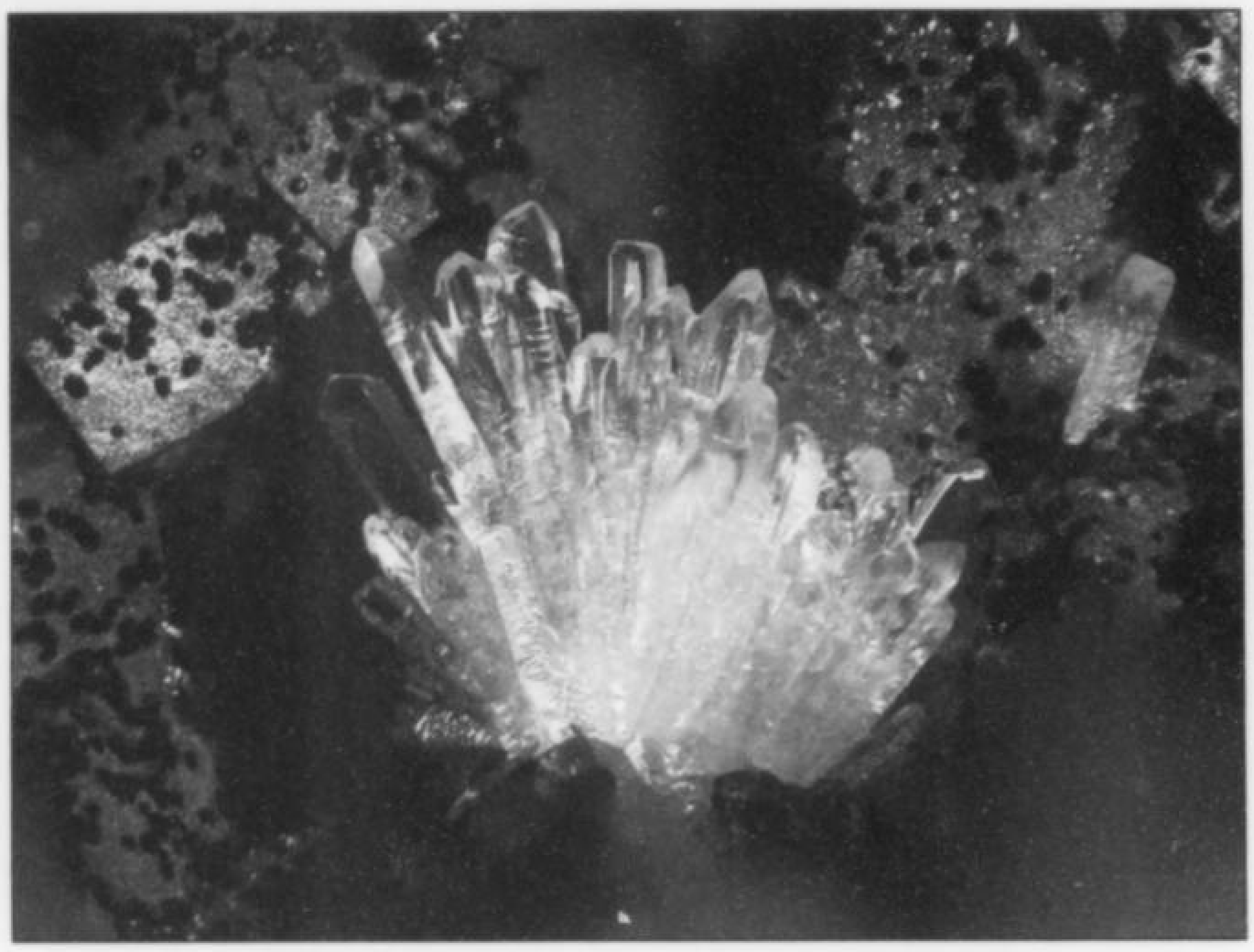


Figure 45. **Aragonite from Tamdrost; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 46. **Chalcocite crystals from Méchoui; field of view 1 mm. G. Favreau specimen; Robert Vernet photo.**

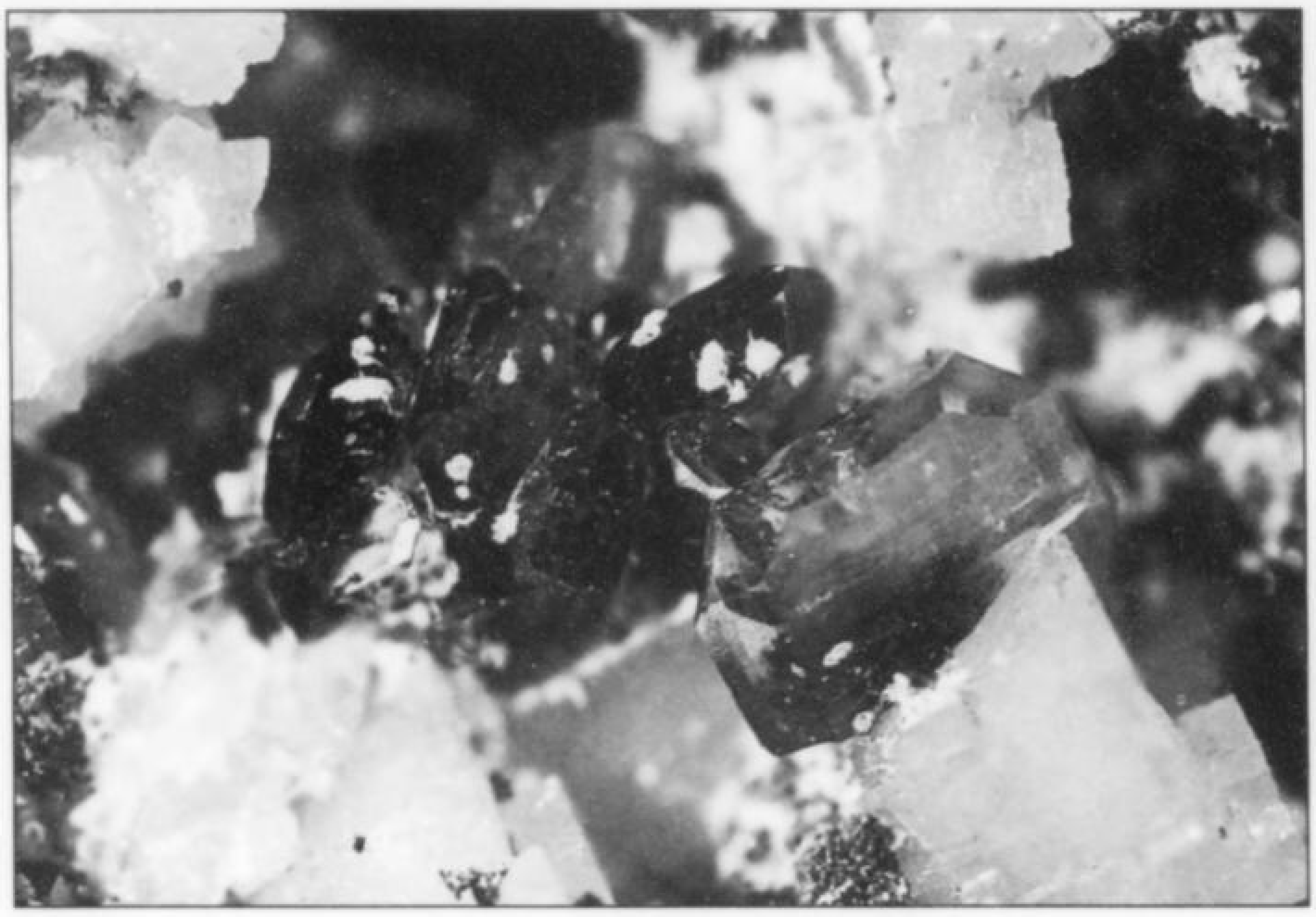


Figure 47. **Honey-colored celestine from Ightem; field of view 4 mm. G. Favreau specimen; Robert Vernet photo.**

Chalcocite Cu_2S

The copper assemblage in the dolomite of Méchoui contains (in addition to lavendulan and conichalcite) abundant chalcocite, as small, black, lustrous crystals. The crystals are tabular and elongated and form V-shaped twins resembling those of plattnerite. Stout chalcocite crystals are found at Bouismas; the largest reach 5 mm (November 2005).

Chalcophyllite $Cu_9Al[(OH)_{12}(SO_4)_{1.5}(AsO_4)_2]\cdot 18H_2O$

One of us (JED) discovered chalcophyllite at Aghbar during the 1970's—unfortunately, it was a one-time find. Tiny (<0.2 mm), bright blue-green tabular crystals of chalcophyllite rest on pink dolomite.

Chromite $Fe^{2+}Cr_2O_4$

Locally chromite occurs in quantities that are mineable as ore. Compact black masses of chromite are distinctive for their density (4.5–4.8) and their magnetism, but above all for their common association of scaly rose-violet stichtite. In Vein 2, Bou Azzer, chromite occurs with quartz in gangue, as pitch-black grains with resinous luster and rarely as tiny (0.5-mm) octahedral crystals which may be acid-etched out of the enclosing dolomite. The edges of these crystals are slightly rounded and dull. Specimens of chromite rich in secondary species, especially talmessite and annabergite, and also containing chromite grains, from Aït Ahmane. Associations with chromite in the district include greenish yellow serpentine, stichtite, uvarovite and transparent gray spherules of prehnite.

Cinnabar HgS

We first identified cinnabar from the district in a sample from Vein 7, Bou Azzer. In this specimen, tiny (<0.1 mm), extremely thin, hexagonal-tabular crystals of cinnabar rest on calcite crystals; also present is pyrargyrite/proustite, as centimeter-size masses with conchoidal fracture. Cinnabar also occurs as tiny orange-red acicular crystals included in transparent calcite.

Clinoclase

(See under Cornubite, Cornwallite, Clinoclase and Strashimirite.)

Clinosafflorite (Co,Fe,Ni)As_2

Clinosafflorite, widespread at Bou Azzer, can be distinguished from safflorite only by X-ray diffraction analysis. In Vein 53 at Aït Ahmane (rich in quartz crystals and fibrous amphiboles), gray, thick-tabular clinosafflorite crystals are associated with octahedral and pyritohedral crystals of nickel-skutterudite.

Clinotyrolite $Ca_2Cu_9^{2+}[(As,S)O_4]_4(O,OH)_{10}\cdot 10H_2O$

Clinotyrolite has been recently identified as pearly blue-green lamellae measuring less than 0.5 mm, in narrow fissures in a zone

Figure 48. **Clinotyrolite from Khder; field of view 3 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 49. **A druse of cobaltarthurite from Oumlil-East; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

of copper-enriched dolomite at Ightem. The mineral also appears near grains of copper sulfide and as chrysocolla pseudomorphs; associated species include conichalcite, lavendulan, annabergite and erythrite.

Cobaltarthurite $Co^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2 \cdot 4H_2O$

The new Co-Fe arsenate cobaltarthurite was discovered in a vuggy gray piece of vein rock in Oumlil-East. Cobaltarthurite forms pale yellow to yellow-brown acicular crystals (<0.5 mm), some in "hedgehog" sprays, associated with karibibite and parasymplesite. At Khder, cobaltarthurite occurs as lustrous, chocolate-brown, platy crystals and rounded crystal groups with arseniosiderite, scorodite and karibibite in cavities in löllingite ore. The crystals, which show no cleavage at all, by far exceed the Spanish type material in both size and quality, allowing a refinement of the structure of whitmoreite-like minerals. Occurring with the cobaltarthurite is an extremely iron-rich member of the arthurite series which may turn out to be a new species.

Cobaltaustinite

(See under Conichalcite-Cobaltaustinite.)

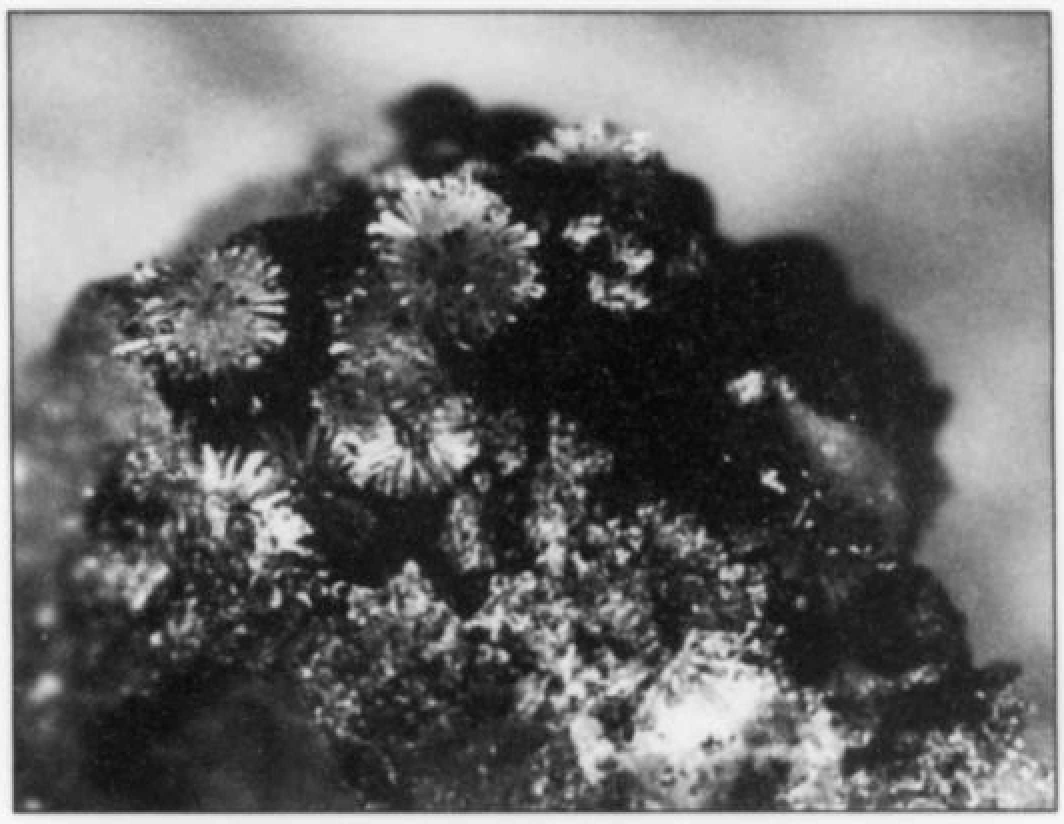


Figure 50. **Cobaltarthurite from Khder; field of view about 3 mm. G. Favreau specimen; Robert Vernet photo.**

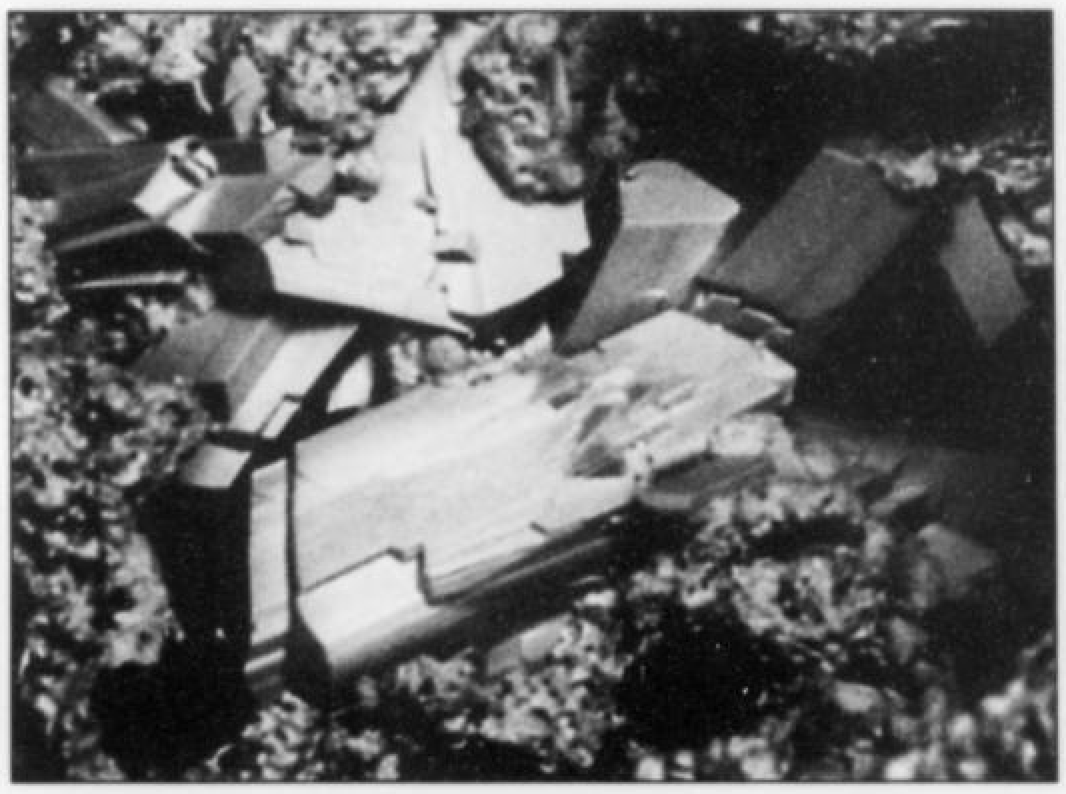


Figure 51. **Short-prismatic cobaltarthurite crystals from Khder, currently among the best crystals known ; field of view 0.4 mm. REM photo by B. Devouard.**

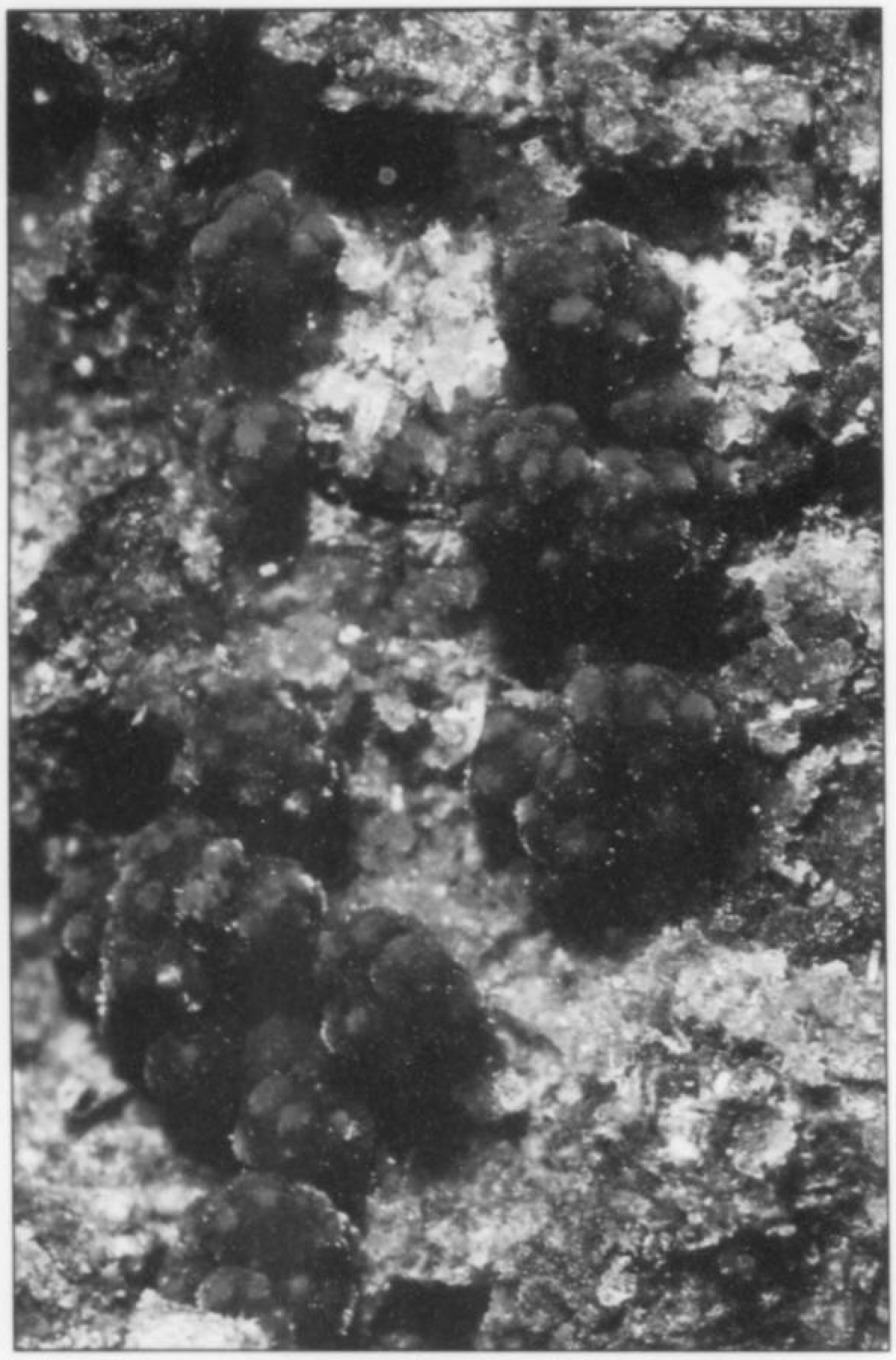


Figure 52. **Richly colored cobaltkoritnigite, from Tamdrost-West; field of view 3.5 mm. G. Favreau specimen; Antoine Iltis photo.**

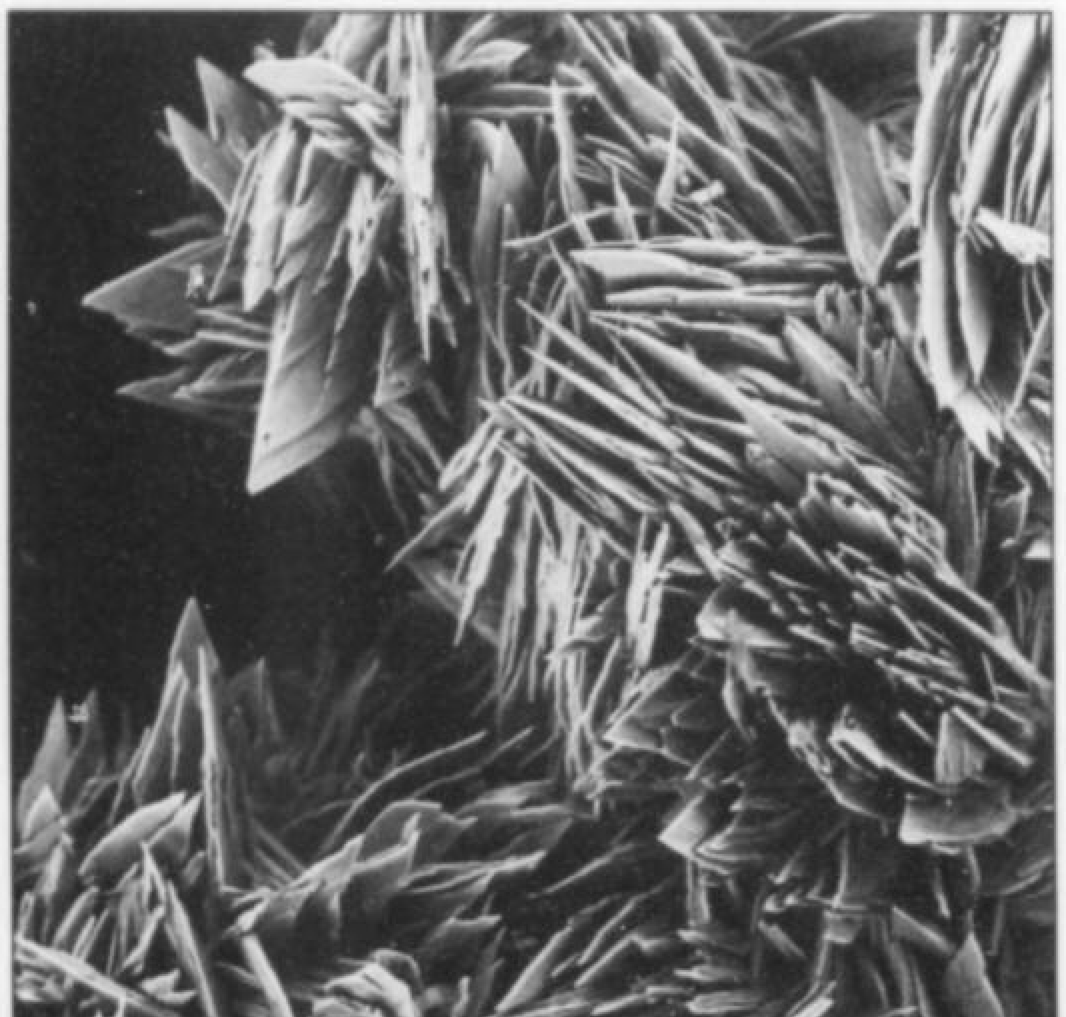


Figure 53. **Cobaltkoritnigite, from Bou Azzer; field of view 0.1 mm. REM photo: Gian Carlo Parodi.**

Cobaltite CoAsS

Cobaltite, one of the most recently formed cobalt sulfarsenides, occurs in minute octahedral crystals associated with erythrite in a safflorite vein. The best crystals are pyritohedrons measuring 7 or 8 mm, found as floaters in a pale brown vein of carbonates. They are of a much paler gray color than skutterudite.

Cobaltkoritnigite $(Co,Zn)(As^{5+}O_3)(OH){\cdot}H_2O$

We have very recently identified cobaltkoritnigite as the most common weathering product of some cobalt ores (skutterudite, etc.). Cobaltkoritnigite from Bou Azzer, unusually, contains no zinc. Pinkish violet efflorescences of this species are widespread on old ore piles, commonly associated with other pink weathering products, chiefly erythrite. The cobaltkoritnigite is more violet-colored and the erythrite more pale pink to red. On wet specimens, as are sometimes collected in old mine tunnels, it is more difficult to distinguish this difference. Cobaltkoritnigite seems to be somewhat soluble in water and may be partially washed away by rain.

Well-developed crystals are very rare. Particularly on the old dumps of Vein 2, Bou Azzer, excellent lance-shaped crystals form aggregates to 1 mm, but easily the best cobaltkoritnigite specimens are those found in early 2000 in the oxidation zone at Aghbar. These display dark violet spherical masses to 5 mm, composed of thin, elongated lamellae; in some cases, red-violet rosette-like structures to 2 mm can be recognized. At Tamdrost, dark violet, velvety-looking botryoids of cobaltkoritnigite to 1 mm occur in cavities in weathered, erythrite-rich skutterudite. By contrast to the ubiquitous erythrite, which is found in cavity zones and small veins everywhere in the district, cobaltkoritnigite is found preferentially—and never alone—in cavity zones which are rich in arsenolite.

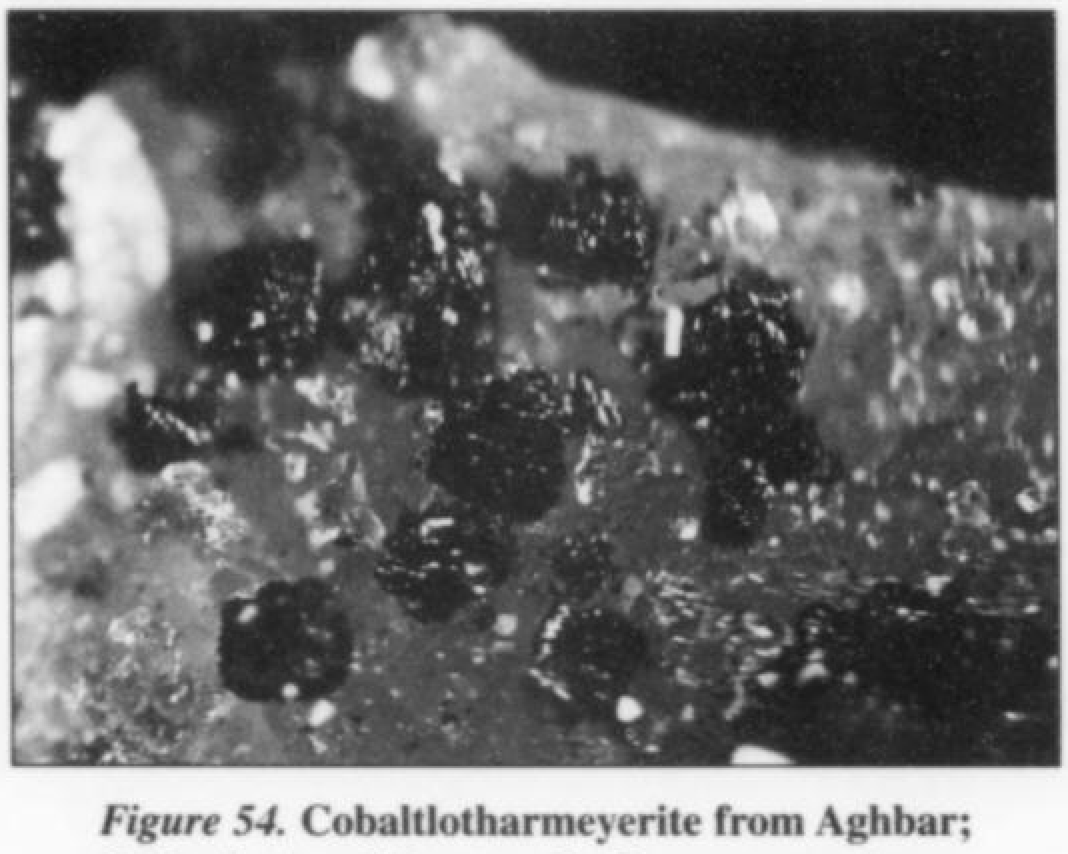


Figure 54. **Cobaltlotharmeyerite from Aghbar; field of view 1.7 mm. G. Favreau specimen; Robert Vernet photo.**

Cobaltlotharmeyerite $Ca(Co,Fe^{3+},Ni)_2(AsO_4)_2(OH,H_2O)_2$

The district's first cobaltlotharmeyerite was found in vuggy pink dolomite in Vein 2, Bou Azzer, as tiny (<0.1 mm) acicular crystals and crystal sheaves resembling goethite. The association with roselite, roselite-beta and sphaerocobaltite, however, pointed to a Co-Fe arsenate, and in 1992 an analysis carried out by H. Sarp in Geneva confirmed this. Cobaltlotharmeyerite was first characterized as a species by Krause *et al.* (1999), based on specimens from Schneeberg, Saxony, but Sarp and Favreau (2000) described the second—and the world's best—occurrence at Bou Azzer. This mineral, a member of the tsumcorite group, forms brown-orange to dark brown-red crystals, greatly elongated along [010], which cluster in tufts, rosettes, and spindle-shaped or lance-shaped aggregates. Its

Figure 55. **Cobaltlotharmeyerite from Vein 2, Bou Azzer; field of view 0.4 mm. REM photo by Gian Carlo Parodi.**

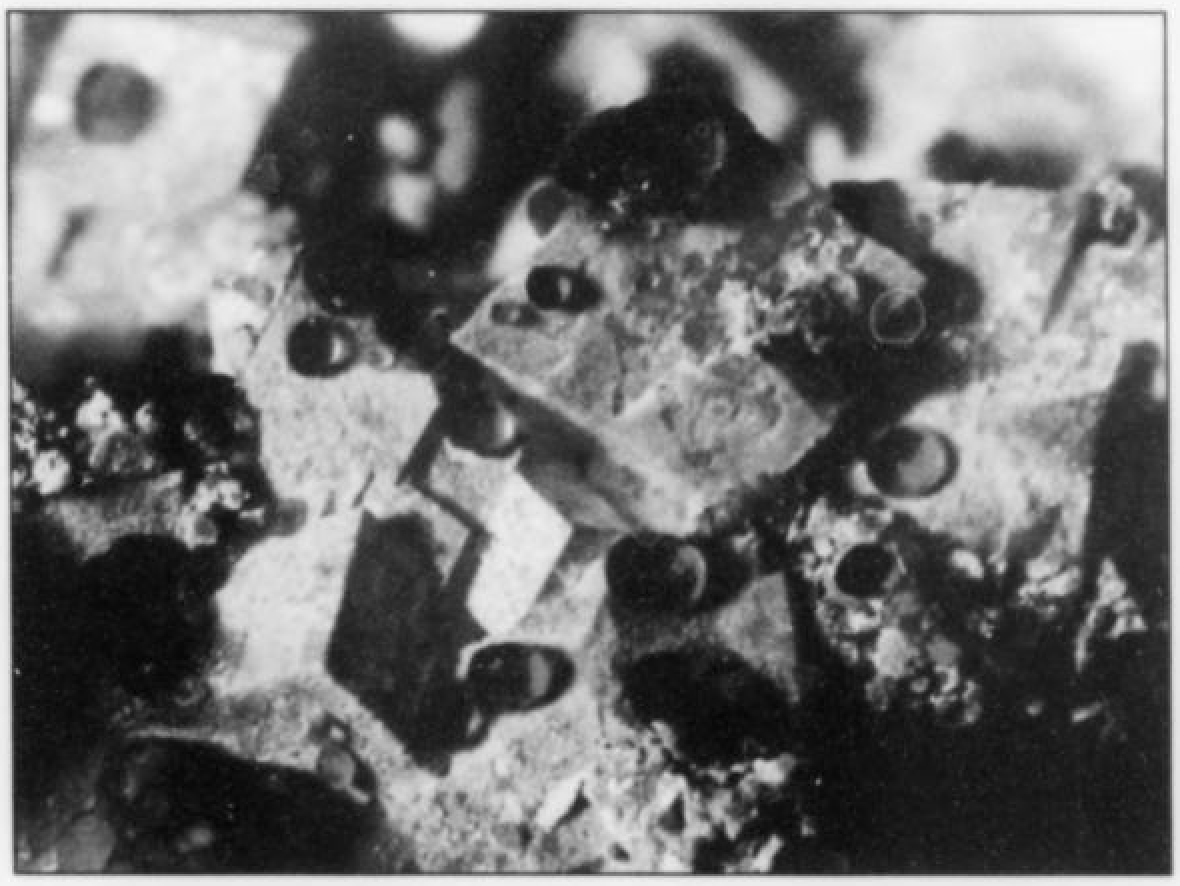


Figure 56. **Conichalcite on dolomite from Ightem; field of view 3 mm. G. Favreau specimen; Antoine Iltis photo.**

associations in Vein 2 include cobaltaustinite and picropharmacolite, brown-red hematite lamellae and colorless prismatic crystals of calcite. The crystals of cobaltlotharmeyerite rest directly on dolomite crystals; as a rule they are free-standing and do not exceed 0.1 mm. At the same occurrence, cobaltlotharmeyerite also forms spherical aggregates, less than 1 mm in diameter, composed of brown, right-angled leafy crystals (resembling roselite-beta); these spherules are sprinkled with younger, minute crystals of quartz.

In April and May 2002 the workings on Vein 2 yielded the finest known specimens of cobaltlotharmeyerite, in excellent crystals—lustrous brown-red, slightly convex lamellae, either free-standing as individuals or aggregated in dark brown fans to 3 mm. These crystals form linings to 1 cm^2 in cavities in quartz and dolomite, with hematite and roselite-beta.

We observed similar cobaltlotharmeyerite crystals, with pale pink roselite-beta crystals, on a dolomite specimen from Aghbar which J. E. Dietrich collected in the 1960's. After 2000, cobaltlotharmeyerite was also identified from the new open-pit mine at Aghbar. Tiny orange-brown "hedgehog" sprays and leafy aggregates (<0.5 mm) are fairly common in several cavity zones in the pale pink dolomite, where its associations include dark green spherulitic cobaltaustinite and large crystals of cobalt-rich talmessite. These are the richest specimens to have come to our notice. In some of them the radial spherules of cobaltaustinite are profusely "garnished" by radiating acicular cobaltlotharmeyerite crystals, creating shapes which suggest floating mines. With the ongoing development of the open-pit mine, cobaltlotharmeyerite has also been identified from a strongly oxidized ore zone rich in erythrite, associated with fine wendwilsonite crystals and with mansfieldite.

In 1998, on a talmessite specimen from a dump of Vein 52, Aït Ahmane, we identified a manganese-bearing variety of cobaltlotharmeyerite, seen as red-brown crystal sheaves measuring less than 0.2 mm. Unfortunately the dump, on which we also found nickellotharmeyerite, was cleared away in 2001.

Conichalcite $CaCu^{2+}(AsO_4)(OH)$ and
Cobaltaustinite $CaCoAsO_4(OH)$

Green-hued members of the conichalcite-cobaltaustinite series are the most widely distributed secondary copper minerals in the Bou Azzer district, but unfortunately they form good crystals only very rarely.

The calcium-copper end-member **conichalcite**, recently identified at the locality, was found in Vein 2, Bou Azzer, as warty crusts,

Figure 57. **Excellent crystals of cobaltaustinite, from Vein 2, Bou Azzer; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

bright spherules, and tiny (<0.1 mm) yellow-green, transparent crystals, with roselite and roselite-beta. In the Méchoui deposit, conichalcite, with erythrite, forms transparent, smooth-surfaced spherules. They are apple-green, but rest on dark matrix and thus appear almost black. Smooth, transparent spherules associated with malachite, azurite, powellite and talmessite have been found in the dolomite of Ightem. In the Oumlil-East open-pit mine, bright green botryoidal layers of conichalcite with chrysocolla are interspersed through masses of weathered serpentinite. At Ambed, conichalcite occurs locally as velvety spherules, partly or wholly encrusted with

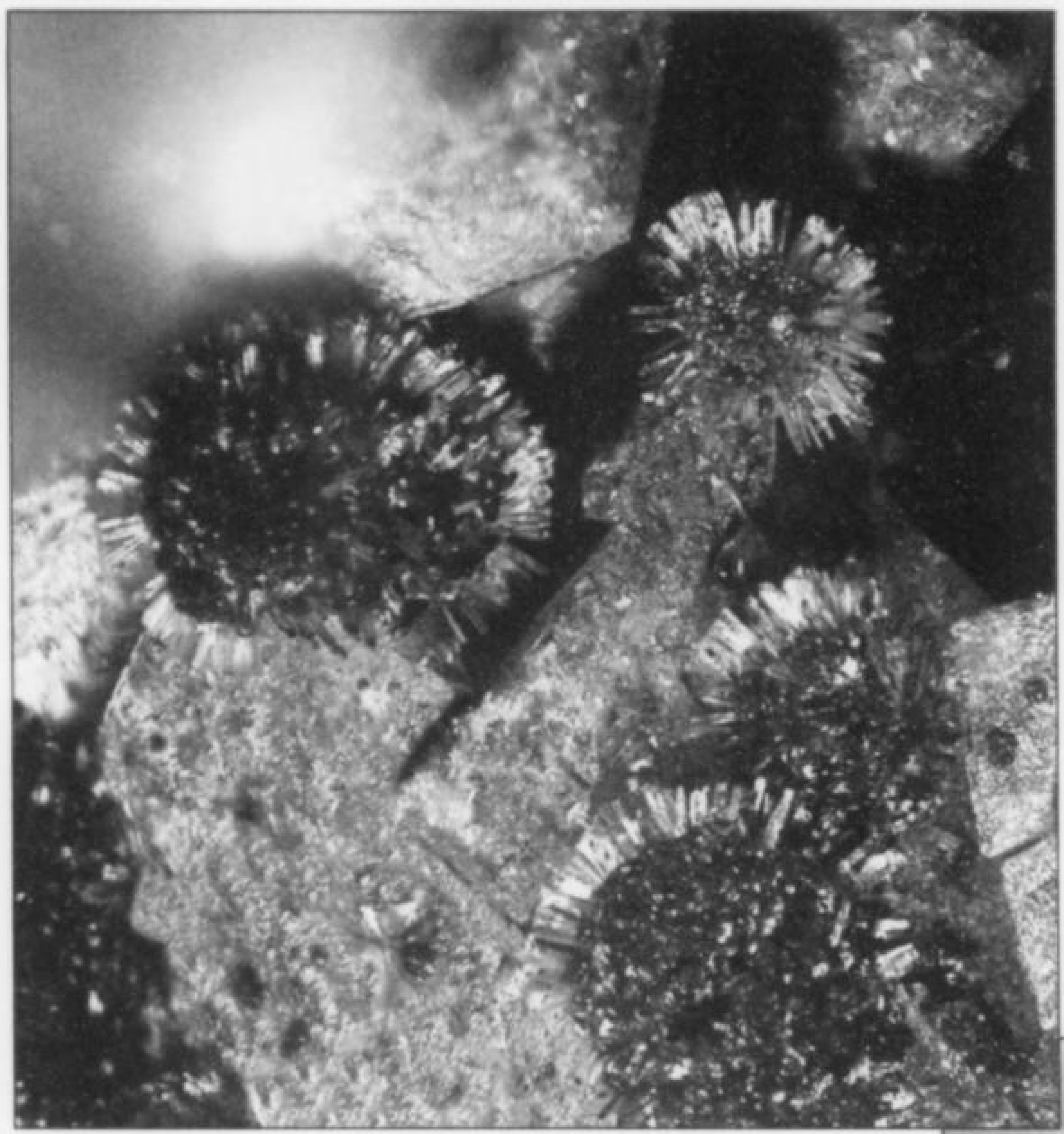


Figure 58. **A rare epitactic growth: green cobalt austinite spheres overgrown by brown acicular crystals of cobaltlotharmeyerite, from Aghbar; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 59. **Cobaltaustinite on dolomite, from Aghbar; field of view 3 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 60. **Deep green cobaltaustinite, from Vein 2, Bou Azzer; field of view 3 mm. G. Favreau specimen; Robert Vernet photo.**

colorless quartz crystals, in brochantite-bearing masses of quartz. At Aghbar, conichalcite rests on transparent, elongated quartz crystals, associated with black heterogenite. In the oxidation zone exposed in this open-pit mine, transparent deep green conichalcite spherules commonly encrust grains of chalcopyrite and chalcocite from which they have obviously formed. Testing by Stefan Weiß shows that most of this conichalcite contains some cobalt ($Co_{0.1\text{-}0.3}Cu_{0.9\text{-}0.7}$), such that the outer edges of the spherules may consist of cobaltaustinite ($Co_{0.6}Cu_{0.3}Zn_{0.1}$). Conichalcite may be confused either with malachite (which is much rarer) or with cobaltaustinite (which is generally better crystallized).

Cobaltaustinite has its own notable occurrences in the district. From our first visit to Aghbar we noticed bottle-green, elongated, chisel-shaped crystals which form sheaf-shaped aggregates and radiating groups; some highly distorted, doubly terminated tetragonal prisms resemble octahedrons. At first we believed that this material was olivenite—but analyses at the Geneva Museum revealed it to be the rare Ca-Co arsenate cobaltaustinite, described in 1988 from Dome Rock, Australia and already considered by Johan *et al.* (1972) to be possibly present in the Bou Azzer district (the mineral was later found on specimens collected by J. E. Dietrich in the 1960's). The world's largest cobaltaustinite crystals—to 3 mm—came from an isolated discovery in Schneeberg, Saxony (Martin and Schlegel, 1992).

The new occurrence in the open pit mine at Aghbar has yielded the richest material to date—with superb single crystals of cobaltaustinite to 2 mm long. These crystals come from a quartz vein where they are associated with pink tabular crystals of roselite-beta and with orange leafy crystals of cobaltlotharmeyerite; the latter seem to have formed at the same time as cobaltaustinite but earlier than the crystals of roselite-beta, which are overgrown on the cobaltaustinite. A pale-colored dolomite vein contains cobaltaustinite as flattened yellow-green crystals, some with blunt terminations, as well as compact, deep green spherules associated with roselite. These spherules have a high copper content, especially in their cores. Olive-green, millimeter-size cobaltaustinite spherules, some with cores of conichalcite, are fairly widespread in the open-pit mines at Aghbar, accompanied by roselite-beta and cobaltlotharmeyerite.

Vein 2, Bou Azzer, yields zinc-rich cobaltaustinite as tiny dark green spherules associated with roselite and hematite. Samples tested by Stefan Weiß contain iron and manganese in addition to zinc, and in some cases nickel as well ($Co_{0.6}Zn_{0.3}Ni_{0.1}$).

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

Connellite was collected quite recently at Ightem, in a remarkable "sulfate paragenesis" where it is associated with gypsum, copper sulfides and deep brown grains of sphalerite, in fissures in a block of dolomite. The connellite forms dark blue coatings (more intensely

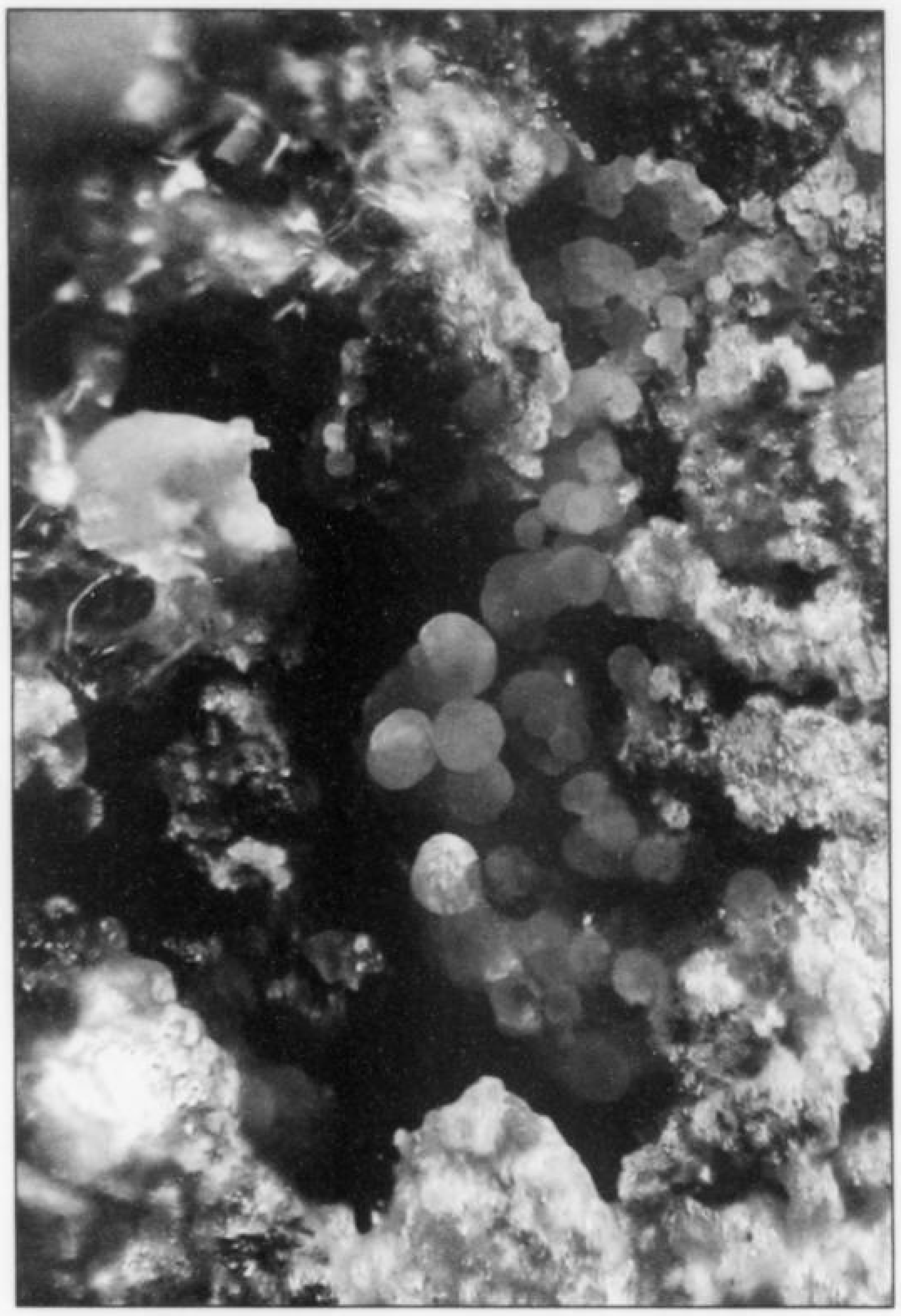


Figure 61. **Spherules of connellite from Ightem; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

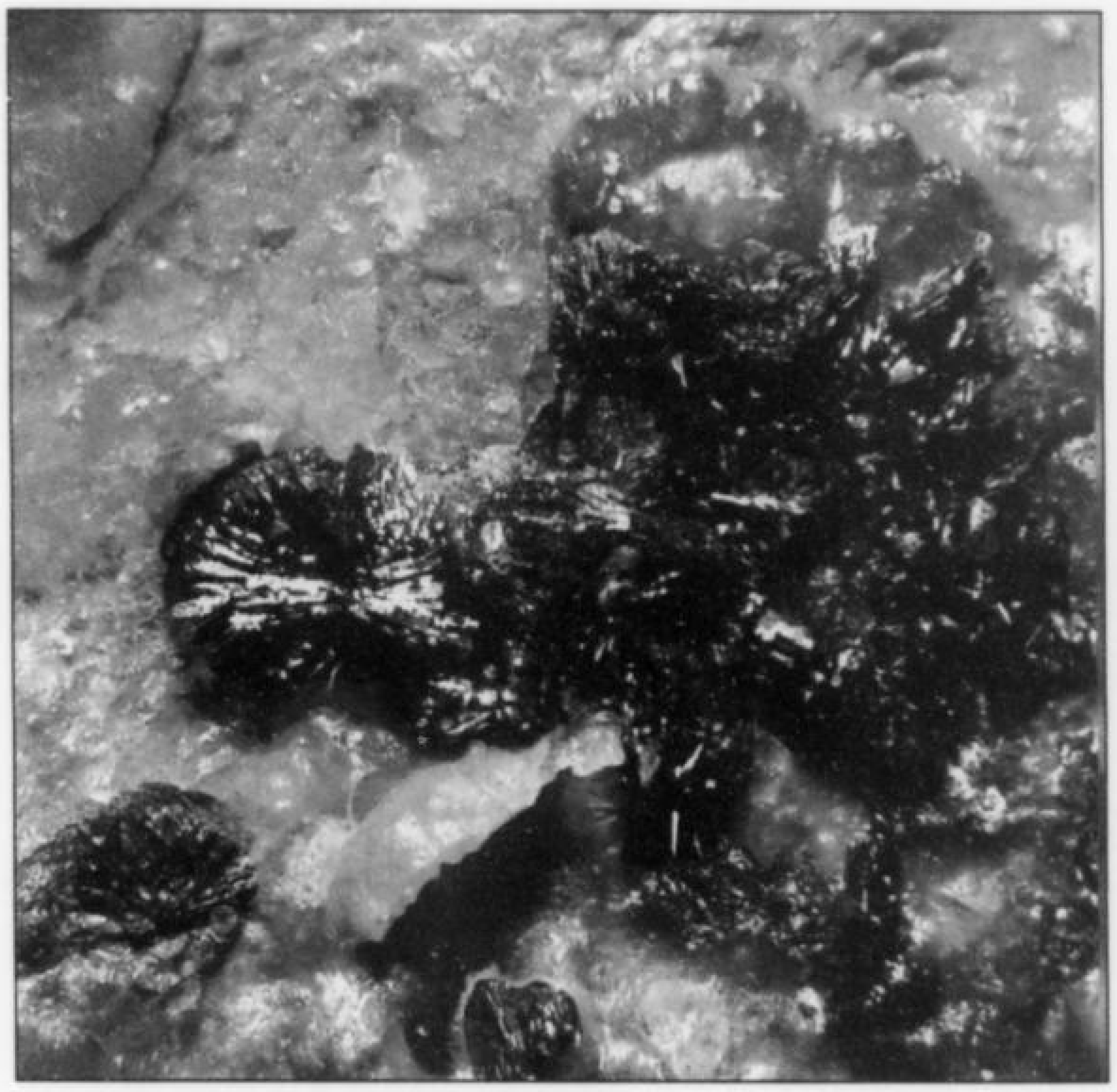


Figure 62. **Clinoclase from a recent discovery at Khder; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

colored than lavendulan) and velvety blue spherules measuring less than 0.1 mm, on small plates of chalcopyrite.

Copper Cu

At Oumlil copper occurs as small grains, in some cases with pharmacosiderite and karibibite, and in other cases with small masses of cuprite coated by conichalcite in a section containing lavendulan and cuproaustinite. Occasionally copper is seen as very thin, lustrous lamellae on the margins of cobaltaustinite spheres which are found embedded in colorless crystals of quartz. At Méchoui I, native copper has been found intergrown with cuprite and also associated with scorodite. It occurs with acicular cuprite at Taghouni and with geminite at Khder.

Cornubite $Cu_5^{2+}(AsO_4)_2(OH)_4$
Cornwallite $Cu_5^{2+}(AsO_4)_2(OH)_4$
Clinoclase $Cu_3^{2+}(AsO_4)(OH)_3$ and
Strashimirite (?) $Cu_8^{2+}(AsO_4)_4(OH)_4 \cdot 5H_2O$

At Khder, in a quartz vein, we discovered an interesting suite of copper arsenates, all new for the Bou Azzer district. Tiny (<0.2 mm), glossy balls of **cornubite** rest in quartz cavities with pale violet-brown scorodite. **Cornwallite** appears as tiny dark green crystals, while **clinoclase** forms greenish blue, radiating crystal groups. Sharp, pale green, millimeter-size crystals, possibly of **strashimirite**, are associated with lavendulan.

Cornwallite

(See under Cornubite, Cornwallite, Clinoclase and Strashimirite.)

Cuprite Cu_2O

In Méchoui, red acicular crystals of cuprite to 0.5 mm are associated with conichalcite, lavendulan and chalcocite in blocks of vuggy pink dolomite. In a quartz boulder infused by chalcopyrite from Vein 2, Bou Azzer, cuprite appears as lustrous, resinous grains and, in cavities, as millimeter-size, nearly black octahedral crystals associated with abundant spherules of conichalcite.

Cyanotrichite $Cu_4^{2+}Al_2(SO_4)(OH)_{12} \cdot 2H_2O$

At Khder, cyanotrichite forms pale blue, in part finely fibrous crusts on vein quartz, with many other secondary copper minerals.

Dolomite

(See under Calcite, Dolomite and Aragonite.)

Erythrite $Co_3(AsO_4)_2 \cdot 8H_2O$

Erythrite is *the* mineral which every collector automatically associates with Bou Azzer. From there come the world's best crystals and richest specimens of the species, far surpassing even the best of the "historical" finds from Schneeberg, Upper Saxony. The very finest erythrite specimens have come from Vein 7 at Bou Azzer. During the 1960's and 1970's, specimens showing erythrite crystals to 2 cm were not unusual from this vein; crystals to 6 cm are documented. According to Jouravsky (1952), crystals from 20 to 25 cm long were met with at the beginning of mining in "*Filon 7*."

After many years during which no further noteworthy finds were made, Vein 7/5 at Bou Azzer began again in 2000 to produce outstanding specimens of erythrite, with deep violet crystals from 1 to 2 cm. The most recent spectacular find came in February 2005 at Oumlil. These specimens show elongated flattened erythrite crystals to more than 3 cm and acicular crystals to 2 cm.

Unfortunately, well-preserved specimens with large crystals are not at all common. Because erythrite forms thin, leafy crystals and is very soft and non-elastic (like vivianite and gypsum), it is difficult to collect and transport without damage. Also, the crystals can have a heavy, dark violet patina which imparts a matte luster. Nevertheless, superlative specimens exist, with centimeter-size crystals showing an intense color and brilliant luster. The smaller crystals are not so deeply colored but are often perfectly formed and wholly transparent.

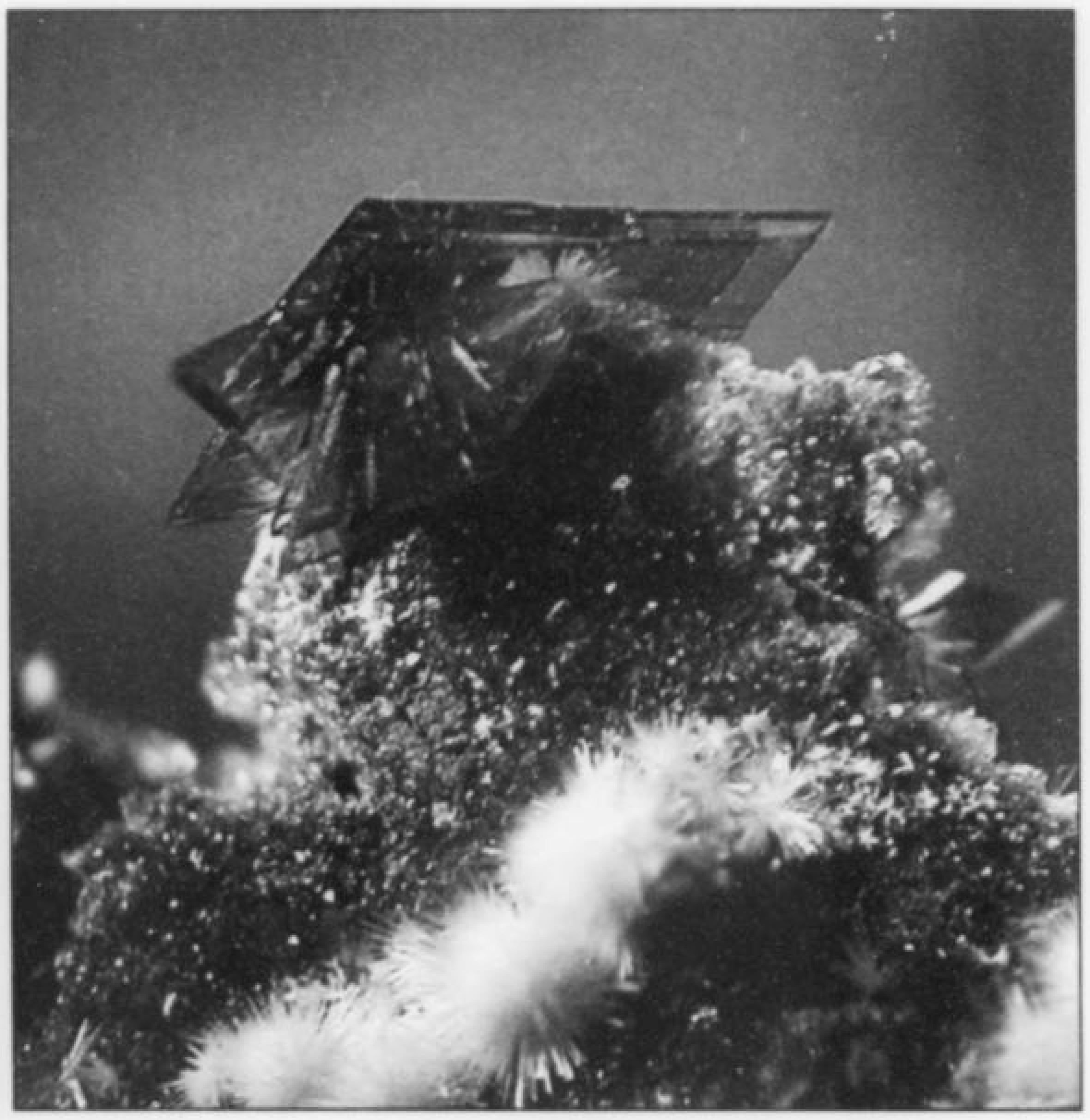


Figure 64. **Erythrite with picropharmacolite, from Vein 2, Bou Azzer; field of view 8 mm. G. Favreau specimen and photo.**

Figure 63. **Typical erythrite crystal, 2.5 mm, from Vein 2, Bou Azzer. G. Favreau specimen and photo.**

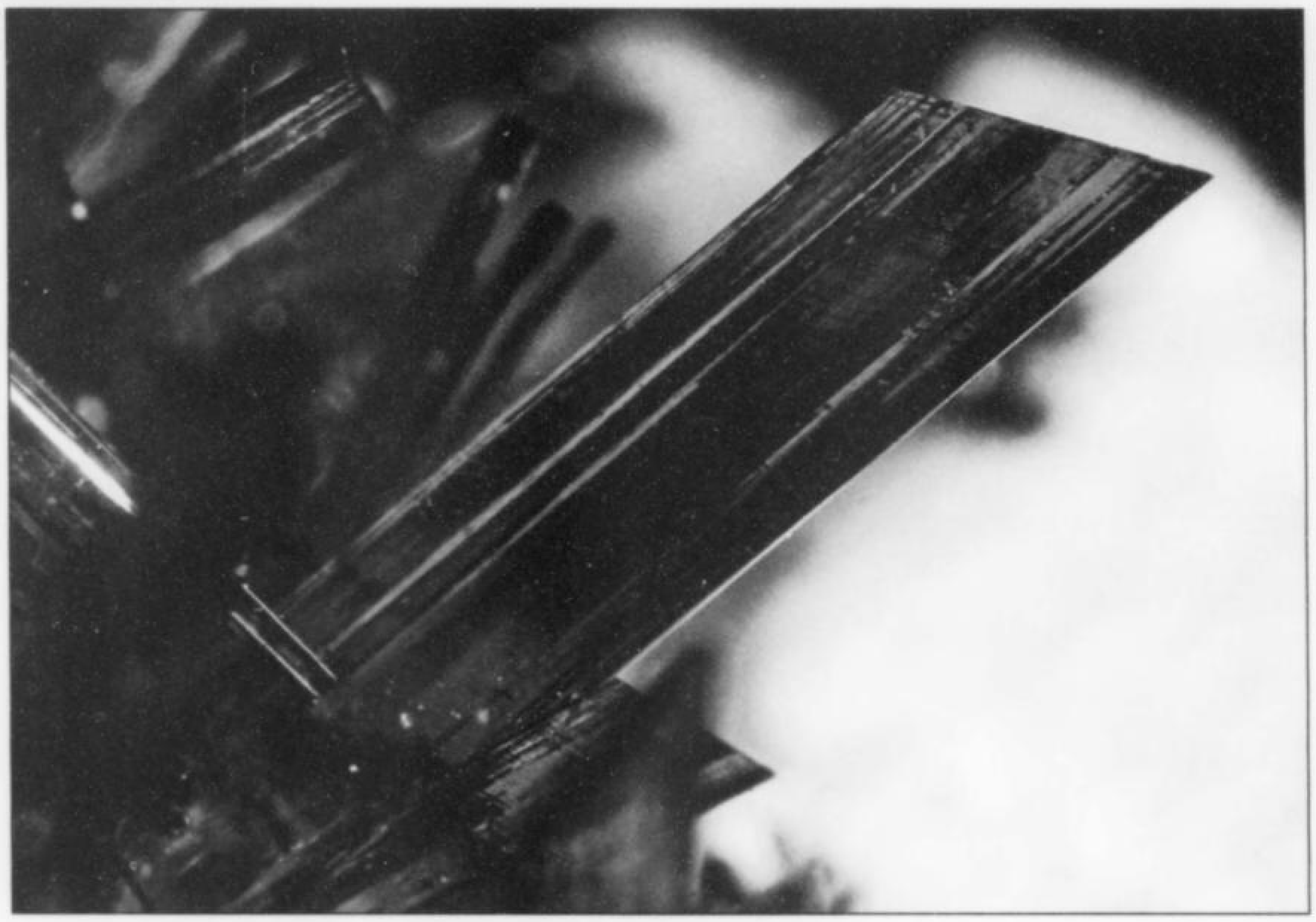


Figure 65. **Erythrite, transparent violet-red crystal, 3 mm, from Bou Azzer. G. Favreau collection; Robert Vernet photo.**

Erythrite is found everywhere in the Bou Azzer mining district. On many dumps the pieces of ore have an earthy pink color (Vein 52, Aït Ahmane), as the cobalt arsenides and sulfarsenides (skutterudite, etc.) have altered to erythrite, which has then altered further to other weathering products. Erythrite also occurs, commonly well-crystallized, at depths to 300 meters—for instance at Aghbar, where there is an unusually deep oxidation zone.

Erythrite, then, is found in widely differing habits, from earthy coatings to very fine crystals. In narrow cavity zones it occurs as more or less compact spherules with velvety surfaces. Millimeter-size as a rule, these spherules are mostly bright pink, in part because of the thinness of the crystals, and in part because of the presence of magnesium (i.e. they are erythrite-hörnesite intermediate crystals). The common associations in this case are cobaltkoritnigite (as small, dark violet masses), arsenolite (as tiny white to pale violet octahedral crystals with prominent adamantine luster) and lavendulan (turquoise-colored spherules in chalcopyrite-bearing zones). In old, wet mine tunnels at Aghbar, old ore piles are seen to be spotted with fluffy, newly formed "blooms" of erythrite which, with drying, quickly turn white.

Erythrite rests most commonly on quartz, dolomite and skutterudite. Particularly on skutterudite ore the erythrite crystals form piles, sometimes of several generations: large, dark tabular crystals rest beside small, pale spherules of younger erythrite formed, cer-

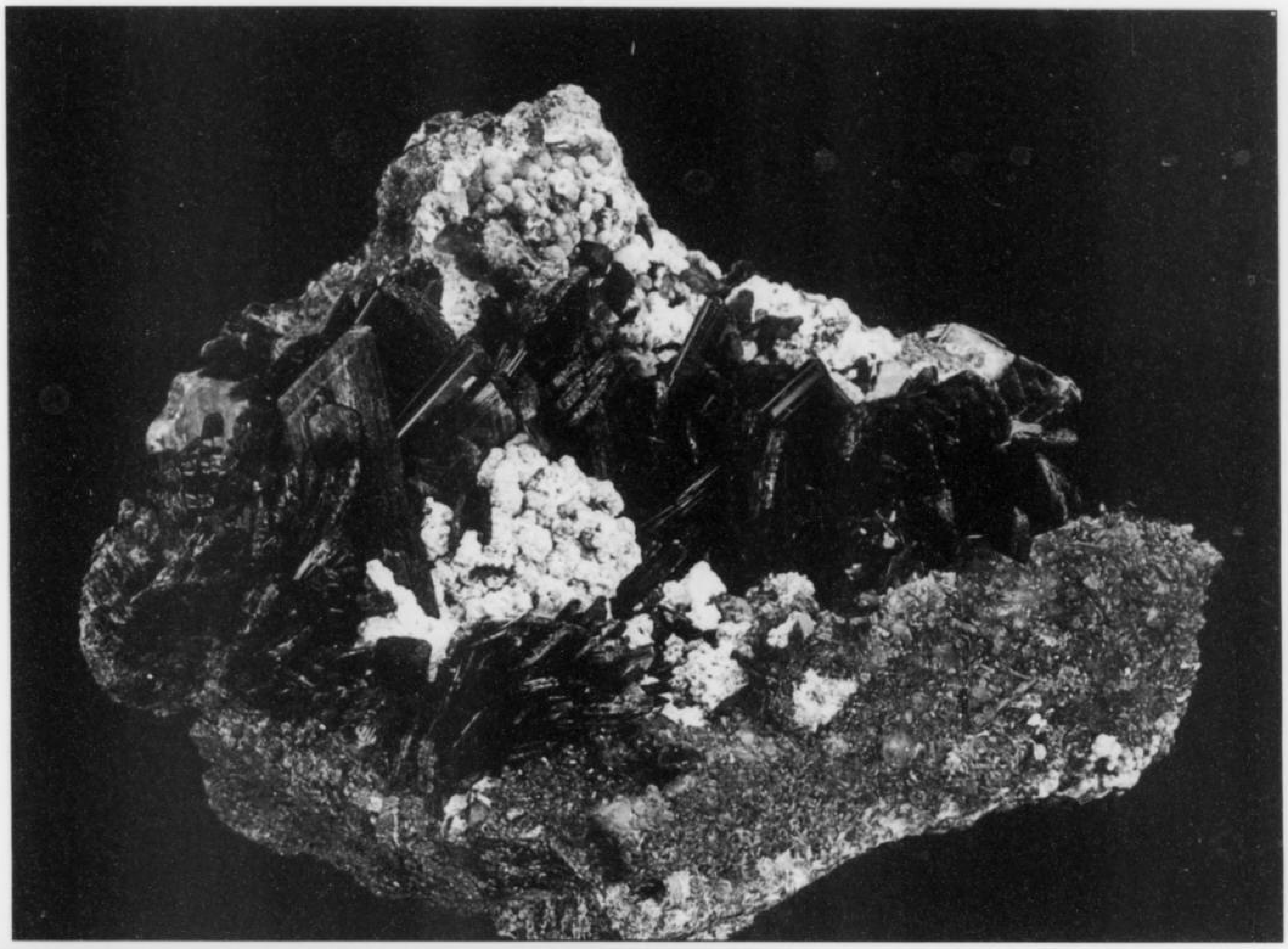


Figure 66. **One of the world's best erythrite discoveries took place in 2000–2001 in Veins 7 and 5 at Bou Azzer. Deep purple-red erythrite crystals partially overgrown by pale pink botryoidal erythrite; the specimen is 5.8 cm wide. Marty Zinn collection via Christine Gaillard; Jeff Scovil photo.**

Figure 67. **Erythrite, fibrous red to white crystals, from Tamdrost; field of view 3 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

tainly, from the rich cobalt content of the matrix material. Typical erythrite crystals are tabular, developed aiong [010] and elongated along [001], with wedge-shaped terminations. Commonly they form fan-shaped aggregates reminiscent of heulandite. In some cases erythrite forms beautiful acicular crystals to 1 cm long and 1 mm thick—as in the finds of early 2001 and 2005 in the oxidation zone of Vein 7. In the Aghbar open pit such acicular crystals have been seen to form flat rosettes, some resting on pink talmessite.

In the dolomite veins of Méchoui, erythrite is associated commonly with roselite-beta. Specimens in which erythrite is accompanied by pure white spherules of picropharmacolite boast a spectacular color-contrast—these come particularly from Vein 2, Bou

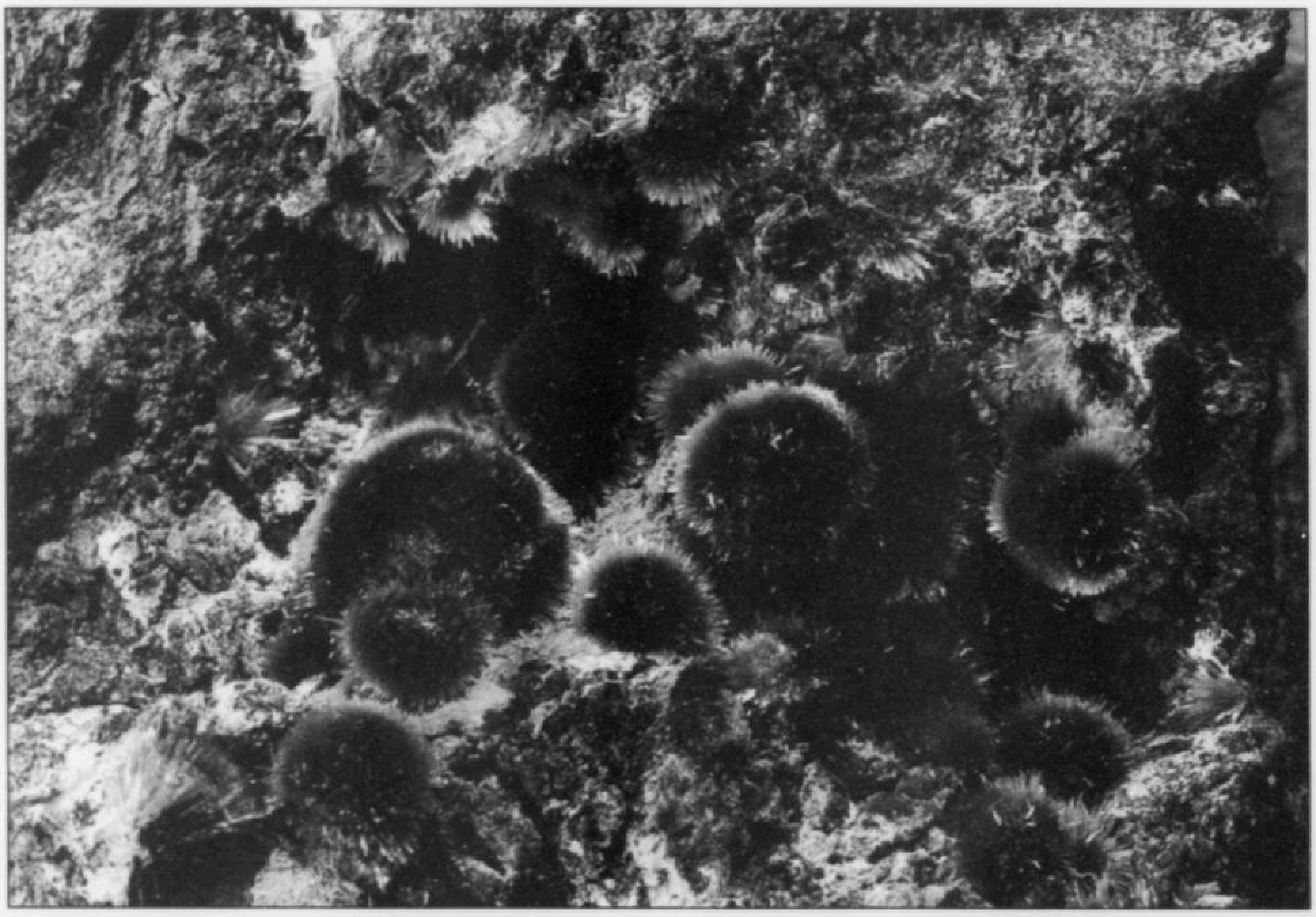


Figure 68. **Acicular erythrite, sprays to 7 mm, from Agoudal. Found in 2005. Ernesto Ossola specimen; Jeff Scovil photo.**

Figure 69. **Cobalt and copper minerals in a dolomite cavity: erythrite and conichalcite from Méchoui. Field of view 3.5 mm. G. Favreau collection; Robert Vernet photo.**

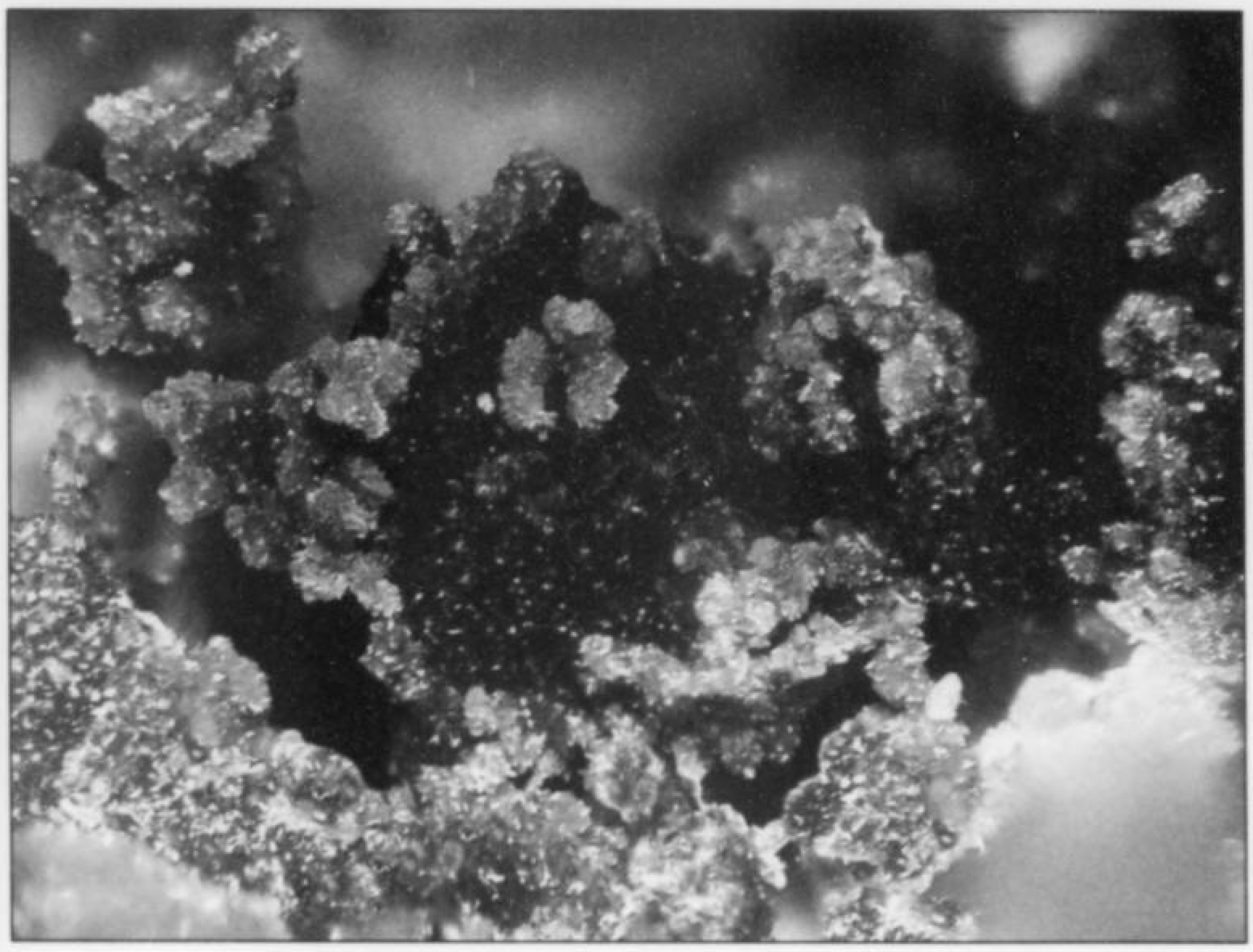


Figure 70. **Ferrilotharmeyerite from Vein 52, Aït Ahmane; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Azzer. Superb micromounts have been found in the Aït Ahmane deposits: particularly in Vein 54, erythrite forms long, pale pink, feltlike fibers, as well as beautiful spherules on talmessite. The most attractive specimens, from Vein 52, show color-zoned mixed crystals, with green lower zones of annabergite and pale pink edges and tips of erythrite.

In addition to the occurrences mentioned above, erythrite is widespread in the district from east to west, and is known in the mines at Ightem and Tamdrost.

Ferrilotharmeyerite $Ca(Fe^{3+},Zn)_2(AsO_4)_2(OH,H_2O)_2$

Ferrilotharmeyerite was found in Vein 52, Aït Ahmane, in a cavity in a specimen of brecciated löllingite ore, accompanied by talmessite. The tiny, red-brown, lath-shaped and acicular crystals are free of Mn and Zn but show traces of Co and Ni. In other samples, ferrilotharmeyerite appears as earthy crusts on carbonate matrix; this material is fairly cobalt-rich, with $Fe_{1.35}Co_{0.65}$.

Small, brown, acicular crystals of similarly cobalt-rich ferrilotharmeyerite line 1-mm vugs in oblong corroded grains (<3 mm) of chalcopyrite/chalcocite, which in turn are encrusted by dark green conichalcite-cobaltaustinite. These mineral aggregates occur, with deep red, 1-mm rhombohedral crystals of sphaerocobaltite, in centimeter-size cavities in a dolomite/serpentinite breccia found in the Aghbar open-pit mine (the discovery took place in 2001; specimens are in the Stefan Weiß collection).

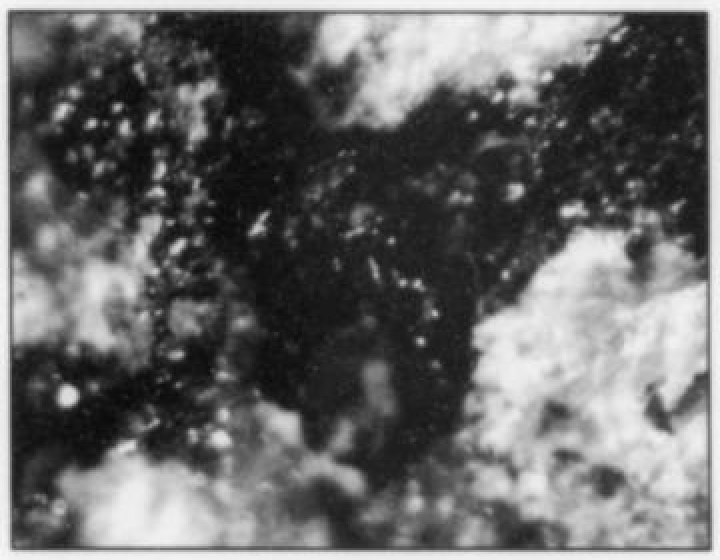


Figure 71. Honey-brown fornacite from Oumlil; field of view 1.5 mm. G. Favreau specimen and photo.

Figure 72. Scanning electron microscope photo of a fornacite specimen; field of view 0.7 mm. The typical tabular but pointed shape of the crystals is evident here. Bertrand Devouard REM photo.

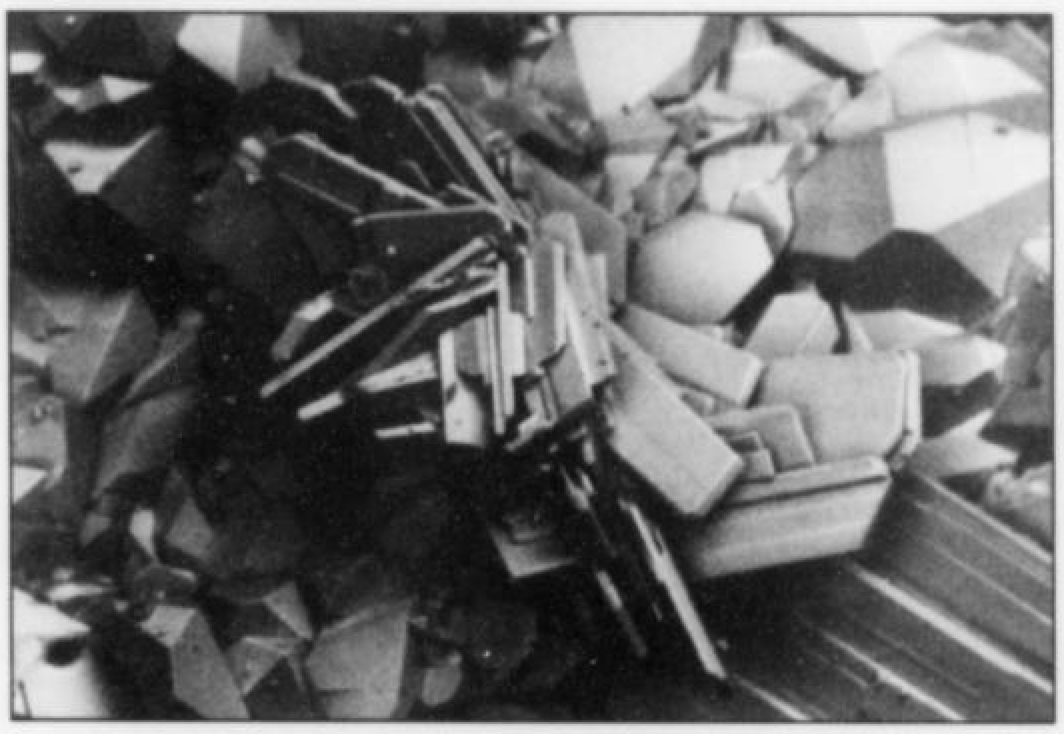


Figure 73. Geminite from Khder; field of view 0.45 mm. REM photo: E. Medard.

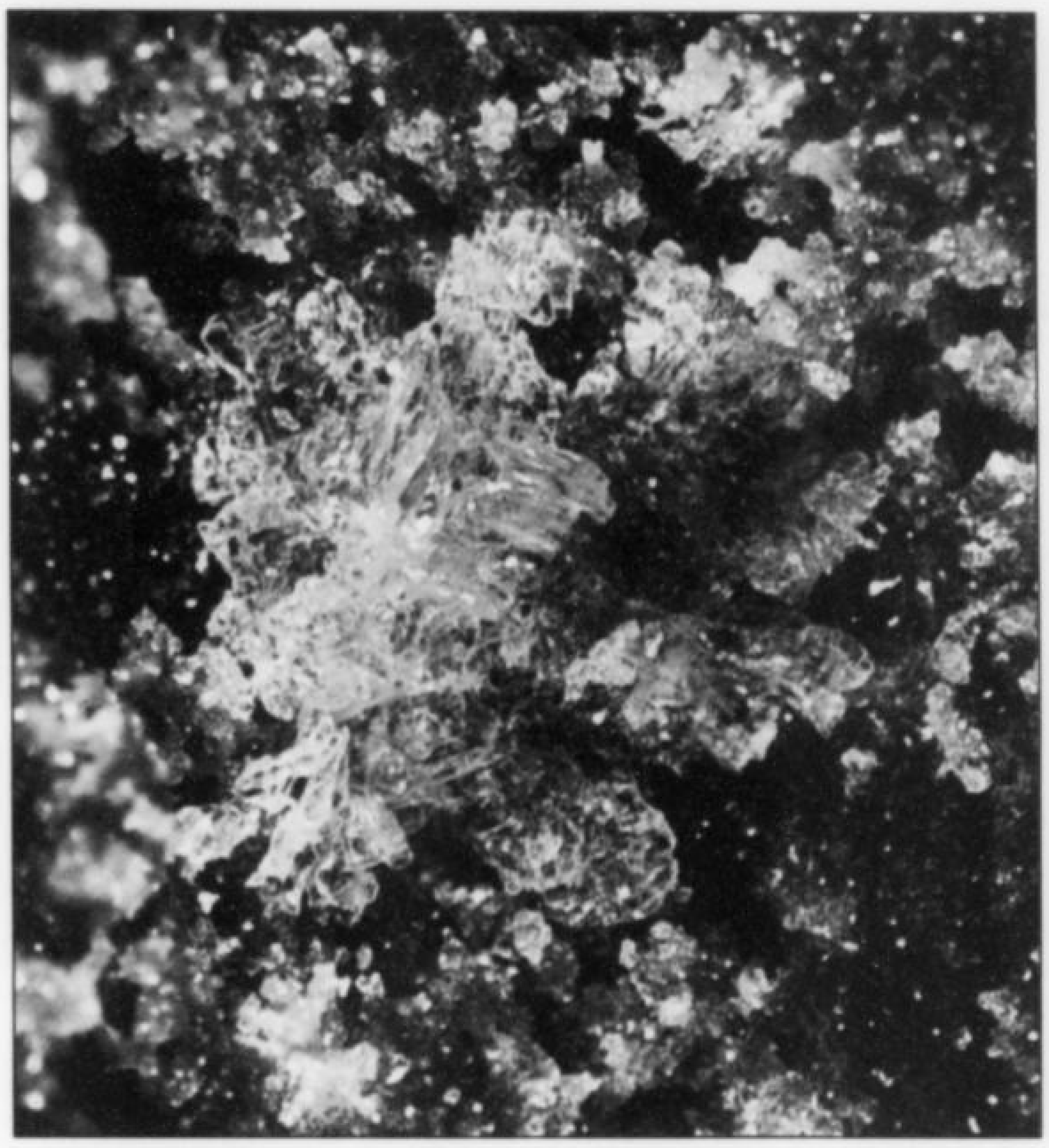


Figure 74. Geminite from Khder; field of view 3.7 mm. G. Favreau specimen; Robert Vernet photo.

Fornacite $Pb_2Cu(AsO_4)(CrO_4)(OH)$

Lamellar, pale honey-brown crystals of fornacite measuring less than 0.2 mm encrust altered galena at Oumlil-East; associations are cerussite, earthy yellow litharge and tiny black mottramite crystals. This fornacite shows a very low content of VO_4.

Geminite $Cu^{2+}(As^{5+}O_3OH)(H_2O)$

Geminite was found at Khder in a weathered piece of löllingite which mainly contained sparkling beige-colored scorodite crusts and matte-lustered spherules of schneiderhöhnite. The copper arsenate geminite, at first though to be lindackerite forms lustrous, pale green, right-angled platelets, some with chisel-shaped terminations, and typical twins measuring less than 0.5 mm.

Gersdorffite NiAsS

The gersdorffite crystals of Aït Ahmane are world-famous and are among the most beautiful of their kind. Matte-gray octahedral crystals measuring from 1 to 4 cm came from Vein 51; they are embedded in calcite, and most are covered by a greenish film. They are simple octahedrons—not always perfectly formed—with a perfect cleavage on (001). They may be acid-etched out of the enclosing calcite, but the acid destroys the green film and commonly etches or destroys the gersdorffite crystals themselves. In some parts of the vein, skeletal nickel-skutterudite crystals and quartz crystals are associated with gersdorffite. Coatings of retgersite seen in occurrences near Vein 51 may easily be removed by washing in water. When the gersdorffite is not clearly crystallized it resembles skutterudite, but the green nickel-bearing alteration films and the cleavage are good indicators of species. Gersdorffite crystals, like skutterudite crystals, are commonly zoned, the outer zones of the gersdorffite crystals being richer in cobalt.

Goethite α-$Fe^{3+}O(OH)$

Because of the of the crystal quality, goethite from Bou Azzer is worthy of notice. In Vein 2, Bou Azzer, goethite occurs commonly in dolomite cavities as 2-mm to 3-mm, lathe-shaped, black to shimmering golden brown crystals with pointed terminations; typical associated species include quartz, dolomite and hematite, and rarely also roselite. Excellent dark brown to red-brown, lathe-shaped

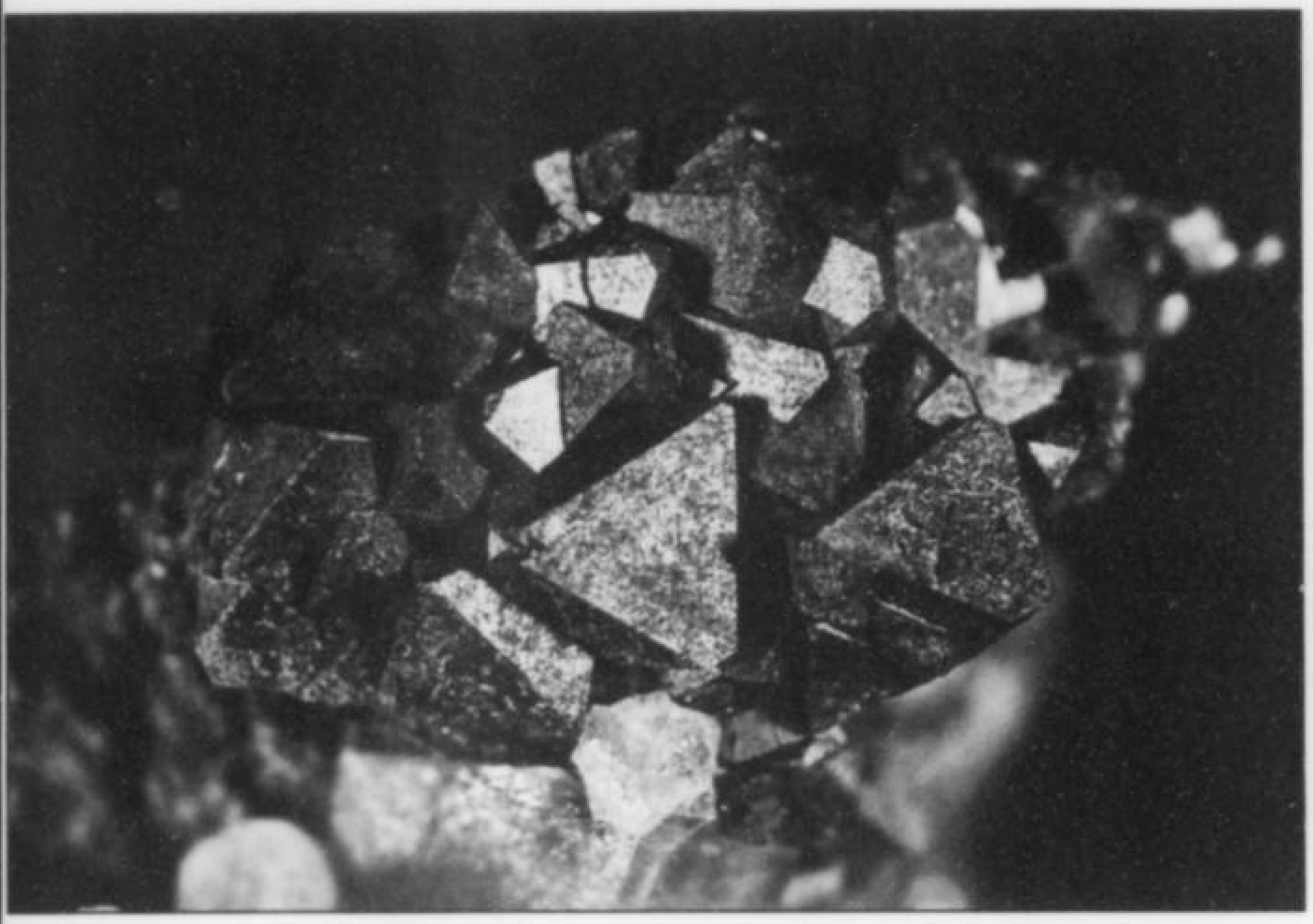


Figure 75. **Octahedral gersdorffite crystals from Aït Ahmane; field of view 8 mm. G. Favreau specimen; Robert Vernet photo.**

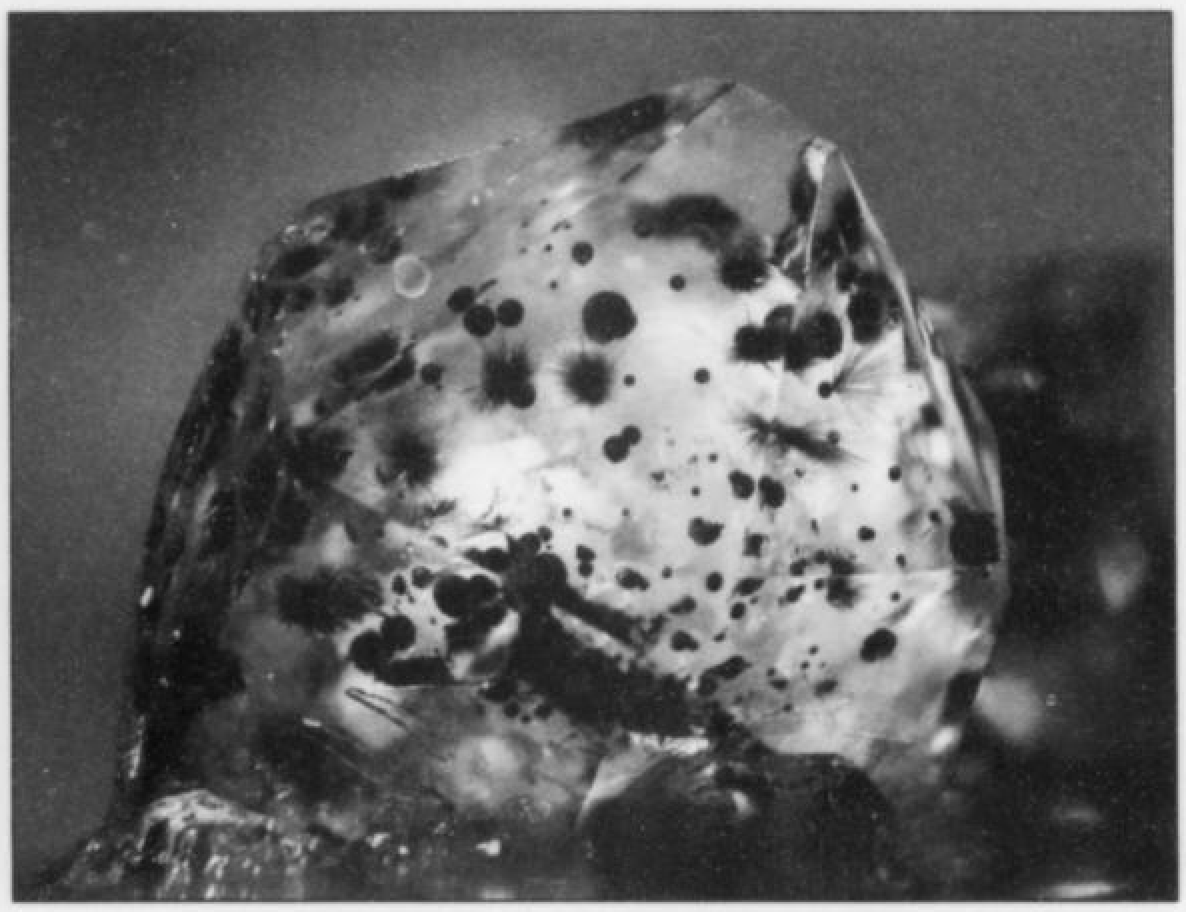


Figure 76. **Goethite sprays in a quartz crystal from Aghbar; field of view 7 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 77. (right) **Goethite crystals from Aghbar; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

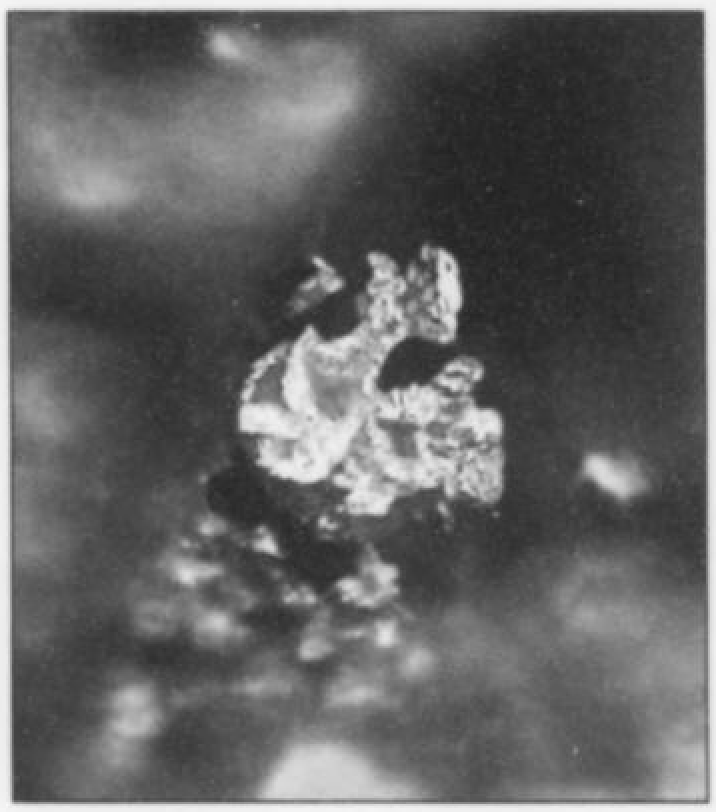
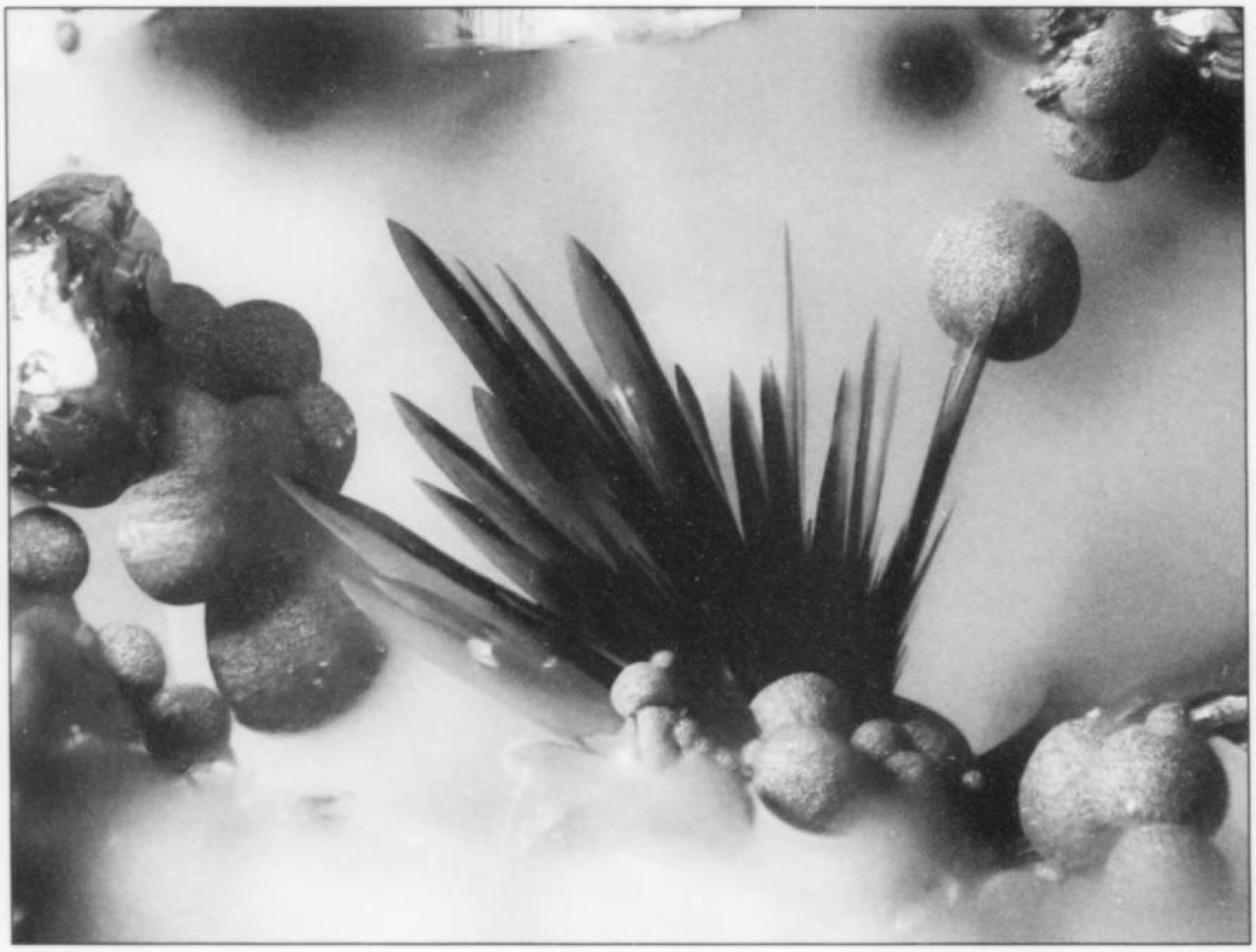


Figure 78. (above) **Gold from Vein 7, Bou Azzer; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**



goethite crystals to 2 cm have been collected in Ightem, where they are associated with löllingite. However, the most beautiful goethite specimens seem to be those from Aghbar: crystal fans associated with sphaerocobaltite and chalcopyrite, and radiating crystal sprays as inclusions in transparent smoky quartz crystals and in calcite.

Gold Au

In 1933 it was mentioned that 6.3 kg of gold had been produced as a byproduct from Bou Azzer district ores; by 1935 the total production was 70.5 kg. As a rule the gold is microscopic and not of interest to mineral collectors. However, it is among the most important of the district's products and has been the object of numerous investigations (e.g. Caillère and Dietrich, 1966; Ennaciri, 1995; Essaraj, 1999; Ghorfi *et al*., 2005). In Vein 51 at Aït Ahmane, in the eastern part of the district, a shear zone in serpentinite containing chalcopyrite, nickeline and rammelsbergite is especially rich in finely divided gold (particles $<$0.05 mm). In the district's western part, gold occurs commonly with the uranium oxide brannerite; here the gold content of the ore reaches 45 grams per ton. Such high concentrations of gold made us curious: how can so much be present without our ever seeing any, despite attentive observation? In May 2001 we gathered specimens from Shaft 1, in Vein 7 at Bou Azzer, where there is a molybdenum-rich zone with microscopic, finely divided molybdenite. In a limited area of the ore mass (the area where bouazzerite was found) the gold content is around 100 grams per ton, occurring as minute grains ($<$0.1 mm) in a brownish green ocher along contacts with quartz. The quartz is gray-white, in some places reddish, and rich in 1-mm grains of chalcopyrite. There are also white masses of calcite with erythrite and roselite-beta. An EDX-analysis of the gold shows a very small

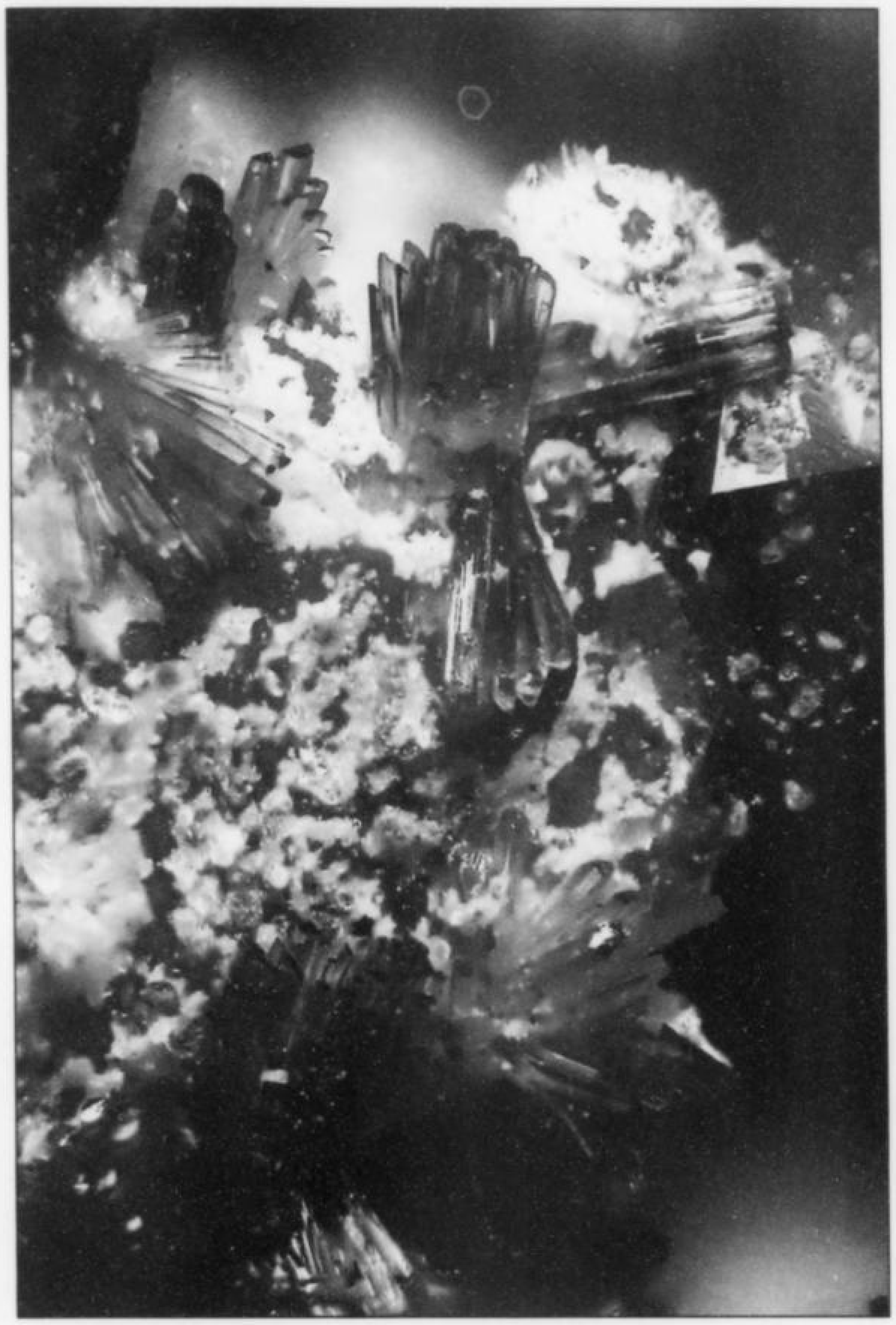


Figure 79. **Excellent crystals of guanacoite, from Taghouni; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

silver content. Close examination of samples from Tamdrost-West reveals visible gold, as tiny grains in earthy, beige-colored material, associated with annabergite and with uranium minerals (nováčekite and zeunerite).

Guanacoite $Cu_2Mg_2(Mg,Cu)(OH)_2(AsO_4)_2 \cdot 4H_2O$

We discovered guanacoite after the reopening of the shaft at Taghouni—unfortunately this was a one-time-only find, in a sample from a quartz vein. The Cu-Mg arsenate, known earlier only from El Guanaco in Chile (IMA 2003-021), forms strikingly turquoise-blue fillings, to 4 mm, of subparallel crystals, in cavities in quartz with chrysocolla and chalcopyrite. The crystals in open pockets are right-angled prisms with flat terminations, displaying conchoidal fracture but no cleavage. In some cases the fan-shaped aggregates show a thin, pale green coating of agardite-(Ce). The Bou Azzer district is the second world locality for guanacoite (Witzket *et al.*, 2006).

Guérinite $Ca_5H_2(AsO_4)_4 \cdot 9H_2O$

White calcium and/or magnesium arsenates from Bou Azzer are often difficult to distinguish visually. We found guérinite in Ightem as thin white scales with a pearly luster, showing a four-sided shape and rounded corners; the mineral occurs at the contact between skutterudite ore and carbonate gangue.

On the old dumps of Vein 2, Bou Azzer, tiny scaly to rosette-shaped aggregates of guérinite rest on tabular erythrite crystals in ore samples richly shot through with picropharmacolite. EDX

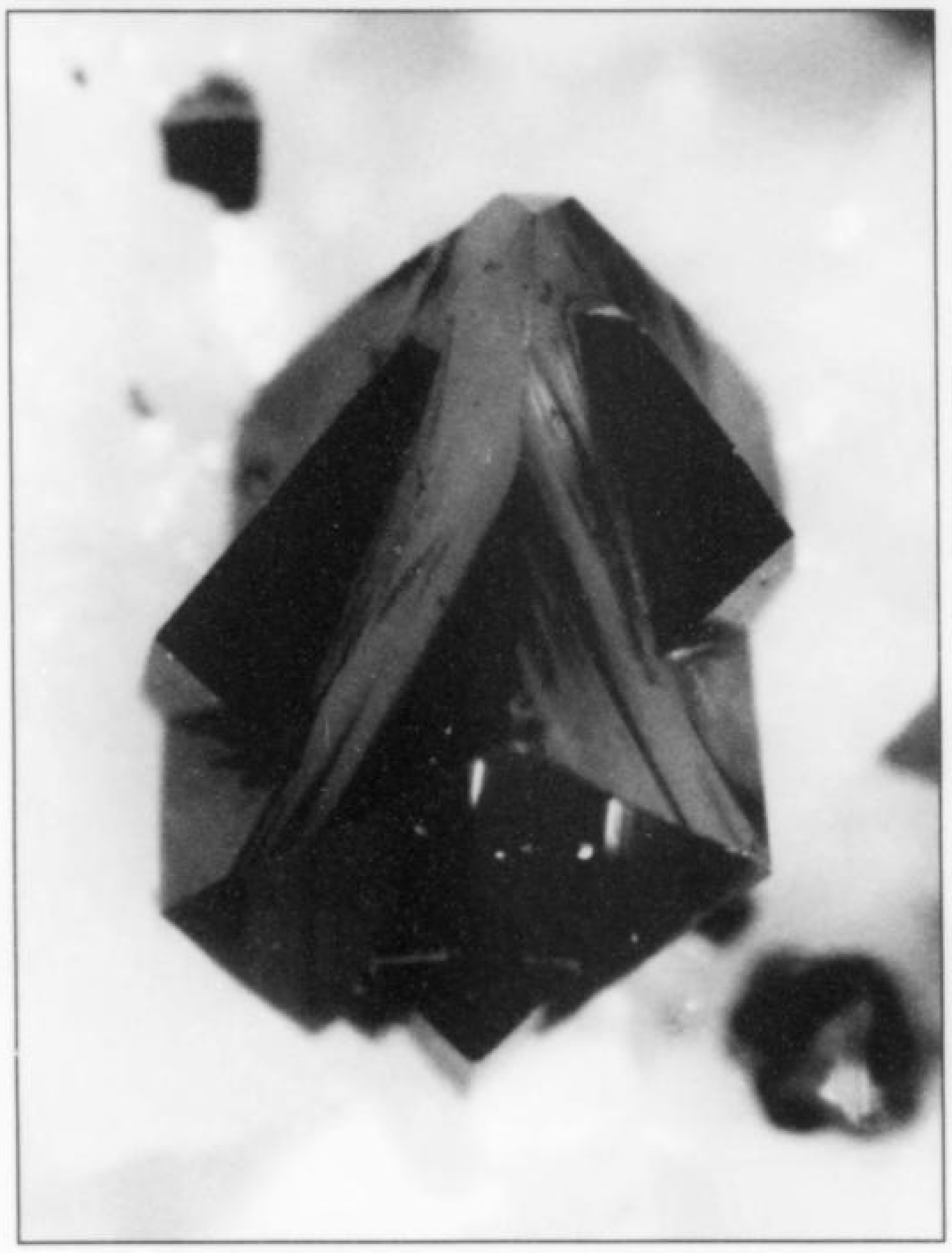


Figure 80. **Twinned crystals of hematite, 1 mm, on pink dolomite from Ightem. Robert Pecorini specimen; Robert Vernet photo.**

Figure 81. **Lustrous twinned crystal of hematite on pink dolomite from Ightem; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 82. **Colorless hemimorphite and turquoise-blue aurichalcite from Ightem; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

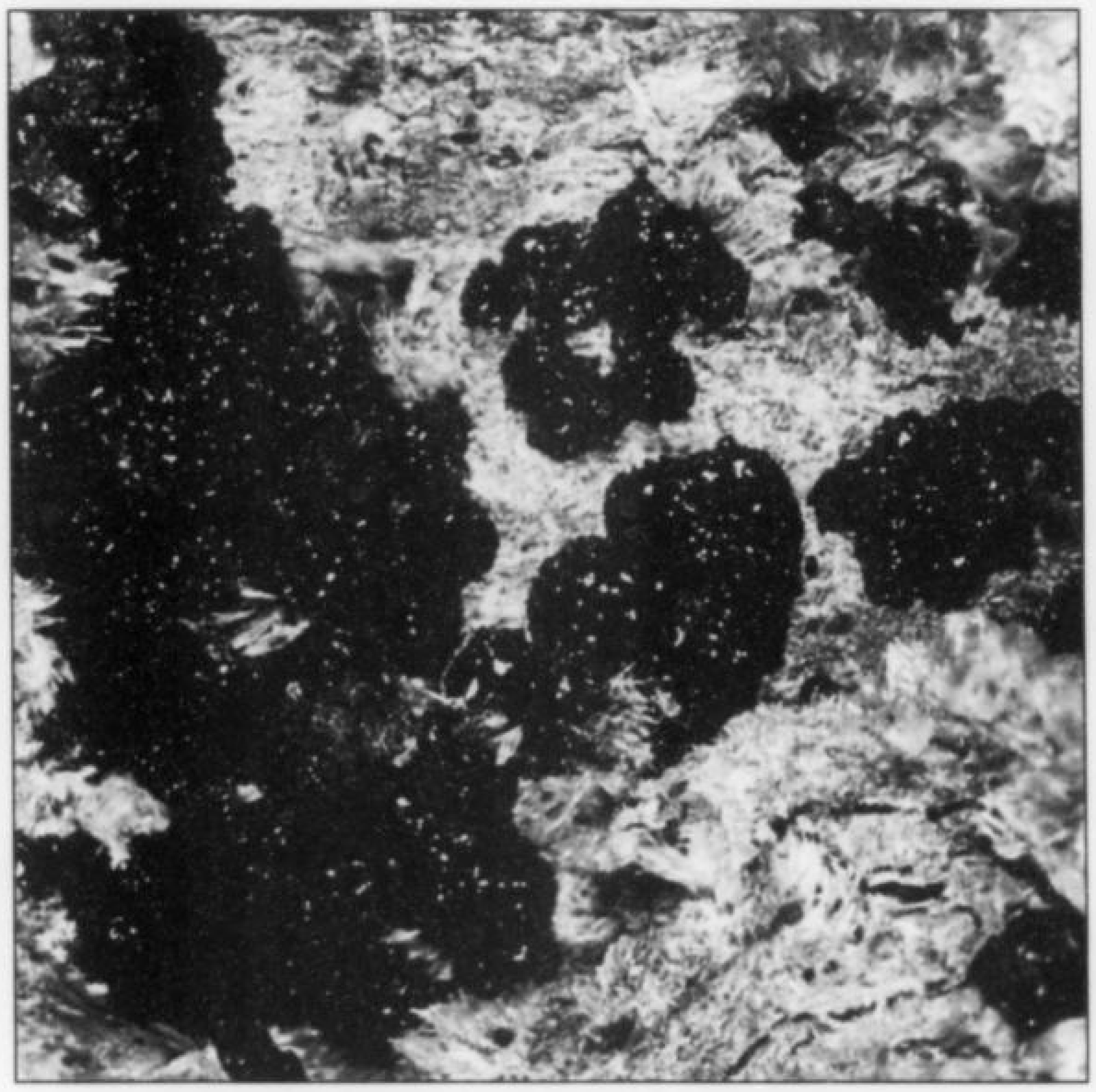


Figure 83. **Botryoidal heterogenite from Aït Ahmane; field of view 4.8 mm. G. Favreau specimen; Robert Vernet photo.**

analyses show a pure calcium arsenate and thus point to guérinite (never before described from the Bou Azzer district).

Hematite Fe_2O_3

Hematite is especially common at Méchoui, in Vein 2 at Bou Azzer, at Aghbar and at Ightem. It is found as lustrous black specimens of the "glasskopf" type, as brown-red leafy or scaly crystals, and as rosette-shaped aggregates (these reaching 5 mm at Méchoui). In Vein 2, Bou Azzer, scaly hematite blankets walls of cavities in dolomite, with roselite, roselite-beta and transparent calcite. Lustrous black, striated rhombohedral crystals of hematite to 2 mm showing only $\{10\bar{1}1\}$ occur at Ightem (Gaudefroy, 1953); these crystals rest, commonly with celestine, magnetite, and cuboctahedral skutterudite crystals to 5 mm, in cavities in pink dolomite. In some cases the rhombohedral hematite crystals form penetration twins resembling those of cinnabar, showing the forms $\{22\bar{4}3\}$ und $\{01\bar{1}2\}$.

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$

In 2002 the dumps at Ightem, besides having given up many specimens of arsenate minerals, gave up the first known specimens of hemimorphite from the district. Hemimorphite is seen in cavities in dolomite, as aggregates of colorless lath-shaped crystals with right-angled profiles measuring less than 1 mm, with adamite, aurichalcite and blue-green mixed crystals belonging to the malachite-rosasite series.

Heterogenite $Co^{3+}O(OH)$

Most heterogenite from the district is powdery or mammillary and glassy. The black cobalt oxide is found on surface exposures and in strongly weathered areas in the mines, commonly with erythrite. Although not itself aesthetic, heterogenite can be a nice contrasting background for colorful secondary species. In Vein 51, Aït Ahmane, as well as at Aghbar, the mineral occurs as lacquer-like black flecks on which pale violet crystals of roselite-beta have grown.

Hörnesite $Mg_3(AsO_4)_2 \cdot 8H_2O$

The magnesium arsenate hörnesite forms from hydrothermal alteration of dolomite, like the abundant picropharmacolite and the rare irhtemite. In the oxidation zone of the Ightem deposit, hörnesite forms fibrous crystals on skutterudite, with vladimirite and gypsum.

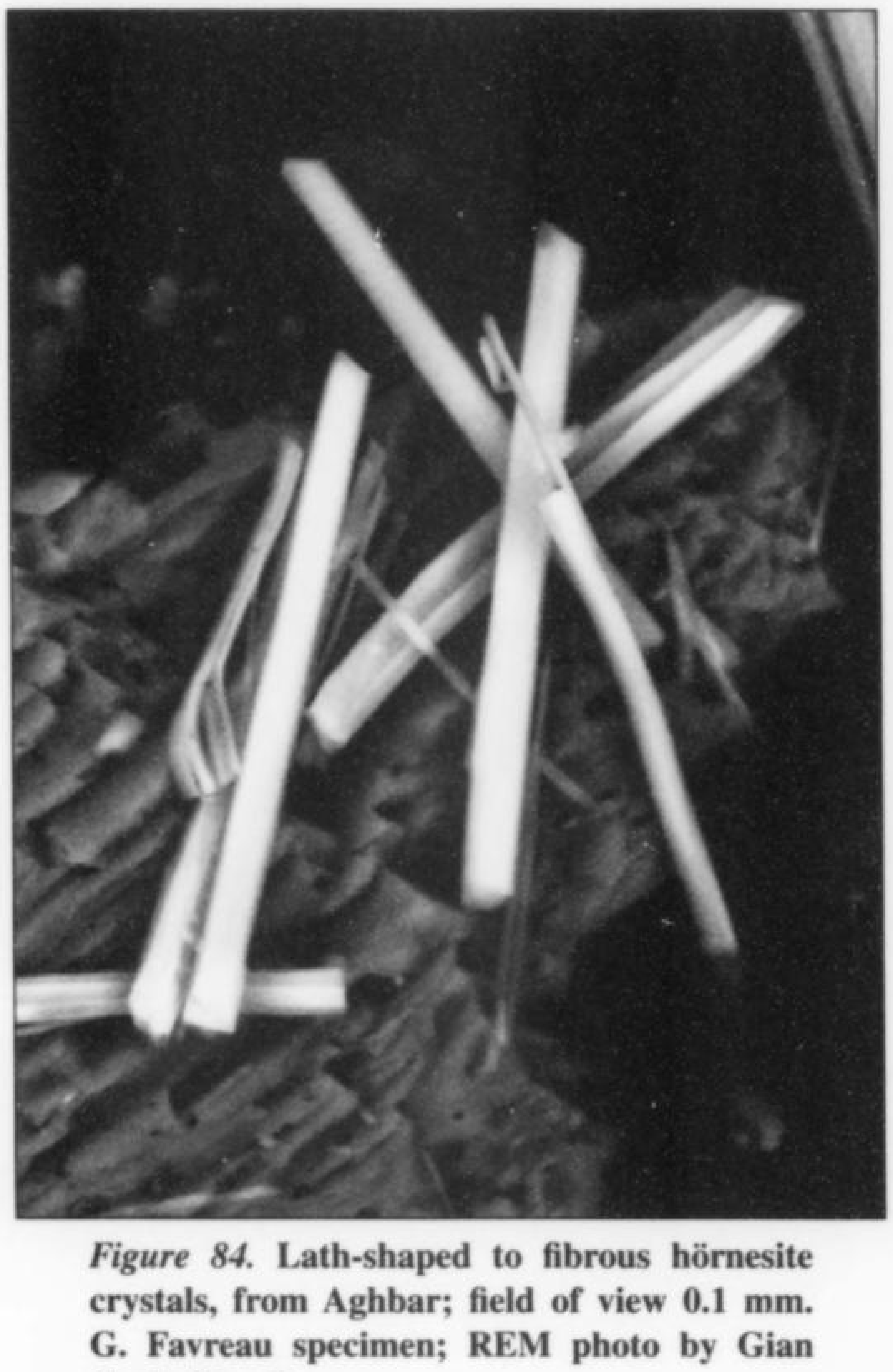
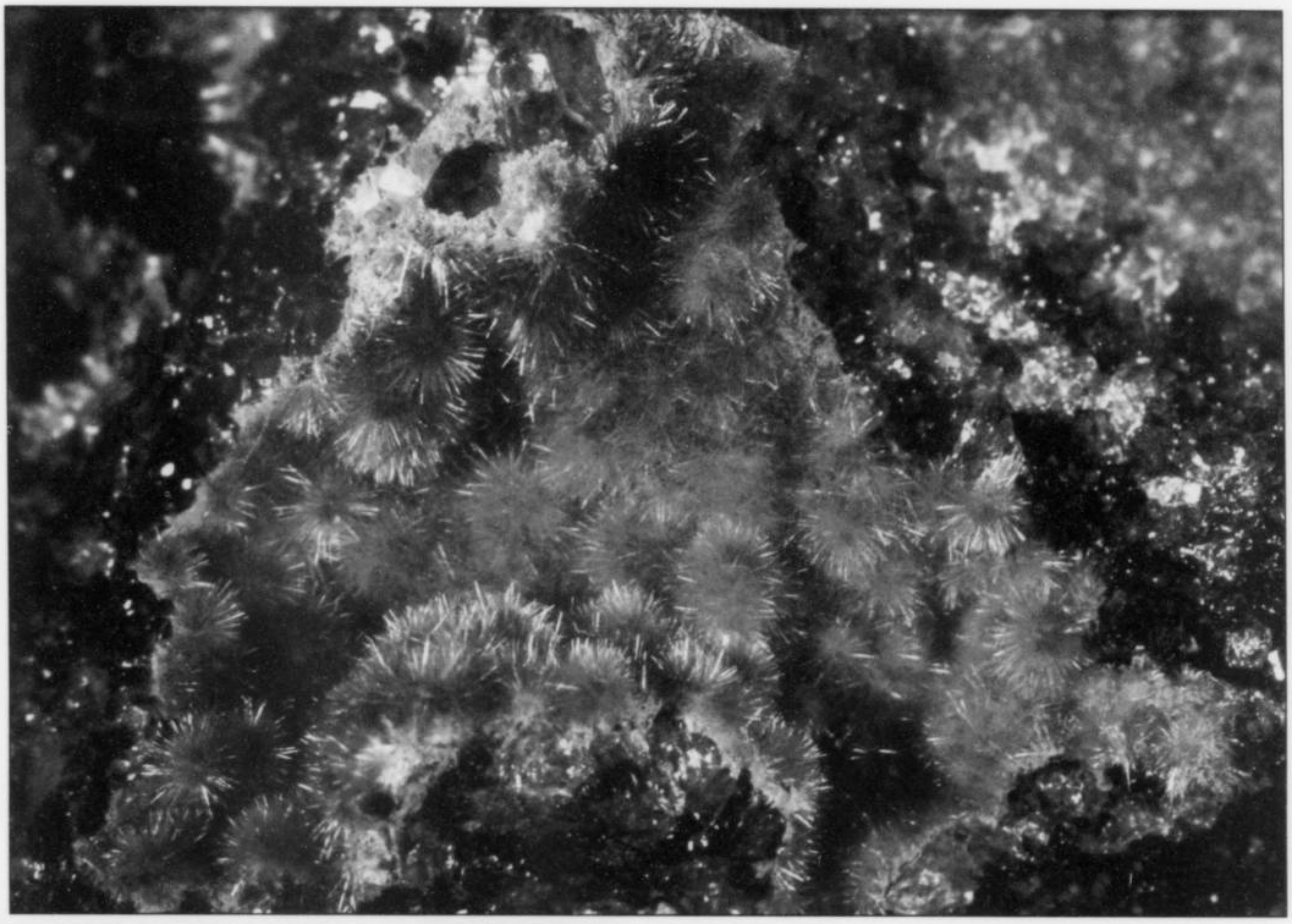


Figure 84. **Lath-shaped to fibrous hörnesite crystals, from Aghbar; field of view 0.1 mm. G. Favreau specimen; REM photo by Gian Carlo Parodi.**

In 2000, the old tunnels at Aghbar yielded compact spherules of radiating fibrous hörnesite crystals; the spherules are a clean-looking white with a soapy luster. The mineral was found again at Aghbar



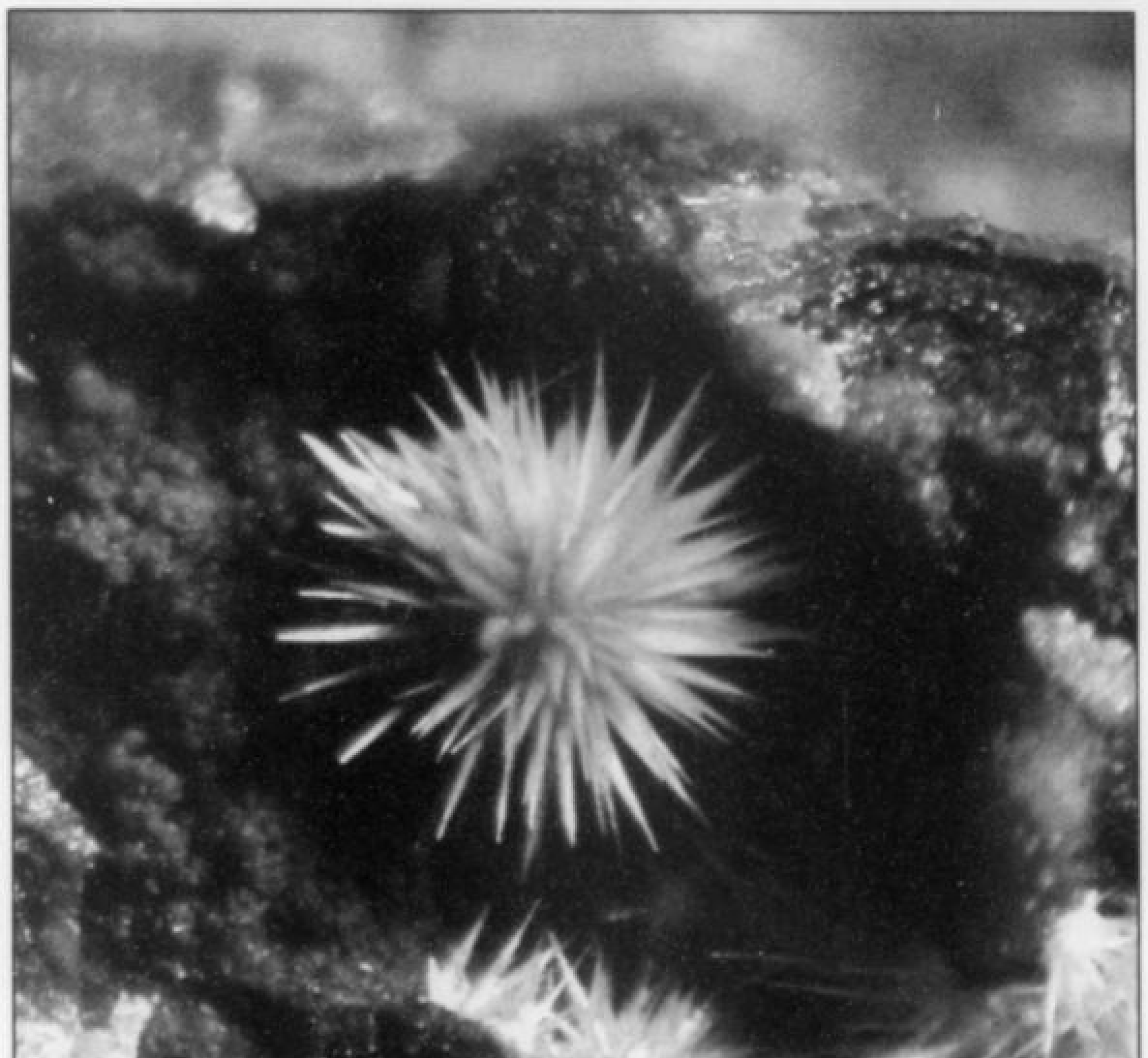


Figure 85. **Outstanding specimen of drusy karibibite in löllingite ore from Oumlil; field of view 2 cm. Robert Pecorini specimen; Robert Vernet photo.**

Figure 86. **Orange-yellow "hedgehog" of karibibite from Khder; field of view 2 mm. G. Favreau specimen and photo.**

in 2005, as spherules and as isolated acicular crystals; the hörnesite of this occurrence contains cobalt and nickel.

Irhtemite $Ca_4MgH_2(AsO_4)_4 \cdot 4H_2O$

Irhtemite was first described as tiny (<1 mm) radial spherules at Ightem (Pierrot and Schubnel, 1972). The spherules are opaque, with a soapy luster, and are white to pale pink (the latter from traces of cobalt). Irhtemite also forms aggregates of jumbled acicular crystals to 8 mm; it is always associated with sainfeldite and picropharmacolite. The calcium magnesium arsenate seems to be a product of the partial dehydration of picropharmacolite, but the conditions of its formation are rather obscure. It is known also from Vein 7 at Bou Azzer.

Karibibite $Fe_2^{3+}As_4^{3+}(O,OH)_9$

Karibibite is not an arsenate (with As^{5+}) but rather, as an arsenite with As^{3+}, is counted among the oxides. Its presence marks a maximally arsenic-rich environment. Bou Azzer is its third noted locality in the world, after Karibib, Namibia (the type locality) and the Kiuare mine in Japan (Schmetzer *et al.*, 1980). Since 1986 the best material has come from cavities in löllingite in the Tantal pegmatite at Urucum, near Galiléia, Minas Gerais, Brazil.

We first found karibibite on an old dump at Tamdrost, in massive pieces of weathered löllingite to 8 cm across. There the mineral is seen as thin, yellow to orange fibers and fan-shaped aggregates associated with glassy, bottle-green, fan-shaped aggregates of parasymplesite and with dark blue grains of pharmacosiderite. We found the best specimens of karibibite in the eastern part of the Oumlil mine. Never before had we seen karbibite of such quality: cavities in massive löllingite to 5 cm wide lined by crystallized quartz are in some cases completely blanketed by karibibite crystal sprays ("hedgehogs") individually to 2 mm in diameter. The intense

Figure 87. **Karibibite "hedge-hogs" from Oumlil-East; field of view 4 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

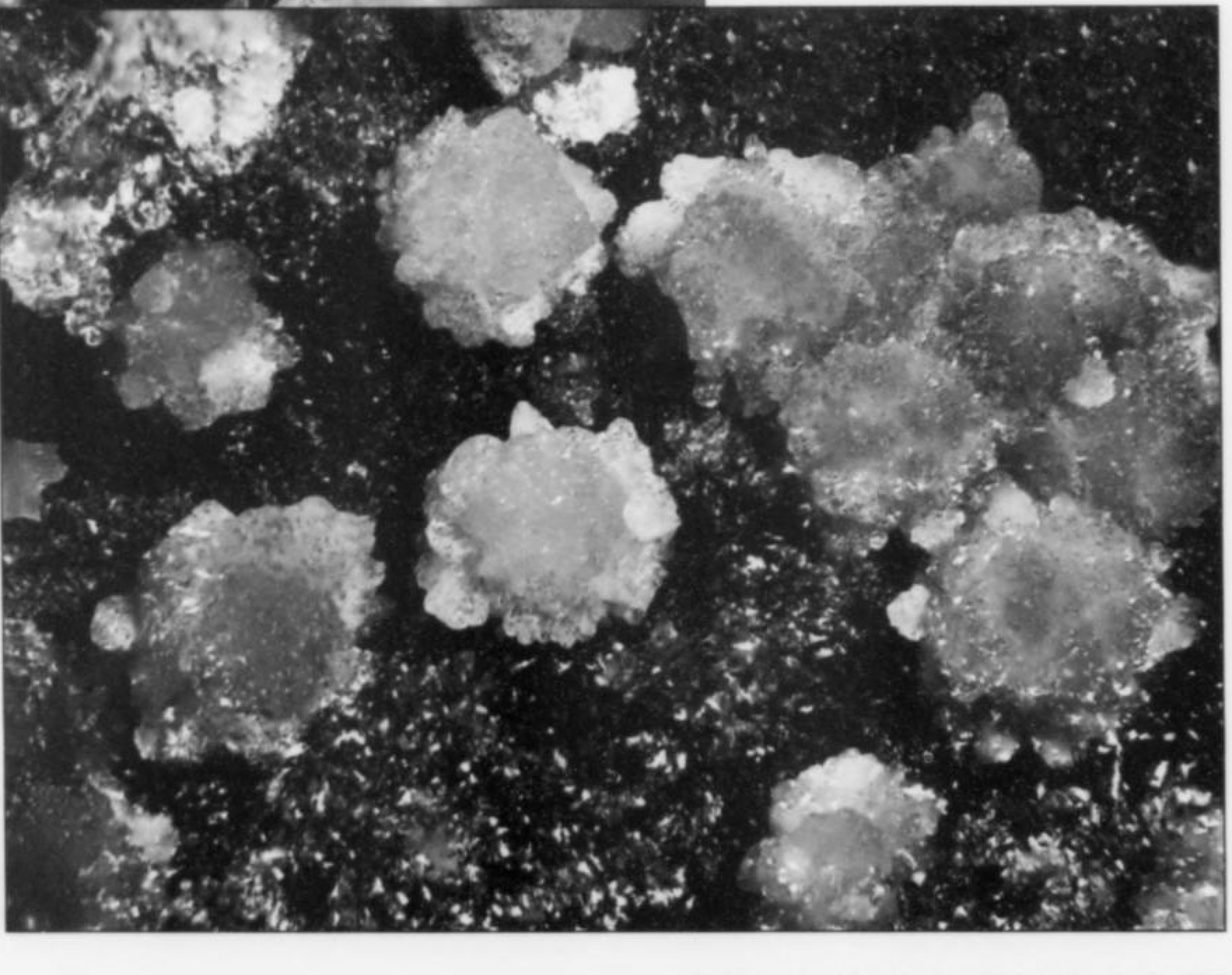


Figure 88. **Karibibite overgrown by colorless scorodite, on drusy blue-green scorodite, from Méchoui; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

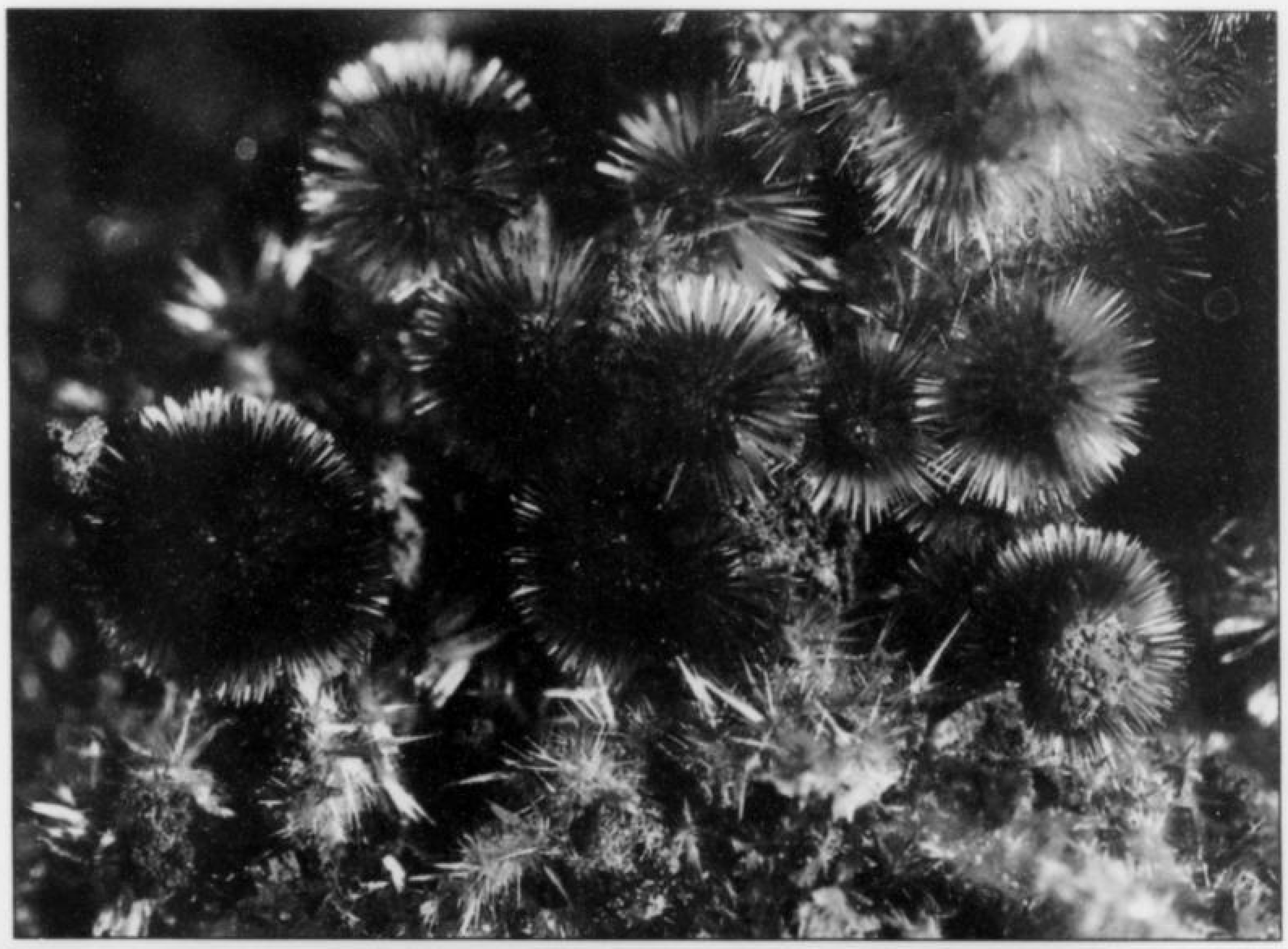
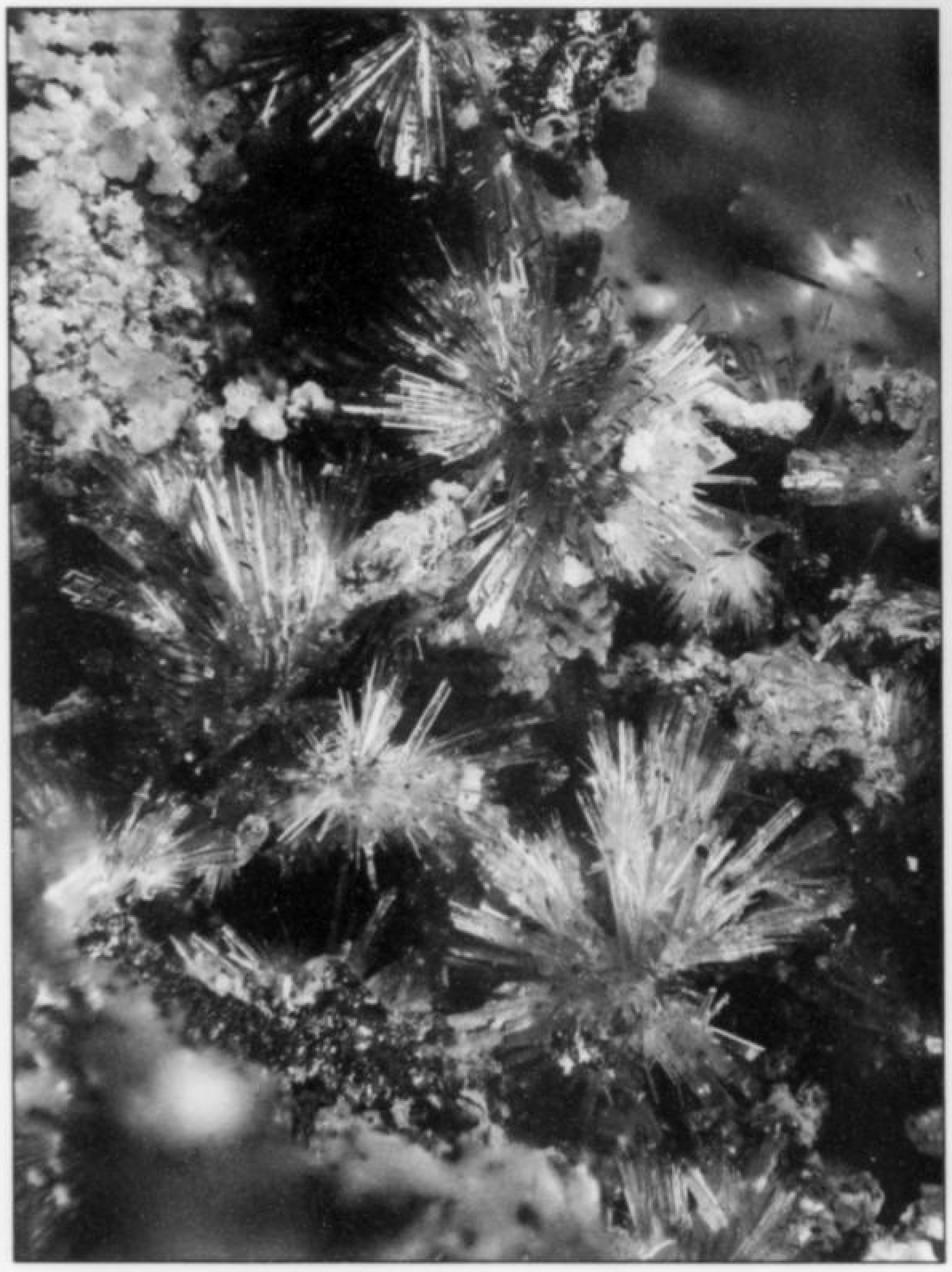


Figure 89. **Orange-brown "hedgehogs" of karibibite from Oumlil-East. Field of view: 3 mm. G. Favreau collection; Robert Vernet photo.**

Figure 90. **Groups of radiating köttigite crystals, from Taghouni; field of view 2.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**



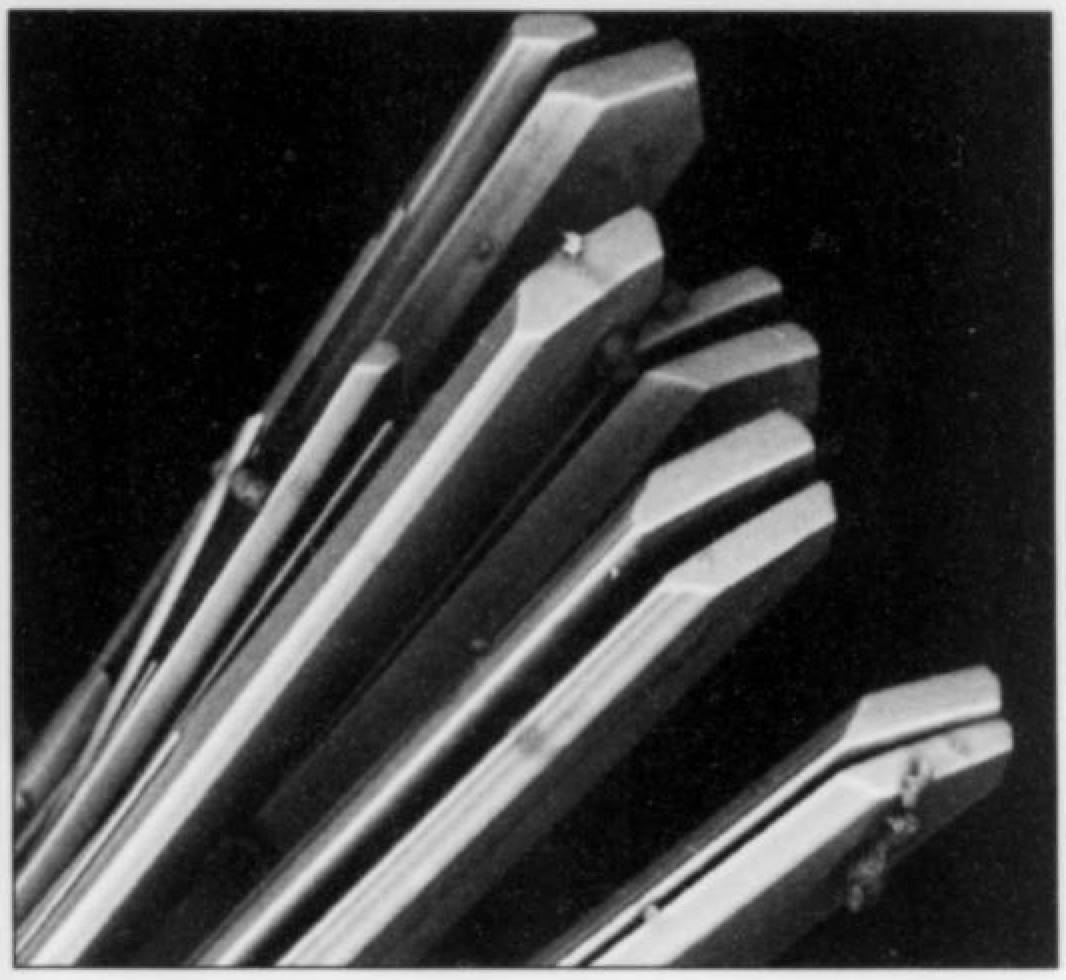


Figure 91. **Köttigite, well terminated crystals, from Taghouni; field of view 0.2 mm. REM photo by Gian Carlo Parodi.**

yellow-orange color of the karbibite is spectacular, recalling cacoxenite, with which it can be confused if one ignores the associated species. Karibibite from Oumlil also forms brown-orange, velvery spherules (<0.5 mm); long, orange fibers on green crusts of pharmacosiderite; and 1 mm-long crystal aggregates on quartz crystals, with schneiderhöhnite, parasymplesite and erythrite.

In general, karibibite is more common in the Bou Azzer district than previously recognized. Orange masses of fibrous crystals come from Vein 52, Aït Ahmane, and small vivid orange "pompoms" on weathered löllingite are found in an iron-rich sector of the Méchoui mine. In the Khder deposit, neighboring Méchoui, similar "pompoms" of karibibite are found with conichalcite and lavendulan.

Köttigite $Zn_3(AsO_4)_2 \cdot 8H_2O$

The zinc arsenate köttigite has been identified in a sample of vein quartz richly infused by chalcopyrite and sphalerite, probably from Taghouni. Besides turquoise-blue secondary minerals including (analyzed) devilline, the specimen shows lath-shaped, blue-gray to pinkish gray crystals of köttigite with a habit resembling erythrite, measuring less than 2 mm. Testing shows the crystals to be relatively rich in iron and cobalt, with traces of copper and nickel ($Zn_{0.55}Fe_{0.26}Co_{0.14}Cu_{0.03}Ni_{0.02}$).

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

Lavendulan is widely distributed in the district (especially in Méchoui, Veins 7 and 2 at Bou Azzer, Aghbar, Tamdrost and Ightem), though always found in small quantities, from earthy efflorescences to rare free crystals.

Transparent blue spherules of lavendulan, with erythrite, have formed from strongly corroded ore in Vein 2, Bou Azzer. At Tamdrost, lavendulan is associated with pharmacosiderite and arseniosiderite. In dolomite from Méchoui, lavendulan is observed with

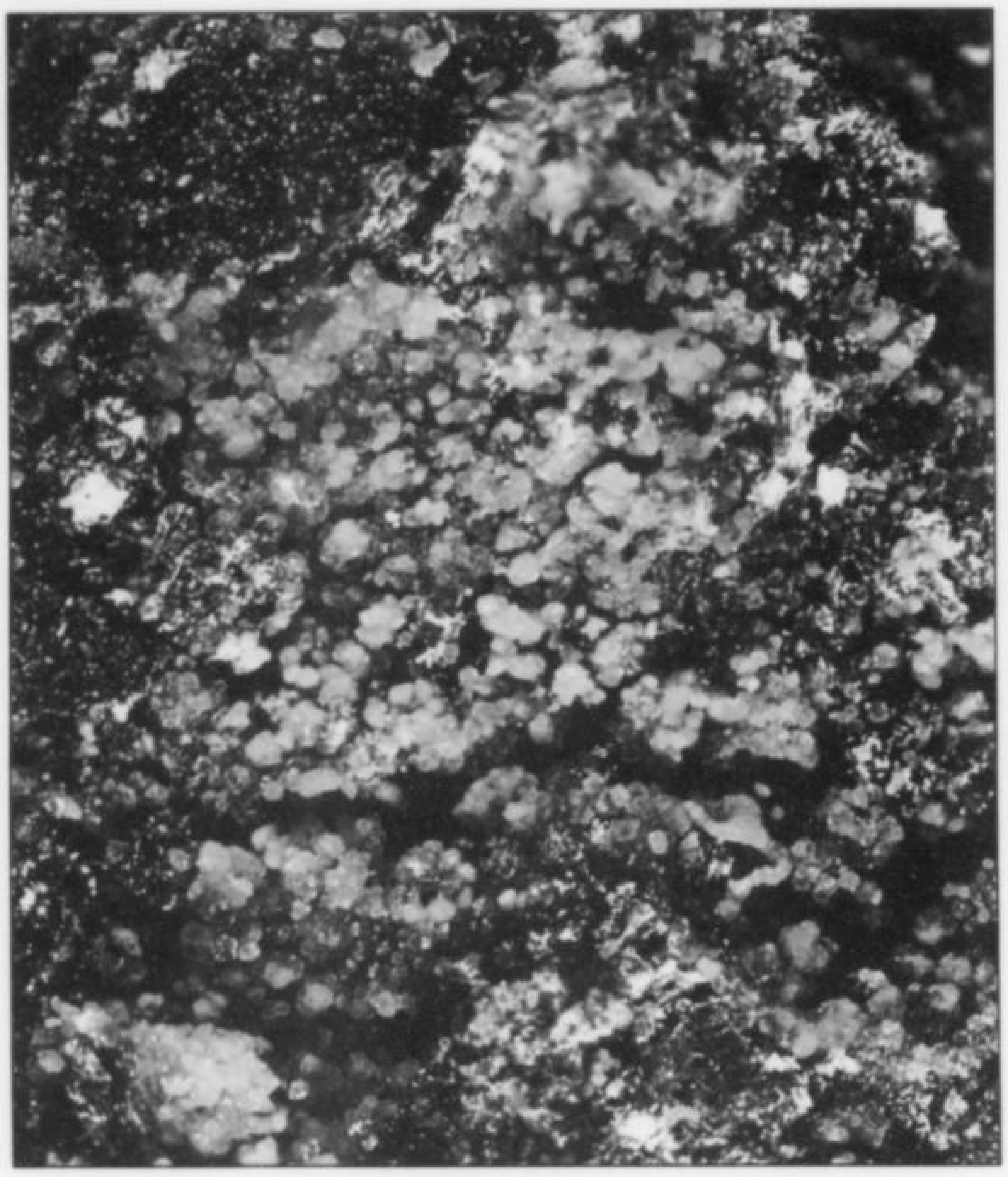


Figure 92. **Lavendulan, from Vein 2, Bou Azzer; field of view 2.6 mm. G. Favreau specimen; Robert Vernet photo.**

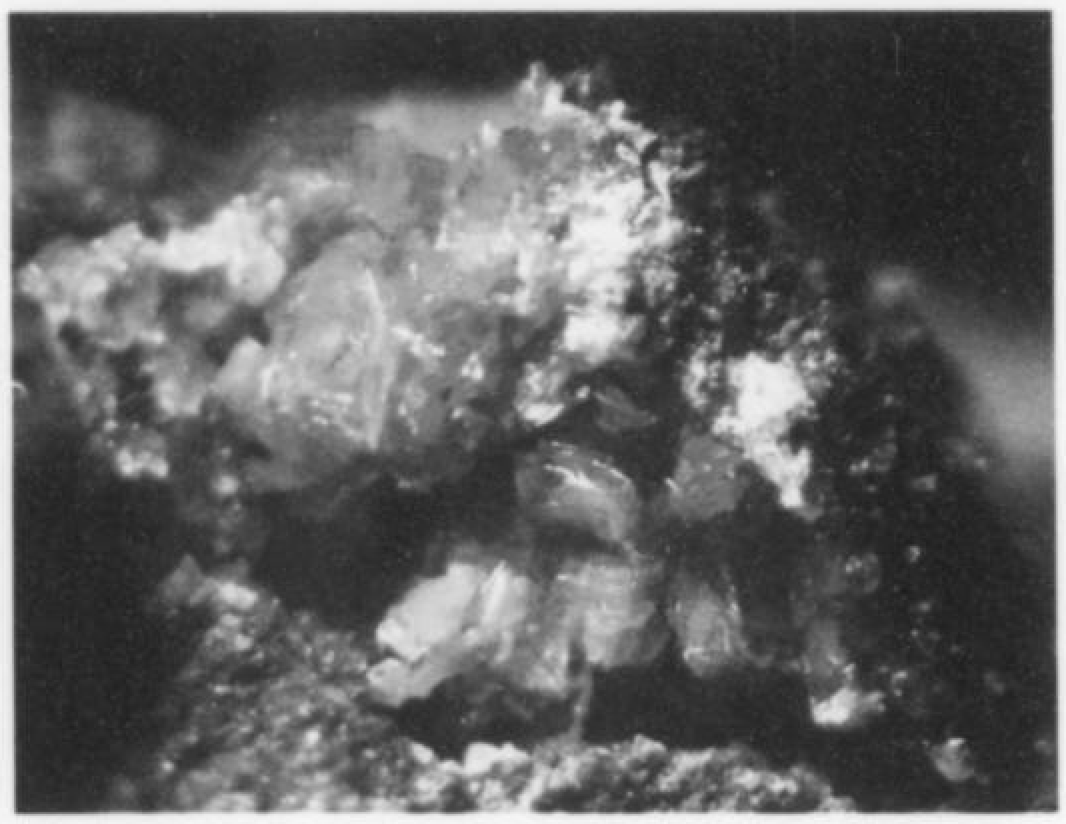


Figure 93. **Lavendulan, from Méchoui; field of view 1.5 mm. G. Favreau specimen and photo.**

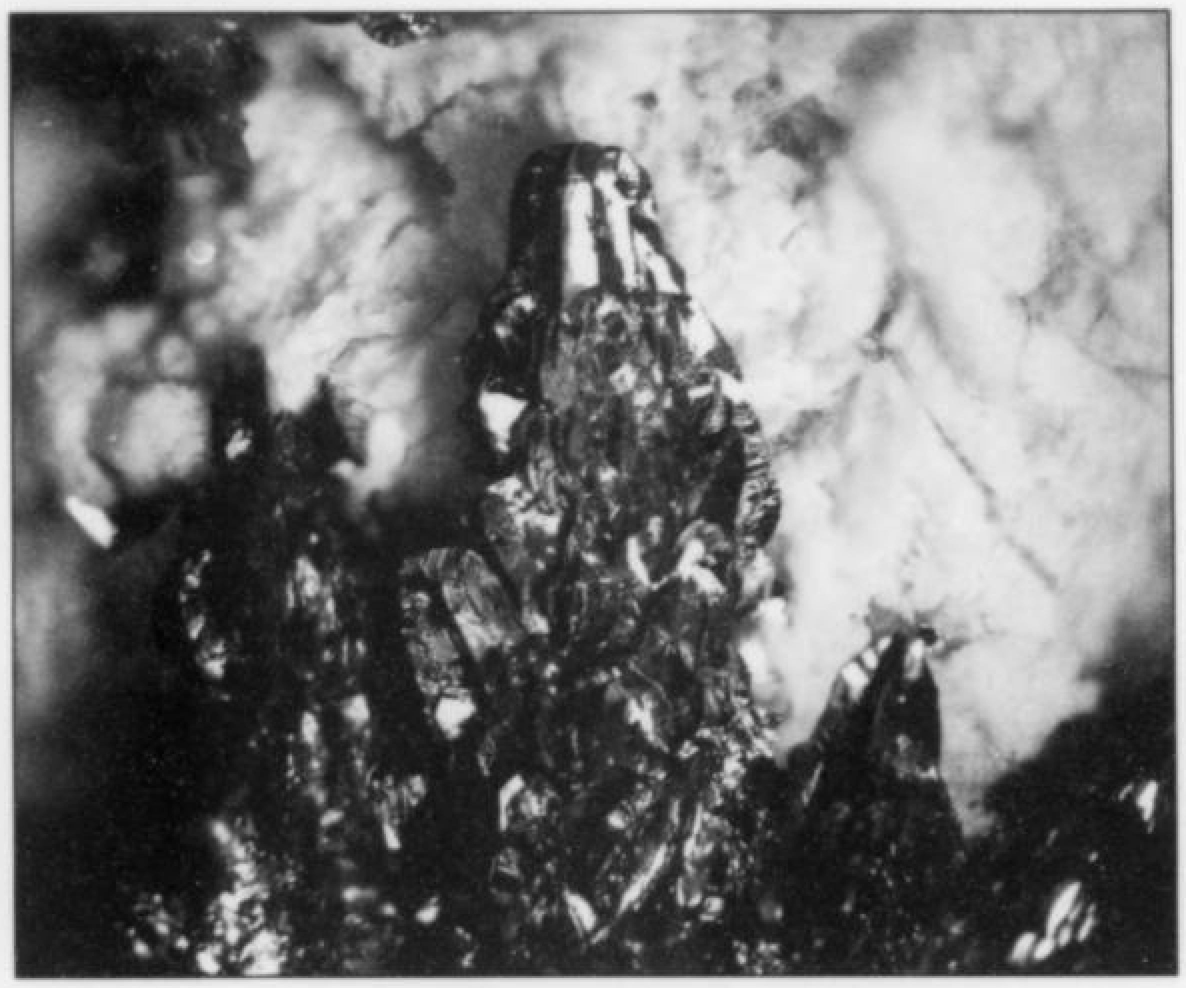


Figure 94. **Löllingite in elongated twinned crystals from Ightem; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

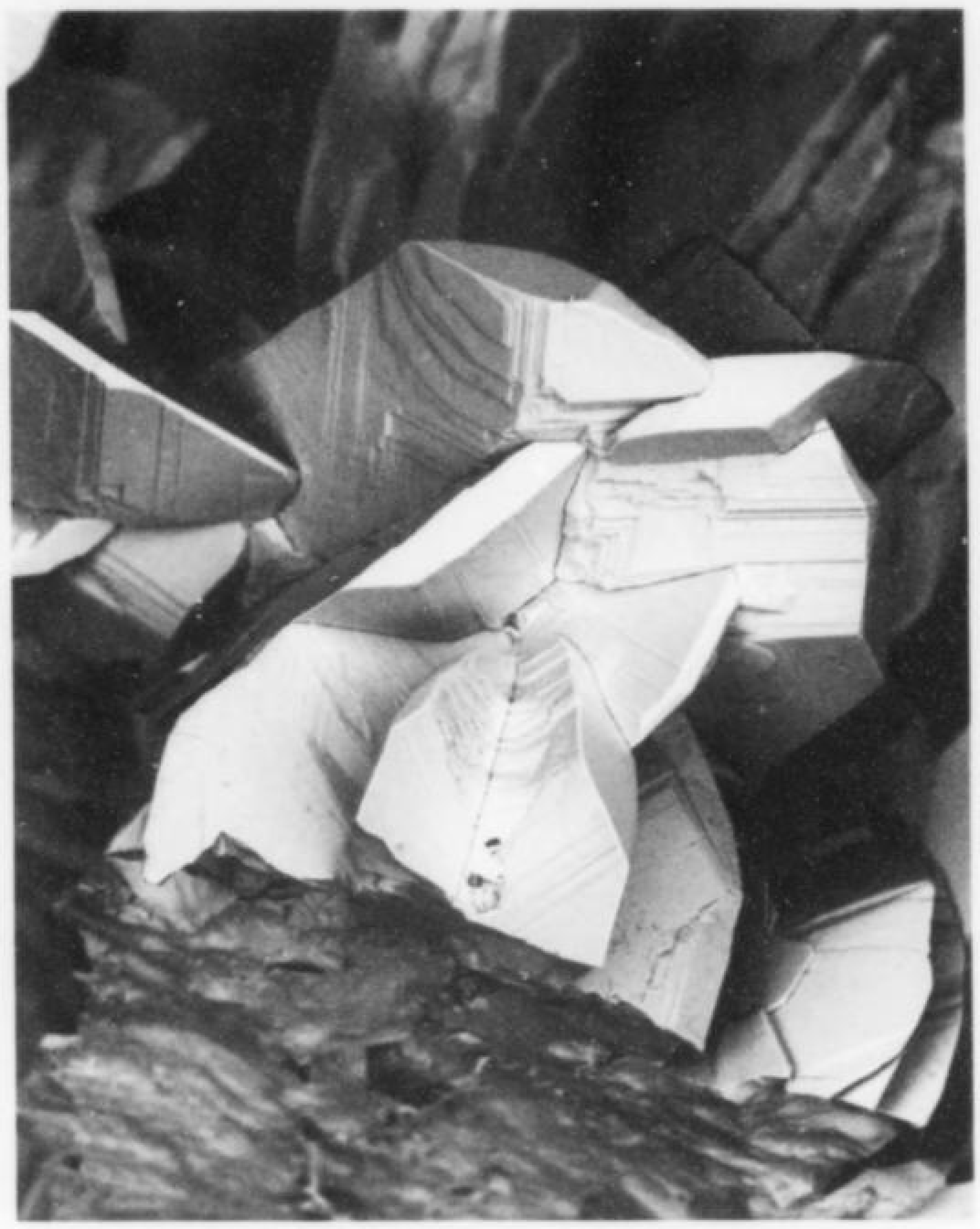


Figure 95. **Lustrous löllingite crystals twinned on (011) from Ightem; field of view 0.3 mm. REM photo: Gian Carlo Parodi.**

chalcocite, covellite and conichalcite; there it commonly forms porous spherules (<1 mm) and soft, tiny, pale blue scales. This same dolomite, however, also harbors the most beautiful lavendulan crystals known to us: turquoise-blue, with a pearly luster and rectangular profile, and reaching 2 mm.

Gaudefroy and Trey (1963) mention lavendulan spherules on green conichalcite from Aghbar. In old mine tunnels in this deposit we observed the mineral as efflorescences, with spherical aggregates of erythrite and with other arsenates; at Ightem it is accompanied by conichalcite and clinotyrolite. At Oumlil, elongated, lath-shaped lavendulan crystals occur in a narrow cavity zone, and specimens found on the dumps display 1-mm lavendulan spherules and acicular erythrite crystals on druses of scorodite.

Fairly well-crystallized, turquoise-blue spherules come from Méchoui 1 and from Khder (with scorodite, schneiderhöhnite and geminite). Lavendulan resembles rare copper arsenates such as arhbarite—but the latter is known in only three specimens from the Bou Azzer district.

Litharge PbO

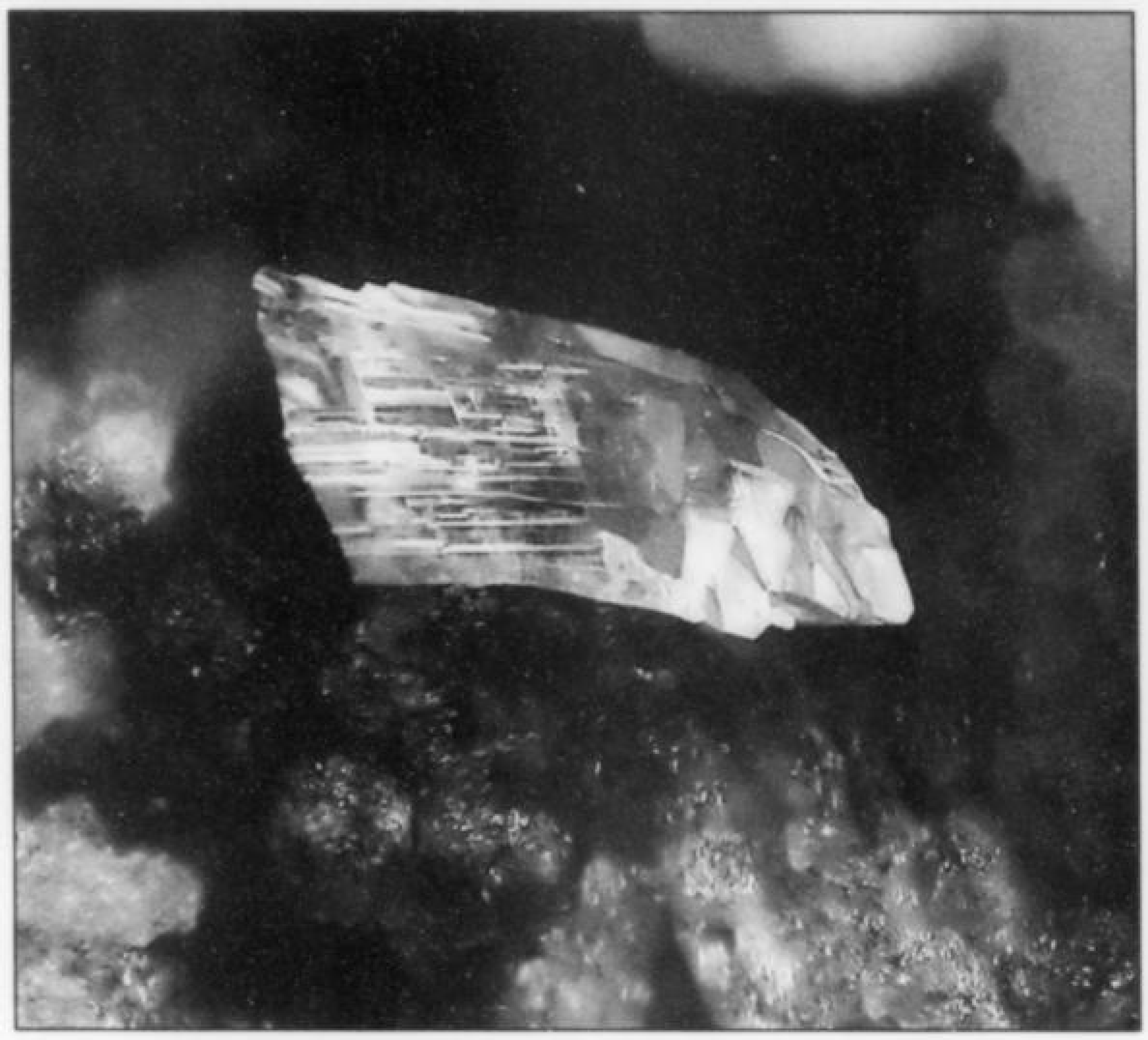
Litharge was recently found as crusts on large cleavage surfaces of galena in the Oumlil-East mine, with mottramite, mimetite and other lead species.

Löllingite $FeAs_2$

Since löllingite is an arsenide of iron, there was for a long time

Figure 96. **Maghrebite crystals resembling gypsum from the Oumlil-East mine; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 97. **Maghrebite, a colorless, transparent crystal, 0.5 mm, from the Aghbar mine. G. Favreau specimen; Heinz Dieter Müller photo.**



no interest in mining it as ore—except for a cobaltoan variety which is found chiefly at Aït Ahmane. Some years ago, however, developments in the prices of raw materials—rather low prices for cobalt but rather high ones for arsenic—inspired a renewal of interest in löllingite, which is widespread through the district. Löllingite plays an important role in the formation of iron-rich secondary minerals, including the arsenates scorodite, arseniosiderite, parasymplesite and pharmacosiderite, as well as the arsenites karibibite and schneiderhöhnite (particularly at Oumlil-East). Löllingite is widely distributed as lustrous granular masses and scaly aggregates; flattened diamond-shaped crystals are rarer. In dolomite from Ightem löllingite is associated with goethite, marcasite and chalcopyrite, and forms elongated, featherlike crystal aggregates, as well as star-shaped, penetration-twinned intergrowths of three individual crystals. From the dumps of Vein 52, Aït Ahmane, have come abundant specimens showing leafy löllingite aggregates to several centimeters. At Tamdrost, löllingite has been found in calcite with silver minerals. At Oumlil-East it forms granular masses to 60 cm; the best karibibite specimens come from cavity-rich parts of this ore zone, which is strongly shot through with quartz.

Maghrebite $MgAl_2[(OH)(AsO_4)]_2 \cdot 8H_2O$

The new mineral species maghrebite comes from the Aghbar mine east of Bou Azzer. In the Aghbar deposit, at least two separate oxidation episodes affected the primary cobalt and nickel arsenides, creating a rich suite of secondary arsenates. During the first phase of oxidation, relatively large crystals of roselite-wendwilsonite and talmessite were deposited with dolomite in cavities in quartz. The second phase of oxidation resulted in deposition of finely crystalline arsenates, including earthy arseniosiderite, cabalzarite and erythrite, over the earlier secondary minerals and in small cracks in the rock. Maghrebite formed during this second phase.

Maghrebite occurs as glassy, colorless, pointed tabular crystals to 0.2 mm. Commonly these occur in fan-shaped aggregates over surfaces measuring to several square millimeters in the narrow fissures. Single crystals display a typically triclinic morphology; resembling gypsum crystals (though more brittle and distinctly harder), they may be elongated along [001], and prismatic, or flattened on [010], and platy. The most prominent forms are {010}, {001} and {110}; {100} and {011} are subordinate.

Maghrebite is a hydrated Mg-Al arsenate, isostructural with laueite and the arsenate analog of the phosphate gordonite. It is the first known representative of the paravauxite-laueite group with (AsO_4^{3-}) as the dominant anion: all of the other representatives of the group are phosphates!

The name is after the large region of northwestern Africa called the "Maghreb," in which Aghbar, the type locality, lies. The word *Maghreb* is derived from the Arabic *al-maghrib*: this "region where the sun sets" is Morocco. The type specimens of maghrebite are stored at the Musée Géologique Cantonal, Lausanne, Switzerland (sample MGL #79792 is the holotype; samples MGL #79793 and #79794 are co-types).

Magnetite $Fe^{2+}Fe_2^{3+}O_4$

Magnetite occurs (with hematite) at Ightem, in dolomite tinted pink by a small manganese impurity. The magnetite forms pseudocubic crystals and distorted icositetrahedrons to 5 mm. This magnetite is nickel-bearing—an unusual phenomenon in terrestrial minerals, though not in meteorites. In serpentinites magnetite appears as rough octahedral crystals measuring between 1 and 2 mm.

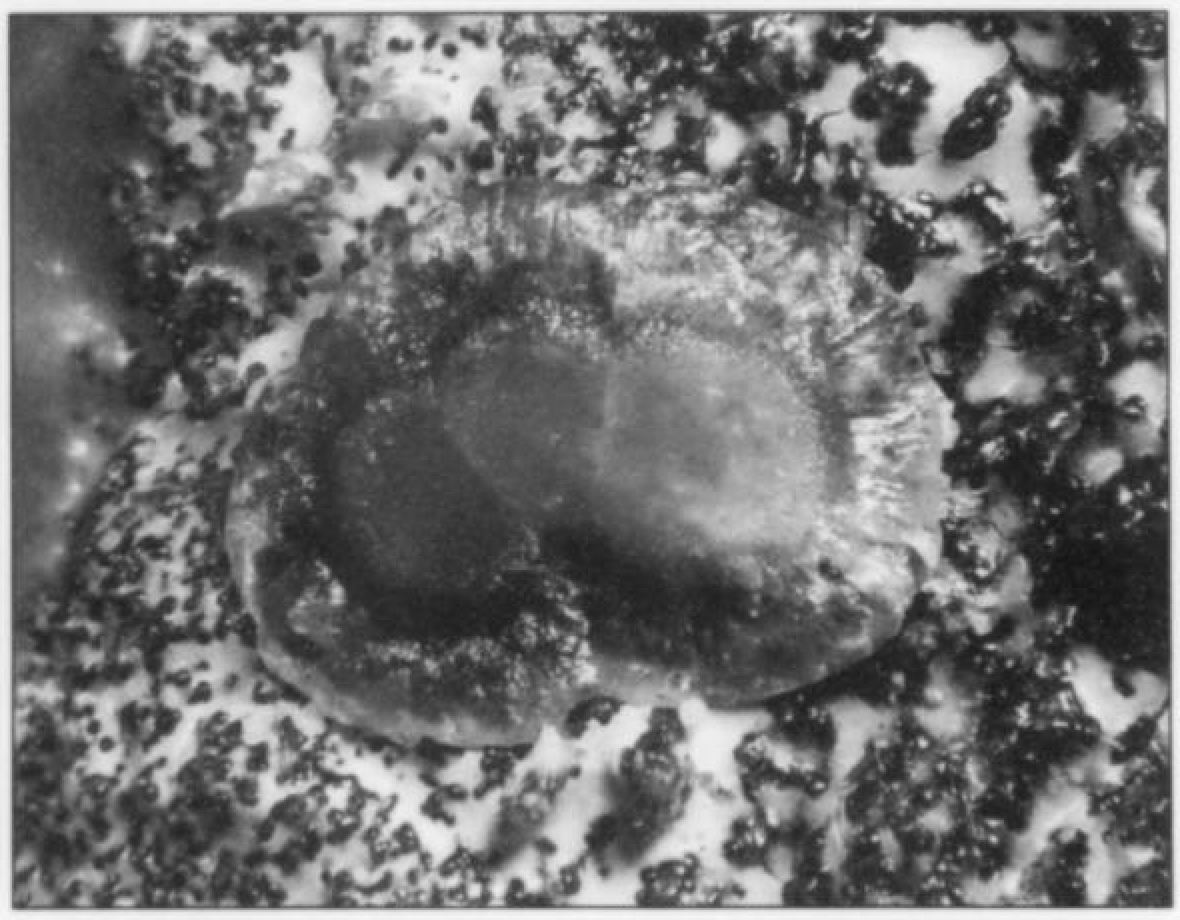


Figure 98. **Cobalt-rich mansfieldite comprises this "fried egg" from Méchoui; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

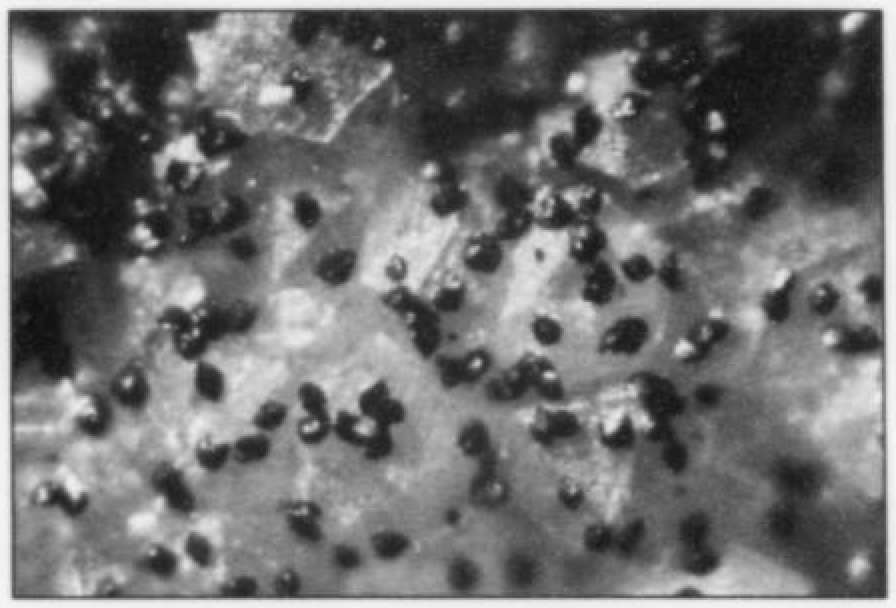


Figure 99. **Tiny crystals of mottramite from Oumlil; field of view 1.5 mm. G. Favreau specimen and photo.**

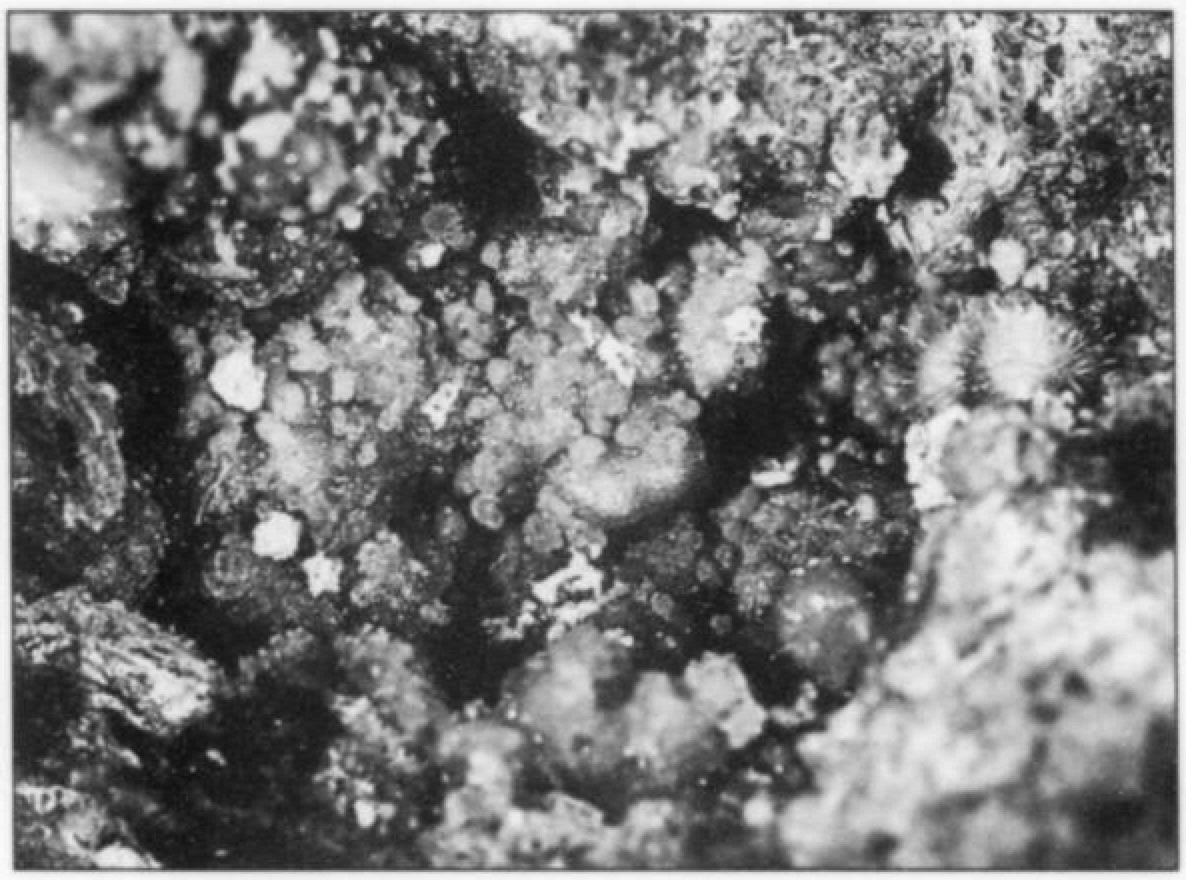


Figure 100. **Nickelaustinite with talmessite, from Vein 52, Aït Ahmane; field of view 8 mm. G. Favreau specimen; Robert Vernet photo.**

Malachite
(See under Azurite and Malachite.)

Mansfieldite $AlAsO_4 \cdot 2H_2O$
EDX analysis has recently identified the aluminum arsenate mansfieldite as pink crusts from Aghbar, together with the new aluminum arsenate maghrebite. Gray to pink spherules of mansfieldite, associated with erythrite, lavendulan, scorodite and alumopharmacosiderite, come from Méchoui. The mansfieldite aggregates, some of which look like fried eggs, resemble mansfieldite from Mount Cobalt, Queensland, Australia.

Maucherite
(See Nickeline, Nickel-skutterudite and Maucherite.)

Metanováčekite
(See Nováčekite and Metanováčekite.)

Metazeunerite
(See Zeunerite and Metazeunerite.)

Mimetite $Pb_5(AsO_4)_3Cl$
Early in 2001, masses of galena to 1 kilogram weight and more were found at Oumlil-East. They are only slightly corroded, and are encrusted by earthy yellow-orange litharge. Among other secondary minerals in evidence are anglesite, fornacite, mottramite and mimetite. The latter was seen in small cavities as orange fibers and as elongated yellow-brown prismatic crystals measuring less than 1 mm.

Mottramite $PbCuVO_4(OH)$
A piece of heavily altered galena from Oumlil-East shows secondary mineralization containing mimetite and druses of brownish black tabular crystals, to 1 mm, resembling wulfenite. Smaller black crystals in the assemblage were analyzed as mottramite. The crystals have resinous luster, and their color as seen in very thin fragments is dark brown. Mottramite is the only vanadium mineral known from the Bou Azzer district.

Népouite $(Ni,Mg)_3Si_2O_5(OH)_4$
In Vein 51 at Aït Ahmane, nickel-rich talmessite forms pale green crusts and tiny crystals on calcite matrix, with nickeline and bright emerald-green népouite.

Nickelaustinite $CaNiAsO_4(OH)$
Nickelaustinite was first described by Cesbron *et al.* (1987) from specimens from Bou Azzer, but regrettably no information about the specific collecting site was provided. Nickelaustinite forms yellow-green to grass-green spheres of radiating acicular crystals, in some cases flattened on (110) and elongated along [001], displaying silky to adamantine luster. The spheres rest, with roselite and calcite, in cavities in a gray dolomite containing granular chalcopyrite and skutterudite.

Since then, of course, we have investigated the district, and we have found that the much more widely distributed cobaltaustinite often shows high concentrations of nickel (also of zinc), with nickel in some cases exceeding cobalt. Visual identifications are unreliable on principle; therefore "nickelaustinite" specimens offered on the market without analytical verification should be regarded as doubtful.

After accounting for many inconclusive cases, we can affirm that nickelaustinite occurs in Vein 52, Aït Ahmane. There it forms—very similarly to cobaltaustinite!—pale green, lustrous, finely leafy aggregates (<0.5 mm) which rest in cavities in compact white talmessite. Similar nickelaustinite aggregates have been found in white quartz and on compact brownish talmessite. This nickelaustinite contains subordinate cobalt as well as subordinate zinc—the latter is not surprising, as sphalerite occurs sparsely in the deposit.

Mining in Vein 59, Aït Ahmane, in 2001–2002 produced a small dump with a rich mineral assemblage: nickel-rich talmessite, cobalt-

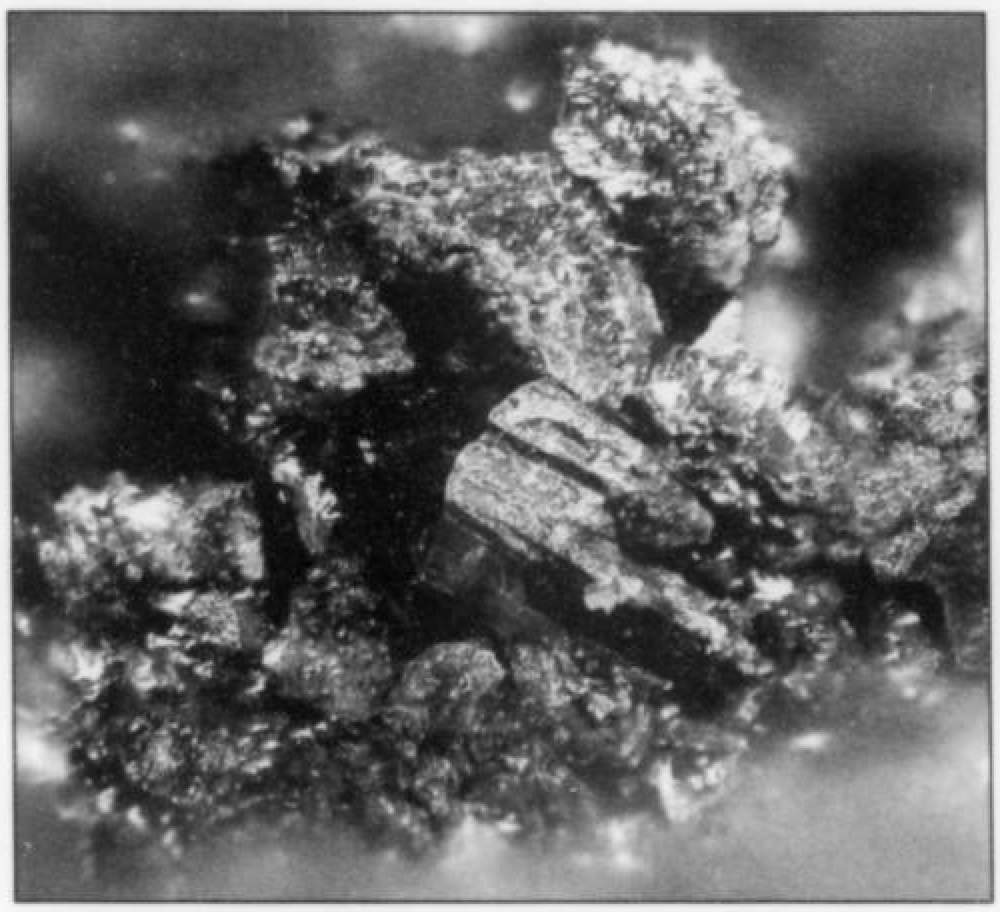


Figure 101. **Platy maucherite crystals from Vein 51, Aït Ahmane; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

koritnigite, vladimirite, annabergite, and small, green, attractive crystals of nickelaustinite, in some cases with talmessite, opal, or flakes of guerinite (?) with a pearly luster.

Nickeline NiAs
Nickel-skutterudite (Ni,Co,Fe)As_{2-3} and
Maucherite $Ni_{11}As_8$

Vein 51 at Aït Ahmane is a particularly rich occurrence where, in addition to octahedral gersdorffite crystals, fist-sized masses of nickeline are still being found. Outer surfaces of this "red nickel ore" may display garnierite-like alteration products, as well as matte-gray nickel-skutterudite; in addition, tiny, striated, tabular crystals of maucherite (<0.5 mm) sometimes appear. Nickel-skutterudite also occurs in Vein 53, as lustrous pyritohedral and octahedral crystals with clinosafflorite. At Ightem, nickeline is found as bronze-colored grains to 1 cm and rounded masses to 20 cm in a dolomitic carbonate vein, with gray, cubic crystals of nickel-skutterudite.

Nickellotharmeyerite $Ca(Ni,Fe^{3+})_2(AsO_4)_2(H_2O,OH)_2$

In Vein 52, Aït Ahmane, we observed very small (<0.1 mm), red-brown spherules in cavities in a vein of white to pink talmessite. Under strong magnification the spherules show sharp crystals resembling beudantite. The material was shown by analysis at the Lausanne Geological Museum to be manganese-rich nickellotharmeyerite. This is the first identification of nickellotharmeyerite from the Bou Azzer district, and the second worldwide locality for the mineral, after Schneeberg, Upper Saxony.

Nickel-skutterudite

(See under Nickeline, Nickel-skutterudite and Maucherite.)

Nováčekite $Mg(UO_2)_2(AsO_4)_2\cdot 12H_2O$ and
Metanováčekite $Mg(UO_2)_2(AsO_4)_2\cdot 4\text{–}8H_2O$

Bültemann (1957) described the uranyl arsenate nováčekite from Vein 5 + 7, Bou Azzer, as small, straw-yellow to yellow tabular crystals, more weakly fluorescent in ultraviolet light than the associated pale yellow to yellow-green uranospinite (some of these specimens also showed associated brannerite). During the 1960's and 1970's, nováčekite was found as opaque, pale yellow tabular crystals to more than 5 mm, associated with pale pink balls of erythrite. In Vein 2, Bou Azzer, we have again found nováčekite, as thin, pale yellow platelets measuring less than 1 mm, with erythrite. It appears that as soon as the crystals are exposed to sunlight they undergo dehydration and become dull, having altered to metanováčekite.

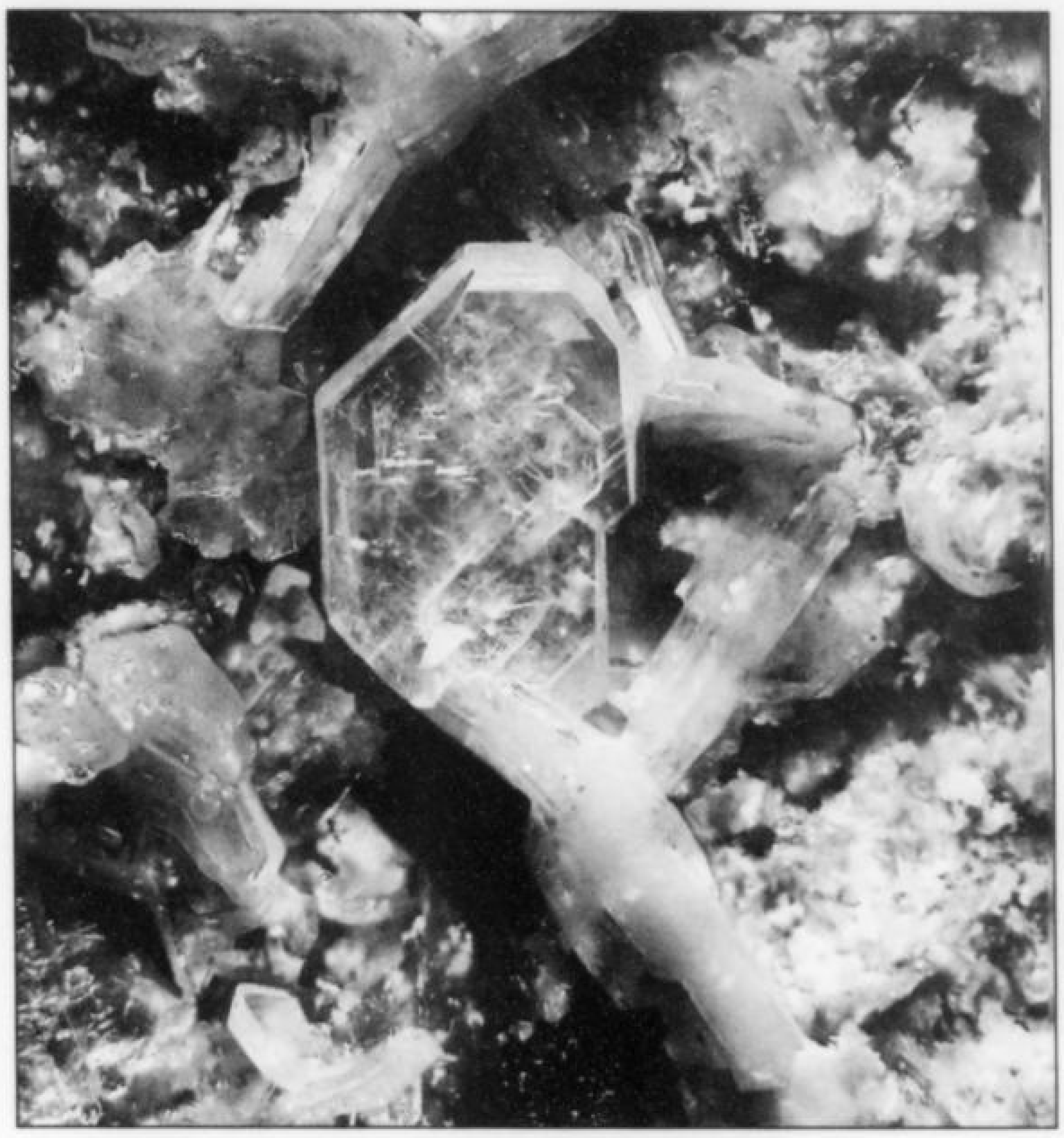


Figure 102. **Nováčekite crystals with green zeunerite, from Tamdrost; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

One of the greatest surprises of our 2001 collecting season was the discovery of nováčekite in a small open-pit mine northwest of Tamdrost, where there was local uranium enrichment in a weathered and strongly fractured cavity zone measuring about 20 × 40 × 40 cm. There, small tufts of erythrite crystals, a little zeunerite, and amber-brown to lemon-yellow nováčekite crystals were collected. The tabular nováčekite crystals have approximately square outlines and are all rounded to some degree. They are generally transparent, but lose their transparency in sunlight as a consequence of dehydration and alteration to pale yellow metanováčekite.

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

Although copper is widely distributed as a subordinate metal in the Bou Azzer district, olivenite is found very rarely. At Tamdrost-West, gray-green acicular crystals of olivenite are associated with yellow-brown pharmacosiderite in cavities in white quartz. Tiny chisel-shaped crystals and fan-shaped crystal groups of olivenite with bottle-green lower zones and pink terminations have also come from this site. EDX analyses of this olivenite show notable traces of cobalt and nickel.

In olivenite from Ightem, zinc substitutes for part of the copper. This zinc-rich olivenite occurs as transparent spherules measuring less than 0.5 mm, associated with powellite. The same ore masses contain attractive green acicular crystals of olivenite with pointed tips, in fan-shaped aggregates.

Opal $SiO_2\cdot nH_2O$

Colorless crusts of opal on erythrite are found in Vein 54, Aït Ahmane.

Parasymplesite $Fe_3^{2+}(AsO_4)_2\cdot 8H_2O$

Despite the enormous amounts of iron and arsenic in the Bou Azzer district, the iron arsenate parasymplesite is fairly rare compared to its cobalt equivalent, erythrite. At Tamdrost, parasymplesite occurs with karibibite in weathered löllingite, forming lustrous

Figure 103. **Olivenite, from Ightem; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

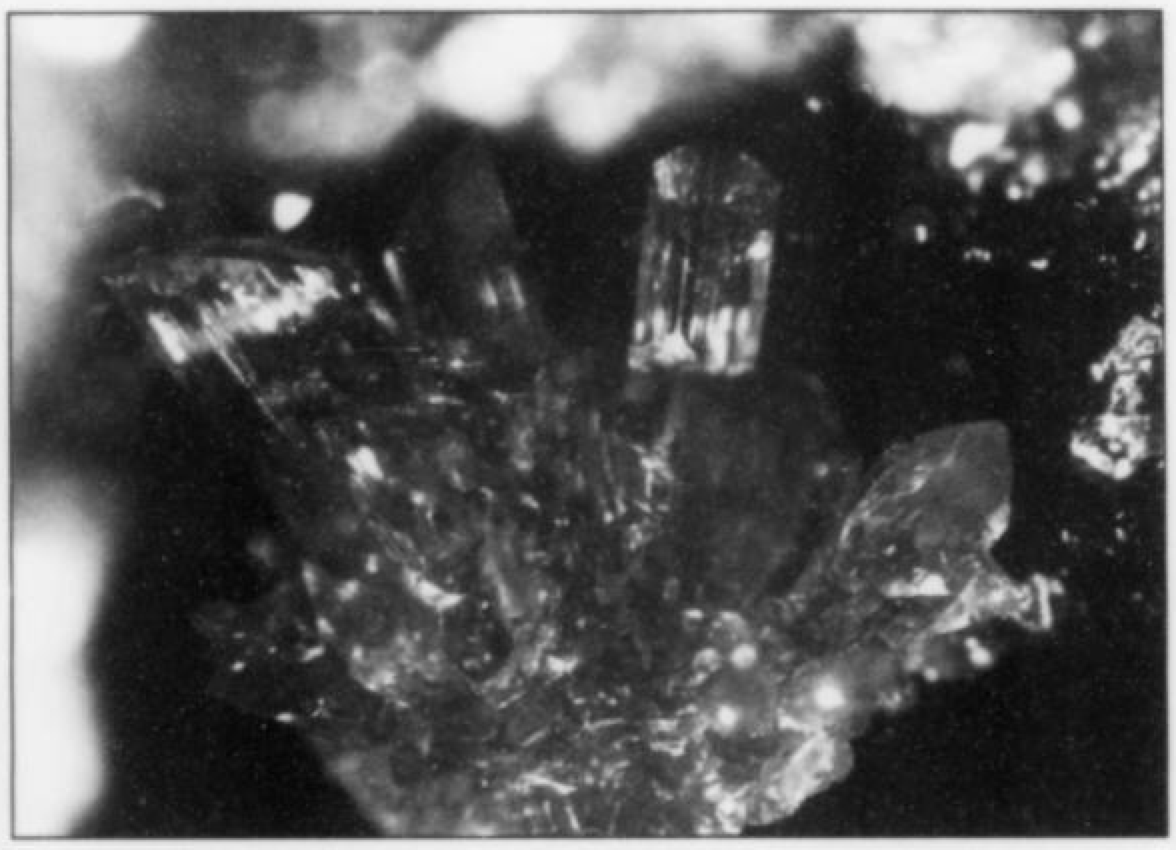


Figure 104. **Cobalt-rich parasymplesite, from Oumlil; field of view 4 mm. R. Pecorini specimen; Robert Vernet photo.**

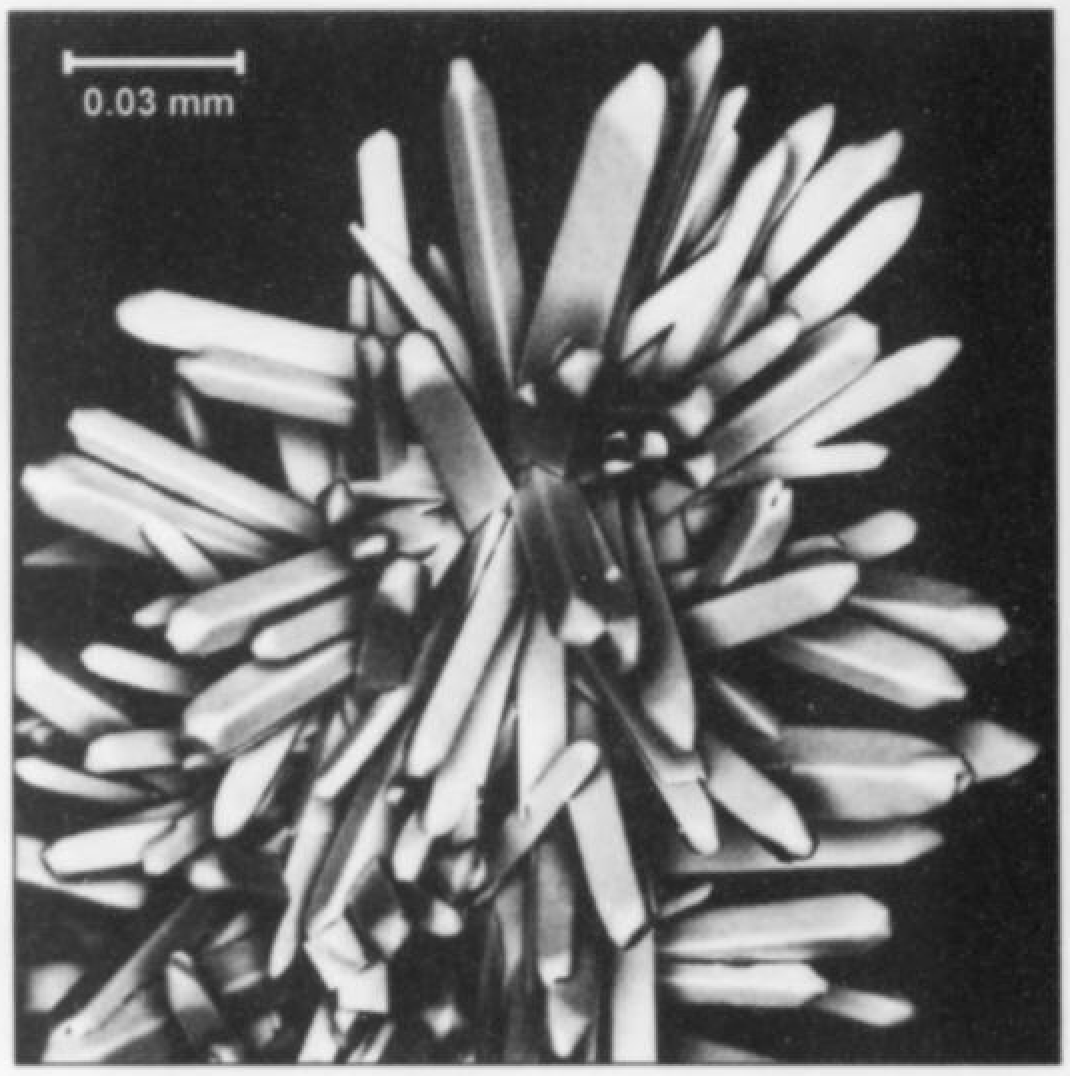


Figure 105. **Cobalt-rich olivenite, from Tamdrost-West; field of view 0.15 mm. G. Favreau specimen; Gian Carlo Parodi REM photo.**

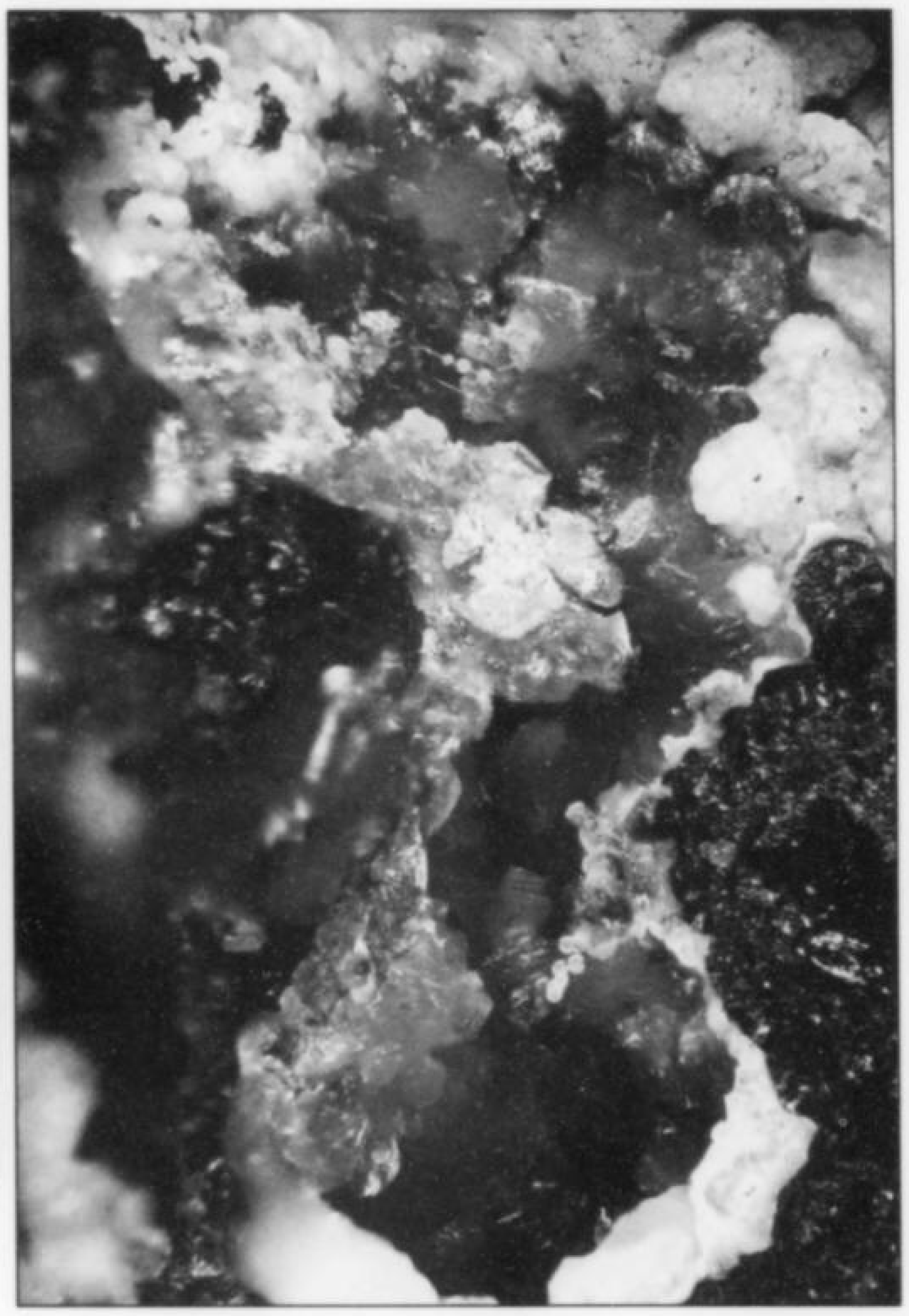


Figure 106. **Parnauite, a new find from Khder; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

lamellar crystals (resembling vivianite) to 1.5 mm, as well as radial aggregates of leafy crystals; the latter are color-zoned green and pink (Schmetzer *et al.*, 1980).

The best specimens were found in early 2001 at Oumlil-East: they show dark green parasymplesite rods to 5 mm with perfect cleavage in the long direction, as well as distorted prismatic crystals on a druse of karibibite over massive löllingite. Specimens showing radial aggregates of gray-green to greenish blue, fibrous crystals were also collected; the terminations and a few particular zones of these crystals, strangely, have a pink color, like that of erythrite. The variable colors probably signify that these are mixed crystals which run compositionally from parasymplesite to erythrite as cobalt substitutes for iron. In many cases the crystals are weathered, and earthy yellow-green pseudomorphs after parasymplesite have been found; commonly these are associated with colorless crystals of pharmacosiderite and with scorodite.

In Vein 59, Aït Ahmane, parasymplesite forms compact gray-blue spherules composed of radiating fibrous crystals, in massive löllingite; more rarely it is found in cavities with lustrous octahedral crystals of arsenolite and with amorphous yellow minerals.

Recently parasymplesite was found at Méchoui as pink acicular crystals and as spherulitic aggregates of brown, cleavable crystals, with distorted erythrite crystals and green cubic crystals of pharmacosiderite.

Parnauite $Cu_9^{2+}(AsO_4)_2(SO_4)(OH)_{10}\cdot 7H_2O$

Parnauite forms yellowish green to bluish green single platelets and clusters (<1 mm) on gangue quartz at Khder, associated with conichalcite and small acicular crystals of olivenite.

Figure 107. **Cobalt-rich pharmacolite, from Bou Azzer-East; field of view 2 mm. G. Favreau specimen and photo.**

Pharmacolite $CaHAsO_4\cdot 2H_2O$

Pharmacolite seems to be the most widespread white arsenate in the district after picropharmacolite. These minerals both form easily as post-mining occurrences and in underground oxidation zones. These colorless to white Ca and Ca + Mg arsenates are not easy to distinguish from each other with the naked eye; specimens must be analyzed.

Guilbert and Schubnel (1969) identified pharmacolite as typical colorless crystals from Vein 7, Bou Azzer: flat, elongated crystals shaped like little boats to 2 mm which form sheaf-like aggregates on quartz, associated with picropharmacolite, erythrite in two generations, and more rarely lavendulan. Small, colorless, rod-shaped crystals with flat or pointed terminations were found on old dumps of Vein 2; these form rosettes and sheaf-like aggregates resembling natrolite in arsenic-bearing cobalt ores, associated with hematite spherules, sphaerocobaltite and picropharmacolite.

A few years ago, on the 40-meter level in Bou Azzer-East, excellent "little boat"-shaped pharmacolite crystals were discovered: colorless to white sheaves and fans to 2 mm are associated with reddish-pink erythrite spherules which reach 1 mm. Unusual pale pink pharmacolite, with gypsum and lavendulan, has also been found on a matrix of diorite. Locally, chalk-white weilite may have formed by dehydration of pharmacolite.

At Méchoui and Ightem, dense gray-white balls of pharmacolite have been found intergrown with soapy-lustered picropharmacolite sprays and matte-black spherules of heterogenite. In May 2000, colorless rosettes of pharmacolite crystals to 2 mm were discovered in sainfeldite-rich specimens from the old adits cut by recent workings at Aghbar.

Pharmacosiderite $KFe_4^{3+}(AsO_4)_3(OH)_4\cdot 6\text{–}7H_2O$

Pharmacosiderite is, like arseniosiderite, a product of the weathering of iron-rich ores, especially löllingite. In Vein 7, Bou Azzer, it forms pale green crusts of very tiny (~0.1 mm) truncated cubes, with erythrite in quartz matrix. Dark green cubic crystals to about 0.5 mm occur with pink cobalt arsenates in Vein 54, Aït Ahmane. Tiny (~0.2 mm) brown or green cubic crystals have been found at Tamdrost, with olivenite and lavendulan; the brown crystals contain iron, arsenic, potassium and considerable aluminum, so that they represent an interesting intermediate phase between pharmacosiderite (Al-free) and alumopharmacosiderite (Fe^{3+}-free).

Figure 108. **Pharmacosiderite from Oumlil-East (resembling fluorite from Cumberland, England); field of view 3 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Like scorodite, pharmacosiderite was considered rare until the beginning of mining at Oumlil-East, where the mineral is found commonly as blue-green, lustrous cubic crystals to 1 mm. Surfaces to 40 × 60 cm (!) encrusted by pharmacosiderite often serve as substrates for crystals of other minerals, among them fibrous karibibite. This pharmacosiderite seems to be unstable as to color, turning brown even if not exposed to sunlight.

Attractive green pharmacosiderite crystals less than 2 mm on edge, with erythrite spherules, on matrix of weathered löllingite have been found at Méchoui 1, and dark blue cubic crystals have been collected rarely in the vicinity.

Picropharmacolite $Ca_4Mg(AsO_3OH)_2(AsO_4)_2\cdot 11H_2O$

The fact that dolomite, a Ca-Mg carbonate, is extremely common in the district explains the wide distribution of picropharmacolite, a secondary Ca-Mg arsenate which is found, in effect, everywhere. It is snow-white in its pure form, but commonly it is tinted pale pink by traces of cobalt. It is sometimes associated with gray to pinkish white sainfeldite.

Dietrich and Schubnel (1969) describe large picropharmacolite specimens consisting of matrix plates to more than 10 cm across on which rest white crystal sprays to 5 mm, from Aghbar. When the old tunnels here were re-opened in 2000, similar specimens were collected, showing newly formed erythrite and white arsenates including sainfeldite, pharmacolite and picropharmacolite. Specimens also came at this time from Méchoui, and specimens showing snow-white picropharmacolite sprays to 2 mm with erythrite and sphaerocobaltite came from the old dumps of Vein 2, Bou Azzer. The association of pink cobalt minerals with white picropharmacolite can make for spectacular-looking specimens!

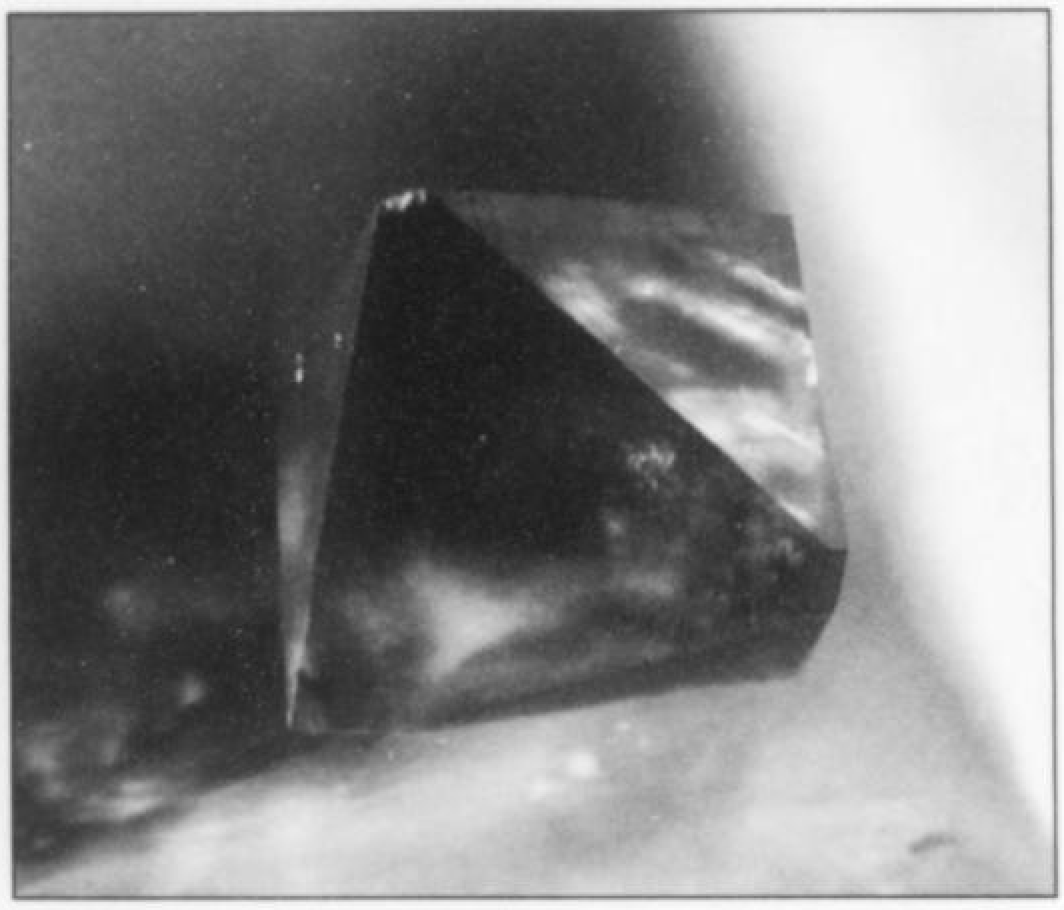


***Figure 109.* A powellite crystal from Vein 2, Bou Azzer; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Powellite $CaMoO_4$

Powellite is never found in large concentrations in the Bou Azzer district, but tiny crystals have been found accompanying secondary copper minerals at several sites characterized by enrichment in molybdenum. In general the powellite is an inconspicuous yellow-brown, but its adamantine luster and its intense yellow fluorescence under shortwave ultraviolet light are typical of the species. Dolomite boulders on a mining path at Ightem were first found to contain tiny, distorted dipyramidal crystals of powellite with truncated tips; more highly lustrous crystals are located in deep cavities where they are protected from weathering. They rest directly on dolomite crystals, on limonitized chalcopyrite crystals, and on malachite spherules. Brown, somewhat larger ($<$0.7 mm) powellite crystals have been found on warty crusts of conichalcite and zinc-rich olivenite. From chrysocolla-included dolomite blocks have come rosette-shaped or spherical aggregates of pale yellow, lens-shaped powellite crystals (0.1–0.3 mm), intergrown with transparent conichalcite spherules and resting in part on pale green annabergite. In the uranium zone at Tamdrost-West, associated with annabergite, we found lens-shaped, yellow-brown powellite crystals ($<$0.5 mm); in Aghbar, colorless to white, dipyramidal powellite crystals ($<$0.1 mm) rest in quartz cavities with conichalcite. In May 2002, Vein 2 at Bou Azzer produced colorless dipyramidal crystals ($<$1 mm) with lustrous mirrorlike faces; these form caps on the tips of scalenohedral crystals of calcite. The best powellite crystals of the district have come from this occurrence; they are honey-brown pseudo-octahedrons, associated with cobaltlotharmeyerite, which can reach 3 to 5 mm.

Prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$

Specimens showing transparent gray spheres of prehnite, with stichtite, in granular chromite, have been collected in a small open-pit mine east of Agoudal and in ore piles of chromite from Inguijem.

***Figure 110.* Proustite crystals from Vein 2, Bou Azzer; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Proustite Ag_3AsS_3

At Tamdrost proustite occurs in calcite veins as dark red crystals not exceeding 4 mm, with löllingite and native silver. Smaller, deep red crystals display hexagonal prisms with low-angle rhombohedrons; larger crystals are commonly rounded and blackish. Associations include tiny hexagonal-tabular crystals and 1-mm rosettes of brownish sphalerite or wurtzite, as well as tiny, bronze-colored, strongly striated columnar crystals of a species which probably is argentopyrite (Permingeat, 1991). From fall 2005 to early 2006 the Bouismas mine produced proustite crystals to 4 mm in cavities in pink dolomite.

Pinpointing exact sub-localities for some of the silver-bearing minerals remains a puzzle. Specimens labeled as having come from Ightem are in circulation, although an occurrence of silver minerals there has not been documented in the literature. Similar-looking specimens are sometimes labeled proustite, sometimes pyrargyrite.

Pyroaurite and Sjögrenite $Mg_6Fe^{3+}_2(CO_3)(OH)_{16}\cdot 4H_2O$

In Ightem, one of us (JED) collected samples of these two dimorphous Mg-Fe carbonates. Specimens showing thin, platy hexagonal crystals were found in a celestine-bearing vein with skutterudite, hematite, magnetite and chalcopyrite (Gaudefroy, 1963). Colorless, transparent lamellae to 3 mm rest on calcite, and yellowish lamellae to 2 mm rest on dolomite. We found pyroaurite at Ightem again in late 2005, as small hexagonal plates (XRD analysis by Paolo Orlandi, Pisa).

Quartz SiO_2

Quartz is common as drusy cavity linings of lustrous crystals from 1 to 2 mm. Milky quartz crystals to more than 5 cm were collected in Vein 7, Bou Azzer. Sceptered crystals, and specimens consisting of "piles" of crystals, are fairly rare. In cavities in dolomite—for example at Aghbar—late-formed quartz can blanket or enclose secondary minerals such as arseniosiderite, conichalcite, cobaltaustinite, erythrite, cobaltlotharmeyerite and sphaerocobaltite.

The most common inclusions in quartz, however, are red-brown to black hematite or "limonite" spherules and yellow-brown, acicular crystals of goethite. The formation of such quartz clearly took place much later than the oxidation of the ores! In general, quartz from the district is colorless to milky white, but iron or manganese can tint it brown or violet, and phantoms can be present. Smoky quartz has been found in small veins around Bou Azzer, its smokiness possibly having been induced by radiation from brannerite.

Rammelsbergite $NiAs_2$

Hochleitner (1985) described an occurrence of good leafy rammelsbergite crystals to 5 mm with skutterudite in the Bou Azzer district. In a specimen of quartz from the old dumps of Vein 52, Aït Ahmane, we found metallic gray masses with perfect cleavage such as distinguishes rammelsbergite from its common associates gersdorffite and skutterudite; furthermore, apple-green stains of annabergite signaled the presence of nickel. In rare cases rammelsbergite specimens display a fishbone-like aspect.

Realgar AsS

Tiny, pale orange, columnar crystals of realgar are known from Vein 7, Bou Azzer. More intensely orange-colored prismatic crystals 1 to 2 mm long on calcite were found in a löllingite vein at Bouismas between November 2005 and early 2006.

Retgersite $NiSO_4 \cdot 6H_2O$

Retgersite was identified in 1993 on specimens of gersdorffite from Vein 51, Aït Ahmane. The nickel sulfate forms small, glassy green, microcrystalline aggregates from 1 to 3 mm, with annabergite. In a carbonate vein in the mine we have found newly formed bright blue-green crusts of retgersite, a few enclosing tiny grains of native sulfur, in the interiors of porous masses of gersdorffite. Since retgersite is easily soluble in water, it is rare in surface exposures even though its parent mineral, gersdorffite, is relatively common; it seldom rains in the area, but even a brief shower can dissolve any retgersite present at the surface.

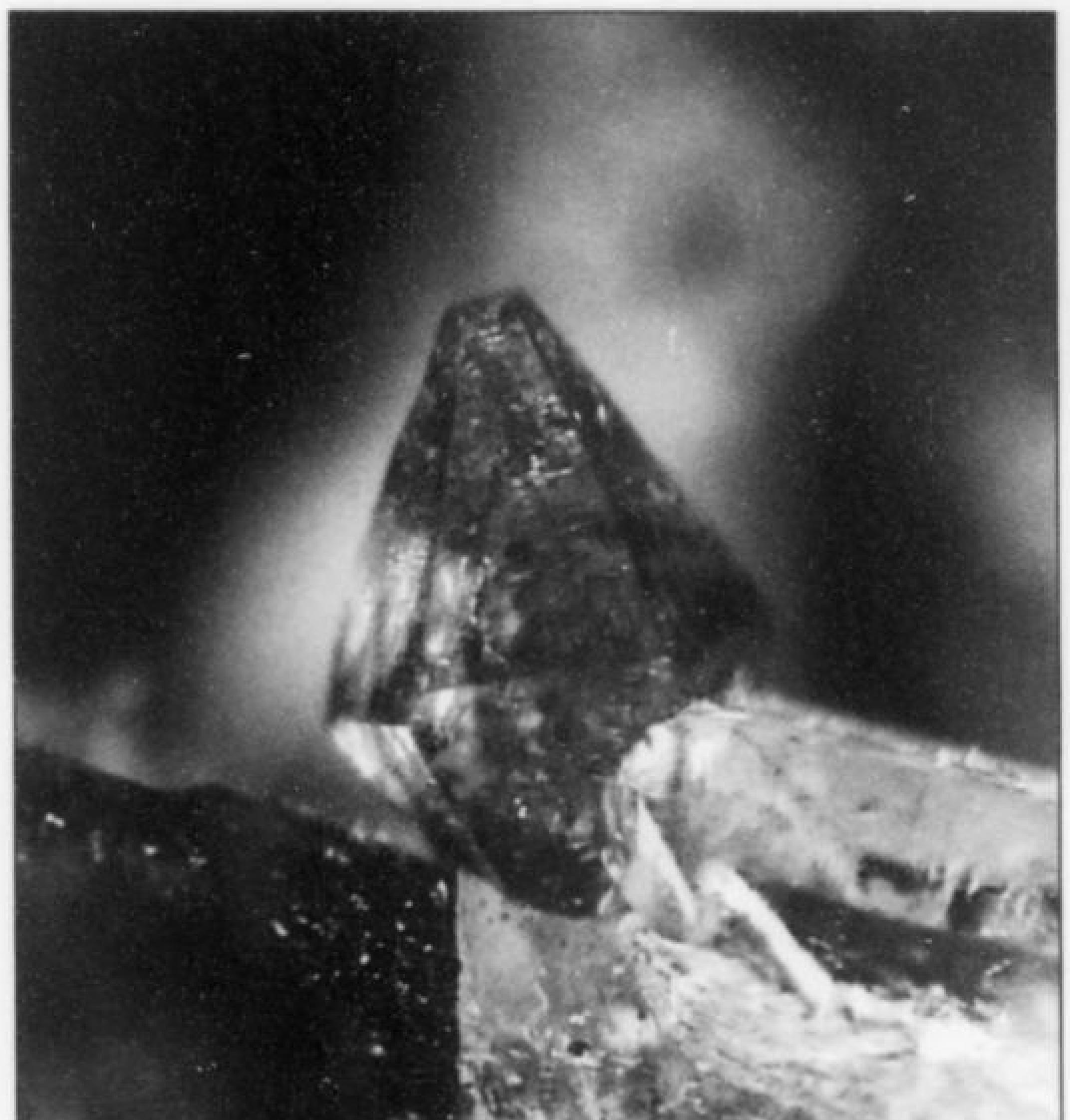


Figure 111. **A pseudo-pyramidal roselite crystal, 0.5 mm, from Vein 2, Bou Azzer. G. Favreau specimen; Robert Vernet photo.**

Figure 112. **Prismatic crystal of roselite, 0.8 mm, from Vein 2, Bou Azzer. G. Favreau specimen; Robert Vernet photo.**

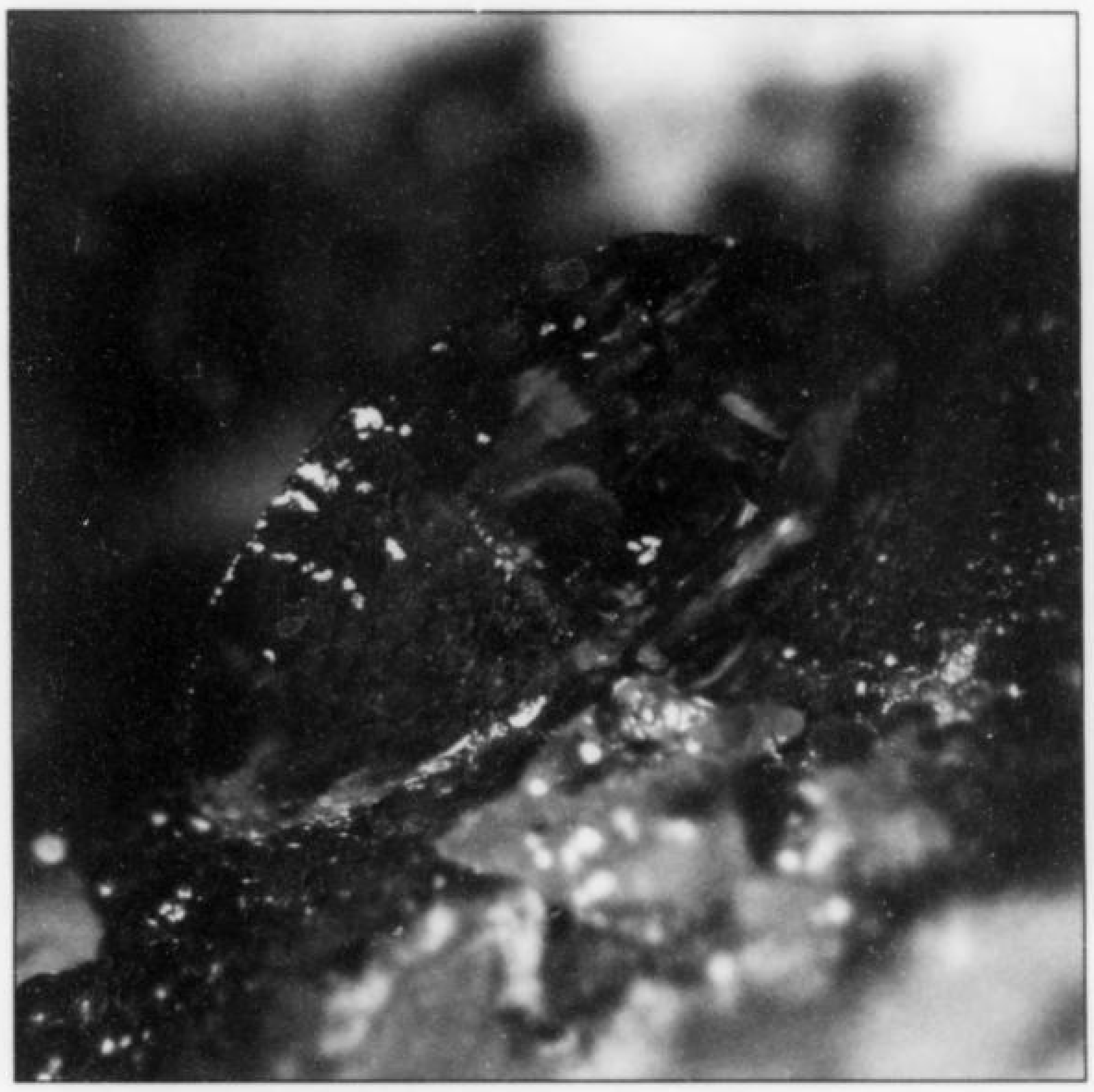
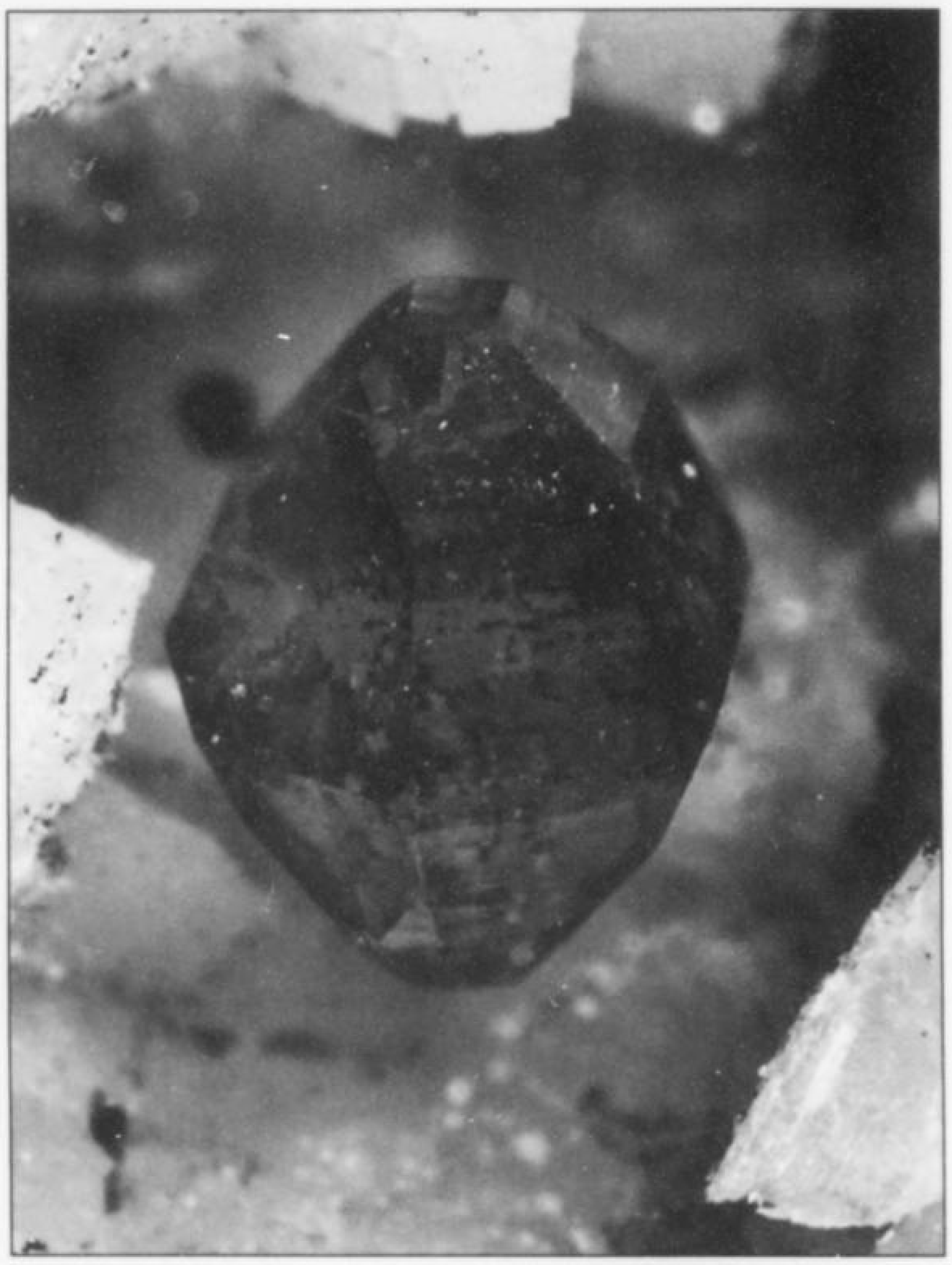


Figure 113. **Roselite twinned crystal, 3 mm, from Aghbar. Michael Praeger specimen and photo.**

Roselite $Ca_2(Co^{2+},Mg)(AsO_4)_2 \cdot 2H_2O$
Wendwilsonite $Ca_2(Mg,Co^{2+})(AsO_4)_2 \cdot 2H_2O$ and
Zincroselite $Ca_2Zn(AsO_4)_2 \cdot 2H_2O$

The Bou Azzer district is by far the world's richest and finest locality for the members of the roselite group, which are otherwise extremely rare. These minerals occur in almost completely continuous solid solution series. In the district the general sequence of crystallization runs as follows: erythrite I (tabular), roselite → wendwilsonite, roselite-beta → talmessite → erythrite II (acicular). Associated with the series are hematite, calcite, cobaltaustinite, cobaltlotharmeyerite and rarely sphaerocobaltite.

Roselite-wendwilsonite is distributed especially widely at Aghbar,



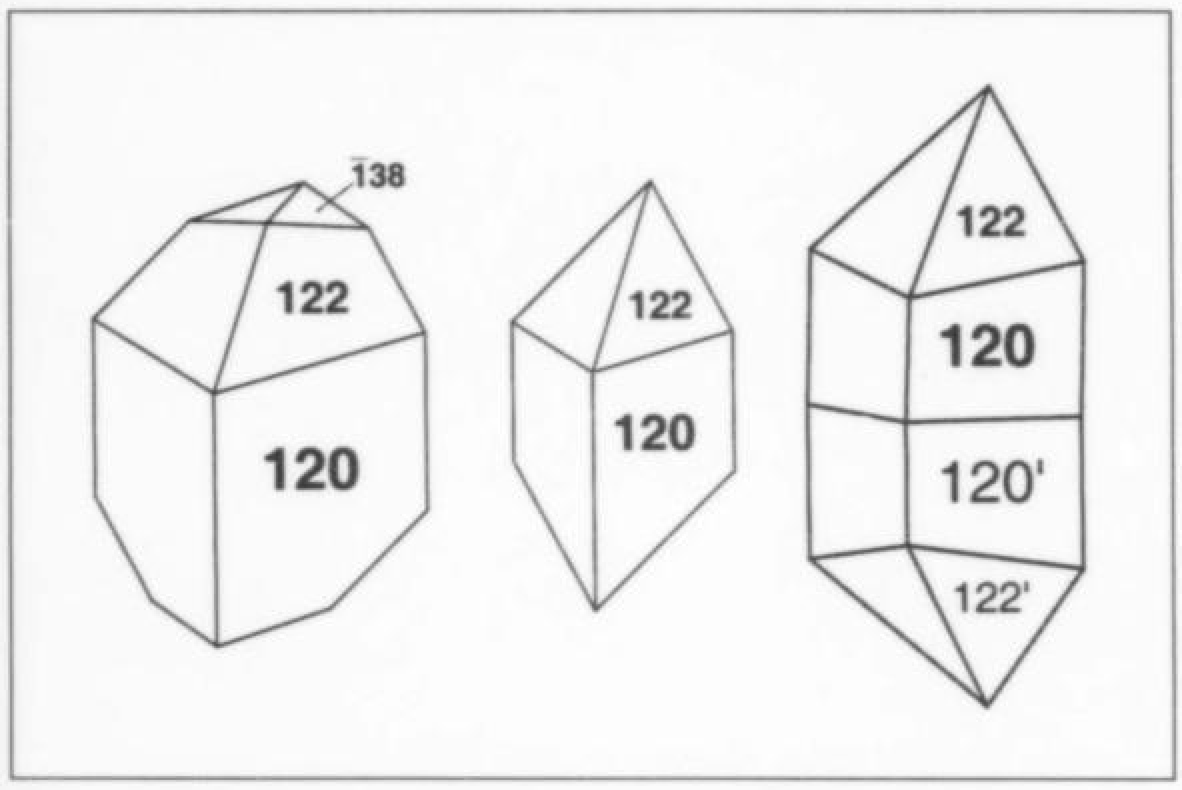


Figure 114. **Roselite crystal habits. Lance-shaped crystals consist of the {120} and {122} forms. Contact twins on ($\bar{1}04$) simulate an orthorhombic symmetry—as in the crystal pictured top right. Drawings and goniometric measurements by Michael Praeger.**

Figure 115. **Roselite crystal, 1.3 mm, from Vein 2, Bou Azzer. G. Favreau specimen; Robert Vernet photo.**

Figure 116. **A typical mineral association from Aghbar: roselite/wendwilsonite (3.5 mm crystal) with cobaltaustinite (green) and cobaltlotharmeyerite (brown). G. Favreau specimen; Robert Vernet photo.**

not only as free crystals in dolomite cavities but also as large grains of massive material. These minerals are not found at the extremities of the district, i.e. at Méchoui or at Aït Ahmane. Well developed crystals are quite common, especially in the cobalt arsenide veins in the central part of the district, around Bou Azzer, where most of the crystals are deep red, fairly cobalt-rich roselite. As a rule these crystals measure from 1 to 3 mm, but beautiful specimens with crystals from 5 mm to 1 cm have been found. During the year 2000, wonderful specimens with pale raspberry-red to red-violet crystals from 2 to 7 mm were found at Aghbar, where they are associated with wendwilsonite: some crystals show compositional zoning in narrow bands (Weiß *et al.*, 2002).

Wendwilsonite is the magnesium-dominant end-member of the roselite-wendwilsonite series. The first description, by Dunn *et al.* (1987), was made from a calcite/arsenate specimen with lustrous crystals to 6 mm. The mineral remained very rare until the new finds of "roselite" at Aghbar in 2000: examination by Weiß *et al.* (2002) disclosed extreme compositional zoning in this new "roselite," with crystals to 7 mm showing cores of magnesium-rich roselite ($Co_{0.5\text{-}0.6}Mg_{0.5\text{-}0.4}$) and outer zones of cobalt-rich wendwilsonite ($Mg_{0.8\text{-}0.6}Co_{0.2\text{-}0.4}$). Magnesium-rich zones are pale violet-red while cobalt-rich zones tend toward a saturated rose-red. Smaller (1–4 mm), pale pink crystals consist primarily through most of their volume of cobalt-poor wendwilsonite ($Mg_{0.8\text{-}0.9}Co_{0.2\text{-}0.1}$), which in

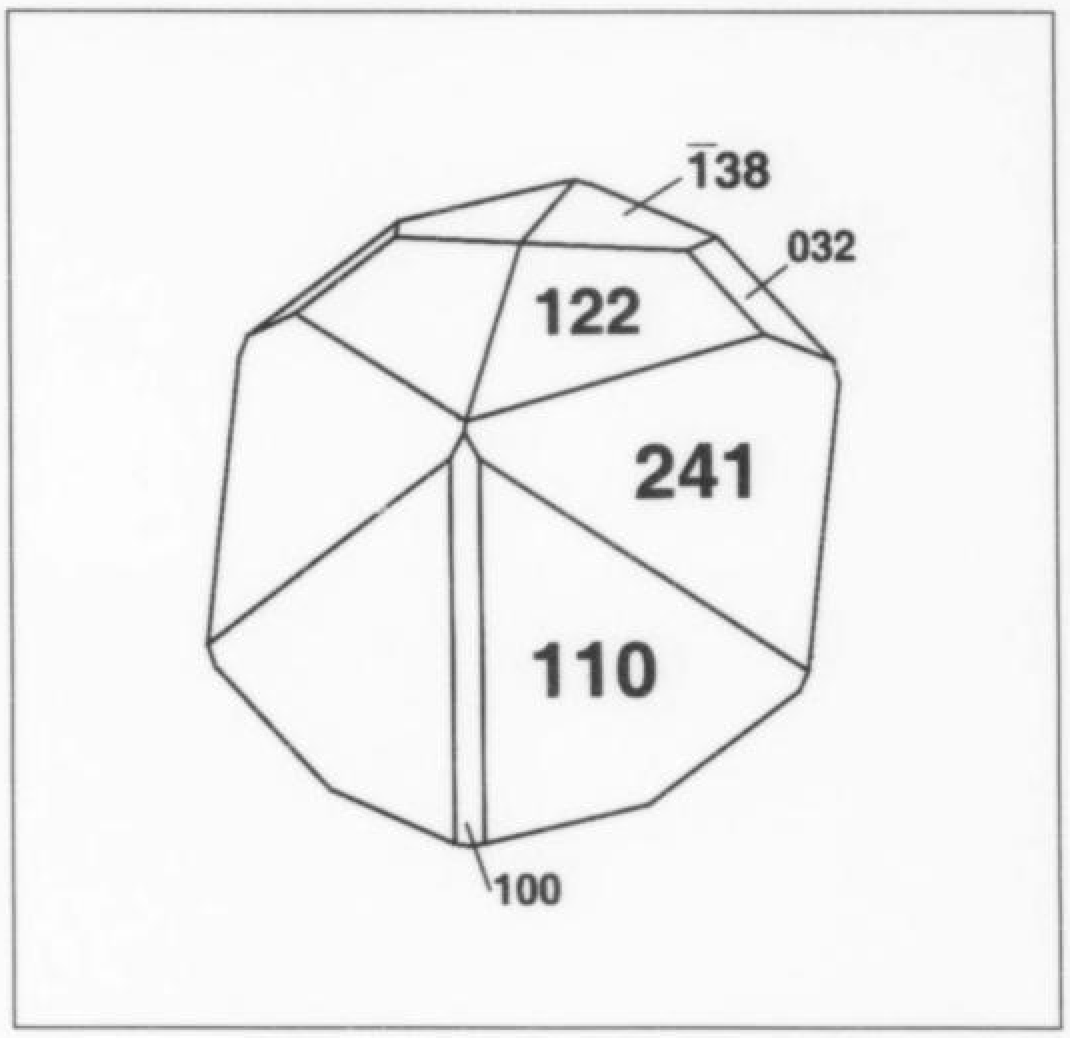


***Figure 117.* Some lens-shaped roselite crystals are rich in faces. Drawing of a 2-mm crystal by Michael Praeger.**

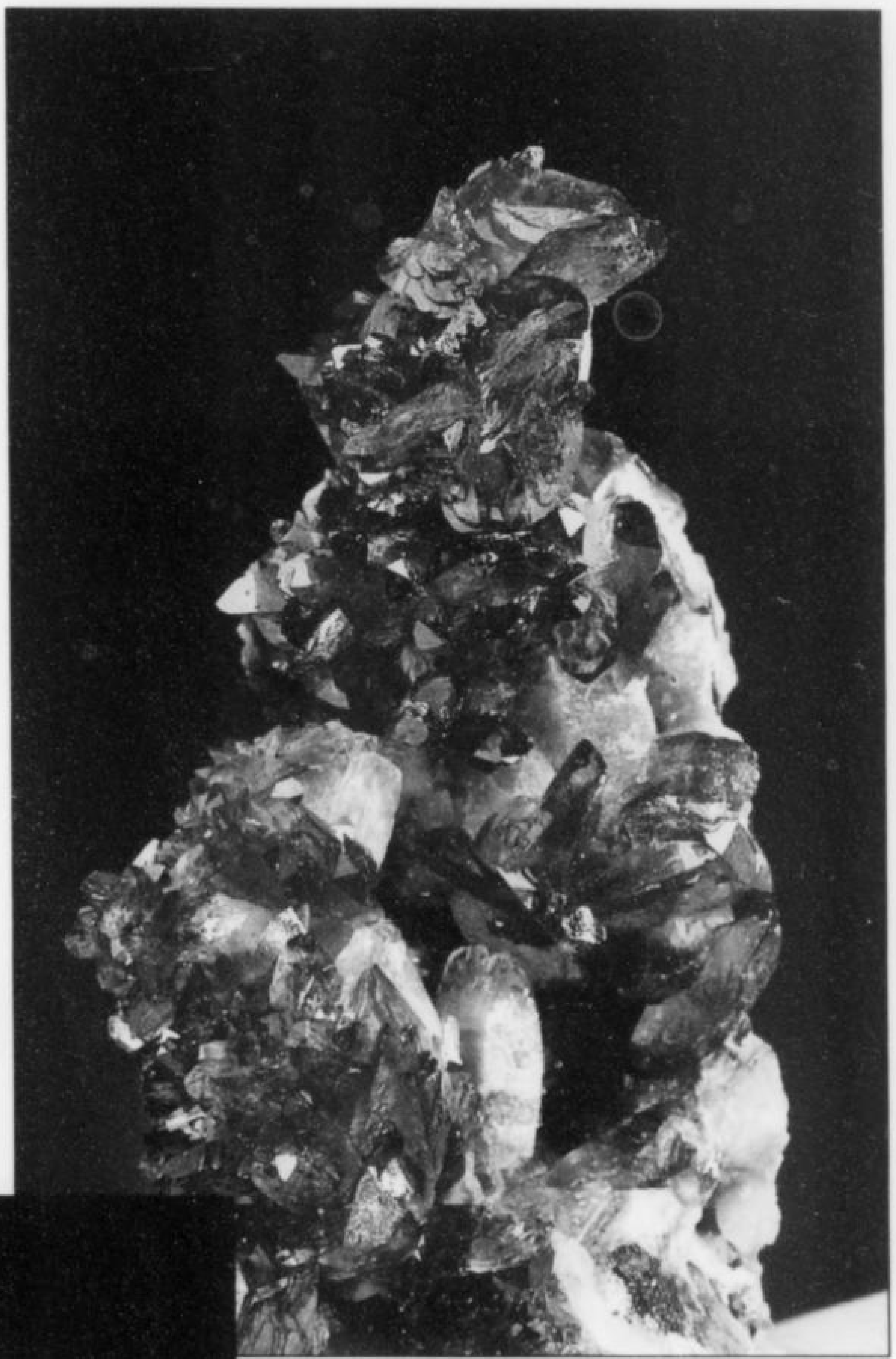


***Figure 118.* Wendwilsonite crystals to 3 mm from Aghbar. Found in 1999. Irv Brown specimen; Jeff Scovil photo.**

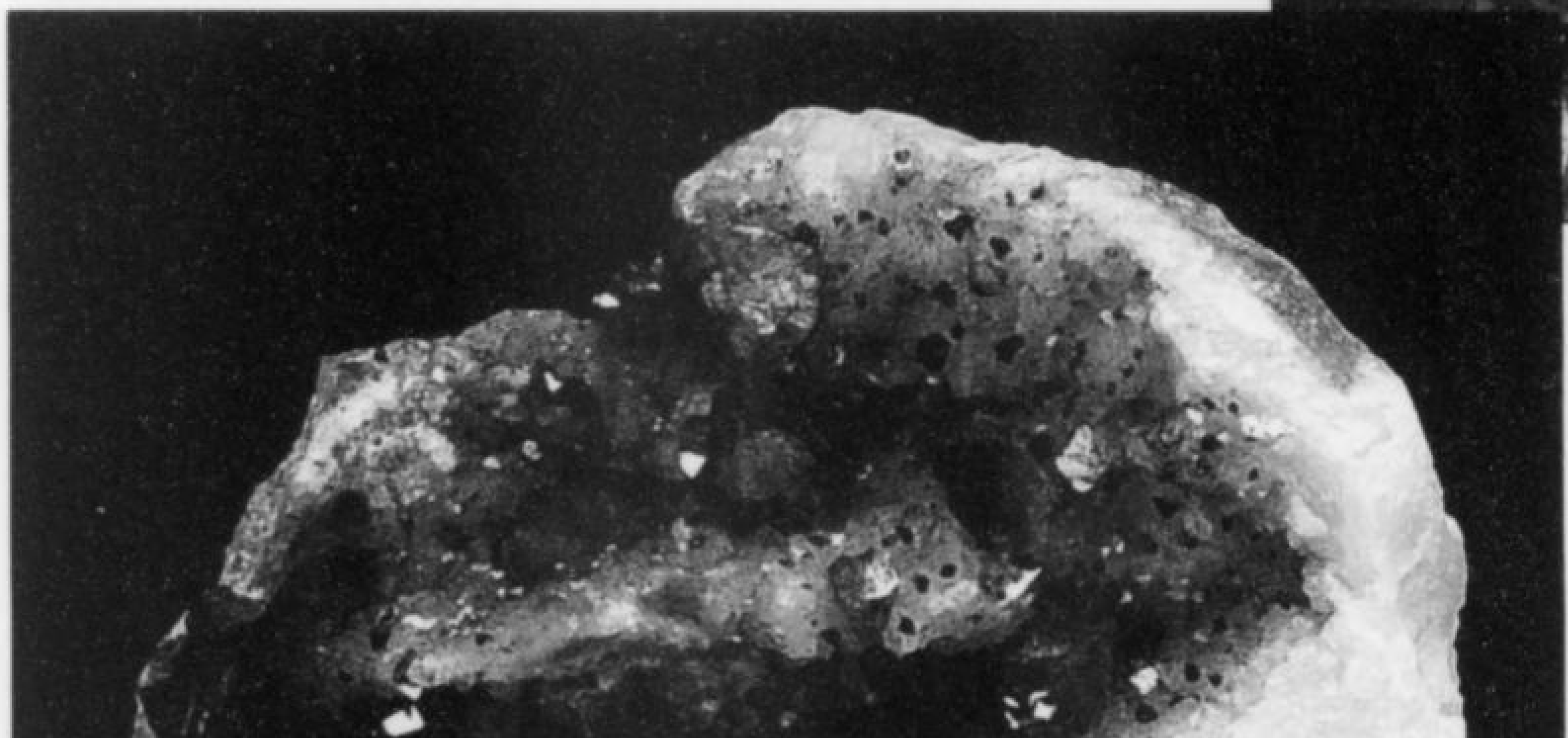


Figure 119.* Cobalt-rich wendwilsonite crystals in a dolomite cavity from the Aghbar shaft. Specimen width: 4.2 cm. Found in 2004. C. Mondeil collection; Louis-Dominique Bayle photo © *Le Règne Minèral.

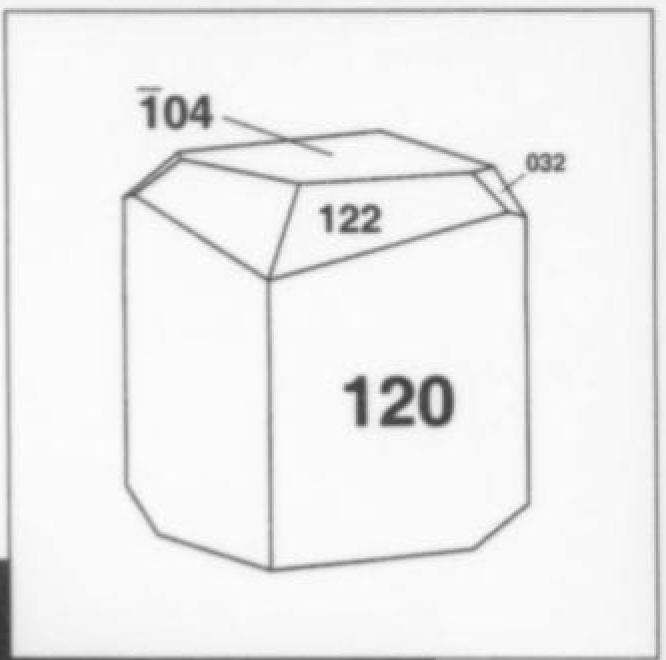
some cases is fairly zinc-rich ($Mg_{0.4-0.45}Co_{0.3-0.35}Zn_{0.3-0.2}$), with Co: Zn = about 1:1.

Roselite-wendwilsonite is commonly associated with roselite-beta or with cobalt-rich talmessite, especially at Aghbar and in Vein 2, Bou Azzer. Sometimes one can observe small roselite crystals completely covered by roselite-beta. Roselite and wendwilsonite are very brittle and show a good to perfect cleavage. Both minerals occur primarily as drusy crusts in cavities; rarer and more avidly sought are free-standing crystals on dolomite or calcite. The colors of the crystals are highly variable, from pale pink (wendwilsonite) through deep red-violet (roselite).

Though generally lens-shaped, the crystals are also highly variable in habit: on the one hand, the prisms {hk0} parallel to the *c* axis are commonly convex (forming lens-shaped crystals), while on the other hand there occur perfectly planar, lustrous faces (forming wedge-shaped or lance-shaped crystals). Pulou and Dietrich (2001) report crystals showing the forms {122}, {$\bar{1}$22} and {010}—known from old Schneeberg, Saxony specimens—as well as the prisms {110} and {120} and the forms {241} (previously unknown in roselite crystals), {302} and {$\bar{3}$04}. As is evident in the crystal drawings, a few forms, e.g. {120} and {122}, are present on nearly all of the crystals, and are commonly dominant; others seem to depend on conditions of crystal formation, so that all in all there is a great variability in crystal habits.

In the year 2000, in the oxidation zone in the Aghbar open-pit mine, unusual crystals, probably twinned, of pale pink, cobalt-poor

Figure 120. (above) **Wendwilsonite crystals to 6 mm, with calcite, from Bou Azzer. François Lietard specimen; Wendell Wilson photo.**



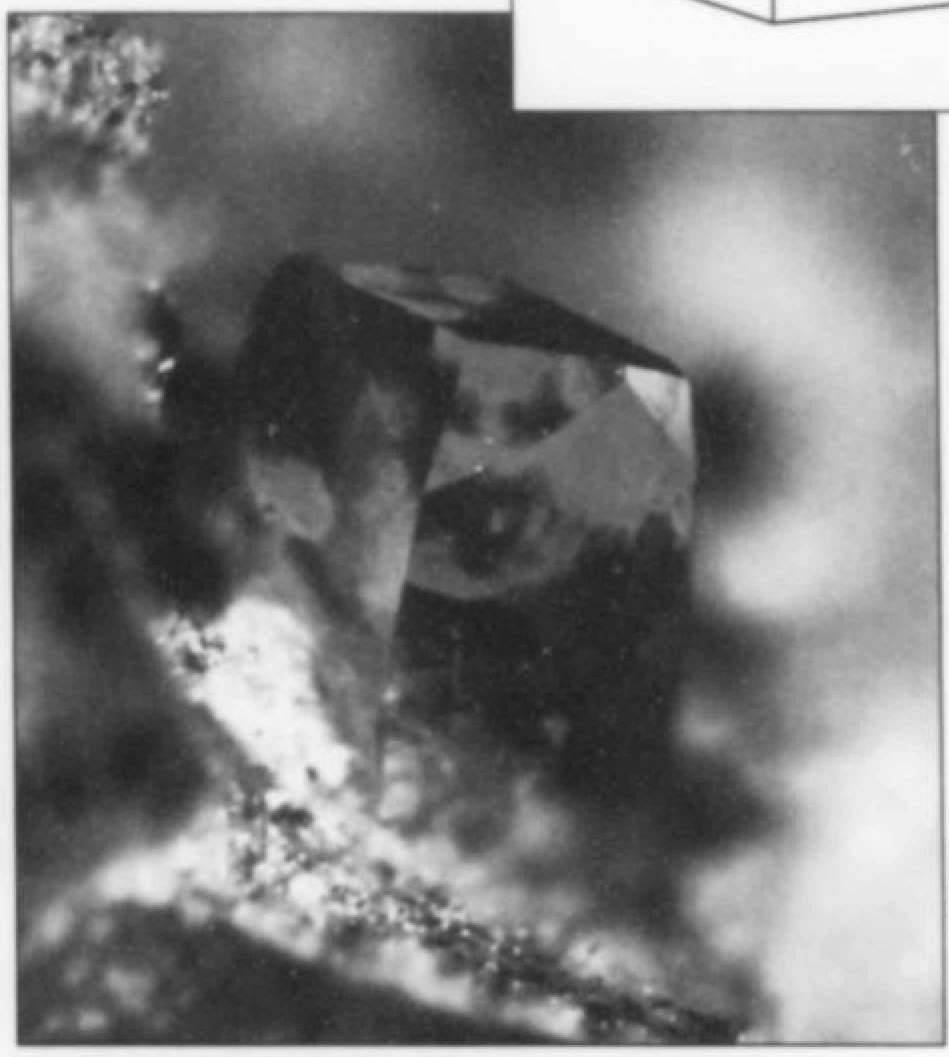


Figure 121. **Wendwilsonite crystal, 1 mm, from Aghbar. The drawing shows how the rare {$\bar{1}$04} form can intersect the prism {120} at almost 90 degrees. Michael Praeger photo and drawing.**

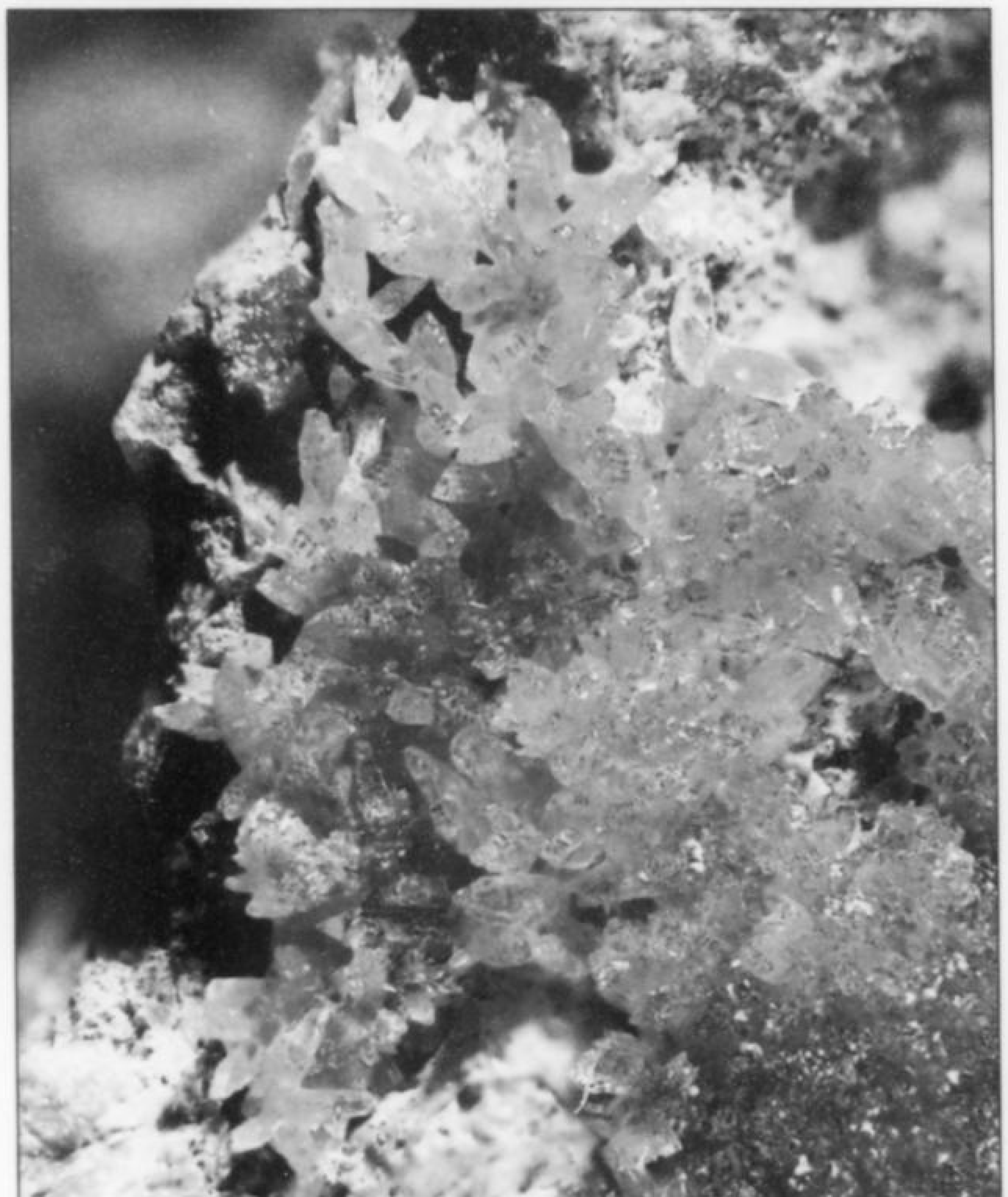


Figure 122. **Wendwilsonite (analytically verified) from Aghbar; field of view 6 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

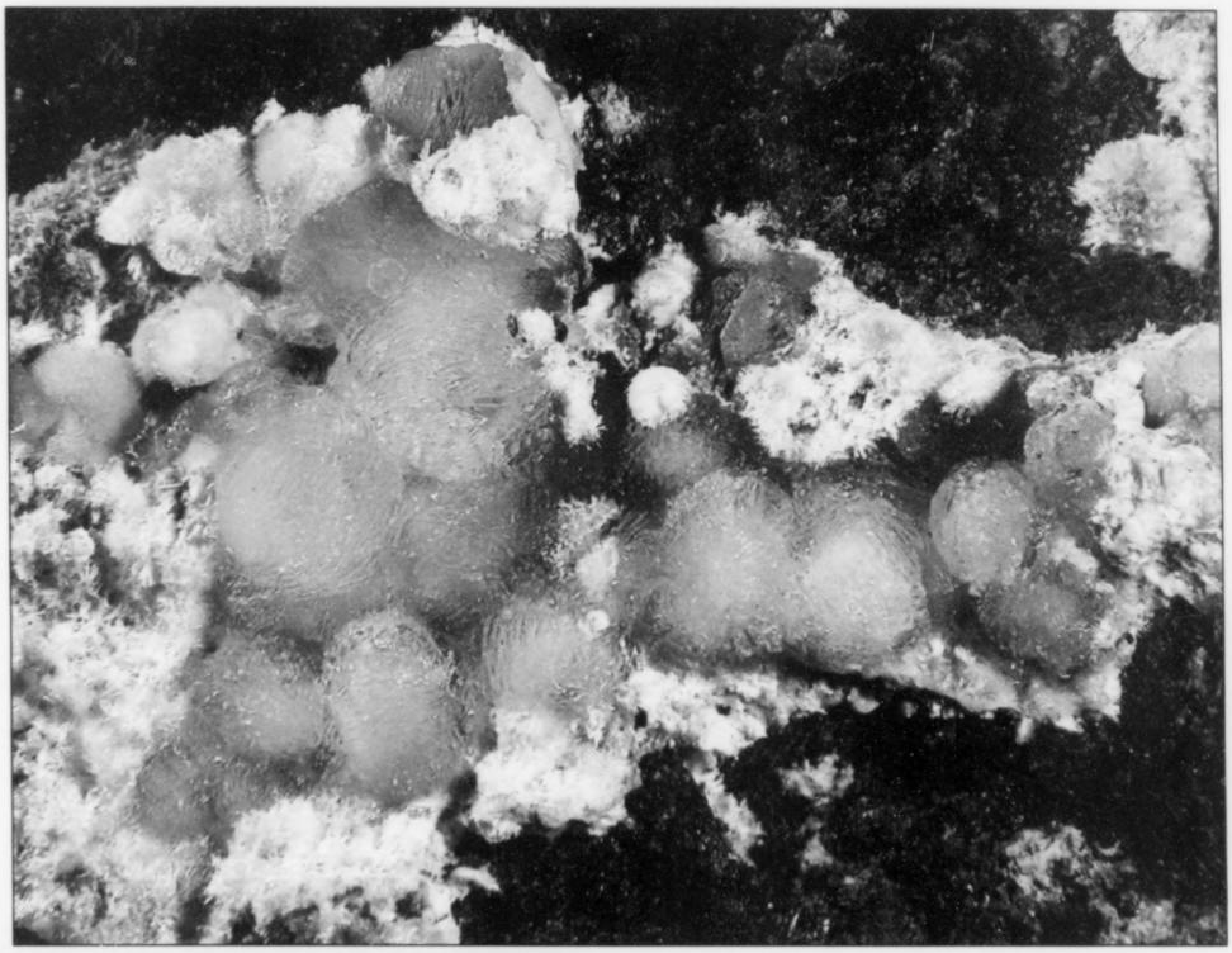


Figure 123. **Cobalt-rich sainfeldite, from Bou Azzer-East; field of view 4.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 124. **Violet-colored cobalt-rich sainfeldite and white spheres of radiating acicular crystals of picropharmacolite, from Bou Azzer-East; field of view 9 mm. G. Favreau specimen; Antoine Iltis photo.**

wendwilsonite were discovered. Measuring only 1 to 2 mm, the crystals resemble little pointed "ships" or hearts occurring with quartz (Michael Praeger, personal communication).

Bou Azzer is the second world occurrence (after Tsumeb) for zincroselite. The first description of Bou Azzer zincroselite was provided by Veselovsky *et al.* (1987), from a specimen found in 1987, probably at Aghbar, showing tiny, colorless to white crystals. A specimen analyzed by Gian Carlo Parodi shows equal amounts of zinc, cobalt and magnesium in a mixed roselite-wendwilsonite crystal. Zincroselite remains today an extreme rarity.

Roselite-beta

(See under Talmessite and Roselite-beta.)

Safflorite $CoAs_2$

Safflorite is widespread throughout the district. At Tamdrost and in Vein 53, Aït Ahmane, it is found as dark gray crests in calcite-filled cavities; acid-etching away the calcite reveals safflorite crystals, although as a rule these are broken, having been cemented by the calcite, like skutterudite, which sometimes also rest on the safflorite crystal crests, as do arsenopyrite crystals. Specimens showing thin, pointed safflorite crystals included by erythrite and arseniosiderite have come from Méchoui.

Sainfeldite $Ca_5(AsO_4)_2(AsO_3OH)_2 \cdot 4H_2O$

Sainfeldite occurs commonly as white formations in arsenic-rich oxidation zones containing picropharmacolite. It forms lustrous, prismatic and lamellar crystals, ideally colorless but often tinted gray to pinkish violet.

Guilbert and Schubnel (1969) mentioned sainfeldite from Vein 7, Bou Azzer, as well as pinkish violet rosettes (<0.8 mm) in aggregates (<5 mm) resembling prehnite, from Aghbar. Good sainfeldite specimens from the 40-meter level in Bou Azzer-East show pale violet spherules to 1 mm as well as attractive pinkish violet sheaf-shaped aggregates of elongated, pointed crystals. These aggregates compose coatings, to 10 cm wide, on smooth-surfaced cleavage fractures in skutterudite, closely associated with spherules of picropharmacolite to 3 mm. On picropharmacolite specimens from Ightem, sainfeldite appears as compact, white to pale pink spherules; similar specimens come from Vein 2, Bou Azzer.

these is a matrix specimen measuring more than 15 cm across which is blanketed by sharp, lustrous scorodite crystals to more than 1 cm, whose blue-green color (in sunlight) recalls fluorite from Cumbria, England; in artificial light the crystals appear gray-brown. The largest crystals noted so far—to 2.5 cm!—came from a one-time discovery in 2004.

Some specimens from Tamdrost show 2 to 3-mm scorodite crystals forming coatings on erythrite crystals which have a black patina.

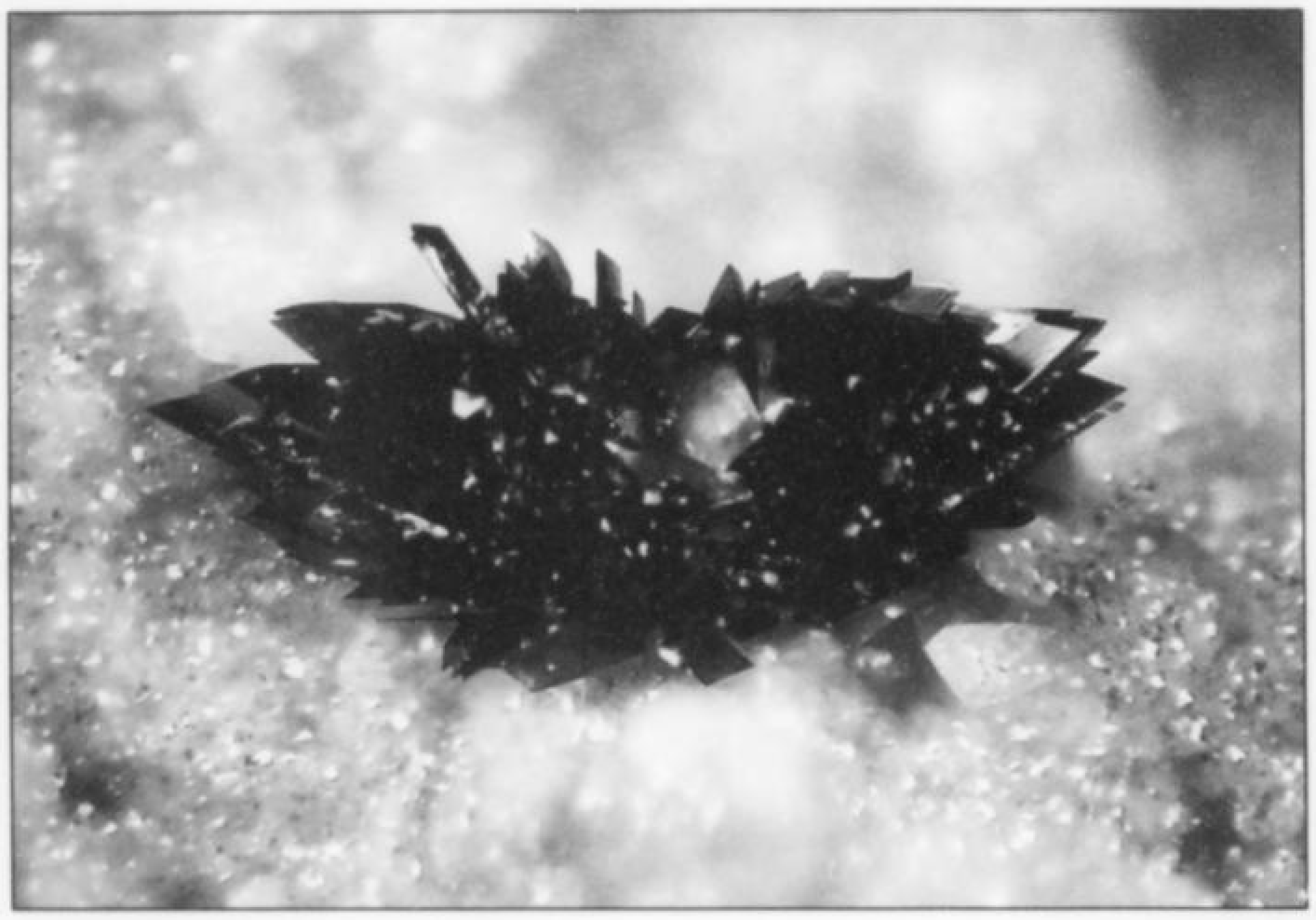


Figure 125. **Perfect rosette of schneiderhöhnite crystals, 1 mm, from Oumlil-East. G. Favreau specimen; Heinz Dieter Müller photo.**

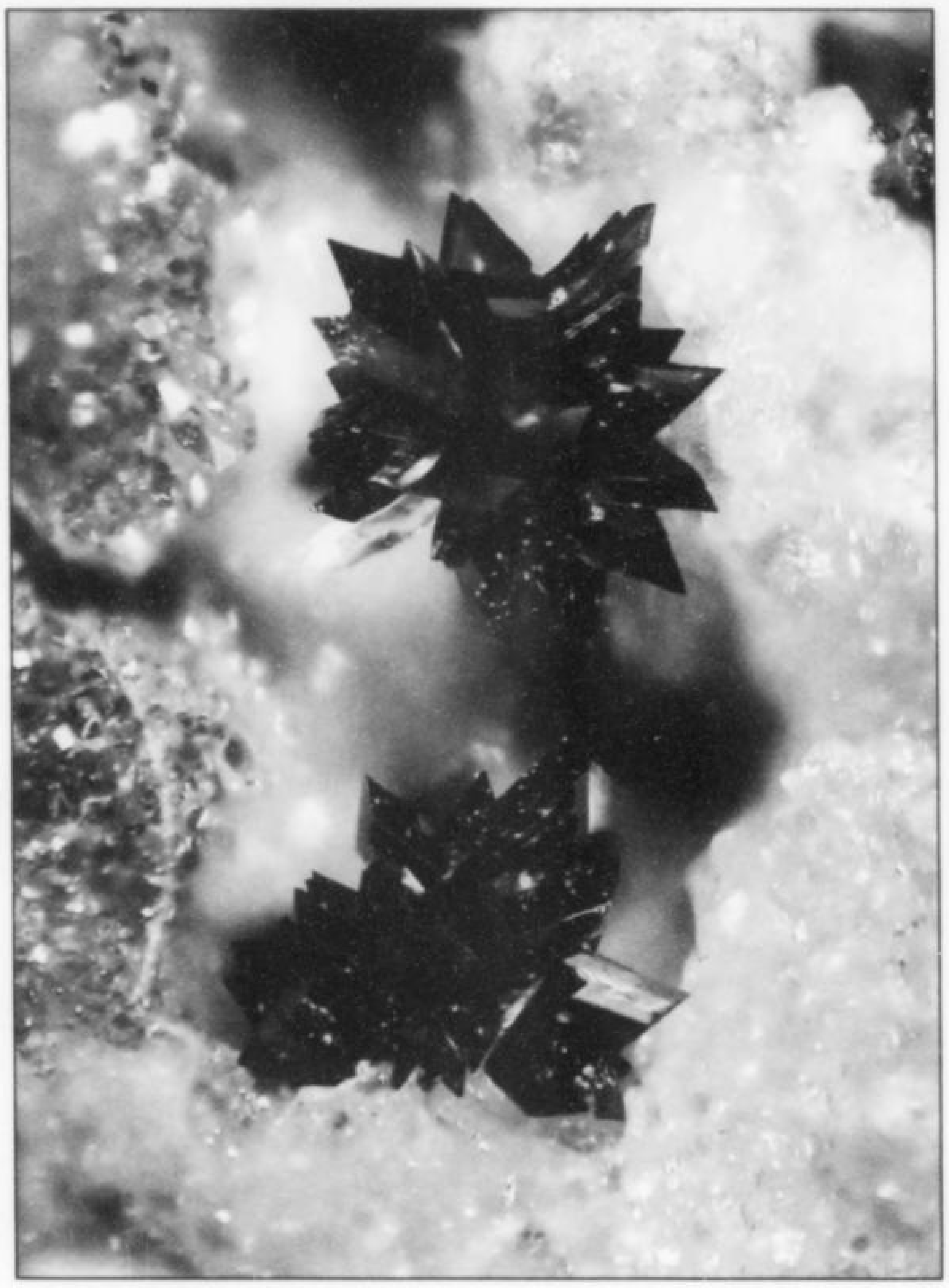


Figure 126. **Lustrous, pitch-black crystal sprays of schneiderhöhnite from Khder; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Schneiderhöhnite $Fe^{2+}Fe^{3+}_3As^{3+}_5O_{13}$

According to Schmetzer *et al.* (1980), schneiderhöhnite occurs at Bou Azzer as black, bladed and tabular crystals with perfect cleavage on {100}, lining cavities in ore. Unlike the type material from Tsumeb, schneiderhöhnite from Bou Azzer contains some cobalt and nickel. Since 1980, excellent specimens of schneiderhöhnite have also been found in Brazil.

Schneiderhöhnite was not found again in the Bou Azzer district until the beginning of new mining in Oumlil-East in 2001; unmistakable evidence of its occurrence here appeared when we thoroughly screened the iron ore piles and examined massive gray, slightly weathered masses of löllingite to several tens of centimeters across, which contained quartz-lined cavities. Schneiderhöhnite occurs in these cavities as sharp, lustrous crystals to 1 mm slightly resembling beudantite crystals in form (pseudo-rhombohedrons with acute angles and triangular terminations). The crystals rest in small cavities, sometimes associated with an amorphous red-brown crust similar to "greenalite" or yukonite. Schneiderhöhnite is very brittle and easily cleavable. The association of schneiderhöhnite with later-formed sprays of karibibite makes for very aesthetic specimens. The most commonly observed formation sequence is quartz → schneiderhöhnite → karibibite → parasymplesite. In Méchoui and in Tamdrost-West, pharmacosiderite joins this paragenesis. At the small deposit at Khder, spherical schneiderhöhnite aggregates to 5 mm have been found in massive, extensively fractured löllingite, with colorless and pale yellow scorodite.

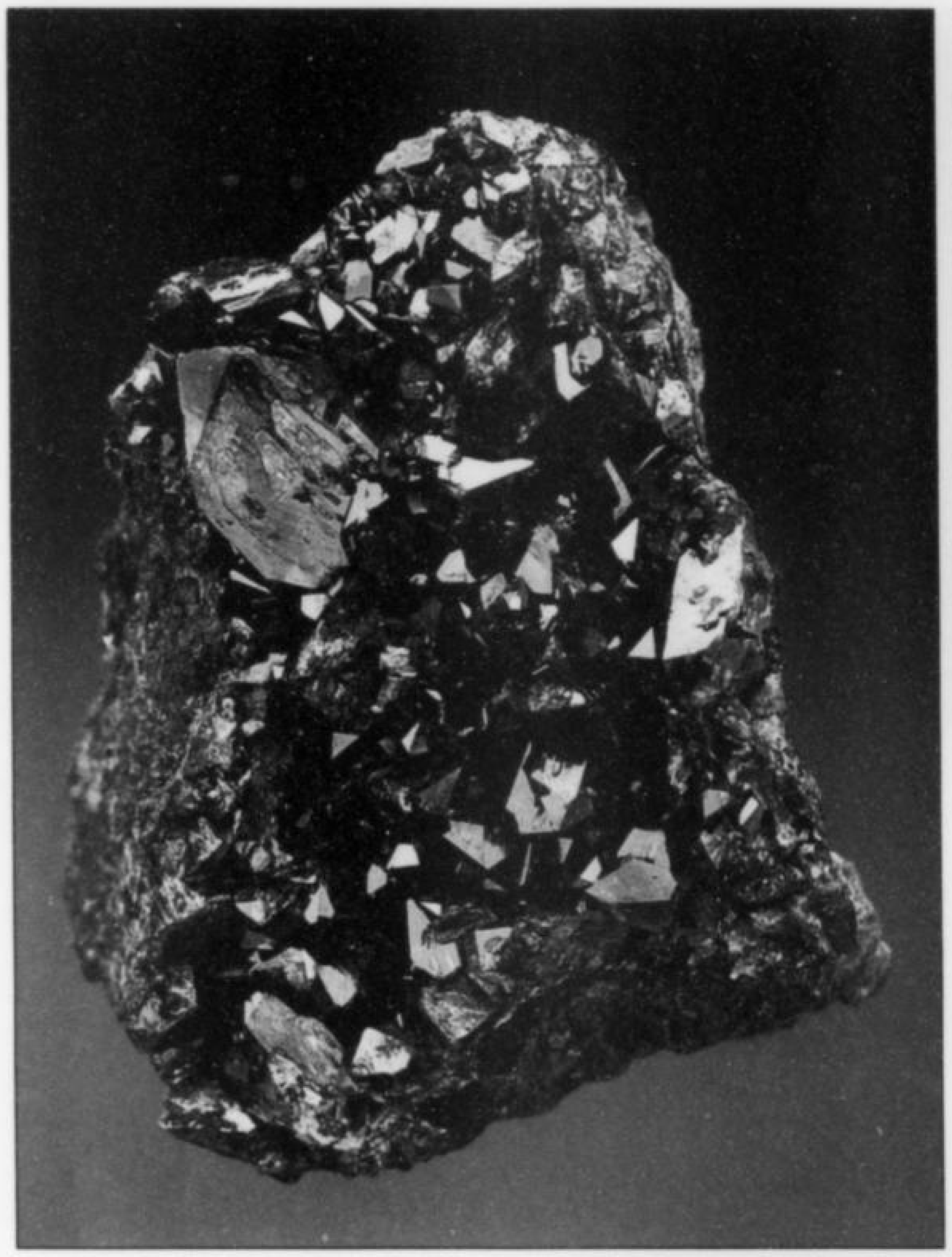
Scorodite $Fe^{3+}AsO_4 \cdot 2H_2O$

At the beginning of the 1980's scorodite from Bou Azzer appeared to be very rare, as remarked by Schmetzer *et al.* (1980). This has changed since since the exploitation of large bodies of löllingite ore at Oumlil. Scorodite has proven to be widespread there as cream-colored to blue-green, 1-mm spherules with rough, prickly surfaces, found in cavities in weathered löllingite.

Since 2001–2002, spectacular, world-class scorodite specimens have come to light from some local areas of this deposit. Among

Silver Ag

Silver occurs abundantly enough at Bou Azzer to have justified mining for it after 1988 (Essaraj, 1999). The rodingite-like rock along some contact zones between serpentinite and quartz diorite has such a high



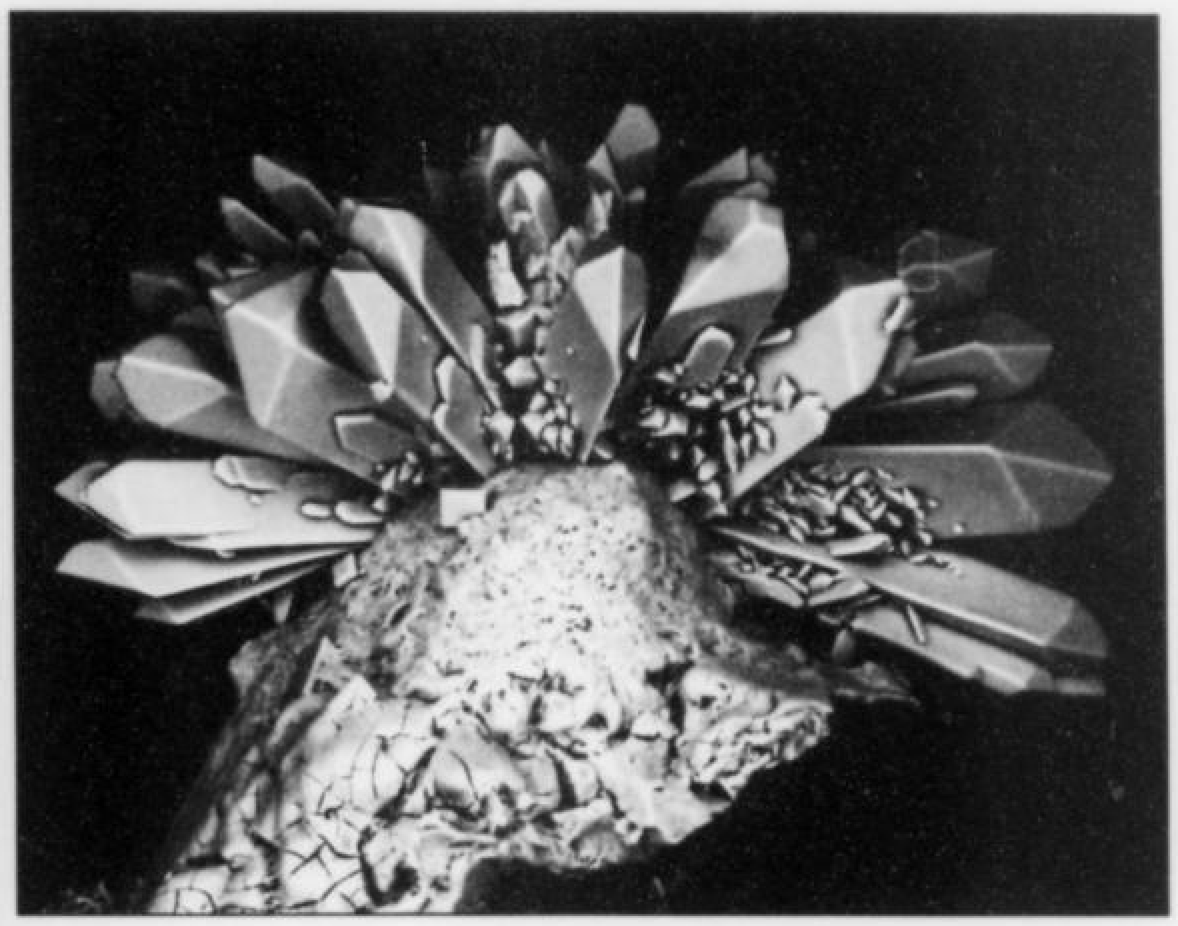
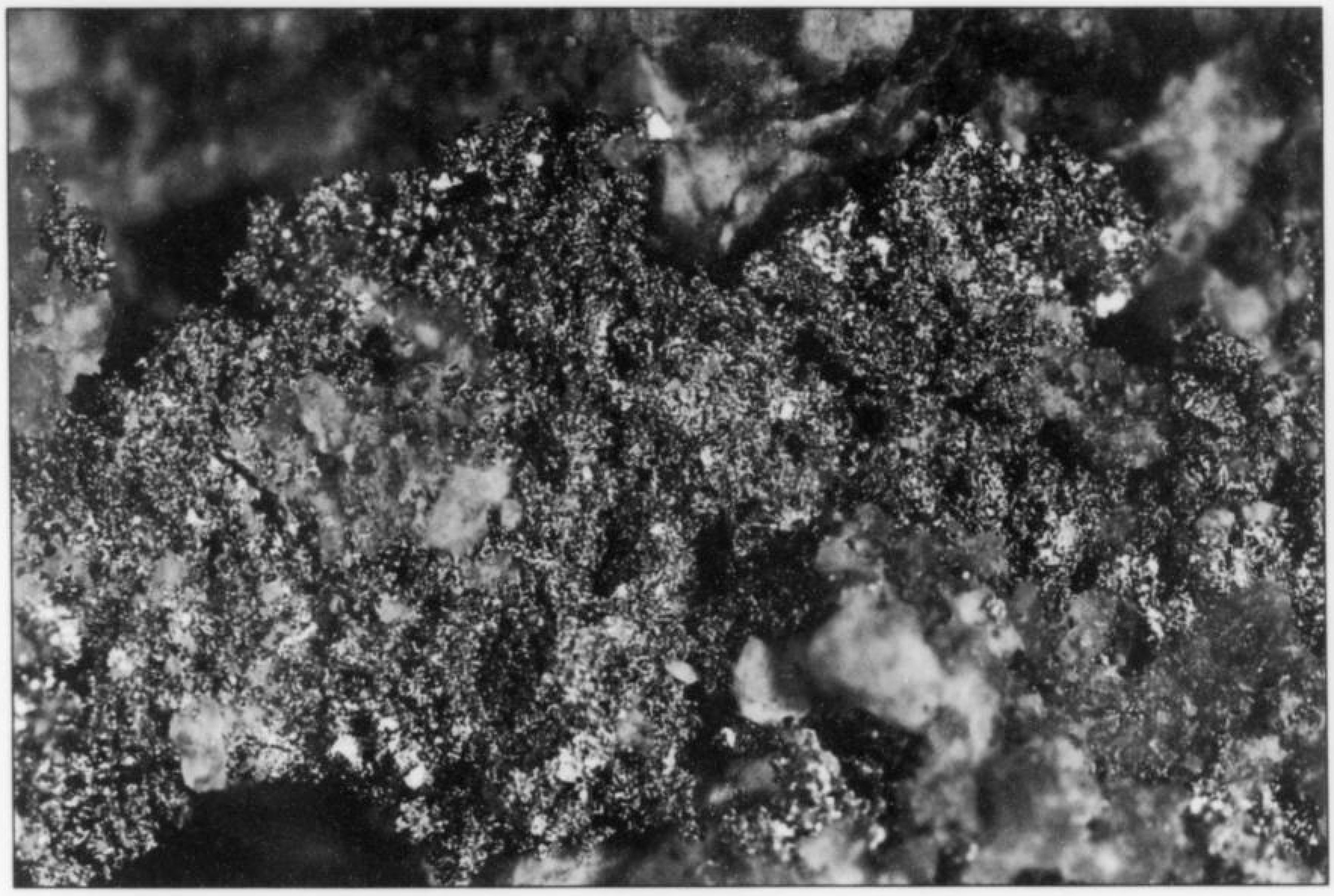


Figure 127. **Scorodite crystals, from Oumlil; field of view about 2 mm. REM photo by Gian Carlo Parodi.**

Figure 128. **Outstanding scorodite specimen, 4.5 cm, probably from Oumlil. Found in 2001. Ernesto Ossola specimen; Jeff Scovil photo.**

Figure 129. **Silver on quartz breccia Bou Azzer; field of view 5 mm. G. Favreau specimen; Robert Vernet photo.**



silver content that brecciated pieces weighing several kilograms and richly infused by native silver (with albite, orthoclase and prehnite) have been found. Lustrous wire silver has come to light from the Bouismas mine, most recently in early 2006. Coatings and scales of metallic silver are quite common in the district; wire silver is rarer. Well crystallized silver is found most frequently in narrow fissures in rhyolite, with arsenides (safflorite, löllingite) or sulfides (chalcopyrite). Fissures in diorite are sometimes filled with white calcite, and when this is acid-etched away, lustrous, thin silver wires to 1 cm may be revealed.

Sjögrenite

See Pyroaurite and Sjögrenite.

Skutterudite $CoAs_3$

The mining company values skutterudite highly: for one thing, it is common, and for another, it has a fairly high cobalt content, varying in the district between 12% and 18.5% (the nickel content is 0.7–7.5%, the iron content 1.4–8.5%). A zoning pattern in the district between high-Co and high-Ni ores was suggested by Jouravsky (1952), further argued for by Leblanc (1975), and proven definitively by Ennaciri (1995). In general, skutterudite shows decreasing cobalt content from the western to the eastern part of the district (from $Co_{0.9}Fe_{0.1}$ to $Co_{0.7}Ni_{0.3}$), while its iron content is at its maximum ($Co_{0.6}Ni_{0.2}Fe_{0.2}$) in the central area around

Figure 130. **Skutterudite crystals in calcite matrix, 6 cm, from the Tamdrost mine. Stefan Weiß photo.**

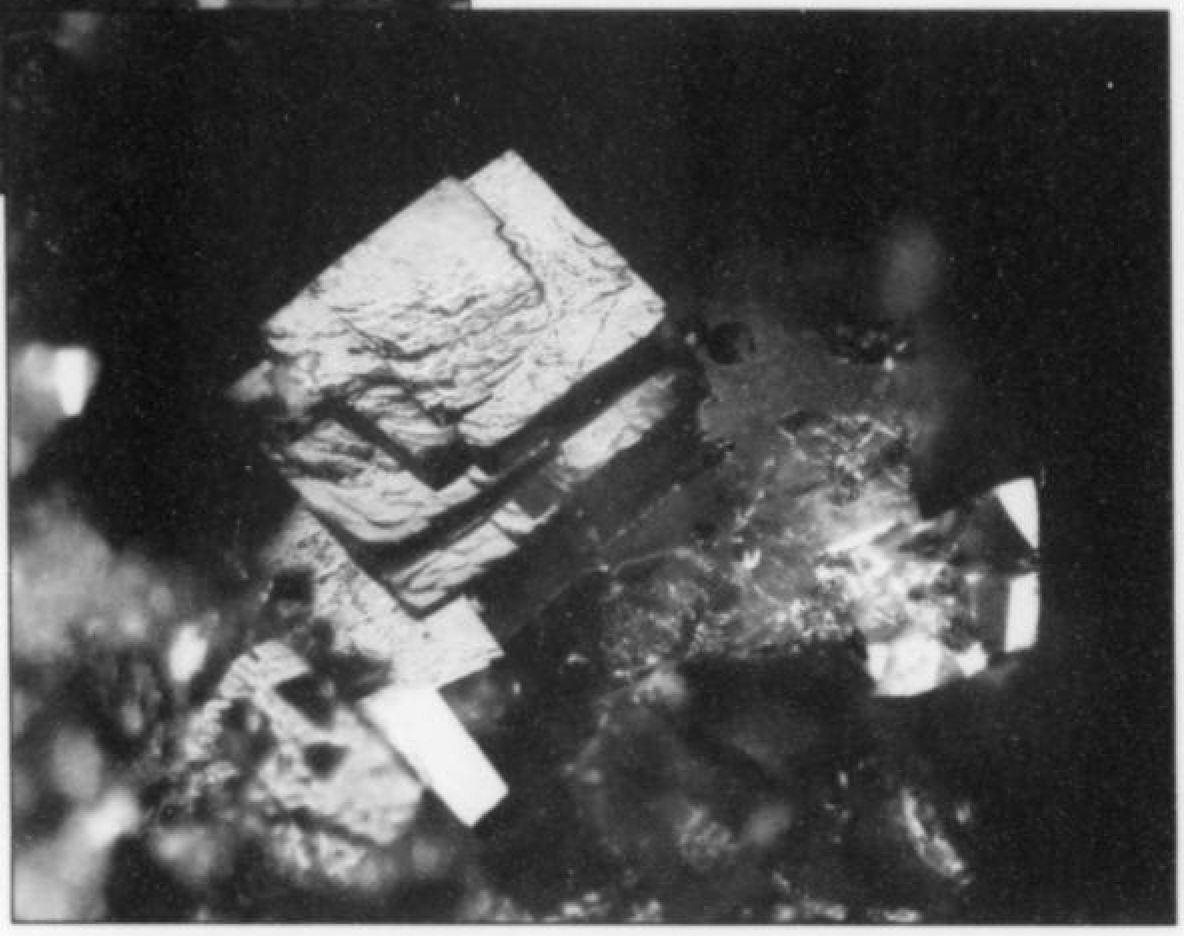


Figure 131. **Deep red rhombohedral crystals of sphaerocobaltite from Agoudal; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Bou Azzer. Also noteworthy is the unusually high gold content of skutterudite—averaging 120 grams of gold per ton (!), according to Leblanc and Fisher (1990).

Skutterudite is cherished also by mineral collectors: the world's largest crystals of the species, to 9 cm, come from Aghbar, and the smaller crystals can be of excellent quality too. Fine display pieces are not too common, since the crystal edges are often damaged during mechanical ore-gathering and since specimens may fall apart during acid-etching treatment.

The crystal faces are commonly concave and show growth hillocks. Sharper, smaller crystals as a rule show combinations of the pyritohedron, rhombic dodecahedron, cube and octahedron; cuboctahedrons are especially common whereas simple octahedrons are rare. In the period 2001–2004, Vein 7 at Bou Azzer yielded highly lustrous, relatively iron-rich crystals to more than 3 cm in cleavable calcite; the outer zones of these crystals are compositionally $Co_{0.6}Ni_{0.15}Fe_{0.25}$—somewhat poorer in nickel and richer in iron than the core zones. Single, loose skutterudite crystals are not very common. They have come from Vein 53, Aït Ahmane, from Aghbar, and especially from Tamdrost, where excellent finds were made in 2005. Exceptional skutterudite crystals with overgrowths of tiny, amber-colored celestine crystals have been found in open cavities not filled by calcite, e.g. at Ightem.

Smolianinovite $(Co,Ni,Mg,Ca)_3(Fe^{3+},Al)_2(AsO_4)_4\cdot 11H_2O$ (?)

Cream-colored fibers and earthy masses of smolianinovite can replace skutterudite crystals. A few of these pseudomorphs are dark brown and faintly translucent, resembling garnets. Smolianinovite from Bou Azzer was first mentioned in 1956, when the species was described from its type locality of Tuva, Siberia (Hintze's *Handbuch der Mineralogie*, Band II, 1960, and Pekov, 1998).

Sphaerocobaltite $CoCO_3$

Unfortunately, the old term "cobaltocalcite" is still misapplied to this cobalt carbonate—leading to a strong possibility of confusion with the pink cobalt-rich calcite which occurs commonly at Bou Azzer. Sphaerocobaltite, however, is easy to identify with the aid of a strong magnet, since, unlike cobalt-rich calcite, it is magnetic. Although Pallix (1978) reported short-prismatic "sphaerocobaltite" crystals to several centimeters long, this is unlikely, as the crystal habit of sphaerocobaltite not prismatic; the material was almost surely cobalt-rich calcite.

True sphaerocobaltite forms tiny (to 0.5 mm), matte-lustered, rhombohedral crystals with sharp edges and slightly convex faces, in Vein 2 at Bou Azzer. The color varies, with crystal size and with the degree of heterogenite association, between pale pink and rose-violet. The crystals rest on dolomite or quartz, with roselite, hematite and cobaltlotharmeyerite. Similar sphaerocobaltite crystals have also come from Aghbar, where they form dark red, rice-grain-like aggregates recalling smithsonite. In both deposits, sphaerocobaltite is commonly associated with lavendulan. The Agoudal mine produces beautiful transparent, sharp-edged rhombohedral crystals of sphaerocobaltite to 1 mm.

Stichtite $Mg_6Cr_2(CO_3)(OH)_{16}\cdot 4H_2O$

Chromium and nickel-bearing orebodies are found throughout the district, and their irregular configurations may impede the mining

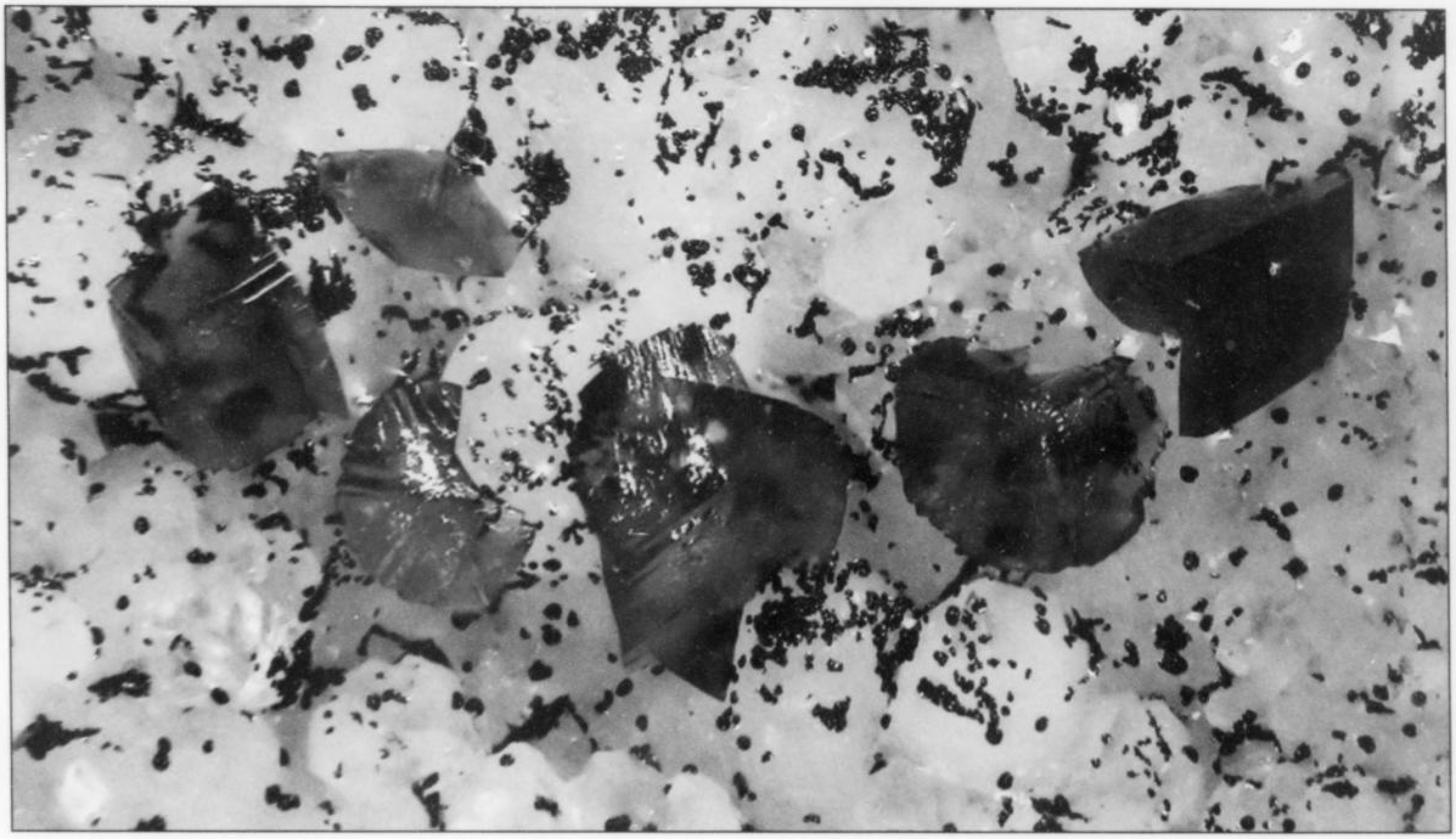


Figure 132. **Transparent red rhombohedral sphaerocobaltite crystals, in part distorted into lenslike shapes, on quartz from Agoudal; field of view 2.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

process. Unusually black ore piles line the side of the road east of Aghbar. This extensive ore material consists of thick masses of a black mineral shot through with small rose-violet veins and coatings. Although rose-colored cobalt minerals are very common in the area, this rose-colored material did not look to us like a cobalt-bearing mineral, reminding us, rather, of stichtite from Australia. X-ray study revealed that indeed it is the rare chromium carbonate stichtite—an iron-rich variety of which was observed at Bou Azzer by Caillère (1942). The ore material consists overwhelmingly of chromite, with fissures and small clefts also containing aragonite and prehnite. Stichtite forms rose-colored, convoluted, locally thick layers which suggest the kämmererite variety of clinochlore.

Stichtite is found commonly elsewhere in the district too. In Vein 2, Bou Azzer and Bou Azzer East, for example, it forms pink to violet-pink seams in pale green serpentinite, and is also found in granular chromite. In Agoudal it is found as lamellae in narrow fissures in chromite. Massive white crusts of a magnesium mineral which regularly accompany stichtite are probably hydromagnesite.

Strashimirite

(See under Cornubite, Cornwallite, Clinoclase and Strashimirite.)

Sulfates

Sulfates are much rarer in the district than arsenates. The most common sulfate species is the calcium sulfate **gypsum**, which occurs as tiny lamellae and colorless crystals in weathered pieces of ore, commonly associated with lavendulan and especially with newly-formed erythrite. The iron sulfate **melanterite** is found as colorless, water-soluble fibers; blue copper sulfate **chalcanthite** lamellae and blue-green aggregates of acicular crystals of the Ca-Cu-Zn sulfate **serpierite** (some accompanied by green spherules of cornwallite) are found at Aghbar. Devilline was analyzed as irregular platy crystals associated with köttigite from Taghouni. Rarely, the barium sulfate **barite** is seen at Bou Azzer as dark yellow to honey-brown, simple, chisel-shaped crystals reaching 2 cm (discovered in 2002).

Sulfur S

Sulfur occurs as a recently formed mineral in oxidation zones, but the vivid yellow crystals are always extremely small (<0.2 mm). In Vein 2, Bou Azzer, and at Aghbar, sharp-cornered, brightly lustrous grains of sulfur are closely associated with erythrite and are also seen with cobaltkoritnigite and arsenolite. Small, rounded grains of sulfur occur with cobaltkoritnigite at Tamdrost-West and with corroded gersdorffite and nickel sulfates in Vein 51, Aït Ahmane.

Talmessite $Ca_2Mg(AsO_4)_2 \cdot 2H_2O$ and
Roselite-beta $Ca_2Co(AsO_4)_2 \cdot 2H_2O$

Talmessite and roselite-beta from Bou Azzer have been somewhat overshadowed by the more spectacular, world-famous erythrite and roselite-wendwilsonite. Nevertheless, the Bou Azzer district has delivered what are far and away the world's best specimens of these two "classics."

Talmessite and roselite-beta form a continuous series; both minerals are triclinic, and both occur commonly as bundle-like aggregates of lath-shaped crystals with rounded terminations. Distinguishing them from each other visually is almost impossible—particularly since talmessite takes on an intense red-pink color when it contains any cobalt at all. By contrast it is much easier to distinguish these two species from roselite and wendwilsonite, with their lens-shaped crystals.

Roselite-beta and (more or less cobalt-rich) talmessite are quite rare worldwide, but in the Bou Azzer district they are widespread; indeed they can be more common than roselite locally. The two species—in a multitude of forms and colors—have been collected throughout the district, for example at Méchoui, in Veins 2 + 7 at Bou Azzer, and at Bou Azzer-East, Aghbar, Oumlil, Tamdrost, Ambed, Ightem and Aït Ahmane. Rarely they are found as free-standing crystals to 1 cm; much more commonly they form rounded clusters, subparallel aggregates, and coral-like spherules.

A few of the attractive crystal groups from Aghbar which formerly

Figure 133. Strawberry-red roselite-beta crystal, 5 mm, from Aghbar. R. Pecorini collection; Robert Vernet photo.

Figure 134. Orange spheres of roselite-beta/talmessite with erythrite in a dolomite cavity, from Méchoui; field of view 2.5 mm. G. Favreau specimen; Robert Vernet photo.

Figure 135. Deep red tabular crystals of roselite-beta, from Vein 2, Bou Azzer; field of view 1.5 mm. J. R. Legris specimen; Robert Vernet photo.

Figure 136. Intergrowths of roselite-beta and cobalt-rich talmessite, from Vein 2, Bou Azzer; field of view 2 mm. G. Favreau specimen; Heinz Dieter Müller photo.

Figure 137. **Leafy orange-red to yellow-brown intergrowth of roselite-beta and cobalt-rich talmessite, with green cobaltaustinite and red cobaltlotharmeyerite, from Aghbar; field of view 4 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 138. **Colorless, cobalt-free crystal of talmessite, from Aghbar; field of view 2.5 mm. G. Favreau specimen and photo.**

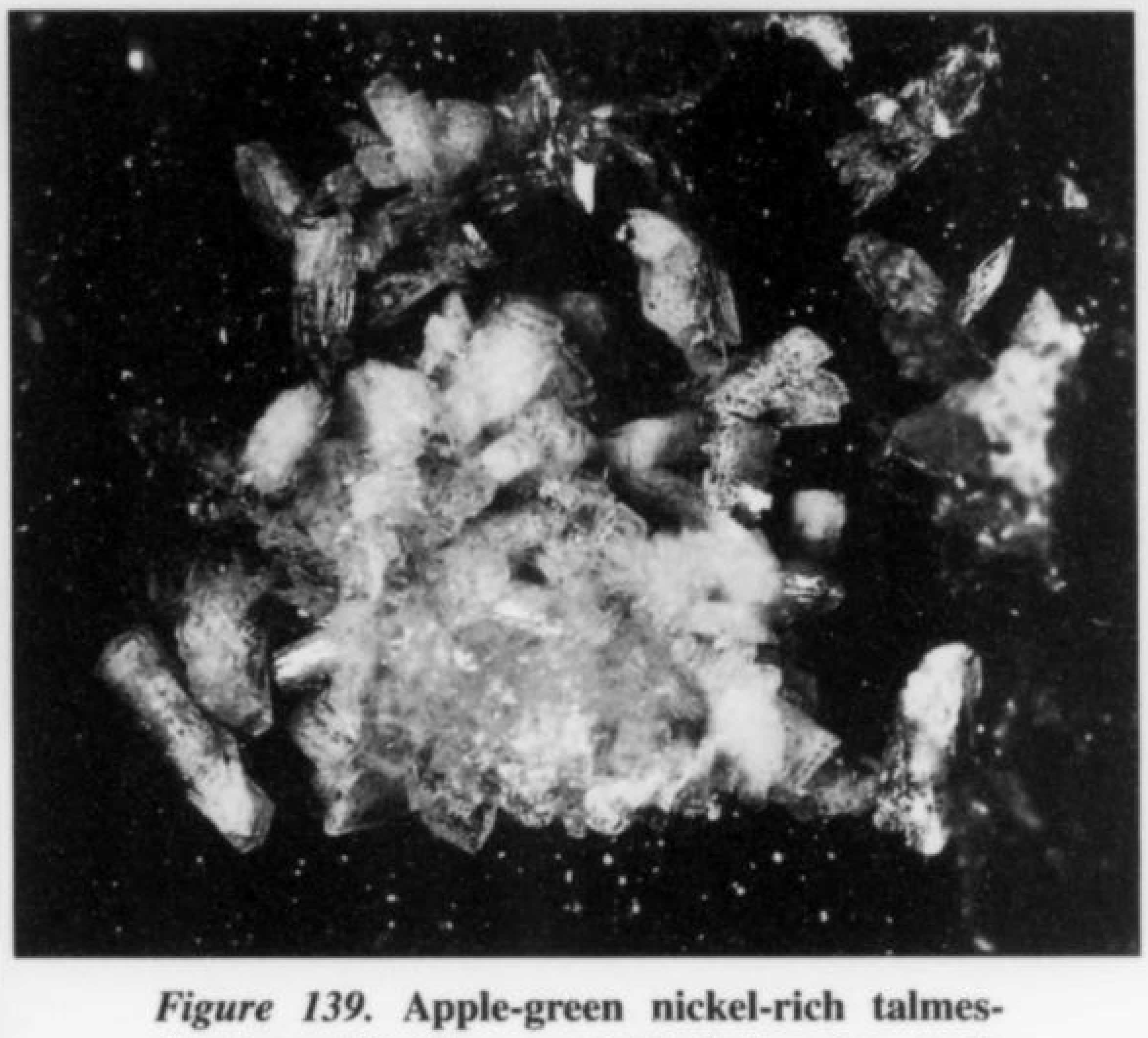


Figure 139. **Apple-green nickel-rich talmessite from Aït Ahmane; field of view 4 mm. G. Favreau specimen; Robert Vernet photo.**

were called "roselite-beta" have core zones consisting of intergrown cobalt-rich talmessite (dominant) and roselite-beta (subordinate); these crystals rest on dolomite matrix, accompanied by wendwilsonite (Weiß *et al.*, 2002). Zinc content in talmessite is attributed to a limited miscibility (to 10 Mol. %) with gaitite.

For decades, talmessite from Bou Azzer was erroneously called "belovite," with reference to a description by Nefedov (1953). One still finds specimens labeled this way in older collections, and the term "belovite" crops up also in older publications (properly it refers today to two rare-earth-bearing members of the apatite group). The triclinic Ca-Mg arsenate was first described from Talmessi, Iran by Bariand and Herpin (1960).

Talmessite is common locally in the Bou Azzer district, especially at Aït Ahmane, where it has been recognized from four different workings. In Vein 51, nickel-rich talmessite forms pale green crusts and tiny crystals on calcite matrix, with nickeline and bright emerald-green népouite. In Vein 52, white talmessite spheres are common in large cavities, with sharp scalenohedral calcite crystals. Some old ore blocks carry massive segregations of talmessite to 10 cm, occasionally with remnants of löllingite and safflorite; cavities in these ore blocks 3 to 4 cm wide may be lined with drusy talmessite, or may harbor glassy talmessite spherules (<2 mm) with pointed crystal-tips showing. Pure talmessite is colorless to white, but crystals containing cobalt are pink, and (more rarely) crystals containing nickel are pale green. The color transitions are subtle and nuanced, and several generations of growth are often discernible, especially for the long-prismatic crystals; color zonation is common. In Vein 59, Aït Ahmane, talmessite forms color-zoned greenish gray spherules. At Ightem, talmessite is found solely as white to pink crystalline crusts with erythrite and annabergite.

The best talmessite crystals, reaching 1 cm, come from the oxidation zone at Aghbar; a highly nickel-rich variety from this mine was described by Cesbron *et al.* (1972).

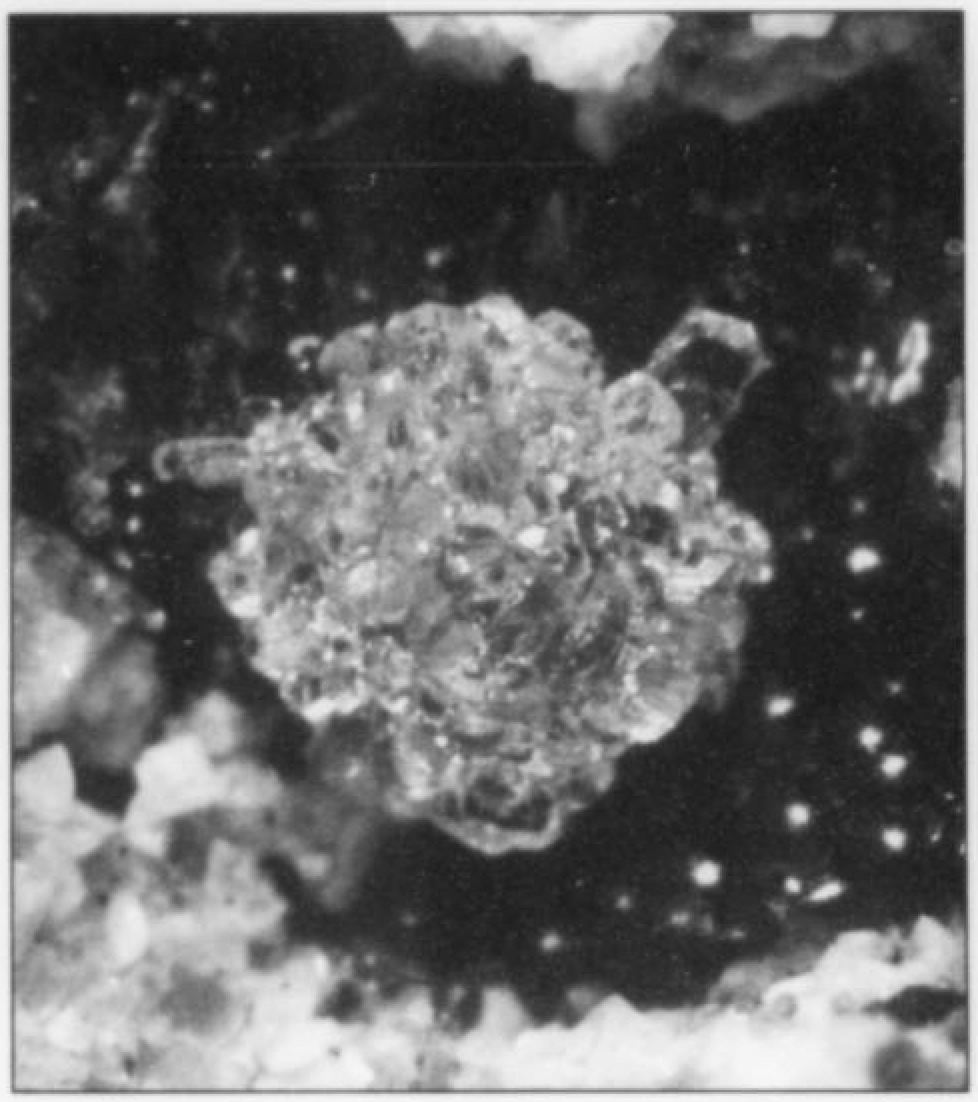
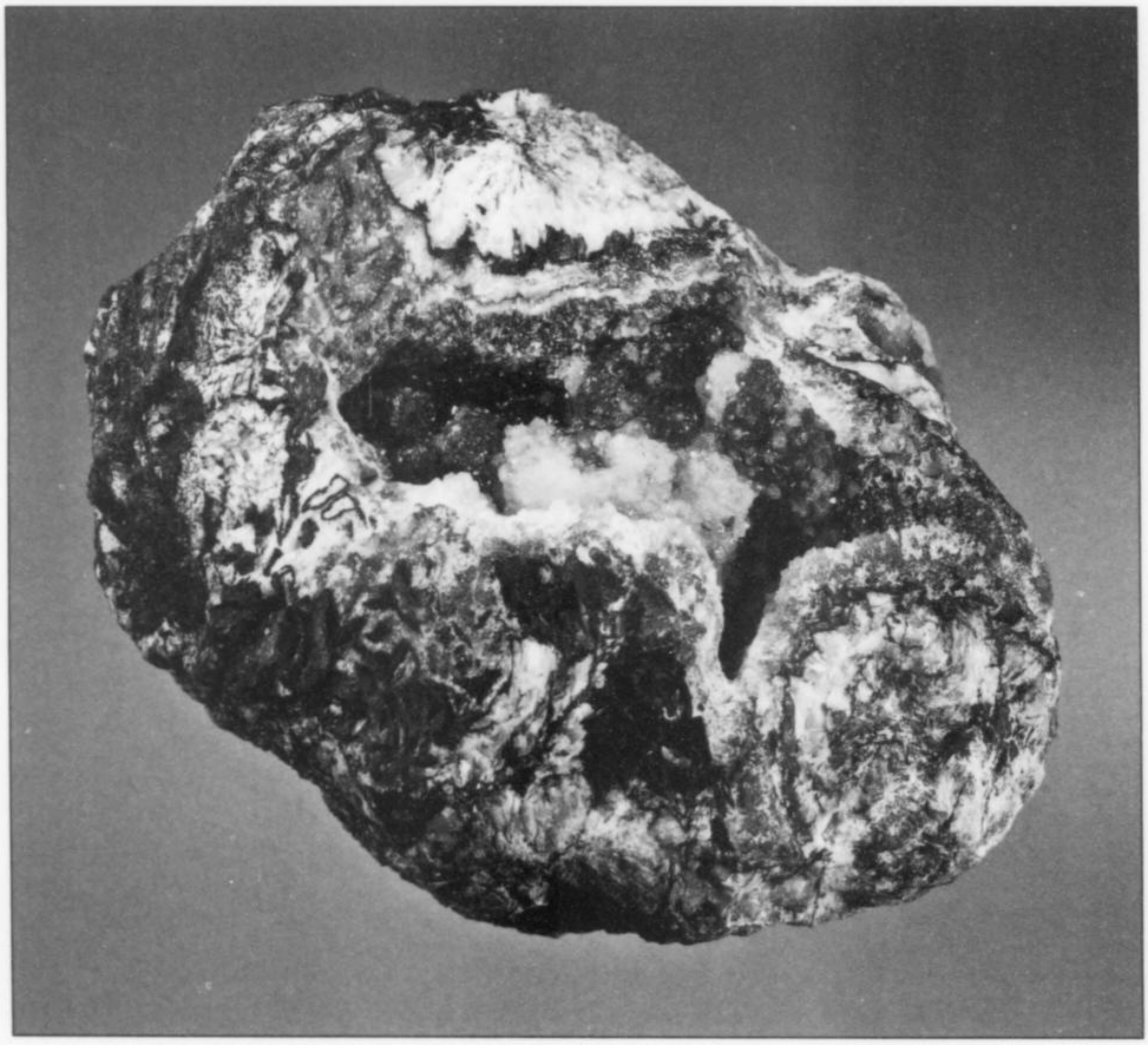


Figure 140. **Colorless talmessite crystal group, 1 mm, on dark green conichalcite, from Ightem. G. Favreau specimen; Robert Vernet photo.**

Figure 141. **An orange-pink cobalt-rich mixed crystal of talmessite and roselite-beta, 1.1 mm, from Bou Azzer. G. Favreau specimen and photo.**

Figure 142. **Raspberry-red talmessite in a quartz druse on limonite-rich dolomite, 9 cm, from Aghbar. Stefan Weiß specimen and photo.**



Roselite-beta occurs at Aghbar and in Vein 2, Bou Azzer, as epitactically oriented crystals on roselite: in these specimens, lustrous, cherry-red roselite crystals are penetrated or enclosed by small orange to pale pink, lath-shaped crystals of roselite-beta; the roselite-beta crystals may completely cover the roselite. In some cases the walls of cavities in dolomite are blanketed by these rounded epitactic intergrowths, which reach 5 mm individually. Associated species include cobaltlotharmeyerite and cobaltaustinite.

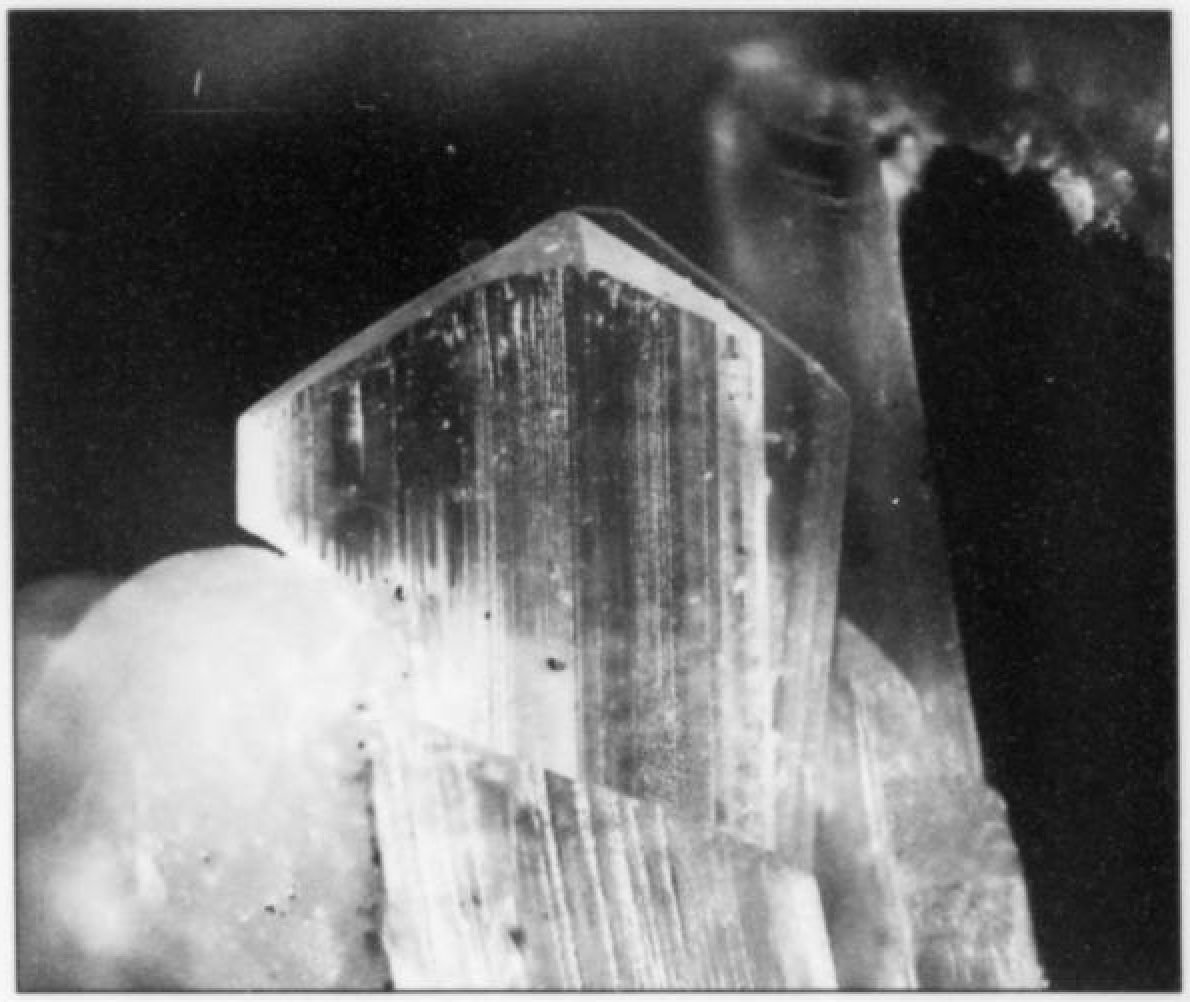


Figure 143. **Vladimirite, from Vein 59, Aït Ahmane; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

qualitatively, which resemble hemimorphite, have come from Vein 53. In Vein 59 we found a weathered piece of calcite/quartz with sparse cavities containing fresh vladimirite aggregates resembling aragonite, with especially sharp development of crystal terminations. Reaching to more than 3 mm, these are the largest vladimirite crystals that we have yet seen.

Walentaite $H(Ca,Mn^{2+},Fe^{2+})Fe^{3+}_3(AsO_4,PO_4)_4 \cdot 7H_2O$

We first identified walentaite from the iron-rich zones at Oumlil-East, where the mineral resembles uranospinite. It forms attractive, yellow, pointed flake-like crystals in tiny (<0.2 mm) rosette-shaped aggregates with pearly luster, resting on druses of pale green pharmacosiderite crystals over iron-rich gangue. To our knowledge, walentaite is the first phosphate-containing secondary mineral seen in the Bou Azzer district.

Wendwilsonite

(See under Roselite-Wendwilsonite-Zincroselite.)

Figure 144. **Vladimirite, from Ightem; field of view 4 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Vein 51 at Aït Ahmane produces specimens showing bright pink, elongated crystals of roselite-beta, some resting on erythrite, associated with heterogenite.

Uvarovite $Ca_3Cr_2(SiO_4)_3$

In a hand-sized piece of chromite from Inguijem, near Agoudal, uvarovite has been observed as tiny (<0.5 mm), bright green, rounded crystals in a vein of calcite.

Vladimirite $Ca_5H_2(AsO_4)_4 \cdot 5H_2O$

Ightem is one of the best of the known occurrences of the rare calcium arsenate vladimirite. Bonnici and Pierrot (1965) described vladimirite from Ightem as thick rosettes of opaque white crystals, but the mineral also forms very thin, colorless acicular crystals to 2 or 3 mm long, as well as small, spearlike, striated and slightly corroded crystals on botryoidal talmessite and on quartz. In a vladimirite-bearing gangue zone associated with a contact between carbonates and skutterudite and molybdenite ores, there is a rich occurrence of secondary minerals including erythrite, roselite-beta, heterogenite, and small violet crystals of arsenolite.

We have found vladimirite at four different sites in Aït Ahmane. In Veins 51 and 52 it forms excellent, fairly large, white to colorless, vertically striated, bladed crystals; however, the best crystals

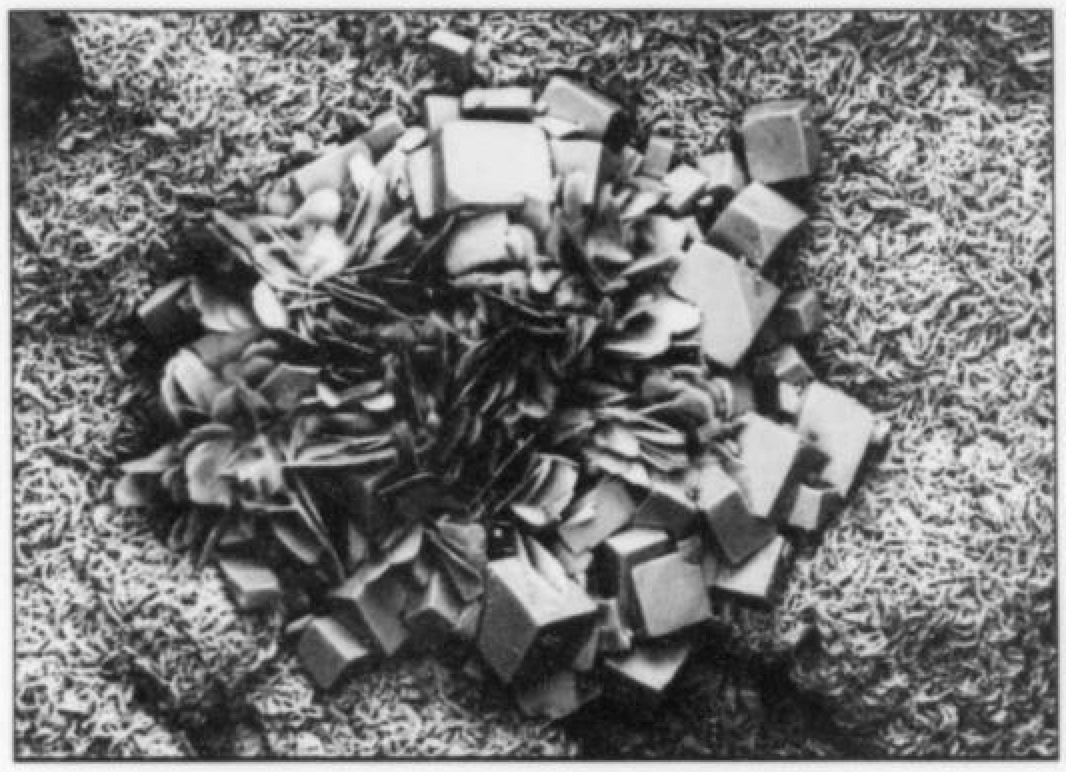


Figure 145. **A detail of a walentaite cluster with pharmacosiderite, from Oumlil-East; field of view 0.3 mm. REM photo by Bertrand Devouard.**

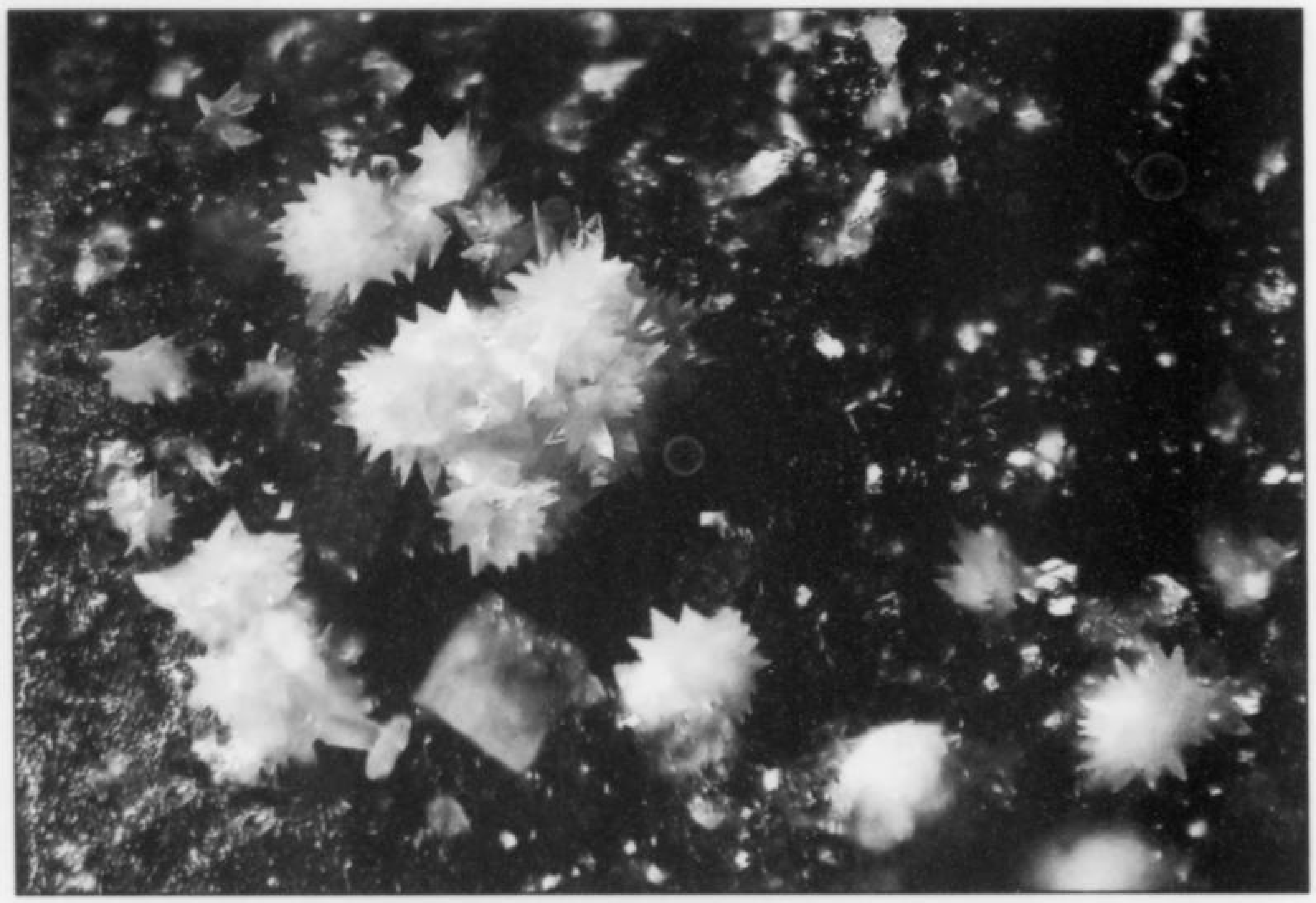


Figure 146. **Walentaite rosettes on pharmacosiderite, from Oumlil-East; field of view 1 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

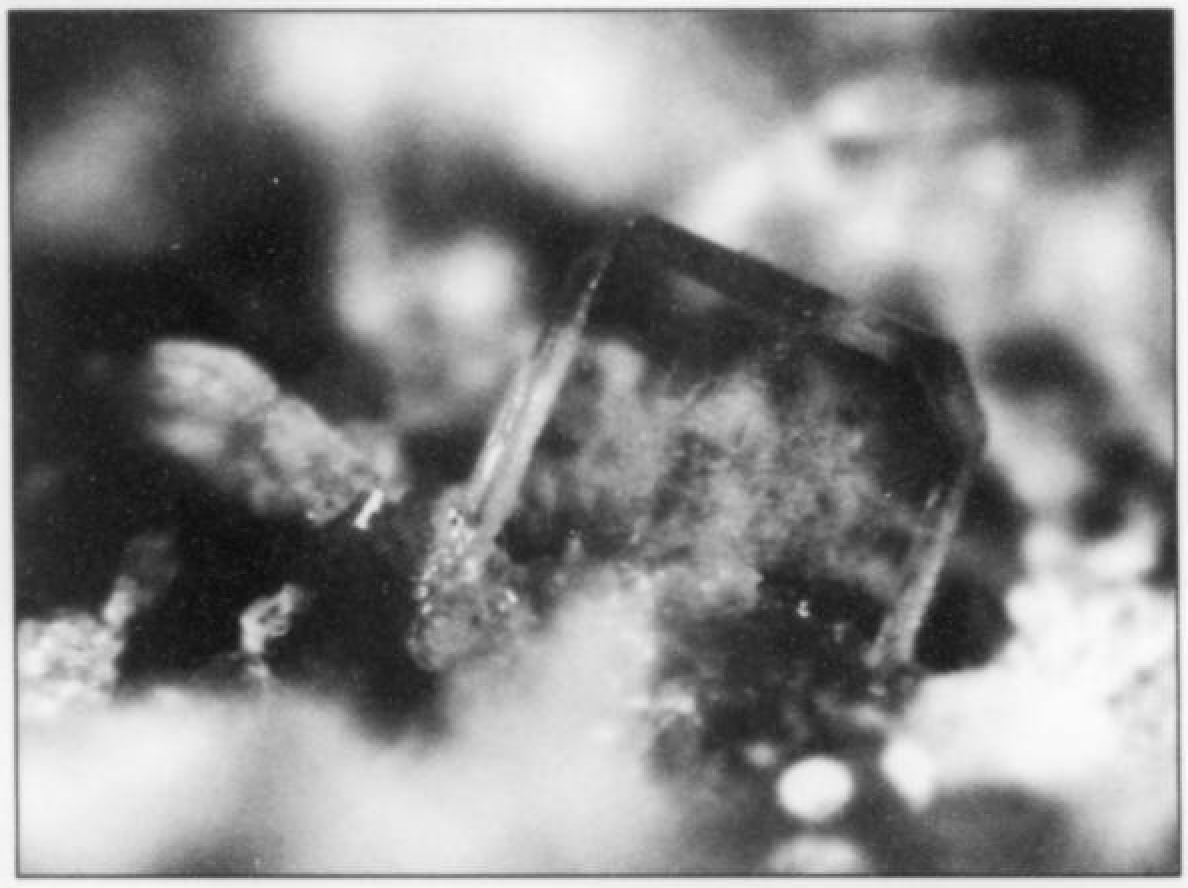


Figure 147. **Transparent zeunerite crystal from Tamdrost-West; field of view 1.5 mm. G. Favreau specimen and photo.**

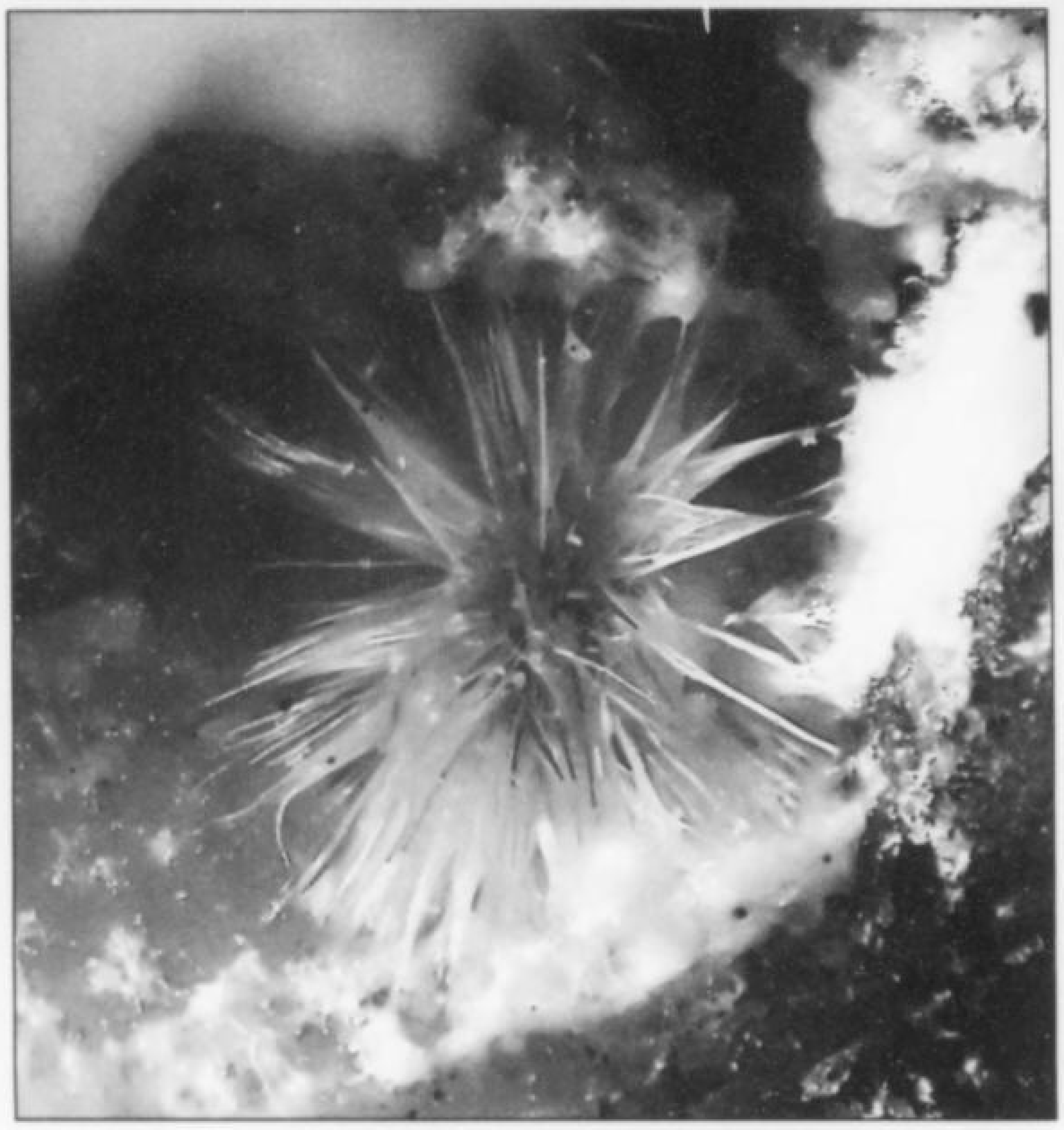


Figure 148. **Fibrous, pale green zálesíite, from Taghouni; field of view 1.5 mm. G. Favreau specimen; Heinz Dieter Müller photo.**

Figure 149. **Opaque green metazeunerite with yellow arseniosiderite on tabular brown barite crystals, from Vein 2, Bou Azzer; field of view 3.5 mm. G. Favreau specimen; Robert Vernet photo.**

Wulfenite $PbMoO_4$

We first found specimens of wulfenite in Méchoui, but could verify no traces of any other lead minerals in the area. Molybdenite is well known from various places in the district, as is powellite, which forms from it. Wulfenite occurs at Méchoui as tiny (<0.5 mm), elongated, cream-colored to yellowish, prismatic crystals with curved faces in cavities in pink dolomite, associated with late-formed, lustrous black scales of chalcocite. In Oumlil-East, wulfenite occurs with galena, mimetite and tiny quartz crystals, as cream-colored tabular crystals 1 mm thick and exceptionally to 1 cm across, and as bright orange platy crystals with yellow mimetite.

Zálesíite $CaCu_6[(AsO_4)_2(AsO_3OH)(OH)_6]\cdot 3H_2O$ and
Agardite (Ce) $CeCu_6[(OH)_6(AsO_4)_3]\cdot 3H_2O$

The minerals of the mixite group are easily miscible with each other chemically. This is apparent in the Bou Azzer district, where the newly identified zálesíite (with predominant calcium) can form with mixite (bismuth predominant) or agardite-(Y) (yttrium predominant). Finely fibrous, pale green crystals of pure agardite-(Ce) overgrow the guanacoite of Taghouni.

***Table 1.* Minerals from the Bou Azzer District.**

(Minerals of the country rocks are not listed.)

Character of best specimens (Column 2)

- * microscopic grains only
- ** massive and finely crystalline only
- *** microcrystals of little specimen interest
- (m) known in significant microcrystal specimens
- (M) known in significant macrocrystal specimens
- (!!) world's best crystal specimens

(TL) type locality in the Bou Azzer district

Sources in the literature (Column 3)

- (1) SCHMETZER *et al.* (1980 or 1982)
- (2) LEBLANC (1975) and PERMINGEAT (1991)
- (3) ESSARAJ (1999)
- (4) WEIβ *et al.* (2002)
- (5) GHORFI *et al.* (2005)
- (6) Newly described in this article

Analyses performed for the preparation of this article by (Column 4)

- CGS Czech Geological Survey/Prague (P. Ondrus, XRD)
- LLS LAPIS-Leserservice (T. Raber, EDX; M. Kotrly, EDX+XRD)
- MGL Musée Géologique/Lausanne (N. Meisser, REM-EDX+XRD)
- MNG Musée d'Histoire Naturelle/Geneva (H. Sarp, REM-EDX)
- MNP Muséum National d'Histoire Naturelle/Paris (G. Parodi, REM-EDX+EMS)
- MNLA Natural History Museum of Los Angeles County (A. Kampf, XRD)
- UCF Université de Clermont-Ferrand (B. Devouard, REM-EDX)
- UIB Universität Innsbruck (S. Krivovichev, Einkristall-XRD)
- UOC University of Chicago (I. Steele, EMS)

Elements				
Arsenic	As	*	(2)	
Awaruite	Ni_3Fe	*	(2)	
Bismuth	Bi	**	(2)	
Copper	Cu	***	(2)	
Eugenite	$Ag_{11}Hg_2$	*	(2)	
Gold	Au	**	(2)	
Iridium	(Ir,Os)	*	(5)	
Osmium	(Os,Ir)	*	(5)	
Sulfur	S	***		
Silver	Ag	(m)	(2)	
Sulfides, Arsenides, Telluride				
Acanthite	Ag_2S	**	(2)	
Alloclase	(Co,Fe)AsS	**	(2)	
Argentopyrite (?)	$AgFe_2S_3$	**	(2)	
Argyrodite	Ag_8GeS_6	*	(2)	
Arsenopyrite	FeAsS	(m)	(2)	MNP
Bismuthinite	Bi_2S_3	*	(2)	
Bornite	Cu_5FeS_4	**	(2)	
Bravoite	$(Fe,Ni)S_2$	*	(2)	
Chalcopyrite	$CuFeS_2$	(m)	(2)	
Chalcocite	Cu_2S	(M)	(2)	MNLA, MNP, LLS
Clinosafflorite	$(Co,Fe,Ni)As_2$	***	(2)	MNP
Covellite	CuS	**	(2)	
Cubanite	$CuFe_2S_3$	*		
Digenite	Cu_9S_5	*	(2)	
Galena	PbS	***	(2)	
Gersdorffite	NiAsS	(M!!)	(2)	
Glaucodot	(Co,Fe)AsS	*	(2)	
Godlevskite	$(Ni,Fe)_9S_8$	*	(2)	
Heazlewoodite	Ni_3S_2	*	(2)	
Idaite	Cu_5FeS_6	*	(2)	
Jordisite	MoS_2	**	(2)	
Kashinite	$(Ir,Rh)_2S_3$	*	(5)	
Laurite	RuS_2	*	(5)	
Linnaeite	$CoCo_2S_4$	*	(2)	
Löllingite	$FeAs_2$	(m)	(2)	MNP
Marcasite	FeS_2	(m)	(2)	
Maucherite	$Ni_{11}As_8$	(m)	(2)	
Millerite	NiS	*	(2)	
Molybdenite (rhenium-rich)	$(Mo,Re)S_2$	**	(2)	
Nickeline	NiAs	***	(2)	
Nickel-skutterudite	$(Ni,Co,Fe)As_{2-3}$	(m)		MNP, MGL
Orpiment	As_2S_3	**	(2)	
Pararammelsbergite	$NiAs_2$	*	(2)	
Pentlandite	$(Ni,Fe)_9S_8$	*	(2)	
Pyrite	FeS_2	(m)	(2)	
Pyrrhotite	$Fe_{1-x}S$	*	(2)	
Rammelsbergite	$NiAs_2$	(m)	(2)	
Realgar	AsS	(m)	(2)	
Safflorite	$CoAs_2$	(m)	(2)	
Skutterudite	$CoAs_3$	(M!!)	(2)	LLS
Sphalerite	ZnS	***	(2)	
Stromeyerite	CuAgS	*	(2)	
Vaesite	NiS_2	*	(2)	
Valleriite	$4(Fe,Cu)S\cdot 3(Mg,Al)(OH)_2$	*		
Sulfosalts				
Emplectite	$CuBiS_2$	*	(2)	
Enargite	Cu_3AsS_4	*	(2)	
Freibergite	$Ag_6Cu_4(Fe,Zn)_2Sb_4S_{13}$	*	(2)	
Luzonite-Famatinite	$Cu_3AsS_4 - Cu_3SbS_4$	*	(2)	
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	***	(2)	
Proustite	Ag_3AsS_3	(m)	(2)	
Pyrargyrite	Ag_3SbS_3	**	(2)	
Tennantite	$Cu_6Cu_4(Fe,Zn)_2(As,Sb)_4S_{13}$	*	(2)	
Tetrahedrite	$Cu_6Cu_4(Fe,Zn)_2(Sb,As)_4S_{13}$	*	(2)	
Wittichenite	Cu_3BiS_3	*	(2)	
Xanthoconite	Ag_3AsS_3	**	(2)	
Halides				
Bromargyrite	AgBr	**	**(6)**	MNP
Chlorargyrite	AgCl	**	(3)	
Halite	NaCl	*		
Oxides, Hydroxides				
Anatase	TiO_2	*	(2)	

Table 1 (continued). **Minerals from the Bou Azzer District.**

Arsenolite	As_2O_3	(m)		MNG
Asbolane	$(Ni^{2+},Co^{3+})_xMn^{4+}(O,OH)_4 \cdot nH_2O$	**		
Brannerite	$(U,Ca,Y,Ce)(Ti,Fe)_2O_6$	(m)	(2)	
Chromite	$Fe^{2+}Cr_2O_4$	***	(2)	MGL, MNLA
Cuprite	Cu_2O	(m)		MNLA
Diaspore	α-AlO(OH)	**	(2)	
Goethite	α-$Fe^{3+}O(OH)$	(M)	(2)	
Hematite	Fe_2O_3	(m)	(2)	
Heterogenite	$Co^{3+}O(OH)$	**		
Litharge	PbO	**	**(6)**	UCF
Magnesiochromite	$Mg^{2+}Cr_2O_4$	***		
Magnetite	$Fe^{2+}Fe^{3+}_2O_4$	(m)	(2)	
Rutile	TiO_2	*	(2)	
Spinel (chromium-rich)	$Mg(Al,Cr^{3+})_2O_4$	**	(2)	
Carbonates				
Aragonite	$CaCO_3$	(M)	(2)	
Aurichalcite	$(Zn,Cu^{2+})_5(CO_3)_2(OH)_6$	***	**(6)**	
Azurite	$Cu^{2+}_3(CO_3)_2(OH)_2$	(m)		
Calcite	$CaCO_3$	(M)		MNG
Cerussite	$PbCO_3$	***	**(6)**	
Dolomite	$CaMg(CO_3)_2$	(M)		
Hydromagnesite	$Mg_5(CO_3)_2(OH)_2 \cdot 4H_2O$	**		
Malachite	$Cu^{2+}_2(CO_3)(OH)_2$	(m)		MNG
Mcguinnessite	$(Mg,Cu^{2+}_2)_2(CO_3)(OH)_2$	**	(1)	
Pyroaurite-Sjögrenite	$Mg_6Fe^{3+}_2(CO_3)(OH)_{16} \cdot 4H_2O$	(m)		
Sphaerocobaltite	$CoCO_3$	(m)		MNG, LLS
Stichtite	$Mg_6Cr_2(CO_3)(OH)_{16} \cdot 4H_2O$	**		MNG
Sulfates				
Anglesite	$PbSO_4$	***	**(6)**	
Barite	$BaSO_4$	(M)	(2)	
Brochantite	$Cu^{2+}_4(SO_4)(OH)_6$	***	**(6)**	MNP
Celestine	$SrSO_4$	(M)	(2)	
Chalcanthite	$Cu^{2+}SO_4 \cdot 5H_2O$	***	**(6)**	LLS
Connellite	$Cu^{2+}_{19}Cl_4(SO_4)(OH)_{32} \cdot 3H_2O$	**	**(6)**	MGL
Cyanotrichite	$Cu^{2+}_4Al_2(SO_4)(OH)_{12} \cdot 2H_2O$	**	**(6)**	LLS
Devilline	$CaCu^{2+}_4(SO_4)_2(OH)_6 \cdot 3H_2O$	***	**(6)**	MGL
Epsomite	$MgSO_4 \cdot 7H_2O$	***		
Gypsum	$CaSO_4 \cdot 2H_2O$	***	(2)	LLS
Hexahydrite	$MgSO_4 \cdot 6H_2O$	**		
Melanterite	$FeSO_4 \cdot 7H_2O$	***	(2)	
Retgersite	$NiSO_4 \cdot 6H_2O$	**	**(6)**	MGL
Serpierite	$Ca(Cu^{2+},Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$	***	**(6)**	LLS
Arsenates, Arsenites				
Adamite	$Zn_2(AsO_4)(OH)$	(m)	**(6)**	MNG
Agardite-(Ce)	$CeCu_6(OH)_6(AsO_4)_3 \cdot 3H_2O$	***	**(6)**	MNLA
Alumopharmacosiderite	$KAl_4(AsO_4)_3(OH)_4 \cdot 6.5H_2O$	(m)	**(6)**	MGL, UCF
Annabergite	$Ni_3(AsO_4)_2 \cdot 8H_2O$	(m)		MNP
Arhbarite	$Cu_2Mg(AsO_4)(OH)_3$	(TL)	(1)	
Arseniosiderite	$Ca_2Fe^{3+}_3(AsO_4)_3O_2 \cdot 3H_2O$	(m)		UCF, MGL, MNP
Austinite	$CaZn(AsO_4)(OH)$	(m)		
Beudantite	$PbFe_3[(As,S)O_4]_2(OH,H_2O)_6$	(m)	**(6)**	MNP
Bouazzerite	$Mg_{4-5}Bi_3(Fe^{3+},Cr^{3+})_7[O_{12}(OH)_2(AsO_3)_2(AsO_4,CrO_4)_7] \cdot 45H_2O$	(**TL** m !!)	**(6)**	UCF, MGL, UIB
Cabalzarite	$Ca(Mg,Al,Fe)_2(AsO_4)_2(H_2O,OH)_2$	*	**(6)**	MGL
Chalcophyllite	$Cu_9Al[(OH)_{12}(SO_4)_{1.5}(AsO_4)_2] \cdot 18H_2O$	***	**(6)**	MNP
Clinoclase	$Cu^{2+}_3(AsO_4)(OH)_3$	***		
Clinotyrolite	$Ca_2Cu^{2+}_9[(As,S)O_4]_4(O,OH)_{10} \cdot 10H_2O$	(m)		MNP
Cobaltarthurite	$Co^{2+}Fe^{3+}_2(AsO_4)_2(OH)_2 \cdot 4H_2O$	(m!!)	**(6)**	UCF, MGL, MNLA, UOC
Cobaltaustinite	$CaCoAsO_4(OH)$	(m)	**(6)**	MNG, MGL, LLS
Cobaltkoritnigite	$(Co,Zn)(As^{5+}O_3)(OH) \cdot H_2O$	(m)	**(6)**	MNP, UCF
Cobaltlotharmeyerite	$Ca(Co,Fe^{3+},Ni)_2(AsO_4)_2(OH,H_2O)_2$	(m!!)	**(6)**	MNG, MNP, MGL, MNLA
Conichalcite	$CaCu^{2+}(AsO_4)(OH)$	(m)		MNG, MGL, LLS
Cornubite	$Cu^{2+}_5(AsO_4)_2(OH)_4$	***	**(6)**	MGL
Cornwallite	$Cu^{2+}_5(AsO_4)_2(OH)_4$	***	**(6)**	LLS
Erythrite	$Co_3(AsO_4)_2 \cdot 8H_2O$	(M !!)		MNP
Ferrilotharmeyerite	$Ca(Fe^{3+}, Zn)_2(AsO_4)_2(OH,H_2O)_2$	(m)	**(6)**	LLS, MGL, UIB
Fornacite	$Pb_2Cu(AsO_4)(CrO_4)(OH)$	***	**(6)**	MGL
Geminite	$Cu^{2+}(As^{5+}O_3OH)(H_2O)$	(m)	**(6)**	UCF, CGS
Guanacoite	$Cu_2Mg_2(Mg,Cu)(OH)_2(AsO_4)_2 \cdot 4H_2O$	(m)	**(6)**	UCF, MNLA, UOC
Guérinite	$Ca_5H_2(AsO_4)_4 \cdot 9H_2O$	***	**(6)**	MNP
Haidingerite	$Ca(AsO_3OH) \cdot H_2O$	***		
Hörnesite	$Mg_3(AsO_4)_2 \cdot 8H_2O$	***	**(6)**	MGL, MNP
Irhtemite	$Ca_4MgH_2(AsO_4)_4 \cdot 4H_2O$	(**TL** m!!)		
Karibibite	$Fe^{3+}_2As^{3+}_4(O,OH)_9$	(m !!)	(1)	MNP
Köttigite	$Zn_3(AsO_4)_2 \cdot 8H_2O$	(m)	**(6)**	MGL
Lavendulan	$NaCaCu^{2+}_5(AsO_4)_4Cl \cdot 5H_2O$	(m)		MNP, UCF, MGL, MNLA
Maghrebite	$MgAl_2[(OH)(AsO_4)]_2 \cdot 8H_2O$	(**TL** m!!)	**(6)**	MGL, UIB
Mansfieldite	$AlAsO_4 \cdot 2H_2O$	**	**(6)**	MGL
Metanováčekite	$Mg(UO_2)_2(AsO_4)_2 \cdot 4–8H_2O$	(m)	**(6)**	MGL

***Table 1 (continued).* Minerals from the Bou Azzer District.**

Mimetite $Pb_5(AsO_4)_3Cl$	***	**(6)**	
Nickelaustinite $CaNiAsO_4(OH)$	(**TL** m)		UCF, MGL
Nickellotharmeyerite $Ca(Ni,Fe^{3+})_2(AsO_4)_2(H_2O,OH)_2$	(m)	**(6)**	MGL
Nováčekite $Mg(UO_2)_2(AsO_4)_2 \cdot 12H_2O$	(m)		MGL
Olivenite $Cu^{2+}_2(AsO_4)(OH)$	(m)	**(6)**	MNP
Parasymplesite $Fe^{2+}_3(AsO_4)_2 \cdot 8H_2O$	(m)	(1)	MNP
Parnauite $Cu^{2+}_9(AsO_4)_2(SO_4)(OH)_{10} \cdot 7H_2O$	(m)	**(6)**	MNP
Pharmacolite $CaHAsO_4 \cdot 2H_2O$	(m)		MNP, MNG
Pharmacosiderite $KFe^{3+}_4(AsO_4)_3(OH)_4 \cdot 6\text{–}7H_2O$	(m)		UCF
Picropharmacolite $Ca_4Mg(AsO_3OH)_2(AsO_4)_2 \cdot 11H_2O$	(M)		MNP, MNG
Roselite $Ca_2(Co^{2+},Mg)(AsO_4)_2 \cdot 2H_2O$	(M!!)		MNP, LLS
Roselite-beta $Ca_2Co(AsO_4)_2 \cdot 2H_2O$	(M!!)	(4)	MNP
Sainfeldite $Ca_5(AsO_4)_2(AsO_3OH)_2 \cdot 4H_2O$	(M)		MNP
Schneiderhöhnite $Fe^{2+}Fe^{3+}_3As^{3+}_5O_{13}$	(m)	(1)	MNP
Scorodite $Fe^{3+}AsO_4 \cdot 2H_2O$	(M)		MNP
Smolianinovite $(Co,Ni,Mg,Ca)_3(Fe^{3+},Al)_2(AsO_4)_4 \cdot 11H_2O$ (?)	**	(2)	
Symplesite $Fe^{2+}_3(AsO_4)_2 \cdot 8H_2O$	**	(1)	
Talmessite $Ca_2Mg(AsO_4)_2 \cdot 2H_2O$	(M!!)	(4)	MNP, UCF, LLS
Uranospinite $Ca(UO_2)_2(AsO_4)_2 \cdot 10H_2O$	***	(2)	
Vladimirite $Ca_5H_2(AsO_4)_4 \cdot 5H_2O$	(m!!)		MNLA, MGL
Walentaite $H(Ca,Mn^{2+},Fe^{2+})Fe^{3+}_3(AsO_4,PO_4)_4 \cdot 7H_2O$	(m)	**(6)**	UCF, MNLA
Weilite $Ca(AsO_3OH)$	**	(2)	
Wendwilsonite $Ca_2(Mg,Co^{2+})(AsO_4)_2 \cdot 2H_2O$	(M!!)	(4)	MNP, LLS, MGL, MNLA
Yukonite $Ca_2Fe^{3+}_3(AsO_4)_4(OH) \cdot 12H_2O$	**	**(6)**	MGL
Zálesíite $CaCu_6[(AsO_4)_2(AsO_3OH)(OH)_6] \cdot 3H_2O$	(m)	**(6)**	MGL
Zeunerite $Cu^{2+}(UO_2)_2(AsO_4)_2 \cdot 10\text{–}16H_2O$	(m)	**(6)**	MGL
Zincroselite $Cu^{2+}(UO_2)_2(AsO_4)_2 \cdot 10\text{–}16H_2O$	***		MNP
Vanadate			
Mottramite $PbCuVO_4(OH)$	***	**(6)**	UCF
Molybdates			
Powellite $CaMoO_4$	(m)	**(6)**	MNP, MGL
Wulfenite $PbMoO_4$	(m)	**(6)**	MNG
Silicates			
Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$	**		
Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$	***	**(6)**	
Kaolinite $Al_2Si_2O_5(OH)_4$	**	(2)	
Montmorillonite $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$	**		
Népouite $(Ni,Mg)_3Si_2O_5(OH)_4$	**		
Opal (variety Hyalite) $SiO_2 \cdot nH_2O$	**	**(6)**	
Prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$	***		
Quartz SiO_2	(M)		
Talc $Mg_3Si_4O_{10}(OH)_2$	**	(2)	
Uvarovite $Ca_3Cr_2(SiO_4)_3$	***	**(6)**	MGL

Blue-green fibrous crystals of zálesíite are found in the mine workings of Aghbar and in Veins 2 and 7, Bou Azzer. Specimens from Aghbar show tiny "hedgehog" sprays, only visible with the aid of the binocular microscope. Vein 2 produces bundled crystal aggregates and thin, felt-like cavity linings in dolomite. Zálesíite from Aghbar is bismuth-free and contains only traces of yttrium and neodymium, whereas zálesíite from Vein 2 contains both bismuth and yttrium.

Zeunerite $Cu^{2+}(UO_2)_2(AsO_4)_2 \cdot 10\text{–}16H_2O$ and
Metazeunerite $Cu^{2+}(UO_2)_2(AsO_4)_2 \cdot 8H_2O$

While digging on an old dump from Vein 2, Bou Azzer, we came upon a dark green, ore-poor piece of serpentinite with a narrow cavity zone in which we saw isolated green, flaky crystals. Nearby rocks were threaded with thin quartz veins showing traces of skutterudite and chalcopyrite, and small, green, square-tabular crystals of zeunerite appeared rarely in tiny cavities in these veins. Some of the zeunerite crystals are flecked with orange arseniosiderite and are associated with lavendulan, erythrite, gypsum, and tiny, transparent, yellow barite crystals. At the site in Tamdrost-East where nováčekite is found, zeunerite occurs as bright green, tabular crystals ($<$0.5 mm) with erythrite. The first specimens of zeunerite seen in the district were opaque, as they had already been brought into sunlight and had dehydrated (forming metazeunerite). Other specimens, which were packed up almost at once after being collected, retained a striking transparency. These crystals are truly beautiful, especially if they rest on yellow nováčekite crystals or pale pink erythrite sprays.

Zincroselite

(See under Roselite, Wendwilsonite, Zincroselite.)

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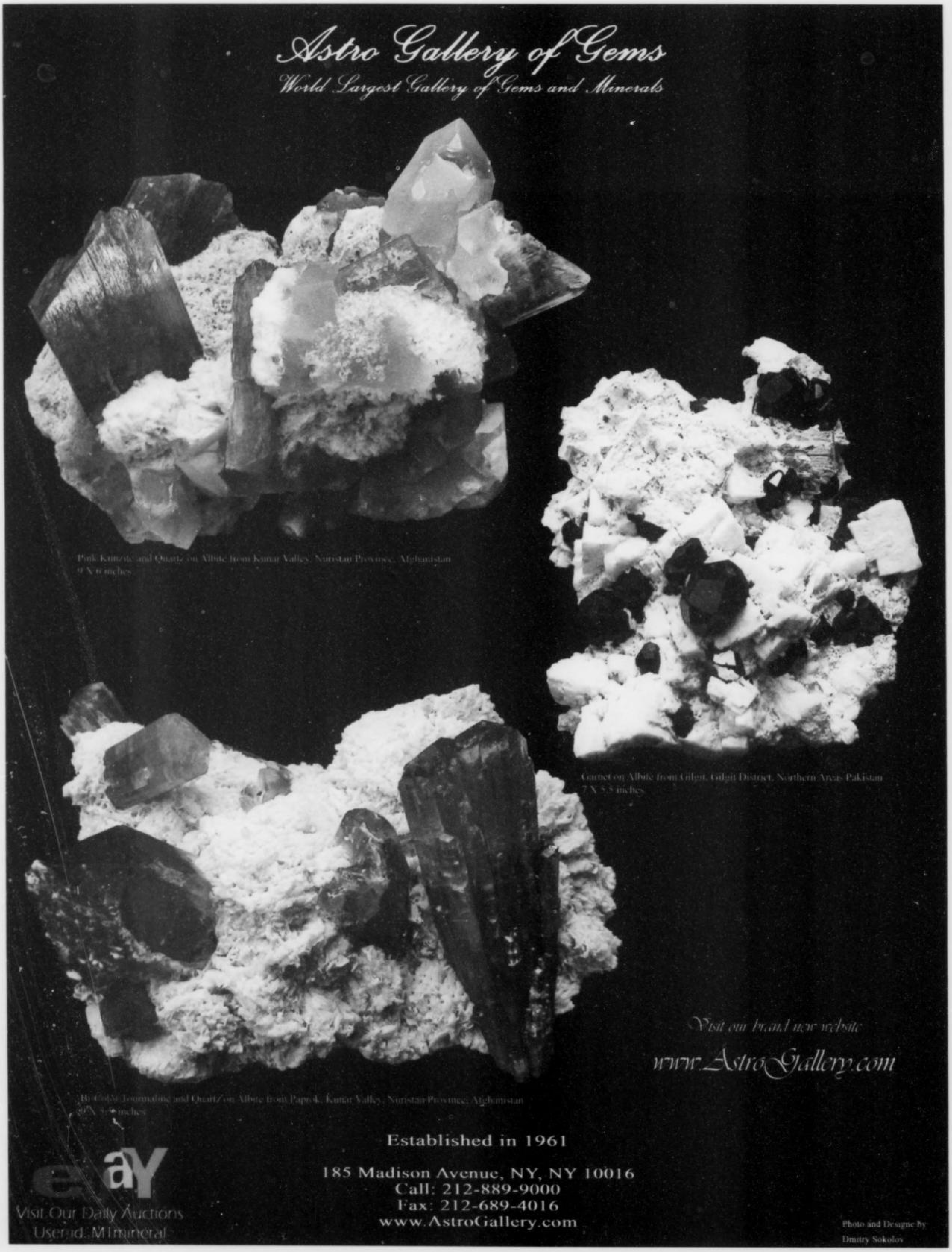
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Sam Gordon and the Tsumeb Azurite

Sam Gordon (1897–1952) was a prominent Philadelphia mineralogist, and the author of many works on descriptive mineralogy and crystallography, including *The Mineralogy of Pennsylvania* (1922) and the description of nine new mineral species. He was also the principal founder (at the age of 19) of *The American Mineralogist* and served as curator of minerals at the Philadelphia Academy of Natural Sciences for 30 years.

Samuel George Gordon was born in Philadelphia on June 21, 1897, the son of German Jewish immigrants Flora and Isaac Gordon, a cigar-maker. He attended classes at the Wagner Free Institute, where the avid young mineralogist and mineral collector Dr. Edgar T. Wherry inspired his interest in mineralogy and became his friend and mentor.

In 1913, at the age of 16, Gordon received a Student Fellowship to work part-time as an assistant in the mineralogy department of the Philadelphia Academy of Natural Sciences. Gordon proved so useful to the Academy that in 1915 he was appointed assistant curator of minerals and given a salary of about $1,000/year.

In 1921 Gordon traveled through Ecuador, Bolivia, Chile and Peru on a six-month collecting trip sponsored in part by George Vaux Jr. (1863–1927), wealthy nephew of William S. Vaux, whose fabulous mineral collection had been bequeathed to the Academy in 1882. His second major collecting expedition, in 1923, was to Greenland, and his third (1925) took him back to the Andes, where he was particularly successful at Llallagua, Bolivia.

Gordon's fourth and most ambitious expedition, eight months long, took place in 1929–1930, taking him to South America and parts of central and southern Africa. He shipped 63 boxes of specimens back to the Academy from Bolivia, and 90 boxes from various localities in Africa, including 12 cases (over 500 pounds) from Tsumeb in South-West Africa. It was at Tsumeb on December 10, 1929 that he discovered one of the most extraordinary pockets of azurite crystals ever encountered in that famous mine.

"The most interesting mineral specimens I collected on this journey," he later wrote, "were the azurite crystals at a copper mine at Tsumeb in South-West Africa. I visited the 8th level workings first, dropping quickly by cage in a vertical shaft some 700 feet deep, and climbing down to the working stopes below. The ore looked very compact and unpromising for finding any azurite crystals. But high up in one place I noticed some bluish stains. With a ladder I reached the blue-stained area, and started to work with a hammer and chisel. In half an hour I had broken into a vug lined with large, beautiful, blue crystals of azurite up to 6 inches long and 3 inches across; one of the prettiest sights you ever saw. Much time was spent in carefully chiseling out these fragile crystals and wrapping them in tissue paper and bags. By noon the best of the crystals had been removed, and the mine superintendant, Herr Keller, appeared. Climbing up and looking into the little cavern, he cried, 'I have worked in this mine fourteen years and I have never seen such fine crystals.' After considerable debate, the Mine Director [Frederick W. Kegel] and I agreed to divide the specimens, which we did. He afterwards asserted that I had gotten the best in the division. These are now among the prized crystals of the Mineral Hall of the Academy."

In 1928 Gordon was promoted from assistant curator to curator at the Academy, though his salary remained minimal. The new species *gordonite* was named after him in 1930. By the early 1930's he had completed the cataloging and arrangement of the Vaux collection and the pre-Vaux specimens, and had installed exhibits of several thousand of the best specimens in exhibit cases of his own design and making. He also set up a mineral research laboratory (complete with chemical analysis apparatus, goniometers and microscopes) in the Academy, and mounted the nation's first display of fluorescent minerals.

During the 1930's Gordon made a number of collecting trips within the United States, to localities in Virginia (1933); North Carolina and Arkansas (1934); California, Nevada, Arizona and New Mexico (1939); Oregon, Washington and South Dakota (1940); and Texas and Arizona (1941). His last foreign expedition, to Chile in 1938–1939, resulted in 26 boxes of specimens including a 171-pound iron meteorite. He took vacation collecting trips in 1946, 1947 and 1948 to Colorado, New Mexico and Arizona, visiting the famous Mammoth mine at Tiger on several occasions. Unfortunately, Gordon had never been appreciated at the Academy, and when he returned from his 1948 trip he found that in his absence his mineralogical laboratory had been eliminated in favor of a newly enlarged Department of Limnology. He was informed that his meager funding was to be phased out, and he was forced to resigned in 1949. The Academy's mineral collection never again had a full-time curator. Sam Gordon died of a heart attack on May 17, 1952, at the age of 54.

Wendell E. Wilson (2007) Mineralogical Record Biographical Archive.